What is OTEC?

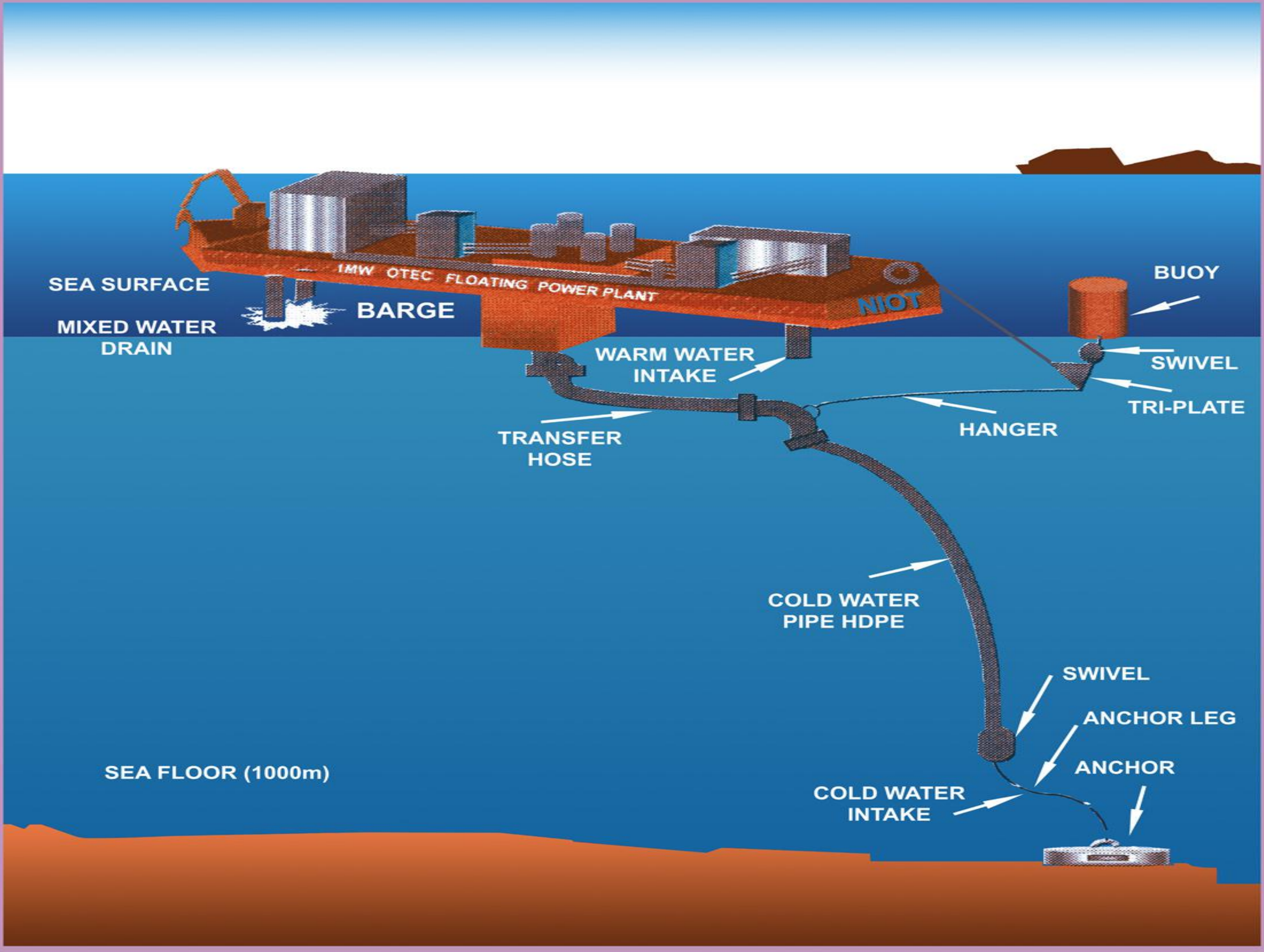
- Manifestation of solar energy
- Top layers of ocean receive solar heating
- Bottom layers receive water from polar regions
- Natural temperature gradient
- Use in Thermodynamic cycle – Generate electricity

PLANT LOCATION

1. **Land based** - Favoured locations : narrow shelves (volcanic islands), steep (15-20 deg) offshore slopes, and relatively smooth sea floors.

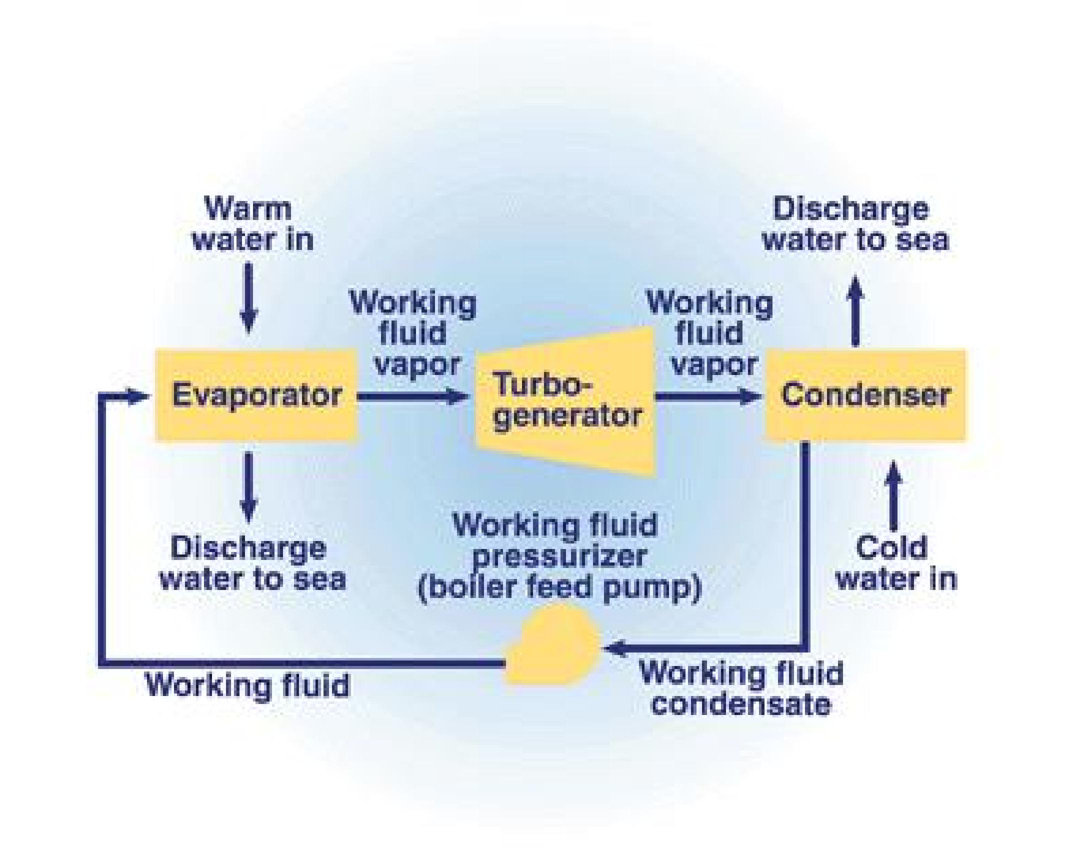
2. **Shelf mounted** - OTEC plants can be mounted to the continental shelf at depths up to 100 meters. A shelf-mounted plant could be built in a shipyard, towed to the site, and fixed to the sea bottom.

3. Off shore **floating** plants


1MW OTEC FLOATING POWER PLANT
NIOT
SEA SURFACE
BARGE
MIXED WATER
DRAIN
BUOY
SWIVEL
WARM WATER
INTAKE
TRI-PLATE
HANGER
TRANSFER
HOSE
COLD WATER
PIPE HDPE
SWIVEL
ANCHOR LEG
ANCHOR
SEA FLOOR (1000m)
COLD WATER
INTAKE

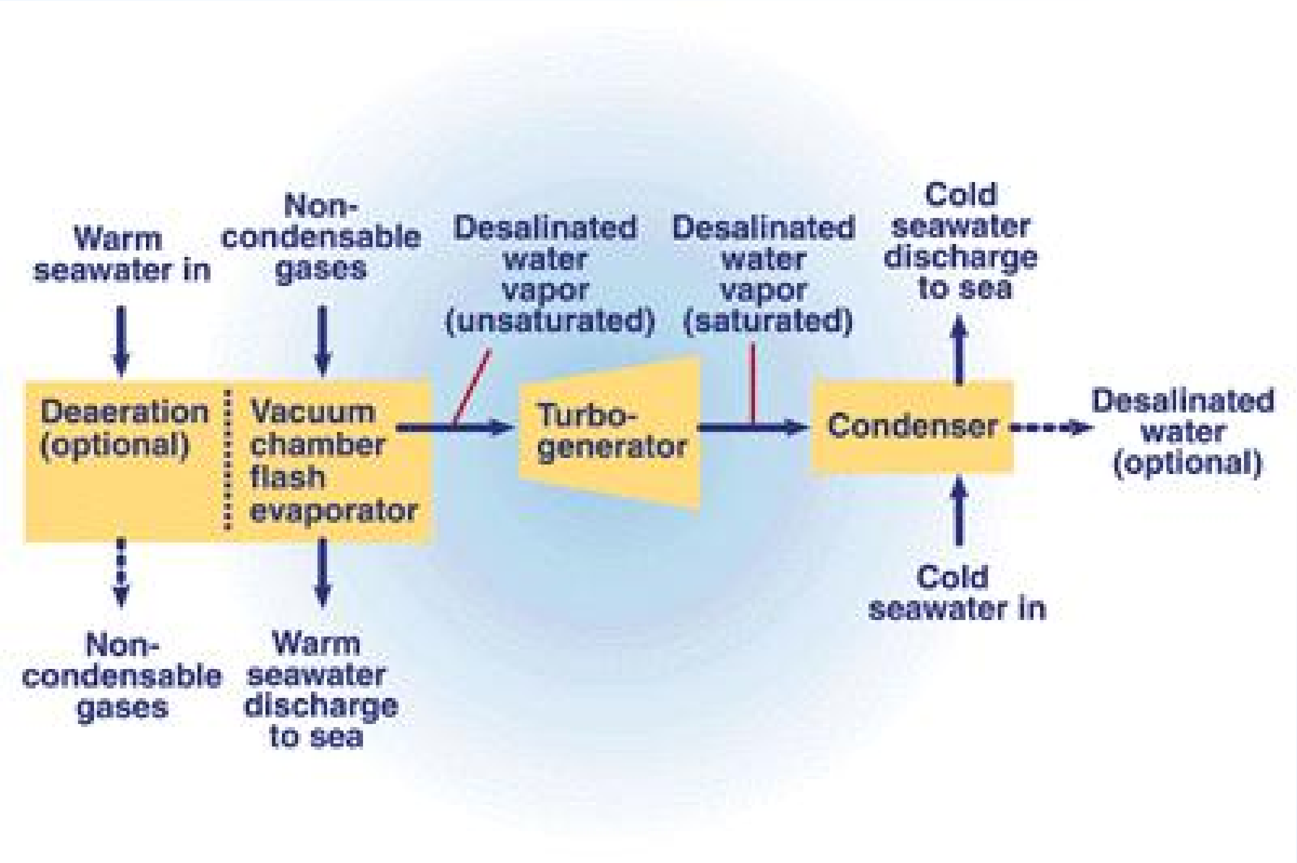
ELECTRICITY PRODUCTION

1. Closed cycle



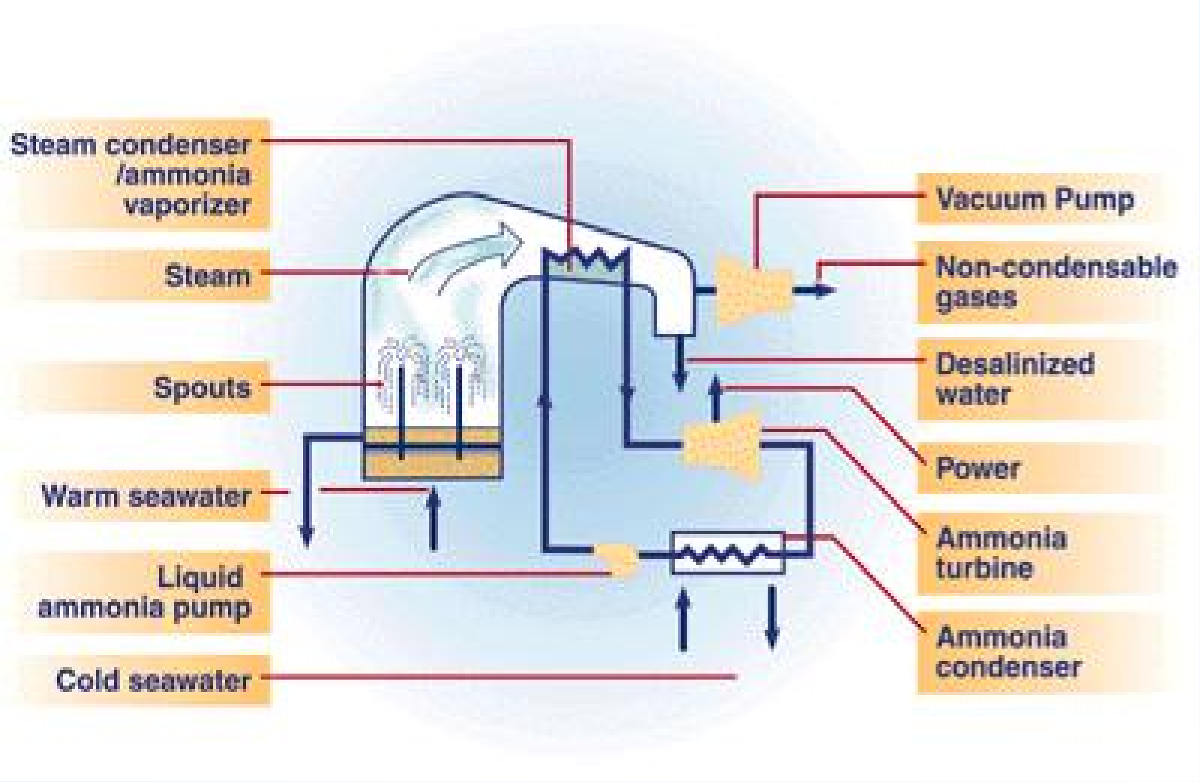
- Ammonia can be used as a working fluid

2. Open cycle



- Water is the working fluid
- Desalinated water can be produced

3. Hybrid cycle

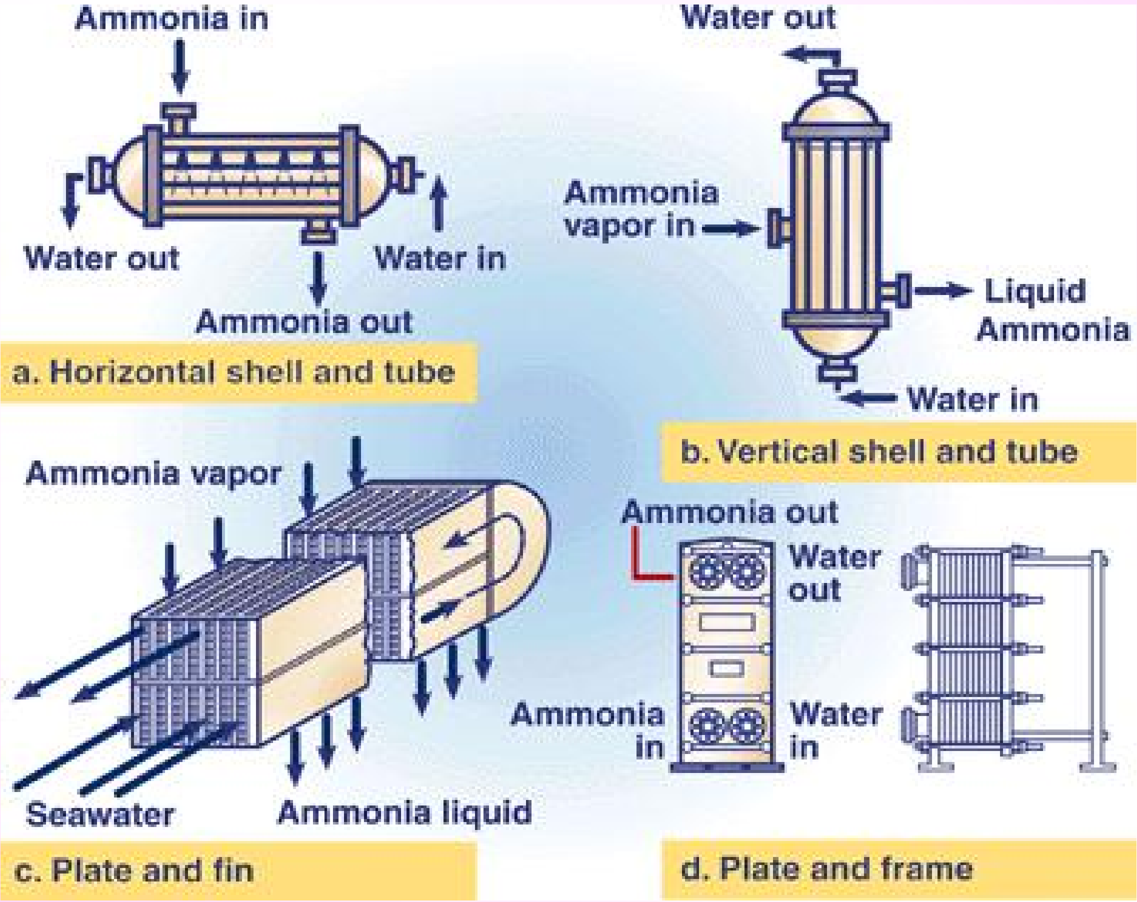


- Ammonia is the working fluid
- Warm sea water is flashed and is then used to vaporize ammo

MAIN COMPONENTS OF AN OTEC SYSTEM

- Evaporators
- Condensers
- Cold-water pipe
- Turbines

HEAT EXCHANGERS



- Shell and tube design can be enhanced by using fluted tubes: the working fluid flows into the grooves and over the crests, producing a thin film that evaporates more effectively

- In an advanced plate-and-fin design, working fluid and seawater flow through alternating parallel plates; fins between the plates enhance the heat transfer

- Original material chosen – Titanium - Expensive, so alternative material – Aluminium.
  Selected Aluminium alloys may last 20 years in seawater.

TURBINES

- **Characterized by low pressure ratios and high mass flow of working fluids.**
- **The turbine is to be designed to have a good isentropic expansion efficiency over a considerable range of pressure ratio**

For a 1 MW OTEC plant, a 4-stage axial flow reaction turbine coupled to a synchronous generator through 2 : 1 speed reduction gear box is chosen.

For a considerable range of pressure ratios the turbine efficiency remains above *0.85*.

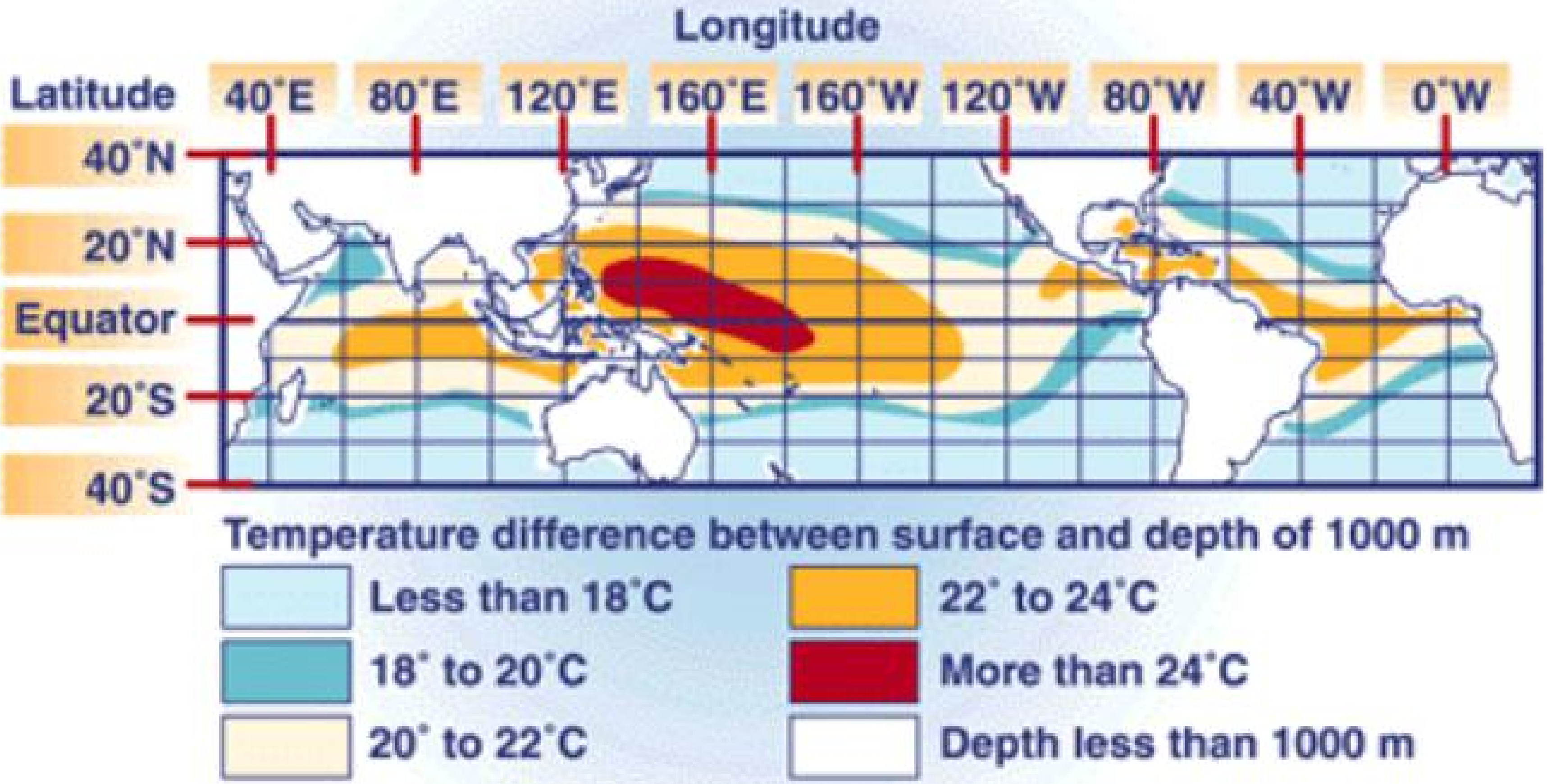
For 100 MW – low speed 200 rpm unit around 45 m in dia.

POTENTIAL

- Equatorial, tropical and sub-tropical regions i.e.
  20 °N to 20 °S, have favorable temperature profile
- Total estimated potential – **577000 MW**

- 99 nations and territories have access to the
  OTEC thermal resource:

  Americas—Mainland - 15
  Americas—Island - 23
  Africa—Mainland - 18
  Africa—Island - 5
  Indian/Pacific Ocean—Mainland - 11
  Indian/Pacific Ocean—Island - 27


Longitude
Latitude
40°E
80°E
120°E
160°E
160°W
120°W
80°W
40°W
0°W
40°N
20°N
Equator
20°S
40°S
Temperature difference between surface and depth of 1000 m
Less than 18°C
18° to 20°C
20° to 22°C
22° to 24°C
More than 24°C
Depth less than 1000 m

Countries with access to deep ocean water within 10Km of shore and favorable business climate:

- Americas—Mainland - 1, Mexico
- Americas—Island - 12
- Africa—Mainland - 1, Tanzania
- Africa—Island - 1, Madagascar
- Indian/Pacific Ocean—Mainland - 1, India
- Indian/Pacific Ocean—Island – 13

OTEC has a high potential especially in small island nations

Potential in SIDS

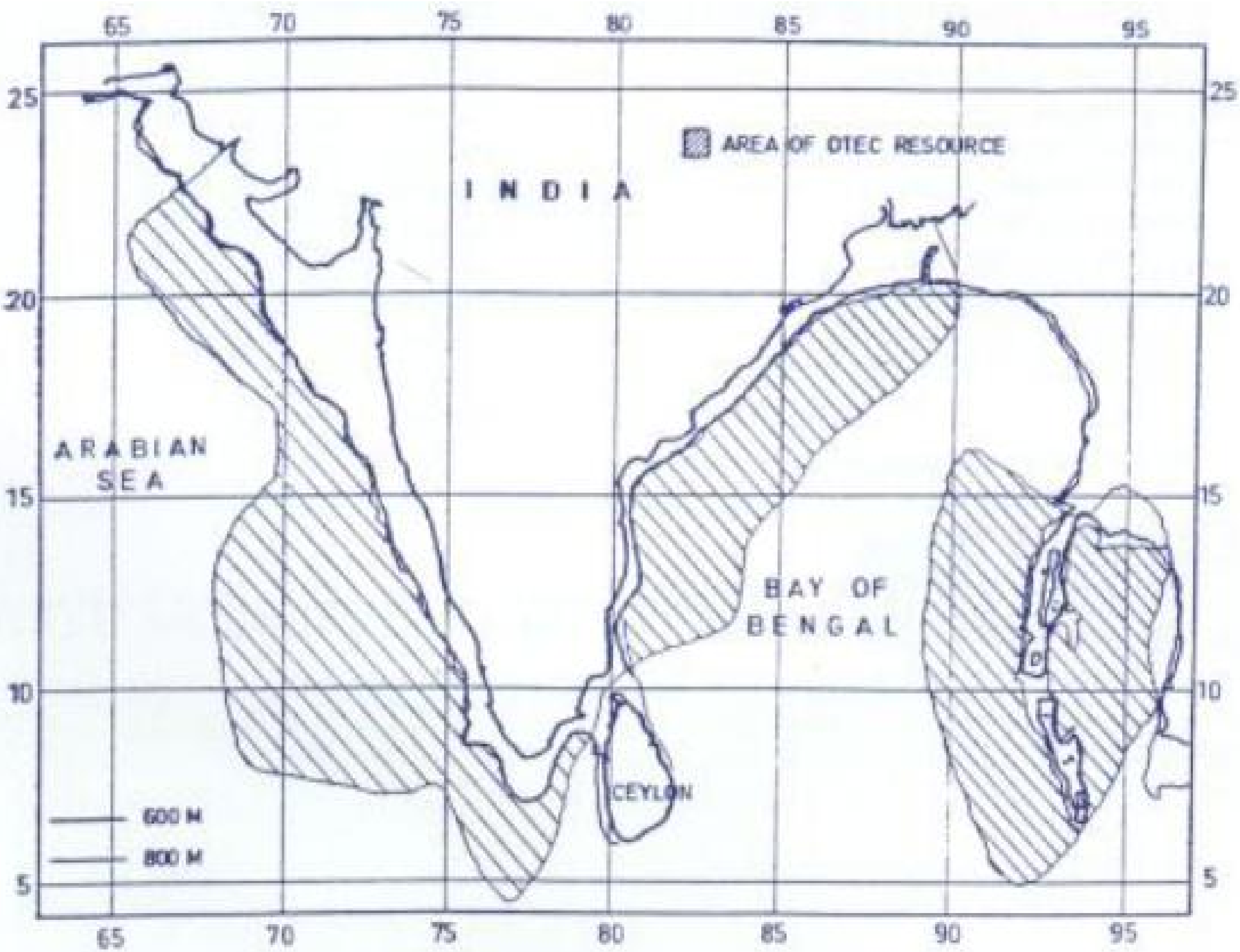
- Islands have a large EEZ (SL's EEZ = 27*area)
- Favorable temperature gradient
- SIDS have to import fuels and energy
- OTEC provides cheaper energy and energy security
- OTEC promotes agriculture – food self-sufficiency
- Fresh water at cheaper cost
- Provides transportation fuels
- Refrigeration, air-conditioning
- Full use of the benefits of OTEC   lower COE

Potential in India

- Estimated overall potential – 180000 MW
- 2.56 million sq.km EEZ

- **Ongoing projects**: The 1 MW barge research and demonstration facility being developed by the National Institute of Ocean Technology, **India** (NIOT) with technical support from Institute of Ocean Energy, Saga University (IOES)

- Identified sites:
  - Kavaratti
  - Kulasekarapattinam
  - Andaman & Nicobar Islands



OTEC resource within EEZ of India

Factors to be considered while choosing a site:

- **Thermal gradient in the ocean**
- **Topography of the ocean floor**
- **Meteorological conditions – hurricanes**
- **Seismic activity**
- **Availability of personnel to operate the plant**
- **Infrastructure – airports, harbors, etc.**
- **Local electricity and desalinated water demand.**
- **Political, ecological constraints**
- **Cost and availability of shoreline sites**

Factors which increase the viability of OTEC:

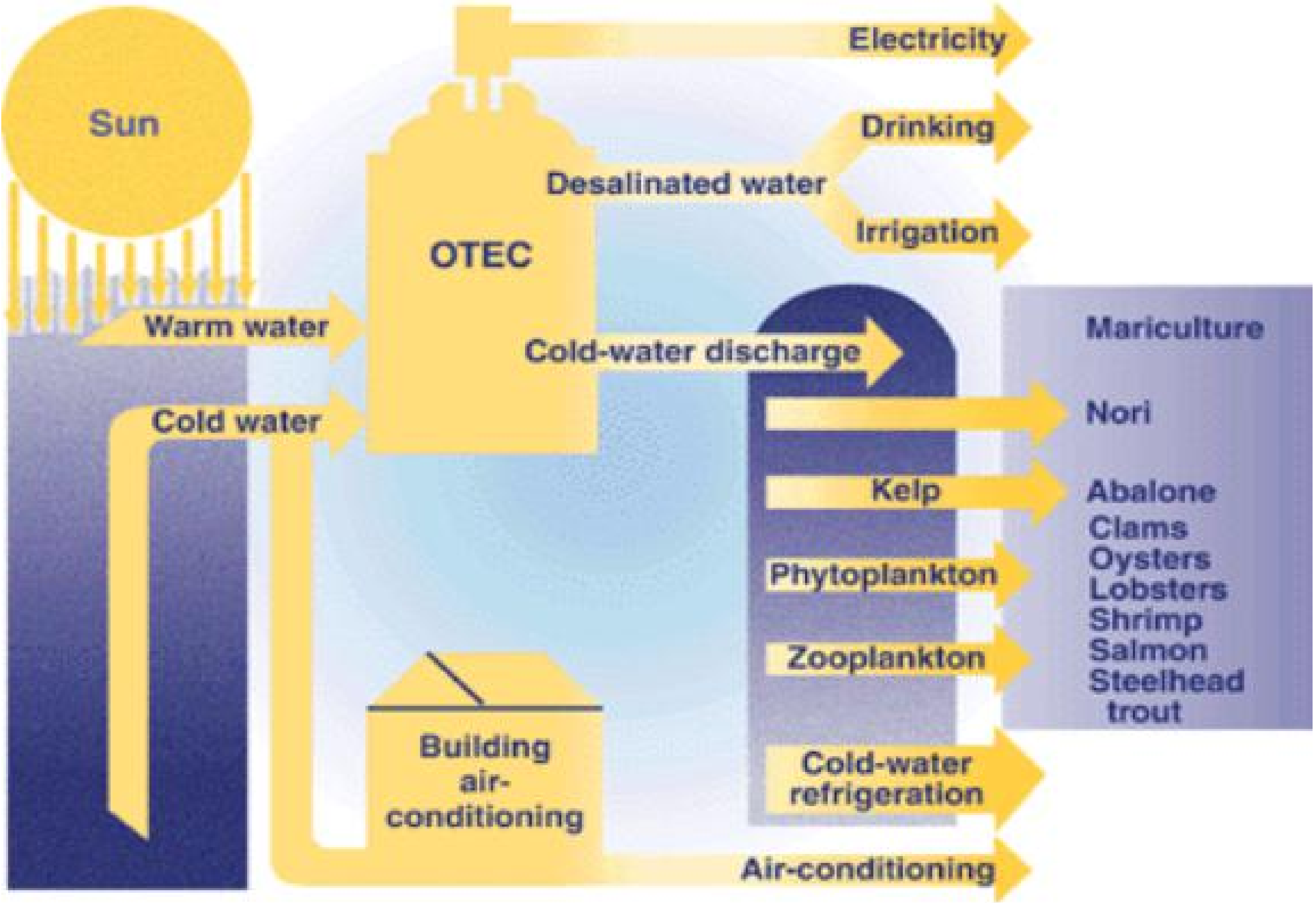
- **Rising price of crude oil, declining supplies**
- **Ever-rising energy demand**
- **Stringent regulations over emission of green house and toxic gases**
- **Need for renewable source of baseload electricity**
- **Energy security**

Environmental Aspects

Positives:

- Environmentally benign - no toxic products are released
- Carbon di oxide emission - less than 1% of fossil fuel plant
- Nutrient rich cold water promotes mariculture
- Chilled soil agriculture – promotes growth of temperate crops in tropical regions.
- Cold water for air conditioning
- Fish will be attracted to the plant, increases fishing in the area
- Fresh water production (1 MW plant -> 4500 m^3)

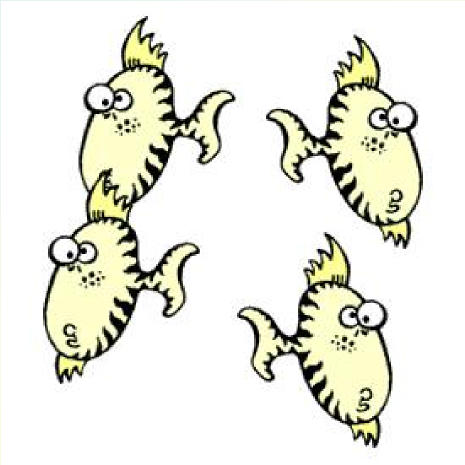
- Promotes mariculture



Environmental Aspects

Negatives:

- Fish eggs and larvae entrained, destroyed
- Sterilization of land by land based plants
- Floating plants – navigational hazard
- Entrainment and impingement of organisms.
- Chlorine used for preventing biofouling – hazardous
- Metal pieces entrained – affects marine orgs.
- Mixing of warm and cold sea water
- OTEC is yet untested on large scale over a long period of time



Commercial benefits of OTEC

- Helps produce fuels such as hydrogen, ammonia, and methanol
- Produces baseload electrical energy
- Produces desalinated water for industrial, agricultural, and residential uses
- Provides air-conditioning for buildings
- Provides moderate-temperature refrigeration
- Has significant potential to provide clean, cost-effective electricity for the future.
- Specially beneficial for small islands as they can become self-sufficient

- Promotes competitiveness and international trade
- Enhances energy independence and energy security
- Promotes international sociopolitical stability
- Has potential to mitigate greenhouse gas emissions resulting from burning fossil fuels.

OTEC R&D

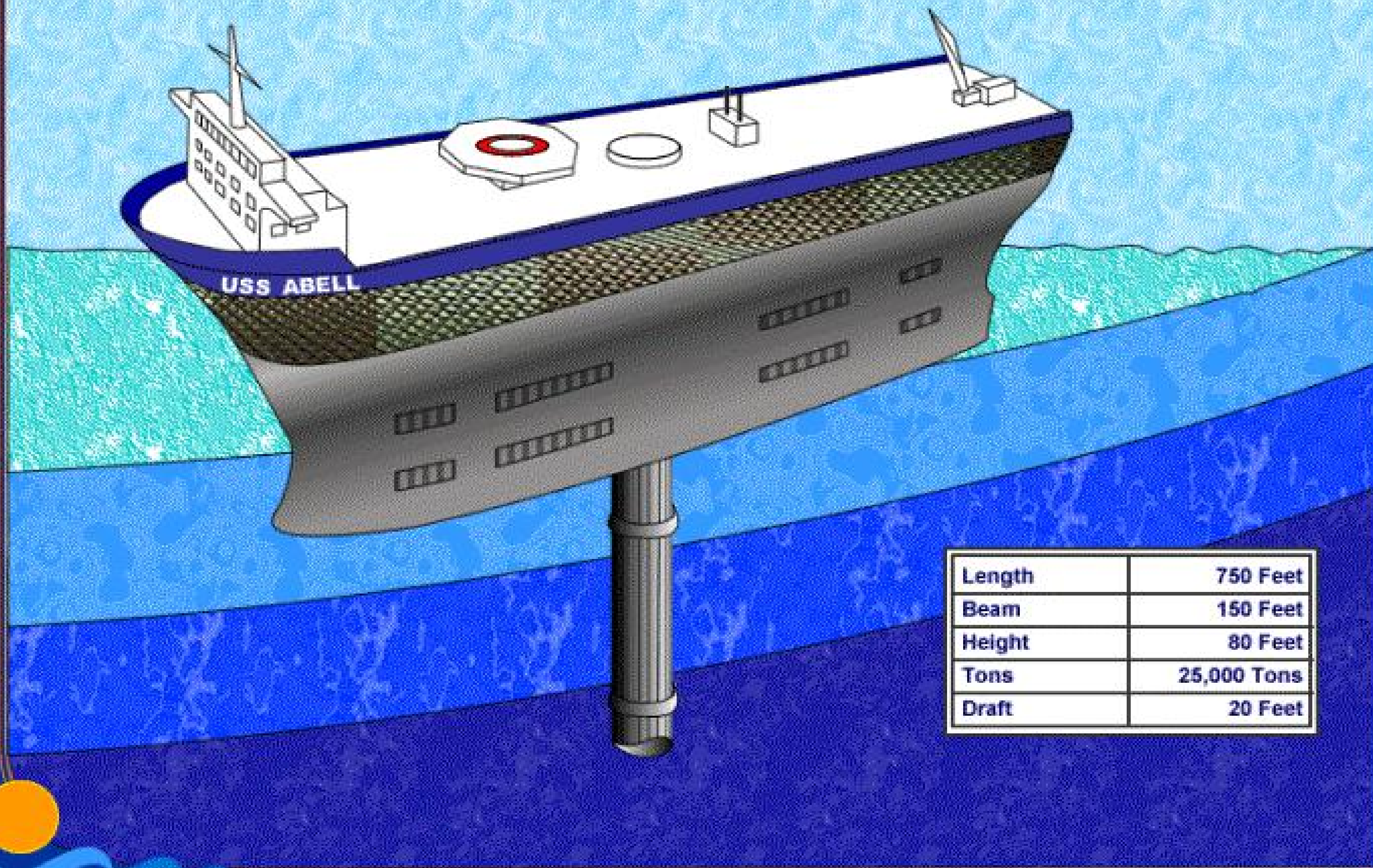
210kW OC-OTEC Experimental Plant (1993-1998) in Hawaii

Major accomplishments of the 210 kW open cycle OTEC project include:

- First net power production from open-cycle process
- Largest OTEC plant yet operated, with largest net power output
- 10 ft diameter, 7.5 ton turbine rotated at 1800 rpm
- Developed use of magnetic bearings for high efficiency very high speed (to 48,000 rpm) vacuum pumps
- Developed and utilized flexible PC-based monitoring and control system
- Demonstrated very high condenser efficiency from structured-packing design
- Successfully demonstrated about 7000 gal/day fresh water production with minimal power loss from an auxiliary vapor to liquid surface condenser

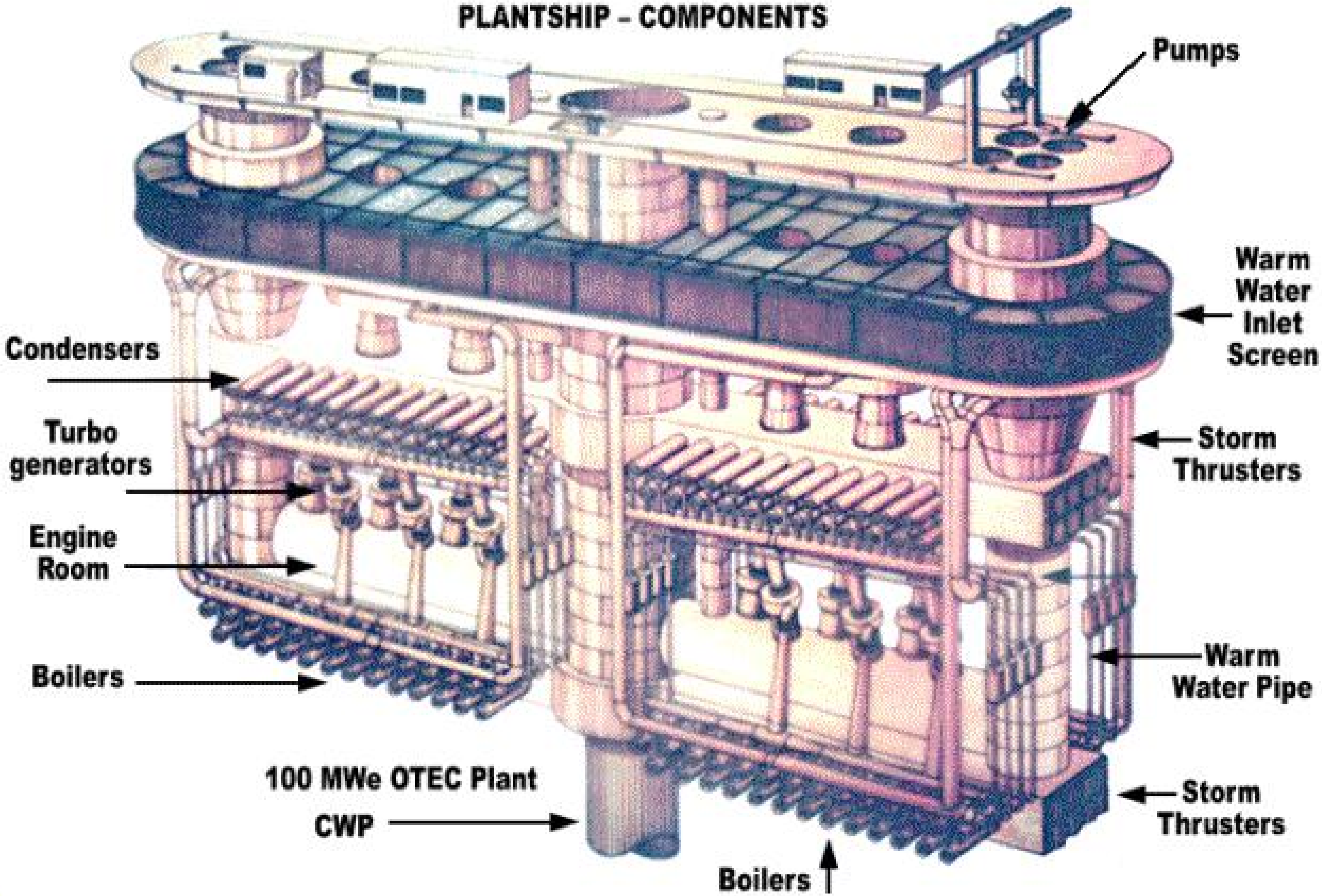
- OTEC is technically feasible and economically favorable
- Mature technology
- Benefits ecology
- More plants of capacity similar to experimental plants can be constructed

Sea Solar Power 100 MW Plantship

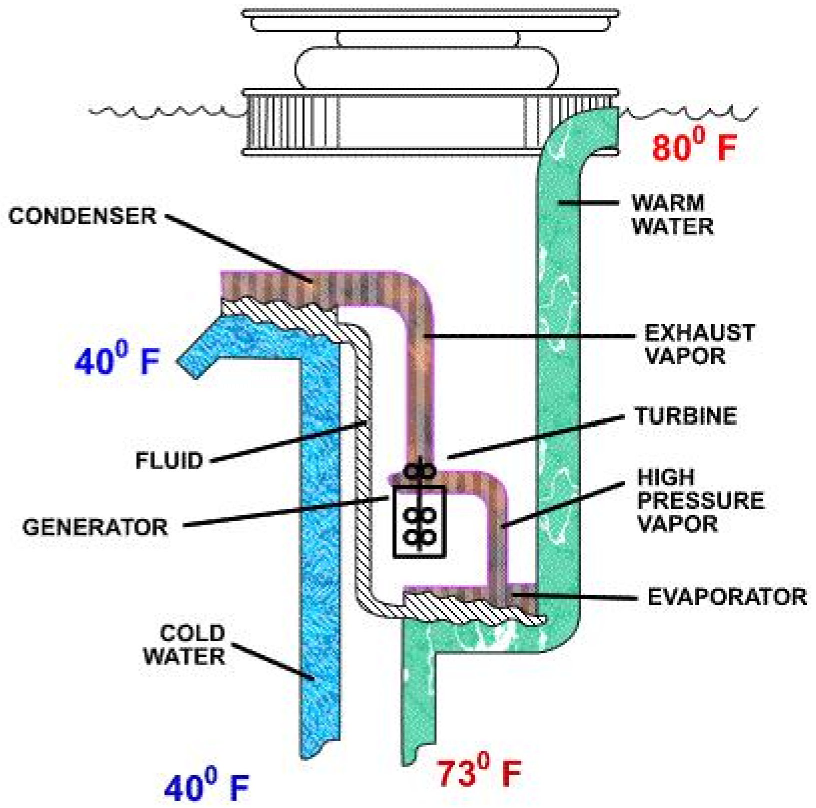


Length	750 Feet
Beam	150 Feet
Height	80 Feet
Tons	25,000 Tons
Draft	20 Feet

PLANTSHIP – COMPONENTS



OTEC



OCEAN THERMAL ENERGY CONVERSION

CLOSED POWER CYCLE

TIDAL ENERGY

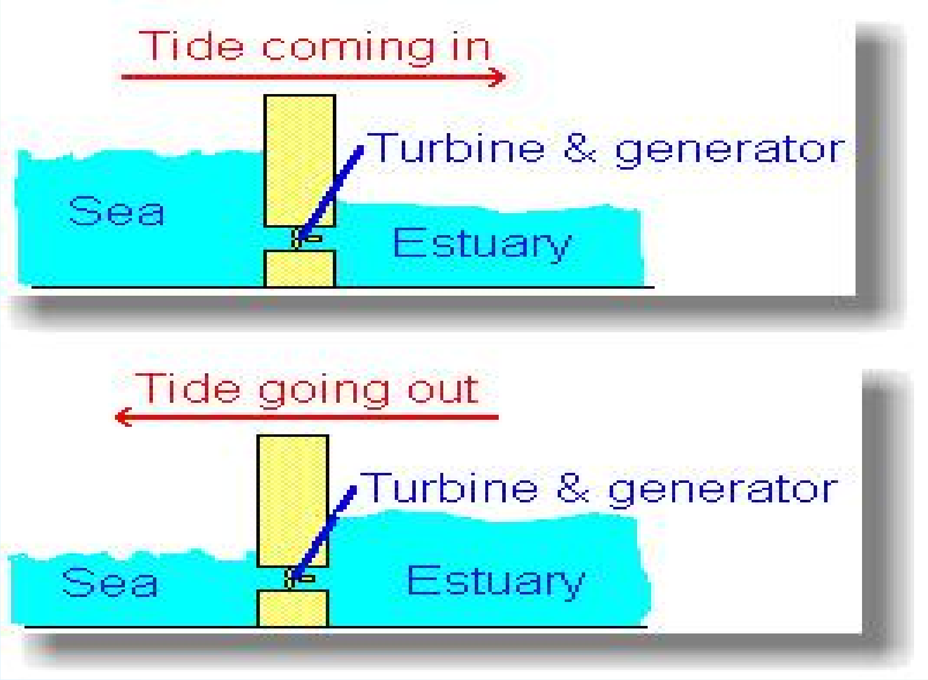
BASICS

- Cause of tides: gravitational force of sun, moon and earth's rotation
- Two tidal cycles per day: 12 hours, 25 minutes
- Tidal range – large at coastal regions with high depth gradient
- Water can be stored in an estuary during high tide
- Release during low tide, through turbines

Photo by C.Cordone

THE TIDAL BARRAGE

- It's a huge dam built across a river estuary. When the tide goes in and out, the water flows through tunnels in the dam.



- Tidal range has to be in excess of 5 meters for tidal power to be fe

- The purpose of this dam or barrage is to let water flow through it into the basin as the tide comes in. As the tide recedes, gates in the barrage that contain turbines are opened, the hydrostatic head causes the water to come through these gates, driving the turbines and generating power.

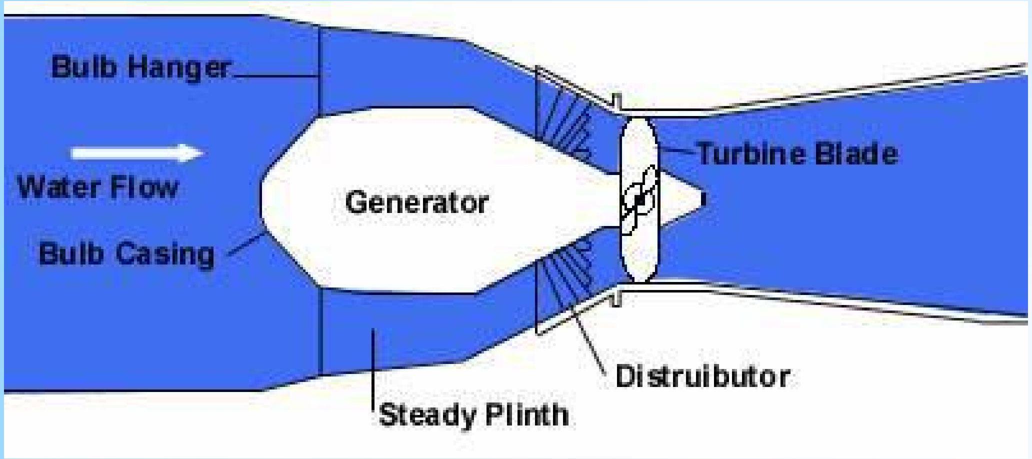
- Power can be generated in both directions through the barrage but this can affect efficiency and the economics of the project

- Components of barrage
  - Caissons
  - Turbines

Types of TURBINES

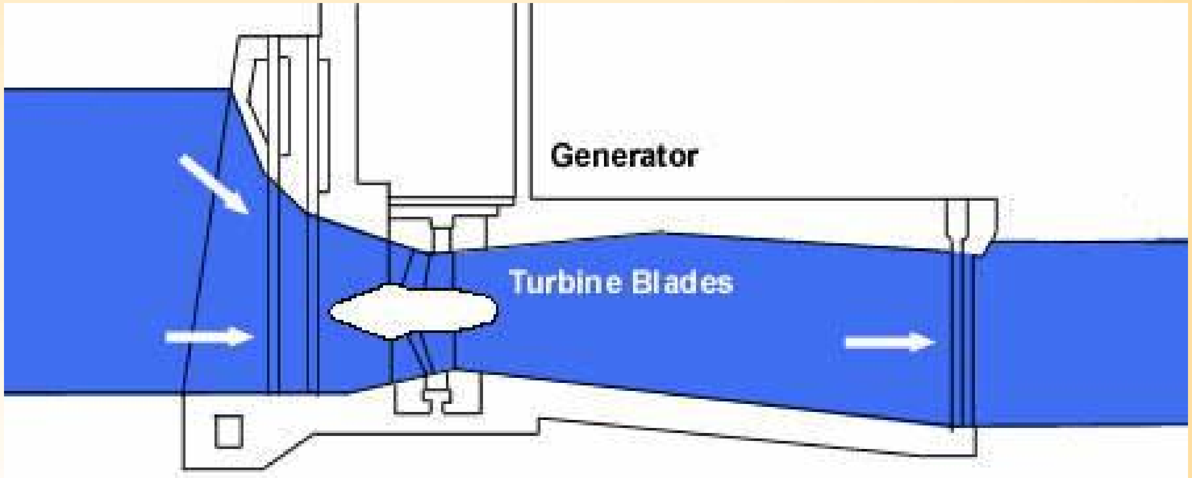
1. Bulb turbine

   Water flows around the turbine. If maintenance is required then the water must be stopped which causes a problem and is time consuming with possible loss of generation.



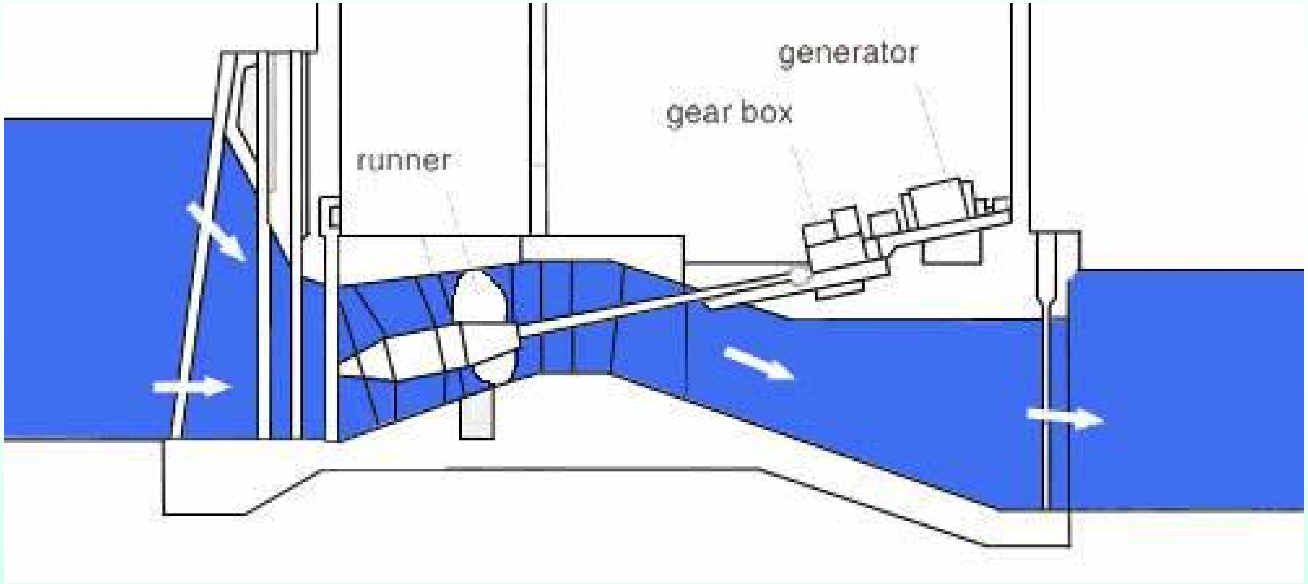
2. Rim turbines

When rim turbines are used, the generator is mounted at right angles to the to the turbine blades, making access easier. But this type of turbine is not suitable for pumping and it is difficult to regulate its performance.



3. Tubular turbines

The blades of this turbine are connected to a long shaft and are orientated at an angle so that the generator is sitting on top of the barrage.
There are only a few commercially operating plants in the world, one of these is the La Rance barrage in France



The power available from the turbine at any particular instant is given by:

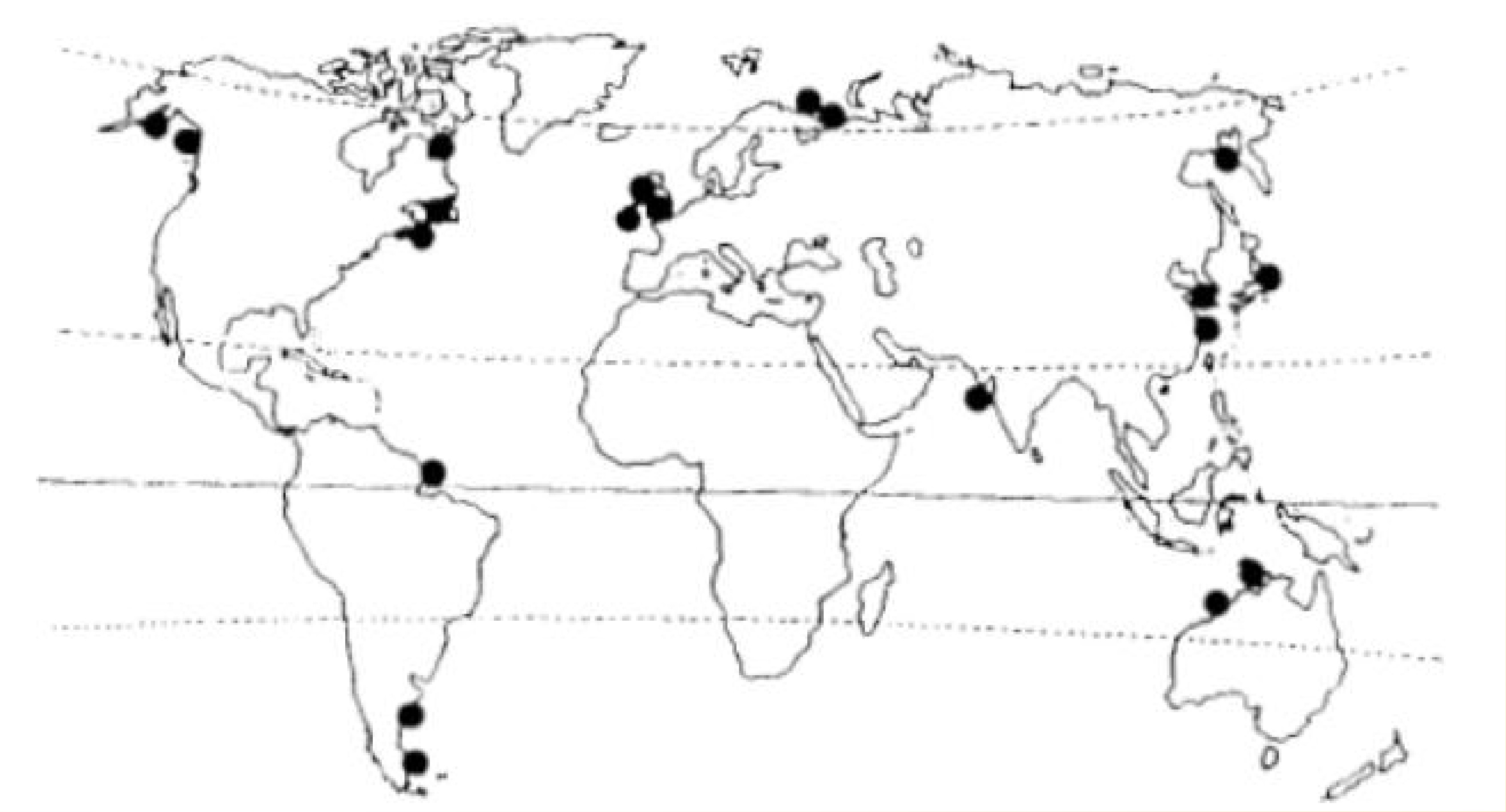
$$P = \rho . g . C_d . A . \sqrt{2 . g . (Z_1 - Z_2)^3}$$

Where,
Cd = Discharge Coefficient
A = Cross sectional area (m2)
G = gravity = 9.81
r = density (kg/m3)

POTENTIAL

- Total tidal energy potential worldwide estimated 500 – 1000 TWh/year
- Only a fraction is exploitable owing to economics & other constraints
- Represents 3 – 7 % of total energy dissipated by tides
- Has potential to contribute upto 10 – 12 % of the total energy obtained from renewable sources worldwide

WORLD AT A GLANCE…..



- The darkened regions shows the potential sites

POTENTIAL

TIDAL ENERGY ESTIMATED DEPLOYMENT in 2010 WORLDWIDE

	Estimated deployment in 2010 **TWh**	**Estimated deployment in 2010** **MW**
WORLD-WIDE	0.586	261.4
EU + EFTA	0.544	240
NAFTA	0.03	17.8
ASIA	0.011	3.2
CIS	0.001	0.4

Key :
EU + EFTA - European Union & European Free Trade Association
CIS - Ex-USSR countries
NAFTA - USA, Canada, Mexico
Asia - All Asian countries and Pacific islands excluding OECD Pacific, Iran, Asian Republics of former USSR

Prospective sites for tidal energy projects

Country	Country	Mean tidal range (m)	Basin area (km²)	Installed capacity (MW)	Approximate annual output (TWh/year)	Annual plant load factor (%)
Argentina	San José	5.8	778	5 040	9.4	21
	Santa Cruz	7.5	222	2 420	6.1	29
Australia	Secure Bay	7.0	140	1 480	2.9	22
	Walcott Inlet	7.0	260	2 800	5.4	22
Canada	Cobequid	12.4	240	5 338	14.0	30
	Cumberland	10.9	90	1 400	3.4	28
	Shepody	10.0	115	1 800	4.8	30
India	Gulf of Kutch	5.0	170	900	1.6	22
	Gulf of Khambat	7.0	1 970	7 000	15.0	24
UK	Severn	7.0	520	8 640	17.0	23
	Mersey	6.5	61	700	1.4	23
USA	Pasamaquoddy	5.5				
	Knik Arm	7.5		2 900	7.4	29
	Turnagain Arm	7.5		6 500	16.6	29
Russian Fed.	Mezen	6.7	2 640	15 000	45	34
	Tugur	6.8	1 080	7 800	16.2	24
	Penzhinsk	11.4	20 530	87 400	190	25

POTENTIAL IN INDIA

- Two estuaries on the west coast : Gulf of Cambay & Gulf of Kutch in Gujarat
- Gulf of Kutch potential estimated to be 900 MW; annual output of 1.6 TWh
- Potential of Gulf of Cambay : 7000 MW, basin area of 1970 sq-km, annual output of 15 TWh
- Along east coast : Sunderbans in West Bengal
- 20 MW power estimated in regions of Dungaduani, Belladonna Creek & Pitts Creek

The La Rance plant

PLANT LOCATION

- Tidal mills built on inlets branching off tidal estuaries
- Average Tidal range : the higher, the better
- Feasibility of plant construction & basin closure
- Environmental consequences

EXISTING PLANTS

Site	Mean Tidal Range (m)	Basin (sq-km)	Installed Capacity (MW)	Approx Output (GWh/yr)	In service (year)
La Rance (France)	8	17	240	540	1966
Kislaya Guba (Russia)	2.4	2	0.4	-	1968
Jingxia (China)	7.1	2	3.2	11	1980-86
Annapolis Royal (Canada)	6	6	17.8	30	1984

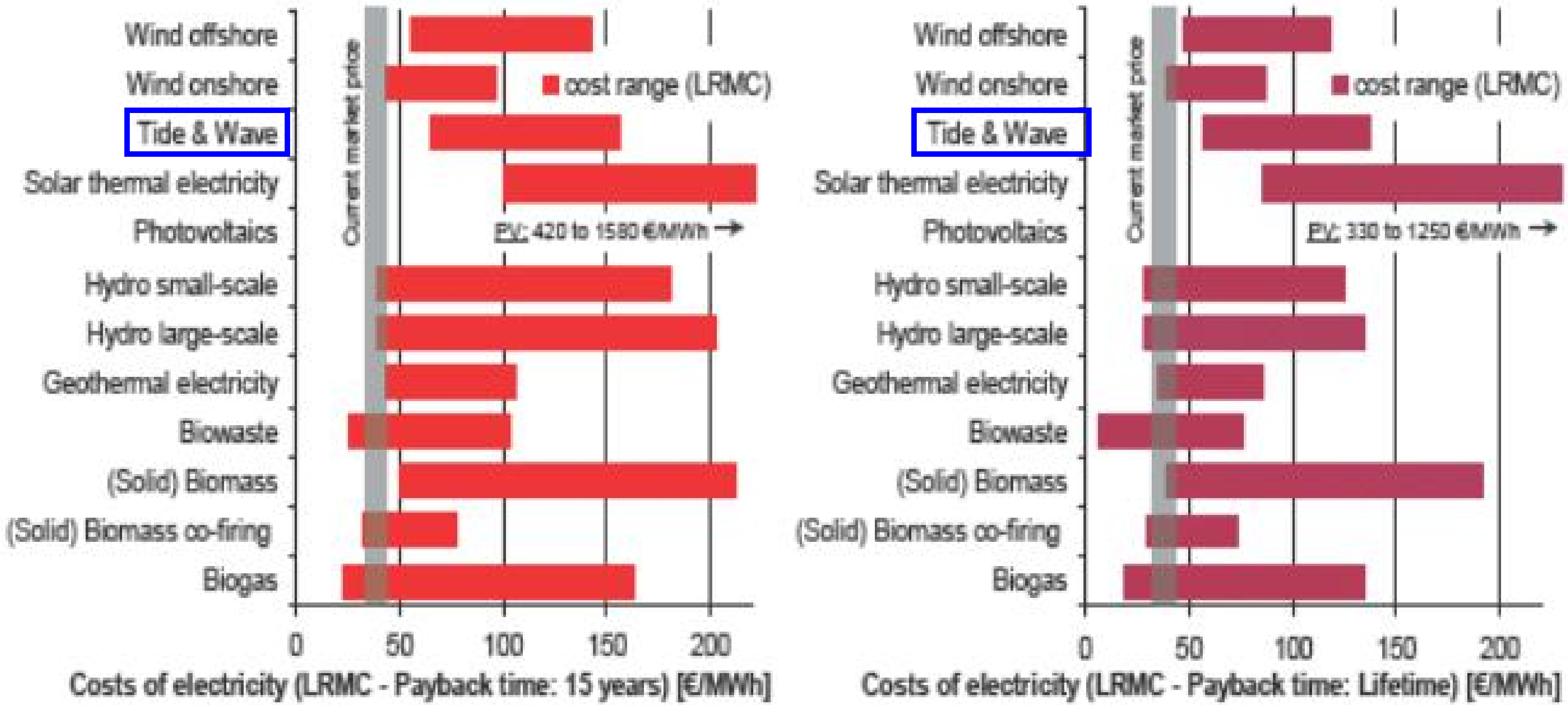
ECONOMICS

- Characterized by high capital costs per MW of installed cap
- High payback period
- Annual operation & maintenance costs are typically less than 0.5 % of initial capital
- Possible consumption of power locally & shorter construction times for small schemes make them more economic compared to large ones
- High capital costs & long construction time make tidal energy sensitive to discount rates
- Non-energy benefits should be taken into account in assessing potential schemes

Comparison of Capital costs

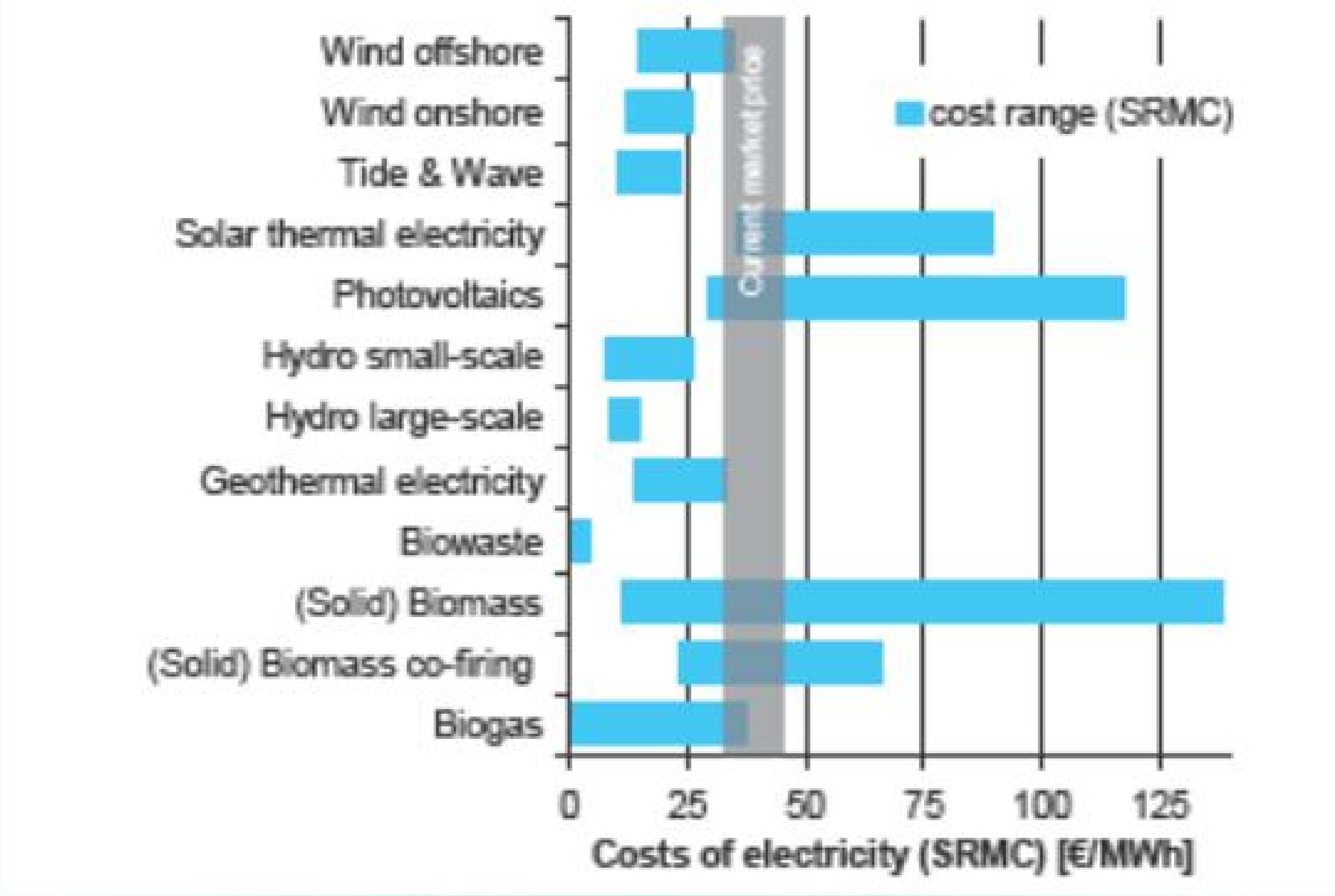
RES-E sub-category	Plant specification	Investment costs	O&M costs	Efficiency (electricity)	Efficiency (heat)	Lifetime (average)	Typical plant size
		[€/kW$_{el}$]	[€/(kW$_{el}$*year)]	[1]	[1]	[years]	[MW$_{el}$]
Wind onshore*	Wind power plant	945 - 1050	36 - 40	-	-	20	2
Wind offshore	Wind power plant – near shore	1750	65	-	-	25	5
	Wind power plant - offshore: 5…30km	1950	70	-	-	25	5
	Wind power plant - offshore: 30…50km	2150	75	-	-	25	5
	Wind power plant - offshore: 50km…	2400	80	-	-	25	5
Geothermal electricity	Geothermal power plant	2000 - 3500	100 - 170	0.11 - 0.14	-	30	5 - 50
Hydro large-scale*	Large-scale unit	850 - 3850	35	-	-	50	250
	Medium-scale unit	1125 - 4875	35	-	-	50	75
	Small-scale unit	1450 - 5950	35	-	-	50	20
	Upgrading	800 - 3600	35	-	-	50	-
Hydro small-scale*	Large-scale unit	800 - 1600	40	-	-	50	9.5
	Medium-scale unit	1275 - 5025	40	-	-	50	2
	Small-scale unit	1550 - 6050	40	-	-	50	0.25
	Upgrading	900 - 3700	40	-	-	50	-
Photovoltaics	PV plant	5400 - 6300	40 - 50	-	-	25	0.005 - 0.05
Solar thermal electricity	Solar thermal power plant	2900 - 4500	165 - 230	0.33 - 0.38	-	30	2 - 50
Tidal energy	Tidal (stream) power plant - shoreline	3000	50	-	-	20	0.5
	Tidal (stream) power plant – near shore	3200	55	-	-	20	1
	Tidal (stream) power plant - offshore	3400	60	-	-	20	2

Returns……



Long run marginal cost (LMRC) – deciding whether to build a plant (for 2004)

Contd..



Short run marginal costs (SMRC) – running costs (for year 2004)

Environmental impact

Local Impact

- **Turbidity**

  Volume of water exchanged between the basin and the sea is lesser, turbidity decreases
  Light from the Sun penetrates the water deeper

- **Salinity**

  Again as a result of less water exchange with the sea, the average salinity inside the basin decreases, also affecting the ecosystem.

- **Sediment movements**

  High volume of sediments moving through estuaries – rivers to sea Barrage in estuary may result in sediment accumulation within the barrage

- **Pollutants**

Reduced water volume – pollutants in basin are less efficiently dispersed. Increased bacteria content – affects human life

- **Fish**

Fish will seek out turbines and attempt to swim through them.

Fish mortality per pass is approximately 15% (from pressure drop, contact with blades, cavitation, etc.).

Research in sonic guidance of fish is ongoing.

Global environmental impact

A tidal power scheme is a long-term source of electricity.

Severn Barrage is projected to save a million tons of coal per year of operation

Decreases the output of greenhouse gases.

SOCIAL IMPLICATIONS:

- During the construction of the barrage, human activity in the area will increase dramatically and continue to be high till completion. The La Rance tidal barrage in France took over 5 years to construct.

- The barrage would affect shipping and navigation and provision would have to be made to allow ships to pass through

- The bay would become available for recreation; the waters would be calmer not immediately after the barrage but further in towards the land. This would be another tourist attraction and become a feature of the area.

- The inundation would cause displacement of people, especially fishermen

CONCLUSIONS…

- Tidal energy is predictable
- Tidal Energy is technologically developed
- Environmental impacts are lesser
- Economics are difficult to get around
- These projects are capital intensive
- Are people really willing to pay?


Romancing the Tide
Creating a new paradigm for renewable energy choices