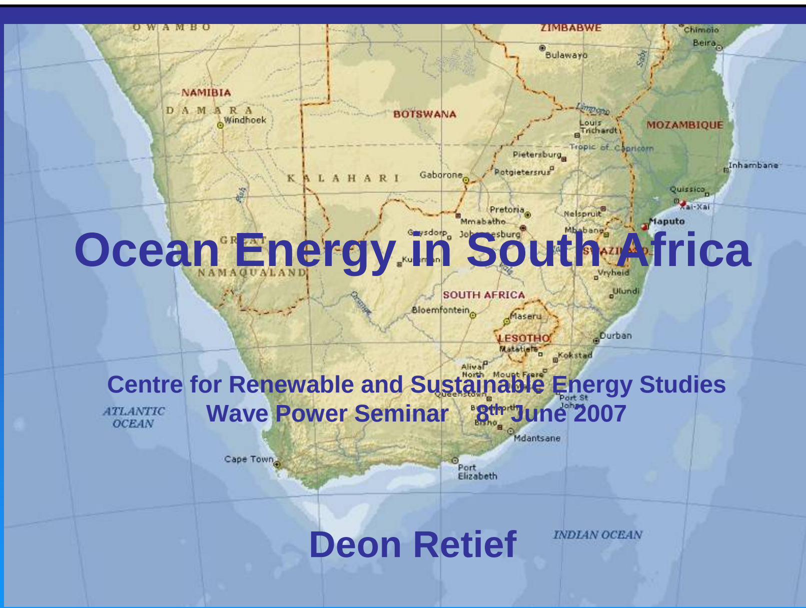
Ocean Energy in South Africa



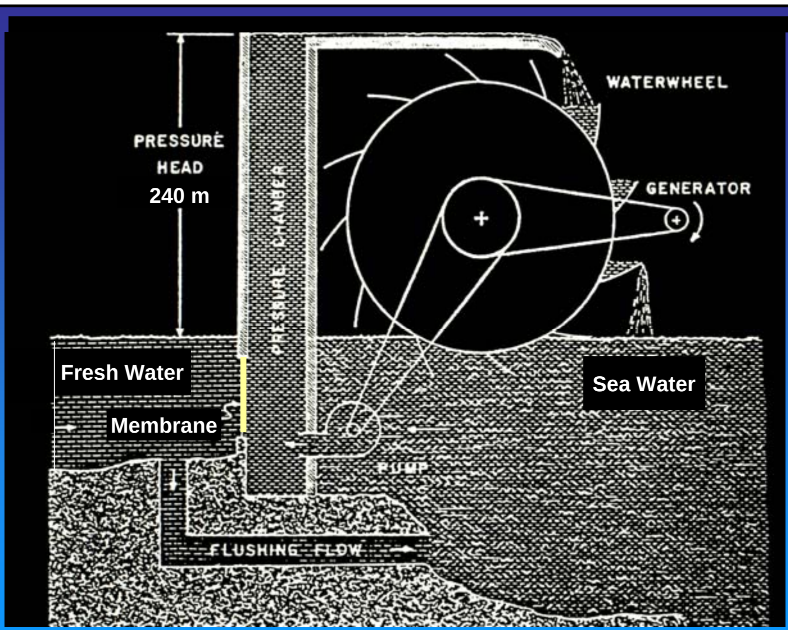
Centre for Renewable and Sustainable Energy Studies
Wave Power Seminar 8th June 2007

Deon Retief

PRESTEDGE RETIEF DRESNER WIJNBERG (PTY) LTD
CONSULTING PORT, COASTAL AND ENVIRONMENTAL ENGINEERS

SOURCES of OCEAN ENERGY

- SALINITY GRADIENTS — 240m head
- THERMAL GRADIENTS
- TIDES
- WAVES
- OCEAN CURRENTS — 0.2m head
- BIO-CONVERSION — -



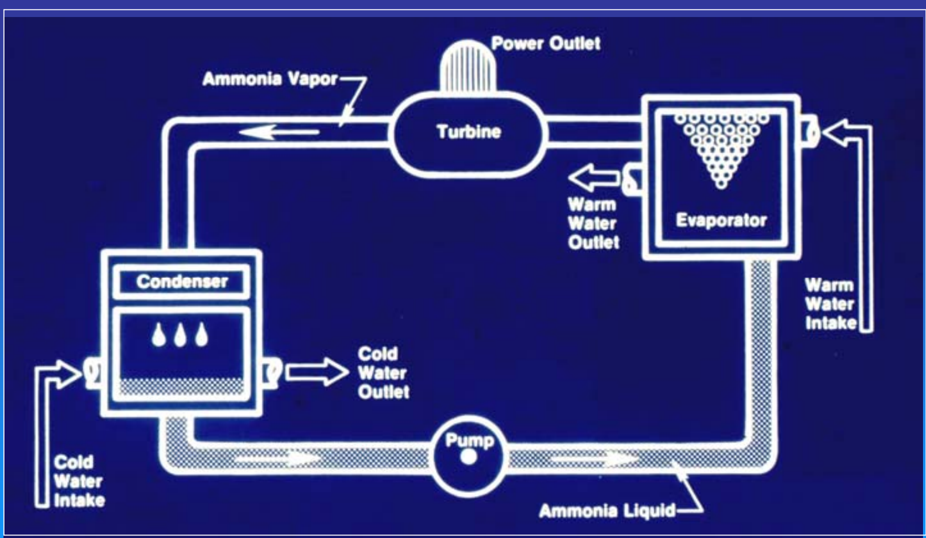
SALINITY GRADIENTS

SALINITY GRADIENTS

- Potential head of 240m at interface of fresh and sea water, particularly river mouths
- Processes include pressure retarded osmosis and reverse electro-dialysis or gas pressure differentials
- Problems with biological fouling of membranes, slow flow rates and brine disposal (can however, be re-used)
- Technology not yet sufficiently advanced

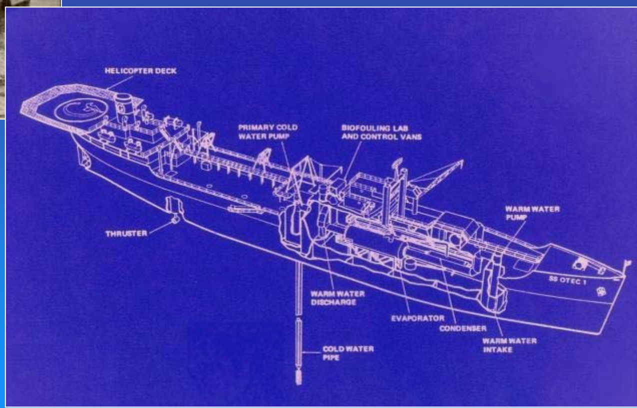
OCEAN THERMAL ENERGY CONVERSION (OTEC)

- Utilises temperature gradient between surface and deep ocean waters(500m to 1000m)
- Based on Claude or Rankine cycles
- Minimum temperature gradient of 20° C, (preferably 24° C) for economic viability.



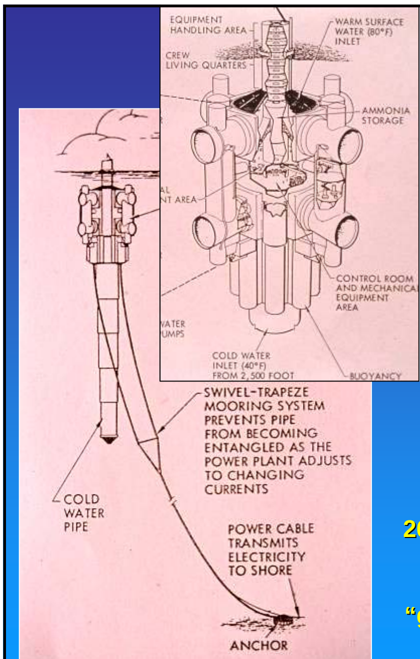
OTEC CYCLE

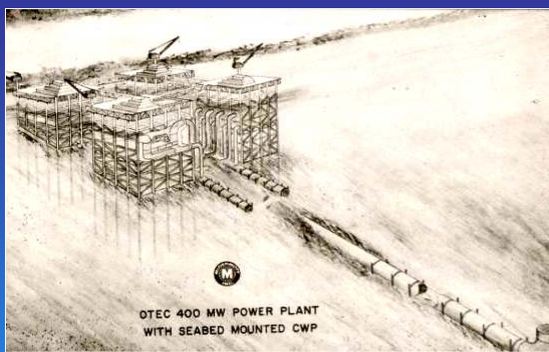
50 kW test platform
off Hawaii
(Mini OTEC)



OTEC 1

Advanced stage of viability testing previously achieved in USA

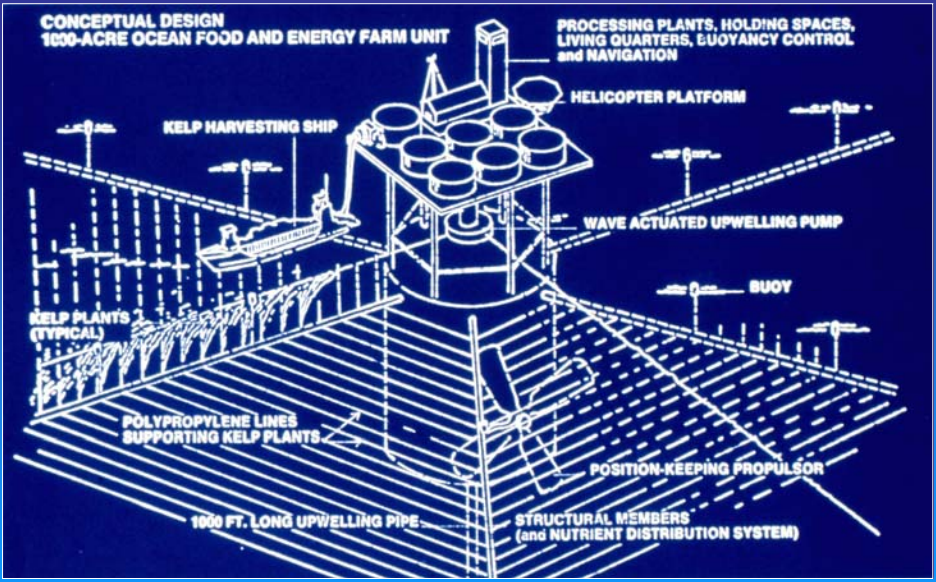




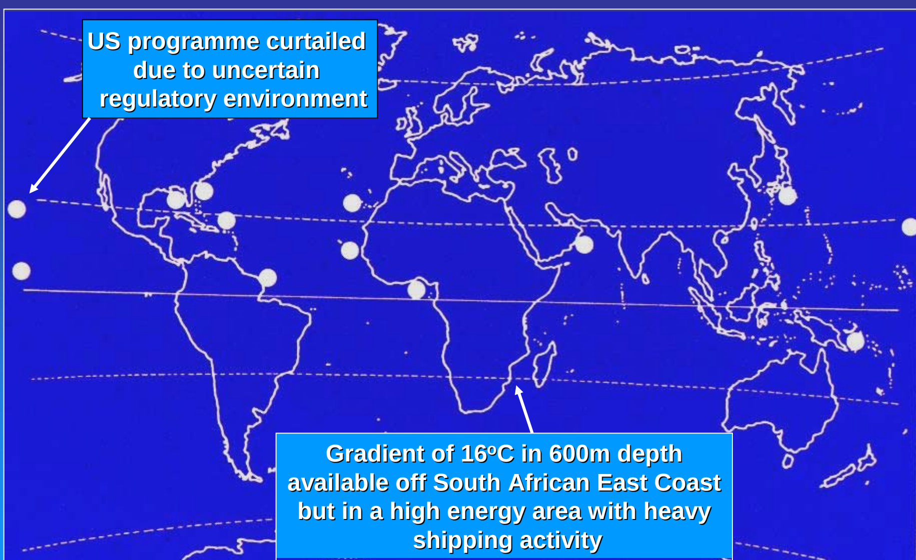
Proposed 400 MW land based converter
(small demonstration plant presently operating in Hawaii)

265 MW floating converter in anchored or "grazing" mode

OTEC CONCEPTS



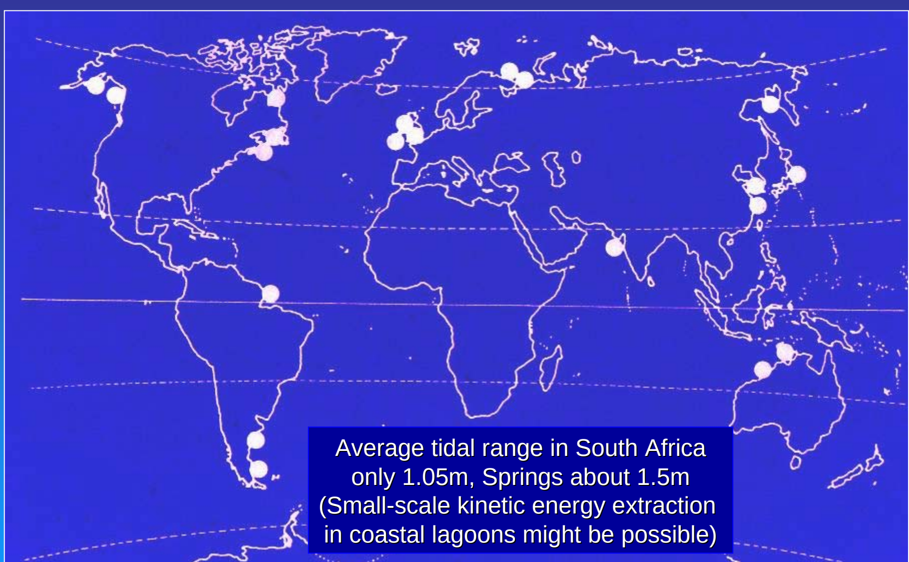
OTEC Powered Marine Farm



Potential OTEC sites close to shore

TIDAL POWER

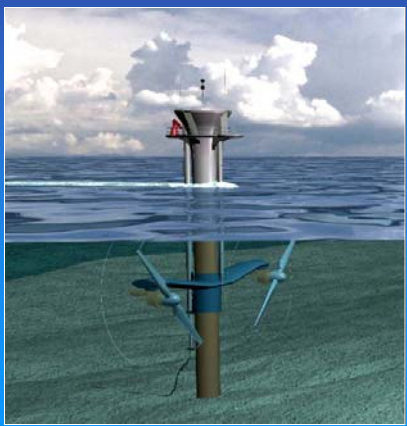
- Generally accepted that a minimum tidal range of 5m (preferably >10m) is required for economic viability in barrage schemes.
- Existing schemes at Rance Estuary (11m to 13.5m range, peak output of 240 MW), and Kislaya Inlet (400kW expanding to 320 MW)
- Many proposals for Severn estuary (UK), Bay of Fundy, South Korea, Japan etc



Sites of Possible Tidal Power Stations with 10m+ range

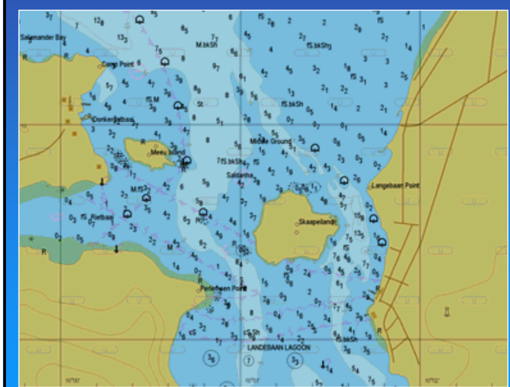
Tidal Streams

Shallow water currents generated by tides, extracted by vertical or horizontal axis turbines, in currents of at least 2m/sec

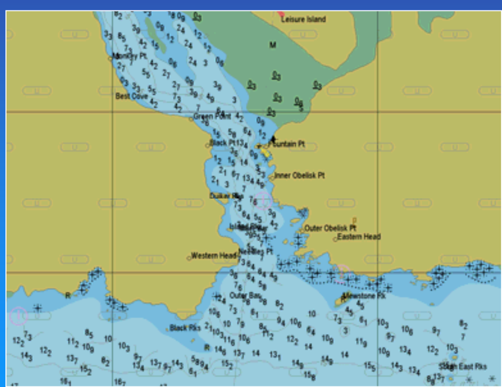


An example is the SeaGen Tidal Stream Turbine, comprising two 15 m diam twin axial flow rotors rated at 1 MW. (Presently undergoing tests in the Strangford Narrows off Northern Ireland)

MOST PROMISING TIDAL STREAM SITES in South Africa with depth averaged currents of about 1m/sec and water depths of 6 to 7 m



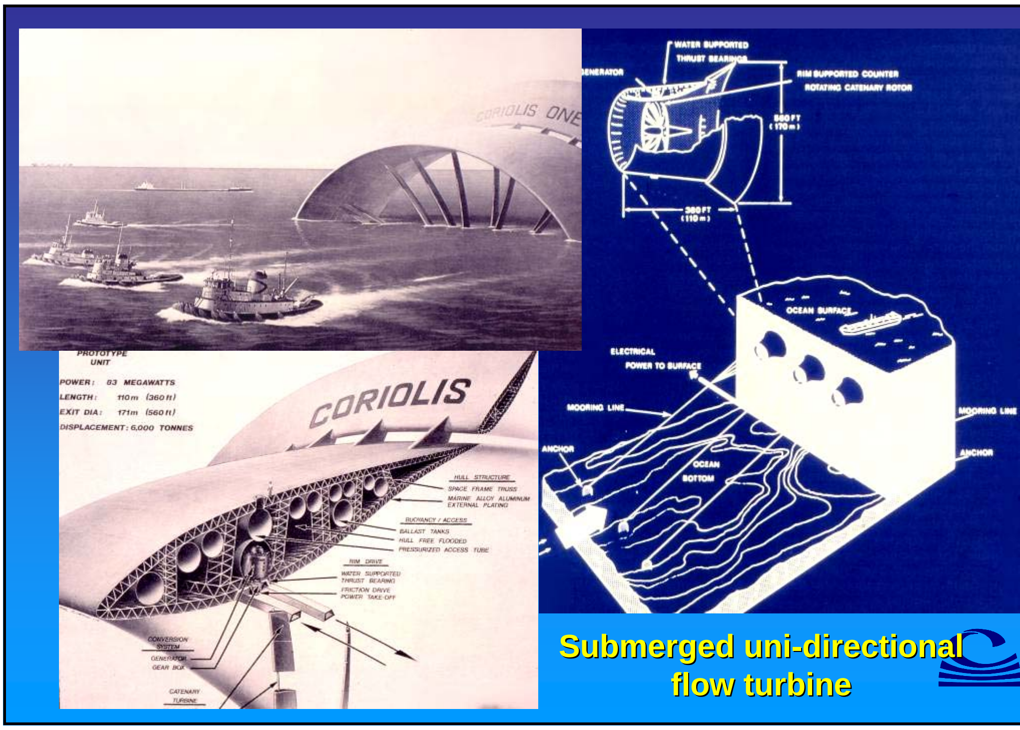
Langebaan Lagoon



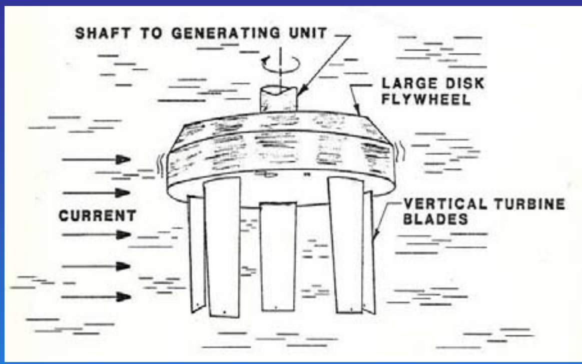
Knysna Heads

OCEAN CURRENTS

- Typified by low energy density and variable direction and velocity
- Extraction can be by vertical or horizontal axis turbine, savonius or hinged blade rotors with flow enhancement ducts, electromagnetic induction etc



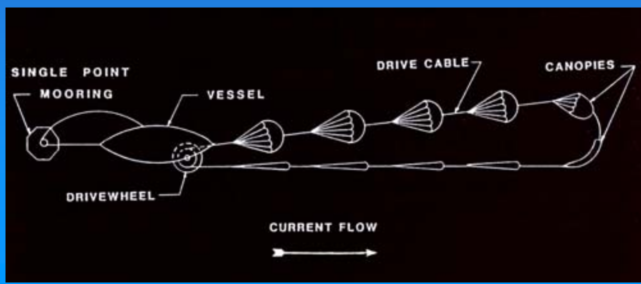
Submerged uni-directional flow turbine

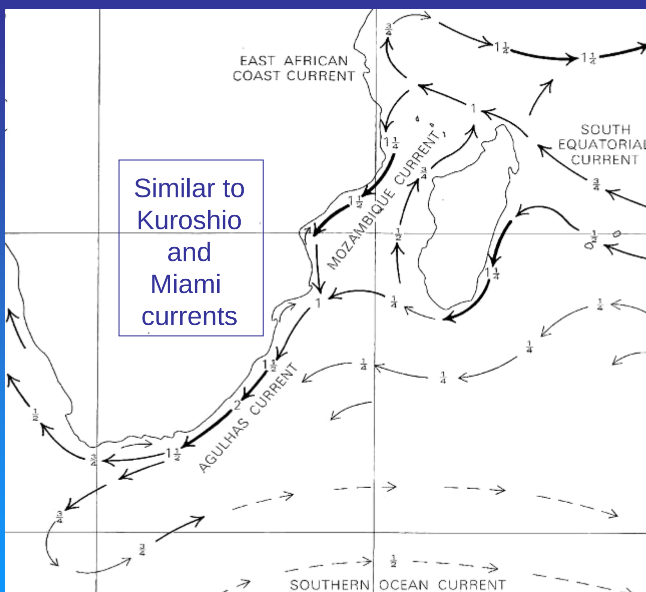


Vertical axis multi directional

(Conversion efficiencies of about 50 to 60%)

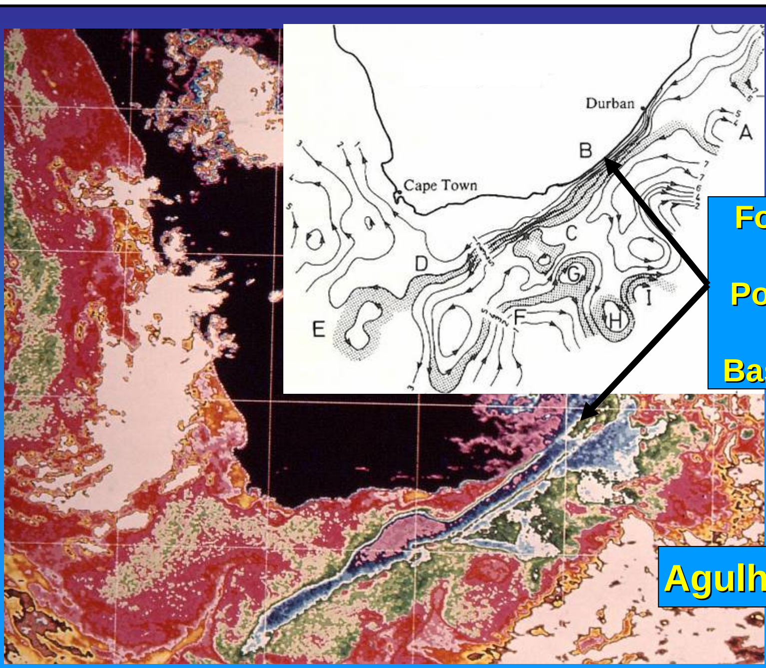
Linear conversion system





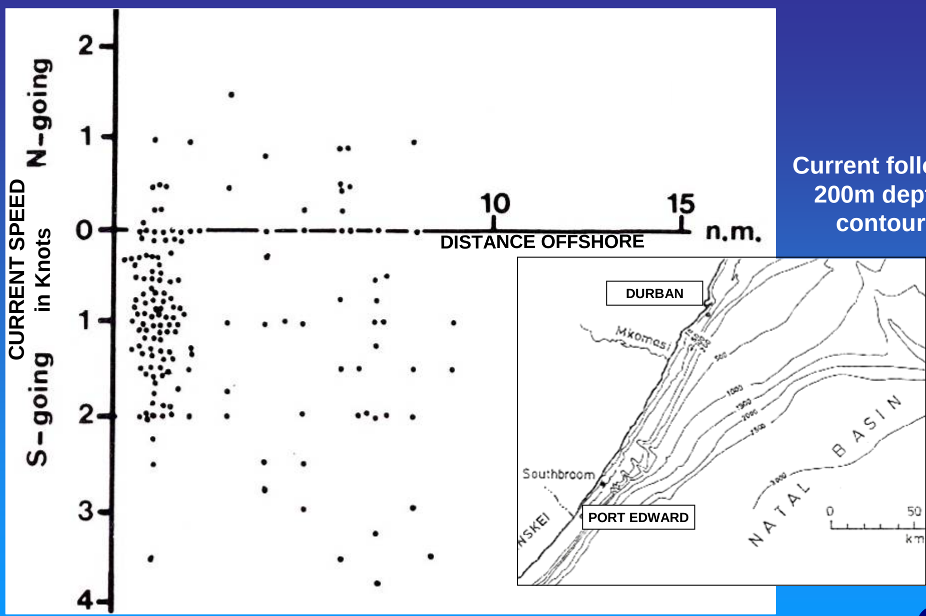
Similar to Kuroshio and Miami currents

Agulhas Western Boundary Current System



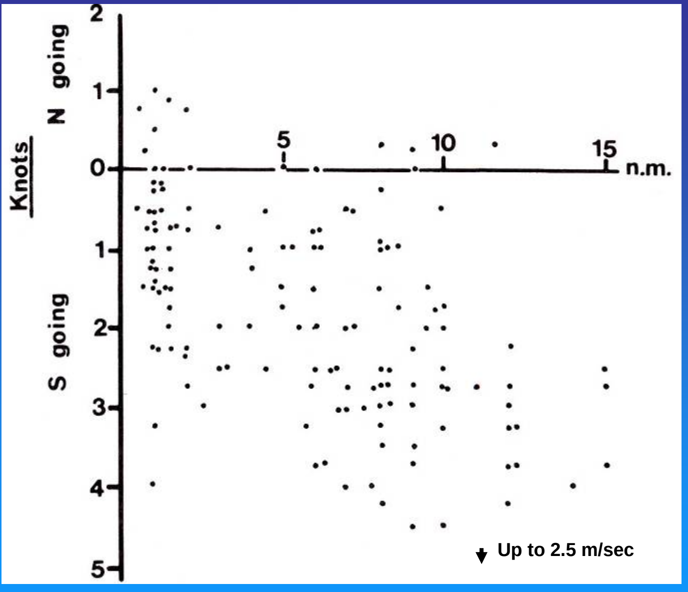
Focus Zone from Port Edward to Bashee River

Agulhas Current



Current follows 200m depth contour

Current drift observations off Port Edward



Average Energy Flux about 2kW/m^2 (= 1kW/m^2 after conversion)

(More information on microstructure needed)

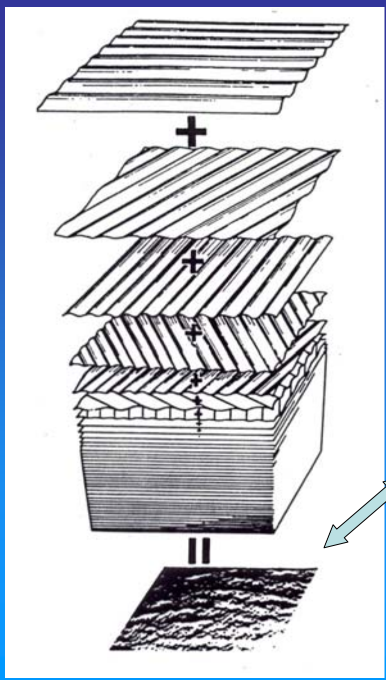
Current drift observations off Bashee River

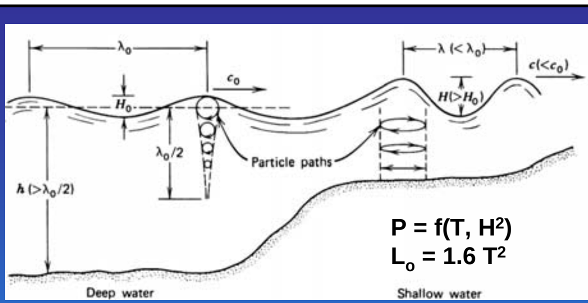
WAVE POWER

Wave Dynamics

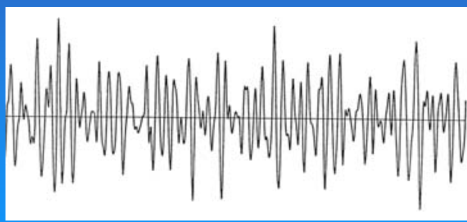
Wave Power Resource

Wave Power Extraction
- Ship Propulsion
- Electricity Generation





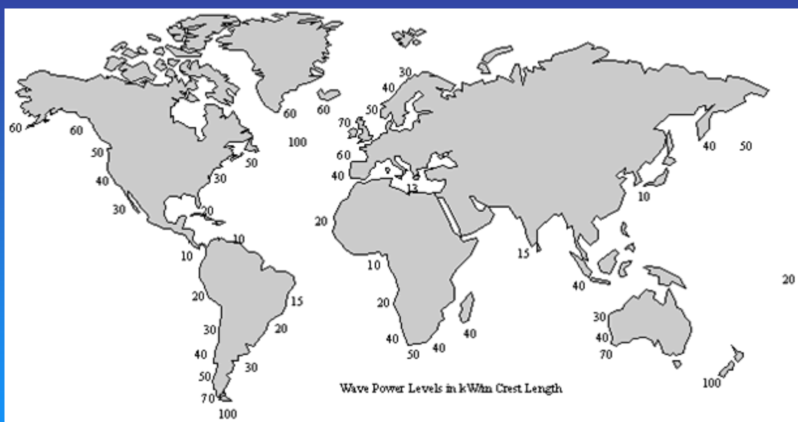
Idealised particle motion



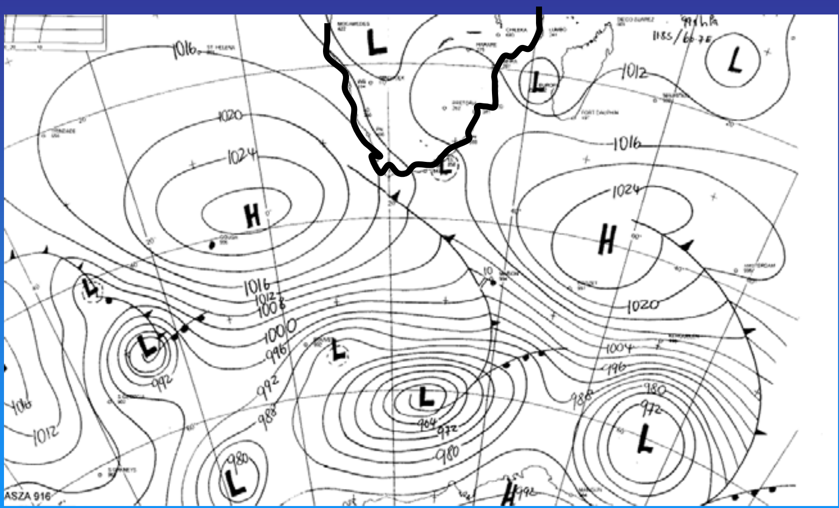
Random spectra

Wave Dynamics

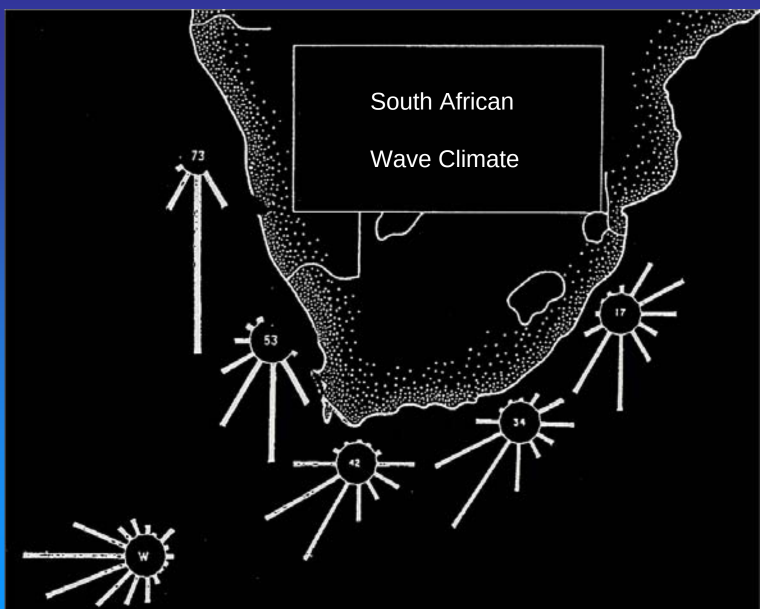
Wave Power Levels - Worldwide



Units: kW/m crest length

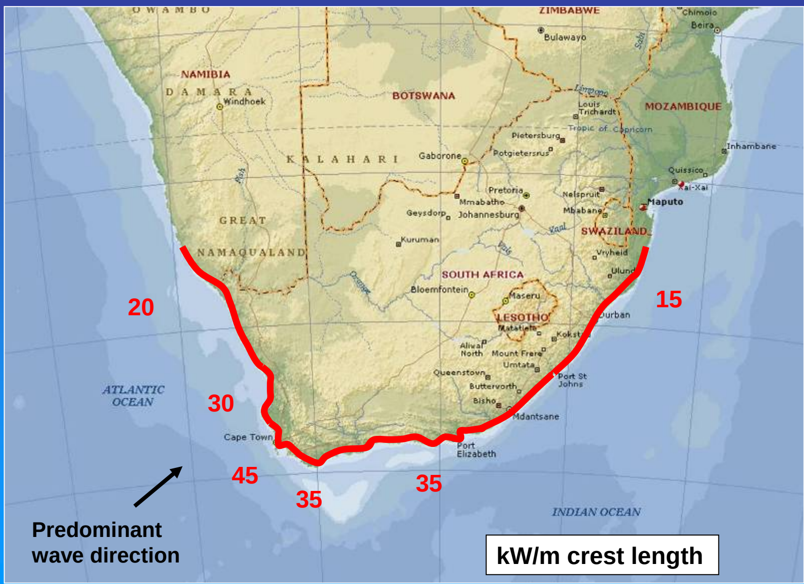


Wave Generation Zone off Southern Africa



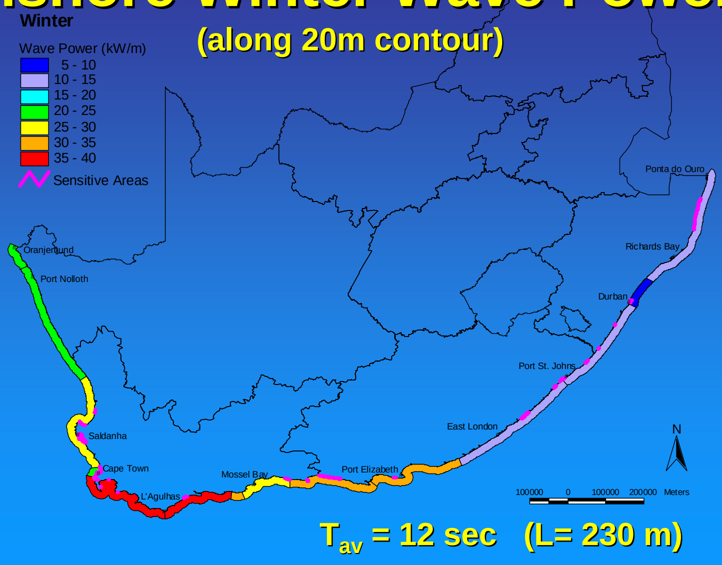
Incident Wave Roses

Offshore Wave Power Levels

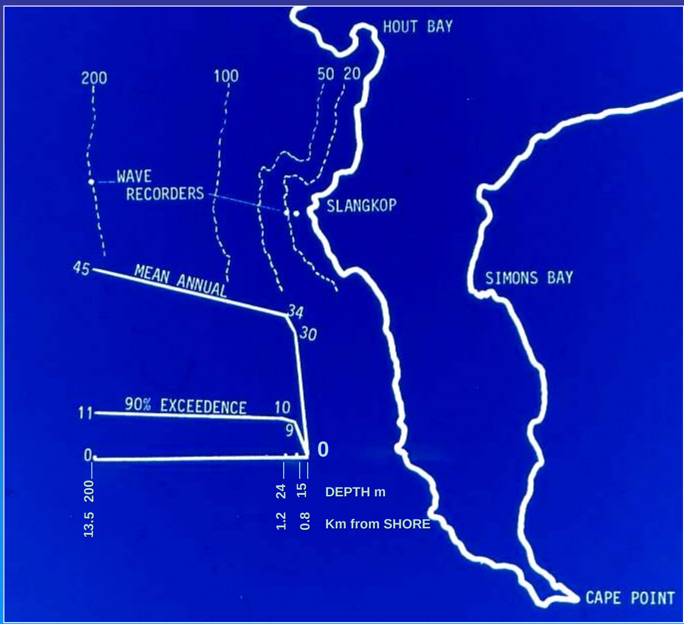


Inshore Winter Wave Power

(along 20m contour)

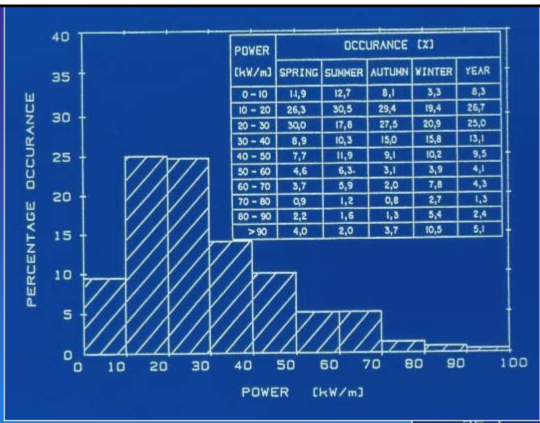


T_{av} = 12 sec (L= 230 m)



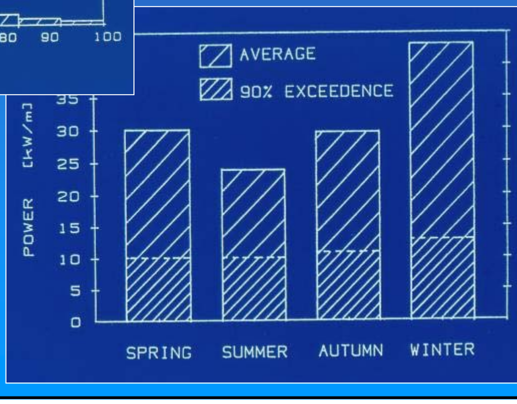
Inshore Power Levels off Slangkop

Examples of resource analysis off SW Coast

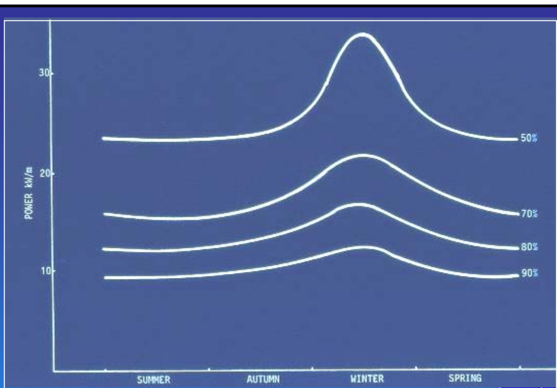


POWER [kW/m]	OCCURANCE [%]				
	SPRING	SUMMER	AUTUMN	WINTER	YEAR
0 - 10	11,9	12,7	8,1	3,3	8,3
10 - 20	26,3	30,5	29,4	19,4	26,7
20 - 30	30,0	17,8	27,5	20,9	25,0
30 - 40	8,9	10,3	15,0	15,8	13,1
40 - 50	7,7	11,9	9,1	10,2	9,5
50 - 60	4,6	6,3.	3,1	3,9	4,1
60 - 70	3,7	5,9	2,0	7,8	4,3
70 - 80	0,9	1,2	0,8	2,7	1,3
80 - 90	2,2	1,6	1,3	5,4	2,4
>90	4,0	2,0	3,7	10,5	5,1

% Occurrence of Power at Saldanha Bay

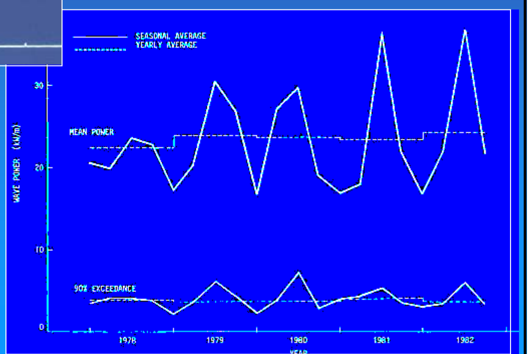


Seasonal Variation at Saldanha Bay



Seasonal variation

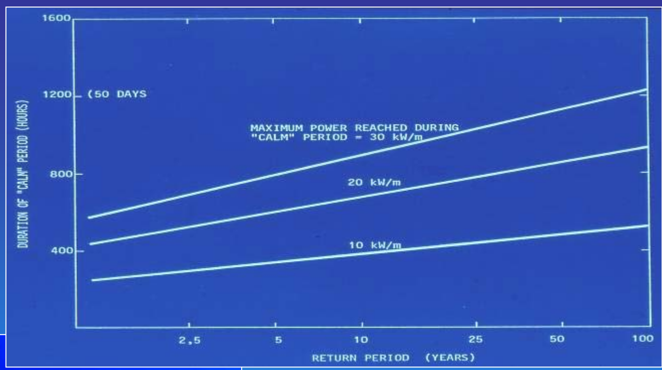
Seasonal and long term variations

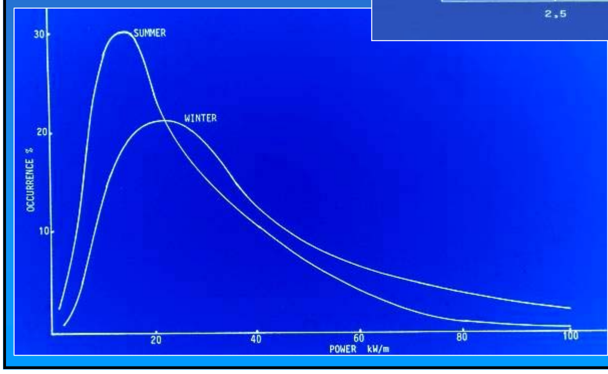


Variation over 5 years

Duration of Calms vs Return Period

(indicates backup or storage requirements)

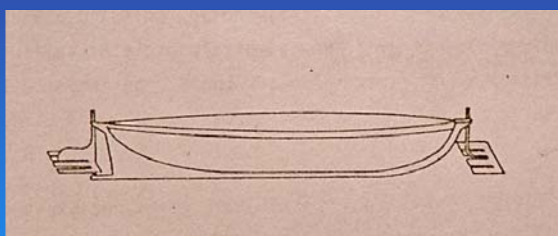




Occurrence Distribution Winter and Summer

Power Extraction

- Vessel propulsion



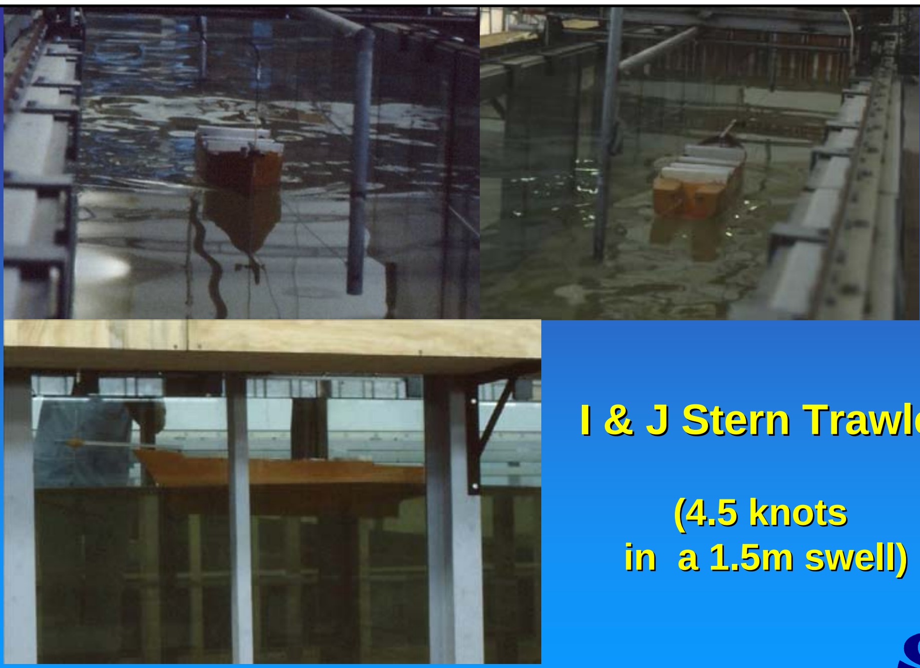
Linden's AUTONAUT



11 knots under
moderate swell
conditions



Prototype bow-mounted
propulsion vanes



I & J Stern Trawler

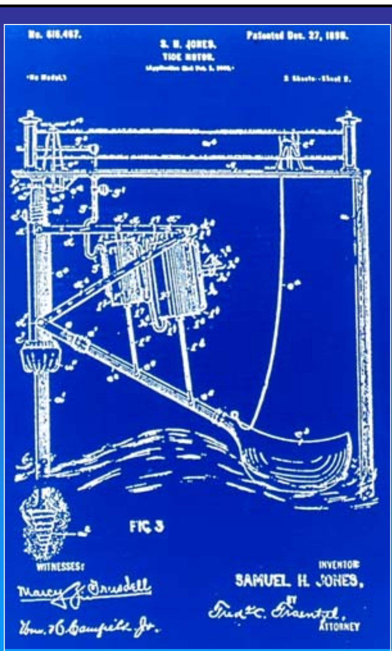
(4.5 knots
in a 1.5m swell)

Free drifting weather buoy

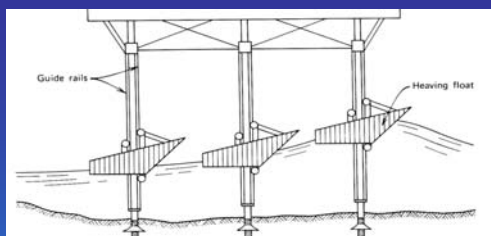
-

Wave propelled
station keeping
in South Atlantic

WAVE POWER CONVERSION



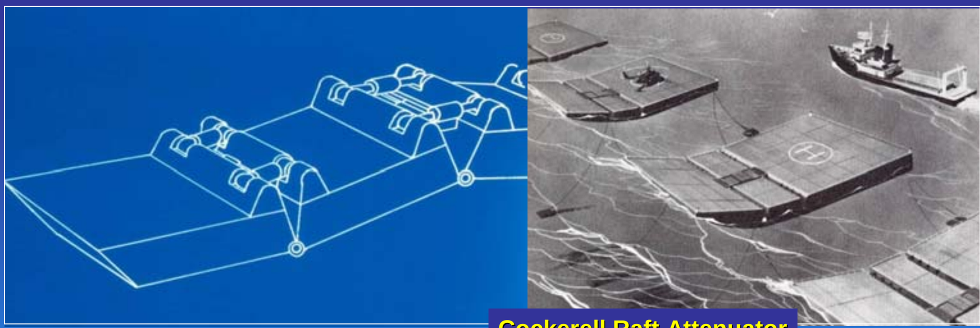
1898 Patent



Early Proposal

Modern Equivalent

POTENTIAL ENERGY



Cockerell Raft Attenuator

Pelamis
750 kW rating in 30m water depths

Potential Energy

WEM
Wave Energy Module

AquaBuoy
250 kW rating
in 50 to 60 m
water depths

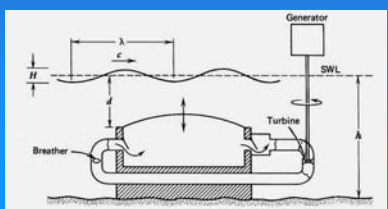
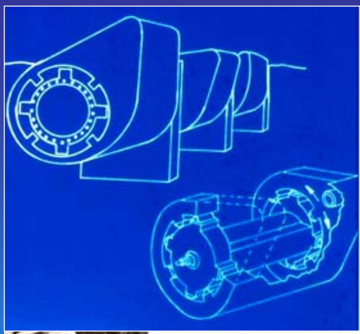
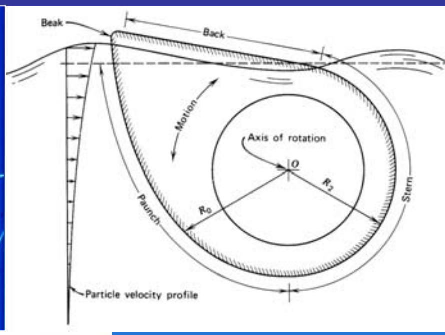


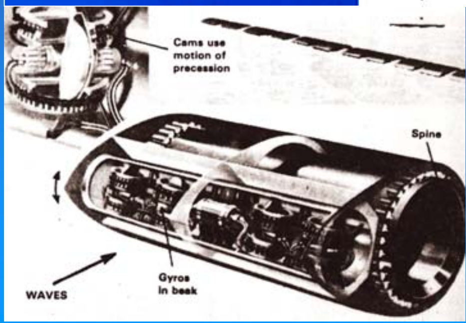
Figure 4.15b Uniform pressure wave pump with turbogenerator.

Pneumatic Wave Pump

POTENTIAL ENERGY

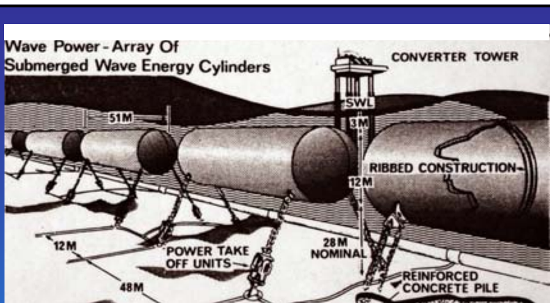




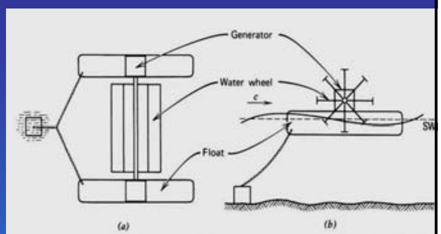


Salter Duck

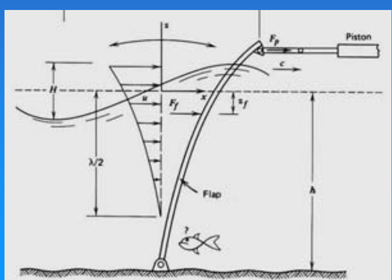
Rotational Converters



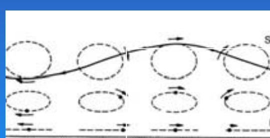
Bristol cylinder

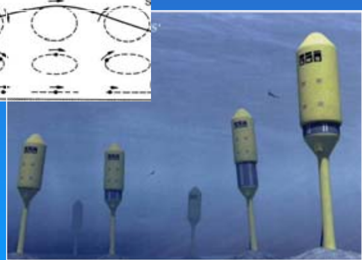


Floating water wheel



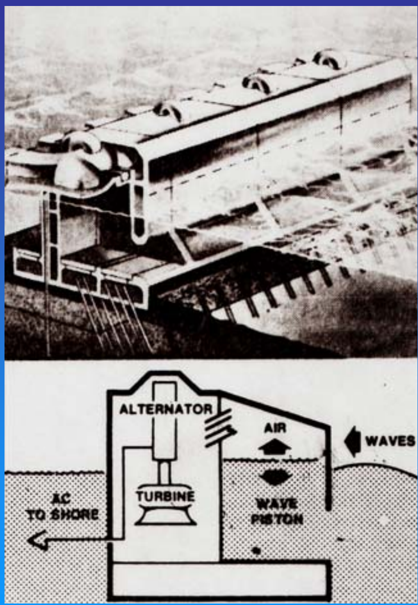
Compliant wave flap

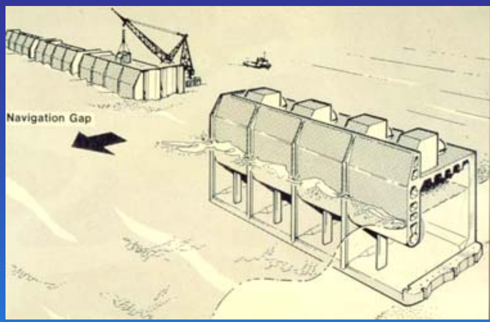


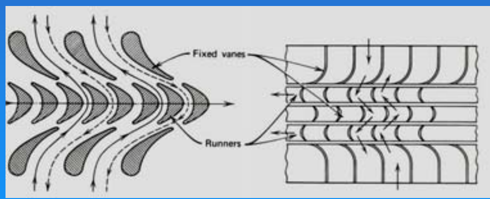


Archimedes Wave Buoy - 1 MW

ROTATIONAL

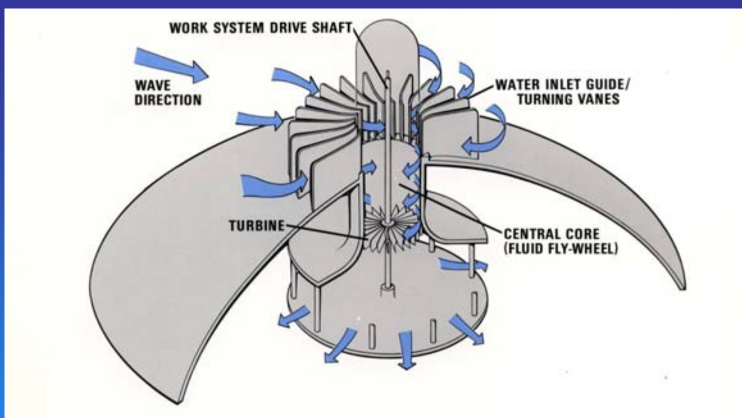




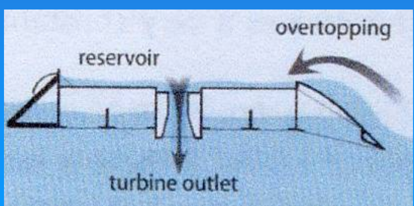


Rectifying Turbines

Early OWC Terminators



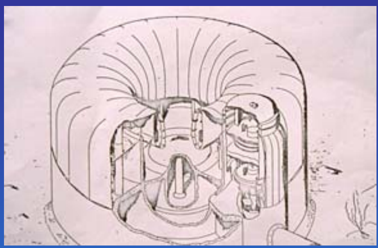
Dam Atoll



Early proposal for Mauritius

Head Enhancement

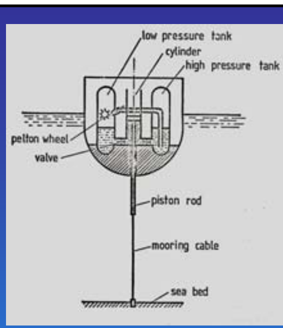
(energy focus techniques)

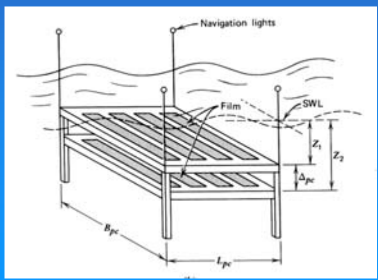


OWC

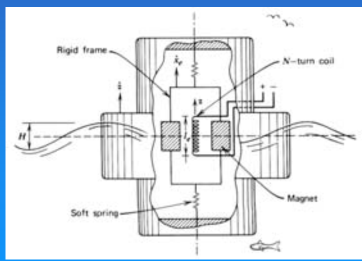
Resonant point absorbers

Heaving buoys





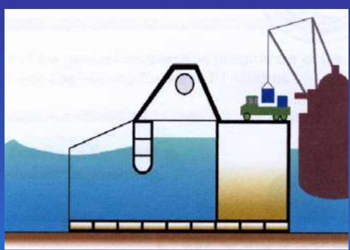
Two layer piezoelectric wave energy conversion



Linear inductance generator

Complex Systems

MORE POPULAR CONVERTERS

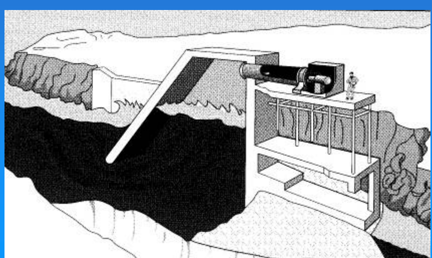


OWC Terminator attached to breakwater

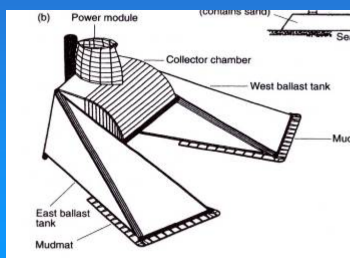
Range of smaller

floating devices

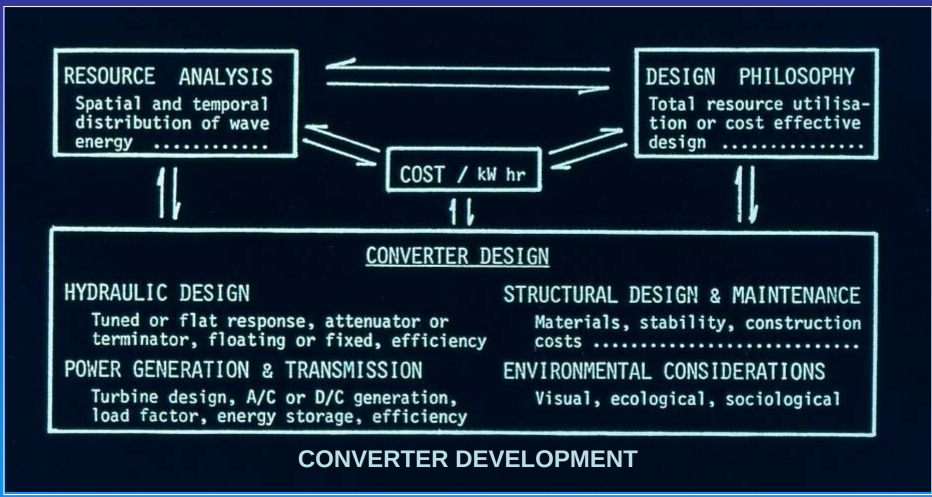
(lower cost demonstration phase)



Shore mounted OWC Terminator



Osprey OWC



CONVERTER DEVELOPMENT

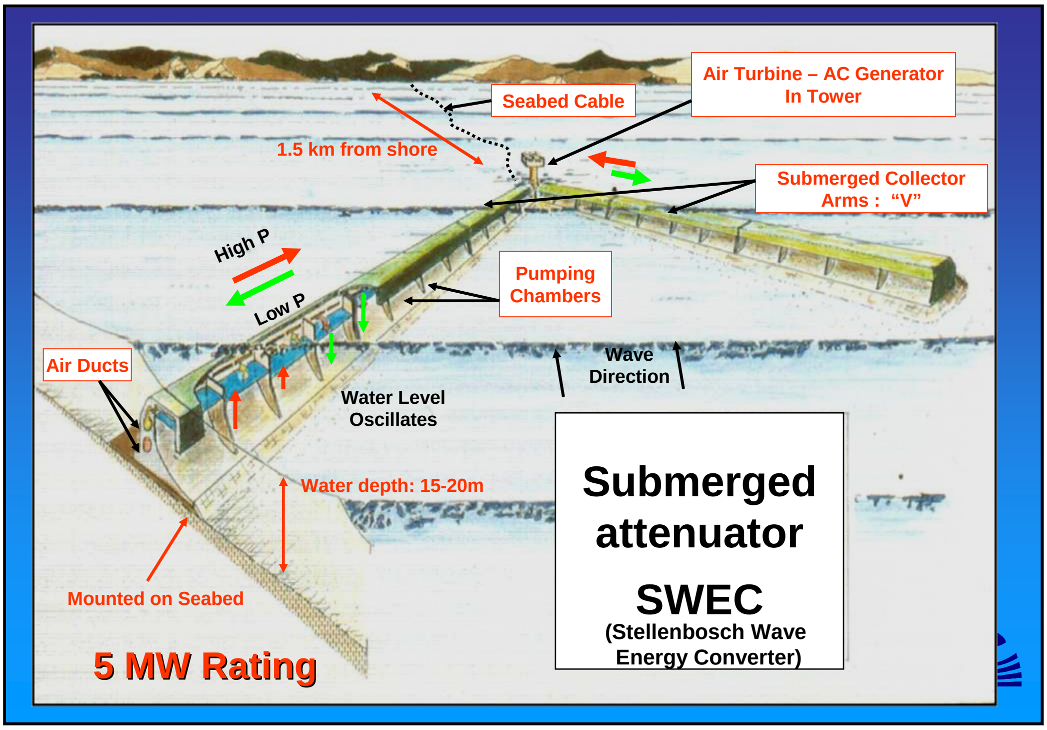
Evaluation Criteria

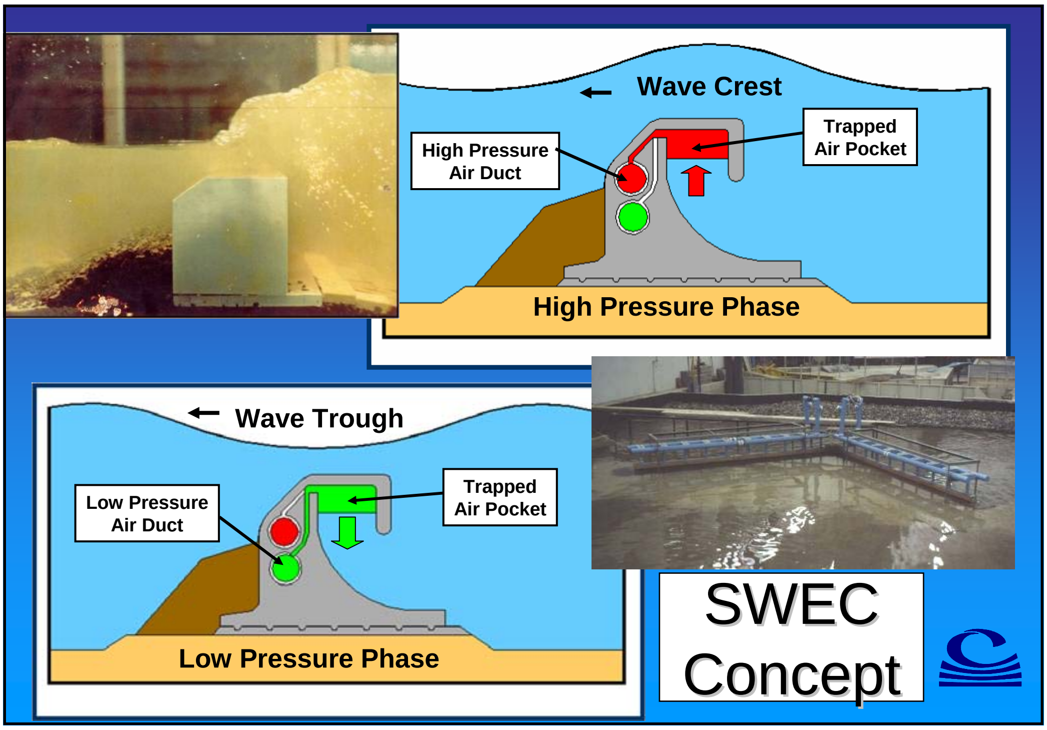
(Resource analysis should relate to converter design)

DESIGN PHILOSOPHY

for the Stellenbosch Wave Energy Converter (SWEC) (1985)

1. Cost efficiency of prime importance
   (conversion efficiency of secondary importance)
2. Avoid need for storm over-design
3. Aim for reliability in aggressive environment
   (design & construction technology to be within existing capability)
4. Minimise need for energy storage
   (optimise device at low power cut-off level to avoid extreme power fluctuations
5. Minimise environmental impact and hazard to shipping
6. Utilise high levels of power inshore

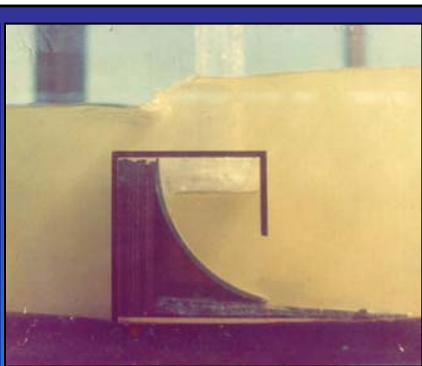

Air Turbine – AC Generator In Tower
Seabed Cable
1.5 km from shore
Submerged Collector Arms : "V"
High P
Low P
Pumping Chambers
Air Ducts
Wave Direction
Water Level Oscillates
Water depth: 15-20m
Mounted on Seabed
5 MW Rating
Submerged attenuator
SWEC
(Stellenbosch Wave Energy Converter)


Wave Crest
High Pressure Air Duct
Trapped Air Pocket
High Pressure Phase
Wave Trough
Low Pressure Air Duct
Trapped Air Pocket
Low Pressure Phase
SWEC Concept

ACHIEVEMENT OF GOALS

1. FIXED STRUCTURE	- Efficient reference frame - Simple technology & maintenance (no moorings or flexible transmission lines, minimum moving parts below water)
2. SUBMERGED STRUCTURE	- Reduced storm impact/loading - Limited visual impact
3. INSTALLATION CLOSE IN-SHORE	- Minimum transmission distance - Depth limited design wave - Narrow wave direction spectrum
4. NON-TUNED, INSENSITIVE DEVICE	- Robust simple control - Not affected by marine growth - Acceptably low capture efficiency

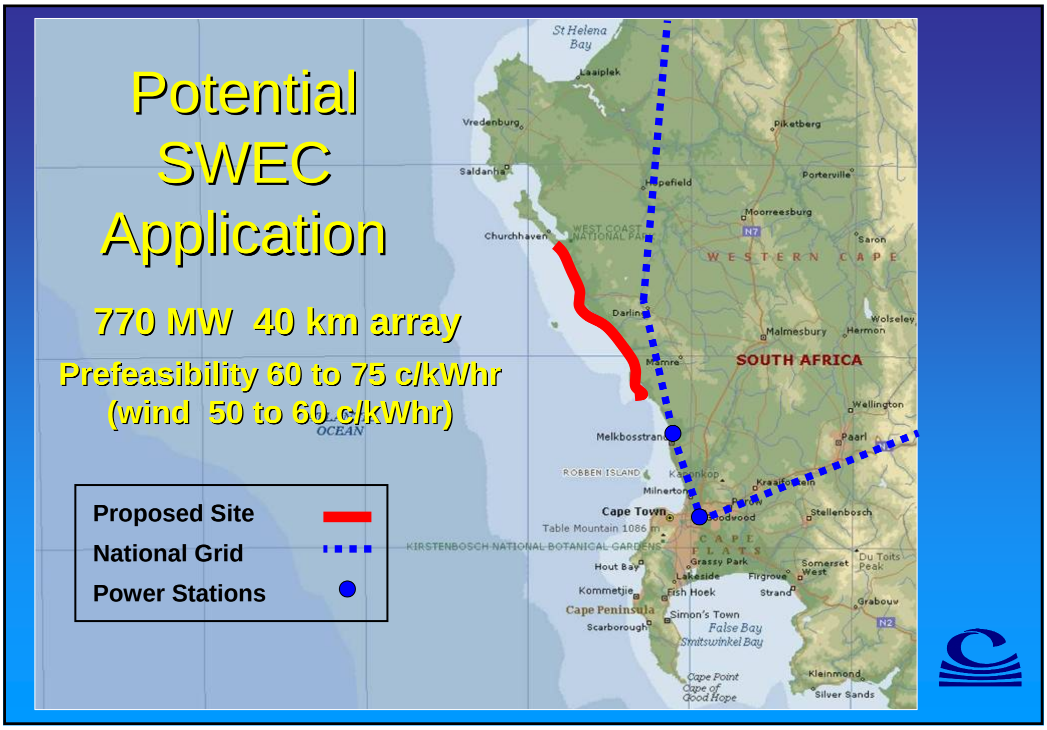
CSIR Laborotories

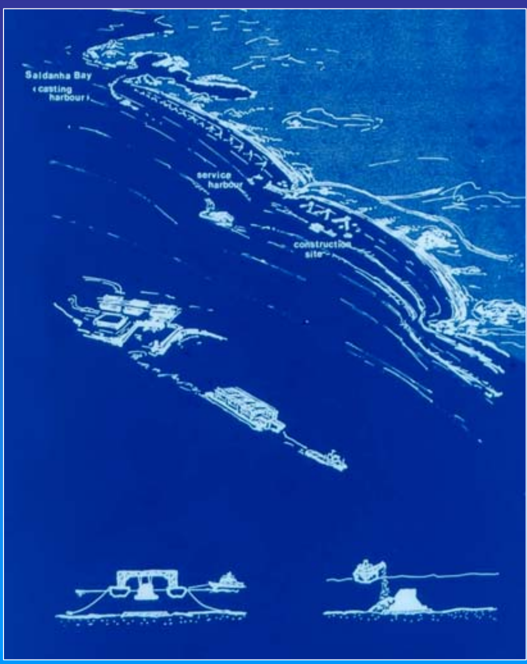


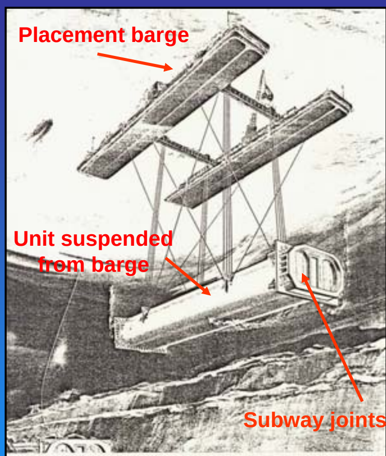
Flume Tests

U.S. Civil Eng. Laborotories

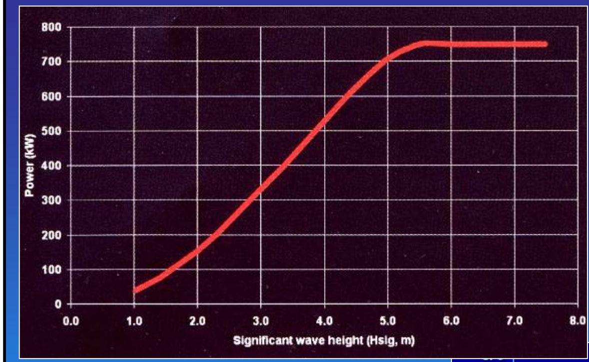
Extensive model test programme







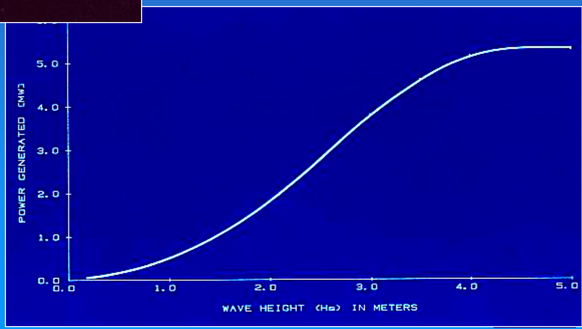
Construction Scenario



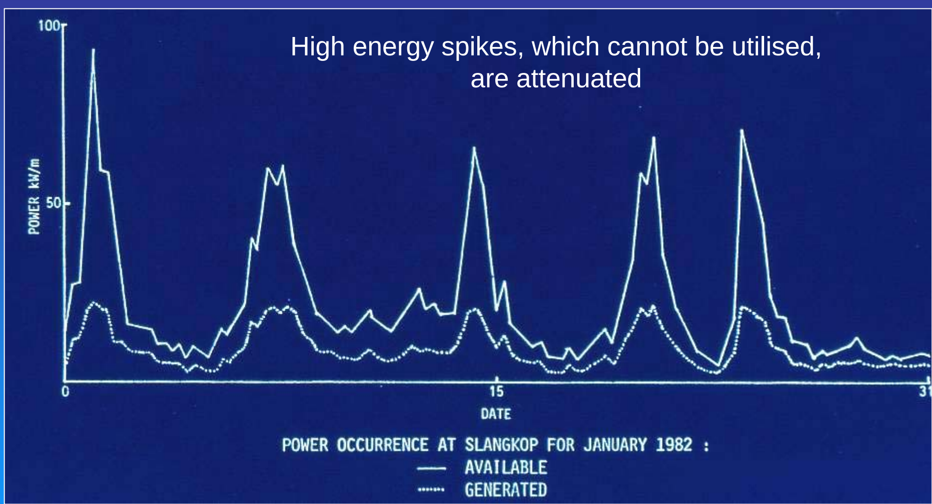
Pelamis

Power conversion with varying wave ht.

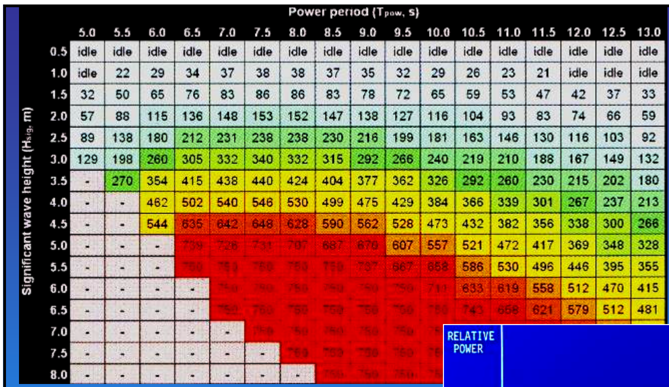
(Power shedding above 5m)



SWEC



SWEC Wave Extraction Characteristics
Effect of Power Shedding & Variable Efficiency

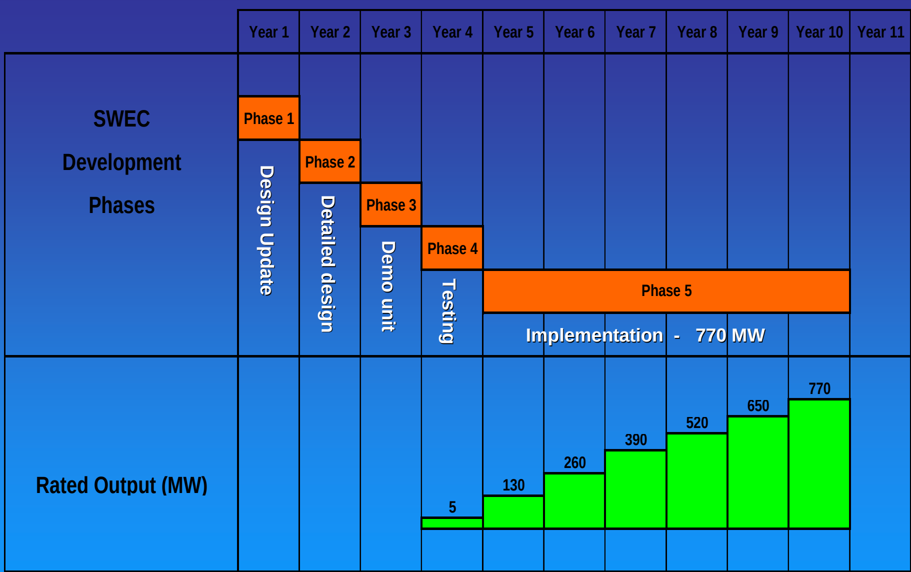


Significant wave height (H_{sig}, m) \ Power period (T_{pow}, s)	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
5.5	-	-	-	750	751	750	750	750	737	667	658	586	530	496	446	395	355
6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
6.5	-	-	-	-	750	750	750	750	750	750	750	743	668	621	579	512	481
7.0	-	-	-	-	-	750	750	750	750	750	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7.5	-	-	-	-	-	-	750	750	750	750	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8.0	-	-	-	-	-	-	-	750	750	750	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Pelamis
(100% at 7.5 sec = 50% at 12 sec)
More suited to locally generated sea

Power conversion with varying T_{peak}

SWEC (100% at 12 sec = 75% at 8 or 15 sec)
More suited to long period swell



SWEC development programme

Constraints to Wave Power Development

1. Shipping:

South bound shipping on the East Coast, utilises the inshore current
West Coast pelagic fishing fleet
Demarcated shipping lanes approaching ports and Capes

2. Environmental Protection

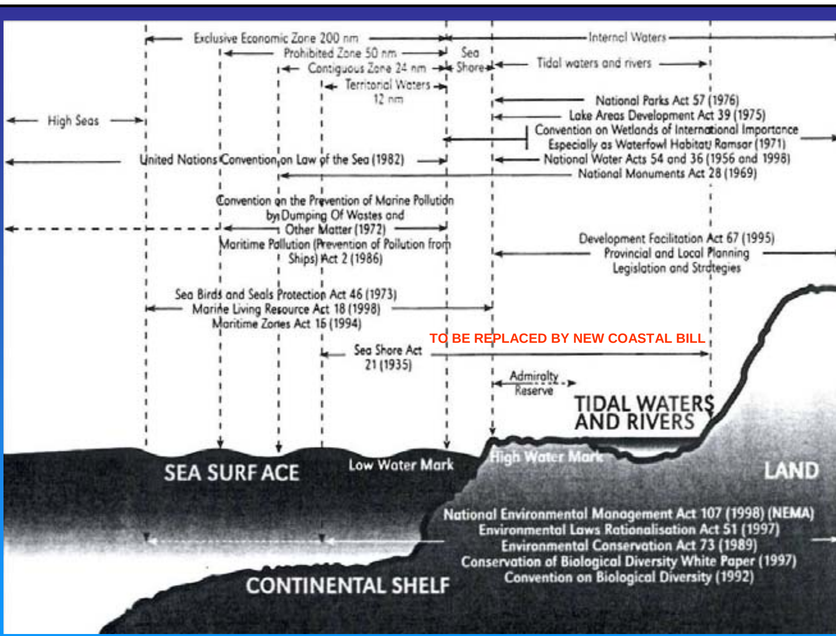
Coastal Sensitivity Atlas, and GIS maps
Protected Coastal Areas (marine reserves etc)
Integrated Coastal Management Bill

3. Legal Constraints

Offshore mining rights (gas, oil and diamonds)
Risk of private investment in Public Domain

4. Unique Engineering Problems

Extremely high inshore storm wave conditions
Freak waves off East Coast due to current/wave interaction
East and West Coast sediment transport >600 000 m^3 pa



Coastal legislation in South Africa

CONCLUSIONS

1. Technology supporting utilisation of Salinity Gradients and Bi-conversion not yet sufficiently developed.
2. OTEC and Tidal energy extraction not viable as significant power sources, along the South African coast.
3. Current Power is available as a relatively stable resource, but at low density levels of about 2 kW/m^2, ie 1kW/m^2 after conversion.
4. Wave Power appears to be the more promising source of ocean energy at offshore levels of up to 45 kW/m annual average and inshore levels reaching 30 kW/m annual average, mainly along the SW coasts, and reducing to probably about 10kW/m annual average, after conversion.
5. Potential converted wave power along the RSA coast, allowing for other constraints, probably totals 8 000 to 10 000 MW.