Green energy...
...Out of the Blue

Dream or reality?

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1) AWW - UGent

- Department of Civil Engineering?
  - Coastal Engineering
  - Roads
  - Bridges
- http://awww.ugent.be/
- Technologiepark 904, 9052 Zwijnaarde, Belgium
1) AWW - UGent

- Design, construction and monitoring of coastal structures, mainly breakwaters and sea dikes
- Development and exploitation of measurement jetty and instruments at Zeebrugge for prototype measurements on breakwater
- Two wave flumes (L =15m and L =30 m)
- Development of numerical wave laboratory for wave propagation and interaction with structures
- Wave energy & Tidal energy
- Integral research (the holy ‘Trinity’)
  - Prototype measurements
  - Fysical modelling(laboratory: wave flumes)
  - Numerical modelling

1) AWW – Ugent: prototype measurement
1) AWW – Ugent: wave flume

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1) AWW – Ugent: Numerical modelling

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2) Marine Energy

- Energy sources:
  1. Tidal energy: dam (French: barrage)
  2. Tidal energy: currents
  3. Wave energy
  4. Osmotical energy: salt/fresh water gradients
  5. Thermal energy: hot/cold water gradients

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3a) Wave Energy?

- Electricity from waves
  - Based on different physical behaviour of waves
    - Both kinetic and/or potential energy
- Depending on the ressource of the waves
- Depending on the converter (Wave Energy Converter): WEC
3a) Waves: origin?

- Sun $\rightarrow$ temperature and pressure differences $\rightarrow$ wind $\rightarrow$ waves

- Waves propagate over long distances without significantly loosing their energy (in deep water)

3a) Waves: where’s the energy?

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3a) Waves: where’s the energy?

- Wave power is expressed in kW/m wave crest of the wave
- Theory (deep water assumption):
  - Power $\sim$ wave height $^2$ and period

$$P = \frac{\rho g}{64\pi} H_m^2 T_m^{-1.0}$$

3a) Waves: where’s the energy?

- Wave power is expressed in kW/m wave crest of the wave
- General theory:
  - Spectral analysis of irregular waves + frequency of occurrence.
  - Power $\sim$ wave height $^2$ and period

$$P(f) = \int g \rho C_p S(f) df$$

$$S(f) = g H_m^4 f_p^{-4} f^{-3} \exp\left(-\frac{5}{4}\frac{f_p}{f}\right)$$

Spectraal densiteitsfunctie (JONSWAP)
3a) Waves: where’s the energy?

Cornett 2008

Available wave power, expressed in kW/m wavecrest. Source: WorldWaves data/OCEANOR/ECMWF.

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3a) Waves: where’s the energy?

- Question to think about
- What’s the ideal place to place Wave Energy Converters?

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3b) Tidal Energy?

- Electricity from tides
  - Based on potential energy
    - Classical hydro, eg. La Rance Barrage (France)
  - Based on kinetic energy
    - The tidal current itself
- Depending on the ressource of tidal current energy
- Depending on the converter (Tidal Energy Converter)

3b) Tidal Energy?

- Origin of tides
  - Gravitational forces earth, sun & moon
  - Water of the oceans reacts to changing forces (rotation and relative movement of earth, sun and moon)
  - Differences in heights and currents!
3b) Tidal Energy?

- Energy content:
  - Same formula as wind!
    - $P = \frac{1}{2} \rho \cdot A \cdot V^3$
    - Rho: density [1,026 kg/m$^3$]
    - A: ‘swept’ area [m$^2$]
    - V: velocity [m/s]
  - Differences:
    - $\rho_{\text{seawater}} \approx 800 \rho_{\text{air}}$ (energy more concentrated)
    - V: current velocities
      - Sea currents: up to 2-3 m/s on springtide
      - Wind: ca. 8-10 m/s average offshore (approx. 5 beaufort)
    - A: swept area TEC $<<$ windmill

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3b) Where is the Tidal Energy?

- Numerical modelling, hydrodynamic models
  - Advantages: cheap, coherent dataset both in time and space
  - Disadvantages: gives overview (unless very fine grid), calculation time, uncertainties (depending on calibration)
- Hydrodynamic models
  - Give indication of tidal current at certain timestep
  - Harbour of Zeebrugge: high content at the dams
### 3b) Wave – Tidal - Wind

<table>
<thead>
<tr>
<th>Waves</th>
<th>Tidal Current</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteo</td>
<td>Dependant</td>
<td>Almost independent, but highly cyclical (ebb-flood // spring – neap tide)</td>
</tr>
<tr>
<td>Energy density</td>
<td>High, less variable than wind</td>
<td>High</td>
</tr>
<tr>
<td>Visual hindrance</td>
<td>Limited</td>
<td>None (except marker buoys or access structures)</td>
</tr>
<tr>
<td>Challenges</td>
<td>- Efficiency</td>
<td>- Efficiency</td>
</tr>
<tr>
<td></td>
<td>- ‘Survivability’</td>
<td>- Reliability in marine environment (salt, biofouling)</td>
</tr>
<tr>
<td></td>
<td>- Grid</td>
<td>- Grid</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complementary and synergetic possibilities need to be researched!</td>
<td></td>
</tr>
</tbody>
</table>

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**Admiralty Charts**

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4.1) Wave Energy Converter

- WEC: Wave Energy Converter
- Classification:
  - Conversion technology
  - Floating/anchored/integrated in coastal structures
4.1) Wave Energy Converters

- 6 main types, all of them under full development
- No clear winner <> wind turbines: 3-bladed horizontal axis turbine

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4.1a) WEC: Point Absorber

Point Absorber:

- A point absorber is a floating structure which absorbs energy in all directions through its movements at/near the water surface.
- The power take-off system may take a number of forms, depending on the configuration of displacers/reactors.

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4.1a) WEC: Point Absorber

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- Wave Star
- FO³ Manchester bobber
- Seabased & Uppsala University
- Aquabuoy (US)
- Powerbuoy (US)
- Wavebob (UK)
- B1 – SEEWEC
4.1a) WEC: B1

Material design for large scale manufacturing
Refining and verification of overall design
Farm design and characteristics
Power generation efficiency

Design and manufacturing of 2nd generation systems and components

SEEWEC project scheme
Core work packages

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4.1a) WEC: Point Absorber

- Main properties of WEC
  - Necessary condition: high power conversion

- Influence of restrictions on power absorption voor different seastates
  - \( P \text{ voor cc, } D=5\text{m, } d=3\text{m, } H_s=1.75\text{m, } T_p=7.4s \)

- Influences of buoy shape, diameter and draft: cone 4 to 8% better then round buoy

Ugent research: PhD research of Griet De Backer
4.1a) WEC: Point Absorber

- Main properties of WEC
  - Necessary condition: high power conversion, **but not enough**!
  - Necessary and fulfilling condition
    - High efficiency
    - Survivability in storm conditions:
      - Stability
      - Structural strength of the WEC

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4.1a) WEC: Point Absorber

- Lessons from the past, provide input for the future

Ugent research: PhD research of Griet De Backer en Chris Blommaert

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4.1b) WEC: Attenuator

Attenuator:
• A floating device which works parallel to the wave direction and effectively rides the waves.
• Movements along its length can be selectively constrained to produce energy.
• It has a lower area parallel to the waves in comparison to a terminator, so the device experiences lower forces.
4.1b) WEC: Attenuator

4.1c) WEC: OWC

Oscillating Water Column (OWC):

- An oscillating water column is a partially submerged, hollow structure. It is open to the sea below the water line, enclosing a column of air on top of a column of water.
- Waves cause the water column to rise and fall, which in turn compresses and decompresses the air column.
- This trapped air is allowed to flow to and from the atmosphere via a turbine, which usually has the ability to rotate regardless of the direction of the airflow.
- The rotation of the turbine is used to generate electricity.
4.1c) WEC: OWC

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4.1c) WEC: OWC

- Mutriku (Gulf of Biskaje, Spain)
- OWC integrated in breakwater

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4.1c) WEC: OWC

Storm during construction of OWC breakwater Mutriku (the nose of a whale…). The water is is pressed through the openings where the (air!) turbines should be placed in a later phase (normally only air can pass this opening, security valves were not yet installed). Foto: José Villate, 2008

4.1d) WEC: Overtopping

Overtopping (terminator type):

- This type of device relies on physical capture of water from waves which is held in a reservoir above sea level
- Before being returned to the sea through conventional low-head turbines which generates power.
- An overtopping device may use reflectors to concentrate the wave energy.
4.1d) WEC: Overtopping

4.1e) WEC: OWSC

Oscillating Wave Surge Convertor (OWSC):
• This device extracts the energy caused by wave surges and the movement of water particles within them.
• The arm oscillates as a pendulum mounted on a pivoted joint in response to the movement of water in the waves.
4.1e) WEC: OWSC

Oyster – Aquamarine Power

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4.1f) WEC: SPD

Submerged Pressure Differential:
- These devices are typically located nearshore and attached to the seabed.
- The motion of the waves causes the sea level to rise and fall above the device, inducing a pressure differential in the device.
- The alternating pressure can then pump fluid through a system to generate electricity.
4.1) WEC: where’s the energy?

• Question to think about **(again)**?
• Where is the ideal place to put WEC’s?

Necessary condition: high resource, good conversion technology
But ‘survivability’ is extremely important
  – Resistance to storm conditions:
    • General stability
    • Structural strength of the parts of the WEC
  – Fishermen: “You want to place devices where we don’t dare to navigate in storms”
• Other criteria:
  – Others users, distance to shore and grid connection, etc., …
4.1) Waves: where is the energy?

- Belgium:
  - Moderate wave climate (approx. 5kW/m), ideal for learning and testing.
  - In the recent years: everybody wanted to test in high energetic zones (now: step by step approach)
  - Future for Belgian industry: high added value
  - Multi-criteria analysis, if possible combine with spatial planning!

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4.2) Tidal Energy Converters: TEC

- Different types, but not as diverse as Wave Energy Convertors.

4.2a) TEC: HATT

HATT:
- This device extracts energy from moving water in much the same way as wind turbines extract energy from moving air.
- Devices can be housed within ducts to create secondary flow effects by concentrating the flow and producing a pressure difference.
4.2a) TEC: HATT

Seagen, MCT
Open Hydro @ EMEC test site
Clean Current Tidal Turbine
Sabella
Hammerfest Turbine

4.2b) TEC: VATT:

Verticale As Turbine.
- This device extracts energy from moving in a similar fashion to that above, however the turbine is mounted on a vertical axis.
- Examples: Gorlov and Darrieus turbines.

Gorlov, ~ Darrieus with inclined blades
Waverotor, Ecofys (Borssele, Schelde, Zeeland!): Darrieus turbine
4.2b) Hydrofoil

Oscillating Hydrofoil:

- A hydrofoil attached to an oscillating arm and the motion is caused by the tidal current flowing either side of a wing, which results in lift.
- This motion can then drive fluid in a hydraulic system to be converted into electricity.

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4.2d) TEC others

VIVACE
Tidal Sails
Tidal Stream

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5) Costs?

- Difficult to assess...
- Developpers are not willing to give away information (commercially sensitive)
- Only generic studies, that give openingprices or expected price evolutions
- Carbon Trust 2006 study

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5) Costs? (CarbonTrust 2006)

In the present market conditions, we consider a rational target for the base cost of energy to be the cost of CCGT, since this is cheapest form of generation.

- We considered two cost points: 2.5p/kWh and 5.0p/kWh. The former reflects the cost of CCGT over the past few years in the UK, and the second is a view of a future cost given a certain sustained increase in fossil fuel prices and the cost of associated carbon emissions, in order to gauge the future progress of wave and tidal stream energy against other, more mature renewables (particularly wind power). We also counted the value of UK Renewable Obligation Certificates (ROCs) and Climate Change Levy Exemption Certificates (LECs). We assumed the overall benefit of these to generators would be 3.5p/kWh. Together with the two electricity cost points, this gave four target cost levels, as shown in Figure 9.

- CCGT = Combine Cycle Gas Turbine

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6) Environmental effects

- Hard to assess...
- Nobody has been able to monitor it
- Lessons from windenergy
  - Local disadvantage: visual hindrance, birds
  - Global advantage: reduction of CO₂
  - How to combine
6) Environmental effects: wind

- Similar effect for tidal and wave!
- Change of physical habitat
- Introduction of hard substrate (concrete, steel)
  - Colonisation of these substrates goes extremely fast!
    - Francis Kerckhof (BMM): Monitoring study C-Power foundation, report will be distributed soon.
    - Olivia Langhammer (Sweden): Foundations of wave energy converters: opening hiding places Crustaceae
    - Eric Stienen: birds are using windmills to rest, extension of feeding territory
- Combinations with aquaculture: breeding place for fish (erosion protection) and mussels
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Conclusion

• Wave and tidal energy: technology and market in full development (15-20 years behind windenergy)
  – Huge challenges: structural, efficiency, economics
• Belgium: moderate resource, but very appropriate as testsite: opportunity for Belgin industry
• Best things come out of the sea!