Recent Advances in Wave Energy Generation

- from the perspective of the Wave Energy Research Group, Aalborg University

by

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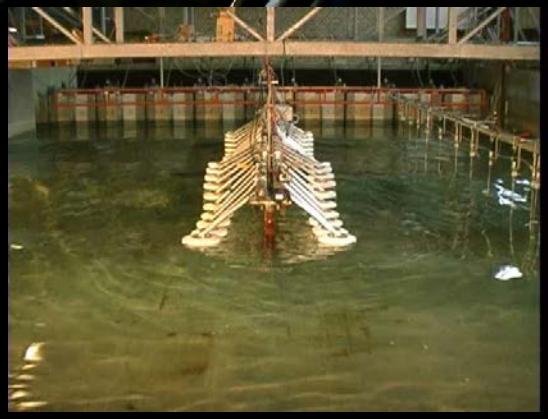
Wave Energy Research Group
Department of Civil Engineering
Aalborg University, Denmark

DAMAS 2013
Dublin
10.07.2013

Wave Energy Research Group

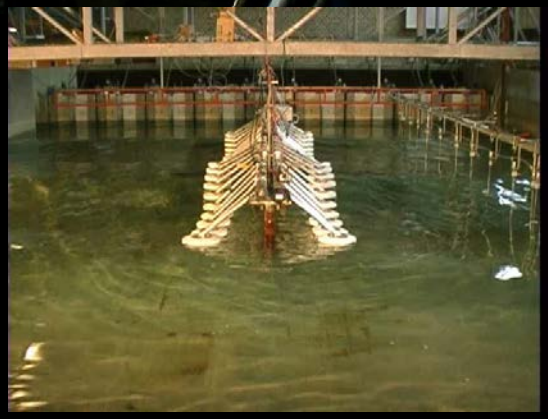
At Aalborg University,
Department of Civil Engineering,
Division of Water & Soil

- Staff: 10-15
- Profile:
  Waves, Mechanics,
  Hydro Dynamics, Control
- Experimentiel testing in lab. and at sea
- 2x 3-D wave tanks, wave and current flumes
- Key operator in Nissum Bredning
- Instrumentation for measuring "anything" ☺
- Numerical modelling



Wave Energy Research Group

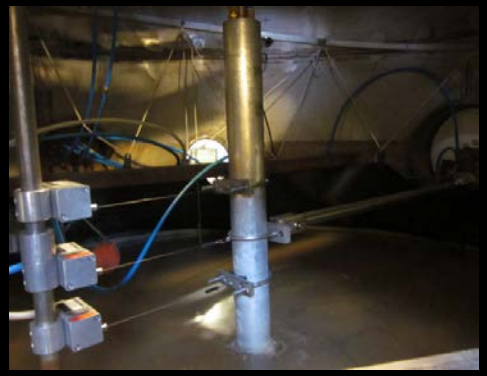
- Have been involved in more than 40+ concepts/projects over the past 12-14 years
- Partner in 4 ongoing EU financed projects
- Involved in all primary Danish, and numerous international, concept developments within the sector
- National and international standardization efforts
- Teaching, courses (Ph.D./external)

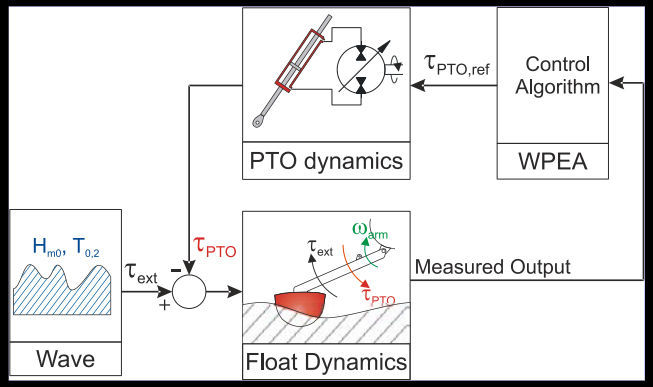


Other relevant research units at AAU

The Wave Energy Research Group is in close cooperation with other research units at the universty

- Structures and geotechnics
  Division of Structures, Materials and Geotechnics
- Power take-off
  Department of Energy Technology, Section of Fluid Power and Mechatronic Systems
- Energy systems
  Department of Development and Planning, The Sustainable Energy Planning Research Group
- Control
  Department of Electronic Systems, Section of Automation & Control





Etc. …
A very interdisciplinary field

Keywords

- Why wave energy?
- Potential
- Concept developments – examples of technologies
- Generic national and international projects
- What's happening now?

Cost of Energy (in Denmark)

ENERGY TYPE	€/MWh
Floating Offshore Wind	400-1500
Wave Energy	~750
Photovoltage	~125
Offshore Wind	75-125
Onshore Wind	40-75
Coal	30-45

30% of our electricity comes from wind.
Why ?

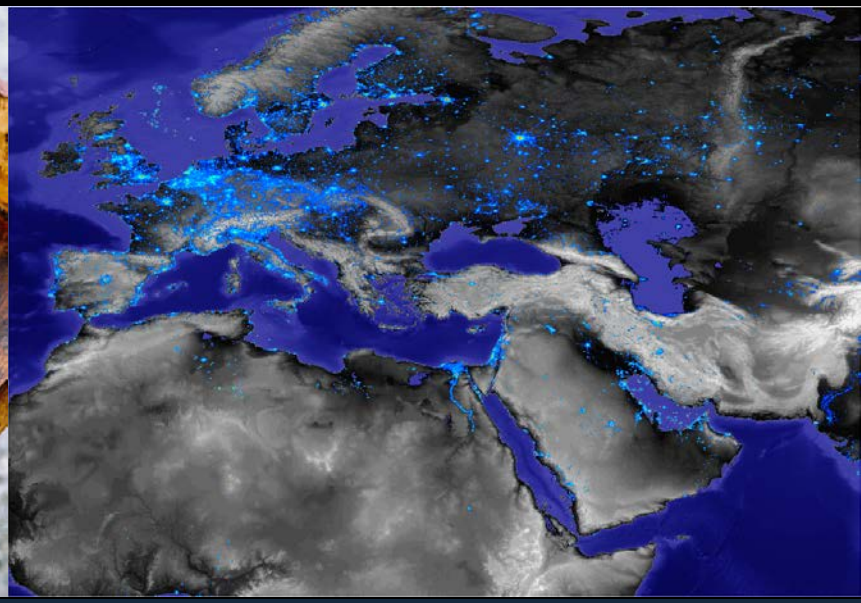
We are interested in Wave Energy.
Why ?

Cost of Energy important but not essential

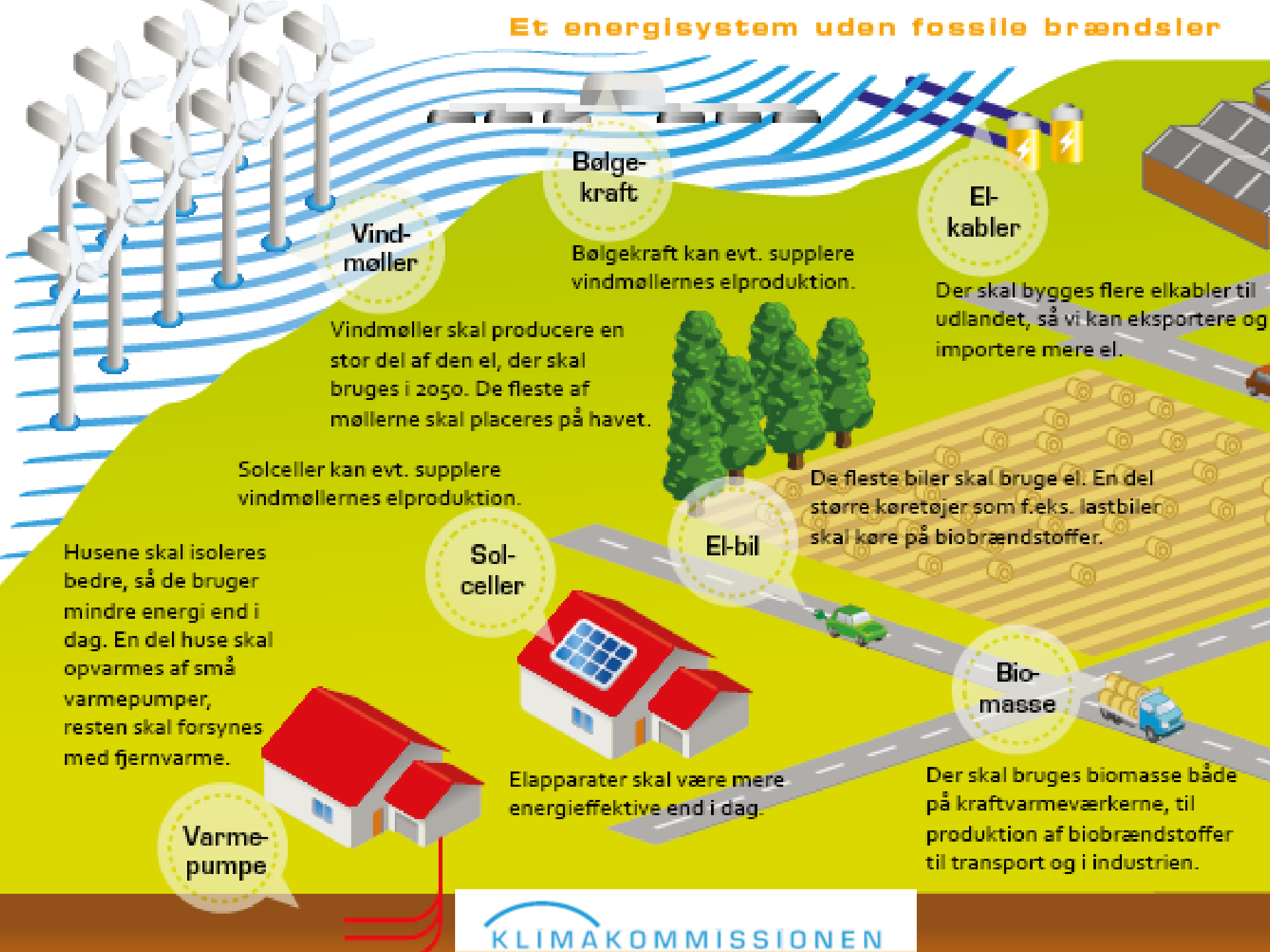
Energy policy is driven by politics

There is a growing demand for clean energy, the main drivers are not just Jobs, Environment, Global Warming

Nations wants to secure energy supply

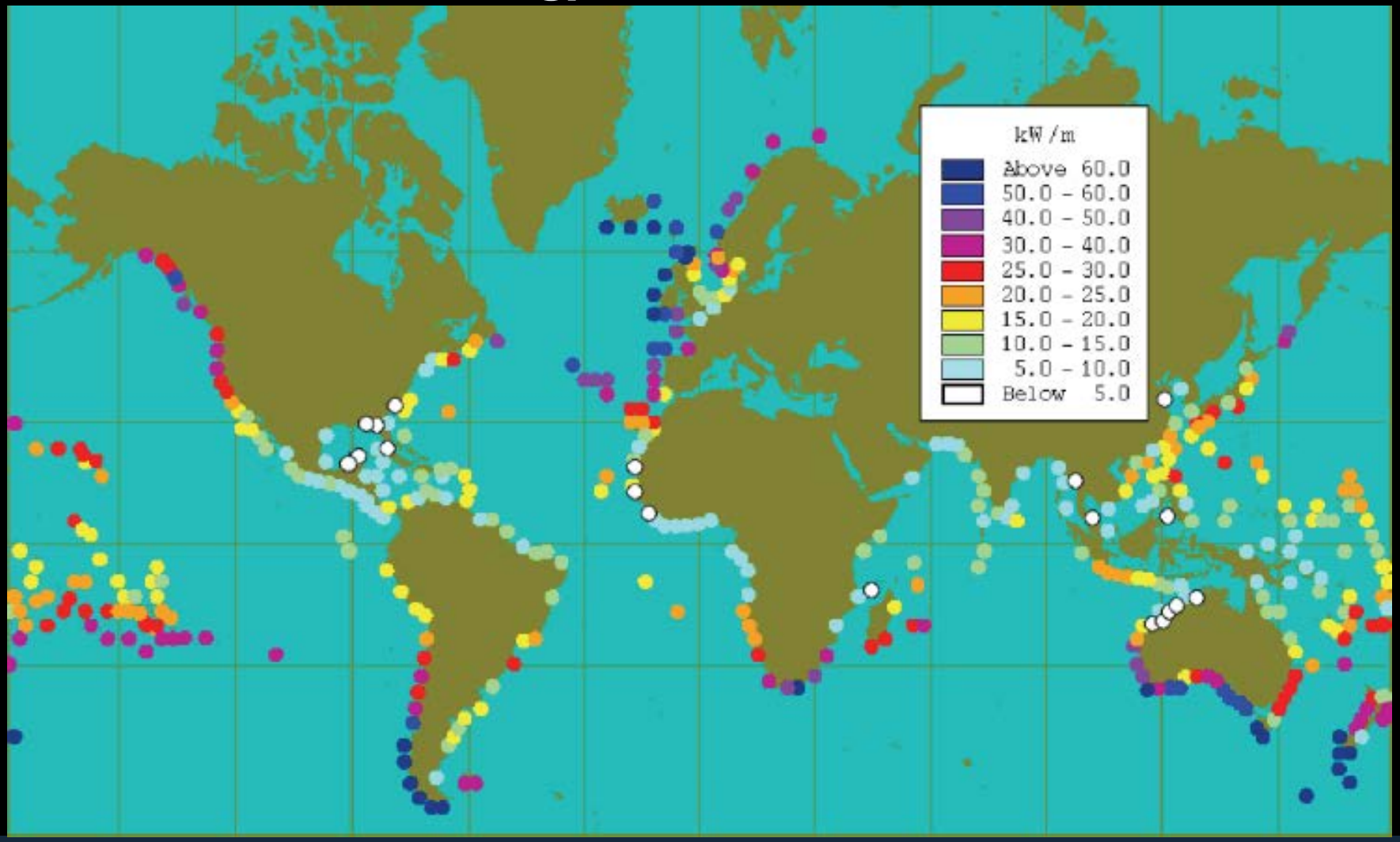


Et energisystem uden fossile brændsler

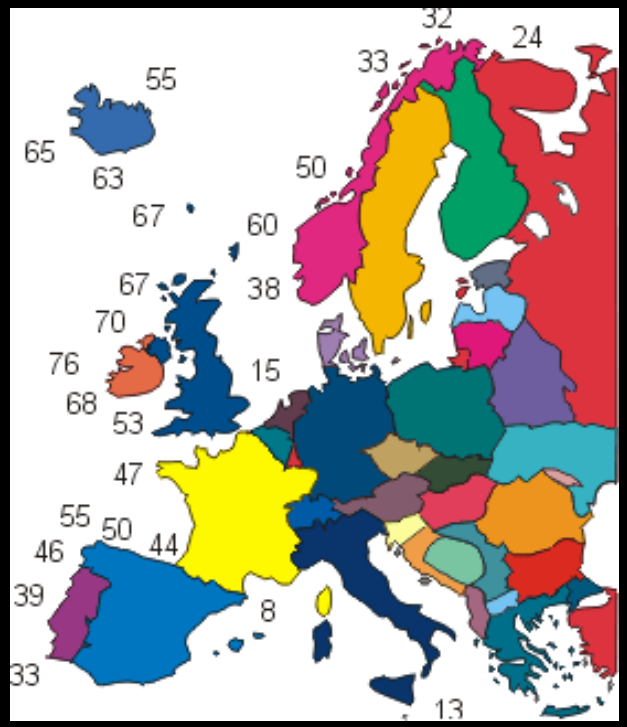


KLIMAKOMMISSIONEN

The Wave Energy Ressource is Enormous.
~ 20 % of Worlds Energy Needs



Potential wave energy in Europe



Denmark's electricity consumption: 3,7 GW

Danish West coast (offshore):

- Up to 25 MW/km
- averagely 16 MW/km
- Around 150 km from the coast
  ~ 2,4 GW

In the European Atlantic/North Sea coasts:
25 - 75 MW/km

Mediterranean sea: 4 - 11 MW/km

Total potential on European coasts: ca. 320 GW

Wave Energy has the potential to contribute significantly to the worlds energy production

Examples of activities (DK focus)

Concept developments

- Wave Dragon – Design study for a 1.5 MW device for deployment at DanWEC, Hanstholm
- Resen Waves – 'Standard' lab. test
- Weptos – 'Large scala' lab. testing conducted in CCOB, Santander, Spain
- Wavestar – Performance measurements on prototype at DanWEC, Hanstholm, cont. Developments in lab.
- Floating Power Plant – Real sea scale testing, combined wind/wave

EU funded projects

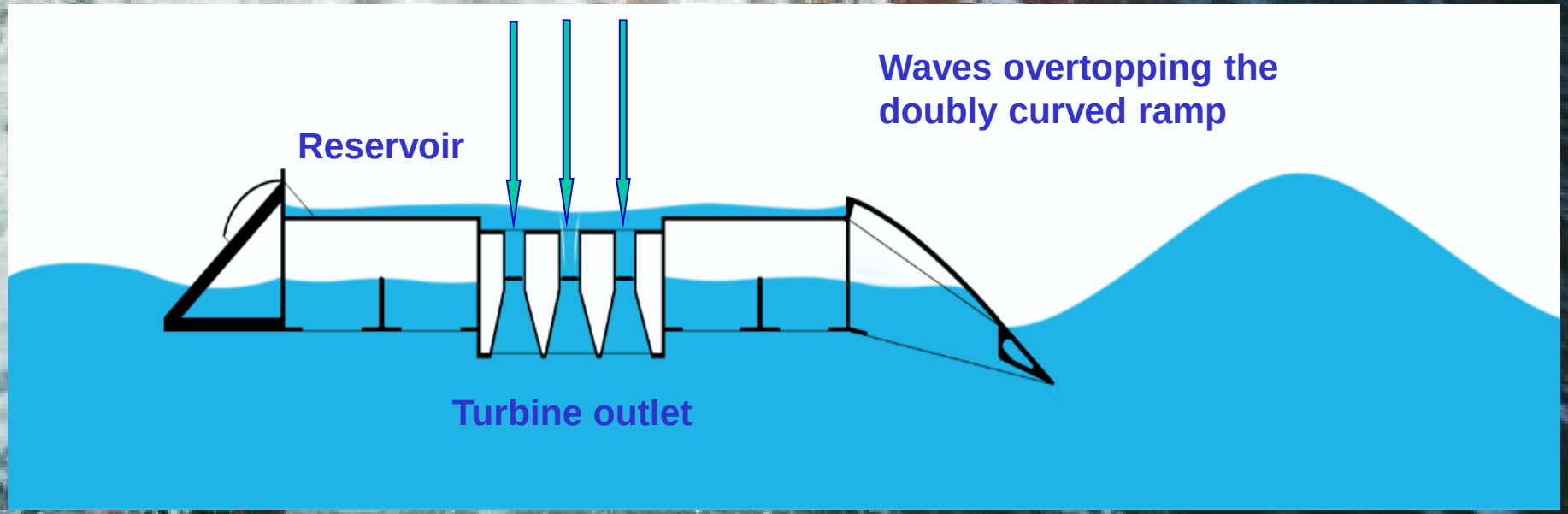
- CORES
- EquiMar
- Marinet
- WaveTrain2
- Hydralab
- Marina
- DTOcean

National, cooperation projects

- SDWED
- Partnership for wave power
- DanWEC
- IEC – TC114 / DS S-614
- FLOAT2

Wave Dragon

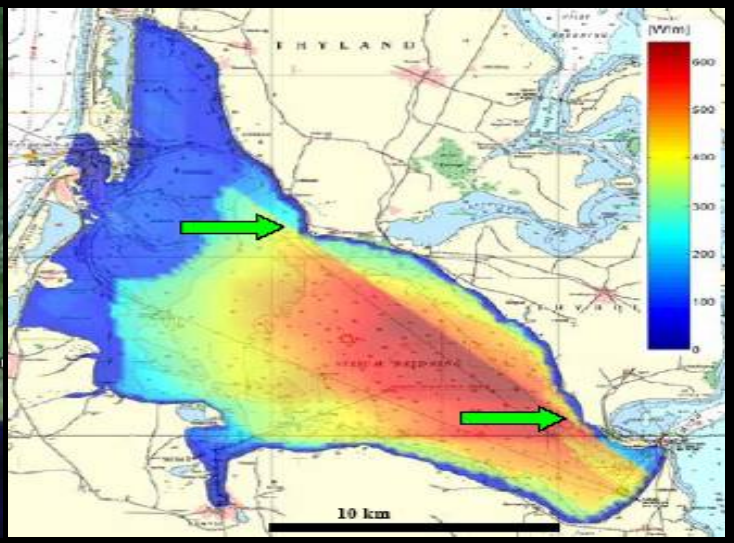
- a slack moored wave energy device of the overtopping type



Prototype Test Location

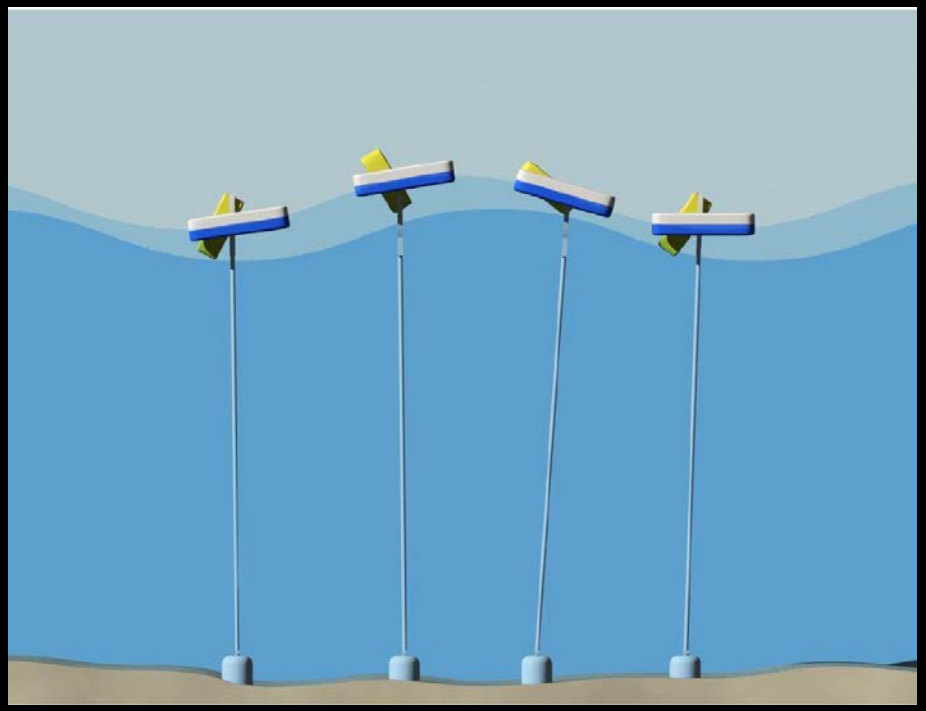
Nissum Bredning

- A benign site in Northern Denmark



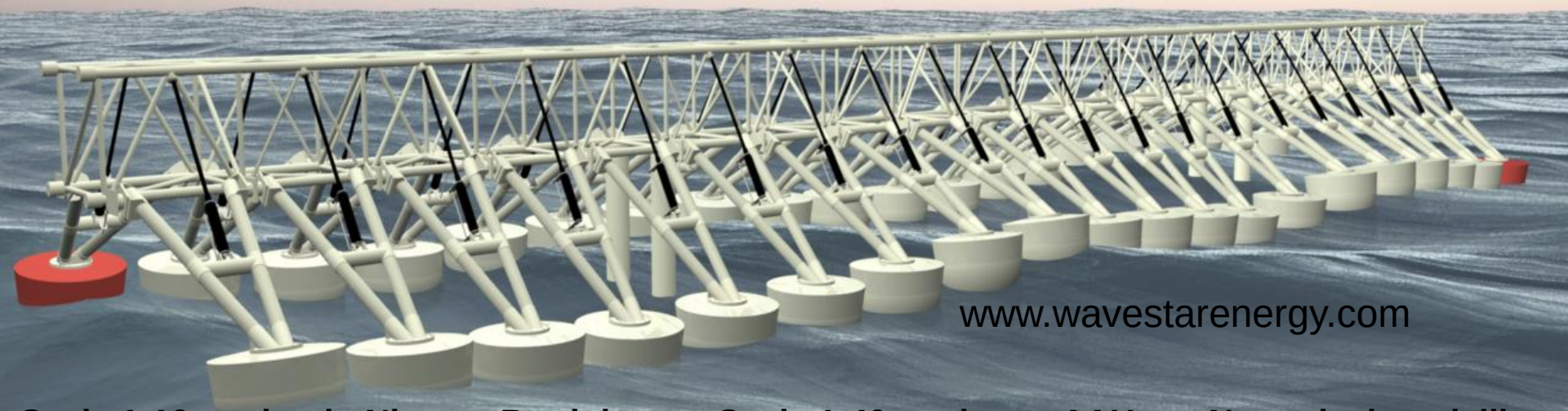
- 1:4.5 scale (compared DK North Sea) prototype in situ at Test Site 1, 2003 – 2005
- Grid connected, Full control system, Highly instrumented

Resen Waves - LOPF



The wave energy converter *Wave Star*

A multi point absorber system

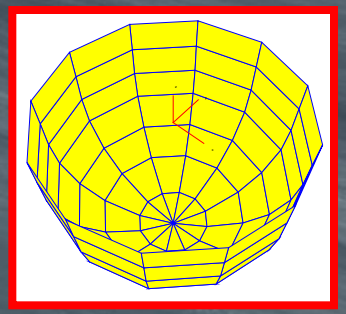


www.wavestarenergy.com

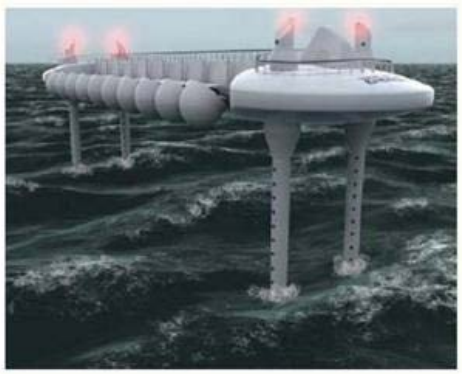
Scale 1:10 testing in Nissum Bredning

Scale 1:40 testing at AAU

Numerical modelling



Scale 1:10 Real Sea Tests in Nissum Bredning

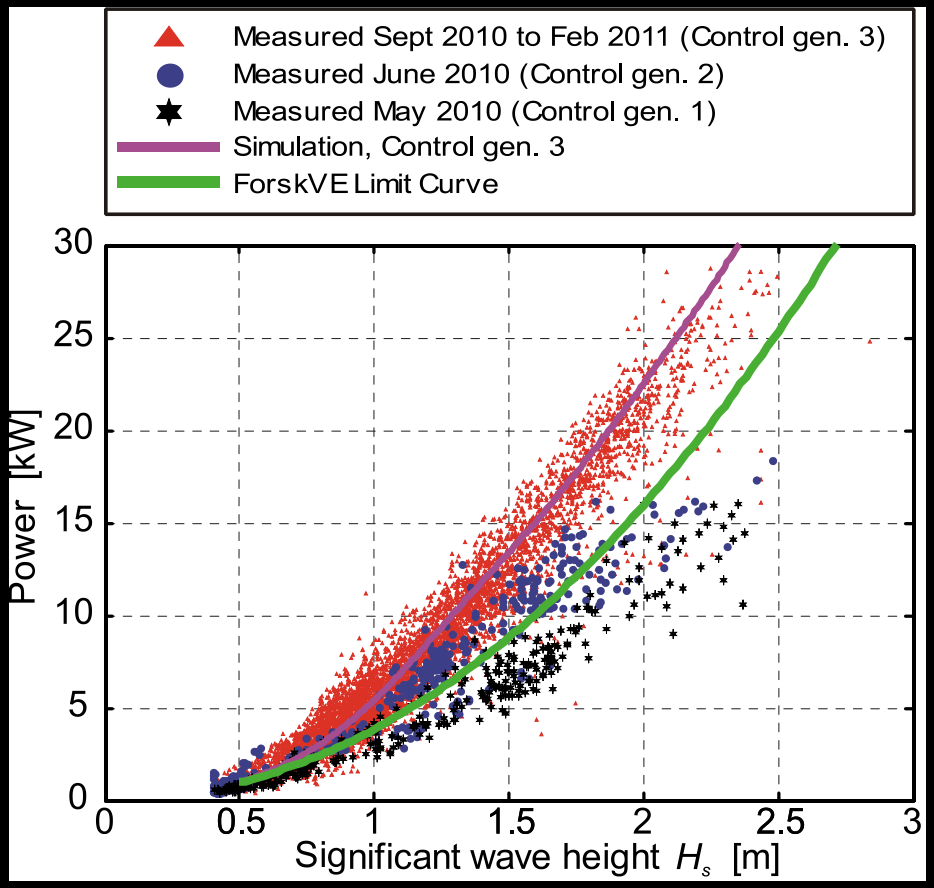



WAVE STAR
ENERGY

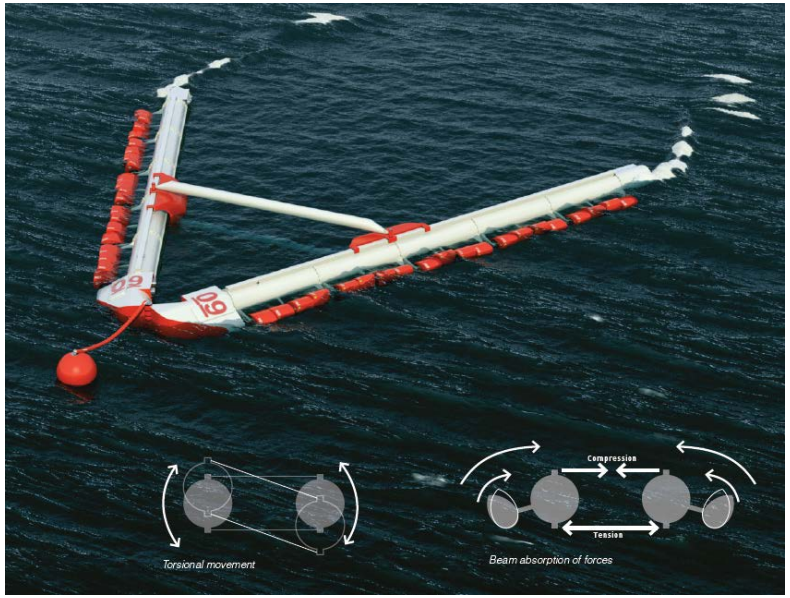
Power measurements from Roshage test unit

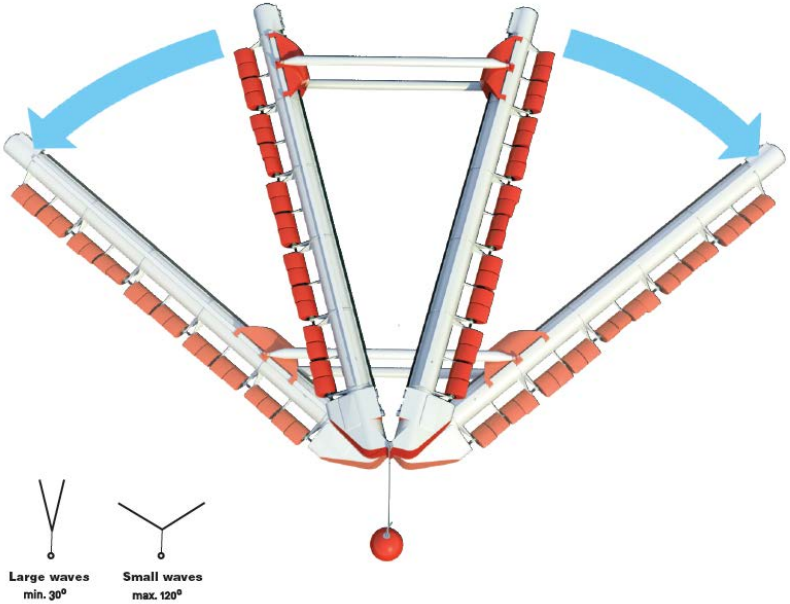
Notes:
- **Power is 10 minute average values of harvested power from one float (hydraulic power leaving one cylinder)**
- **A typical wave period for the Roshage location is used for the simulated curve**

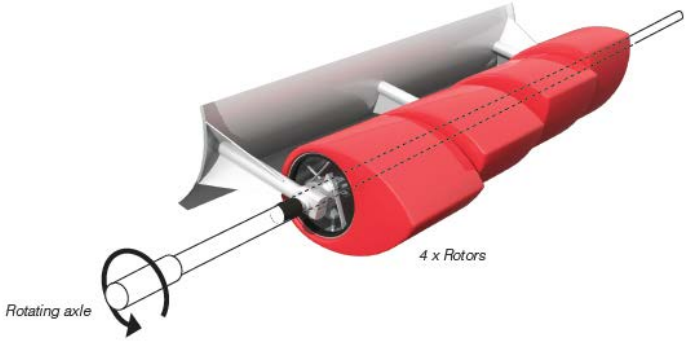
- **Online data at http://wavestarenergy.com/concept**

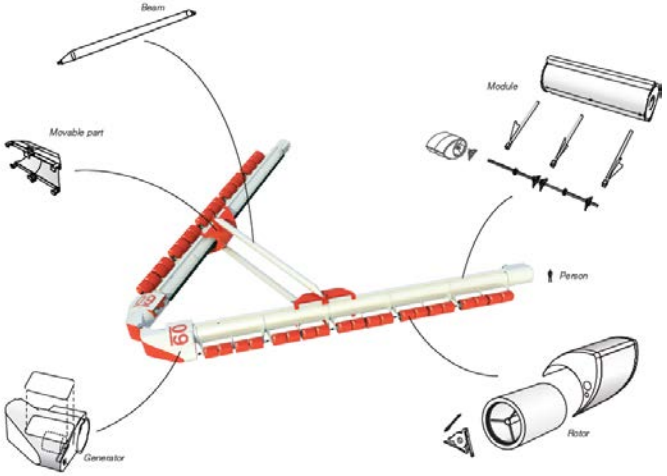


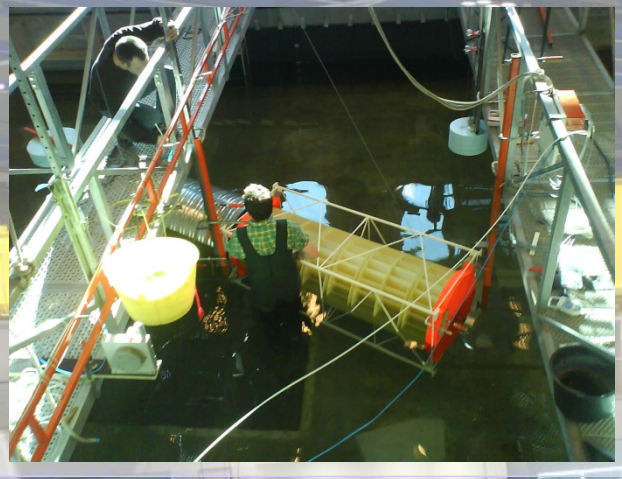
Weptos

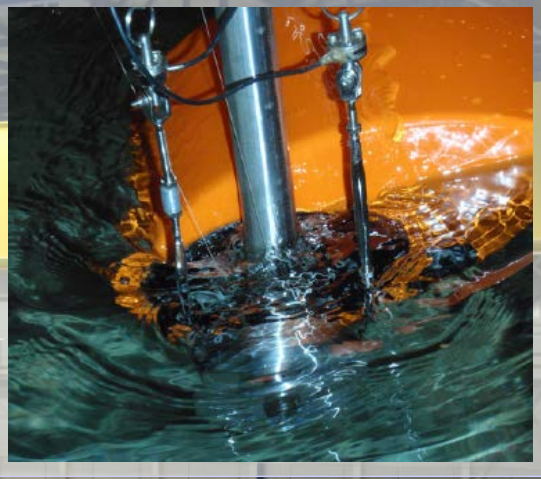

Torsional movement
Compression
Tension
Beam absorption of forces

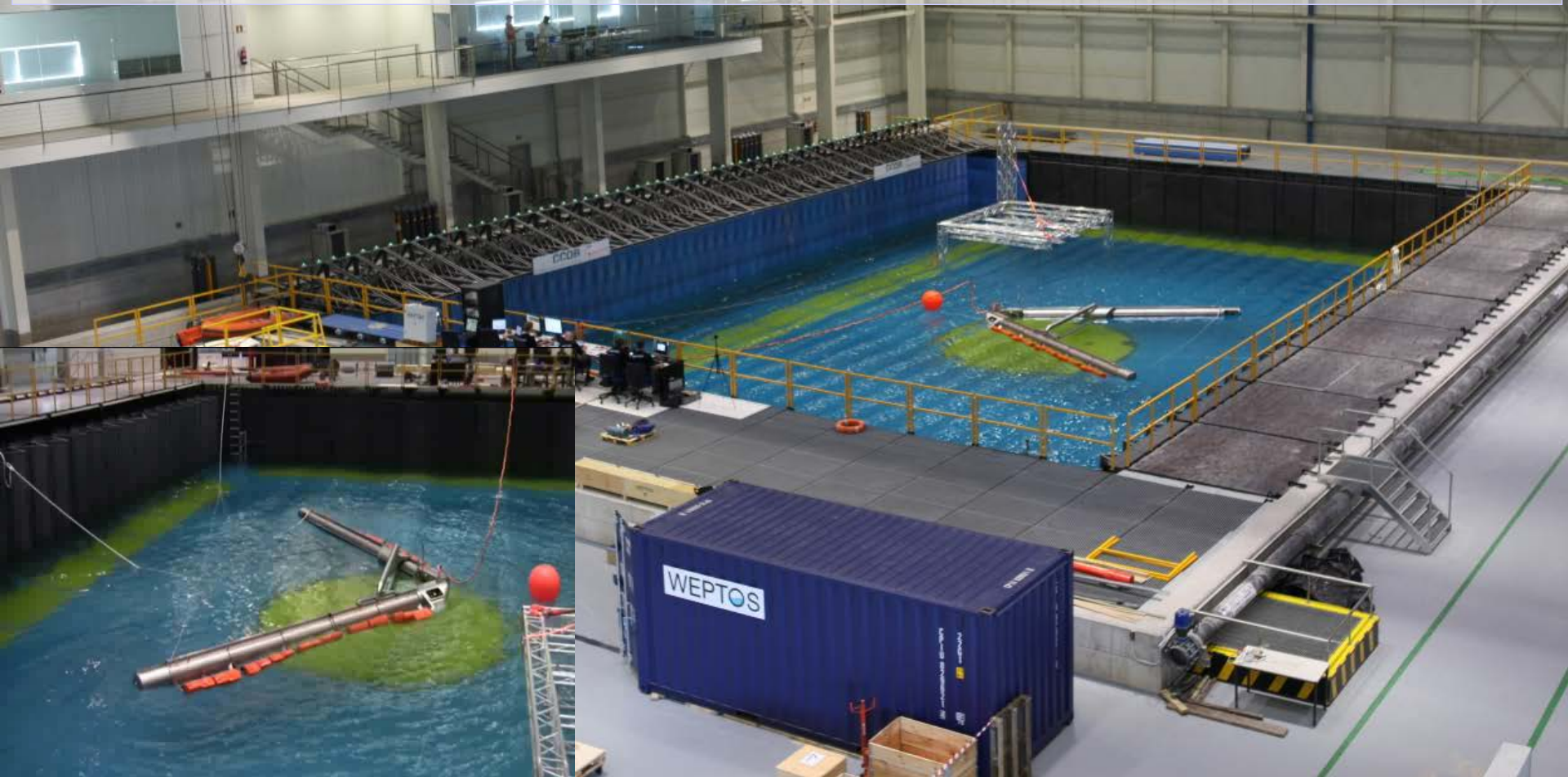

Large waves
min. 30°
Small waves
max. 120°


4 x Rotors
Rotating axle


Beam
Module
Movable part
Person
Rotor
Generator






WEPTOS

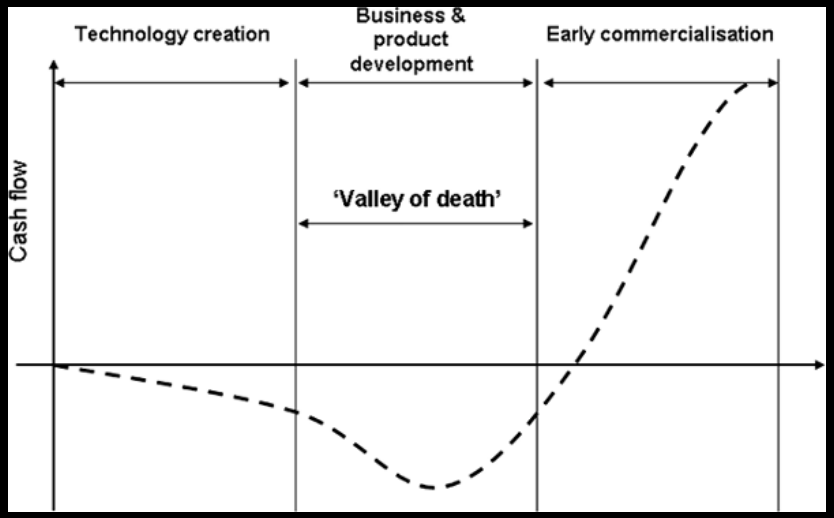
Floating Power Plant - Combined wind and wave

Very large numbers of ideas....

- Hundreds of concepts for utilization of wave energy – and even more patents!
- Still new concepts coming and being tested
- Some promissing concepts, but the race is still open!
- No convergence so far...

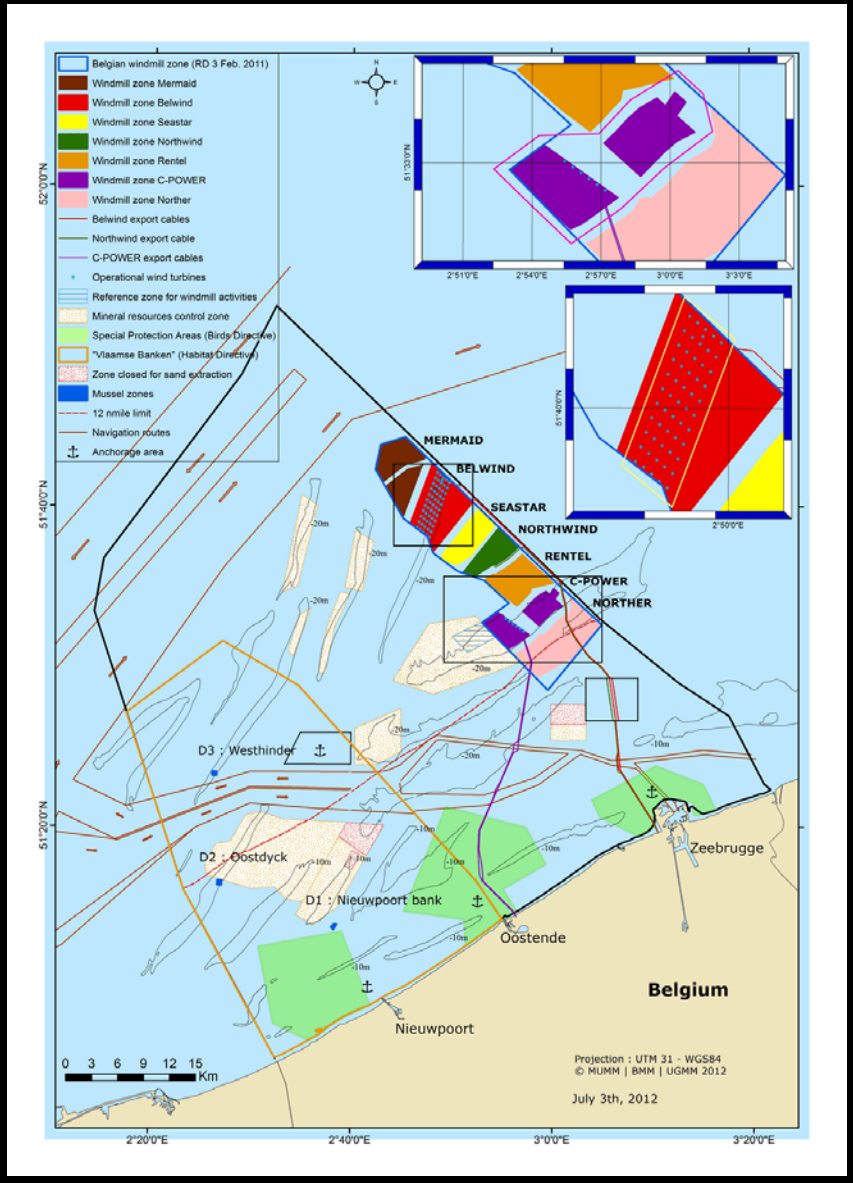
And large challenges…

- Valley of death – spec. private cap.
- Very cap. intensive
- Small vs. large installations
- Market
- Externalities



MERMAID, Belgium

- OTARY RS (65%) and Electrabel, Group GDF SUEZ (35%)
- 450 MW wind / 20 MW wave
- Creation of a market!



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Funded by

Danish Agency for Science Technology and Innovation
Ministry of Science Technology and Innovation

The International Research Alliance

SDWED

STRUCTURAL DESIGN OF WAVE ENERGY DEVICES

AALBORG UNIVERSITY
Department of Civil Engineering

DTU Technical University of Denmark

RAMBØLL

DHI

AALBORG UNIVERSITY
Department of Energy Technology

WaveEnergy Centre
Centro de Energia das Ondas

COPPE UFRJ

Fraunhofer

THE UNIVERSITY OF EDINBURGH

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

DNV

SDWED

The Alliance – The Project: Structural Design of Wave Energy Devices

Objective of the project

Strengthen and consolidate Denmark's position as one of the leaders in wave energy research, through the formation of a **strategic international research alliance** focusing on the structural design of Wave Energy Devices

Project granted by the **Danish Council for Strategic Research**
Call: **Strategic Research in Sustainable Energy and Environment**
Theme: **Energy Systems of the Future**

5 years (2010-2014)

12 Partner organizations - 6 Danish (73 %), 6 International (27 %)

Budget: 25 mil. dkr. (19.6 DSF, 5.4 Co-fin.)

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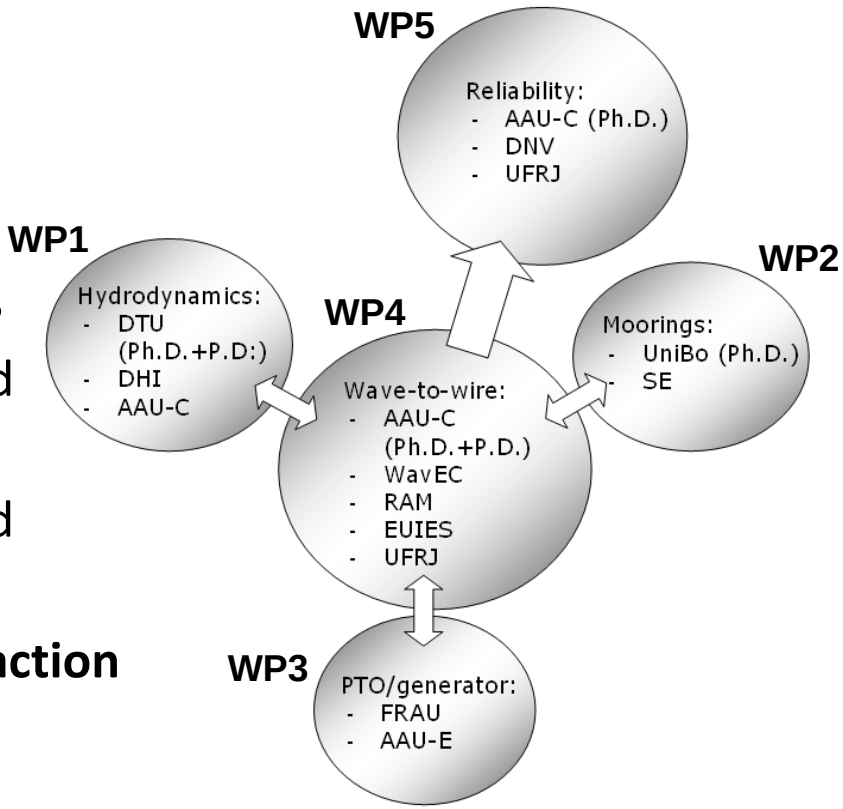
Department of Civil Engineering

Funded by
Danish Agency for Science Technology and Innovation
Ministry of Science Technology and Innovation

Anticipated main results

A **novel advanced wave-to-wire model** synthesized from the following results related to wave energy devices to be generated in the project:



- Advanced knowledge on **wave loadings**
- Advanced knowledge on loads from and behaviour of **mooring systems**
- Advanced knowledge on loads from and behaviour of **PTO systems**
- New advanced knowledge on the **interaction** of the mentioned elements
- Advanced knowledge on the structural **reliability** of the devices

Challenges …

- Large device variations
- Multiple disciplins involved
- Heavy interactions

Need for a 'JPEG' approach!

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Department of Civil Engineering

Challenges …

Incorporation of experiences from associated more established fields

- Often same tools but opposite goals:
  - e.g. maximize motions or overtopping rather than minimizing, as in e.g. ship and breakwater design
- Need for more complex models (include non-linearities and interactions)

Need to consider both power production and extreme conditions

- Balance structural loads in both conditions

Balance maximizing power production through advanced control against structural wear

Balance overall power production against installed generator capacity

What do we want to achieve?

Overall: Reduce cost of energy….

Need tools for WED design and optimization

Different needs in

- Operating conditions
- Extreme conditions

Focus on

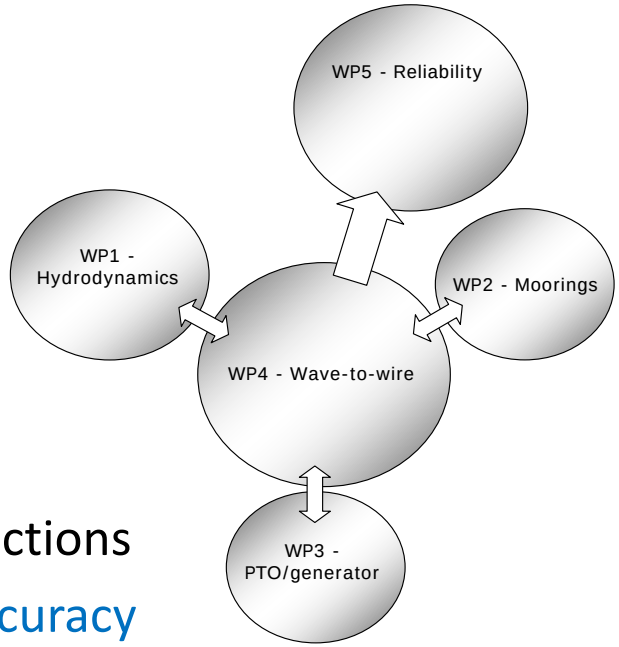
- Power production optimization
- Structural design

Many different WED types

- Provide ’building blocks’

Complex systems, non-linear behavior and interactions

- Need to balance computational speed and accuracy



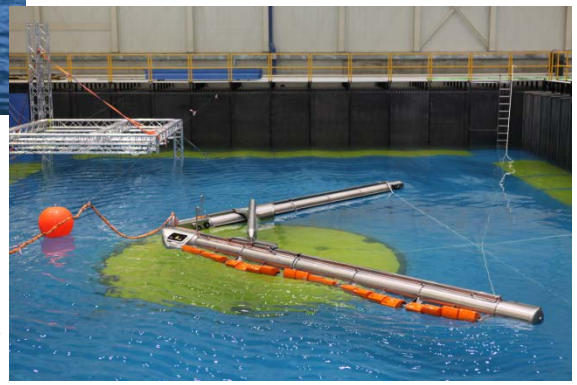
Project test cases

Dexawave:
Operating cond.:
HD – lin.
Moorings – important, interaction
PTO – simple, passive damping
Extreme cond.:
CFD for structural loading
Moorings – dyn. analysis

Weptos:
Operating cond.:
HD – multibody, highly non-linear, hydrostatics, variation of geometry
Moorings – important, weak interaction
PTO – highly non-lin.
Extreme cond.:
CFD for structural loading
Moorings – dyn. analysis

Wavestar:
Operating cond.:
HD – lin./non-lin.
Moorings – N.A.
PTO – time dom. adv. control
Extreme cond.:
Simple – floaters out of water

Increasing complexity



Researcher training

Ph.D.'s	Post Doc.'s
NN1, AAU-C	NN, AAU-C
NN2, AAU-C	Robert Read, DTU
NN, DTU	
NN, UniBo	

Andrew Zurkinden, AAU-C
Simon Ambühl, AAU-C
Torben Christensen, DTU
Giovanna Bevilacqua, UniBo
Francesco Ferri, AAU-C

Morten Kramer, AAU-C

Autumn 2010	**Ocean Energy Structures, 1 ECTS**	AAU: JPK
28-10-2010	Lecture 1: Overview of the wave energy sector / The Wave Dragon Case	JPK
12-10-2010	Lecture 2: Overview of existing wave energy converter technologies	JPK
26-10-2010	Lecture 3: Hydraulic and structural evaluation and development of wave energy	JPK
02-11-2010	Lecture 4: Performance evaluation of wave energy concept prototypes	JFC
09-11-2010	Lecture 5: Integration of wave energy into the grid	JFC
Nov. 2010	**Master lecture at Helsinki University: Wave Energy Challenges - How to harness the ressource**	WAVEC,
22-25.03.2011	**Lectures at Padova and Bologna University, Italy (8 hours in total) on Maritime Energy**	AAU: PF
	Lecture 1-2: Risk Related to the development of Maritime Energy (4 hours)	
	Lecture 3: LCA of Maritime Energy (1 hour)	
	Lecture 6-7: Wave Forces on Structural Elements on Maritime Energy Devices (2 lectures)	
	Lecture 8: Tool for development of Maritime Energy (1 hours)	
Spring 2011	**Ph.D. courses on Wave Energy Utilization, 3 weeks at AAU**	AAU: JPK
03-06.05.2011	Introduction to Wave Energy Utilization, 2 ECTS - 7 Lectures	AAU: LM,
09-13.05.2011	Experimental Testing for Wave Energy Utilization, 3 ECTS - 13 Lectures	AAU: JPK
16-20.05.2011	Advanced Control Theory for Wave Energy Utilization, 3 ECTS - 17 Lectures	AAU: MK,
Jan. 2012	**Lectures on Exp. Testing for Wave energy Utilization, Arr. by Israel Martinez Barrios, Acciona Energía, Spain ?**	AAU: JPK

To date 33 ECTS (~150 lectures) given


PHD COURSES 2011
on Wave Energy Utilization

May 3 - 6, 2011
Introduction

May 9 - 13, 2011
Experimental Testing

May 16 - 20, 2011
Advanced Control Theory

Wave Energy Research Group
Department of Civil Engineering
AALBORG UNIVERSITY
SDWED

PhD Courses on
Wave Energy Utilisation

In May 2011, the Wave Energy Research Group at Aalborg University, Department of Civil Engineering offers three consecutive weeks of PhD courses focused at the utilization of wave energy. During each week an independent course will be given. Thus, it is possible to sign up for just one, two or all three of the individual course, as it fits your interests, profile and time schedule. The courses are arranged through the Doctoral School of Engineering, Science and Medicine at Aalborg University.

For PhD students registered at a university, participation in the course itself is free. However, a contribution (stated for each individual course) will be charged to cover expenses for lunches, coffee, transportation, etc.

For non-PhD students, an additional registration fee (stated for each individual course) will also be charged.

The fees will be charged after the registration deadline is passed and registrants have got the confirmation of participation.

PHD COURSES 2011

Programmes for the PhD courses available at waveenergy.civil.aau.dk

May 3 - 6, 2011
Introduction to Wave Energy Utilization
(Max. no. of participants: 25)
Contribution to course expenses: €90,-
Additional registration fee (non-Ph.D. students): €515,-

May 9 - 13, 2011
Experimental Testing for Wave Energy Utilization
(Max. no. of participants: 12)
Contribution to course expenses: €120,-
Additional registration fee (non-Ph.D. students): €750

May 16 - 20, 2011
Advanced Control Theory for Wave Energy Utilization
(Max. no. of participants: 12)
Contribution to course expenses: €135,-
Registration fee (non-Ph.D. students): €750,-

INFORMATION:
Jens Peter Kofoed (jpk@civil.aau.dk)
Vivi Søndergaard (vs@civil.aau.dk)

REGISTRATION:
http://www.adm.aau.dk/fak-tekn/phd/kurser/index.htm#civ_eng

DEADLINE: 18 MARCH 2011

STRUCTURAL DESIGN OF WAVE ENERGY DEVICES
COURSE 1 (2 ECTS) May 3-6, 2011

Introduction to Wave Energy Utilization

Over the recent years there has been increased attention on the development of devices for utilization of wave energy. This course will give introductions to all the main subjects of relevance within the field, with focus on the technical aspects. The course will include the following subjects:

- Overview of international situation, policies and perspectives
- Wave energy resource
- Wave energy concepts
- Project management and finance
- Socio-economics and market
- Policy making
- Environmental issues
- Spatial planning
- Site visits at Nissum Bredning and/or Hanstholm test sites.

The course will be given as a combination of traditional lectures and workshops.

Prerequisites: Interest in the field, technical/engineering background.

Lecturers:
Lucia Margheritini, Post Doc, Dept. of Civil Engineering, Aalborg University
Jens Peter Kofoed, Associate Professor, Dept. of Civil Engineering, Aalborg University
Hans Christian Sørensen, Chairman, Ceo, WaveDragon, SPOK and C-Questor
Kim Nielsen, Wave Energy consultant, Ramboll
Henrik Lund, Professor, Dept. of Development and Planning, Aalborg University

COURSE 2 (3 ECTS) May 9 - 13, 2011

Experimental Testing for Wave Energy Utilization

The work on development of devices for utilization of wave energy typically involves intensive laboratory and real sea testing. The objective of this course is to introduce and apply wave analysis theory, laboratory measuring techniques, prototype monitoring and control. The course will include class room lectures, laboratory exercises in wave tanks/flumes and analysis of prototype data from real sea testing. The course will include the following subjects:

- Time and frequency domain wave analysis
- Reflection wave analysis
- 3-D wave analysis
- Laboratory and prototype measuring techniques
- Analysis of real sea data
- Probabilistic design of wave energy devices
- Numerical modeling of waves and wave energy devices

The course is of relevance to PhD students and others with interests in development of wave energy devices, especially with focus on experimental testing. An important element of the course will be hands-on exercises in wave laboratories and analysis of data from these.

Prerequisites: Knowledge of varies wave energy technologies, fluid mechanics and wave kinematics.

Lecturers:
Jens Peter Kofoed, Associate Professor, Dept. of Civil Engineering, Aalborg University
Morten Kramer, Post Doc, Dept. of Civil Engineering, Aalborg University
Harry Bingham, Associate Professor, Dept. of Mechanical Engineering, DTU
John Dalsgaard Sørensen, Professor MSO, Dept. of Civil Engineering, Aalborg University
Thomas Lykke Andersen, Associate Professor, Dept. of Civil Engineering, Aalborg University

COURSE 3 (3 ECTS) May 16 - 20, 2011

Advanced Control Theory for Wave Energy Utilization

When working with optimization of the power performance of a wave energy device, the control hereof, via the power take-off system is of paramount importance. This course will focus on this issue, and go through the basics of control of wave energy devices (based on wave activated bodies) and work its way through to stochastic optimal control of ditto. The topics will include:

- Optimal control of wave energy devices
- Basic mechanics of wave energy devices with power output control.
- Optimal control for linear and nonlinear systems. Linear quadratic control.
- Control using noise free observers.
- Stochastic optimal control of wave energy devices.
- Grid requirements and control of grid converters

The course is of relevance to PhD students and researchers with particular interests advanced control of wave energy devices.

Prerequisites: Some general knowledge of dynamic structures/mechanical systems, potential flow (linear wave) theory, Fourier transform and stochastic processes, as well as good skills in mathematical analysis.

Lecturers:
Søren R. K. Nielsen, Associate Professor, Dept. of Civil Engineering, Aalborg University
Jie Li, Professor, Dept. of Building Engineering, Tongji University
Peter Frigaard, Associate Professor, Dept. of Civil Engineering, Aalborg University
Morten Kramer, Post Doc, Dept. of Civil Engineering, Aalborg University
Remus Teodorescu, Vestas Professor in Power Electronics, Dept. of Energy Technology, Aalborg University

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Publication and dissemination

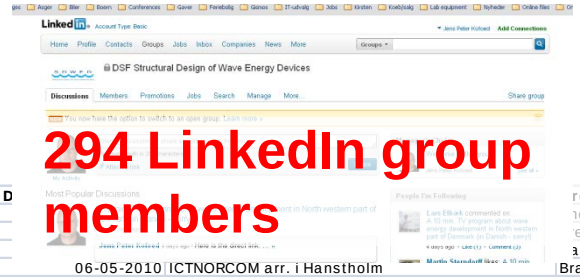
Journal / Publication name	Issue	Volume	Year	Publication Title	Lead Author	Affiliation	Co-Athours	Affiliation
ICASP 2011, Zurich, Switzerland				Probabilistic Design of Wave Energy Devices	[illegible]	[illegible]	Peter Kofoed	AAU
ICOE 2010, Bilbao, Spain				Modelling of the Overtopping Flow on the Wave Dragon Wave Energy	Parmeggiani, S.	AAU	Pecher, A., Kofoed	AAU
10th Symposium on Overset Composite Grids and Solution Technology.				Multiple-domain finite difference solutions for oceanwave-structure int	Robert Read	DTU	Harry Bingham	DTU
National Conference: Convegno Nazionale di Idraulica e Costruzioni Idr				Wave structure interaction in an overtopping based wave energy co	[illegible]	[illegible]	[illegible]tini, L. &	UniBo
ICS2011, Szczecin, Poland				Wave loadings acting on an innovative breakwaters for energy	[illegible]	[illegible]	[illegible] F., Buccin	.../AAU
ICOE 2010, Bilbao, Spain				Integration of Wave Energy Converters into Coastal Protection	Zanuttigh, B.	UniBo	Martinelli, L., Ruol,	UniBo/AAU
ICREPQ 2011, Las Palmas, Spain				Wave Energy Power Output Variability of Different Wave Energy	[illegible]	[illegible]	H.C., He	.../AAU
Risø Energy Report 9 - Non-fossil energy technolo	9		2010	Hydropower, Chap. 7	[illegible]	[illegible]	[illegible] P.	AAU
ISOPE 2011, Hawaii, US				Performance assessment of the Pico OWC power plant following the E	Pecher, A.	AAU	Le Crom, I, Neuma	WAVEC/AAU
EWTEC 2011, Southhampton 2011				Wave Pressures and Loads on a Small Scale Model of the Svaheia SSC	M. Buccino	Uni. Naples	D. Vicinanza, F. Cia	Uni. Naples
EWTEC 2011, Southhampton 2011				Experiments on the WavePiston, Wave Energy Converter	E. Angelilli	UniBo	B. Zanuttigh, J. P.	UniBo, AAU,
EWTEC 2011, Southhampton 2011				[illegible] ment of Best Practices for the Engineering Performa	C. M. Johnstone	Uni. Strathclyde	.. many .. J. P. Kofo	a. o. AAU
EWTEC 2011, Southhampton 2011				[illegible] ng of the Langlee Wave Energy Converter focusing	J. Lavelle	AAU	J. P. Kofoed	AAU
EWTEC 2011, Southhampton 2011				Predictability of the Power Output of Three Wave Energy Technologies	J. F. Chozas	AAU	a. o. J. P. Kofoed	AAU
EWTEC 2011, Southhampton 2011				Hydrodynamics around DEXA devices and implications for coastal prot	M. Castagnetti	UniBo	B. Zanuttigh, E. An	UniBo, AAU,
EWTEC 2011, Southhampton 2011				Performance Assessment of the Wave Dragon Wave Energy Converte	S. Parmeggiani	AAU	J. F. Chozas, A. Pe	AAU, WD

SDWED Symposia

1st: 46 participants

2nd: 70 participants

66 papers published



294 LinkedIn group members

Project website

38 press clips

46 invited lectures and public presentations

06-05-2010	ICTNORCOM arr. i Hanstholm	BrainsBr				Size of Audience	15
19-05-2010	Viborg Technical High School	General					100
20-05-2010	Bølgekrafttræf / Ocean Energy Open Days	Wave E					100
18-06-2010	Visit by Danish and Norwegian Utility Leaders	Status o					25
11-09-2010	Siemens Wind Power Family Day	Exhibition of small wave flume with overtopping device	AAU				16
26-09-2010	Seminar 'Who is who' in Offshore Renewable Energy	Public entities training on wave energy	WavEC				
29-09-2010	DNF Naturvidenskabsfestivalugen 2010	Når bølgerne går højt	AAU				
30-09-2010	DNF Naturvidenskabsfestivalugen 2010	Når bølgerne går højt	AAU	JPK			
01-10-2010	DNF Naturvidenskabsfestivalugen 2010	Når bølgerne går højt	AAU	JPK			
27-0	[illegible]	[illegible]	AAU	Lab			
[illegible]	[illegible]	[illegible]	AAU	JPK			
09-11-2010	HTX Sønderjylland	Når bølgerne går højt	AAU	JHN			34
10-11-2010	Nørresundby gymnasium	Når bølgerne går højt	AAU	LM			120
[illegible]	[illegible] geenergi	Utilization of Wave Energy – potentials, challenges and	AAU	JPK		Ringkøbing ~10	
[illegible]	[illegible] offshore alliance	Danish Wave Energy Activities international perspective	RAM	KIN		ness School	40
18-01-2011	IDA arr. on Wave Energy	Hvad er bølgeenergi?	AAU	JPK			38
18-03-2011	YOUNG ENERGY konference		AAU	LM			
06-04-2011	Forskningensdag, Inst. For Byggeri og Anlæg	Performance assessment of Wave Energy Converter	AAU	AFS			70
11-04-2011	Visit by Connie Hedegaard to DanWEC, Hanstholm	Aalborg Universitets aktiviteter indenfor vedvarende en	AAU	PF/J			15
23-05-2011	Visit by Reza UHM	RE projects at UHM	AAU	JPK			12
27-05-2011	SKUB Elevuniversitet	Bølgeenergi	AAU	JHN		~60	

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Questions - comments?

Thank you!