ET1 - MRE Resource Assessment

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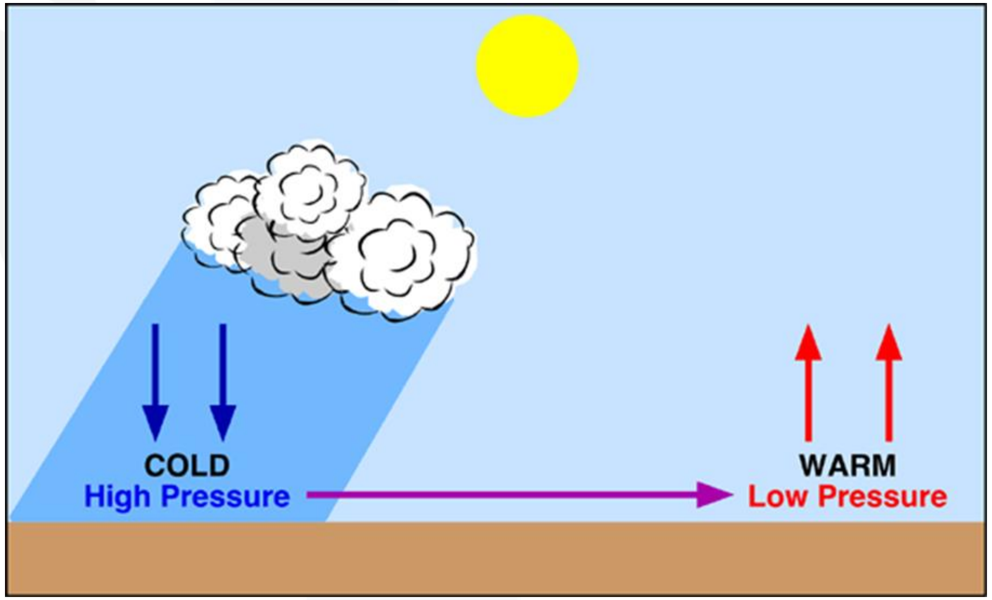
Overview of module

- Wave, Tidal, Offshore Wind, OTEC & Salinity
  - Resource
  - Theory
  - Energy global distribution
  - Energy resource measurement

Offshore Wind

Wind resource

- When air is heated, its density gets lower and thus moves to the higher layers
- This results to a low barometric area (Low). Colder and denser air that creates a high barometric area (High) that moves lower of the up-coming hot air. In this way, air is moving from low barometric areas to high barometric areas.

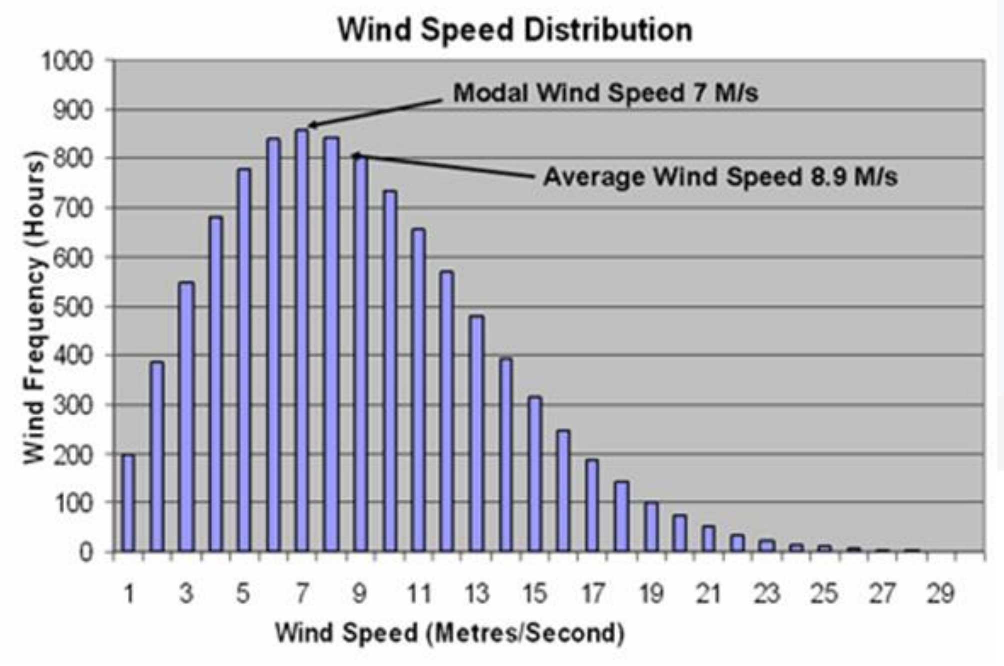


Wind flow from the high to the low pressure region

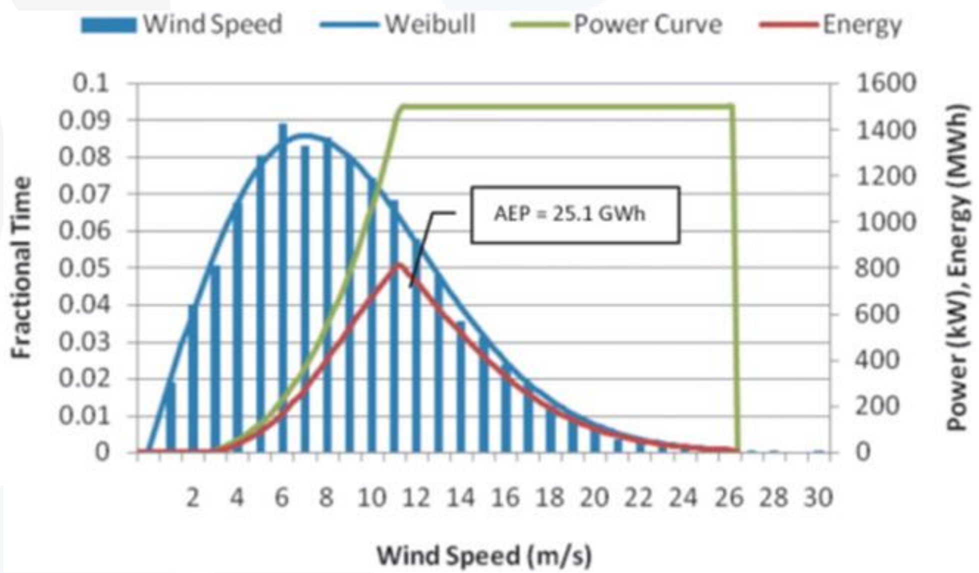
Source: Semantic scholar

Wind Theory

- The scale of the available resource (mean annual wind speeds and direction data)
- How the resource varies overtime (daily, monthly, yearly and long term periods)
- The wind speed distribution (for a site the energy that can be generated from a site by a specific)



Source: mpoweruk



Wind speed vs. Weibull probability distribution, power curve for 1.5 MW wind turbine, and energy production curve, with resulting AEP estimate

Source: Renewable energy focus

Resource measurement

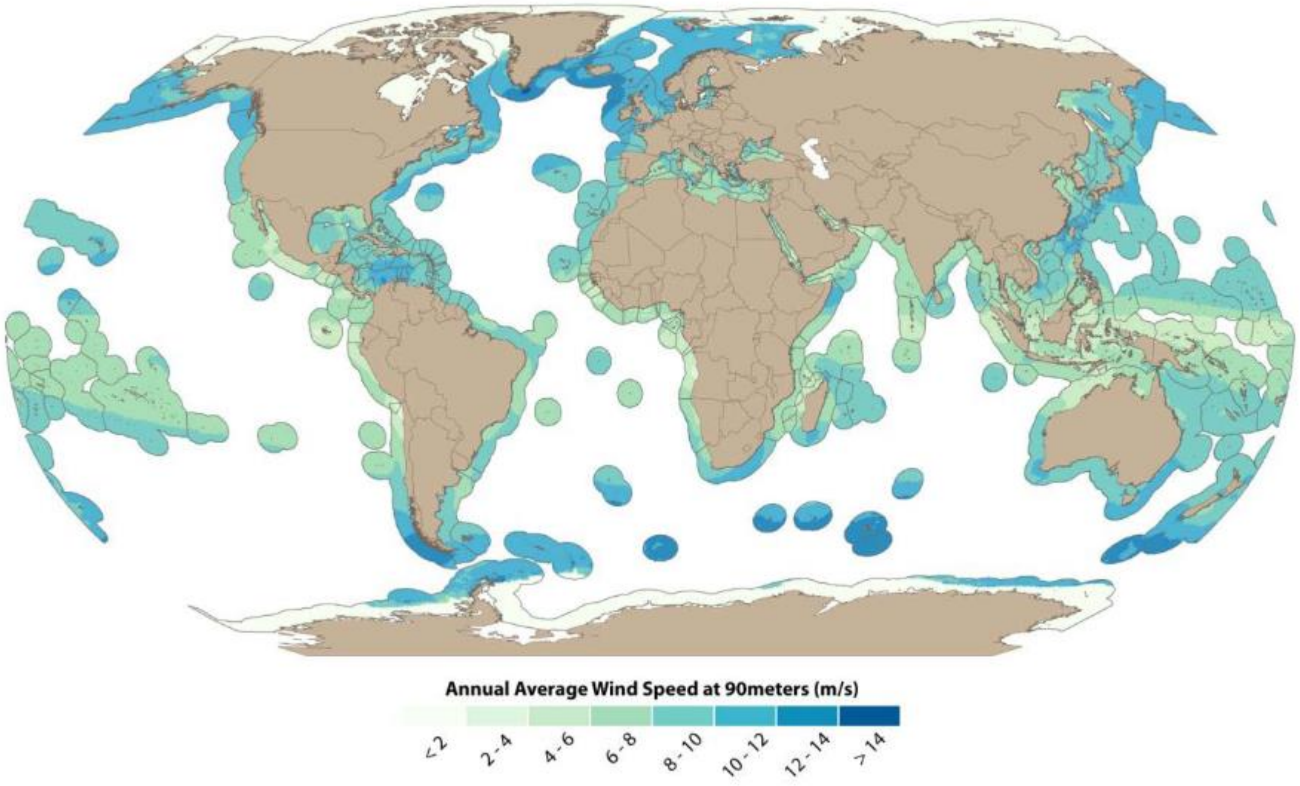
- The basic elements of a wind resource assessment campaign include use of **on-site meteorological masts** outfitted with redundant anemometers at multiple heights, collecting data for a minimum of one year
- Wind speed and direction are the main parameters to be measured
- Mathematical models establish the speed at different points

Offshore meteorological mast

Source: Wind Energy The Facts

Global Distribution

- Global geostrophic winds are generated by a combination of solar convection cells called Hadley cells and the Coriolis Effect produced by the earth's rotation.
- Differential heating between the land and sea and other effects caused by local geography can also have an impact on the strength and direction of the wind resource.
- The International Energy Agency (IEA) estimates that offshore wind has the potential to generate more than 420 000 TWh per year worldwide



Annual average wind speed at 90m

Source: NREL

Wave energy

Wave resource

- Wave motion is an oscillatory phenomena, which is a sequence of repeated events of passing waves.
- Wave energy is a stored, moderately high density form of solar energy derived from the interaction between the water surface and prevailing winds.
- Energy is transferred from the wind to the waves, as the winds blowing over the water surface cause the water particles to adopt circular motions, this motion transfers kinetic energy.

Wave resource

- The amount depends on the following key factors:

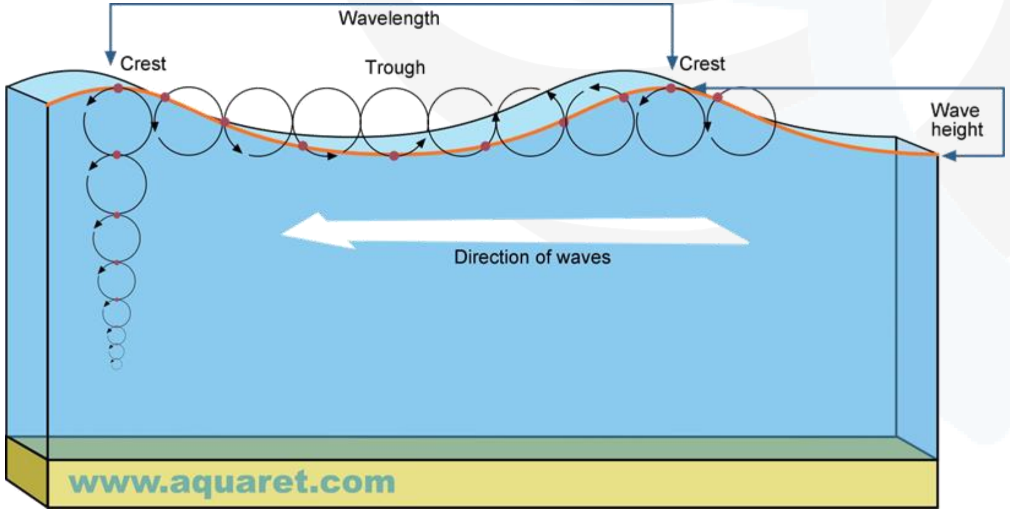
  - Wind strength: the average of persistent wind velocity
  - Wind duration: the time that wind blows in one direction
  - Fetch: the distance over which the wind blows uninterrupted in one direction

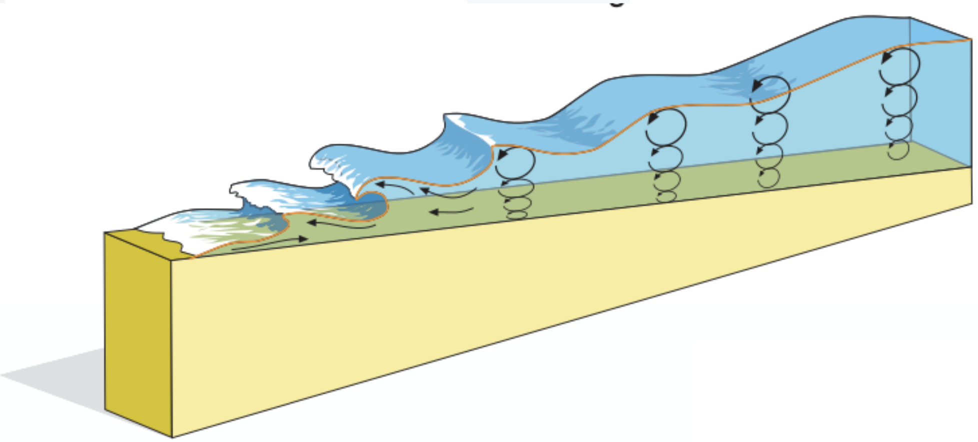
- The energy transferred will be affected by other factors such as water depth, seabed conditions and interaction with tides.

Wave theory

- Waves represents a water surface displacement from a still water level (SWL), displacement upwards is called “crest” and downwards “trough”.

  Waves have both kinetic energy (EK, moving water molecules) and potential energy (Ep, water molecules displaced vertically against surface tension ~ Coriolis Effect).





Wave theory

- The seas contains locally generated waves with small wavelengths (generated by local wind) and other waves (swell) generated elsewhere and travel an appreciable distance. These waves are a form of oscillatory wave and are defined by the following parameters:

  - Waveheight (H)
  - Wave period (T); time between successive wave crests
  - Wave length (λ): horizontal distance between successive wave crests

Wave Power

- Wave power which is available at a particular location at a particular time, including information about its variability on short timescales (from hours to days). This can be assessed by making wave measurements at the position of interest.

  Wave power climate at a particular location. The wave power climate includes the monthly, seasonal and annual statistics of wave power as well as a consideration of the variability of wave power on monthly, seasonal, annual and inter-annual timescales.

$$P = \frac{1}{32\pi}\rho g^2 H_s^2 T_e \text{ (W/m)}$$

  For a given wave period and height, we can compute the power that can be extracted per meter of crest of that wave.

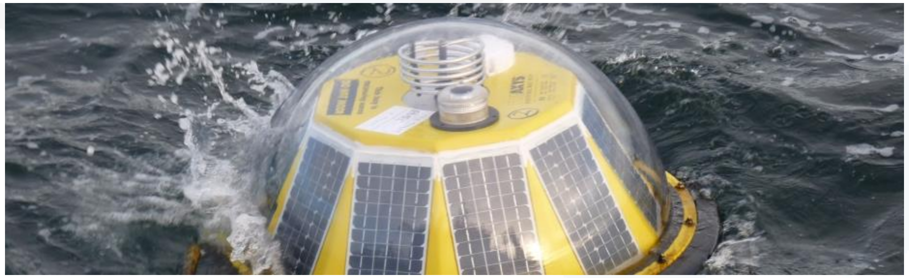
Source: http://www.aquaret.com/

Wave resource measurement

- Preliminary assessment of the wave power resource in the area of interest. This can be done by using summary statistics derived from one of the global models.
- Assess the inter-annual variability of wave power at the model site to ensure that the scheme is economically robust.
- If the climate statistic from global models are suitable then it is necessary to confirm the suitability of the WECS site, a programme of measurements to check the model results and to develop a measured climatology should be started.
- The results of the resource assessment will be deeply analysed.
- The wave power resource at the site of interest shall be subject to rolling review as more information becomes available.

Resource measurement instruments

- Surface-following buoys – suitable for monitoring at a fixed position in depths greater than 10 m.
- Acoustic Doppler Current Profilers (ADP) – which may be particularly suitable for shallower water.
- Pressure sensors – suitable for use in shallow water.
- HF Radar – a medium to long range remote sensing method.
- X-band radar – a short range high resolution remote sensing method.

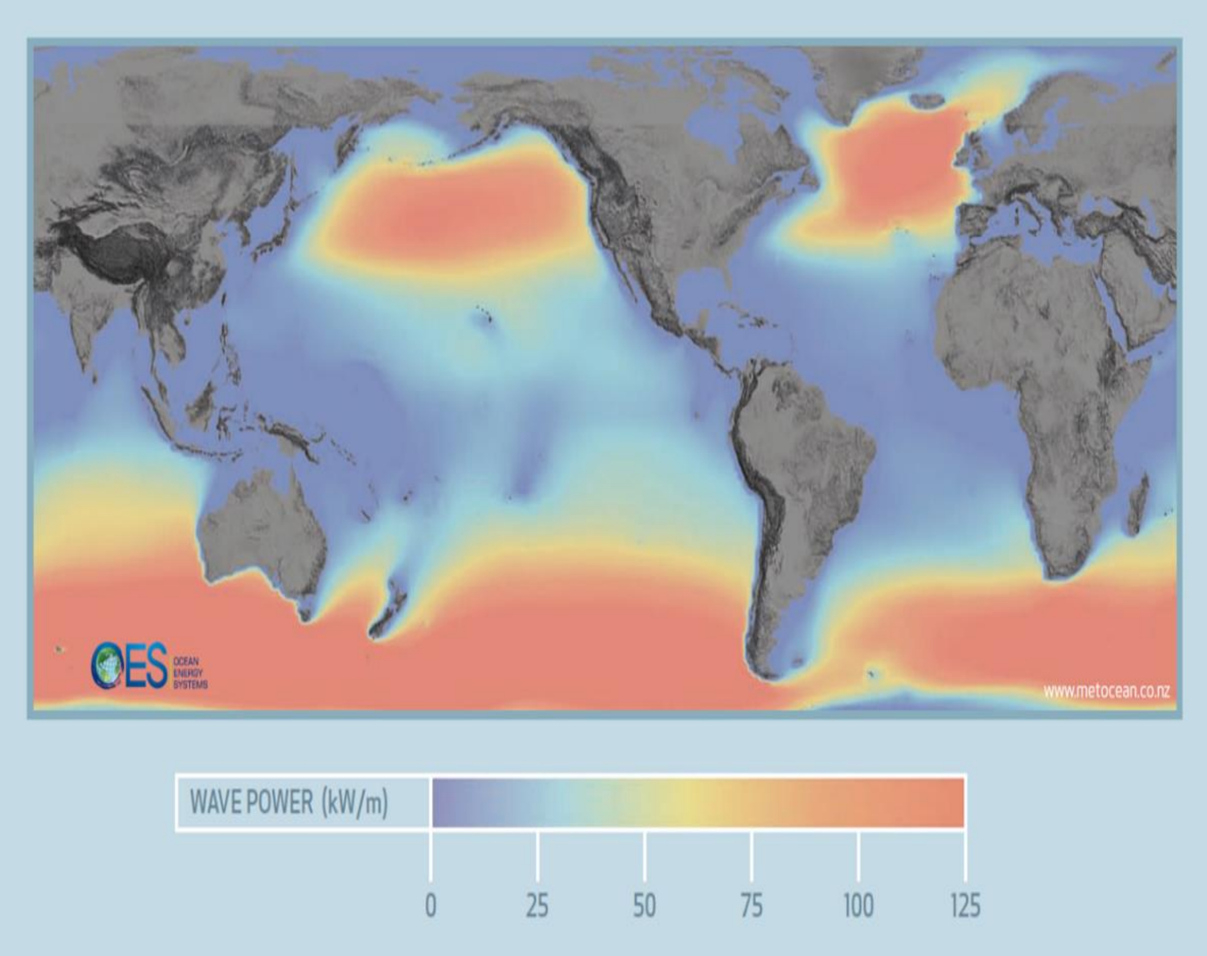


Wave buoy data

Source: EMEC Standards, assessment of wave energy resource

Global Distribution

- The wave energy resource in more than 2TW in all the oceans at one time.
- There are several regions with high incident wave power levels, well suited for wave energy exploitation like extreme latitudes (between 40° and 60° latitude in the North and South).



Source: IEA-OES, 2014b

World wave power distribution

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Tidal Energy

Tidal resource

- Created by the gravitational pull of the moon and sun on the seas
  → predictable

- Strong tidal streams arise when the tidal flows are constrained by land, islands and shallows.

Astronomic motions + topography

Fall of Warness, Orkney Island

Source: Aquatera

Tidal resource

- Astronomical components: gravitational effect (moon and sun) + centrifugal effect (rotational motion)

- Full moon & new moon → SPRING TIDES
- 1st quarter & 3rd quarter → NEAP TIDES

Bi-monthly cycle

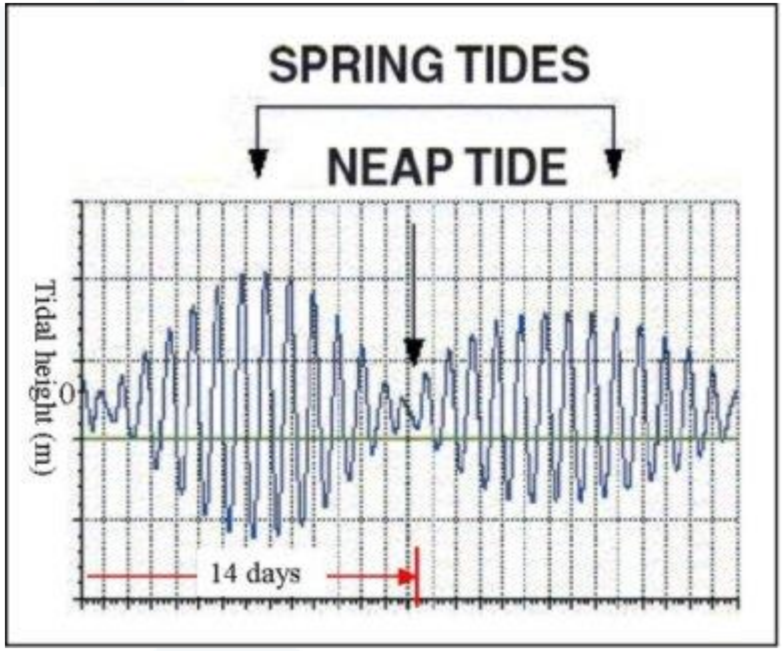
- Rotation of the earth around its axis → EBB & FLOOD

Diurnal-semi-diurnal-mixed cycle

- Tidal flow has 4 times the energy intensity of a good wind site and 20 times the energy intensity of sunshine

Tidal theory

- The complexity of tidal regimes comes from the fact that:
  - Flood and ebb tides are of different range, and the corresponding flow velocity will be of different strength
  - The first and second tidal cycles have different amplitudes
  - The local tidal flow pattern is not necessary sinusoidal
  - The amplitude of the 14 day spring-neap cycle varies continuously, peaking and troughing twice per year



Spring&Neap tides

Source: Strath University

Tidal theory

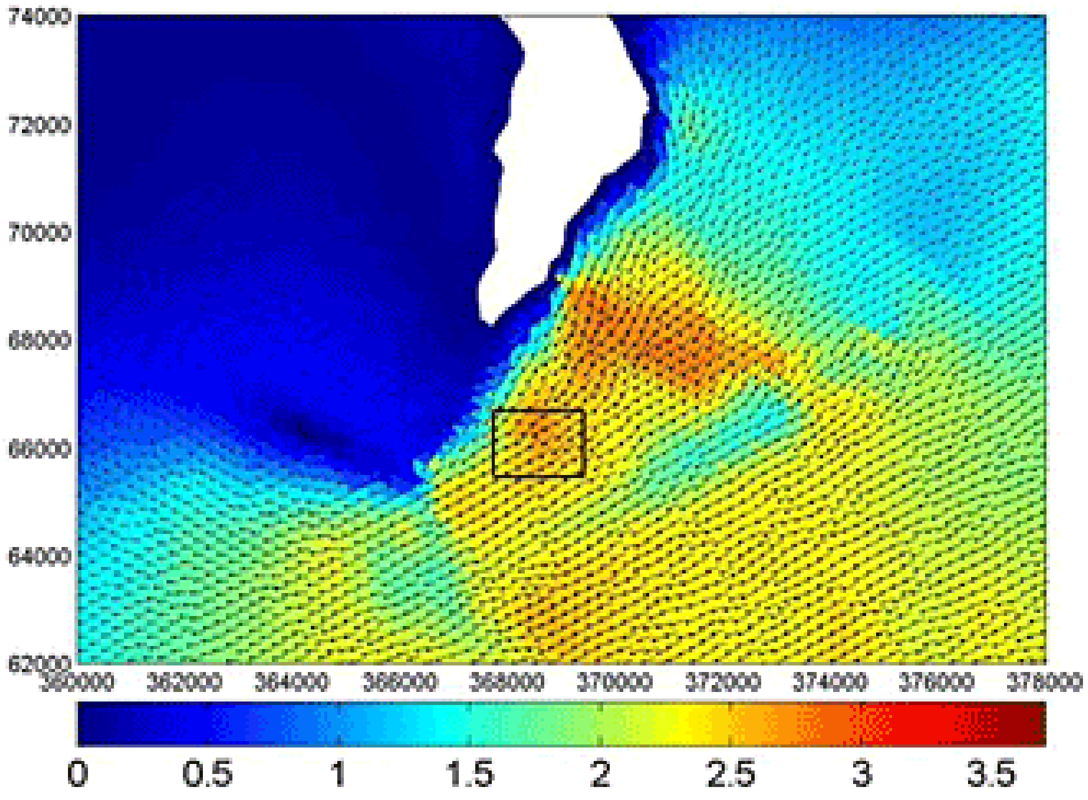
- Defining tidal flow regime:
  - Flow exceedance curve: accurate on site measurements and accurate tidal stream model that can predict the flow velocity/direction over a giving year and location
  - Velocity shear and flow direction: the hub height velocity at a site depends critically on both the average velocity shear profile at that site and the position of the turbine in that site

- Tidal flow regime modelling: tidal heights can usually be predicted to sufficient accuracy

Tidal theory

- Tidal flow regime modelling:

- With numerical models
- Very computationally intensive
- Must be validated by measurements



Tidal flows around Portland Bill headland

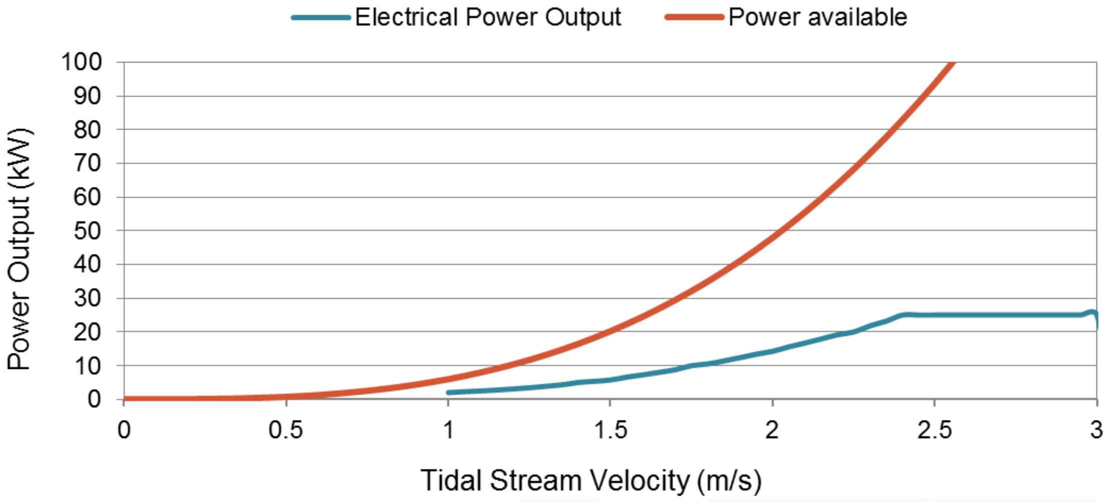
Source: University of Southampton

Tidal Power

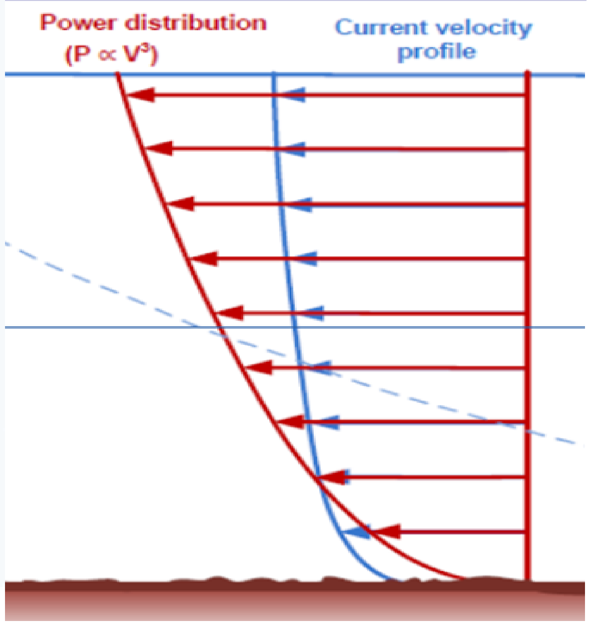
- Velocity distribution in the water column:

  - Velocity ~ 0 m/s near the seabed because of the friction water/seabed
  - Velocity increases with the decreasing depth
  - Maximum available energy near the water level

  Power distribution



Turbine Electric Power Output Curve with the Power Available on site



Power distribution Vs velocity

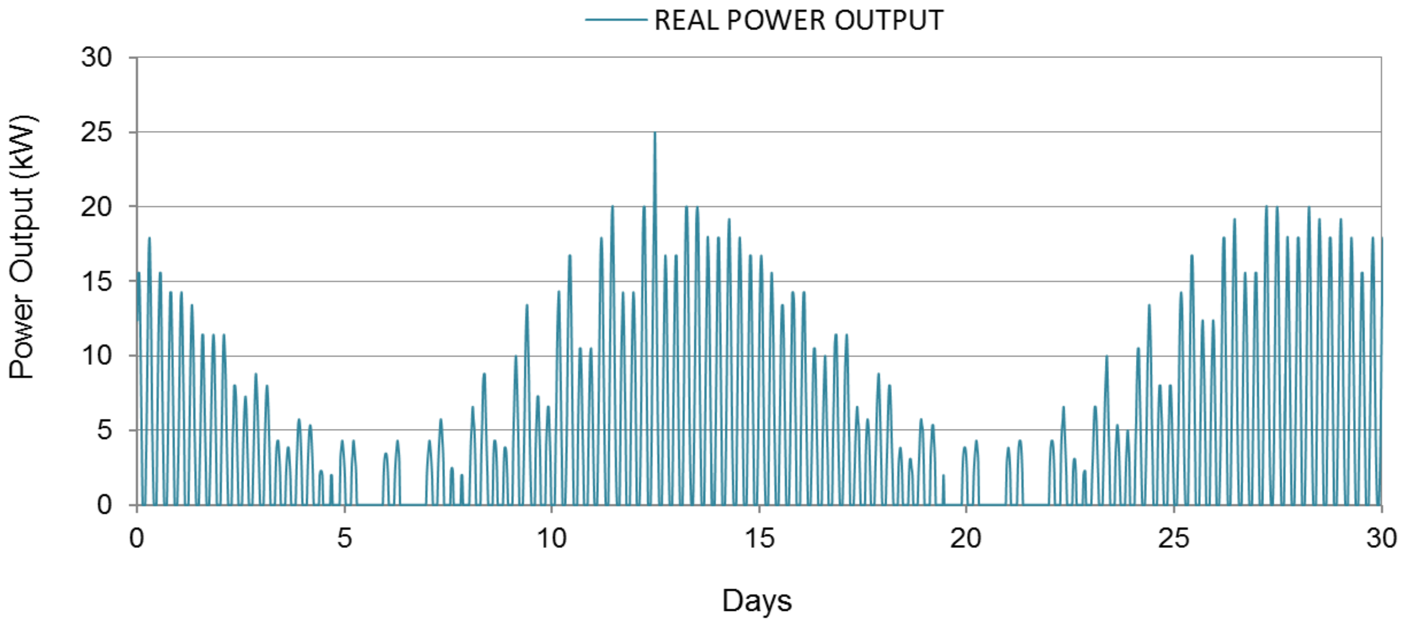
Source: University of Strathclyde

Tidal Power

- Actual power that can be converted into a usable mechanical form

P = Power
Cp = Power coefficient of maximum value of 0.59
p = density of the fluid
A= area of flow
V = velocity

$$P = \frac{1}{2} C_p \, p \, A \, V^3$$



Power output variation

Source: [University of Strathclyde]

Resource measurement

- Acoustic Doppler Current Profiler (ADCP)

Seabed Mounted ADCP

- ✓ Single point
- ✓ 30 days
- ✓ Turbulence
- ✓ Analysis + Prediction at any date in past or future
- ✓ 30 days measurements can be representative of the resourc

ADCP

Source: UniqueGroup

Source: Measuring discharge with acoustic Doppler current profilers from a moving boat

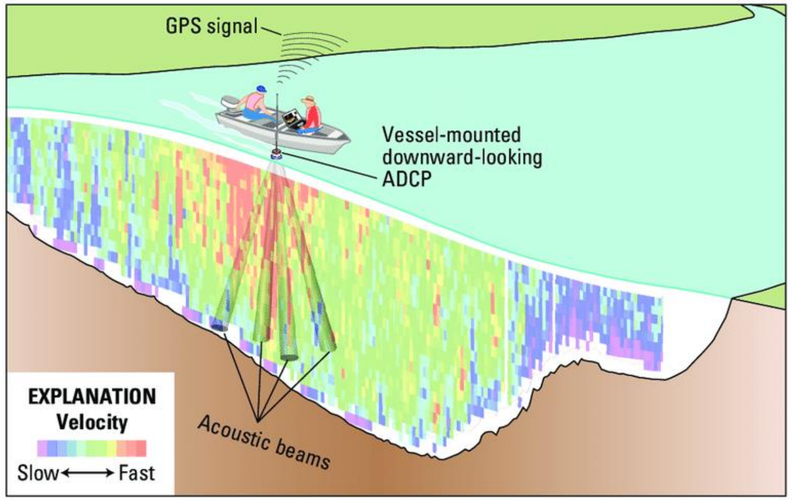
Resource measurement

- Vessel Mounted ADCP

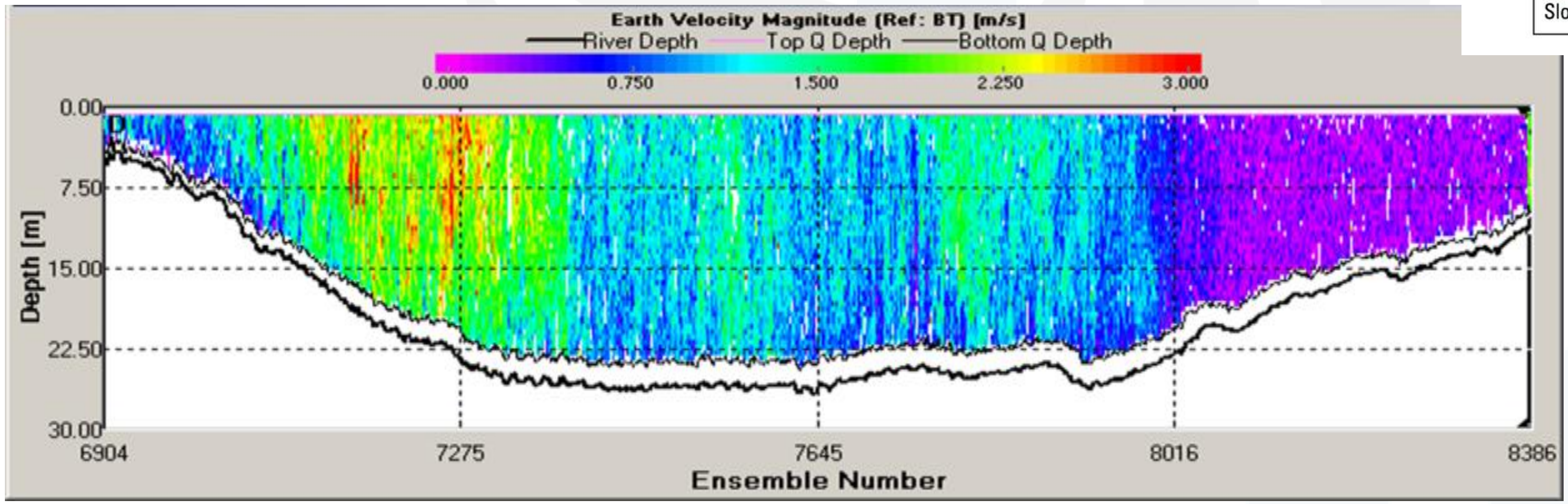
Map of currents over one tidal cycle (13 hours)

Every run line repeated every hour

Also possible in real time for operational support



Boat mounted acoustic doppler



Contour of velocity magnitude in a river cross section measured using an RDI Rio Grande broadband ADCP

Source: Sandia Energy, Budi Gunawan, Ph.D. Vincent S. Neary, Ph.D., P.E.

Global Distribution

- The available sites for tidal stream are nature limited
- The strongest marine currents are found in narrow straits, around headlands, between islands, bays and estuaries entrances
- In 2000. Blue Energy reported that only around 450GW of total tidal current resource could potentially be harnessed

Global distribution of tidal resource

Source: Aquatera

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OTEC & Salinity

OTEC resource

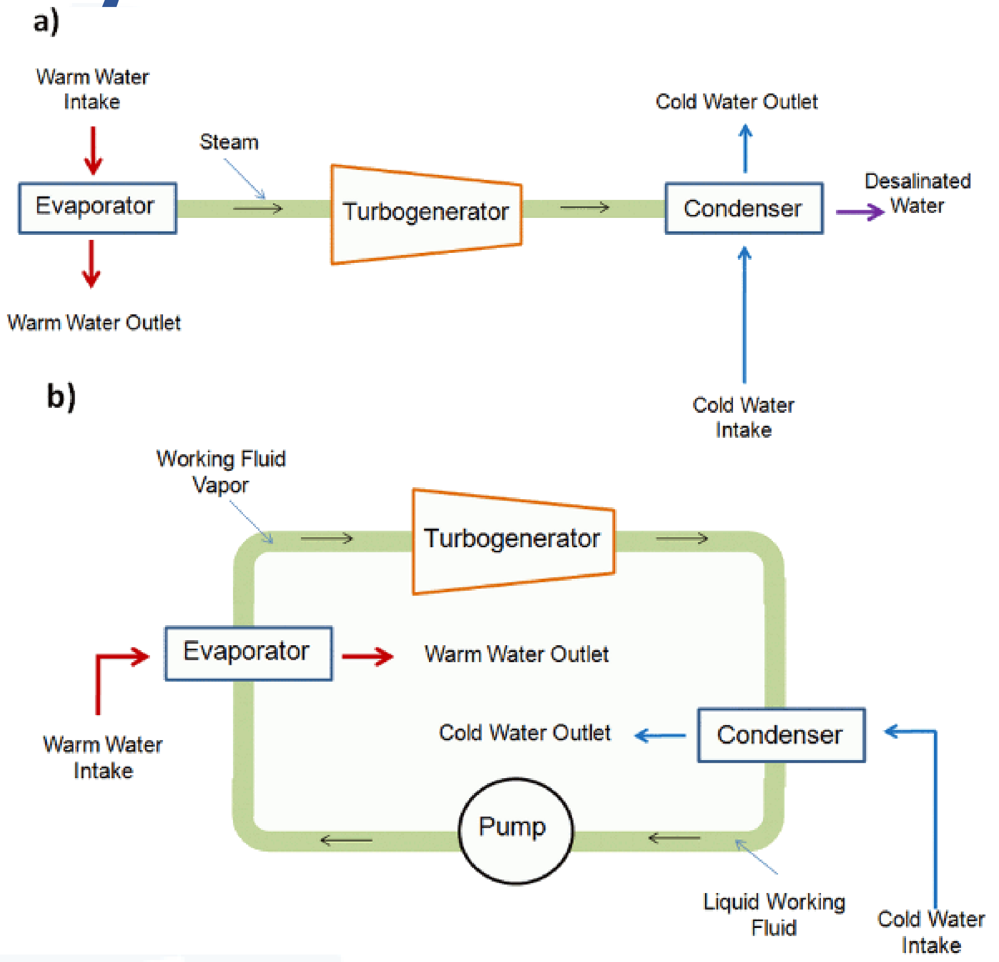
- Ocean Thermal Energy Conversion (OTEC) is a method of generating electricity which relies on the temperature difference between surface and subsurface ocean waters.
- In order for this technology to be economically viable, the temperature difference must be 20°C and the cold deep water must be no more that 100 m below the surface.
- The largest temperature differences, and therefore the largest resources for OTEC, are generally near the equator where the effects of the sun heating the ocean surface are greatest.

Salinity resource

- The principle behind salinity gradient power is that there is a difference in entropy between salt and fresh water which can be exploited for the production of energy.
- This form of energy is a complex concept as it cannot be detected in the same way as other forms of energy such as solar, wind or wave. However, considering that the reverse process, desalination of seawater, requires large amounts of energy, the principle behind salinity gradient power is more logical.
- There are two methods in development: reverse electro-dialysis (RED) and pressure retarded osmosis (PRO). Both of these processes use alternate chambers separated by semi-permeable membranes.

OTEC Theory

- Schematics of (a) open cycle and (b) closed cycle OTEC systems.
- The warm water is used to heat and vaporise a liquid, normally one with a low boiling point. As the expanding vapour expands it drives a turbine. Cold water brought up from the deep water is then used to condense the vapour back into liquid.



Schematics of (a) open cycle and (b) closed cycle OTEC systems

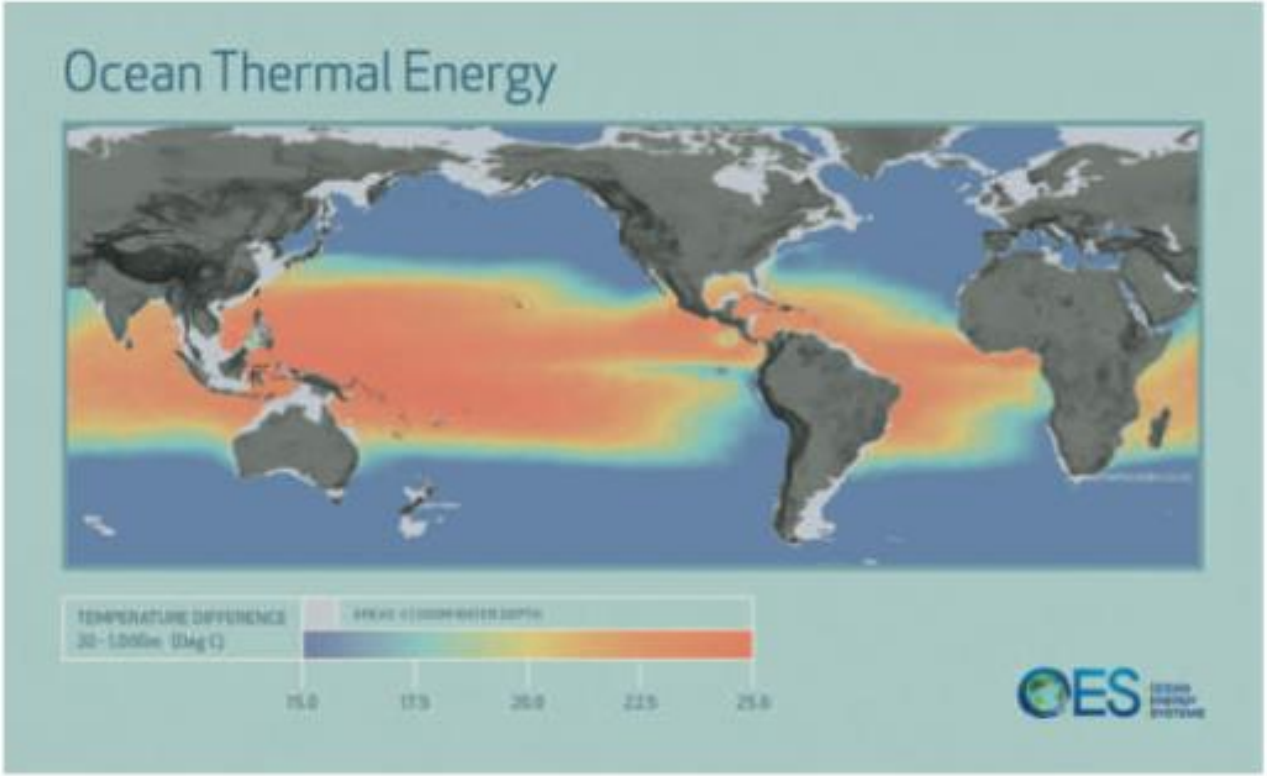
Source: Stanford University, Fall 2010

Salinity theory

- The RED method involves the migration of salt ions, by osmosis, through the semi-permeable membrane, thereby creating a low voltage current.
- The PRO method uses a membrane which is more permeable to water than to salt. Water molecules will be forced through the membrane to the salt water side. As water molecules pass through the membrane, hydrostatic pressure will increase on the seawater side, up to a maximum of 26 bars. This pressurized water is used to drive a turbine and make electricity.

OTEC Global Distribution

- OTEC resources are widespread. At least 98 nations and territories have been identified with access to OTEC thermal resources within their 200 nautical mile exclusive economic zone
- The total estimated available resource for OTEC could be up to 30 terawatt (TW) and deployments up to 7 TW would have little effect on the oceanic temperature fields

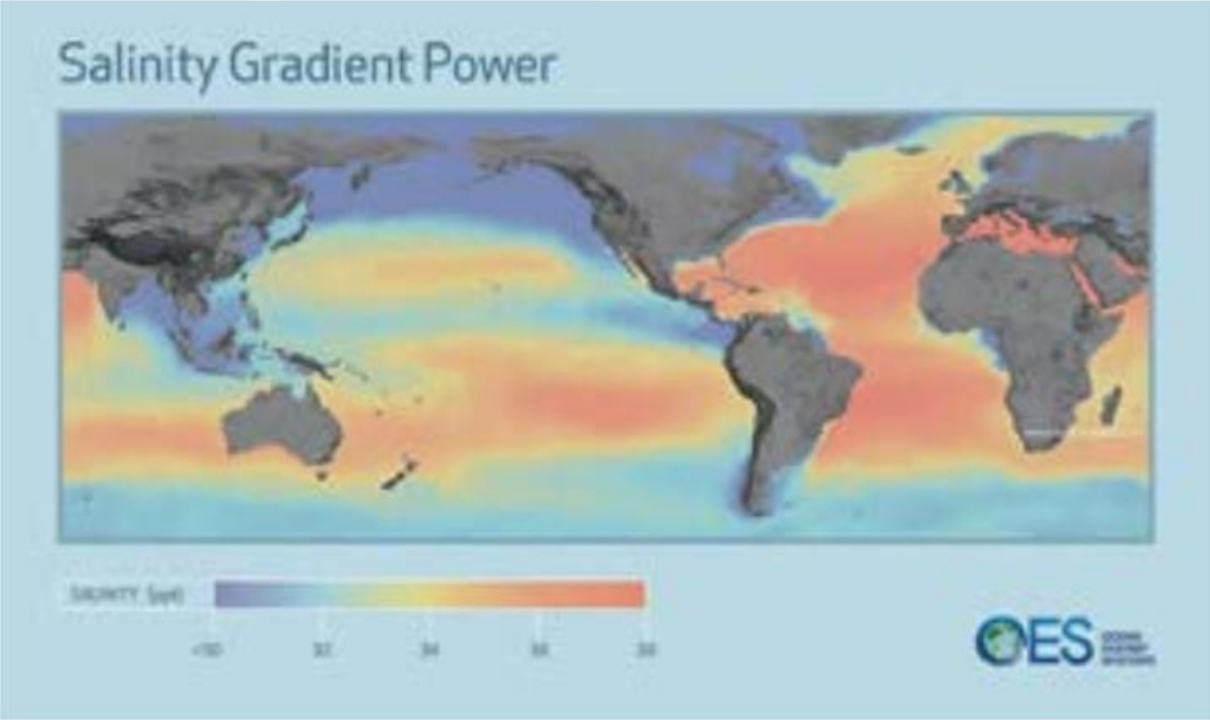


World OTEC resource

Source: International Energy Agency – Ocean Energy Systems (IEA-OES) 2014

Salinity Global Distribution

- Global technically exploitable potential is currently estimated at around 647 GW
- Although lack of consideration of legal and environmental parameters may have led to an overestimation.
- Ocean salinity gradients have an estimated technical potential of about 1650 TWh/year;



World Salinity Gradient resource

Source: Salinity gradient energy technology brief, IRENA

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Wave

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OTEC&Salinity

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Questions ET 1

10 minutes for Qs

First break