Utilization of Marine Renewable Energy: Aspects and Applications Part 2

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Outline

Part 2 - Applications

- Energy
  - Small scale
  - Large scale
- Water
- Air conditioning

What/when was the first application of marine renewable energy?

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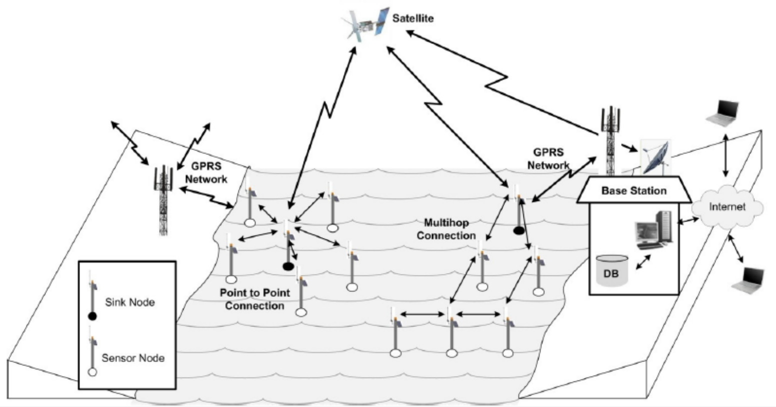
- When : 3000 BC

What/when was the first application of marine renewable energy?

- When : 3000 BC (Along the Nile in 5000 BC)
- What:

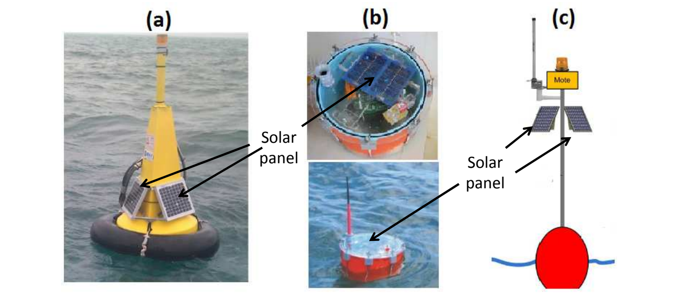
What kind of applications require small scale MRE?

Marine based sensors



[0] Albaladejo et al, *Wireless sensor networks for oceanographic monitoring: A systematic review.* Sensors, 2010

Marine based sensors - Solar

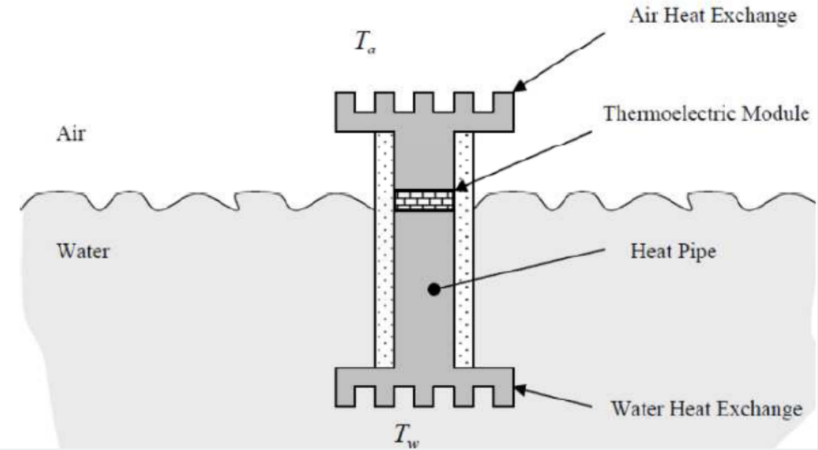


Marine based sensors - Ranking of possible energy sources

Rank	Resource	Energy density	Availability
1	Wave	500 - 50000 W/m^2	24 hours per day
2	Solar	50-500 W/m^2	Day time only. Reductions due to cloud coverage and misalignment of PV panel with incoming sunlight.
3	Wind	100-1000 W/m^2	24 hours per day. Highly variable. Reductions due to logarithmic friction layer towards the ocean surface.
4	Currents	0.1-10 W/m^2	Site dependent.
5	MFC	0.1 W/m^3	On the sea floor
?	Thermal	Unknown	Possibly more consistent that solar and wind.

[0] Davidson, *Energy Harvesting for Marine Based Sensors*, PhD Thesis, *Available at:* *https://www.researchgate.net/profile/Josh_Davidson3*

Thermal energy harvester



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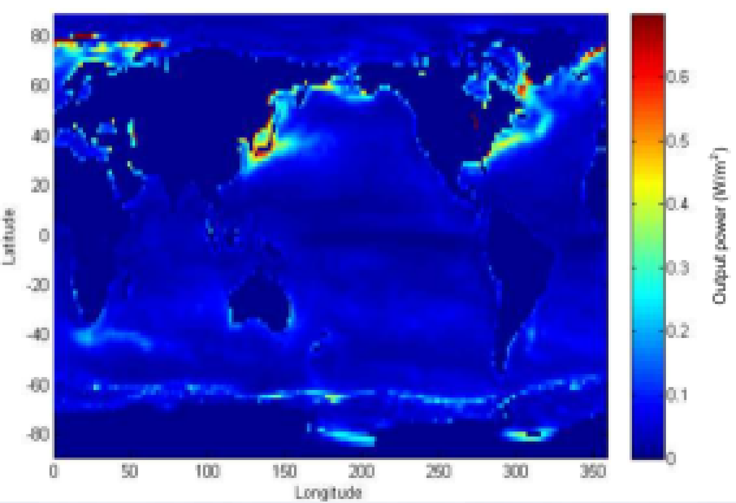

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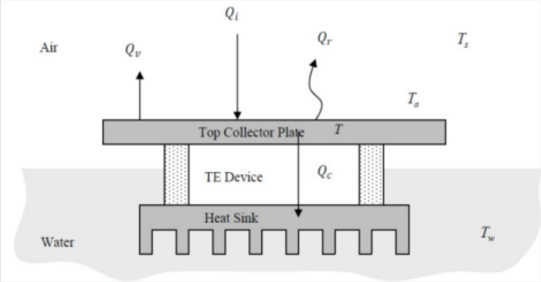
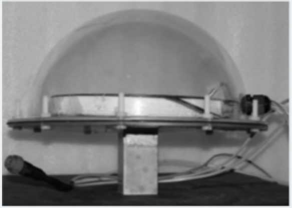
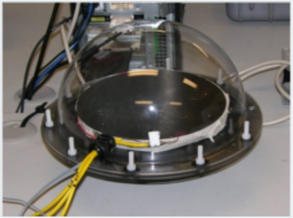
Not enough power! Can we improve this somehow???

Solar thermal collector

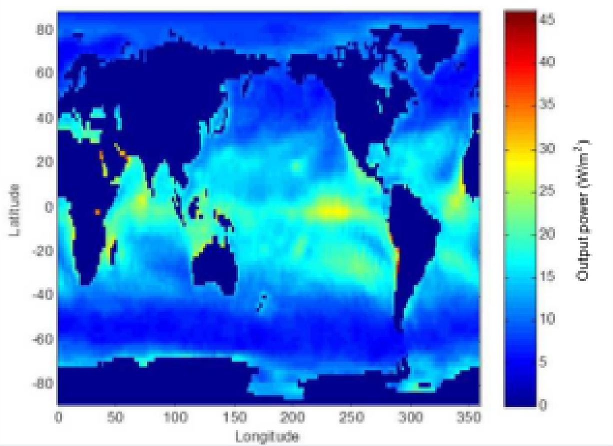






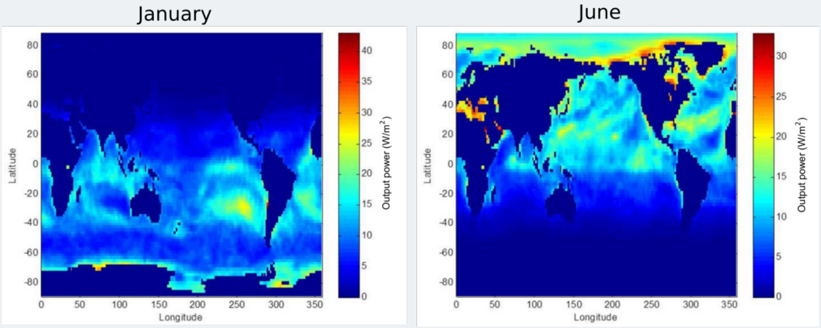
[0]Davidson, *Energy Harvesting for Marine Based Sensors*, PhD Thesis, *Available at:* *https://www.researchgate.net/profile/Josh_Davidson3*

Solar thermal collector - Annual average power



[0] Davidson, *Energy Harvesting for Marine Based Sensors*, PhD Thesis, *Available at:* *https://www.researchgate.net/profile/Josh_Davidson3*

Solar thermal collector - Seasonnal dependence



[0] Davidson, *Energy Harvesting for Marine Based Sensors*, PhD Thesis, *Available at: https://www.researchgate.net/profile/Josh_Davidson3*

[0] Google Images

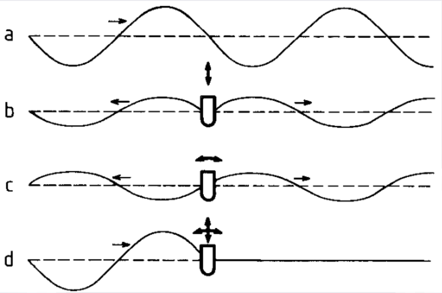
Outline

- Will just focus on wave energy in today's lecture

Wave absorption

- Conservation of energy stipulates that the energy transported by a wave should diminish after passing a WEC.
    - The difference in the wave's energy before and after intercepting the WEC should ideally be the amount of electrical energy produced by the WEC.
- For a wave to be diminished, another wave must destructively interfere with it. Thus, during the process of absorbing energy from a wave, a WEC creates its own wave which destructively interferes with the incoming wave, reducing the receding wave on the lee-ward side.
- Falnes[1] described the crux of this concept as; "for an object to be a good wave absorber it must be a good wave maker".

[1] J. Falnes. *Ocean Waves and Oscillating Systems : linear interactions including wave-energy extraction*, 2002.



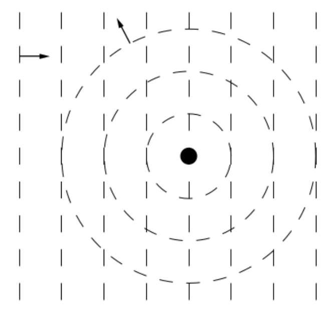
To absorb waves means to generate waves.

- Curve **a** represents an undisturbed incident wave.
- Curve **b** illustrates symmetric wave generation (on otherwise calm water) by a body oscillating in heave (up and down).
- Curve **c** illustrates antisymmetric wave generation by a body oscillating in surge.
- Curve **d**, represents the superposition (sum) of the above three waves, illustrating complete absorption of the incident wave energy

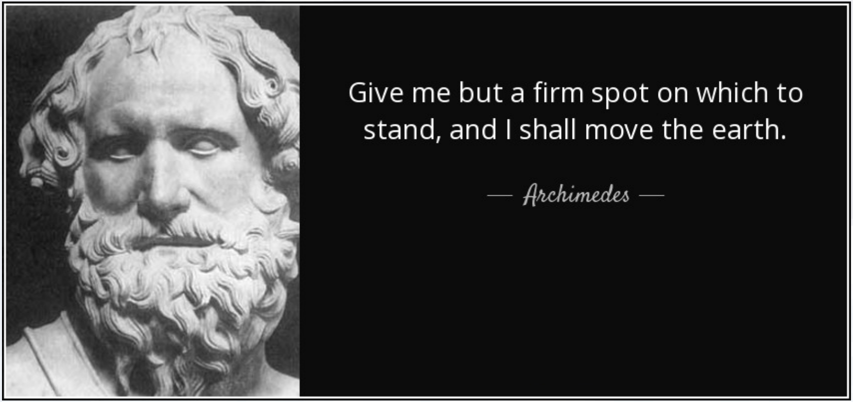
[1] J. Falnes. *Ocean Waves and Oscillating Systems : linear interactions including wave-energy extraction*, 2002.

- A wave energy converter (WEC) can absorb power from a greater area than its own cross-section
- The maximum capture width for a heaving axi-symmetric body is equal to the wavelength divided by 2π.

$$\text{Capture width} = \frac{\text{Absorbed power}}{\text{Power per meter of wavefront}}$$



[1] J. Falnes. *Ocean Waves and Oscillating Systems : linear interactions including wave-energy extraction*, 2002.


Give me but a firm spot on which to stand, and I shall move the earth.
— Archimedes —

How does Archimedes point relate to wave energy conversion?

How does Archimedes point relate to wave energy conversion?

- To convert motion into power you need something to react against.
- Power is not derived from motion itself, but rather from relative motion between objects.

Reaction frame of reference

- In his review of WECs, Bracewell[2] identified that all proposed types of WECs have three things in common;

[2] R. Bracewell. *Frog and PS Frog: A study of two reactionless ocean wave energy converters*, PhD thesis, Lancaster University, 1990.

Reaction frame of reference

- In his review of WECs, Bracewell identified that all proposed types of WECs have three things in common;
    1. They need a working surface for the waves to act against,

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Reaction frame of reference

- In his review of WECs, Bracewell identified that all proposed types of WECs have three things in common;
  1. They need a working surface for the waves to act against,
  2. There must be something providing a *stable frame of reference* to react these wave forces against, and

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  3. The working surface must be capable of being moved by the wave forces relative to this frame of reference.

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  3. The working surface must be capable of being moved by the wave forces relative to this frame of reference.
- He also notes that, for the devices reviewed, the frame of reference was the largest single element in the final estimated cost of power produced.

[2] R. Bracewell. *Frog and PS Frog: A study of two reactionless ocean wave energy converters*, PhD thesis, Lancaster University, 1990.

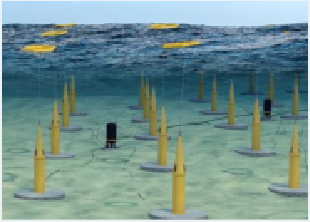
What can be used to provide the reaction frame of reference?

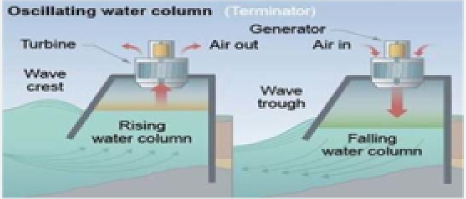
What can be used to provide the reaction frame of reference?

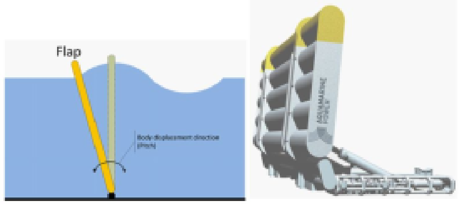
- French[3] identifies four options for the reaction:

[3] MJ French. *On the difficulty of inventing an economical sea wave energy converter: a personal view.* Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 2006.

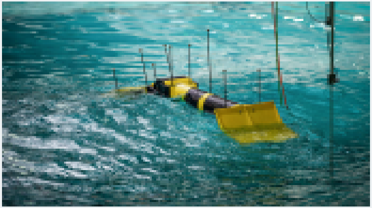
1 : Reaction against the sea floor

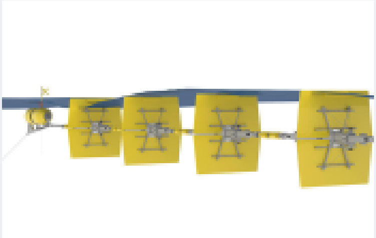




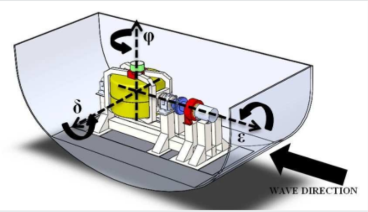


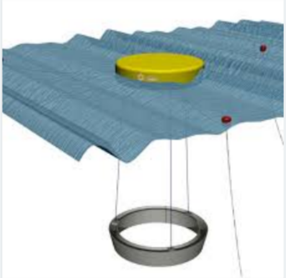
2 : A large structure with extreme dimensions of the order of a wavelength which is subject to a number of wave forces of different phases that provide reactions for each other,

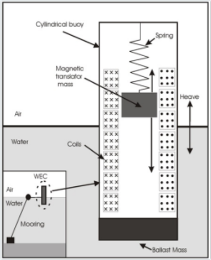


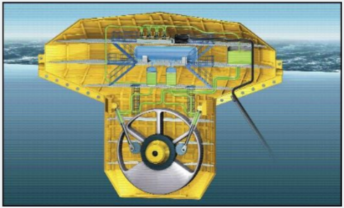


3 : Reacting against a mass that is part of the WEC

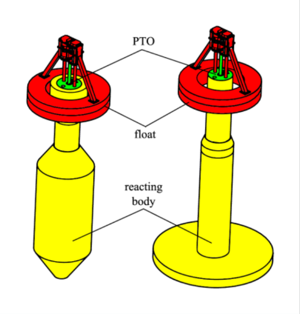


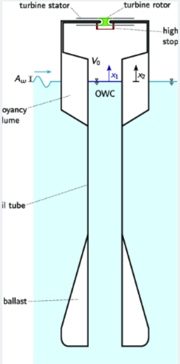


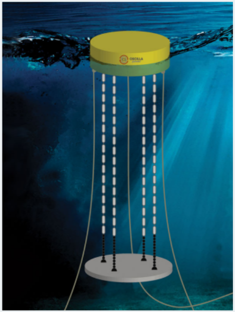




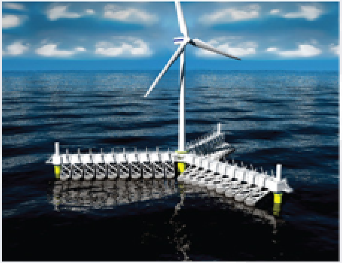
4 : Reaction from a part of the sea

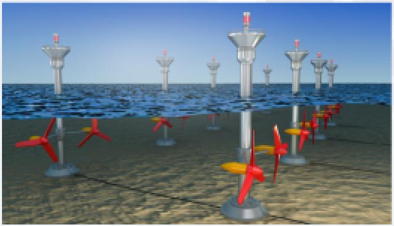


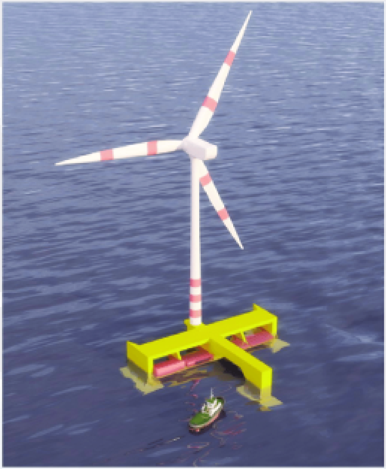




Which other marine renewable energies have similar requirements?







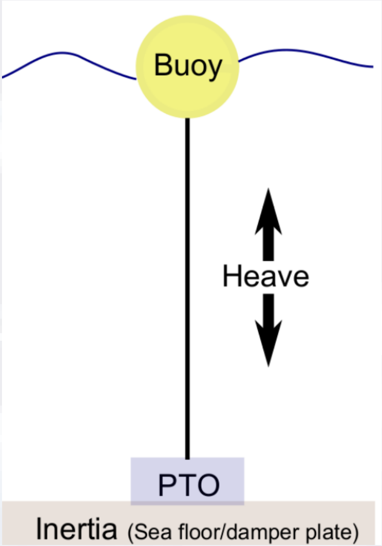
Consider the simple WEC

- What should be the radius of the buoy???
- Answer : It depends on the input wave spectrum

Design principle

- Maximum energy will be absorbed by the WEC if it resonates with the input waves

Let's model the WEC to determine its natural frequency...



Model

- As a simplified approximation, we can model the WEC as a mass-spring-damper system

$$m\ddot{x} + b\dot{x} + kx = F_{Wave}(t) + F_{PTO}(t) \quad (1)$$

Model

- As a simplified approximation, we can model the WEC as a mass-spring-damper system

$$m\ddot{x} + b\dot{x} + kx = F_{Wave}(t) + F_{PTO}(t) \quad (2)$$

- The natural frequency of such a system equals?

Model

- As a simplified approximation, we can model the WEC as a mass-spring-damper system

$$m\ddot{x} + b\dot{x} + kx = F_{Wave}(t) + F_{PTO}(t) \tag{3}$$

- The natural frequency of such a system equals:

$$\omega_n = \sqrt{\frac{k}{m}} \tag{4}$$

Model

- As a simplified approximation, we can model the WEC as a mass-spring-damper system

$$m\ddot{x} + b\dot{x} + kx = F_{Wave}(t) + F_{PTO}(t) \tag{5}$$

- The natural frequency of such a system equals:

$$\omega_n = \sqrt{\frac{k}{m}} \tag{6}$$

- The spring restoring co-efficient, k, and the mass of the sphere, m, both depend on the radius of the buoy (as we will see). So we can design the buoy radius so that the WEC resonates at a chosen frequency

Mass

- Mass equals half the volume times the density of water

$$m = (1/2)(4/3\pi R^3)(\rho_{Water}) \quad (7)$$

Spring

- The hydrostatic spring force equals the mismatch between buoyancy and gravity as the buoy moves away from its equilibrium into /out of the water.
- This equals the change in the weight of the fluid displaced by the submerged part of the WEC.
- Weight = Volume × Density of water × Gravity
- Force = Δ Weight = Δ Volume × Density of water × Gravity
- At equilibrium, we will approximate the change in volume as the cross-sectional area × the heave displacement

$$\Delta Volume = \pi R^2 x \tag{8}$$

- Therefore:

$$F_{spring} = \rho_{Water} g \pi R^2 x \tag{9}$$

- Therefore:

$$k = \rho_{Water} g \pi R^2 \tag{10}$$

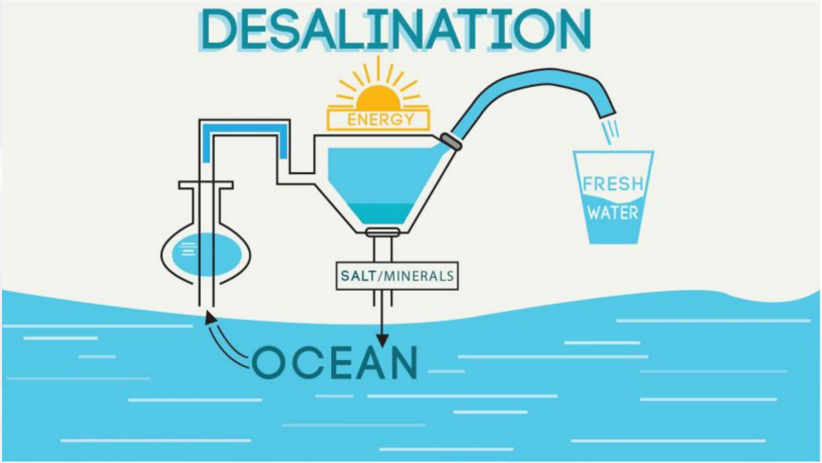
Natural frequency

$$\omega_n = \sqrt{\frac{k}{m}} \tag{11}$$

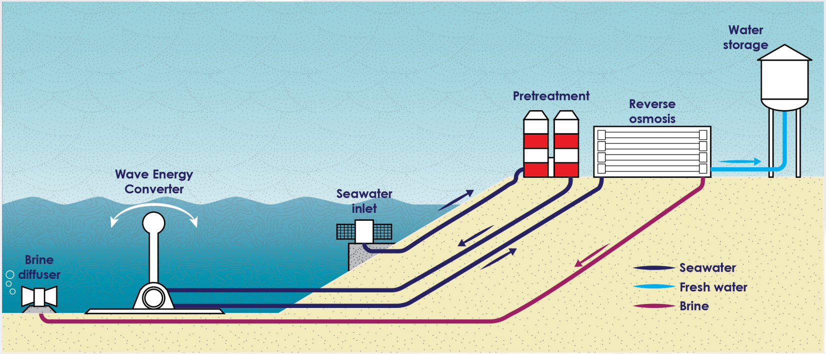
$$\omega_n = \sqrt{\frac{\rho_{Water} g \pi R^2}{\frac{4}{6}\pi R^3 \rho_{Water}}} \tag{12}$$

$$\omega_n = \sqrt{\frac{g}{\frac{4}{6}R}} \tag{13}$$

$$R = \frac{4\omega_n^2}{6g} \tag{14}$$

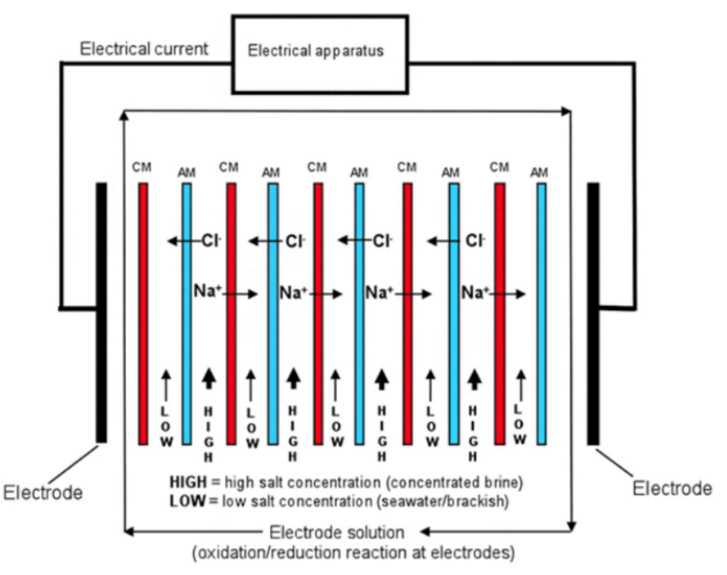


[3] http://inwrdam.org.jo/2019/01/saline-water-desalination/

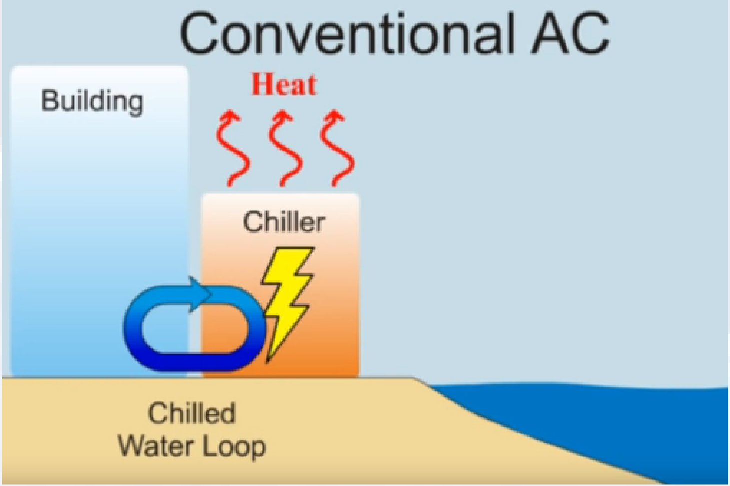


[3] https://www.aquatechtrade.com/news/aquatech-news/desalination-wave-powered/

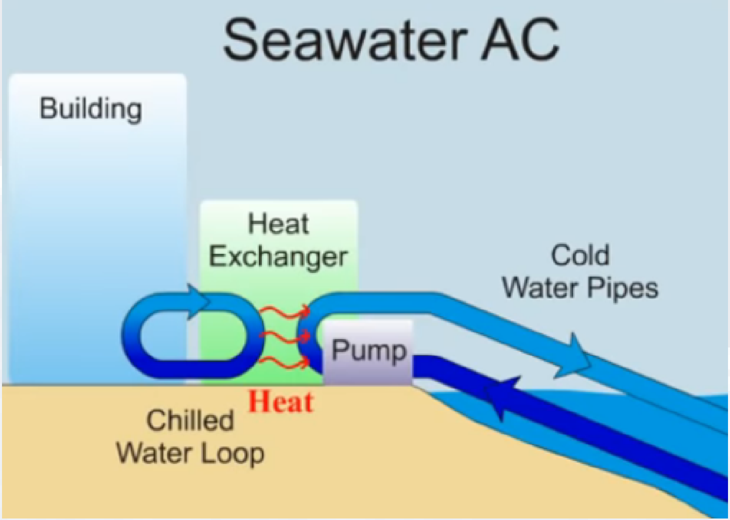
Can use the output brine from the desalination for salinity gradient energy...



Air conditioning



[3] https://www.makai.com



[3] https://www.makai.com

Final thoughts...