A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory

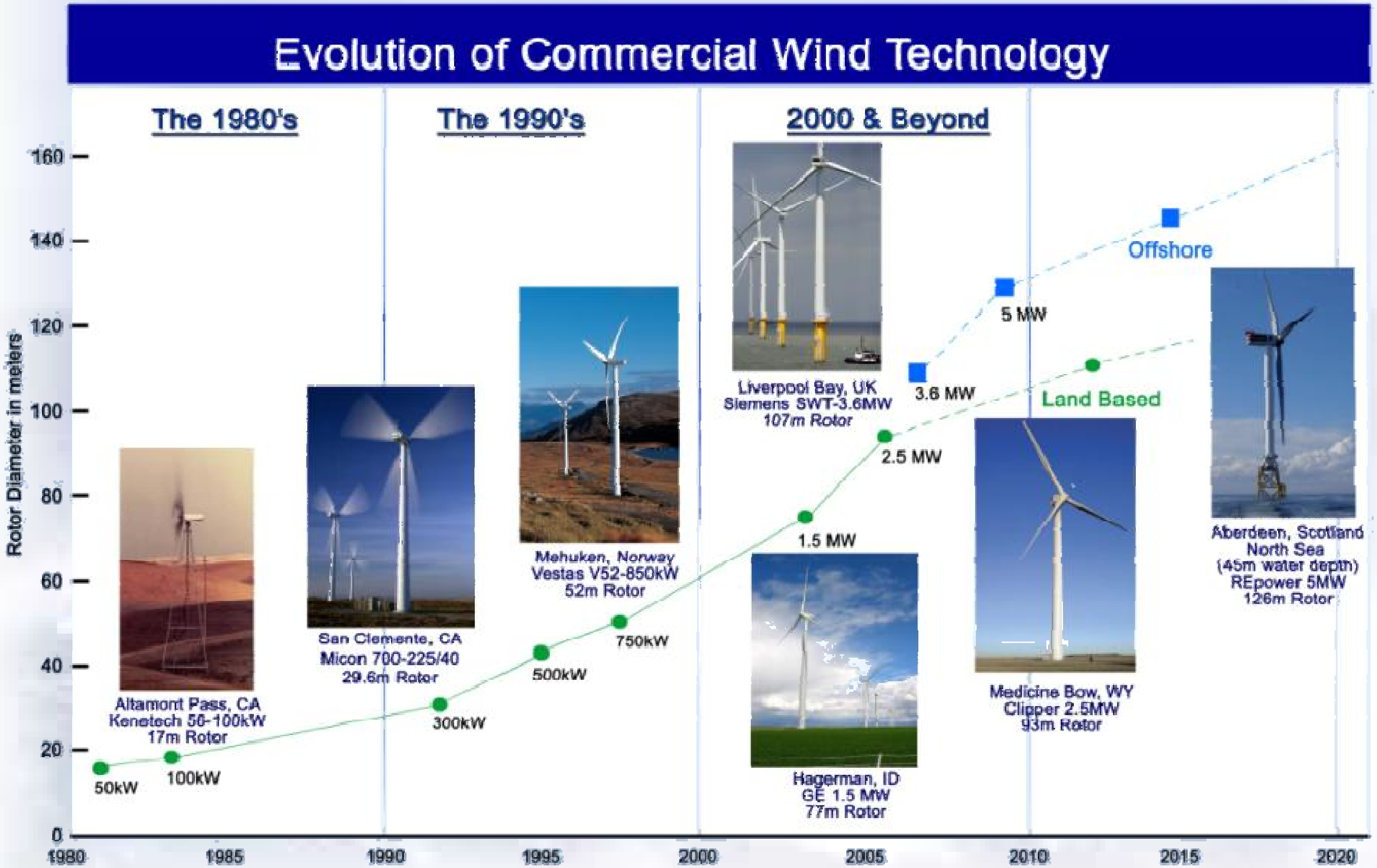
Innovation for Our Energy Future

Learning from Wind Energy's Experience

Global Marine Renewable Energy Conference
Washington, DC
April 14-15, 2009

By
Robert Thresher, PhD, PE
NREL Research Fellow
National Wind Technology Center

1. Build Prototypes at a Practical Size and Make Them Work, Then Scale for Economy



2. Perform Rigorous Testing:

Measure all the Relevant Inputs and Outputs (Wave Tanks Tests, Subscale Prototype Tests, and then Full Scale)

3. Perform Environmental Studies at Early Test and Demonstration Sites

October 11-12, 2007
Hatfield Marine Science Center
Newport, Oregon

Contact: George Boehlert (george.boehlert@oregonstate.edu)

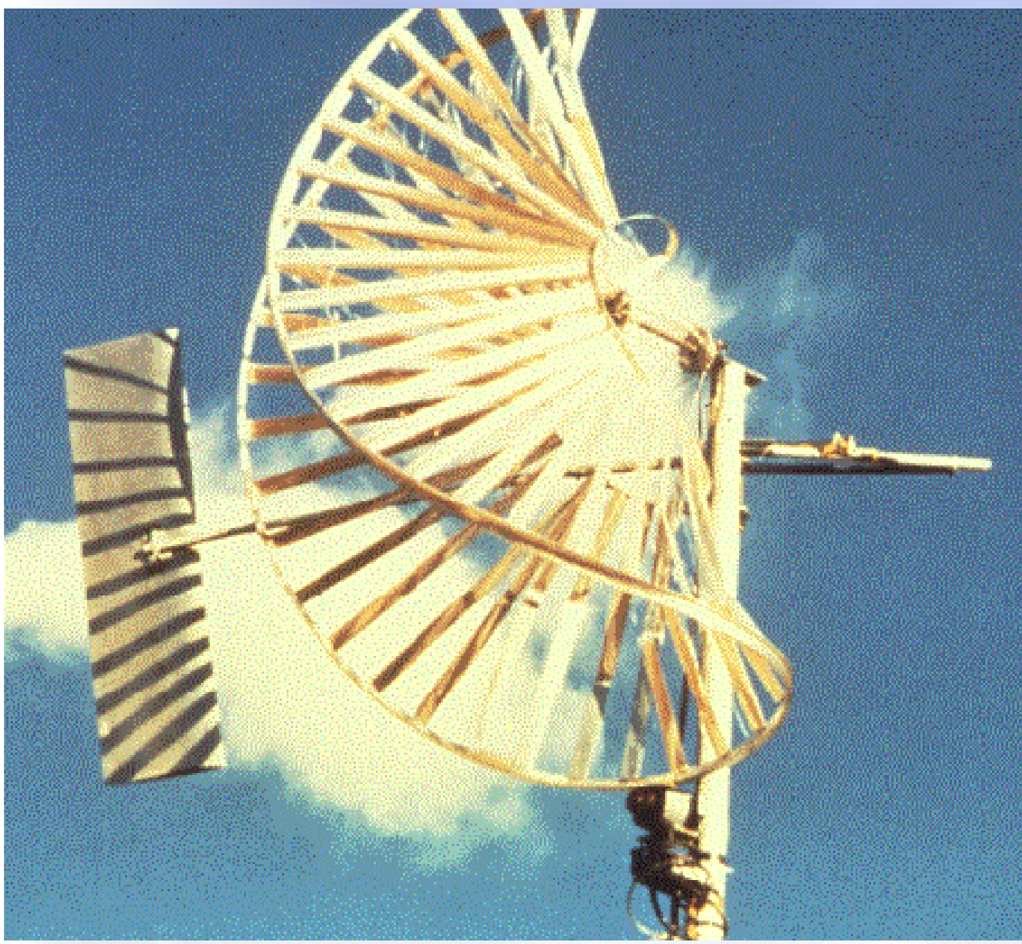
Ecological Effects of Wave Energy Development in the Pacific Northwest: A Scientific Workshop

PURPOSE OF WORKSHOP

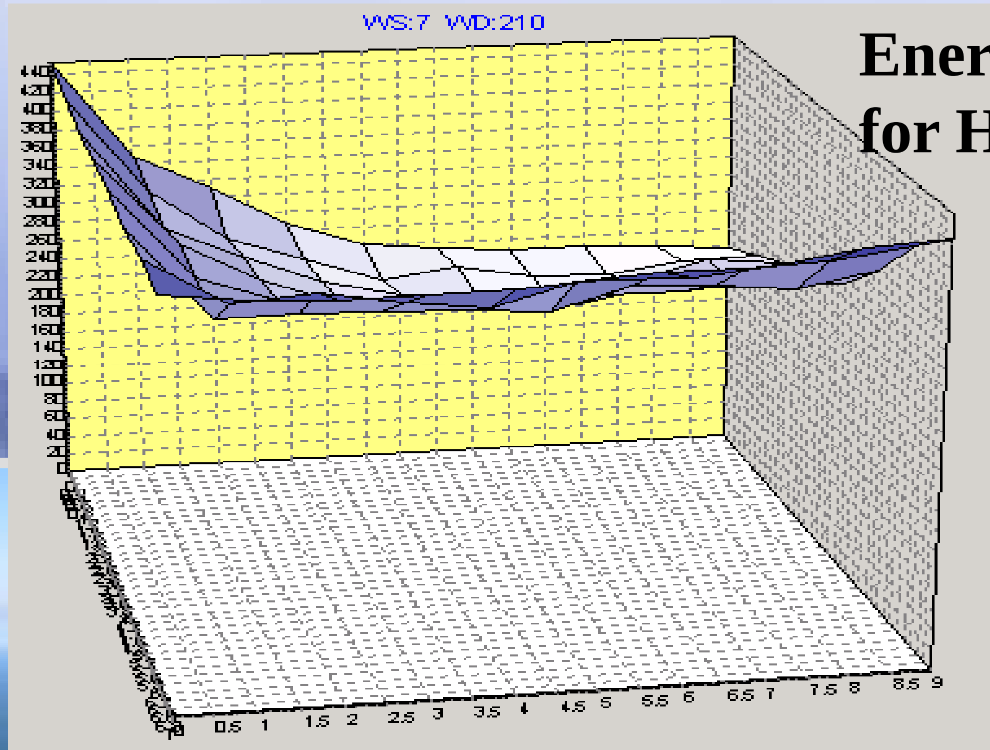
The conversion of ocean waves into electricity has the potential to provide clean, reliable and low-cost electricity to the economy while posing minimal impacts on the environment. However, in order for wave energy to develop and fulfill these assumptions, we must reduce the uncertainties about the technology's effects on the marine environment. We must assess the potential environmental impacts of wave energy, determine what is known and unknown, and identify a rigorous set of scientific studies to address concerns. This information is needed to support the permitting process as well as to make responsible decisions to site facilities and to minimize environmental impacts.

http://ir.library.oregonstate.edu/dspace/handle/1957/9426

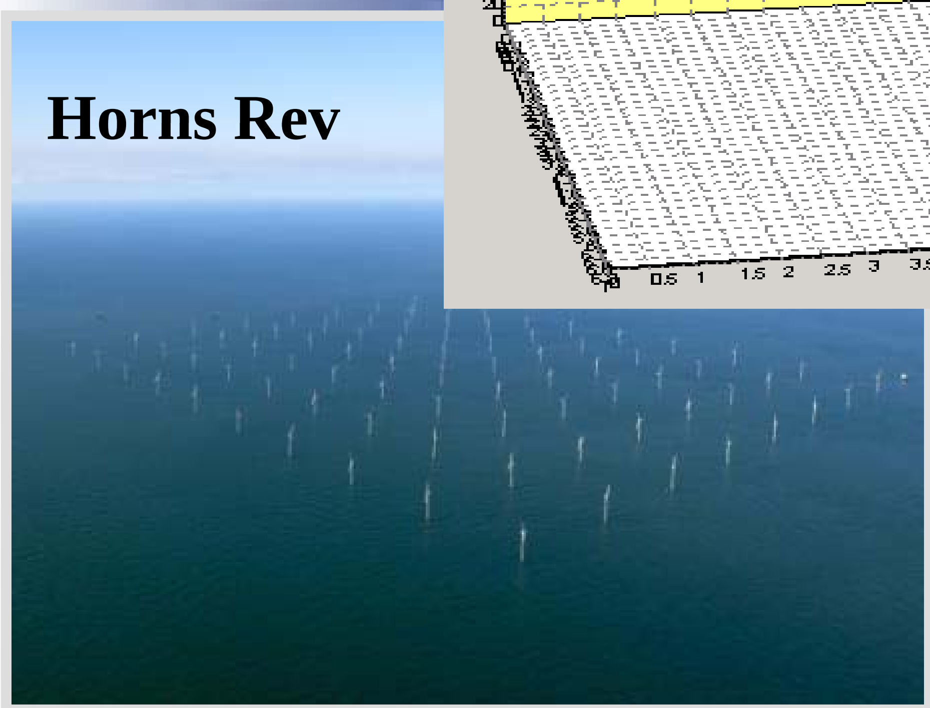
4. Expect Prototypes Machines to Fail and Learn from the Failures: Test, Measure, Analyze, Model, and Redesign



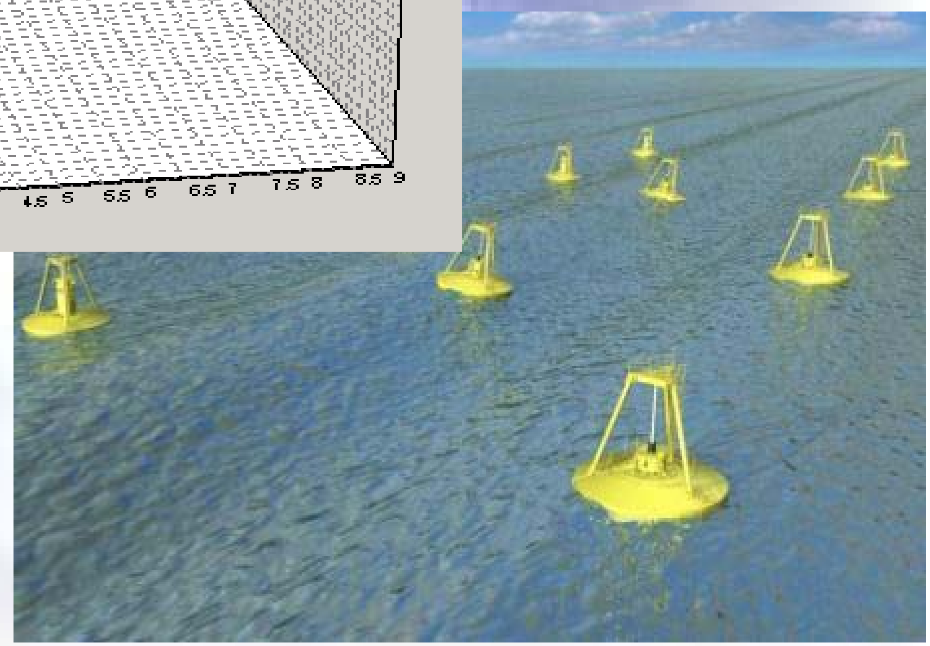
5. Develop and Verify Energy Loss Models for Arrays and Complex Flow Situations



Energy Losses for Horns Rev



Horns Rev



6. Develop Optimal Theories and Models to Bound Performance and Guide Designs

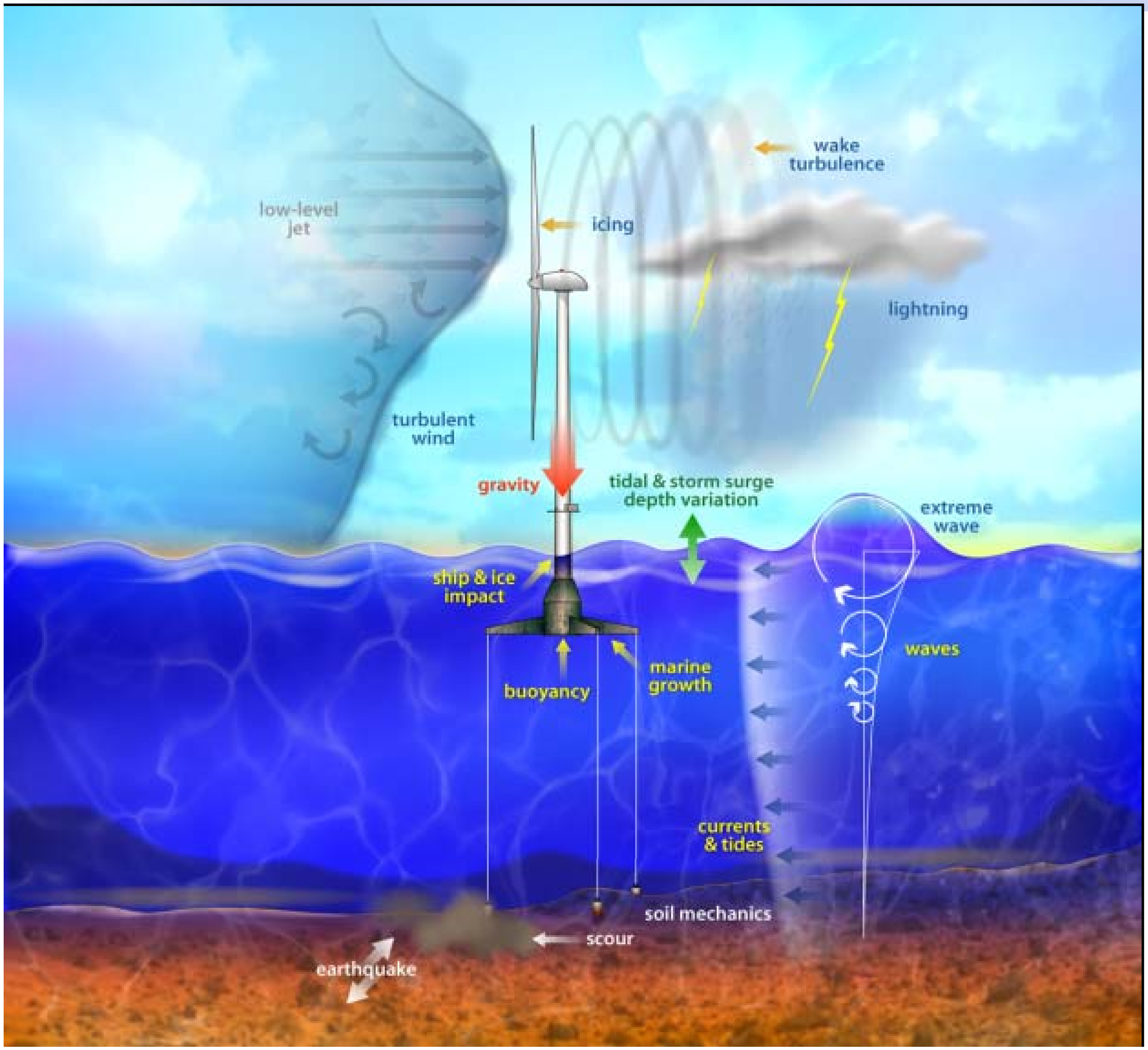
- Rotors:
  - "Betz" limit $P_{max} = \frac{16}{27}\left(\frac{1}{2}\rho A V^3\right)$
  - Losses:
    - Drag
    - Wake rotation
    - Power train inefficiencies
    - Generator rating
- Heaving buoys:
  - "Evans-Newman" limit $P_{max} = \left(\frac{\lambda}{2\pi}\right)\left(E c_g\right)$
  - Losses:
    - Sensitivity to waves
    - Separated flow
    - Power train inefficiencies
    - Generator rating
  - Gains:
    - Oscillate buoy horizontally (in addition to heave)
    - Spread buoy across wave
    - Spread buoy along wave (e.g., Pelamis)

$$\textit{Wave Energy Density} \qquad E = \frac{1}{2}\rho g\left(\frac{H}{2}\right)^2$$

$$\textit{Group Velocity (Deep)} \qquad c_g = \frac{\lambda}{2T}$$

$$\textit{Wavelength (Deep)} \qquad \lambda = \frac{gT^2}{2\pi}$$

7. Model the Important Physics and Validate the Models with Test Data: If you do not Calculate the Dynamic Loads Correctly the Device Will Fail

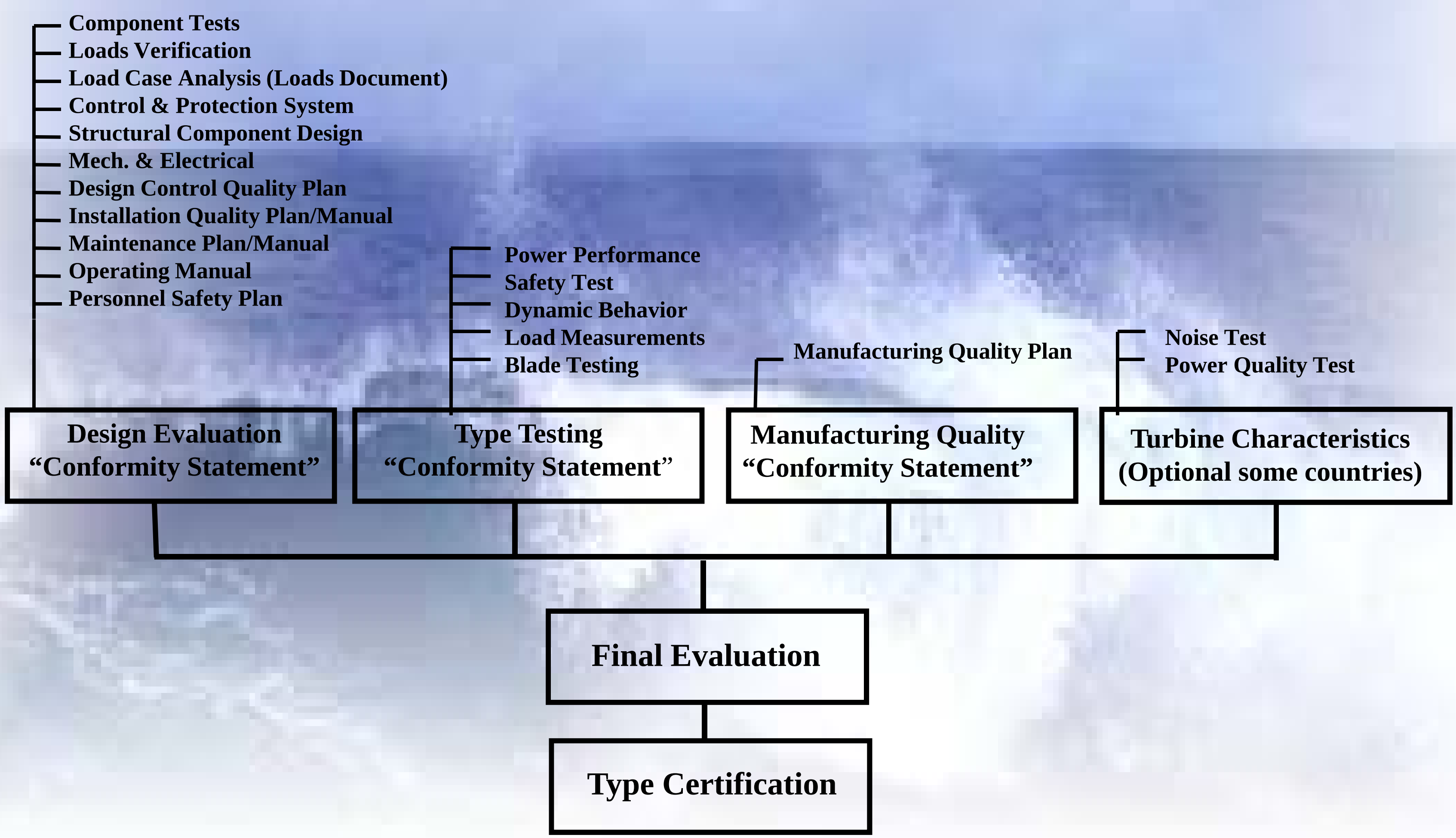


- **Turbulence**
- **Irregular waves**
- Gravity / inertia
- Aerodynamics:
  - induction
  - skewed wake
  - dynamic stall
- Hydrodynamics:
  - scattering
  - radiation
  - hydrostatics
- Elasticity
- Mooring dynamics
- Control system
- Fully coupled

8. Develop Comprehensive Standards for Ocean Energy Systems at an Early Stage

(Standards are critical for financing and commercialization)

Example: IEC 61400 - Standards For Wind Turbines



9. Develop and Verify Economics Models

Carbon Trust Report 2006: Future Marine Energy

Results of the Marine Energy Challenge:

Cost competitiveness and growth of wave and tidal stream energy

http://www.carbontrust.co.uk/publications

Figure 6 Capital costs of first prototypes and first production models

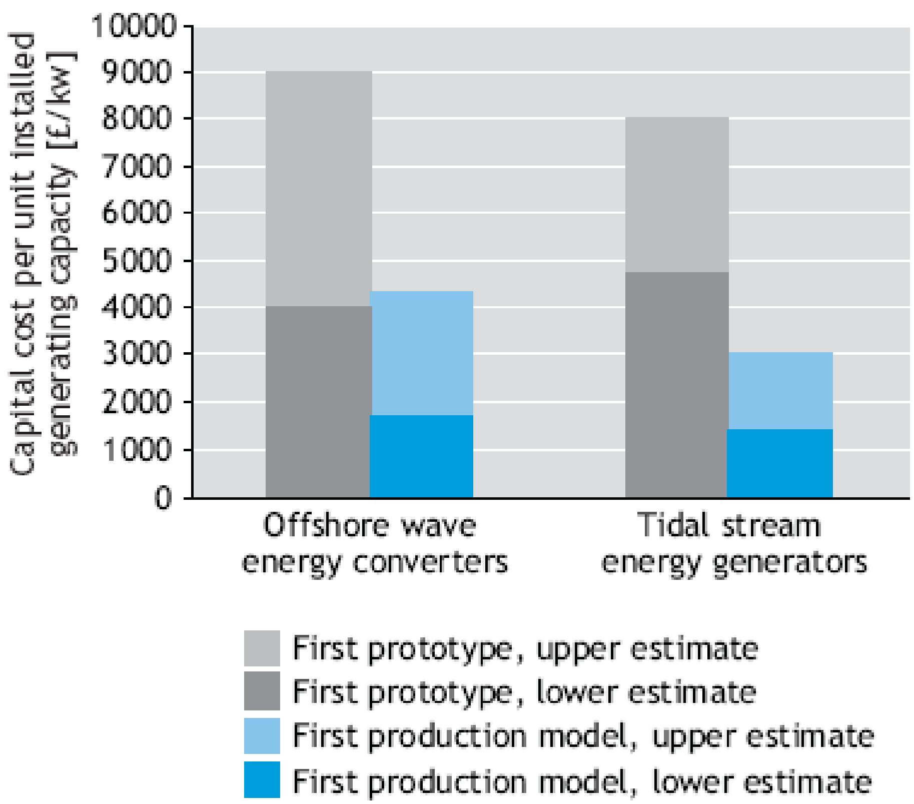
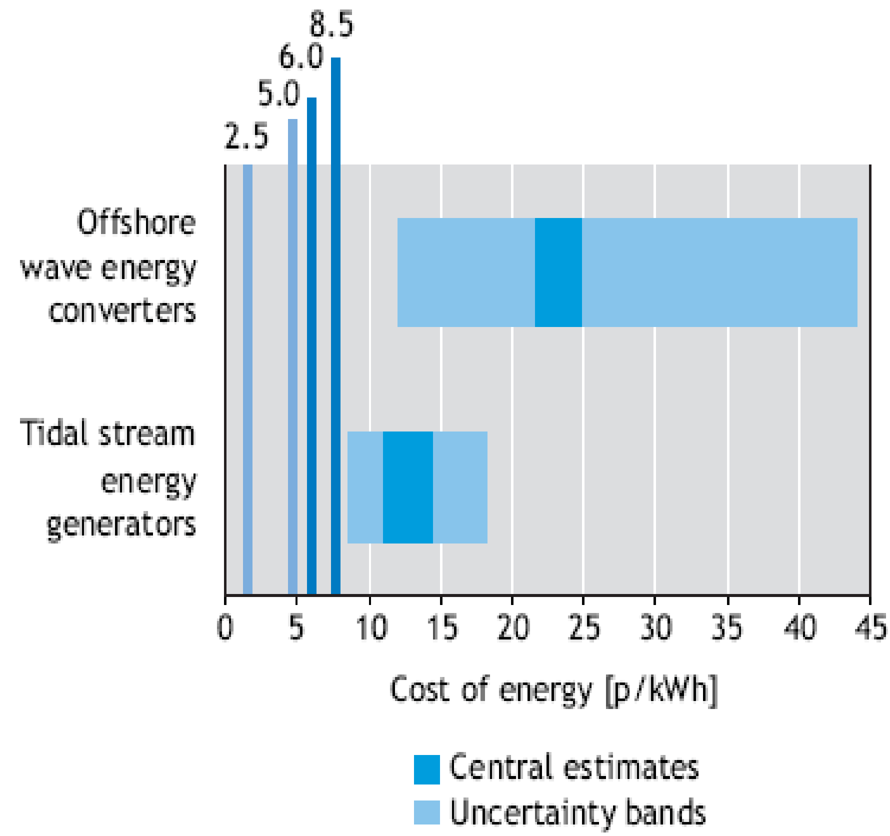
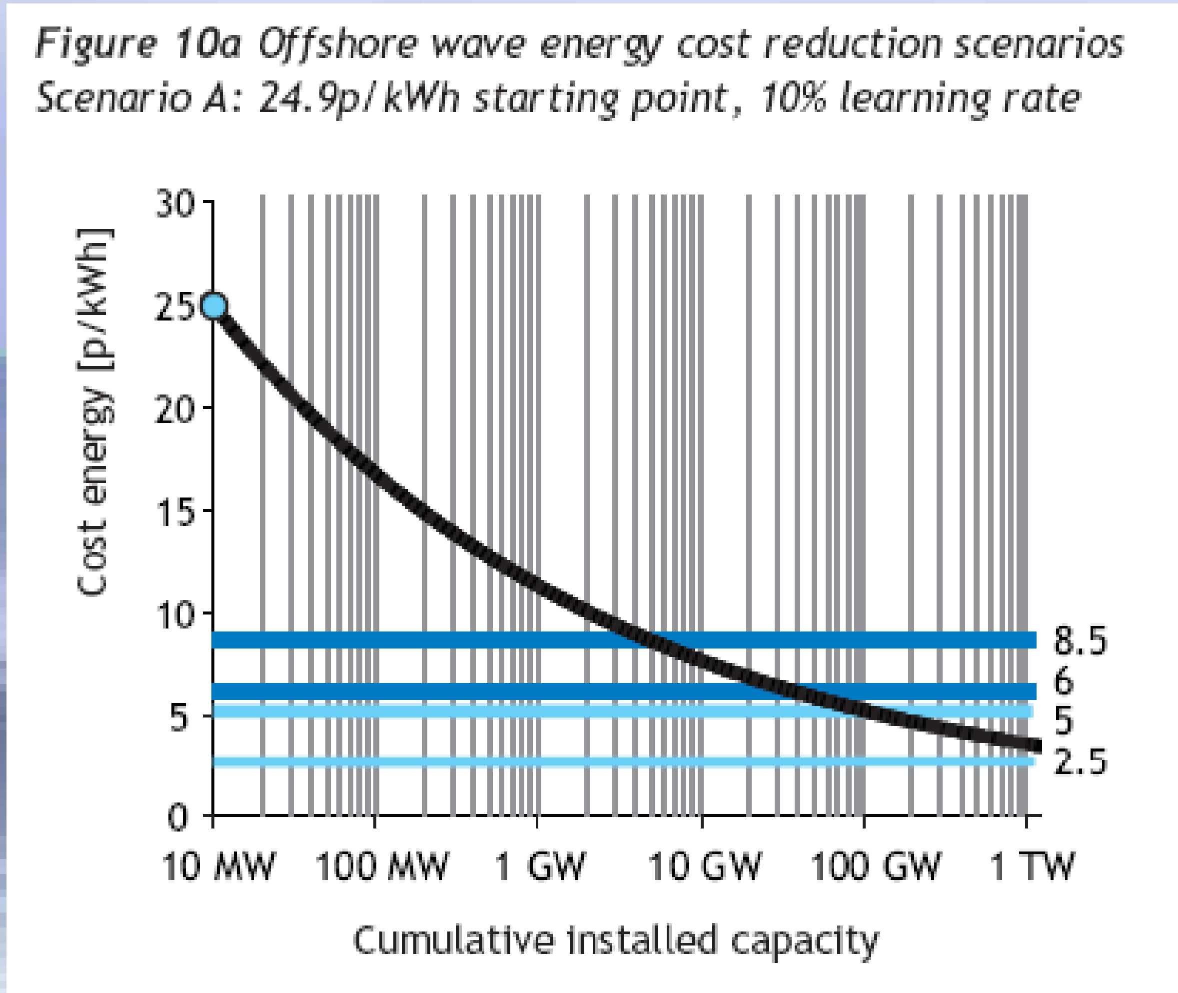


Figure 7 Costs of energy today



10. Focus On Technology Innovation, Scale, and Reliability to Reduce Cost for Prototype Evolution

(Learning Curves Provide Minimal Benefit in Early Generations)



Carbon Trust Scenario Learning Curve

http://www.carbontrust.co.uk/publications

Thresher’s of Lessons from Wind’s Experience

1. Build Prototypes at a Practical Size and Make Them Work, Then Scale for Economy
2. Perform Rigors Testing
3. Perform Environmental Studies at Early Test and Demonstration Sites
4. Expect Prototypes Machines to Fail and Learn from the Failures
5. Develop and Verify Energy Loss Models for Arrays and Complex Flow Situations
6. Develop Optimal Theories and Models to Bound Performance and Guide Designs
7. Model the Important Physics and Validate the Models with Test Data
8. Develop Comprehensive Standards for Ocean Energy Systems at an Early Stage
9. Develop and Verify Economics Models
10. Focus On Technology Innovation, Scale, and Reliability to Reduce Cost