Renewable Ocean Energy for The APEC Region

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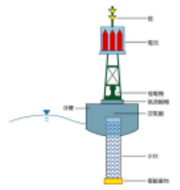
Wave Power

- There are many wave power patents in the world.
- The most feasible concept is using the air as a medium. The navigation light buoy is an example.

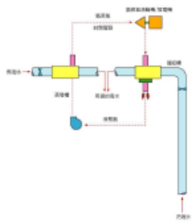


Energy Density

- Kinetic < Potential < Thermal
- 1 m/s current=0.05 meter head
- 1 gram water exits one cal. heat as it decreases 1 degree Celsius. This heat can raise itself 420 meters height!

Closed Cycle OTEC

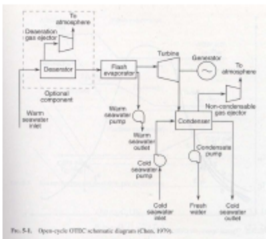
- OTEC is the abbreviation for Ocean Thermal Energy Conversion. The closed cycle is using ammonia as the heat transfer medium within a closed loop.



Ocean Current

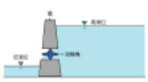
- The energy density of ocean current is very low. It is similar to wind energy.
- The issue is how to install and maintain the big sea water turbine at deep ocean.

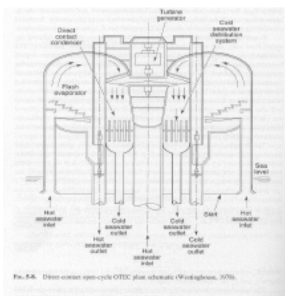
Open Cycle OTEC



Tidal Power

- The tidal power plant is like the dam power plant.
- The technology is already commercialized.





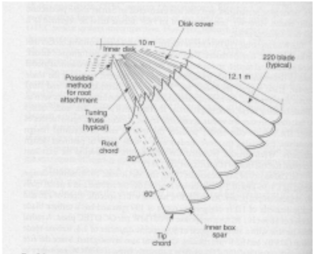


Fig. 5-9. Partial assembly of composite turbine rotor (Penney, 1986).

OTEC

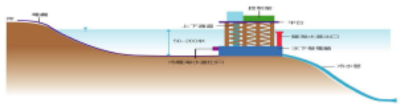
- Because the cold water flow rate is very large, the cold water pipe diameter should be very large, say 10 meters.

OTEC

- Avery $ Wu(1994) estimated that about 3 CMS cold and warm sea water can generate 1 MW net power.
- The sea surface temperature in the tropical and sub-tropical region is quite stable day and night, year round. In fact, the sea surface is a large, perfect solar board.
- Avery $ Wu(1994) estimated that the global useful sea area can generate power exceeding 10 million MW without changing the sea surface temperature.

Shelf-mounted OTEC

- For shelf-mounted OTEC the only problem is the bottom cold water pipe. Because of the sediment slumping, the bottom cold water pipe safety becomes unpredictable.



OTEC

Copy from the book "Renewable ocean energy from the ocean – A guide to OTEC"

useful tropical ocean area, the total power generated on board would exceed 10 million MWe; if each plant generated 200 MWe of net power, the plants would be spaced 32 km (20 miles) apart. For comparison, the total U.S. electricity-generating capacity in 1987 was 165 thousand MWe.

Floating OTEC

- The moored floating OTEC plant is a good concept. The CWP is much easier than that of shelf-mounted OTEC. If the electric power is to be transmitted to shore, there is a distance limit.
- Another option is to electrolyze water to become hydrogen and oxygen then synthesize them with coal to produce the methanol and ammonia as fuel, which can be transported everywhere.
- A drifting grazing OTEC plantship is another choice.

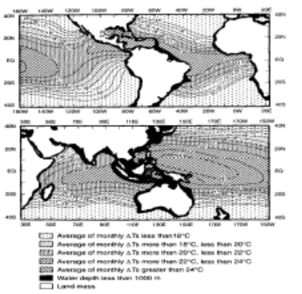


Fig. 1-1. Ocean temperature resource for OTEC (U.S. Department of Energy, Assistant Secretary Energy Technology, Division of Solar Technology).

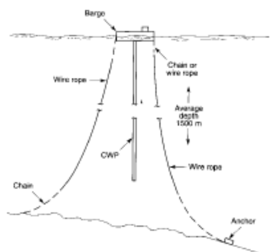


Fig. 1-9. Diagram of mooring options for an OTEC barge (Ross and Wood, 1981).

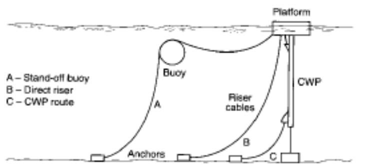


Fig. 1-10. Diagram of power cable deployment options for moored OTEC power plant (Schultz et al., 1981).

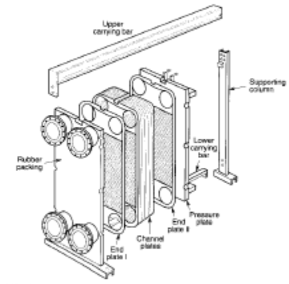


Fig. 4-17. Schematic view of Alfa-Laval plate heat exchanger (Berndt and Connell, 1978).

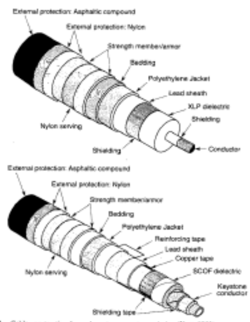


Fig. 4-62. Cable construction for underwater power transmission (Kurt, 1981).

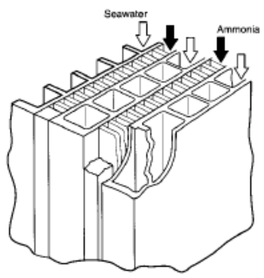


Fig. 1-8. Fluid flow paths in plate heat exchanger.

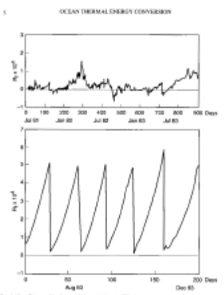


Fig. 4-12.

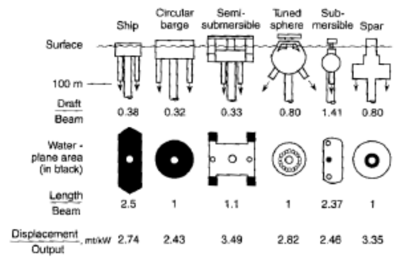


Fig. 1-11. Alternative platform configurations for moored OTEC power plants (Waid, 1978).

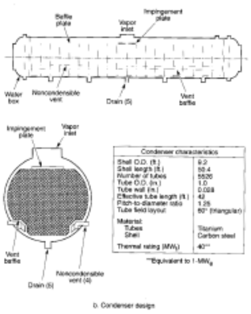


Fig. 4-13b. (continued).

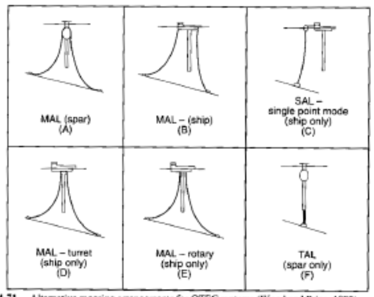
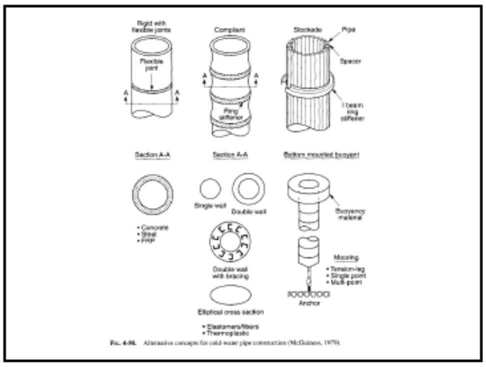
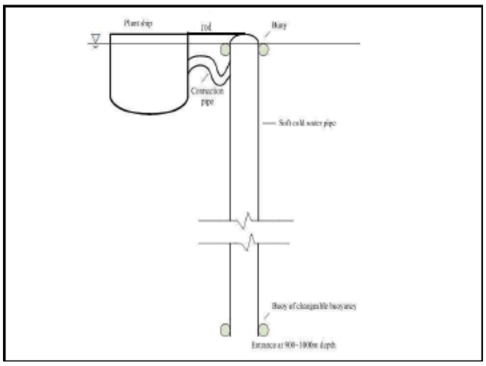
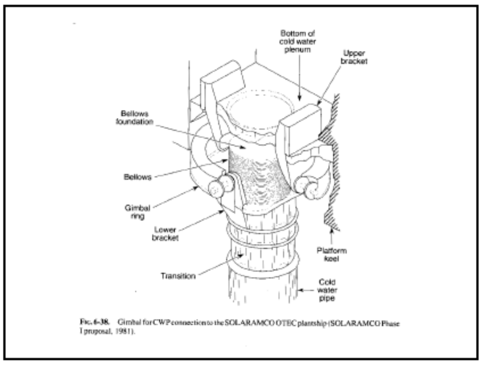
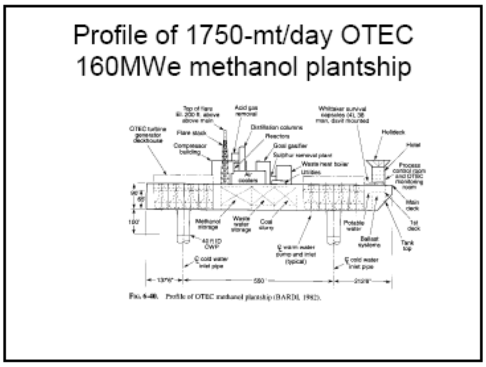


Fig. 4-71. Alternative mooring arrangements for OTEC systems (Wood and Price, 1980).









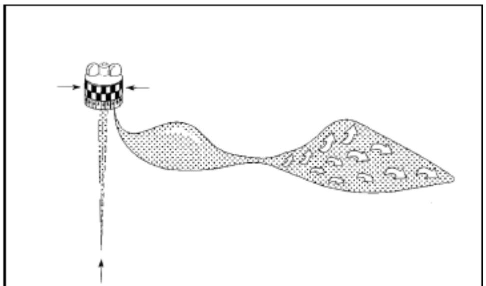
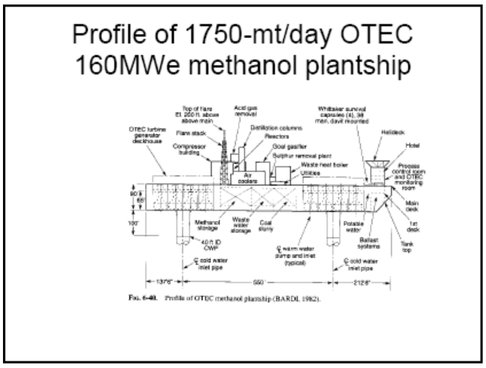
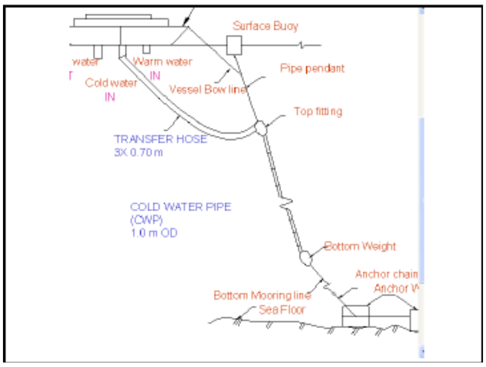
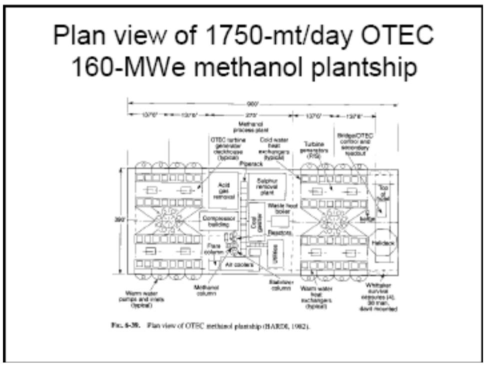


FIG. 9-1. Discharge flow field for an OTEC plant (Jirka et al., 1979).







Cost Estimate for Grazing OTEC First 200-MWe Methanol Plantship

Subsystem	Cost ($M1990)	Uncertainty
Platform	190.7	-14.0 -- +16.9%
Power system	180.4	-23.4 -- +17.6%
Water ducts	30.8	-24.9 -- +69.0%
CH_3OH production	311.2	-16.5 -- +16.5%
CH_3OH synthesis	68.0	-15.0 -- +15.0%
Service & maintenance	39.2	-15.0 -- +15.0%
Electrolysis	58.4	-30 -- +35.0%
Deployment	39.0	-30.6 -- +81.4%
Acceptance, incl. fac., E&A	45.1	-20 -- +20%
Weighted cost uncertainty		-13 -- +24%
Direct cost	855.6	
Interest during construction (15% of direct cost)	131	
Tot. investment		
Nominal	986	
Minimum	789	
Maximum	1292	

Note: 1990$=1980$x1.369=1983$x1.128

Open Cycle OTEC

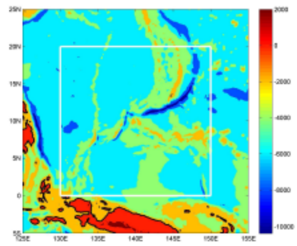
- The open cycle OTEC has the shortcoming that the water vapor pressure is low. Therefore, the turbine should be very large. Hence it is not suitable for a plantship.
- If instead of plantship an artificial island, which can be built by the light reinforced concrete, is used, the open cycle OTEC may be feasible because the heat exchanger and ammonia are not necessary. The plant capacity can be several GW.

OTEC Methanol Financing

- Mossman (1989) proposed a financial evaluation for a 200MWe OTEC methanol plantship. Two years of financed construction followed by an operating life of 25 years are assumed. The analysis calculates a quantity termed "the adjusted present value" (APV), which measures the profitability of a potential venture.
- Some assumptions are the following:

1. Permanent financing interest rate is 13%.
2. An interest rate of construction financing is 12%.
3. The debt is 80%.
4. The design methanol production rate per OTEC plantship is 199 million gallons per year. The annual coal cost is 23,5 million dollars (470,000 tons/year at $50/ton). Coal and methanol shipping costs are $20/ton each.
5. Operating and maintenance costs are assumed to be $50.9M/year.
6. The cost of the second vessel is 0.8 times that of the first and an experience factor of 0.93 for each doubling of he number produced.
7. The government provides an incentive commitment for the production of low-polluting vehicle fuels.
8. An investment tax credit (ITC) of 10% has been used.

Note: The crude oil price in 1990 was $20/bbl.



OTEC CLOSED-CYCLE COST EVALUATION 373

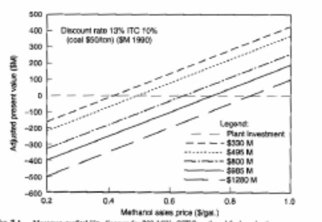


FIG. 7-1. Mossman profitability diagram for 200-MWe OTEC methanol fuel production.

1945-2005颱風

- zonal_0_5and125_130
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 1.0 0.0 0.0 0.0 0.0 1.0 0.0

- zonal_0_5and130_135
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 1.0 0.0 0.0 0.0 0.0 1.0 0.0

- zonal_0_5and135_140
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 8.0 0.0 1.0 0.0 0.0 0.0 0.0

- zonal_0_5and140_145
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 12.0 0.0 0.0 0.0 0.0 1.0 0.0

- zonal_0_5and145_150
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 11.0 1.0 1.0 0.0 0.0 0.0 0.0

Profit to investor with OTEC methanol (discount rate=13%;construction interest=12%; ITC=10%;APV=0)

Plant No.	n^{th} plant Inves.($M)	Total prod. (Bgal/y)	Sales Price ($/gal)	Gasoline price incl. import and carbon tax ($/gal)	CH_3OH price incl. auto cost and carbon tax ($/gal)	Net profit to investor replacing gasoline by CH_3OH ($B/y)
1	960	0.20	0.75	1.53	1.56	-0.003
2	768	0.40	0.70	1.53	1.47	0.013
3	768	0.60	0.68	1.53	1.44	0.029
4	714	0.80	0.67	1.53	1.42	0.051
8	664	1.6	0.64	1.53	1.37	0.143
16	618	3.2	0.62	1.53	1.33	0.35
32	575	6.4	0.60	1.53	1.29	0.85
64	534	13	0.58	1.53	1.25	1.97
128	497	25	0.55	1.53	1.21	4.50
256	462	51	0.53	1.53	1.18	10.0
427	438	85	0.52	1.53	1.15	18.0
512	430	102	0.51	1.53	1.14	22.0

Note: In automobile miles/gal, 1.8 gallons CH_3OH=1.0 gallon gasoline.

1945-2005颱風

- zonal_5_10and125_130
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 51.0 27.0 7.0 3.0 2.0 3.0 2.0

- zonal_5_10and130_135
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 75.0 41.0 8.0 6.0 4.0 3.0 3.0

- zonal_5_10and135_140
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 107.0 42.0 13.0 10.0 4.0 4.0 1.0

- zonal_5_10and140_145
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 106.0 39.0 19.0 5.0 5.0 2.0 2.0

- zonal_5_10and145_150
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 114.0 39.0 14.0 5.0 1.0 2.0 3.0

1945-2005颱風

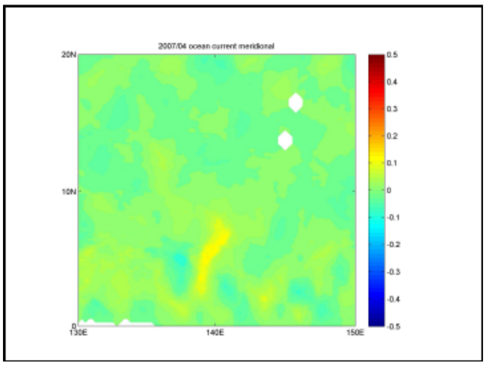
- zonal_10_15and125_130
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 106.0 114.0 45.0 23.0 12.0 28.0 26.0

- zonal_10_15and130_135
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 120.0 115.0 41.0 24.0 15.0 27.0 22.0

- zonal_10_15and135_140
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 125.0 87.0 55.0 24.0 16.0 24.0 17.0

- zonal_10_15and140_145
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 103.0 88.0 46.0 14.0 9.0 22.0 11.0

- zonal_10_15and145_150
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 102.0 88.0 17.0 16.0 8.0 12.0 11.0



1945-2005颱風

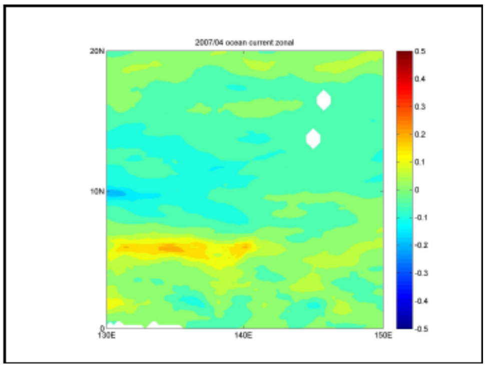
- zonal_15_20and125_130
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 73.0 88.0 69.0 32.0 32.0 47.0 33.0

- zonal_15_20and130_135
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 65.0 104.0 53.0 25.0 31.0 43.0 30.0

- zonal_15_20and135_140
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 62.0 88.0 36.0 27.0 28.0 28.0 32.0

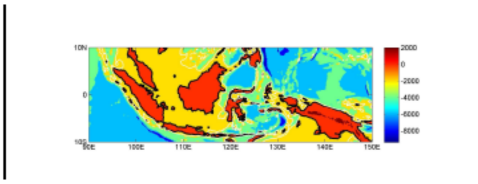
- zonal_15_20and140_145
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 74.0 67.0 40.0 19.0 18.0 21.0 17.0

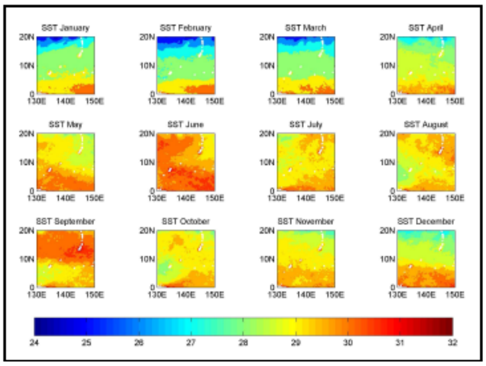
- zonal_15_20and145_150
- TD TS Hu1 Hu2 Hu3 Hu4 Hu5
- number 49.0 62.0 27.0 14.0 15.0 13.0 7.0

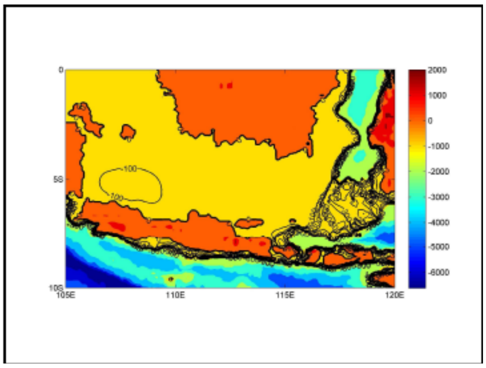


Saffir-Simpson Scale

- TD-----< 34 (海浬**knots)**
- **Tropical Storm**TS-----34-63
- **Hurricane**1------64-82
- **Hurricane**2------83-95
- **Hurricane**3------96-112
- **Hurricane**4------113-134
- **Hurricane**5------>134
- **(1 knot = 1.15mph = 1.852 km/h)**
- （美國一級颶風等於我們中度颱風）







Conclusion

- The key technologies can be studied and assessed separately.
- Once all technologies are accomplished, a small scale pilot plant, say 5 MW, may be built.
- An international cooperation is encouraged. Due to the favorable marine environment, Indonesian may be the best site to test the pilot plant.

The Energy from Taiwan Current

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The Energy From Taiwan Current

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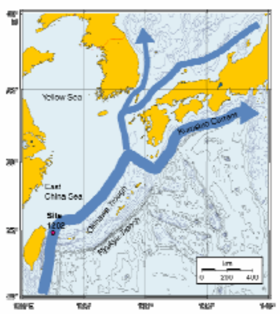
- Potential power generation (PPG)
  = (available ocean energy)
  *(extractable fraction)
  *(power generation efficiency)
- Profits = PPG * (Benefits/kW - cost/kW)
  benefits = selling price, enhanced fishing, …
  cost in the sense of dollar value, environmental impact, …

Comparison of ocean energy

Ocean energy	Total amount	Amount at a point	availability	technology
Ocean wave	medium	low	coastal	Low
OTEC	high	high	open ocean	High
Tidal height	small	high	Bay, estuary	Low
Ocean current	Medium	High	Along current	medium
Salinity				

Why it is not commercialized yet? No guaranteed profits!

- **Technological barrier**
  (scale of the system is beyond any existing ocean engineering system)
- **Uncertainty on the investment**
  (no experience on system of similar principle, nor scale)
- **Initial investment is too large**
  (US$9B for a commercial OTEC)



Taiwan Current and Kuroshio

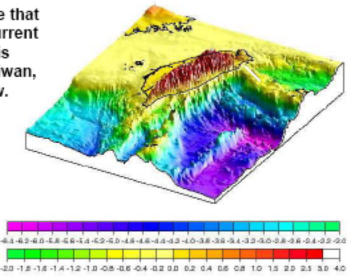
What can we do now?

- Collect and analyze data to find the best site for testing
- Develop prototype systems
- Integration of international efforts

Efforts made in Chinese Taipei

- Find potential sites
- Survey the available KE for power generation
- Collect available technology: designs and field tests
- Long term plan

Find a place that has high current speed and is close to Taiwan, and shallow.



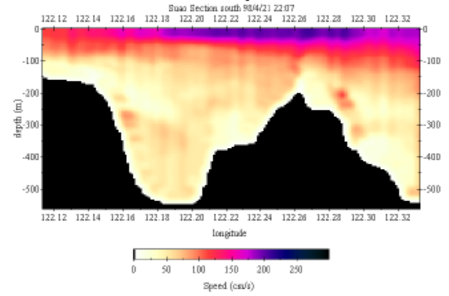
3-D bathymetry (NTUIO)

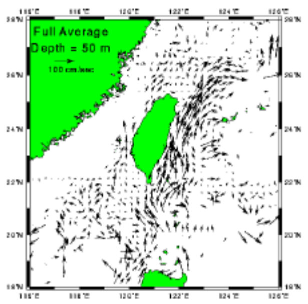
Power transport in a current

- Power transported by ocean current (J/s/m/m)：
- $P = 0.5 \int \rho v^3 \, dz \, dx$
- ρ is water density, about 1024 kg/m^3
- v is current speed, m/s
- dz dx is a small cross section of current

- Finding location of high speed current is the most important task

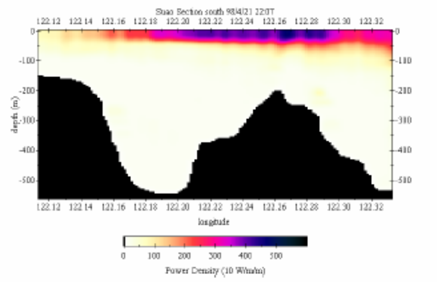
One section of current speed NE of Taiwan

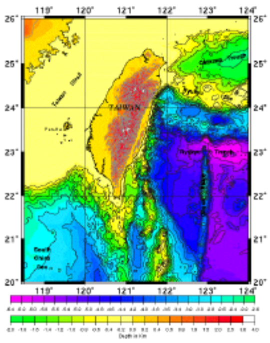




Mean Current Speed at 50 m depth (from NTUIO)

One section of power flux NE of Taiwan



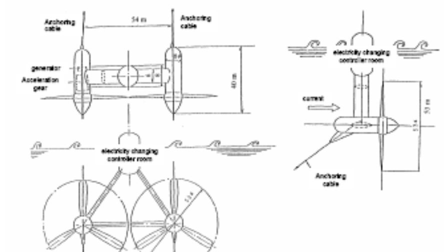


Power generating system is simpler at shallower depth, and closer to shore

Bathymetry (from NTU)

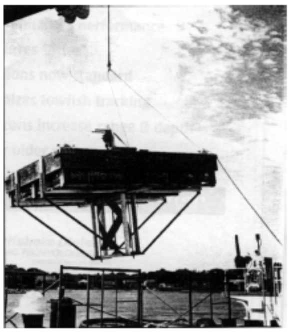
Total power from 1-section across the Taiwan Current

- 1.35 GW off Suao (at NE of Taiwan Island)
- It is a conservative estimate because most of the ocean current energy is contained in the form of potential energy; once the K.E. is extracted from Taiwan Current, some PE will be converted to K.E.
- Total available PE for the subtropical North Pacific is 40 peta Joule

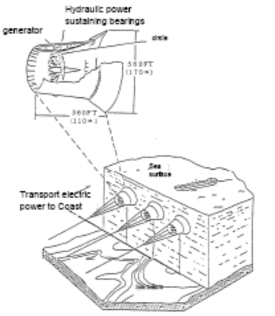


Propeller type
similar to wind power turbine

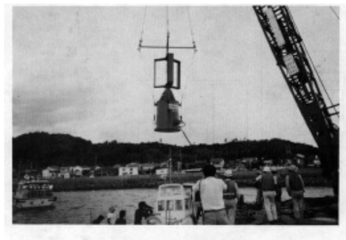
Helical Turbine (stable rotation and power generation)

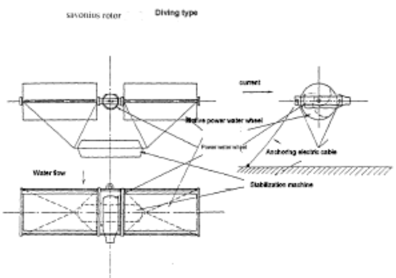


Axial turbine proposed in the Coriolis Project



Tidal Current Energy

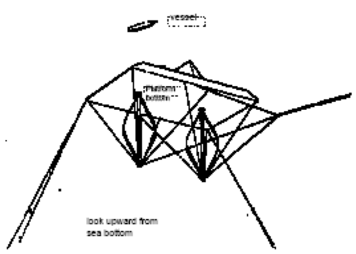




Underwater Savonius Wheeler type

What happened to the earlier studies

- in **Japan**:
  the result is discouraging
  – too little power was generated by tidal current with axial turbine
  => no participation by oceanographers, nor ocean engineers
  => the design may be wrong
- in **USA**:
  huge turbine was built to extract KE from Gulf Stream.
  no report on the result of the field study
  => it is likely that there was loss of equipment
  => real ocean current is really powerful,
  safety measures should be scaled up with the system
- in other places:
  no known field experiment of a large system was successful



Darrieus turbine and platform