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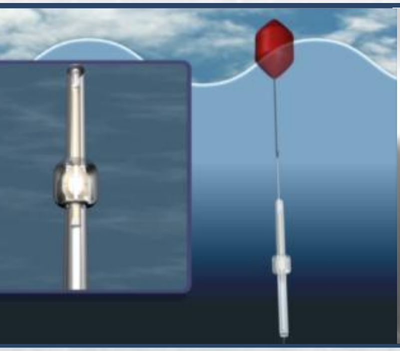
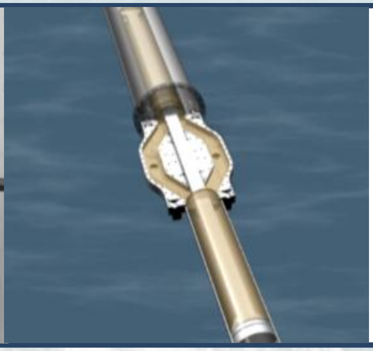
Wave Energy Converters & system engineering in startups





KSEE

Kongsberg

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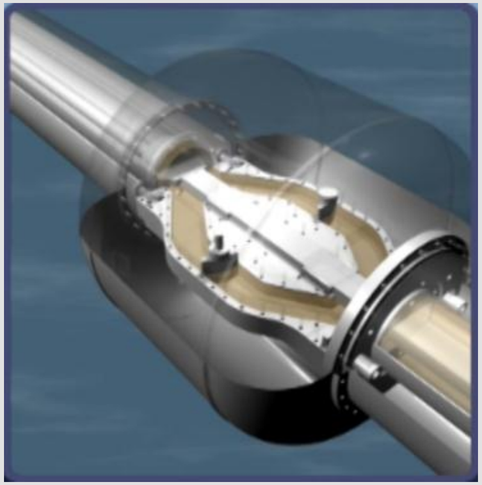
Patrik Möller, CEO & system architect

Outline

- Why harvesting energy from the oceans?
- Wave power 2012: Problem statement
- CorPower Ocean Wave Energy Converter concept
- Managing from concept to utility scale wave farms - keeping the concept real
- Structured development & best practices for ocean energy systems
- System engineering in startup environments



Why is wave power exciting?

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- **Huge available resource – clean and renewable energy**

  Energy: 80 000 TWh/year [1], economically exploitable = 2000-4000TWh.

  Power: 2 TW globally (annual average), 0,5 TW economically exploitable [2,3]

Potential : 10-20% of global electricity production (20261 TWh electricity, 143 000TWh energy, 2008)

- **Predictable output** – power levels can be forecasted 1-2 days in advance
- **Timing** different compared wind and solar – beneficial for grid balancing
- **Seasonal load –** correlating with electricity consumption. (Northern HS)
- **Power density** 10x wind and 100x solar.[4] (@ 40kW/m)

[1] IEA 2007, [2] McCormick, Mechanical Engineering-CIME 131.5 2009, [3] Jacobson, 2009, [4] www..aquaret.com

Wave power 2012: Problem statement

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1. **High Cost Of Electricity (COE)**, 0,15-0,50 EUR/kWh range, with a questionable return on investment unless significantly subsidized with feed-in-tariffs, or other governmental financial support programs. [1,2,3]

AND

2. **Large and heavy units - Limited practical scalability** for utility scale wave farms due to low energy density [kW per m3 and kg]

   Excessive amounts of steel and concrete [tons] as well as large sea areas [km2] for commercial scale wave energy conversion.

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[1] "Case study feasibility analysis of the Pelamis wave energy converter in Ireland, Portugal and North America", G.J. Dalton et al, HMRC University College Cork, Renewable Energy 35 (2010) 443-455

[2] "Levelised cost of Wave and Tidal energy in the UK: Cost competitiveness and the importance of banded Renewable Obligation Certificates" G Allan, K. Swales, Energy Policy 39 (2011) 23-39

[3] "Wave Power - Surveillance study of the development", Elforsk rapport 11:02

Wave power COE: Root cause observations

1. High CAPEX cost per rated kW capacity

Case A: Large and heavy units, with high COGS (Cost-of-Goods-Sold) per rated maximum capacity. [1]

Case B: PTOs with Custom built components – high material cost and limited power density. [3,4]

(Common issue with many devices having A: Hydraulic PTOs B: linear generators)

2. **Low capacity factor** (actual delivered power / rated max power) over a year,

as a result of poor conversion performance in wave environments outside of optimal window of operation.[1, 5, 6]

(Large hydraulic WECs often operate poorly in low waves,
Linear generators often not scaled for larger waves)

3. High Operations & Maintenance (O&M) cost

Early stage designs with reliability issues combined with complicated off-shore service schemes, resulting in high operational costs (O&M can be 40% of COE[5]) as well as significant downtime with lost production. [5, 6]

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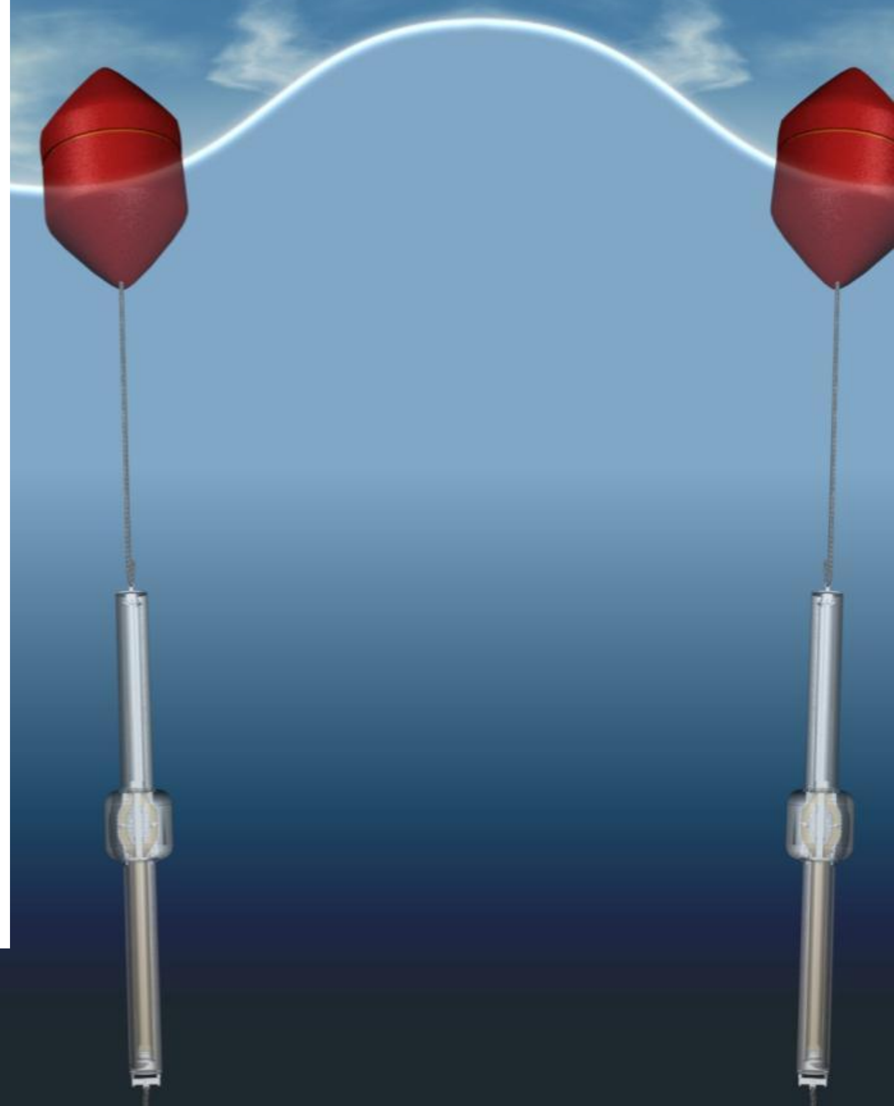
[3] "Design of a linear generator for Wave Energy Plant". MSc report ISSN 1401-5757, Uppsala University 2003, [4] "Linear Generator for Direct Drive Wave Energy Applications", M. Mueller, XIX Int Conf on Electrical Machines - ICEM 2010, Rome, [5] "The potential of wave energy", J. Hayward and P. Osman. CSIRO, March 2011, [6] "Accelerating marine energy", Carbon Trust, July 2011

CorPower Wave Energy Converter concept

Feature	Advantage
Light units, low inertia	Energized by small waves
Phase control	High capacity factor High energy density
Small units in array	Mass production → CAPEX cost ↓
Quick replace scheme	Effective service → OM cost ↓
Distributed generation	Fault tolerant, predictable output



CorPower Wave Energy Converter concept

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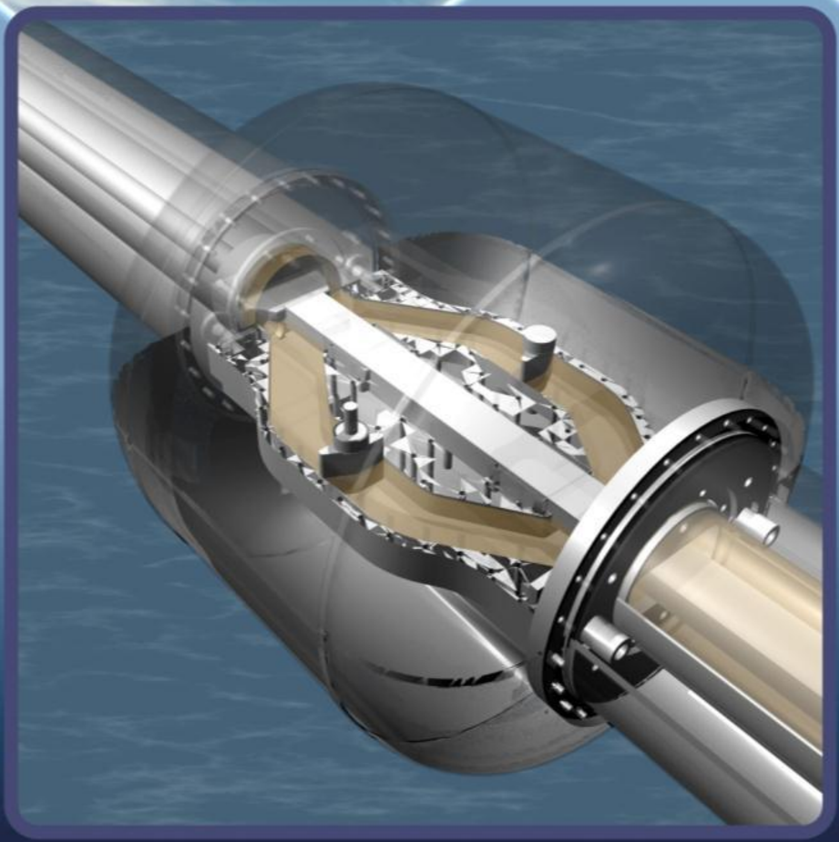

Parameter	Compared to competition
Cost of Energy EURc/kWh	3-5x lower (2x OS wind)
Energy density kW/ton	5-30x higher
Sea area km2/MW	20x smaller
Capacity factor	2x higher
Survivability	Designed to be submersed

Global wave energy resource could be havested with: 5M units - 100kW capacity, or 1.5M units - 330kW capacity

Structured development & best practices

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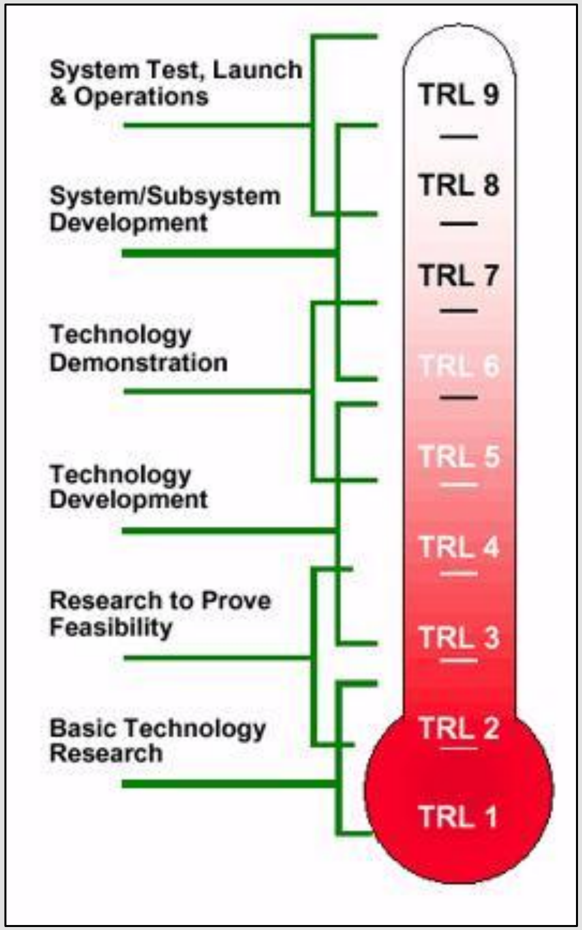
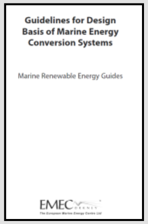
Technology Readiness levels (TRL), NASA



Best practices - Ocean Energy Converters

IEA OES-HMRC. Guidelines for the Development & Testing of Wave Energy Systems, 2010

Equimar. Protocols for the Equitable Assessment of Marine Energy Converters, 2011



EMEC. Guidelines for Design Basis of Marine Energy Conversion Systems, 2009

Germanisher Lloyd. Guideline for the Certification of Ocean Energy Converters.

DNV. Guidelines on Design and Operation of Wave Energy Converters. May 2005.

5 stage - structured development plan

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Stage	TRL	Key	Device scale	Facility	Typical duration
STAGE 5: Economics validation	TRL 9	Multi-device array	1:1 pilot array	Open Ocean site	1-5 years
STAGE 4: Device validation	TRL 8	Single device, exposed sea, grid connected	1:1 single device	Exposed ocean site	12-36 months
	TRL 7	Single device, sheltered sea, grid modelled		Sheltered Ocean site	
STAGE 3: Systems Validation	TRL 6	Integrated system sea trials	1:4-5 scale	Benign site	6-18 months
	TRL 5	Sub-assembly bench test		Device Lab	
STAGE 2: Design Validation	TRL 4	Sub-systems assessment	1:10 scale	3D tank test Modelling	6-12 months
STAGE 1: Concept Validation	TRL 3	Device optimization	1:25-50 scale	Tank tests Modelling	3-9 months
	TRL 2	Performance convergence			
	TRL 1	Confirmation of operation			

Definition and measurement of Stage Gates critical for success.

Example: Size, COGS, kW/kg, kW/m3, survivability

System engineering in startups

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- Limited resources – team size, facilities, expensive development tools
- Often no time/money for parallel tracks – modelling and simulation capabilities is critical for making early decisions
- Single project venture - No room for major failures (game over)
- High pressure to accelerate design and evaluation processes (investors, ROI)
- Fast decisions, minimal bureaucracy
- In early phase, often 1 person per technical discipline, clear responsibilities, highly motivated team
- Relying heavily on support from industry best practices and established competence centers for guidance
- Many specialist disciplines are contracted for periods when needed

Thank you!

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