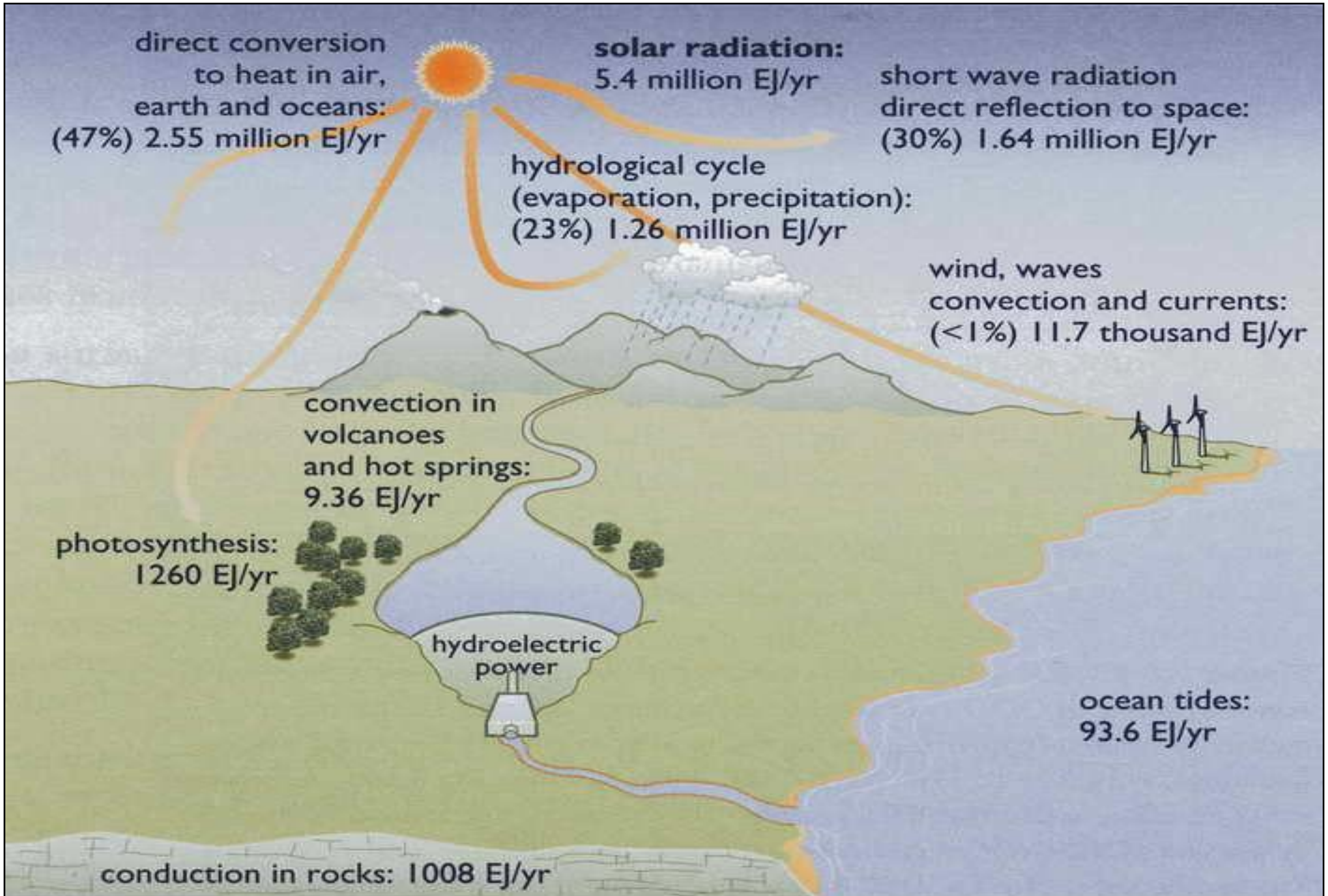
Ocean Energy

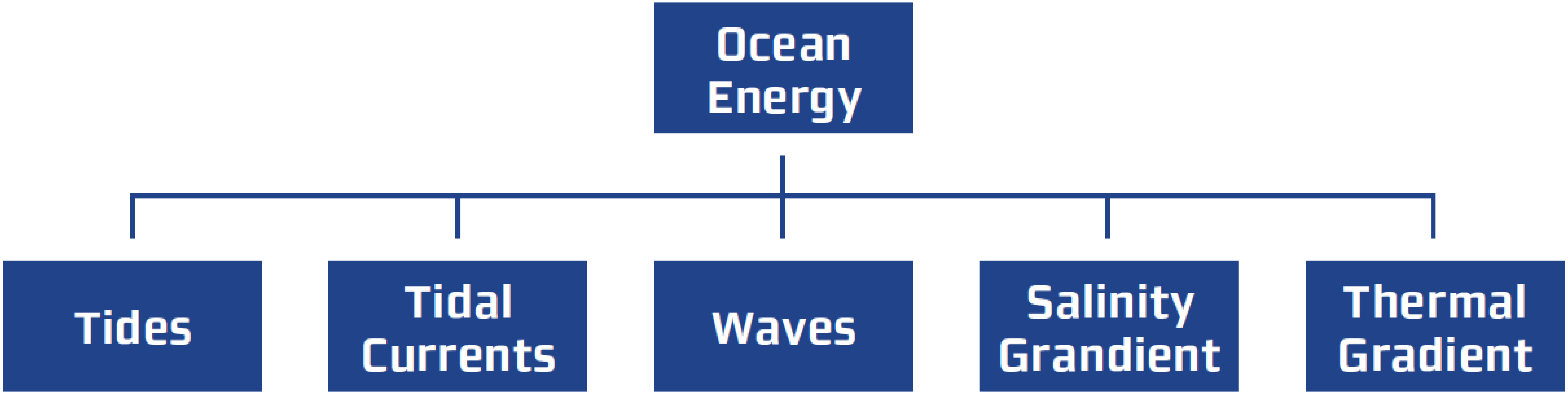
Sources of New Energy



Boyle, *Renewable Energy,* Oxford University Press (2004)

- Renewable
  - Hydro Power
  - Wind Energy
  - Oceanic Energy
  - Solar Power
  - Geothermal
  - Biomass

- Sustainable
  - Hydrogen & Fuel Cells
  - Nuclear
  - Fossil Fuel Innovation
  - Exotic Technologies
  - Integration
    - Distributed Generation



Which are not driven from solar energy???

Overview of Ocean Energy

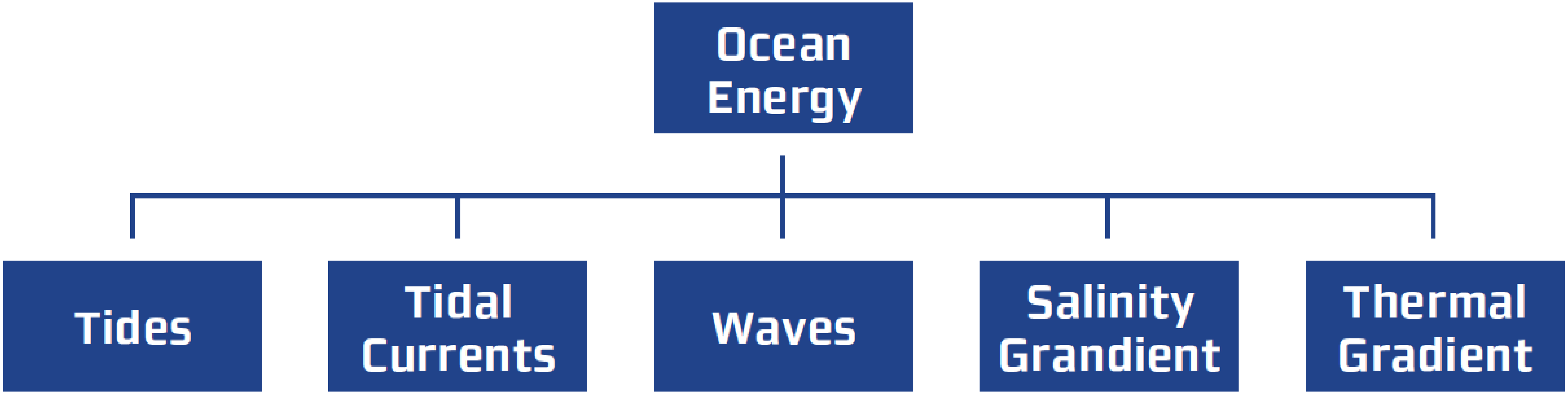
-ocean energy is replenished by the sun and through tidal influences of the moon's and sun's gravitational forces

-near-surface winds induce wave action and cause wind-blown currents at about 3% of the wind speed

-tides cause strong currents into and out of coastal basins and rivers

-ocean surface heating by some 70% of the incoming sunlight adds to the surface water thermal energy, causing expansion and flow

-wind energy is stronger over the ocean due to less drag, although technically, only seabreezes are from ocean energy



- **Hydro power** – solar heating evaporates water from the surface of the oceans, form clouds, condenses as rain, falls over land, causes rivers to flows to feed dams that generate electricity
- **Wave energy** – winds generate large ocean waves that can be used to generate power from its potential and kinetic energy.
- **Ocean temperature energy conversion (OTEC)** – temperature gradient between the surface and bottom of the ocean can be utilized in a heat engine to generate power
- **Tidal energy** – caused by lunar and solar gravitational forces acting together with that from the earth on the ocean waters to create tidal flows manifested by the rise and fall of waters that vary daily and seasonally from a few centimeters up to 8-10 meters in some parts of the world. The potential energy of the tides is tapped to generate power.

Ocean Energy

- Tides
- Tidal Currents
- Waves
- Salinity Grandient
- Thermal Gradient

Estimated Global Electricity Production from ocean sources	(TWh/year)
Tidal	0.3K
Tidal current	0.8K
Ocean wave	8K-80K
Salinity gradient	2K
Thermal energy	10K
Total Oceanic Resources	**~20K-90K**
Total world electricity production from all sources	**17.45K**

-250 Billion barrels of oil worth of energy coming into ocean every day

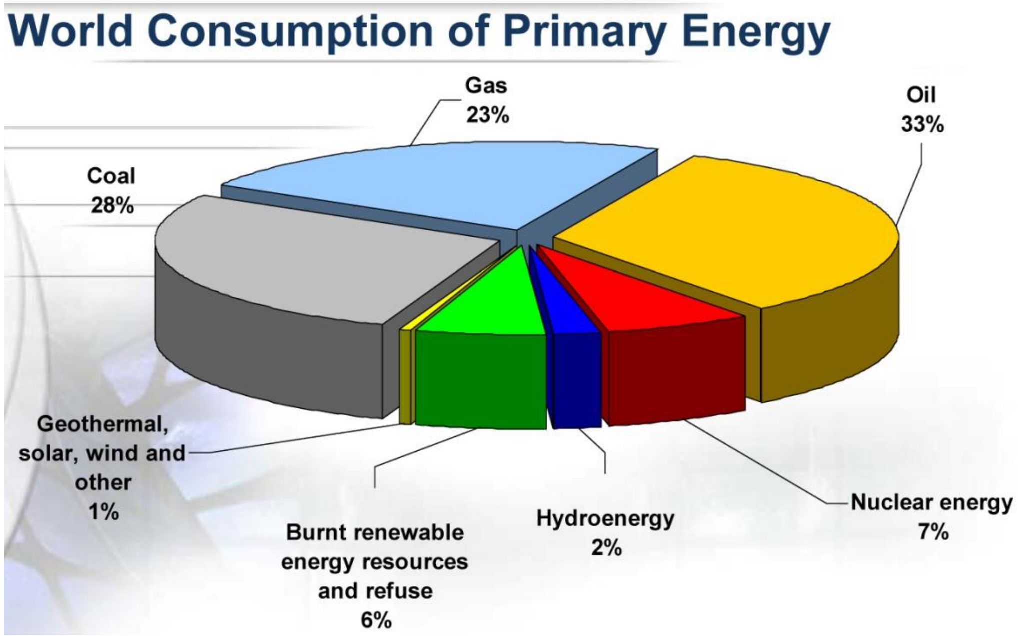
-80 million barrels of oil per day produced

World's electricity consumption 17,000 TWh/yr

Table compiled from International Energy Agency, Policy Report, 2006

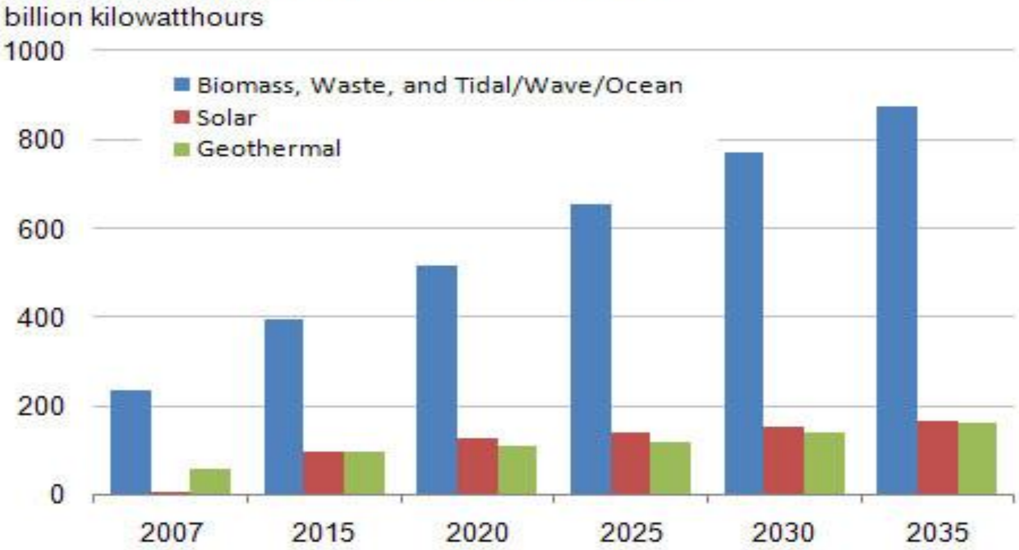
Introduction

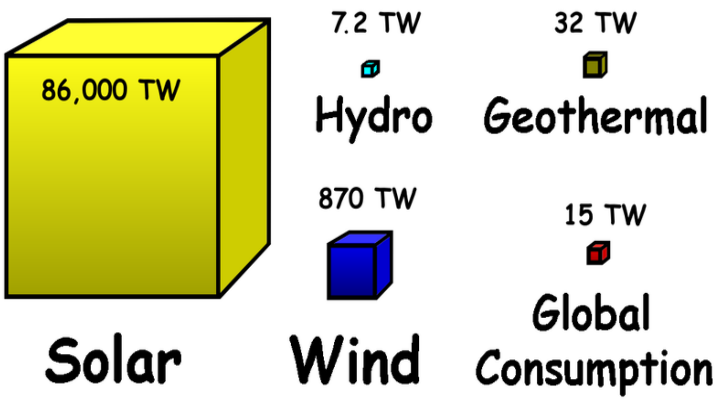
Energy…
Present and Future



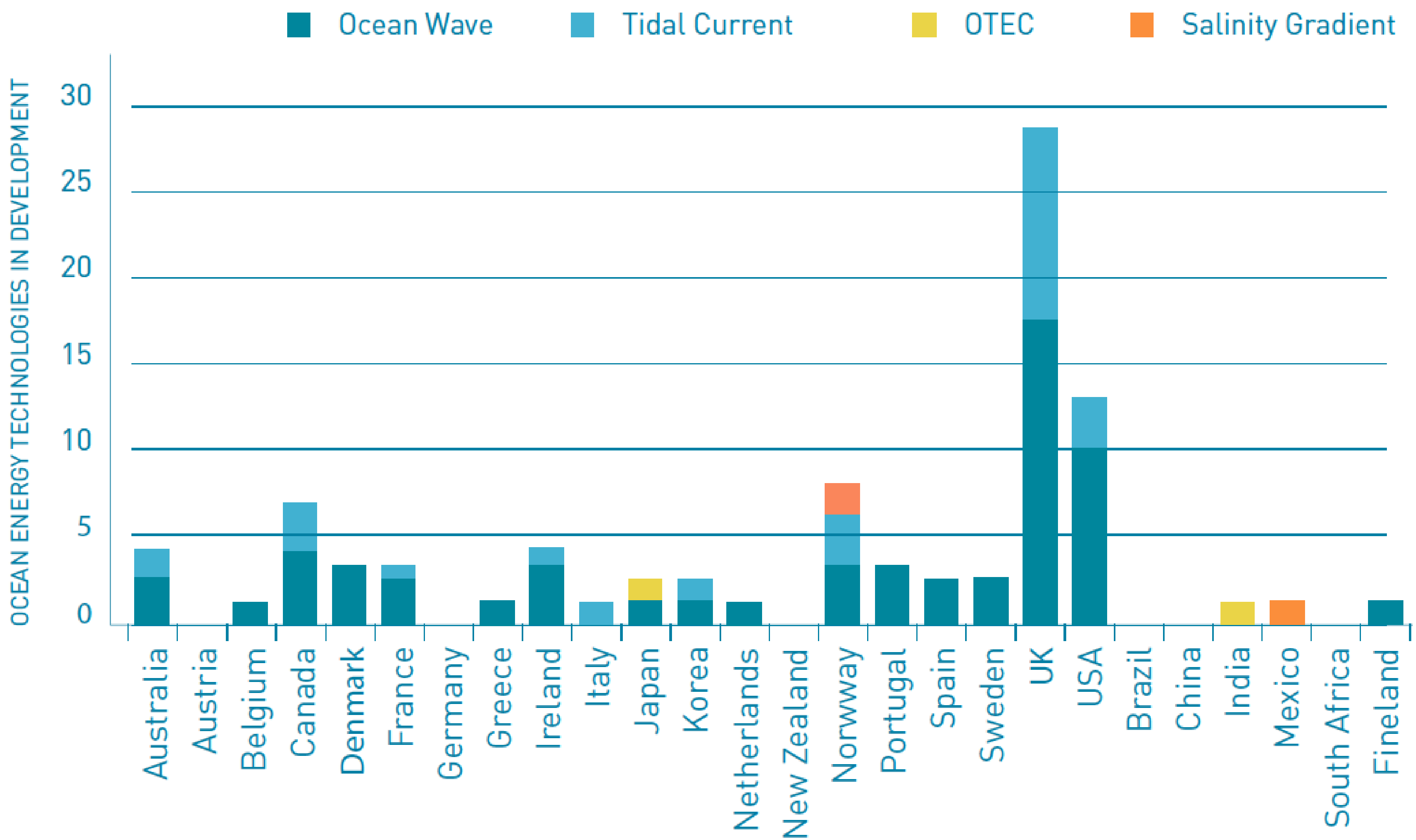
Federal Agency for Science and Innovation, 2008, Moscow, Russia

Figure 7. World renewable electricity generation by energy source, excluding wind and hydropower





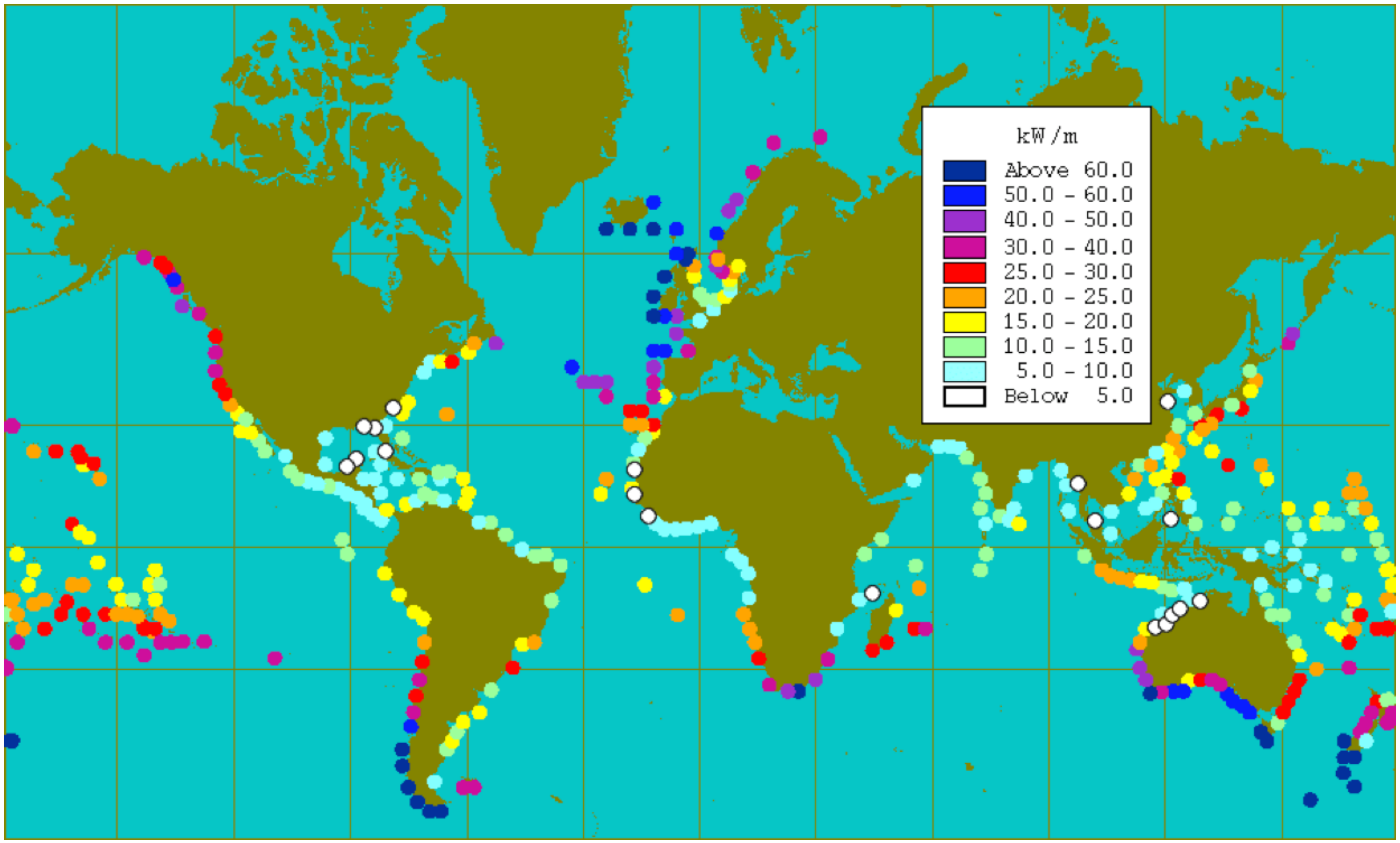
DISTRIBUTION OF CONVERSION TECHNOLOGIES BEING DEVELOPED WORLDWIDE



International Energy Agency, Policy Report, 2006

Power From Ocean Waves

- Wave energy is strongest on the west coasts and increases toward the poles.
- At approx. 30 kW/mcl in the Northwest (yearly avg.), a single meter (3.3 feet) of wave has the raw energy to power about 23 homes.



Why Ocean?

- The ocean is the world's largest solar collector and can provide huge amount of energy (kinetic and thermal) which is absolutely clean (zero CO2 emission), sustainable, strategic, and predictable.
- Changes in salinity, thermal gradients, tidal sea level change and currents, or ocean waves can be used to generate electricity.
- The number of ocean energy technology concepts has increased to +100 known devices.
- Available global Ocean Energy resource is in the same order of magnitude of the present electricity production worldwide (even more!).

- Tidal Power
  - Technologies
  - Environmental Impacts
  - Economics
  - Future Promise
- Wave Energy
  - Technologies
  - Environmental Impacts
  - Economics
  - Future Promise

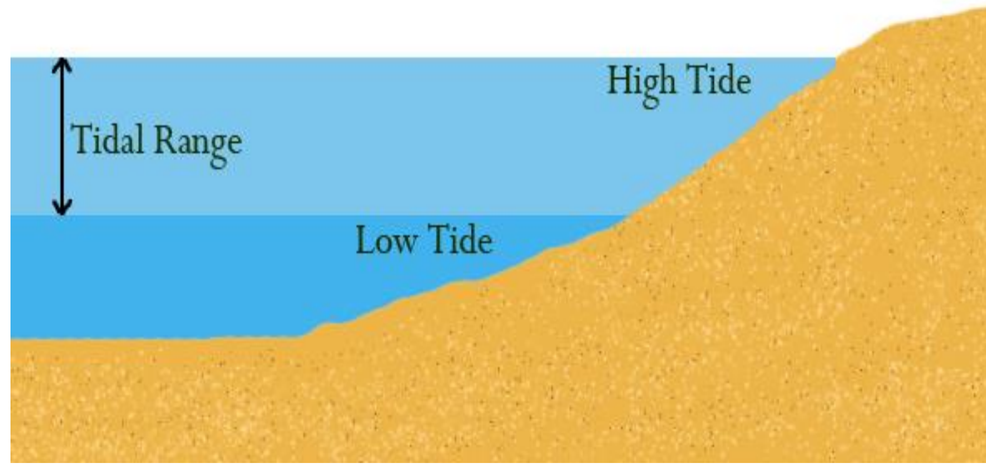
Hydrokinetic vs. Hydropower

- To understand ocean current energy, the distinction between hydropower and hydrokinetic power must be understood
- **"Hydropower"**
  - Alters the environment to create useable energy from rivers and streams
- **"Hydrokinetic"**
  - Harnesses the existing flow, current or velocity of water without altering the environment

Tidal Power

Tidal Motions

Tidal Forces



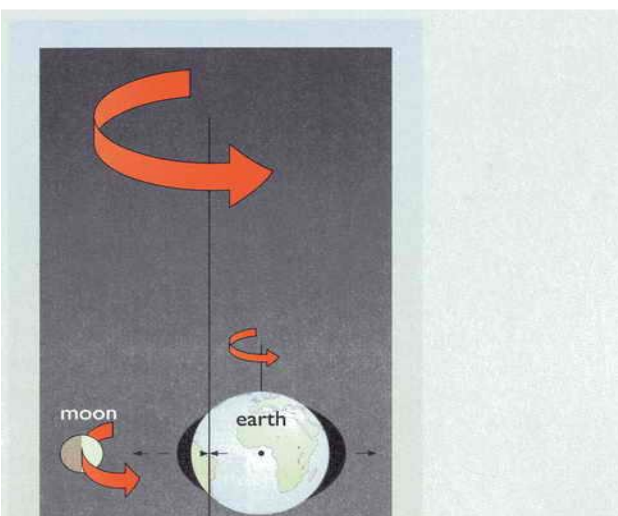


Figure 6.3 Relative rotation of the earth and the moon (not to scale)

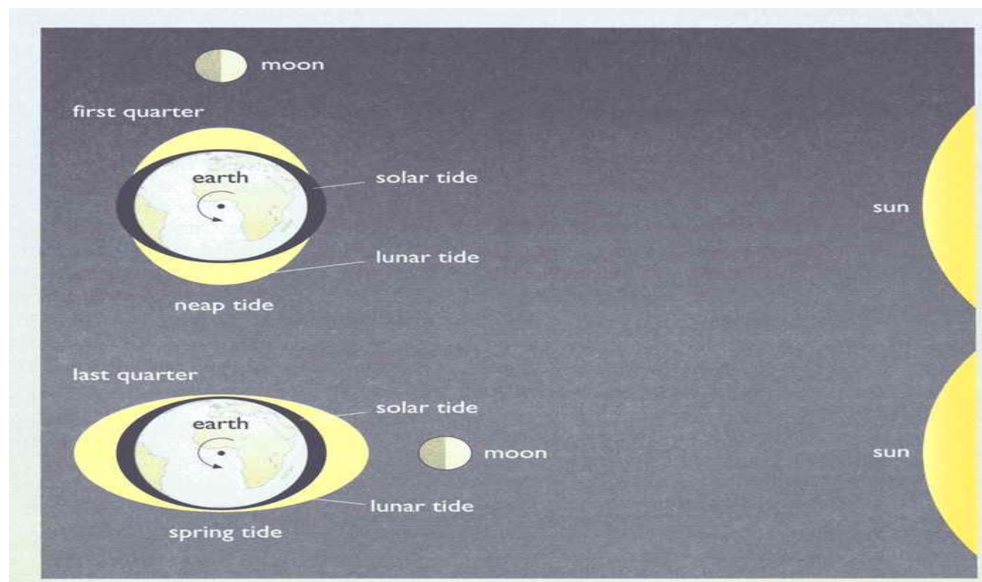
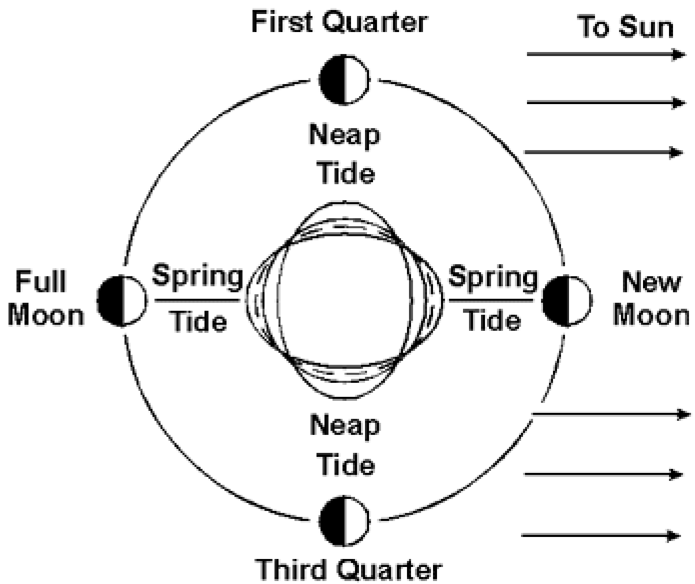
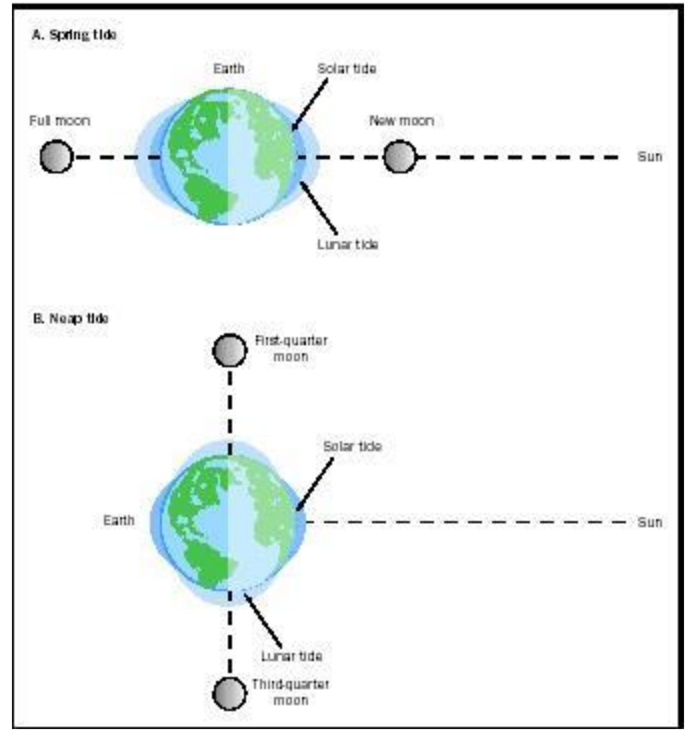
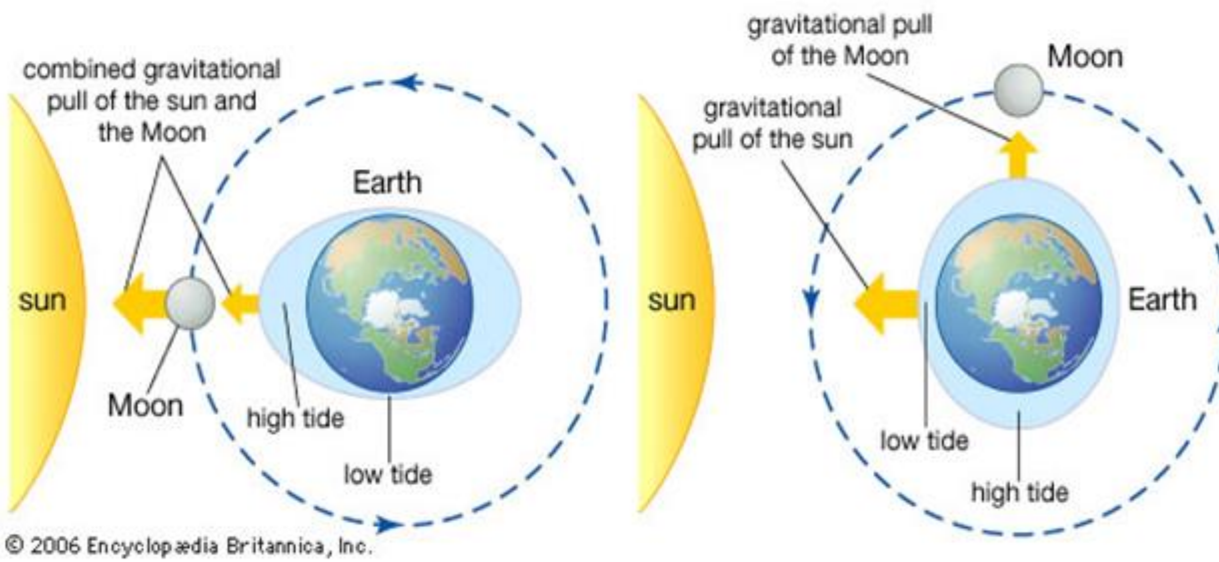


Figure 6.4 Influence of the sun and the moon on tidal range (not to scale)

Boyle, *Renewable Energy,* Oxford University Press (2004)


First Quarter
To Sun
Neap
Tide
Full
Moon
Spring
Tide
Spring
Tide
New
Moon
Neap
Tide
Third Quarter


A. Spring tide
Earth
Solar tide
Full moon
New moon
Sun
Lunar tide
B. Neap tide
First-quarter
moon
Solar tide
Earth
Sun
Lunar tide
Third-quarter
moon


combined gravitational
pull of the sun and
the Moon
Earth
sun
Moon
high tide
low tide
gravitational pull
of the Moon
Moon
gravitational
pull of the sun
sun
Earth
low tide
high tide
© 2006 Encyclopædia Britannica, Inc.

Natural Tidal Bottlenecks

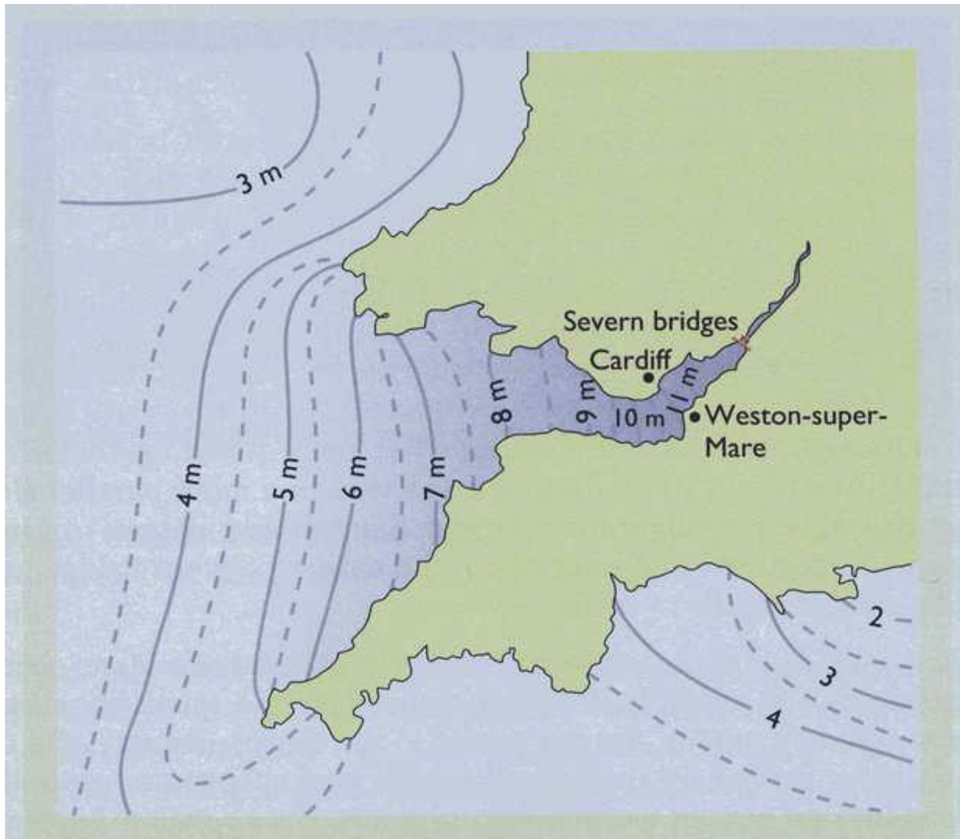
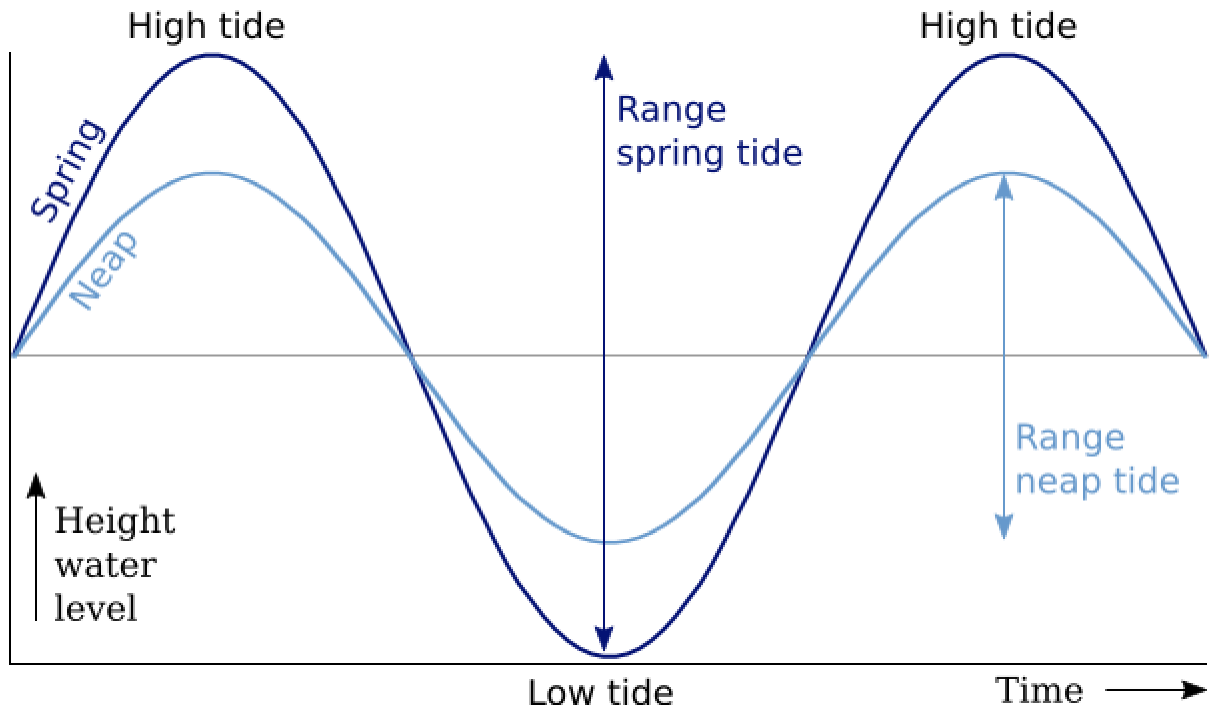
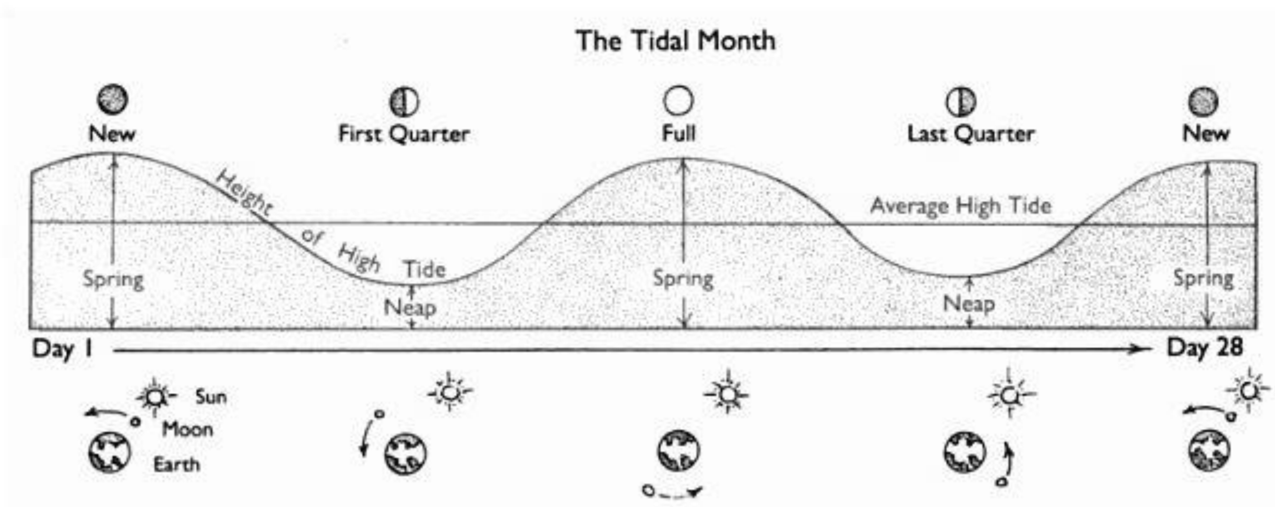


Figure 6.5 The effects of concentration of tidal flow in the Severn Estuary (tidal ranges in metres)

Boyle, *Renewable Energy,* Oxford University Press (2004)


High tide
High tide
Spring
Neap
Range
spring tide
Range
neap tide
Height
water
level
Low tide
Time


The Tidal Month
New
First Quarter
Full
Last Quarter
New
Height of High Tide
Average High Tide
Spring
Neap
Spring
Neap
Spring
Day 1
Day 28
Sun
Moon
Earth

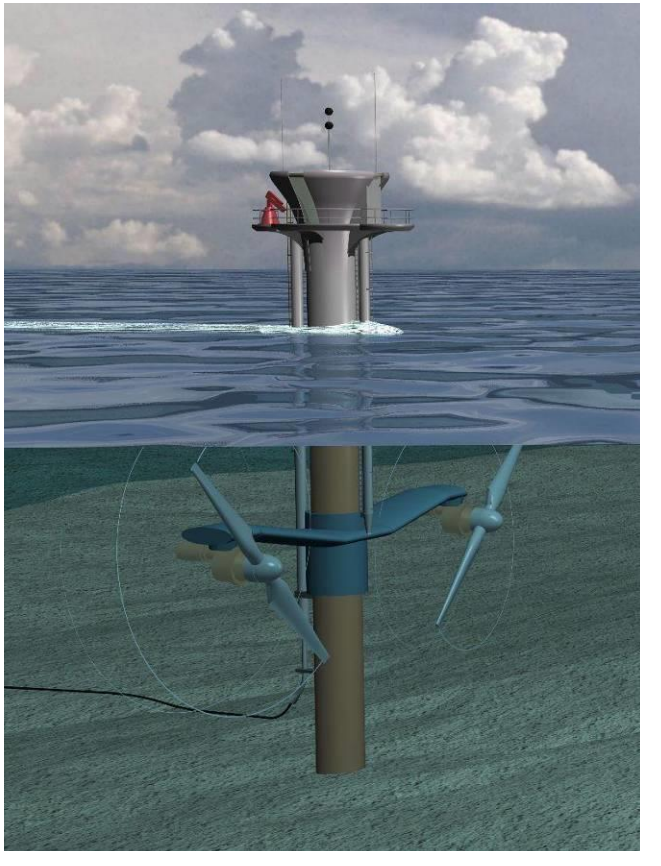
Tidal Energy Technologies

1. Tidal Turbine Farms
2. Tidal Barrages (dams)


c MCT Ltd 2003

Tidal Turbines (MCT Seagen)

- 750 kW – 1.5 MW
- 15 – 20 m rotors
- 3 m monopile
- 10 – 20 RPM
- Deployed in multi-unit farms or arrays
- Like a wind farm, but
  - Water 800x denser than air
  - Smaller rotors
  - More closely spaced



MCT Seagen Pile

http://www.marineturbines.com/technical.htm

Oscillating Tidal Turbine

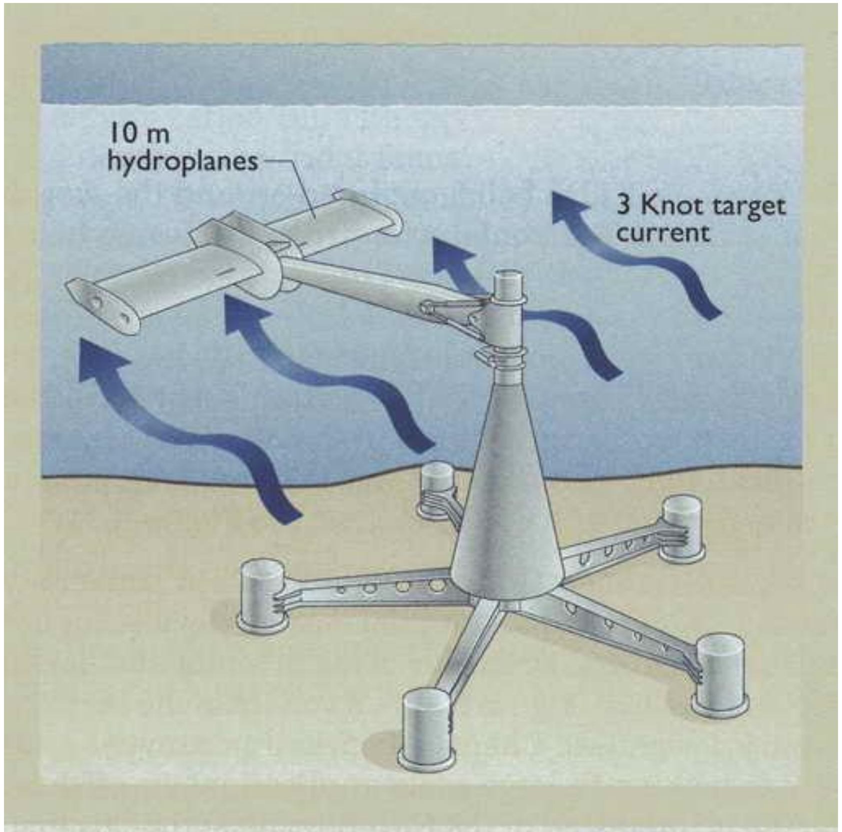
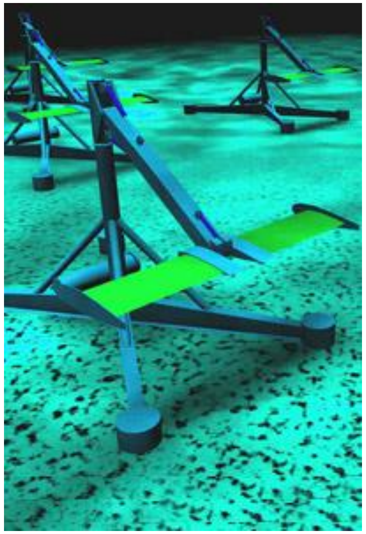


Figure 6.29 Stingray tidal generator

- Oscillates up and down
- 150 kW prototype operational (2003)
- Plans for 3 – 5 MW prototypes



http://www.engb.com

Boyle, *Renewable Energy,* Oxford University Press (2004)

Polo Tidal Turbine

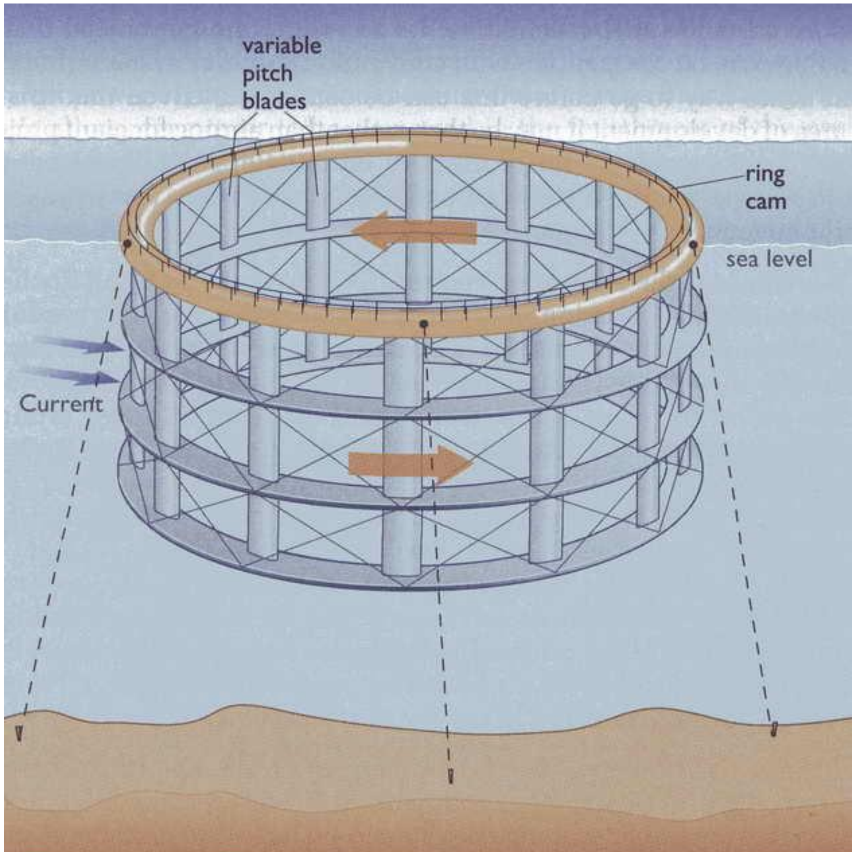


Figure 6.35 Salter's proposed 'Polo' turbine. The cylindrical rotor assembly rotates on roller bearings in a ring cam system which is anchored to the sea bed

- Vertical turbine blades
- Rotates under a tethered ring
- 50 m in diameter
- 20 m deep
- 600 tonnes
- Max power 12 MW

Boyle, *Renewable Energy,* Oxford University Press (2004)

Advantages of Tidal Turbines

- Low Visual Impact
  - Mainly, if not totally submerged.
- Low Noise Pollution
  - Sound levels transmitted are very low
- High Predictability
  - Tides predicted years in advance, unlike wind
- High Power Density
  - Much smaller turbines than wind turbines for the same power

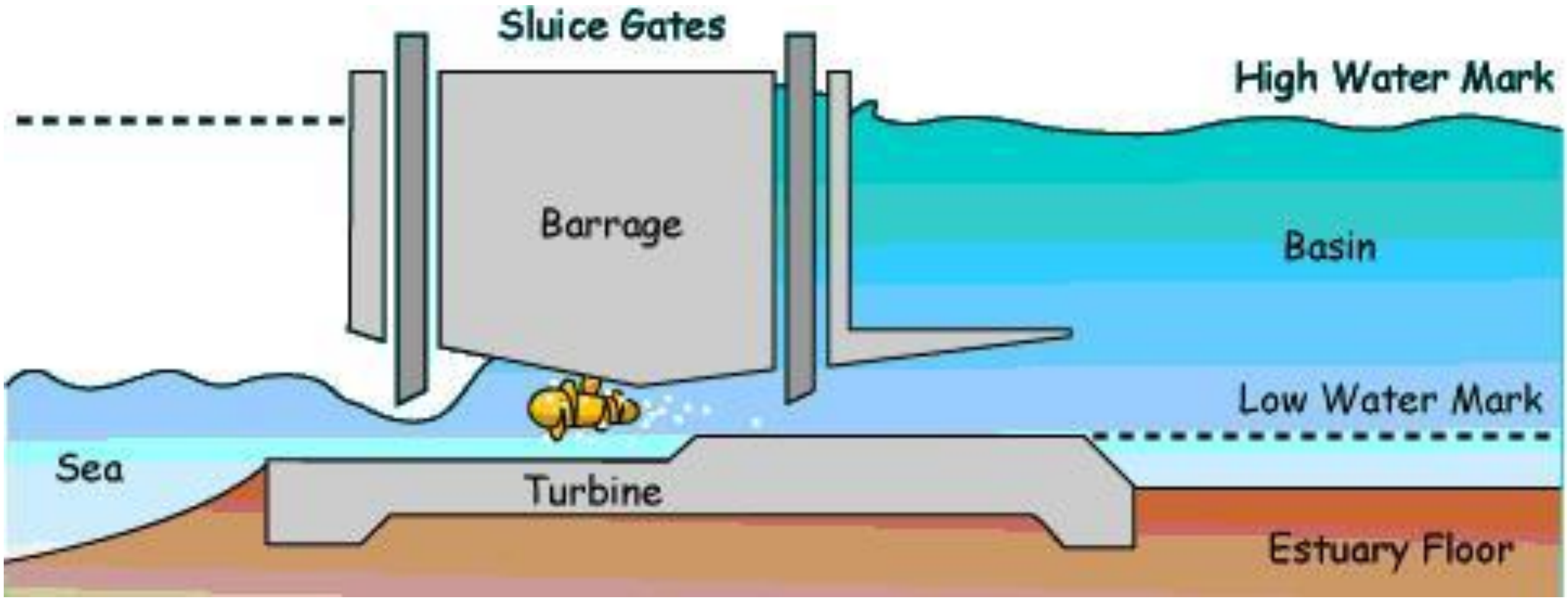
http://ee4.swan.ac.uk/egormeja/index.htm

Disadvantages of Tidal Turbines

- High maintenance costs
- High power distribution costs
- Somewhat limited upside capacity
- Intermittent power generation

2. Tidal Barrage Schemes

(Conventional) Tidal Energy



Technologies for harnessing energy from tides by building barrage across estuary are well developed, but this type of conversion process could have significant impact on local ecosystem.

Definitions

- Barrage
  - An artificial dam to increase the depth of water for use in irrigation or navigation, or in this case, generating electricity.
- Flood
  - The rise of the tide toward land (rising tide)
- Ebb
  - The return of the tide to the sea (falling tide)

Potential Tidal Barrage Sites

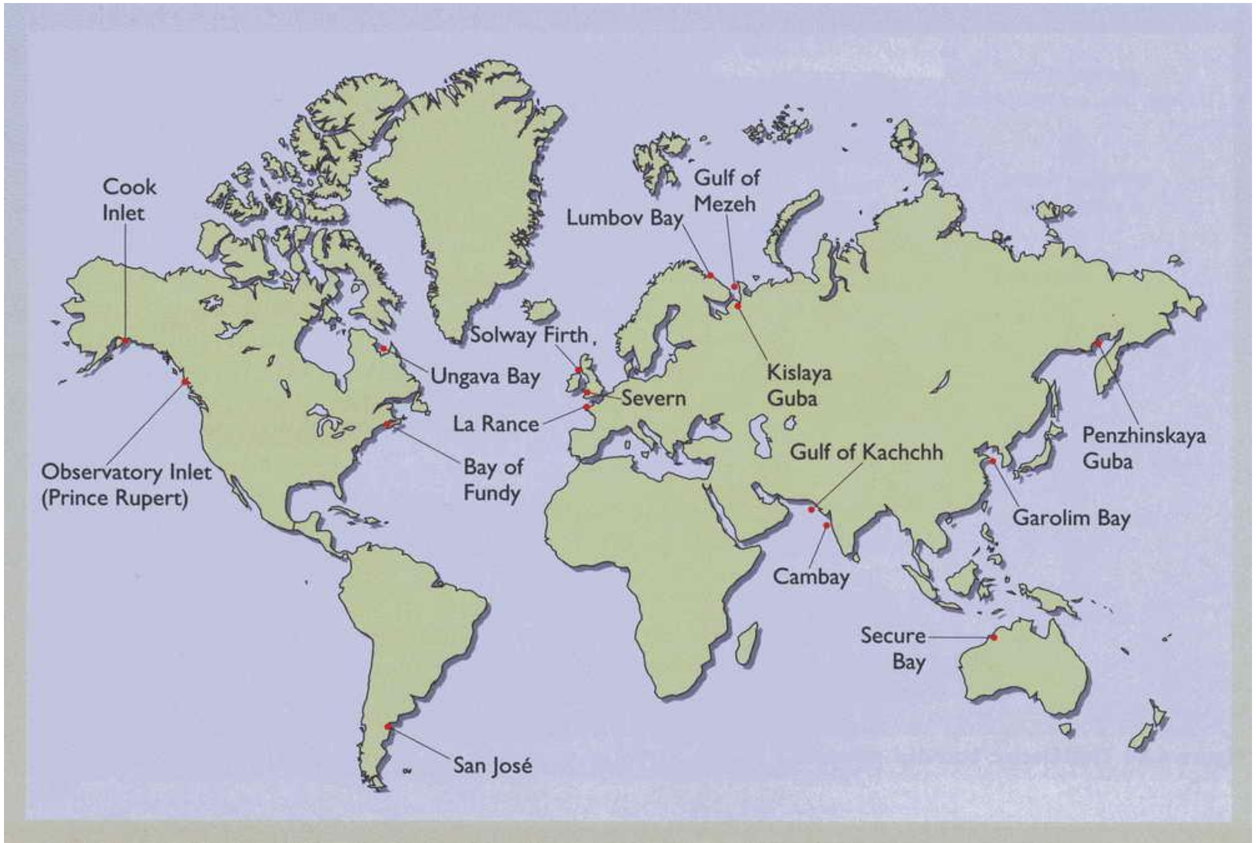


Figure 6.23 Some world locations for potential tidal power projects

Only about 20 sites in the world have been identified as possible tidal barrage stations

Boyle, *Renewable Energy,* Oxford University Press (2004)

Tidal Barrage Tubular Turbine

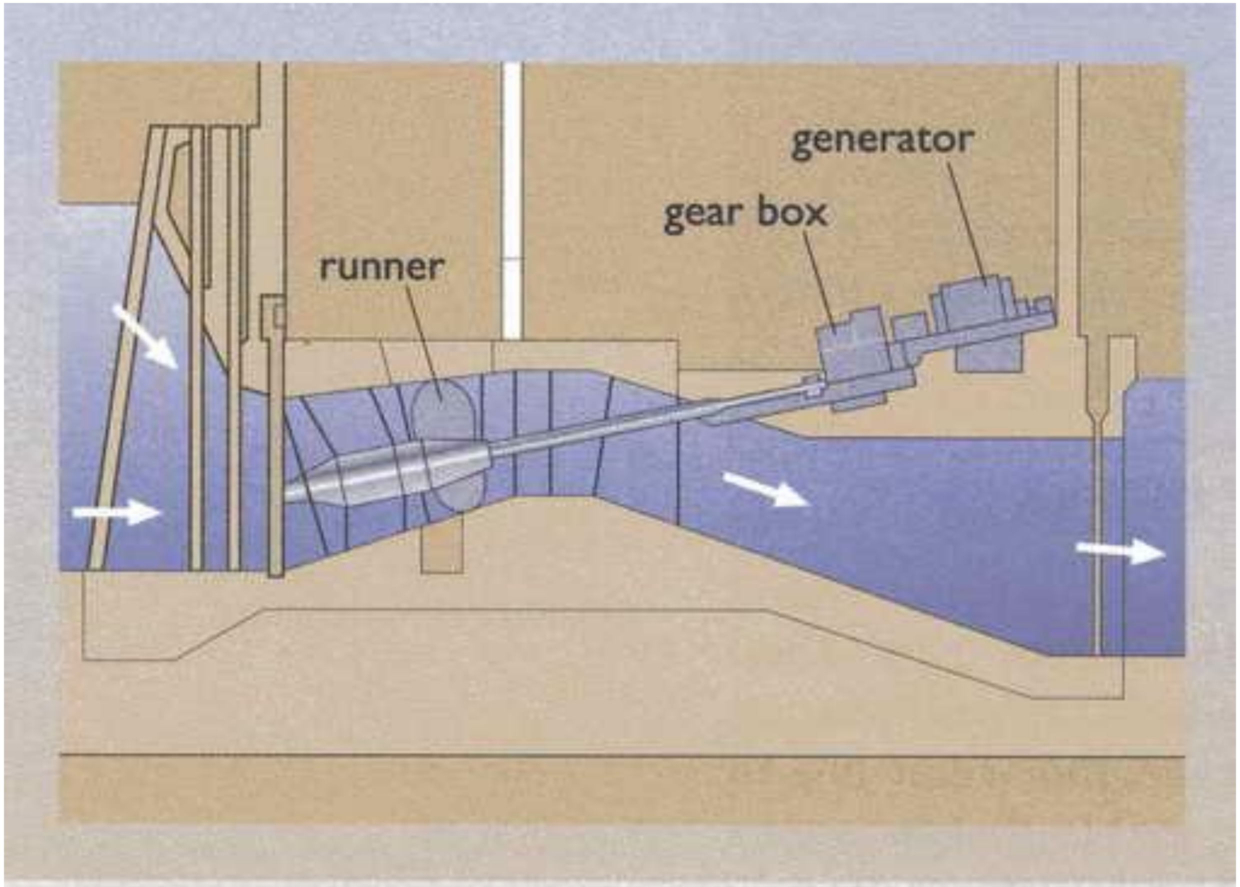


Figure 6.13 Tubular turbine

Boyle, *Renewable Energy,* Oxford University Press (2004)

La Rance Tidal Power Barrage

- Rance River estuary, Brittany (France)
- Largest in world
- Completed in 1966
- 24×10 MW bulb turbines (240 MW)
  - 5.4 meter diameter
- Capacity factor of ~40%
- Maximum annual energy: 2.1 TWh
- Realized annual energy: 840 GWh
- Electric cost: 3.7¢/kWh

Boyle, *Renewable Energy,* Oxford University Press (2004)

Tester *et al., Sustainable Energy,* MIT Press, 2005

La Rance River, Saint Malo

La Rance Barrage Schematic

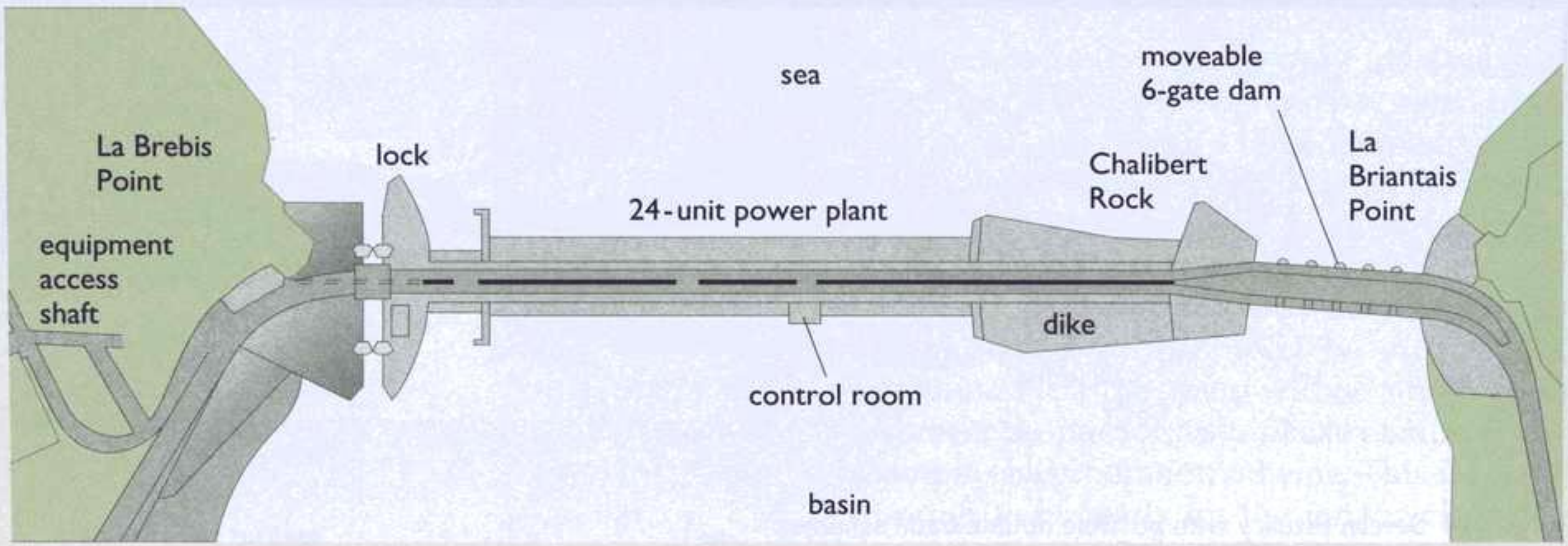
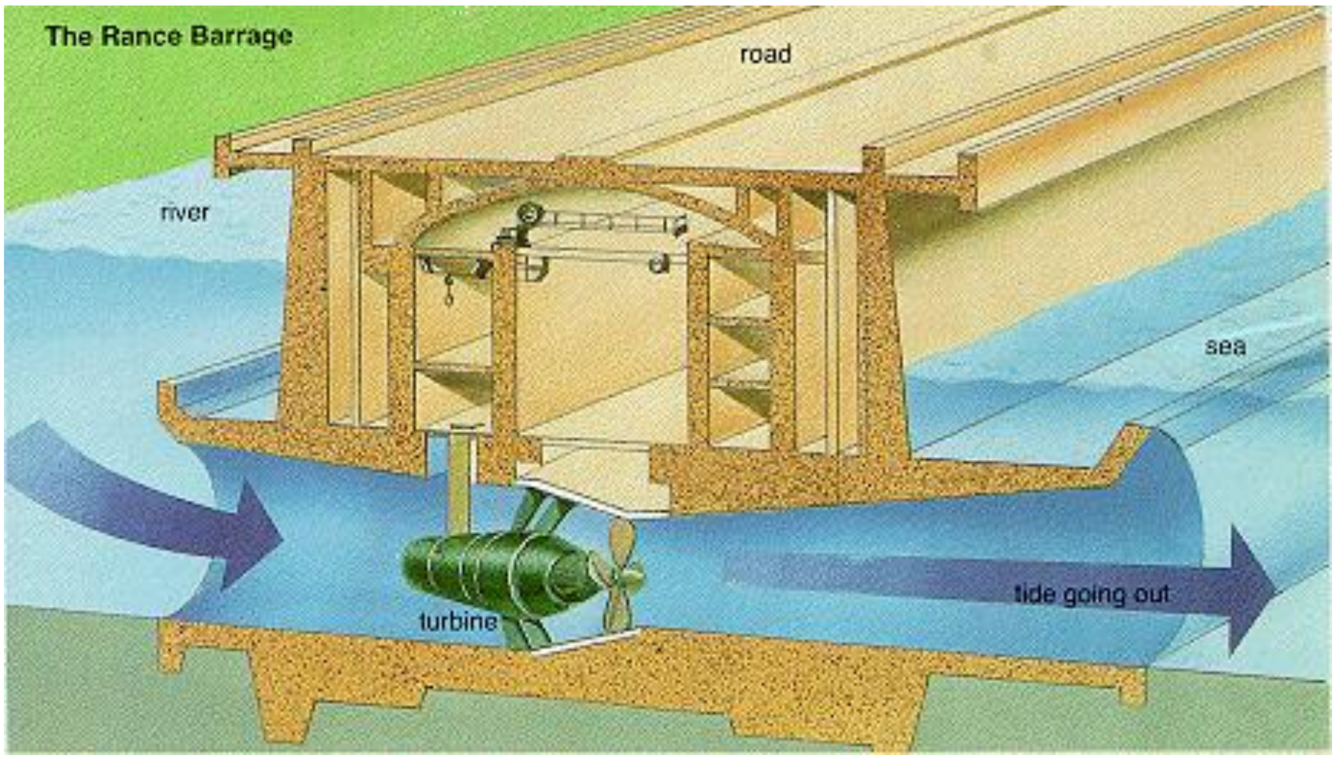


Figure 6.15 Layout of the Rance Barrage

Boyle, *Renewable Energy,* Oxford University Press (2004)

Cross Section of La Rance Barrage



http://www.calpoly.edu/~cm/studpage/nsmallco/clapper.htm

Tidal Barrage Energy Calculations

R = range (height) of tide (in m)
A = area of tidal pool (in km^2)
m = mass of water
$g = 9.81\ m/s^2$ = gravitational constant
$\rho = 1025\ kg/m^3$ = density of seawater
$\eta \cong 0.33$ = capacity factor (20-35%)

$$E = \rho g \int_0^R z A_z \, dz$$

$$= A\rho g \frac{R^2}{2}$$

$$E = \eta m g R / 2 = \eta(\rho A R) g R / 2$$

$$E = 1397 \eta R^2 A$$ kWh per tidal cycle

Assuming 706 tidal cycles per year (12 hrs 24 min per cycle)

$$E_{yr} = 0.997 \times 10^6 \eta R^2 A$$

Average power

$$P = W / Time\, in\, \text{seconds} = \frac{A\rho g R^2}{2x22350}$$

$$P = 224 A R^2 KW$$

Tester *et al., Sustainable Energy,* MIT Press, 2005

La Rance Barrage Example

$\eta = 33\%$
$R = 8.5$ m
$A = 22$ km^2

$$E_{yr} = 0.997 \times 10^6 \eta R^2 A$$
$$E_{yr} = 0.997 \times 10^6 (0.33)(8.5^2)(22)$$
$$E_{yr} = 517 \text{ GWh/yr}$$

Q. A simple single basin type tidal power plat has a basin area of 22km^2 with a tide range of 10 m. The turbine Stops when tide falls blow 3 m. calculate average power generated during one filling emptying process if efficiency is 74% and specific gravity of sea water is 1.025

Tester *et al.*, *Sustainable Energy,* MIT Press, 2005

Wave Energy

Wave Structure

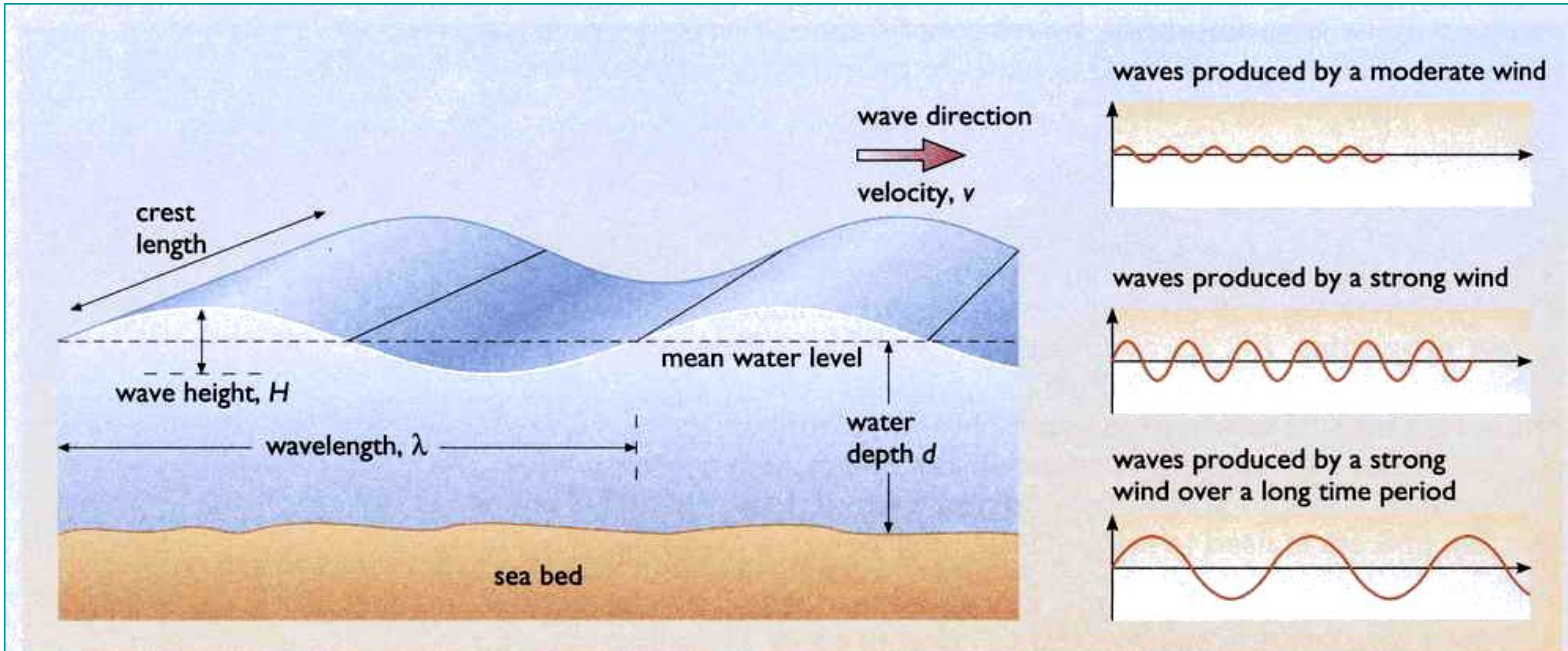
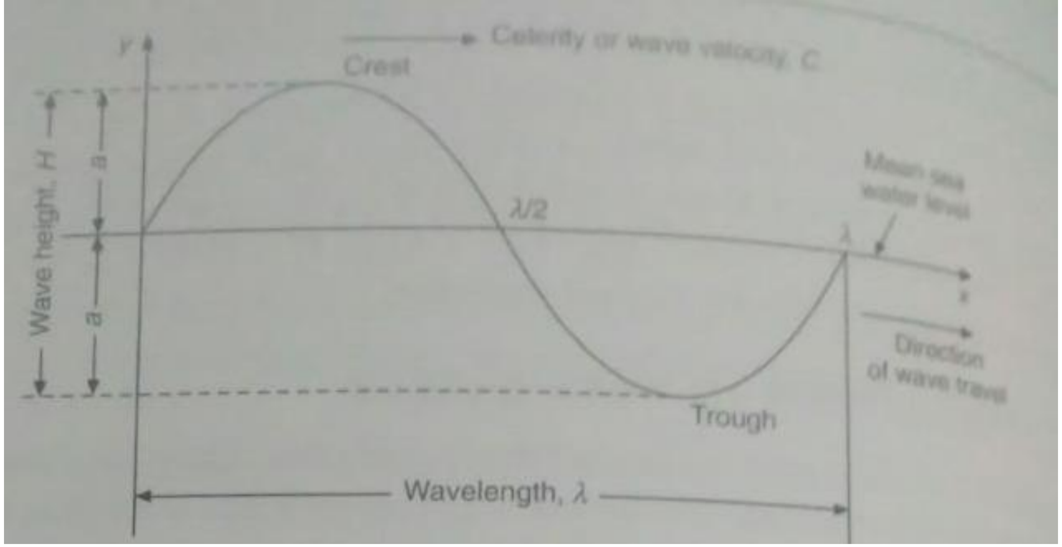


Figure 8.5 Characteristics of an idealized wave

Boyle, *Renewable Energy,* Oxford University Press (2004)



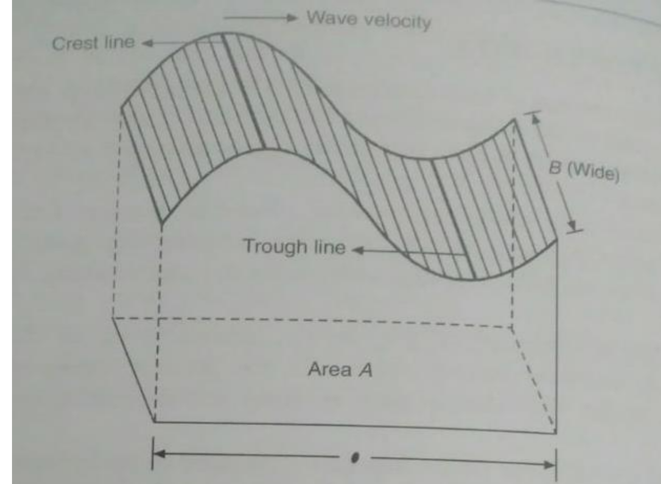


Figure 11.19 Water wave width B and length λ ($B > \lambda$).

H=wave hight
A=amlpitude=H/2
T= time period=4-12 s
f=frequency
λ=wave length

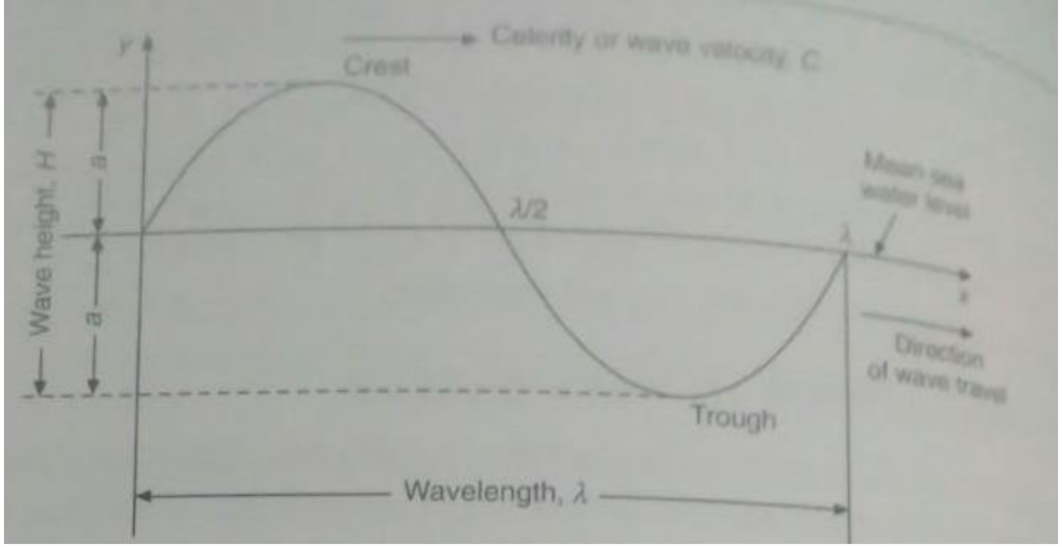
Wave velocity C = λ/T
T =1/f
λ= 1.56 T ^{2} m

Wave Power Calculations

P = Power in kW per meter of wave crest length $$P = 0.96H^2T$$

Example: H= 3m and T = 10s

$$P = 0.96H^2T \;= 0.96x3^2 \times 10 = 86.4\frac{kW}{m}$$



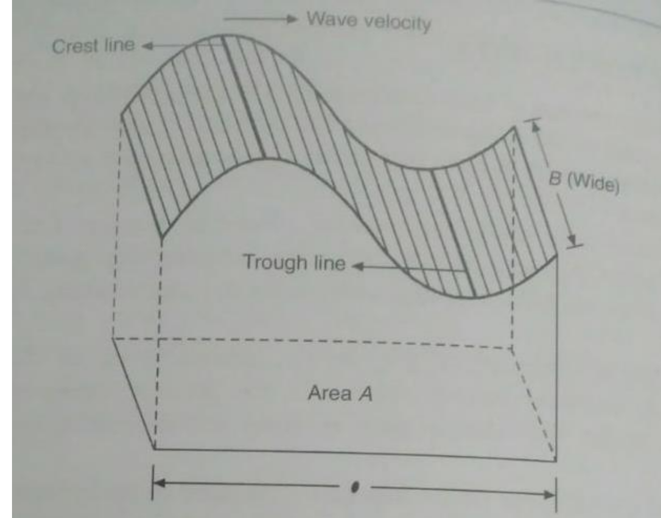
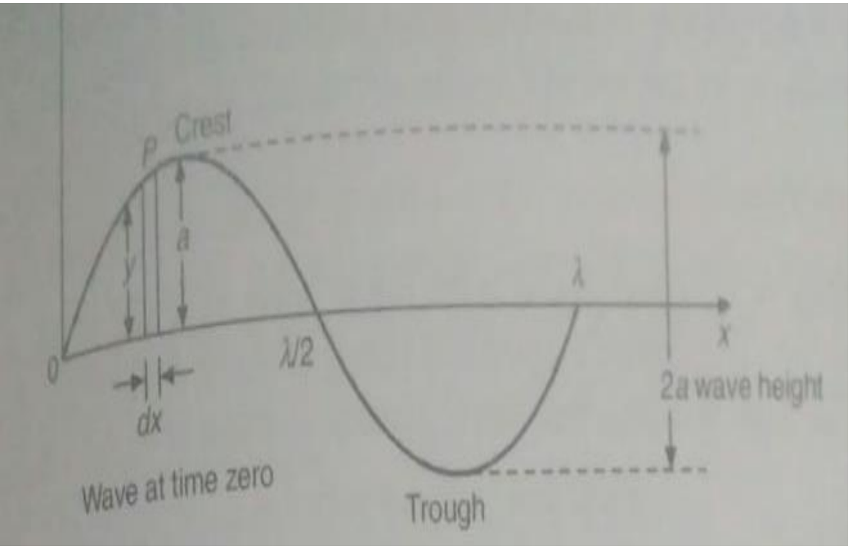


Figure 11.19 Water wave width B and length λ ($B > \lambda$).

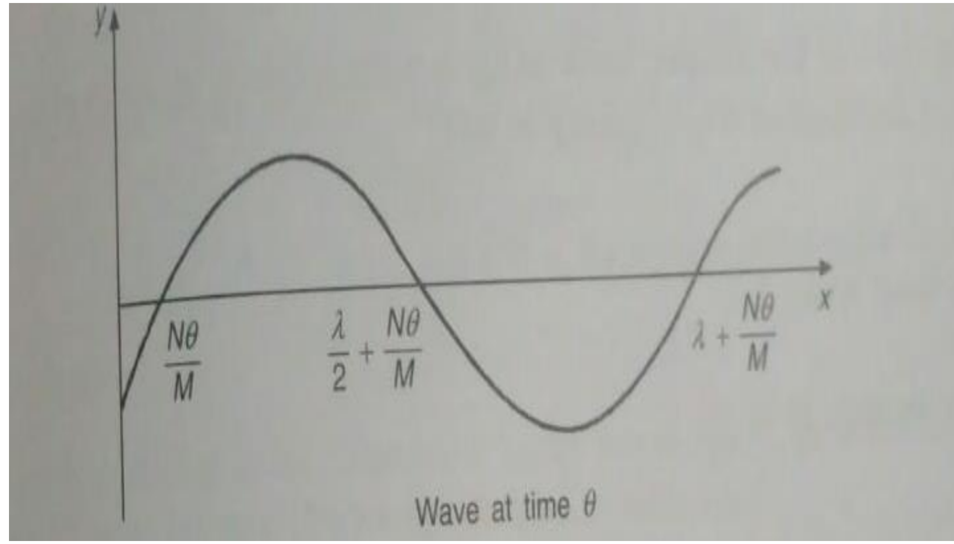
EXAMPLE 11.3

A progressive sea wave has a wave width of 100 m with a period of 5 seconds. Calculate the wavelength, the wave velocity and the wave area.

$$\begin{aligned}
\text{Wave Length, } \lambda &= 1.56T^2 \\
&= 1.56 \times 5^2 = 39 \text{ m} \\
\text{Wave velocity, } C &= \frac{\lambda}{T} = \frac{39}{5} = 7.8 \text{ m/s} \\
\text{Wave area, } A &= \text{wave length} \times \text{wave breadth} \\
&= \lambda \times B \\
&= 39 \times 100 \\
&= 3900 \text{ m}^2
\end{aligned}$$



Crest
P
a
y
0
dx
λ/2
λ
x
2a wave height
Trough
Wave at time zero



y
x
$\frac{N\theta}{M}$
$\frac{\lambda}{2} + \frac{N\theta}{M}$
$\lambda + \frac{N\theta}{M}$
Wave at time θ

Global Wave Energy Averages

Average wave energy (est.) in kW/m (kW per meter of wave length)

http://www.wavedragon.net/technology/wave-energy.htm

Wave Energy Potential

- Potential of 1,500 – 7,500 TWh/year
  - 10 and 50% of the world's yearly electricity demand
  - IEA (International Energy Agency)

- 200,000 MW installed wave and tidal energy power forecast by 2050
  - Power production of 6 TWh/y
  - Load factor of 0.35
  - DTI and Carbon Trust (UK)

- "Independent of the different estimates the potential for a pollution free energy generation is enormous."

http://www.wavedragon.net/technology/wave-energy.htm

Wave Energy Supply vs. Electric Demand

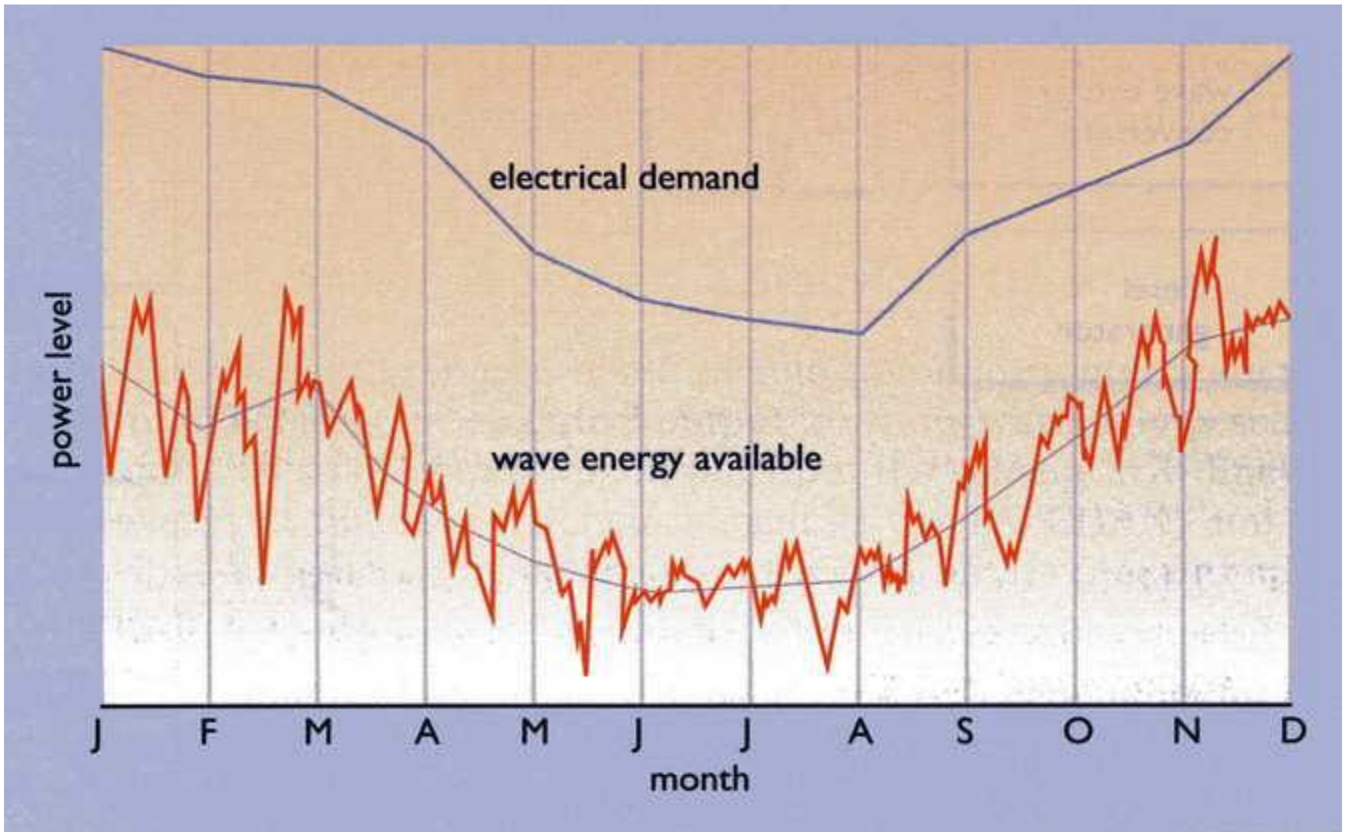


Figure 8.37 Seasonal availability of wave energy and electrical demand for the UK

Boyle, *Renewable Energy,* Oxford University Press (2004)

Wave Energy Environmental Impacts

Wave Energy Environmental Impact

- Little chemical pollution
- Little visual impact
- Some hazard to shipping
- No problem for migrating fish, marine life
- Extract small fraction of overall wave energy
  – Little impact on coastlines
- Release little CO_2, SO_2, and NO_x
  – 11g, 0.03g, and 0.05g / kWh respectively

Boyle, *Renewable Energy,* Oxford University Press (2004)

Wave Energy Summary

Wave Power Advantages

- Onshore wave energy systems can be incorporated into harbor walls and coastal protection
  - Reduce/share system costs
  - Providing dual use
- Create calm sea space behind wave energy systems
  - Development of mariculture
  - Other commercial and recreational uses;
- Long-term operational life time of plant
- Non-polluting and inexhaustible supply of energy

http://www.oceansatlas.com/unatlas/uses/EnergyResources/Background/Wave/W2.html

Wave Power Disadvantages

- High capital costs for initial construction
- High maintenance costs
- Wave energy is an intermittent resource
- Requires favorable wave climate.
- Investment of power transmission cables to shore
- Degradation of scenic ocean front views
- Interference with other uses of coastal and offshore areas
  - navigation, fishing, and recreation if not properly sited
- Reduced wave heights may affect beach processes in the littoral zone

http://www.oceansatlas.com/unatlas/uses/EnergyResources/Background/Wave/W2.html

Wave Energy Summary

- Potential as significant power supply (1 TW)
- Intermittence problems mitigated by integration with general energy supply system
- Many different alternative designs
- Complimentary to other renewable and conventional energy technologies

http://www.oceansatlas.com/unatlas/uses/EnergyResources/Background/Wave/W2.html

World Oceanic Energy Potentials (GW)

Source	Potential (est)	Practical (est)
Tides	2,500 GW	20 GW
Waves	2,700[3]	500
Currents	5,000	50
OTEC[1]	200,000	40
Salinity	1,000,000	NPA[4]
World electric[2]		2,800
World hydro	4,000	550

[1] Temperature gradients
[2] As of 1998
[3] Along coastlines
[4] Not presently available

Tester *et al.*, *Sustainable Energy,* MIT Press, 2005