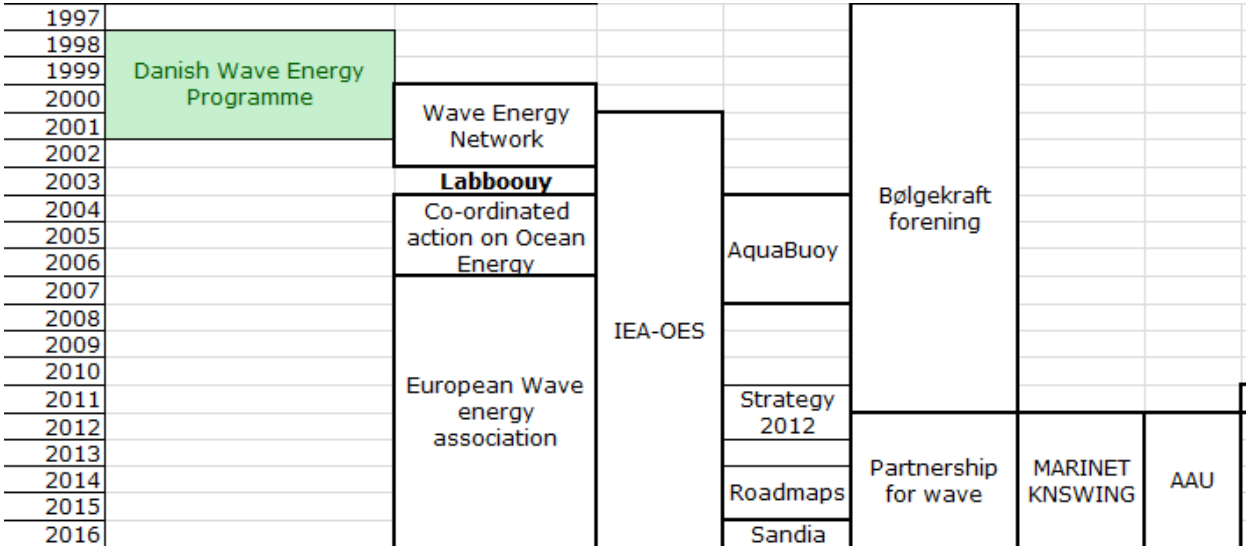
WAVE ENERGY RESEARCH AND DEVELOPMENT IN A 40 YEARS PERSPECTIVE

RAMBOLL

TU DELFT LUNCH LECTURE
22-05-2017

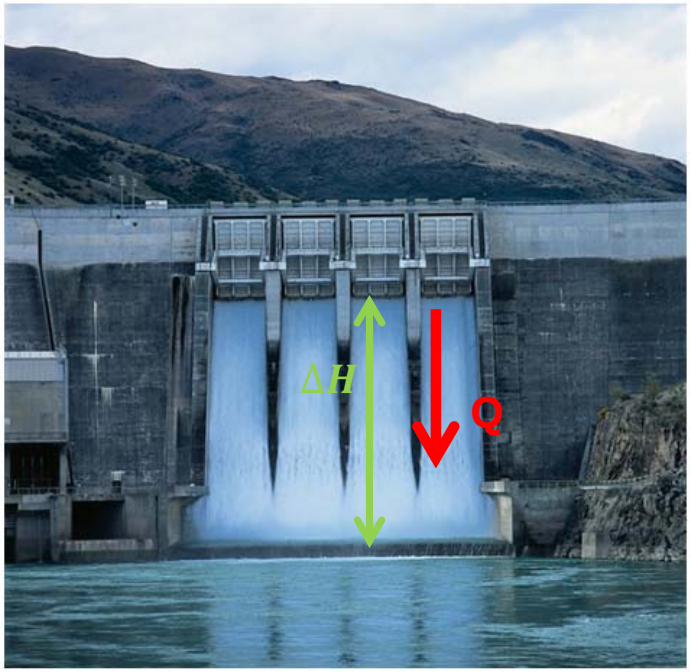
OBSERVATION PERIOD 1977 – 2016..

Year	Danish Projects	EU projects
1977	Initial Idea	
1978	Float pump tests	
1979	Graduation Project	
1980	PhD study on Wave Power	
1981	Department of Ocean Engineering	
1982	Technical University of Denmark	
1983		
1984	Test in the sound Øresund	
1985	Department of Ocean Engineering	
1986	Technical University of Denmark	
1987	Projektering af et Bølgekraftværk,	
1988	B Højlund Rasmussen	
1989	Hanstholm Fase I	
1990	Bølgeenergi forskningsprojekt FP1	
1991	Danish Wave Power Aps	Preliminary actions
1992		
1993	Hanstholm Fase II	
1994		OWEC-1
1995		
1996	Danish Wave Power Aps	



THE ENERGY CRISIS 1973

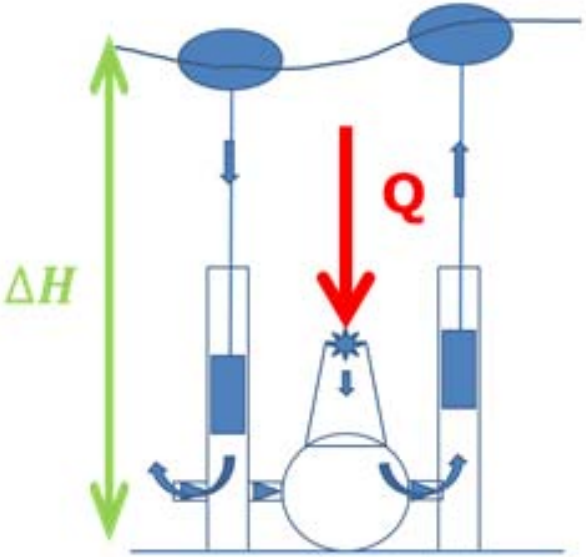
WE NEED ALTERNATIVES TO OIL – HOW I GOT INVOLVED1977



Lecture on Water turbines

$$Power = \rho \cdot g \cdot Q \cdot \Delta H$$

FIRST WAVE PUMP
DTU STUDENT PERIOD 1977 - 1979



INTERNATIONALAL WAVE ENERGY SYMPOSIUM IN 1979

Energy costs estimated between 0,6 – 1,5 DKK/Kwh (0,08 – 0,2 €/kWh)

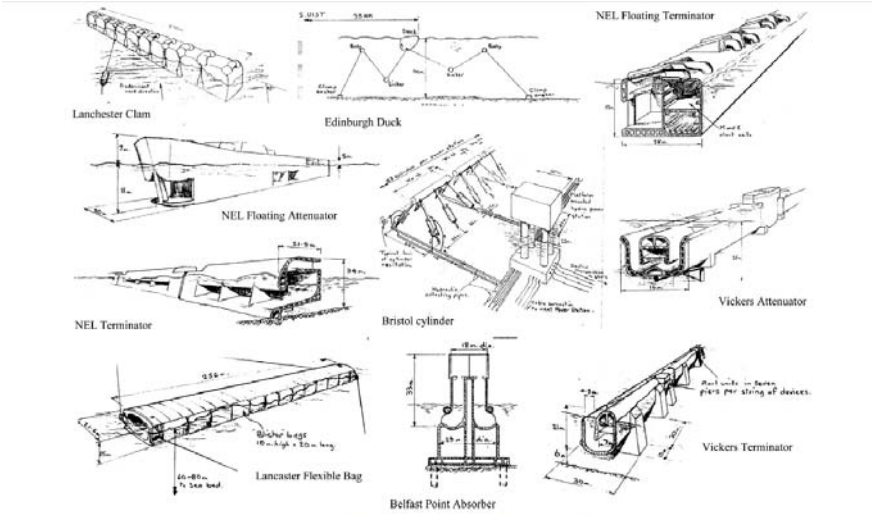
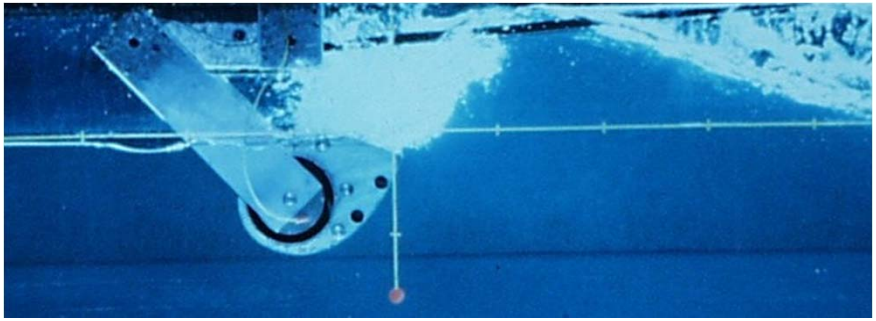
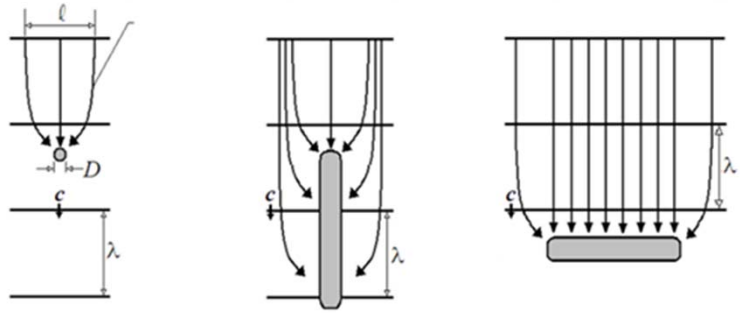


Fig. 9. Pictures of wave energy converters investigated in Ref. [43].



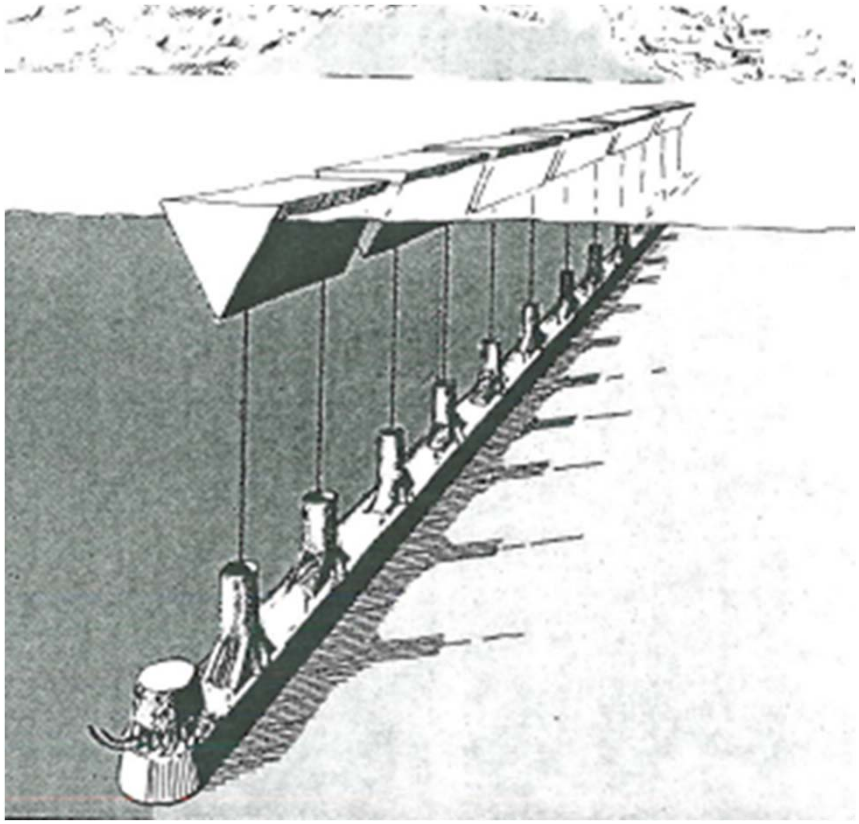
Salters DUCK



a. Point-Absorber b. Attenuator c. Terminator

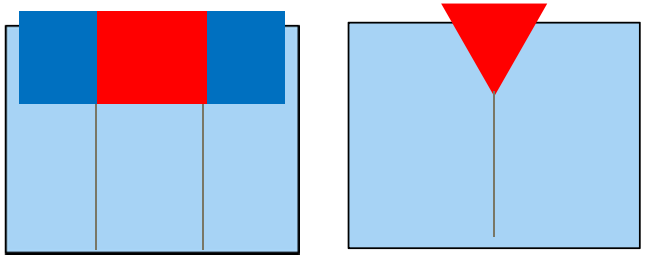
Gothenburg, Sweden

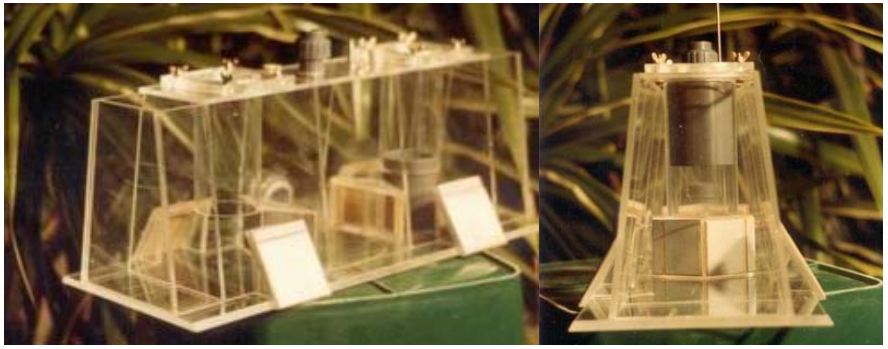
PHD PROJECT
“WAVE ENERGY CONVERTERS” DTU 1979 - 1982



Bølgeenergimaskiner I

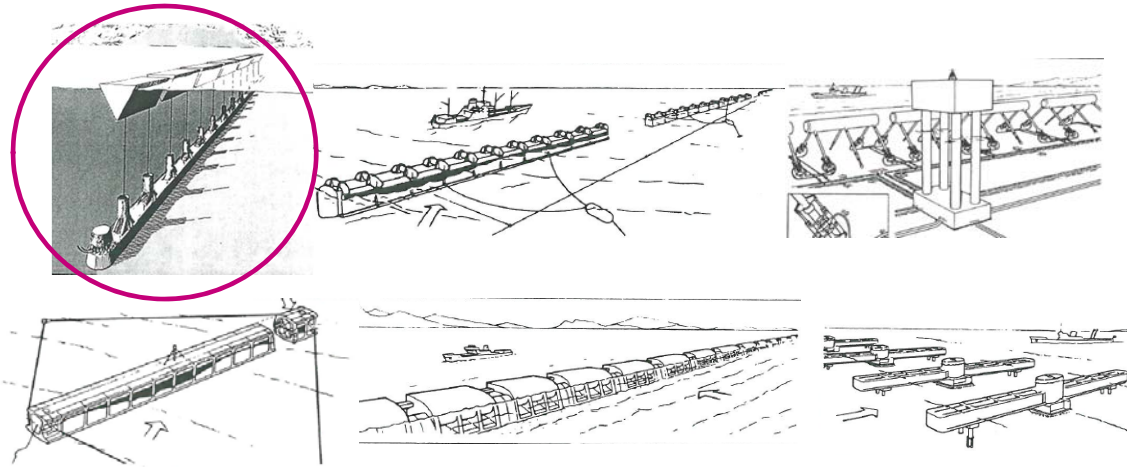
Bølgeenergimaskiner II

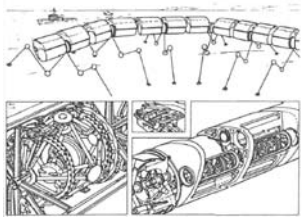




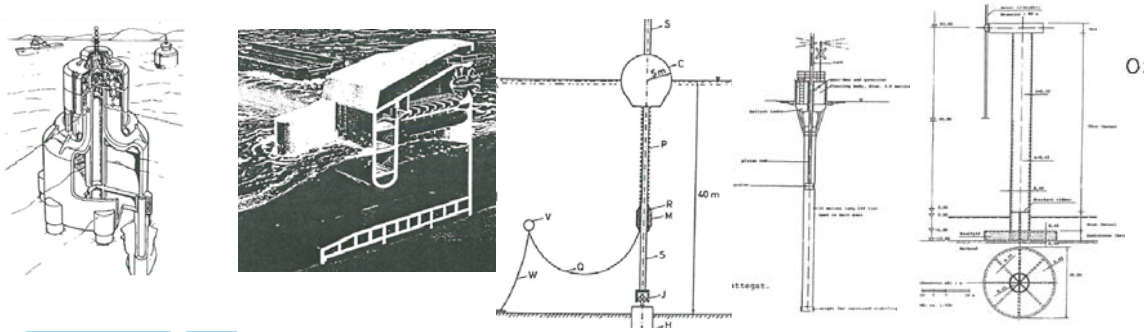
STATE OF THE ART 1983

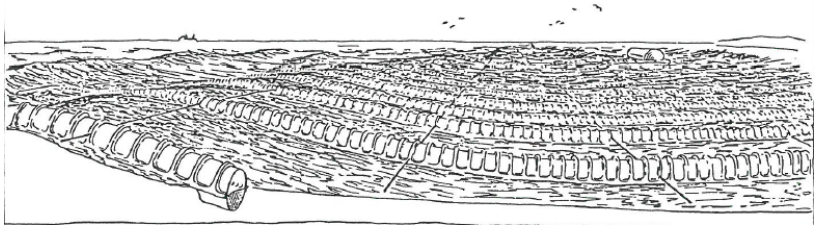
Rendel Palmer,Tritton, Kennedy, Donkin. United Kingdom wave energy program e Consultants' 1981 assessment. UK: Department of Energy; 1982.





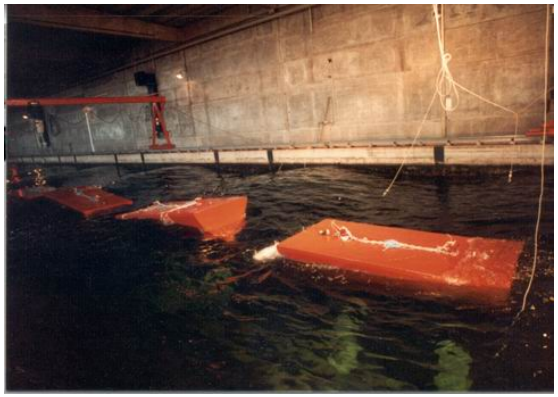
Land	projekt	energipris øre/kWh
Japan	Kaimai	
England	Salter's Duck	61
"	Bristol Oscillating Cylinder	130
"	Lancaster Flexible Bag	138
"	Sea Clam	79
"	Nel OWC	112
"	Belfast OWC	150
"	Vickers Attenuator	105
Norge	Budal og Falnes Point Absorber	65
Sverige		data ej til rådighed
Danmark	KN's metode	41
"	Kristian Herts	data ej til rådighed
Offshore vindkraft		45





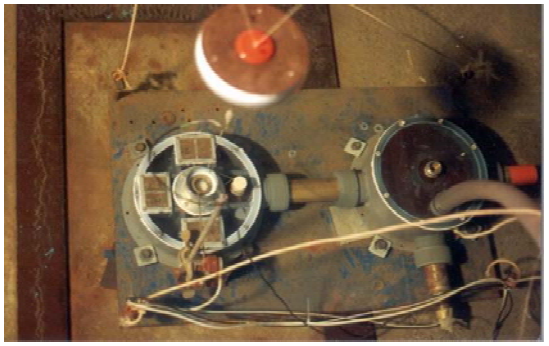
RAMBOLL

WAVE POWER PILOT PROJECT
1 KW GRID CONNECTED WAVE POWER IN ØRESUND
1984 – 1986 (POST DOC DTU)



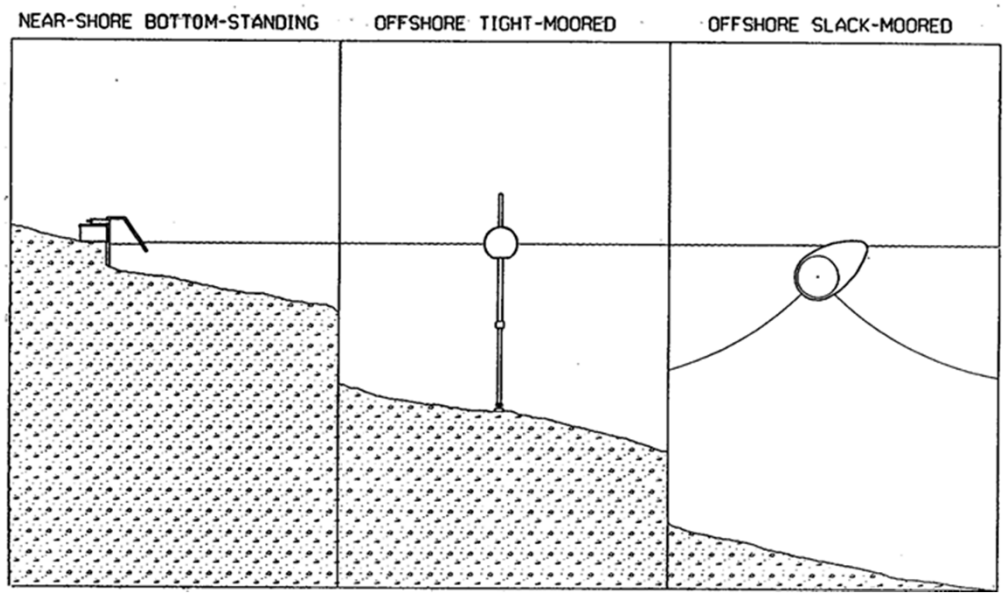
RAMBOLL

FIND A BLACKSMITH TO HELP THE DEVELOPMENT
1987 – 1991 (BUDGET 1.500.000€)
DANISH WAVE POWER APS



RAMBOLL

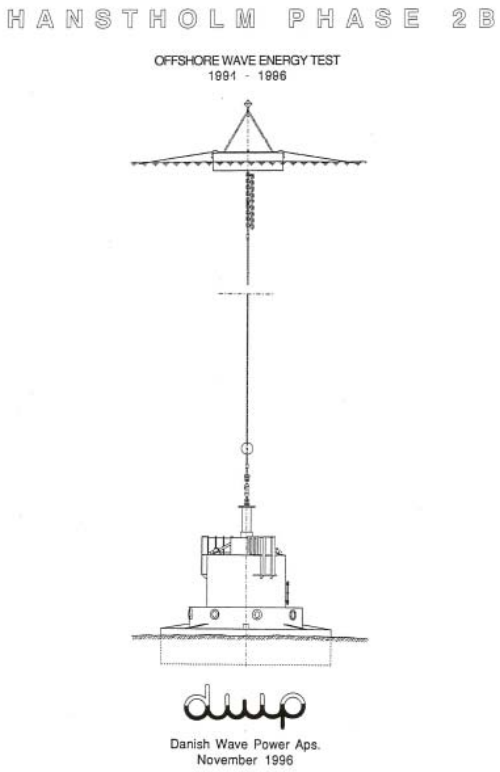
PRELIMINARY ACTIONS ON OCEAN ENERGY, 1991 - 1993
EUROPEAN COMMISSION JOU2-0003-DK



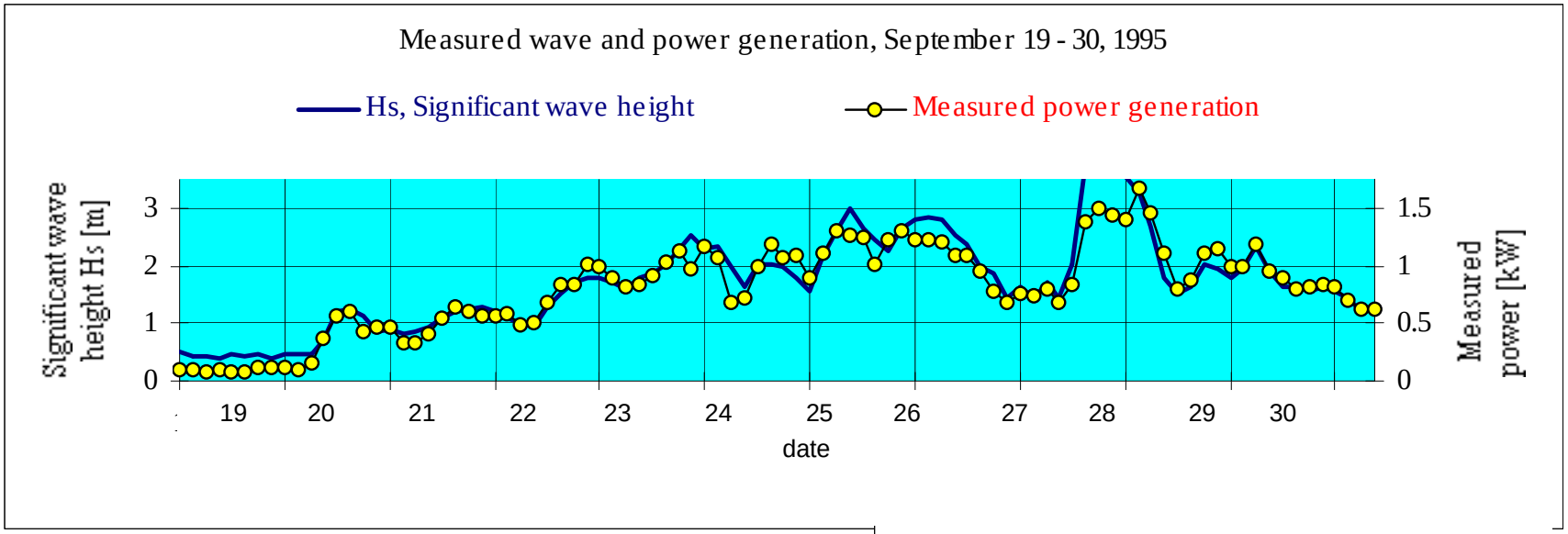
B0 Project management, *Peter Randløv, BHR*
B1 Device fundamentals/Hydrodynamics, *UCC Garreth Thomas*
B2 Device Components and Materials, *DWP Kim Nielsen*
B3 Power take-off Systems, *Ued Stephen Salter*
B4 Electrical systems, control and Grid Interactions, *Queens William Beattie*
B5 Methodology for Reliability and Economic assessment, *ETSU Tom Thorpe*

HANSTHOLM PHASE II 1993 – 1996
DANISH FUNDING

DWP-Test 1996



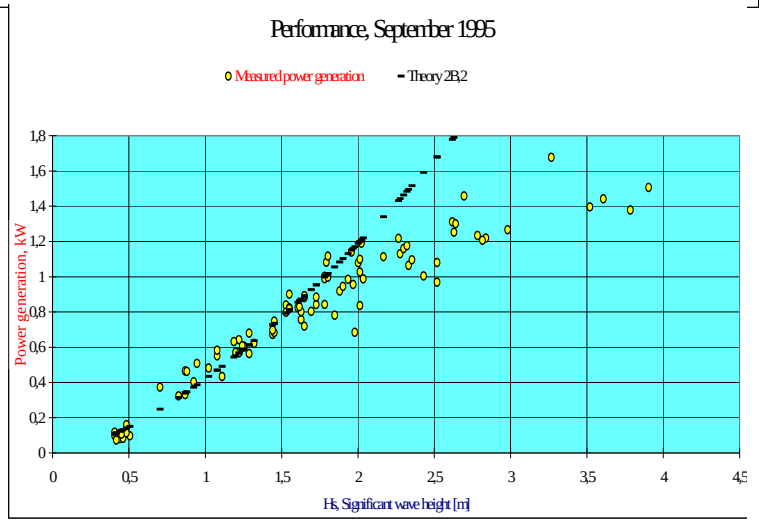
RAMBOLL



$$P = \alpha A_w H_s^{1,5} \quad [\text{kW}]$$

A_w [m²] is the float water plane area

Hs. [m] the significant wave height



JOULE II 1993 – 1996
OFFSHORE WAVE ENERGY CONVERTERS, OWEC-1

OWEC 1 20 researchers during a project meeting in Gothenburg 1994

Comparison of point absorbers

Numerical models

Testing of IPS –point absorber

EU co-operation

Pico plant was planned build in the same period

DANISH WAVE ENERGY PROGRAMME 1998 – 2002
BUDGET 3.000.000 €

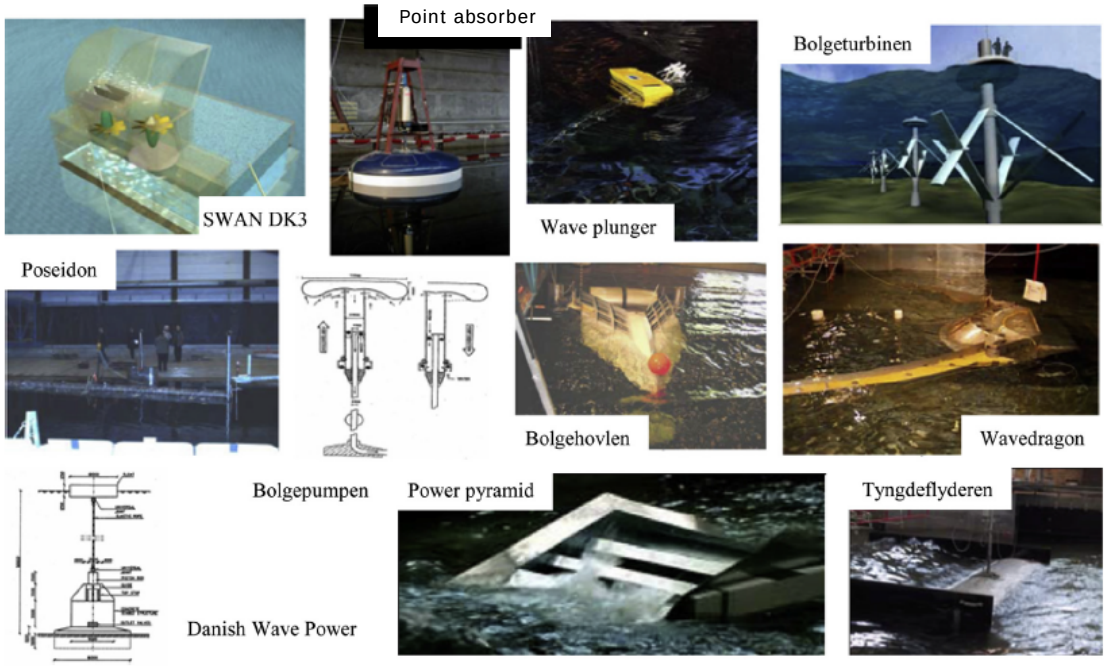


Fig. 10. Pictures of wave energy converters investigated in Ref. [9].

Meyer NI, McDonald Arnskov M, Vad Bennetzen LCE, Burcharth HF, Bunger J, Jacobsen V, et al. Bølgekraftprogram: Afsluttende rapport fra Energistyrelsens Rådgivende udvalg. Rambøll, Teknikerbyen 31, 2830 Virum, Denmark: Bølgekraftudval Bølgekraftudvalgets Sekretariat; 2002. In Danish.

STRUCTURED DEVELOPMENT AND GUIDELINES FOR TESTING AND PRESENTATION OF RESULTS

Idée
⇓
Ansøgning til Bølgekraftforeningen
⇓⇑
Bølgekraftforeningens konceptudvalgs behandling
⇓
Model af princip, Trin 0
og
Kravlegårdsforsøg (visualisering og simple målinger), Trin 1
⇓
Fremlæggelse og diskussion på bølgetræf
⇓
Ansøgning om mellemfaseafprøvning
⇓⇑
Bølgkraftudvalgets anbefalinger
⇓
Mellemfaseafprøvning (måling af energiproduktion og overlevelse) Trin 2
⇓
Ansøgning om videreudvikling
⇓⇑
Bølgkraftudvalgets anbefalinger
⇓
Videreudvikling (optimering af energiproduktion og overlevelse og teknisk økonomisk vurdering) Trin 3
⇓⇑
Bølgkraftudvalgets anbefalinger
⇓
Prototype udvikling og forsøg (20 - 100 kW) Trin 4
⇓
Demonstrationsforsøg (100kW - 1 MW) Trin 5
⇓
Markedsdannelse
⇓
Kommercielt Trin 6

Søtilstand H_s [m]	<0.5	1	2	3	4	5	>5.5
Effekt per meter [kW/m]	-	2	12	32	66	115	>145
Timer pr. år	966	4103	1982	944	445	211	119

Tabel 8.2 Referencefordeling af signifikante bølgehøjder

Ansøger: Castelmain Scandinavia / Ralph Mogensen		**Projekt navn:** Swan DK3	
J.no. 51191/00-0012 J.No. 51191/00-0016	Tilsagnsdato: 09-03-98 13-03-00	Bevilling: 570.000 kr. 380.000 kr.	Afprøvningssted: DHI DHI

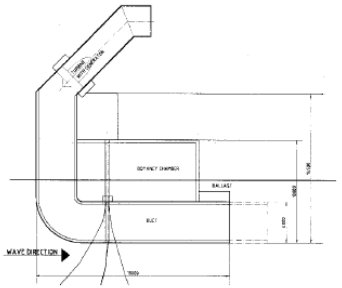
Rapporter
Swan DK3, Hydrauliske modelforsøg for bølgekraftværket Swan DK3, December 1998.
Swan DK3, Materiale studie. Stål, Fiberforstærket plast, Ferrocement.

Princip: Det danske projekt er en videreudvikling af et japansk system kaldet "Backward bent duct buoy (BBDB)" opfundet af Youshi Masuda.

Til en forankret flyder er fastgjort et vandfyldt kanalsystem, som er monteret under en flyder med åbninger agterud, og som foran flyderens stævn bøjes op gennem vandoverfladen, således at kanalens forreste del er delvist luftfyldt.

Når flyderen vippes i bølgerne, aktiveres en vandsøjle, som er indesluttet i kanalen og den ovenliggende luft i kanalens foreste, lodrette del presses ind og ud gennem en luftturbine, som driver en generator.

Status: Forsøg med energiproduktion på DHI blev afsluttet december 1998. Overlevelses og designstudie afsluttet maj 2001. Forsøg med luftturbine påbegyndt.

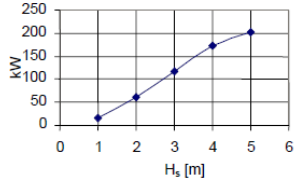


Swan DK3 set fra siden

Hoved data
Vanddybde:
Længde: 19 m
Bredde: 16 m
Højde: 10 m
Egenvægt flyder: 175 ton

Materialevalg:
Stål: 175 ton (skrog)
Stål: 55 ton (forankring)

Absorbed Power, Swan DK3



Power take-off: *Luft turbine(r)* (54 %)
Installeret effekt: 200 kW
Middel energiabsorption: 441.234 kWh
Middel el-produktion: 238.202 kWh
Forankringssystem: *Slæk forankring*

Videreudvikling:
- Numerisk model
- Turbinegenerator studie og design

RAMBOLL

WAVE DRAGON 1997 - ONGOING

Wave Dragon

Ansøger:		Projekt navn:	
Löwenmark F.R.I / Erik Friis-Madsen		WAVEDRAGON	
Journal no.	Tilsagns dato:	Tilskud	Afprøvnings sted
J.No. 51191/97-0007	22-04-98	500.000 kr.	AAU
J.No. 51191/98-0047	27-04-99	320.000 kr.	AAU
J.No. 51191/99-0046	13-09-99	300.000 kr.	AAU
J.No. 51191/00-0013	10-03-00	752.500 kr.	Power Take Off
J.No. 51191/00-0067	15-11-00	476.000 kr.	AAU
J.No. 51191/01-0017	22-06-01	150.000 kr.	Udviklingsplan
J.No. 51191/01-0033	12-10-01	9.589.000 kr.	Nissum bredning

Rapporter:

Evaluation of the hydraulic response of the Wave Dragon, Aalborg University, February, 1999
The Wave Dragon: 3D overtopping tests on floating model, Aalborg University, May, 1999
Forsøg til belysning af hydraulisk respons, Rapport fase A, H.C. Sørensen EMU, E. Friis Madsen, Löwenmark, F.R.I, Februar 1999.
The Wave Dragon tests on a modified model, AAU, September 1999.
Hydraulic Model tests on Modified Wave Dragon, AAU, November 2001.

Princip: Bølger fanges og koncentreres mellem lange fangarme og skylles op i et flydende reservoir. Vandet fra dette reservoir ledes tilbage i havet gennem en eller flere vandturbiner.

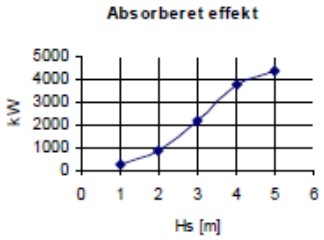
Status: Model skala 1:50, forsøg til belysning af overlevelsesforhold og energiproduktion udført på AAU. Forsøg til belysning af energiproduktion udført på AAU. Studie af vandturbiner til pulserende og varierende effektniveau gennemført under Joule Kraft. Bygning af en model i skala 1:4.5 til afprøvning ved Folkecenterets prøvestation i Nissum Bredning .

Hoveddata:

Længde:	147 m
Bredde:	259 m
Højde:	16 m
Egenvægt:	21.750 ton
Volumen:	22.000 m^3

Materialevalg:

Stål:	350 ton
Beton:	21.400 ton



Power take-off : *PTO virkningsgrad* (51 %)

Installeret effekt:	4.400 kW
Middel energiabsorption:	8.175.000 kWh
El-produktion:	4.170.000 kWh

Forankringssystem: *Slæk forankring*

Områder som kræver fortsat udvikling:
Optimering af design herunder

- Forankringssystemet og bevægelser
- Niveau regulering af reservoir

RAMBØLL

FLOATING POWER PLANT 1997 - ONGOING

RAMBOLL

Poseidons Organ

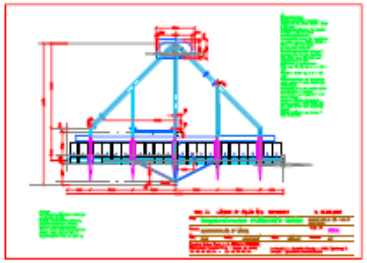
Ansøger:		Projekt navn:	
Torben Holm / Birch & Krogboe		Poseidons Organ	
J.no.	**Tilsagnsdato**	**Bevilling**	**Afprøvnings sted**
51191/97-0017	22-04 98	50.000	AAU
51191/98-0034	03-07-98	30.000	AAU
51191/99-0007	04-02-99	50.000	DHI
51191/99-0034	05-11-99	320.000	DHI
51191/00-0036	19-09-00	288.000	DHI
51191/01-0018	22-06-01	2.222.750	DHI

Rapporter:

Tyngdeflyderen – et koncept til udnyttelse af bølgeenergi Forår 1998, AAU
Tyngdeflyderen – performance in shortcrested waves and profile design study, Nov 2000
Slutrapporter for Fase1, Fase 2 og Fase 3 er udsendt.

Princip: Poseidons Organ er en stor flydende rørkonstruktion, hvorpå en række hængslede flydere er monteret.

Status: Projektet har fået udført målinger, funktionsafprøvning og stabilitet i 2 og 3D bølger på AAU af model 1: 100. Delmodel af flyder/pumpe i målforhold 1:25 er afprøvet og optimeret på DHI. En hel model 8 x 5 meter bred i skala 1:50 er bygget og afprøvet på DHI.

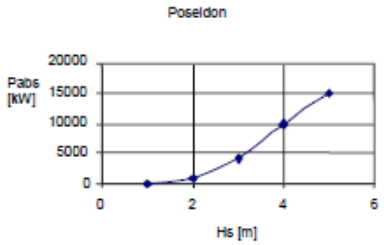


Hoveddata

Længde:	200 m
Bredde:	420 m
Højde:	20 m
Volumen	25000 m^3
Egenvægt:	20000 ton

Materialevalg:

Stål:	17000 ton
Beton	3000 ton
Forankring:	1500 ton



Power take-off : *Vandturbiner* (81 %)

Installeret effekt:	18 MW
Årlig energiabsorption:	15.600 MWh
Årlig el-produktion:	12.600 MWh

Forankringssystem: *slæk*

Områder til fortsat udvikling:

- Flowdesign bør optimeres
- Teknologisynergi med vind og solenergi

WAVEPLANE 1998 – 0NGOING

Bølgehøvlen

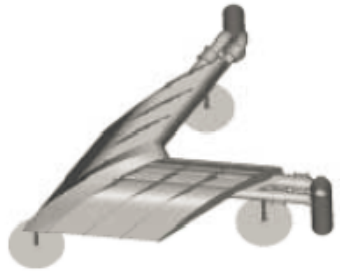
Ansøger:		Projekt navn:	
WavePlane International / Erik Skaarup MEK DTU		Bølgehøvlen	
Journal nummer	**Tilsagnsdato:**	**Bevilling:**	**Afprovningssted**
J.No. 51191/98-0008	26-01-98	489.000 kr.	DMI
J.No. 51191/99-0069	19-09-00	245.000 kr.	DHI
J.No. 51191/00-0018	14-07-00	325.000 kr.	DTU

Rapporter:

WavePlane, model tests With a Wave Energy Converter, DMI 98070, dato 1998 04 03
DMI 99084, dato 1999 05 26
DMI 98070, dato 1999 11 26
Velocity Measurements of the WavePlane subject to Regular and JonSwap Waves, R.Mikkelsen MEK, DTU Januar 2002
The Wave Plane tests at DHI the 27th, 28th, 29th August and 14th October 2001, 28-02-2002

Princip: Bølgerne skyller over en strandbred og fanges i tragte mellem lameller. Vandet fra tragtene strømmer ned i et vandretliggende rør, hvor vandmasserne sættes i en spiralformet strømning. Denne strømning udnyttes til at drive en turbine.

Status: Projektet har fået udført målinger af energiproduktion (hydraulisk effekt) på Dansk Maritimt Institut og virkningsgraderne for turbinen undersøges på DTU.

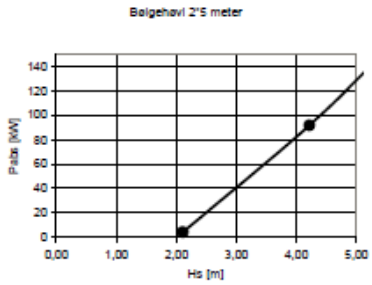


Hoveddata

Længde:	10 m.
Bredde:	10 m.
Højde:	5 m.
Volumen:	50 m^3
Egenvægt:	45 ton

Materialevalg:

Stål:	20 ton
Beton:	25 ton



Power take-off : *Kaplan vandturbine* (81 %)

Installeret effekt:	130 kW
Årlig energiabsorption:	117.150 kWh
Årlig el-produktion:	94.892 kWh

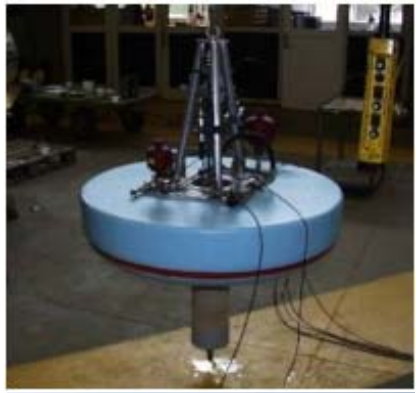
Forankringssystem: *Slæk forankring*

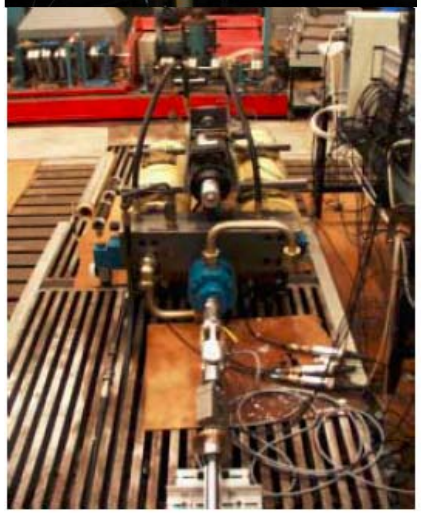
Områder til fortsat udvikling:

- Design og layout bør præciseres
- Udvikling af turbine generator enheder

RAMBØLL

POINT ABSORBER 1998 - 2002





Point absorber

Ansøger:		Projekt navn: Point Absorber (PA)	
RAMBØLL / Kim Nielsen MEK DTU / Georg Christensen			
Projekt J.No	**Tilsagnsdato**	**Bevilling kr.**	**Afprøvningsfacilitet**
51191/97-0033	20-04-98	350.000	DMI
51191/98-0050	12-11-98	480.000	DMI
51191/99-0022	27-07- 99	200.000	Nissum Bredning
51191/99-0074	25-09-99	370.000	Numerisk model
51191/00-0014	10-03-00	590.000	DMI
51191/00-0043	14- 07-00	425.000	PTO

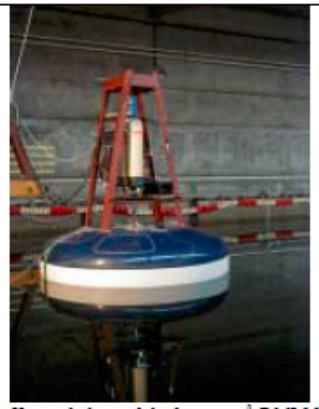
Rapporter:
Point absorber optimering og design, overlevelsesforsøg, April - November 1998.
Point absorber, on the optimization of wave energy conversion, July 1999.

Princip: Bølgerne bevæger en flyder op og ned i forhold til havbunden. Den relative bevægelse aktiverer en pumpe, som via et hydraulisk system driver en hydraulikmotor, som driver en el-generator.

I det hydrauliske system er der indbygget hydrauliske akkumulatorer, som udjævner den pulserende energi fra bølgerne.

Flyderen er forankret med et tov til et anker på havbunden.

Status: Overlevelsesforsøg udført på DMI juli 1998. Optimering af energiproduktion udført juni 1999. Afprøvning af Power Take-off på DTU samt forsøg i skala 1:4 på DMI forår 2001.



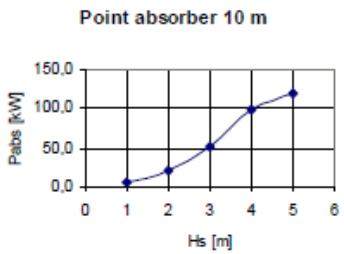
Kvart skala model afprøves på DMI 2001

Hoveddata:

Vanddybde:	50 m
Diameter:	10 m
Højde:	2.5 m
Flyder volumen:	200 m^3
Egenvægt flyder:	50 ton
Egenvægt bundkonstruktion:	100 ton

Materialevalg:

Stål:	60 ton
Ballast beton	90 ton



Power take-off: *Hydraulisk* (65 %)

Installeret effekt:	120 kW
Middel energiabsorption:	195.000 kWh
El- produktion:	127.000 kWh

Forankringssystem: *Stramt forankret*

Maksimal forankringskraft:	4.500 kN

Områder som kræver fortsat udvikling:

- End-stop komponent
- Hydraulisk sammenkobling af flere enheder
- Eltransmission

RAMBØLL

IEA –OES 2001 - ONGOING

HTTPS://WWW.OCEAN-ENERGY-SYSTEMS.ORG/

Figure 2 | Attendees of the 2nd Executive Committee Meeting | 21 March 2002, Harwell, UK

EXCO 2003 UK

EXCO 2004 CPH

EXCO 2017 Monaco

IEA OES 2017

ANNUAL
REPORT
OCEAN ENERGY SYSTEMS
2015
OES

Dissemination
Roadmap
Cost of energy
Environmental Acceptance
Technology development
Web GIS Database

1999 - 2016 PELAMIS

OCEAN POWER DELIVERY

1999	2000	2001	2002	2003	2004	Onwards

Concept development

Primary R&D & modelling

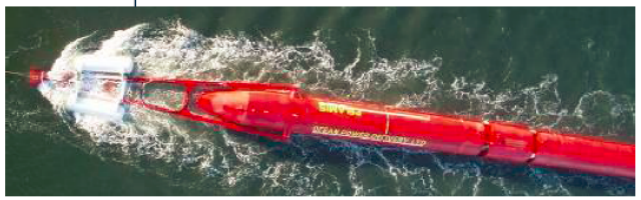
7th-Scale prototype

Full-scale R&D & design

Full-scale joint test

Production prototype

Cost reduction & performance enhancement



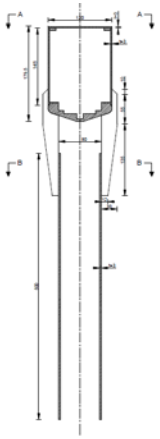
RAMBOLL

LABBOUY EU PROJECT, GREECE 2001 - 2003

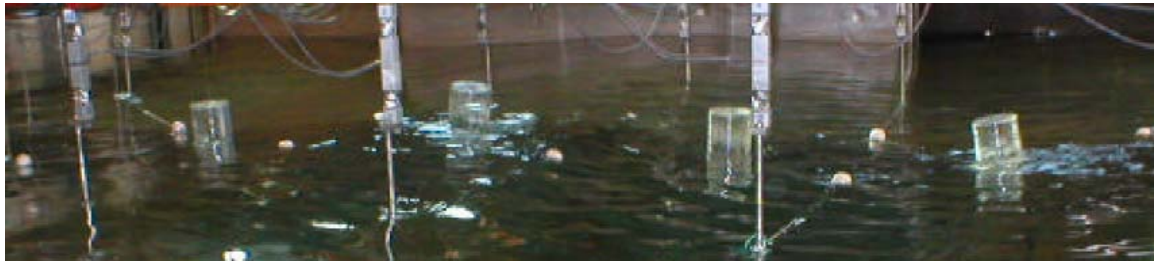
CRESS
Technical University of Athens
Queens University
University College Cork
Rambøll

AQUA ENERGY, USA 2002 - 2007

- Numerical modelling
- Hose Pump test Dunlup UK
- 1:50 scale testing Ireland, AAU
- 1:10 scale testing DK
- 1:2 scale testing USA



Float ashore on July 30 2007



RAMBOLL

CA-OE: CO-ORDINATED ACTION ON OCEAN ENERGY 2004 - 2007

WP 1: Workshop 1 Numerical and experimental modelling
April 4 – 5, 2005 Denmark

EU-OEA - founded

Development of Standards, EMEC 2005

WP 2: Workshop 2 Component Technologies and Power Take-off
November 1-2, 2005 Sweden

The basis for SeaPower was formed

WP 3 Workshop 3 System design, Construction, Reliability & Safety
March 30 -31 2006 Holland

IEA-OES Annex II workshop 29th of March 2006 in Amsterdam.

Pre-conference workshop at the 6th European Wave Energy Conference
Learning experience from prototype testing at sea
August 30, 2005, Glasgow,

The Partners of the CA-OE project and EPSRC Supergen Marine[1] project arranged a pre-conference workshop prior to the 6th European Wave Energy Conference in order for the

International Conference on Ocean Energy
Bremerhaven, Germany, October 23-24, 2006

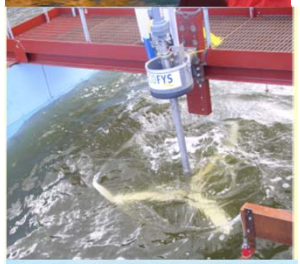
This new conference event **ICOE** brought together research and development, industries, project developers, utilities, policy makers and organizations involved in ocean energy. The first conference was organized by OTTI Germany.

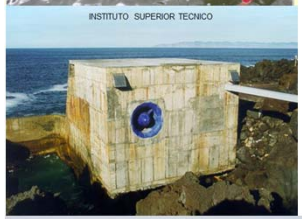
WP 4 Workshop 4 Performance Monitoring of Ocean Energy Systems
November 16-18 2006 Portugal

18th November 2006, Visit to PELAMIS, Peniche Shipyard, OPD

On Saturday a visit to the shipyard with 3 prototypes of the Pelamis getting prepared for installation and with a combined rating of 2.25MW was arranged. The trip gave a good impression of the converter size.

WP5: Workshop 5 Environmental, Economics, Development Policy and Promotion of Opportunities April 25 - 27 2007 Denmark





CA-OE PARTNERS

Core Group

RAMBOLL	DK
UNIVERSITY OF STRATHCLYDE	UK
CENTRE FOR RENEWABLE ENERGY SOURCES	GR
UNIVERSITY COLLEGE CORK	IE
WAVE ENERGY CENTRE	PT

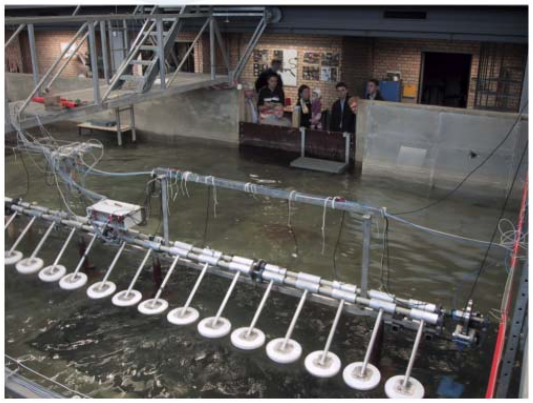
OE Developers

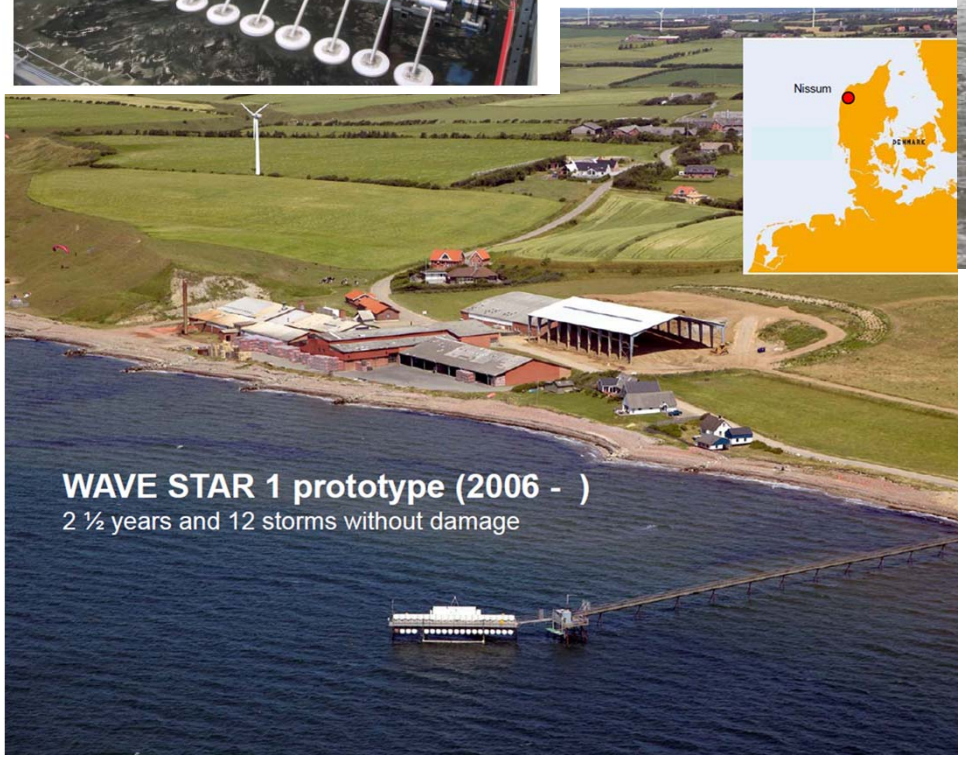
• OCEAN POWER DELIVERY LIMITED	UK
• TEAMWORK TECHNOLOGY BV	NL
• QUEEN'S UNIVERSITY BELFAST	UK
• INSTITUTO SUPERIOR TECNICO	PT
• AQUAENERGY DEVELOPMENT UK LIMITED	UK
• WAVE DRAGON APS	DK
• INGENIOERFIRMA ERIC A ROSSEN	DK
• OCEAN ENERGY LIMITED	IE
• WAVEPLANE PRODUCTION A/S	DK

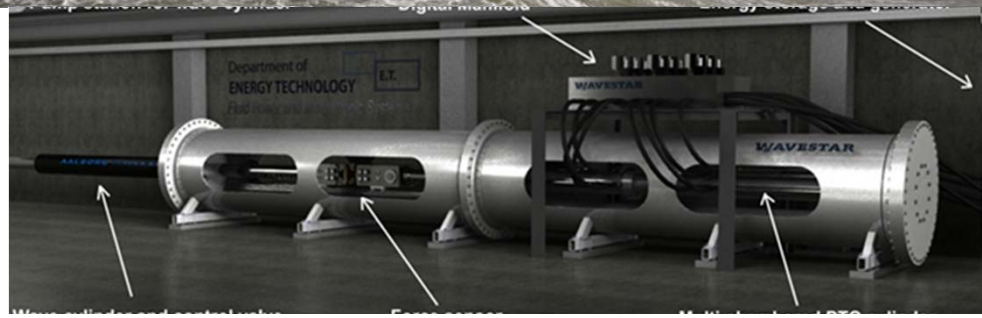
Universities

NL	TECHNISCHE UNIVERSITEIT DELFT
DE	TECHNISCHE UNIVERSITAET MUENCHEN
GR	NATIONAL TECHNICAL UNIVERSLTY OF ATHENS
NL	ECOFYS B.V.
PT	Instituto Nacional de Engenharia, Tecnologia e Inovação.
PT	THE ROBERT GORDON UNIVERSITY
CA	POWERTECH LABS INC.
DK	DHI - INSTITUT FOR VAND OG MILJOE
UK	LANCASTER UNIVERSITY
DK	SPOK APS
FR	Institut francais de recherche pour l'explittation dela mer
DK	AALBORG UNIVERSITET
UK	THE UNIVERSITY OF EDINBURGH
FR	ECOLE CENTRALE DE NANTES
FR	ECOLE GENERALISTE DES INGENIEURS DE MARSEILLE
BG	BULGARIAN SHIP HYDRODYNAMICS CENTRE -
UK	UNIVERSITY OF SOUTHAMPTON
BE	UNIVERSITEIT GENT
DE	UNIVERSITAET HANNOVER
SW	UPPSALA UNIVERSITET
GR	UNIVERSITY OF PATRAS
SW	CHALMERS TEKNISKA HOGSKOLA AB

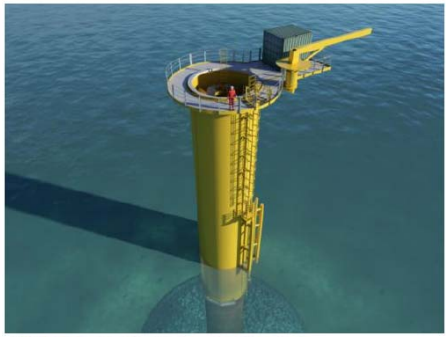
WAVESTAR 2004 - 2016







DEVELOPMENT OF DANWEC 2012
2M€ GREENLAB-



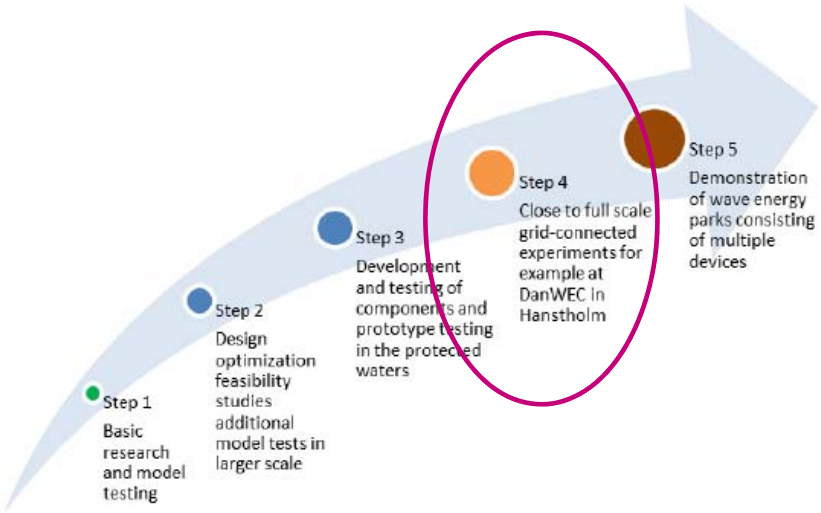
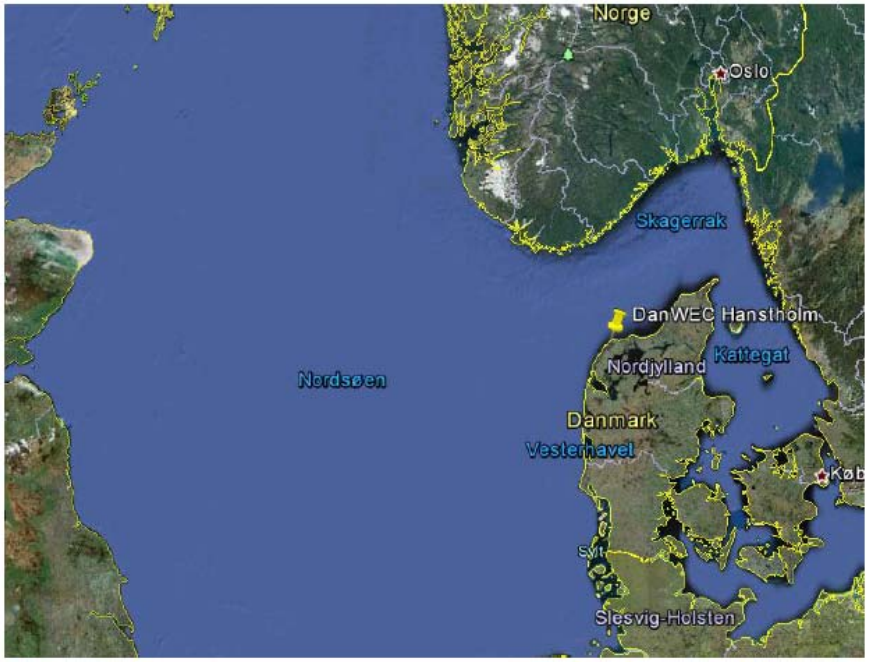


Fig. 3 The typical steps of involved in Wave energy development, the testing at DanWEC is likely to be at step 4



IEC TC 114 PT 102 (2012– 2015)

IEC 62600-102 TS ED.1: MARINE ENERGY - WAVE, TIDAL AND OTHER WATER CURRENT CONVERTERS - PART 102: WAVE ENERGY CONVERTER POWER PERFORMANCE ASSESSMENT AT A SECOND LOCATION USING MEASURED ASSESSMENT DATA

IEC TS 62600-1:2011 Edition 1.0 (2011-12-07) Marine energy - Wave, tidal and other water current converters - Part 1: Terminology	EN, ES
IEC TS 62600-2:2016 Edition 1.0 (2016-08-10) Marine energy - Wave, tidal and other water current converters - Part 2: Design requirements for marine energy systems	EN
IEC TS 62600-10:2015 Edition 1.0 (2015-03-27) Marine energy - Wave, tidal and other water current converters - Part 10: Assessment of mooring system for marine energy converters (MECs)	EN
IEC TS 62600-100:2012 Edition 1.0 (2012-08-30) Marine energy - Wave, tidal and other water current converters - Part 100: Electricity producing wave energy converters - Power performance assessment	EN
IEC TS 62600-101:2015 Edition 1.0 (2015-06-05) Marine energy - Wave, tidal and other water current converters - Part 101: Wave energy resource assessment and characterization	EN
IEC TS 62600-102:2016 Edition 1.0 (2016-08-09) Marine energy - Wave, tidal and other water current converters - Part 102: Wave energy converter power performance assessment at a second location using measured assessment data	EN

RAMBOLL

FORMATION OF DANISH PARTNERSHIP 2012 - ONGOING

- Floating Power Plant
- CrestWing
- WavePlane
- WaveDragon
- ResenWave
- WEPTOS
- WavePiston
- KNSWING
- Leancon

2011-12 DANISH STRATEGY ON WAVE ENERGY

PARTNERSHIP FOR WAVE POWER

Grid-connected Proto types

2-5 MW (2015-25)

Small Parks

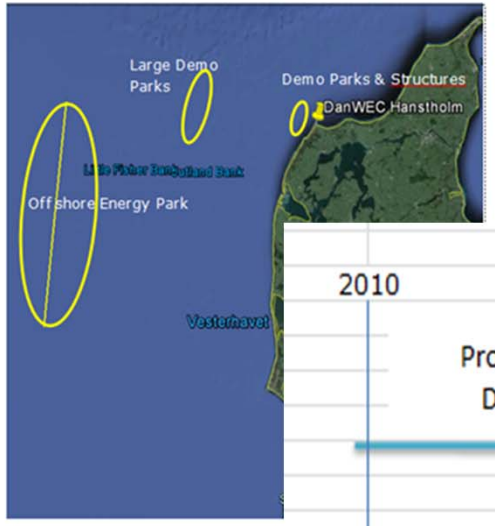
10 – 20 MW (2020-30)

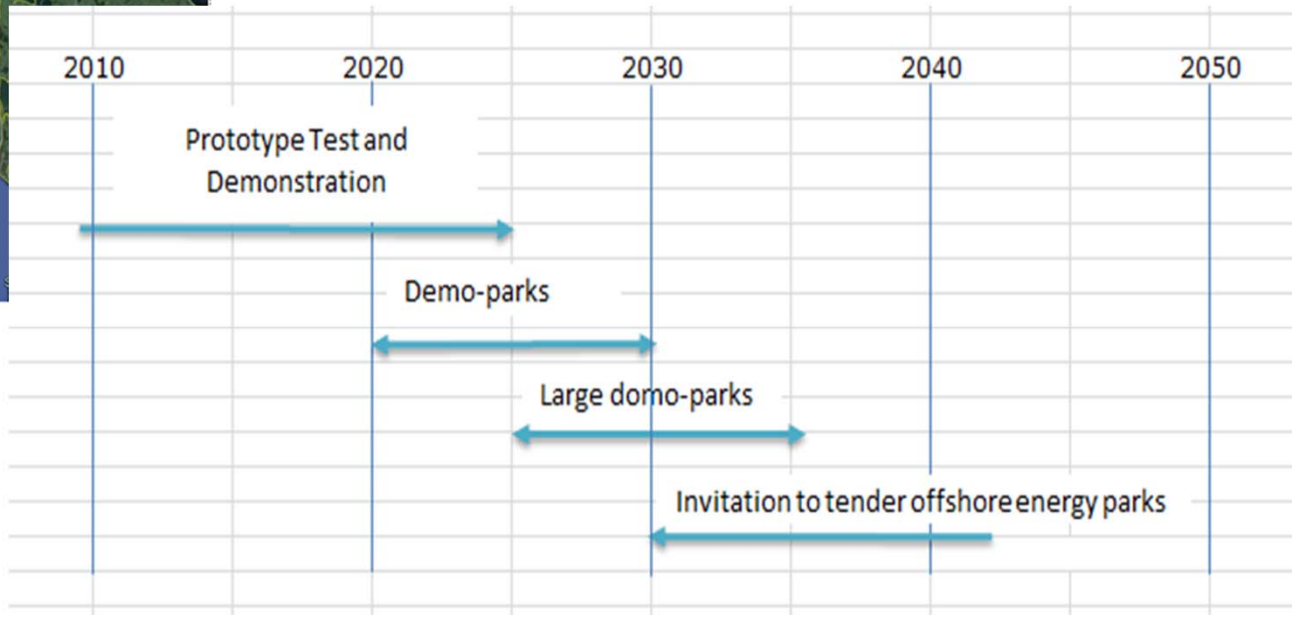
Large Demo Parks

30 – 60 MW (2025-2035)

Off-shore Energy Parks

500 – 1000 MW (2030 -





RAMBOLL

ROAD MAP 2015

DK Development Plan Wave Power Danish part of the North Sea	2015-2020	2020-2025	2025-2030	2030-2050
Installed Power [MW]	4 MW	15 MW	40 MW	500 MW
Annual Production [MWh/y]	7.000 mWh/Y	30.000 MWh/Y	100.000 MWh/Y	1.500.000 MWh/Y
CAPEX [DKK/KW]	45.000 DKK/kW	35.000 DKK/kW	20.000 DKK/kW	20.000 DKK/kW
OPEX [DKK/KW]	2.000 DKK/kW/Y	1.750 DKK/kW/Y	1.000 DKK/kW/Y	750 DKK/kW/Y
Life time [Years]	10	10	10	20
Load factor [%]	25%	25%	30%	35%
Availability [%]	80%	90%	95%	98%
Anualized O&M Costs [DKK/kWh]	1,14	0,88	0,40	0,25
LCOE	4.5 DKK/kWh	3.0 DKK/kWh	1.5 DKK/kWh	0.90 DKK/kWh
Amoritations factor	0,13	0,13	0,13	0,09
Intrest r	0,05	0,05	0,05	0,07

RAMBOLL

DEVELOPMENT OF NEW "OLD" IDEAS 2012

KN SWING illustrations

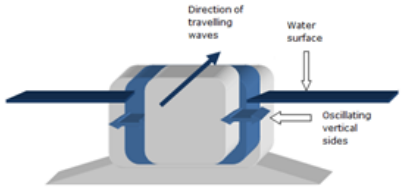


Figure 1 Example a: cross section with oscillating vertical sides i.e. flexible bags.

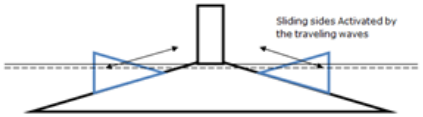


Figure 2 Example b: cross section with sliding oscillating vertical sides.

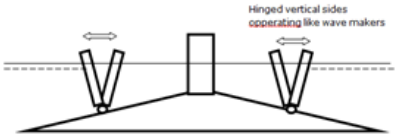


Figure 3 Example c: cross section with oscillating vertical flaps.

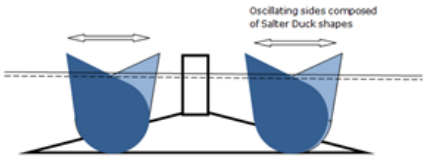


Figure 4 Example d: cross section with oscillating "Salter Ducks"

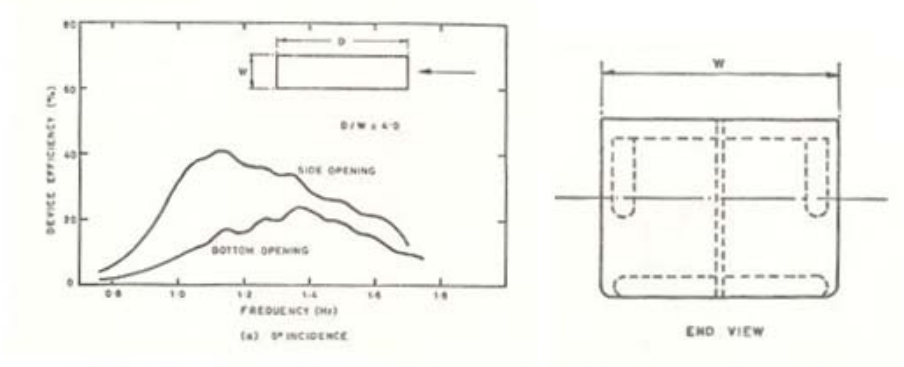
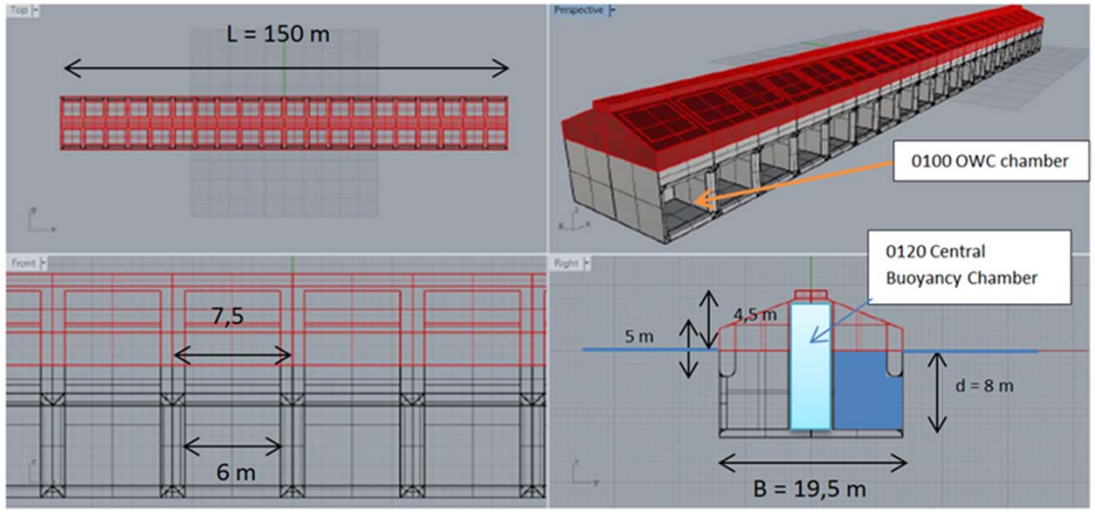


Figure 2 Moody's I beam Attenuator described at the symposium in 1979 in Gothenburg.

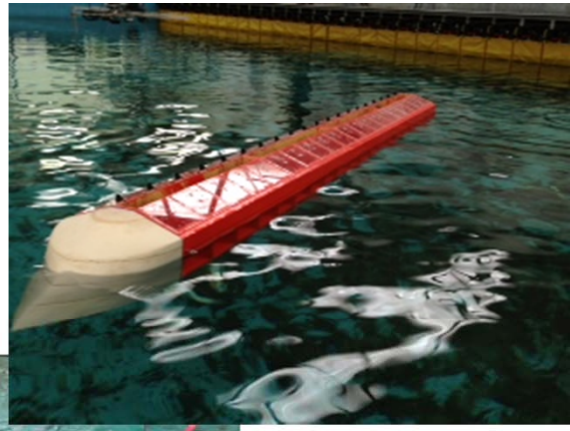


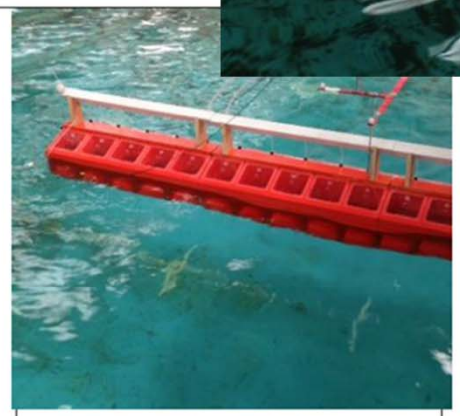
RAMBOLL

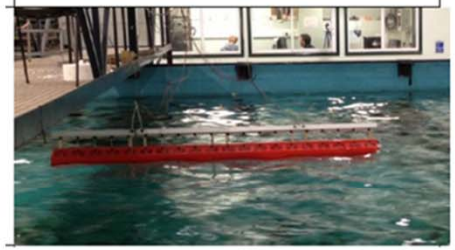
KNSWING WITH BA STUDENTS DTU

MARINET I: 2013 UCC-HMRC OCEAN WAVE BASIN

MARINET II: 2015 PORTA FERRY







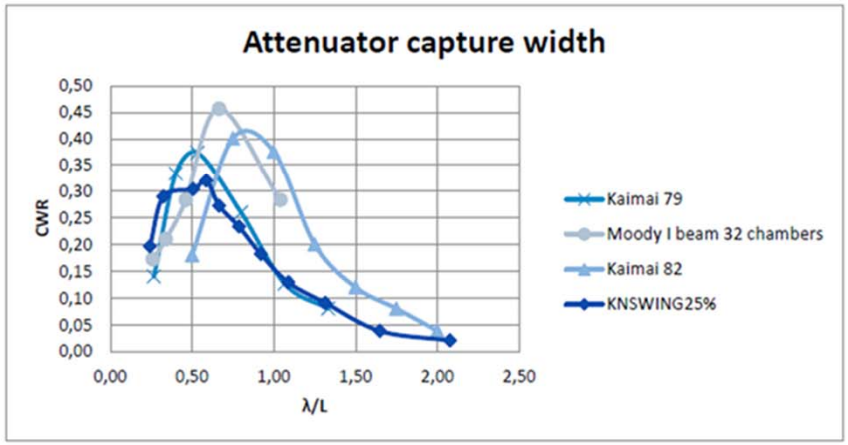
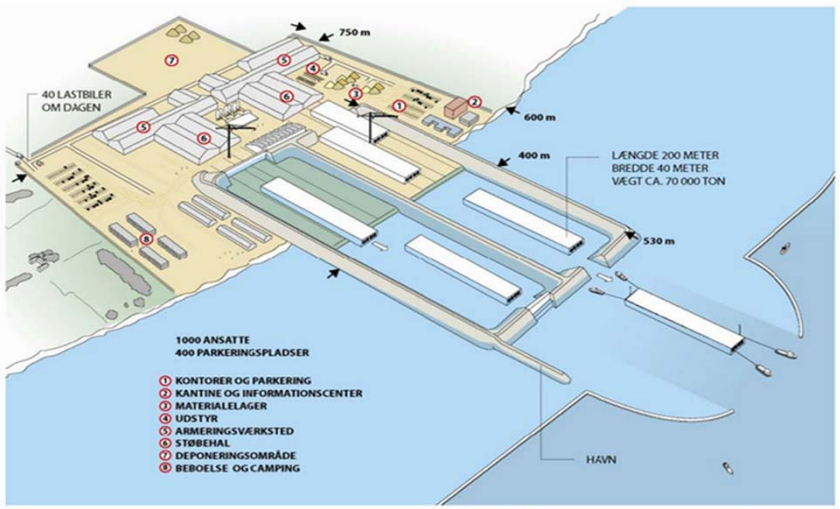


Figure 19 Comparison with previous Attenuator experiments

TU DELFT LUNCH LECTURE
22-05-2017

MOORING SYSTEMS FOR LARGE WEC'S AAU 2015 - 2017

Fig. 1. The four partner WECs in the present research project: Floating Power Plant, KNSwing, LEANCON Wave Energy and Wave Dragon.



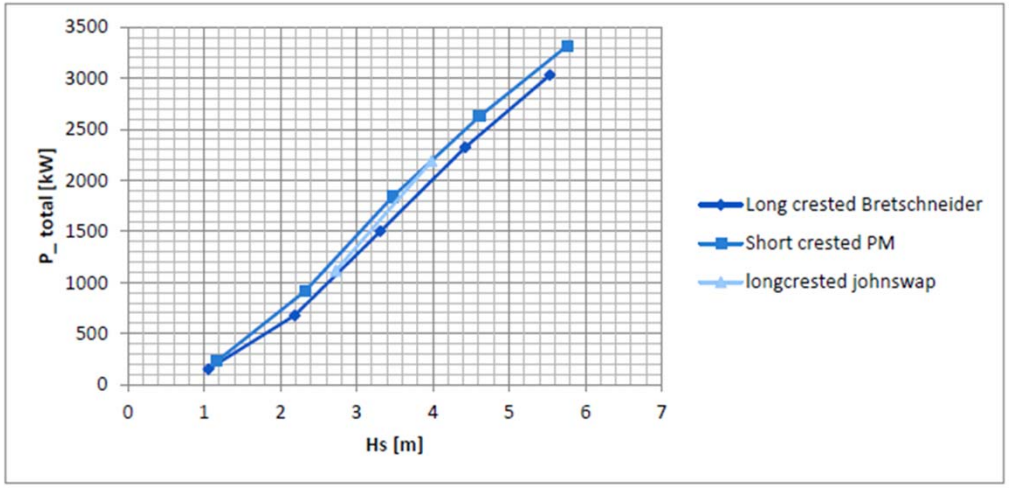
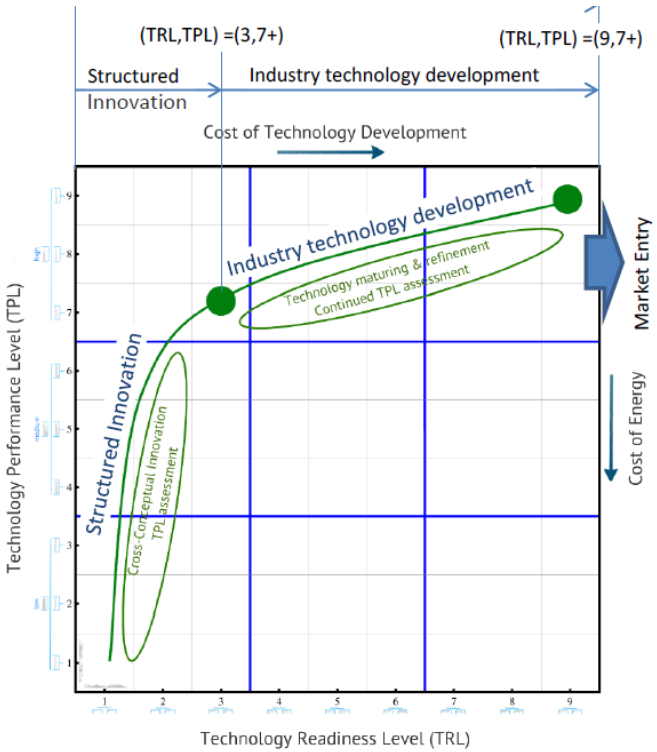


Figure 20 Performance in irregular sea-states

RAMBOLL

USA SANDIA – WAVE SPARK PROJECT 2016 - 2017



SAND2017-4472 O

Summary:

		Technology Performance Level:	5,6	5 Thresholds Breache
C1	**Have market competitive cost of energy**		5,8	
C1.1		Have as low CAPEX as possible	6,0	All Thresholds OK
C1.2		Have as low an OPEX as possible	5,0	All Thresholds OK
C1.3		Be able to generate large amount of electricity from wave energy	4,9	All Thresholds OK
C1.4		Have high availability	7,0	All Thresholds OK
C2	**Provide a secure investment opportunity**		3,6	
C2.1		Be low risk under design conditions	5,2	All Thresholds OK
C2.2		Be survivable	2,4	3 Thresholds Breached
C3	**Be reliable for grid operations**		6,0	All Thresholds OK
C4	**Be beneficial to society**		6,8	All Thresholds OK
C5	**Be acceptable for permitting and certification**		6,0	2 Thresholds Breached
C6	**Be acceptable w.r.t safety**		7,0	All Thresholds OK
C7	**Be deployable globally**		7,0	All Thresholds OK

TPL Scoring Tool Version 2.02 -- Published April, 2017

Note 1: Version 2.01 was published - June, 2016. [SAND2016-8624 O]
Note 2: The weights are subject to revision in future versions.

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WAVE ENERGY PROJECTS 2016

SWEDEN
- Waves4power
- CorPower Ocean
- Seabased

NORWAY
- Havkraft AS
- Ocean Energy AS

BELGIUM
- FlanSea
- Laminaria

GERMANY
- Sinn Power
- NEMOS GmbH

IRELAND
- OE Buoy
- Sea Power

PORTUGAL
- AW-Energy
- Bombora

AUSTRALIA
- Wave Swell Energy

USA
- Waveswing Americ
- Resolute Marine Energy/ SurgeWEC™
- Columbia Power Technologies
- Life safer
- Azura

KOREA
- pendulum WEC
- Heaving semi-sphere
- wave-offshore wind
- Yongsoo OWC

CHINA
- Sharp Eagle
- Institute of Electrical Engineering

SPAIN
- MARMOK-A-5
- UNDIGEN+

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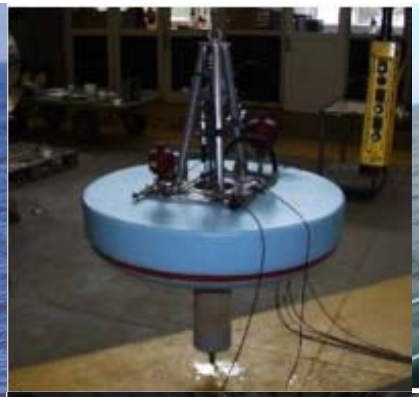
DEVELOPMENT V KIM NIELSEN 1977 - 2017



DWP-Test 1996

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THANK YOU

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TU DELFT LUNCH LECTURE
22-05-2017