



Applications of Electroactive Polymers in Electrical Power Generation Using Ocean Waves

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Ocean Wave Energy

Oceans cover more than 70% of Earth's surface. The ocean can produce two types of energy:

- 1. Thermal energy from the sun's heat, and**
- 2. Mechanical energy from the tides and waves.**

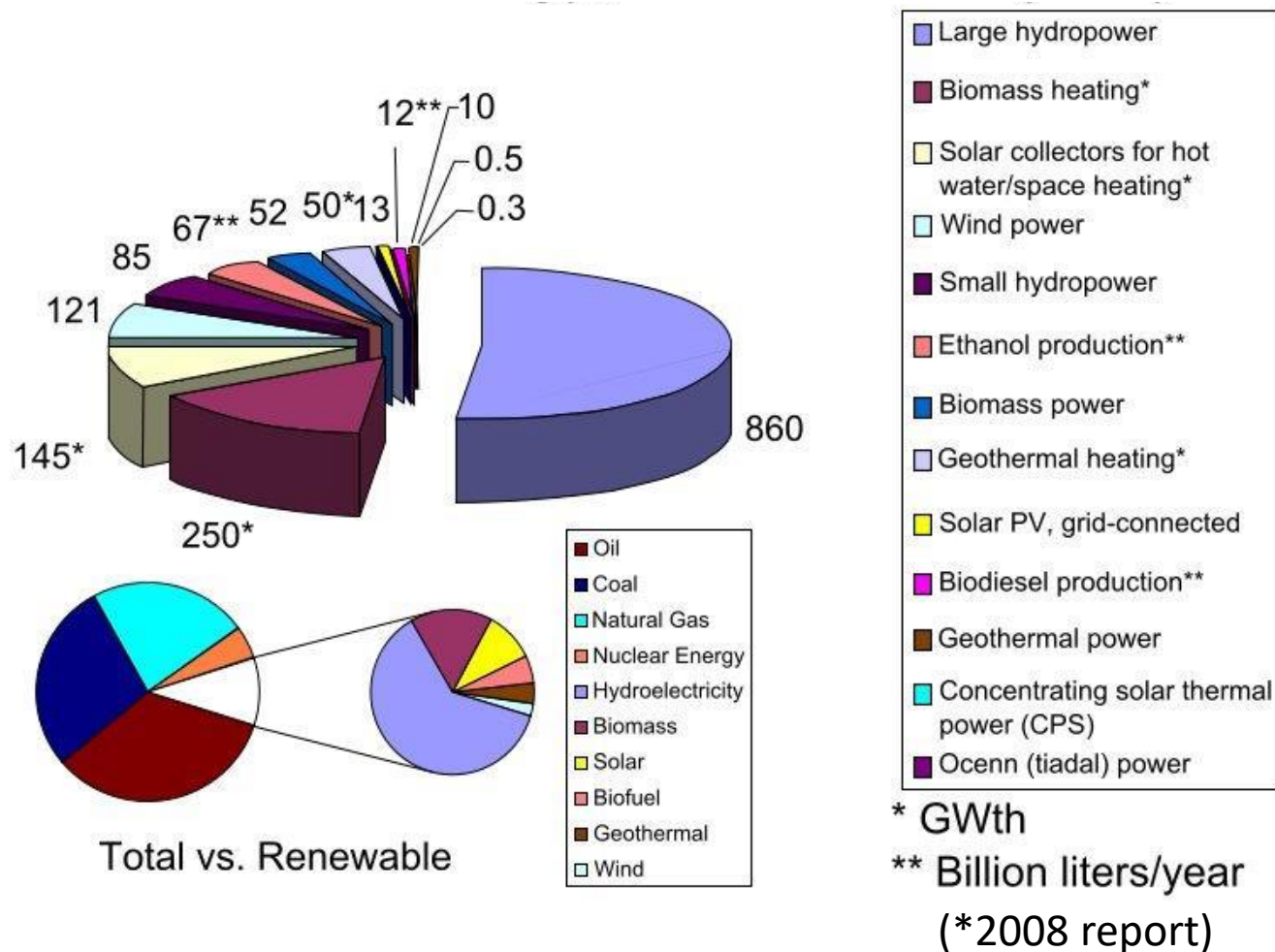
Advantages of Ocean Energy Resources

- 1. Always available and free**
- 2. Environmentally friendly**
- 3. Renewable and sustainable**



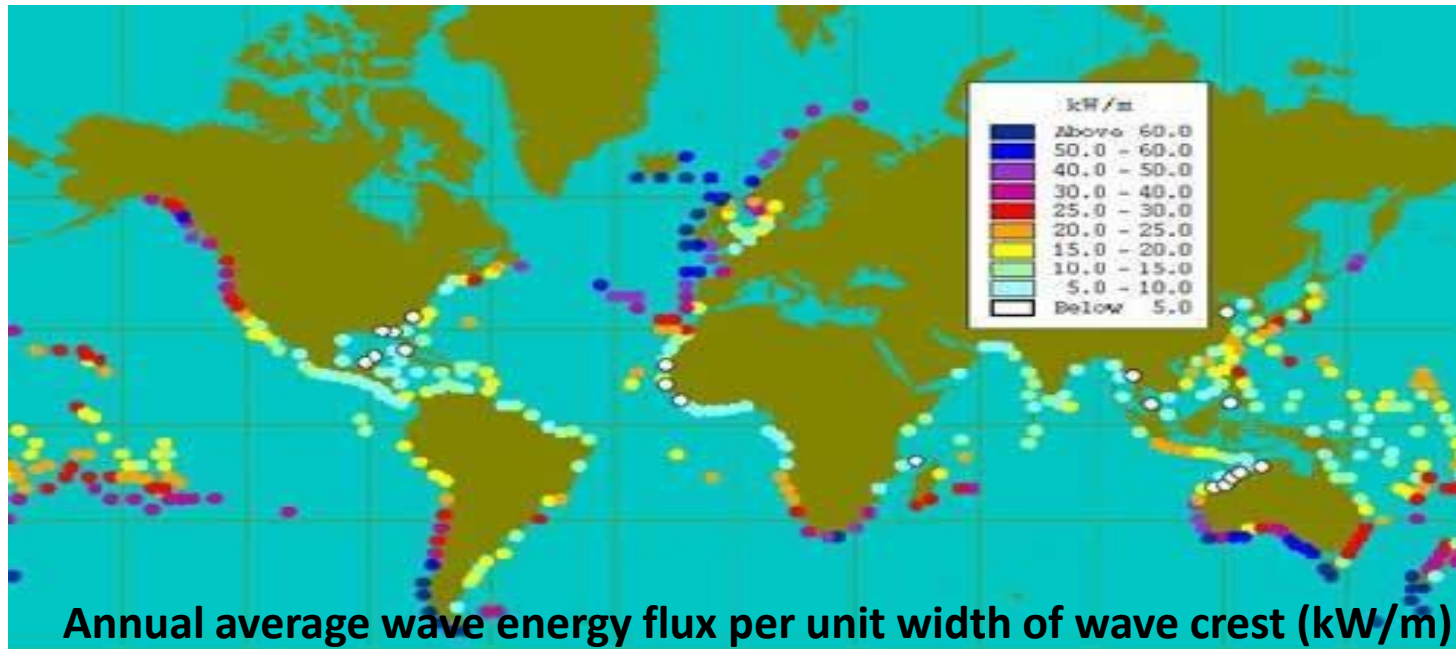


Renewable Energy (GW)*





Global Wave Power Distribution



Annual average wave energy flux per unit width of wave crest (kW/m)

Estimated Wave Resource by Region in US*

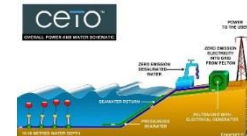
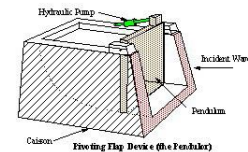
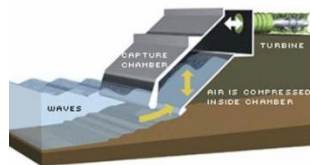
US Wave Resource Region (>10kW/m)	TW Hours/yr.
New England and Mid-Atlantic States	100
Northern California, Oregon and Washington	440
Alaska (not including the Berling Sea)	1,250
Hawaii and Midway Island	330

http://www.oceanor.no/projects/wave_energy/ (Hagerman 2004).



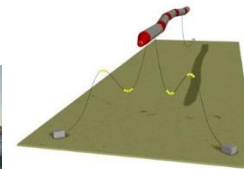
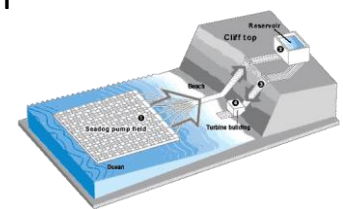
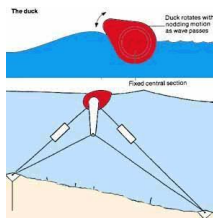
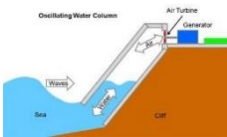
Wave and Tidal Energy

Wave and tidal energy harvesting has been around for a few decades. But it has only been in recent years that it has started to become more realistic due to advance in research and technology. Some speculate that wave and tidal energy can supply at least 10 percent of the world's energy consumption. How much power can be harvested is determined mainly on the wave activity.



Examples of Wave Energy Devices

They have been invented to harvest energy from waves and sea currents. They can be divided into three main categories: on shore, off shore, and near shore. Each type has its own benefits and drawbacks covering issues such as efficiency, cost per Watt, environmental and social impact.





From Ocean Wave Energy To Electrical Power

Basic Methods for Converting Wave Energy to Electricity

Methods/Devices	Motions Used	Mechanical Principle	Converting Mechanism
Float/Buoyant Systems	Heave or Pitch	Piston Movement	Conventional Generator
Oscillating Water Columns	Wave Surge and/or Sway	Turbine Movement	Conventional Generator
Tapered Channel/tapchan Systems	Elevated Reservoir	Guided Water Flow	Standard Hydropower Technologies



<https://liveknowledgeworld.files.wordpress.com>

Four Steps



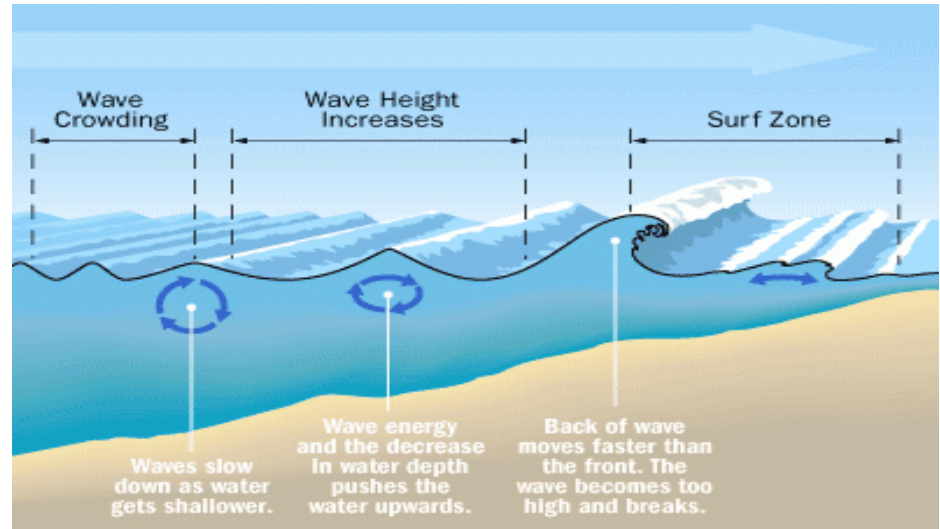
<http://bluebird-electric.net>



Ocean Waves: Characteristics and Motion

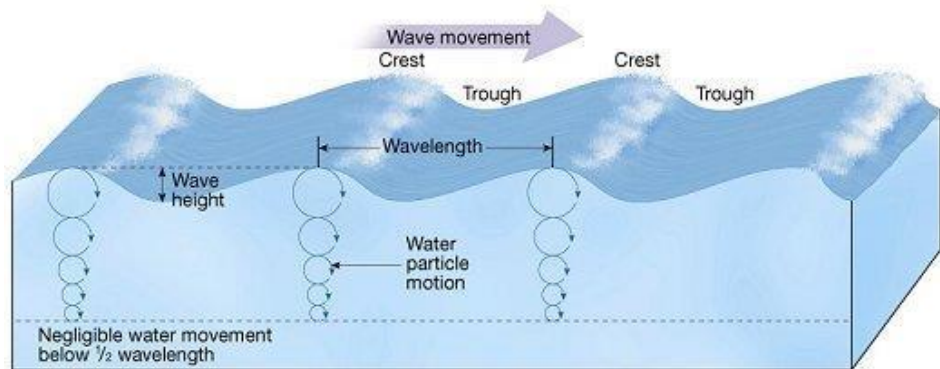
Waves in different Zones

- Stable Waving
- Wave Crowding (approaching shallower)
- Wave height increasing
- Surfing



Characteristics in Stable Waving Zone

- Waving height
 - waving length
 - Crest and trough
 - Wave movement
- All have 'regularity'.

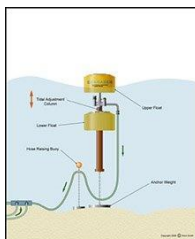


(Source: Pearson Prentice Hall Inc.)

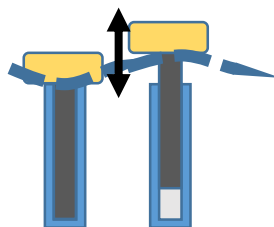
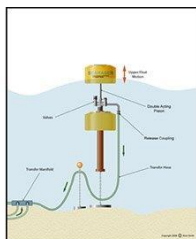


Converting Wave Motions to A Piston Motion

Upper float lowered
in trough of wave

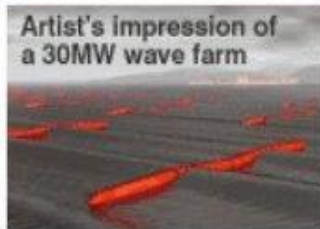


Upper float elevated
on crest of wave



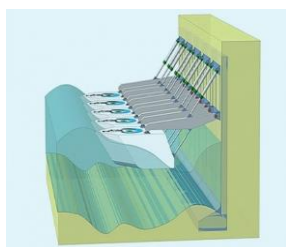
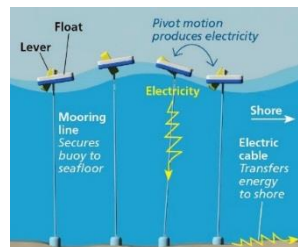
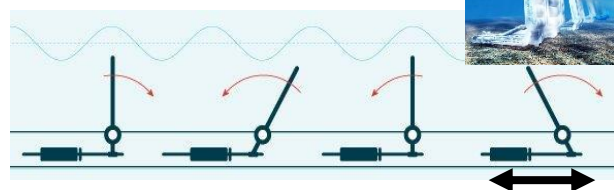
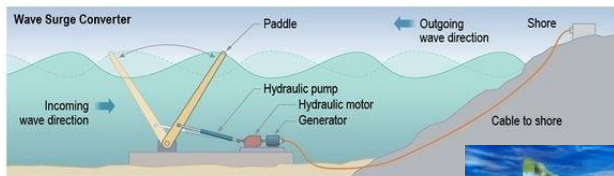
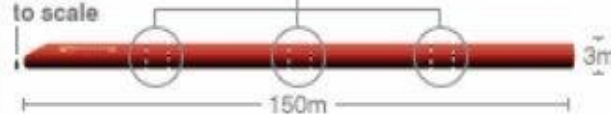
PELAMIS WAVE POWER GENERATOR

Artist's impression of
a 30MW wave farm



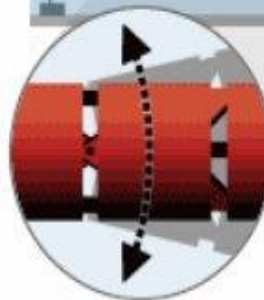
Each Pelamis has three power conversion
modules that together generate 750kW.

Person
to scale

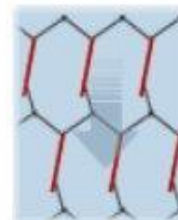


Wave
direction

Waves move across the sea and cause the Pelamis
to rise and fall in a snake-like motion.



Sections move
against each other
on hinges resisted
by hydraulic rams,
driving generators
to produce electricity.

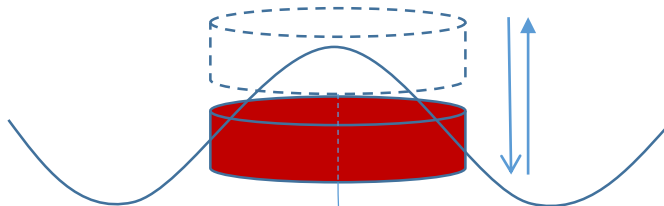


A 'wavefarm'
would have
40 machines
over a square
km, generating
power for
20,000 homes.

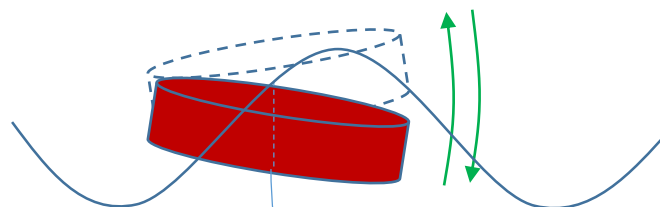
Ocean Power Delivery Ltd.

Wave Motions and Buoyant Motions When Moored and Unmoored Buoys Are Used

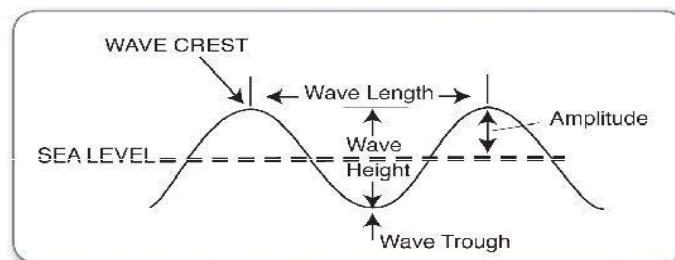
Heave Motion



Pitch Motion



Wave Characteristics



Seabed (Moored)



Piezoelectric Materials Based Technologies for Converting Ocean Wave Energy to Electricity

Advantages of Using Piezoelectric Materials for Energy Conversion

- Simplicity (from four steps to one or two steps)
- Low cost (Less system building and maintenance requirements)

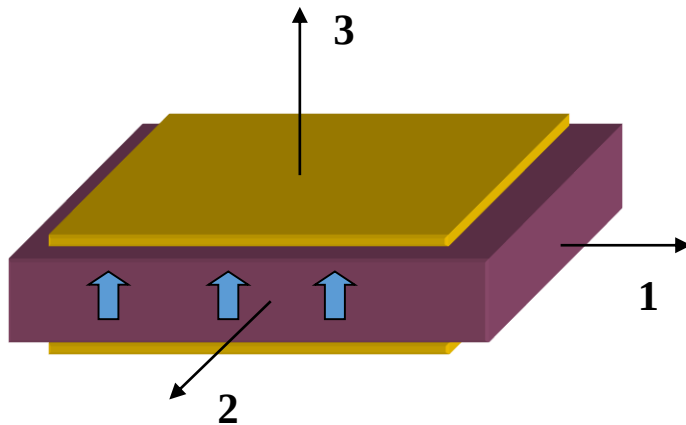
Piezoelectricity of Materials

Equations	Units
$d = (dD/dX)_E = (dS/dE)_X$	(C/N or m/V)
$e = (dD/dS)_E = -(dX/dE)_S$	(C/m or N/Vm)
$g = (dE/dX)_D = (dS/dD)_X$	(Vm/N or m ² /C)
$h = (dE/dS)_D = -(dX/dD)_S$	(V/m or N/C)

Coupling factor

$$k_{31} = \frac{d_{31}}{\sqrt{s_{11}^E \epsilon_3^T}}$$

Efficiency of energy conversion



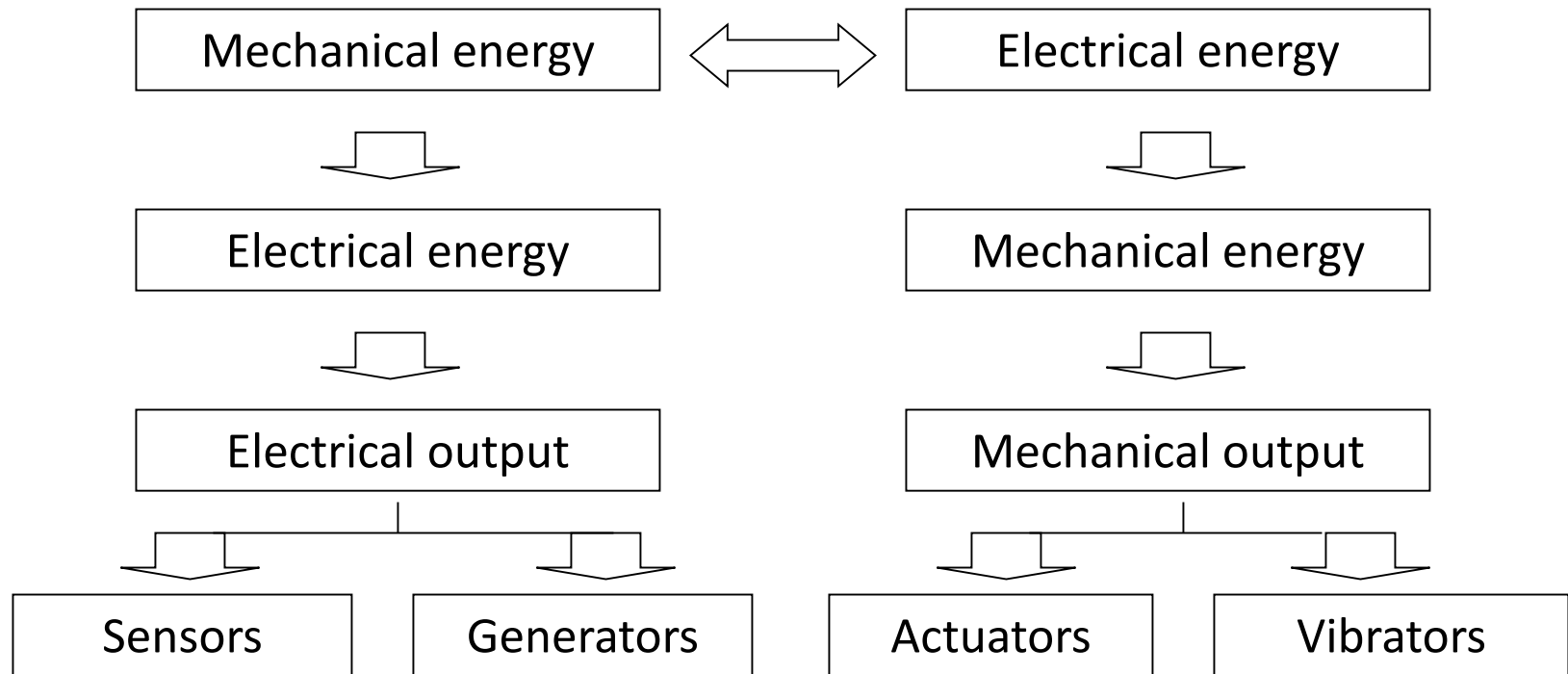
d₃₁: the polarization (or released charge flow) is in 3 direction and the applied force is in 1 direction.

d₃₃: both the polarization (or released charge flow) and the applied force in 3 direction.



Electromechanical Functionality of Piezoelectric Materials

Conversion between the mechanical energy and the electrical energy



$$\text{Efficiency} = \frac{\text{converted electric energy}}{\text{input mechanical energy}} \quad \text{Or} \quad \text{Efficiency} = \frac{\text{converted mechanical energy}}{\text{input electric energy}}$$

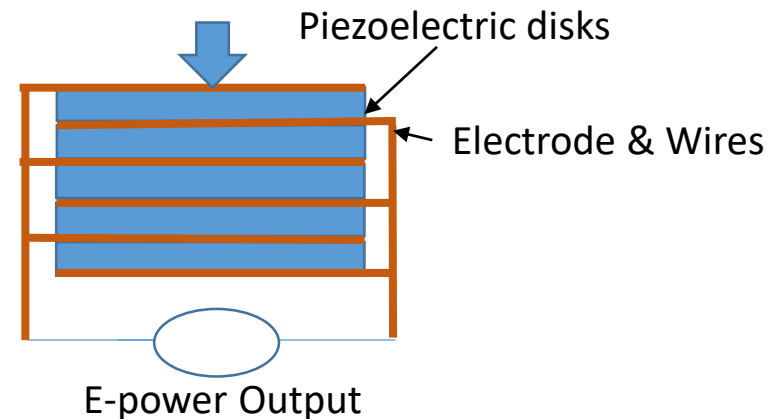
Two Representative Functional Elements in Converting Devices Using Piezoelectric Materials

Piezoelectric ceramics PZT based:

Functional Elements:

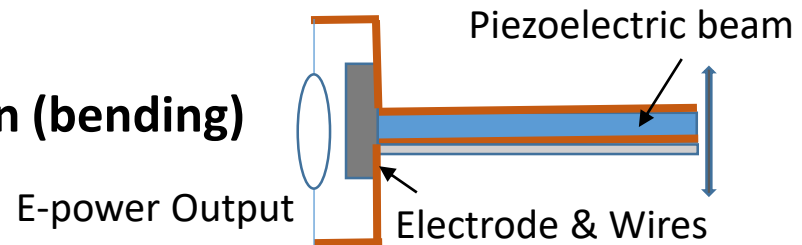
Stack piezoelectric disks

Piezoelectricity utilized: d_{33}

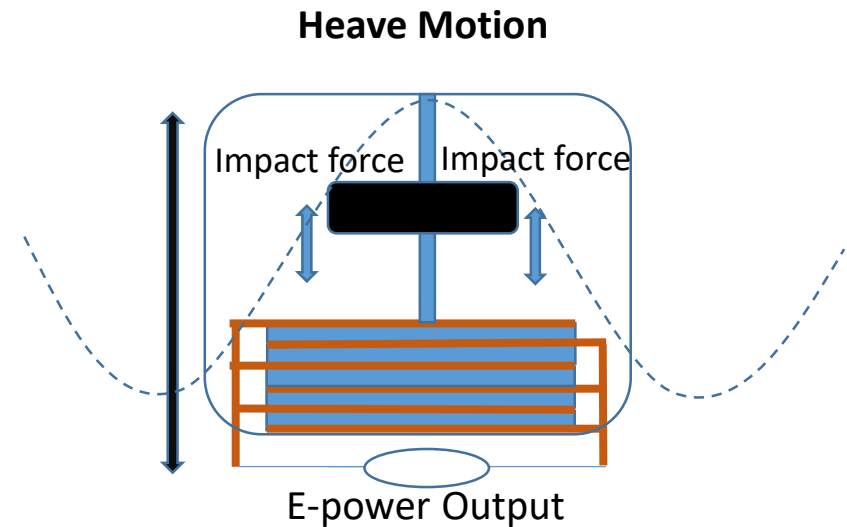
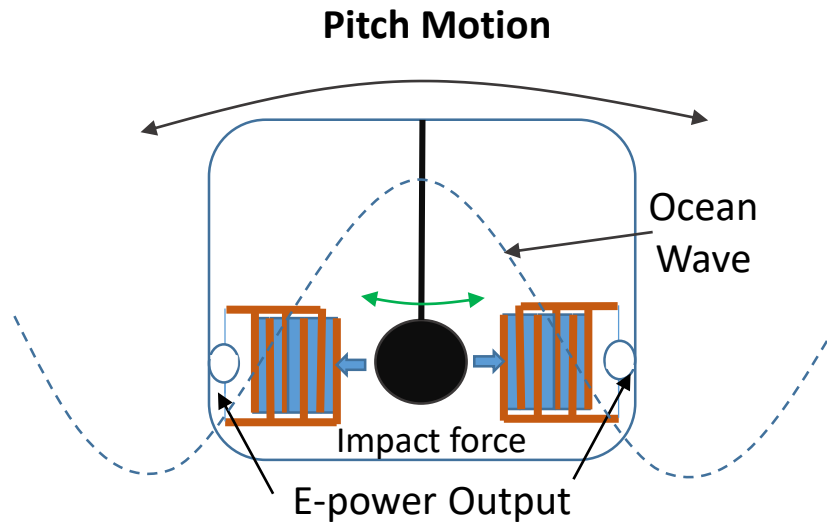


Piezoelectric cantilevers:

Piezoelectric utilized: oscillation (bending)



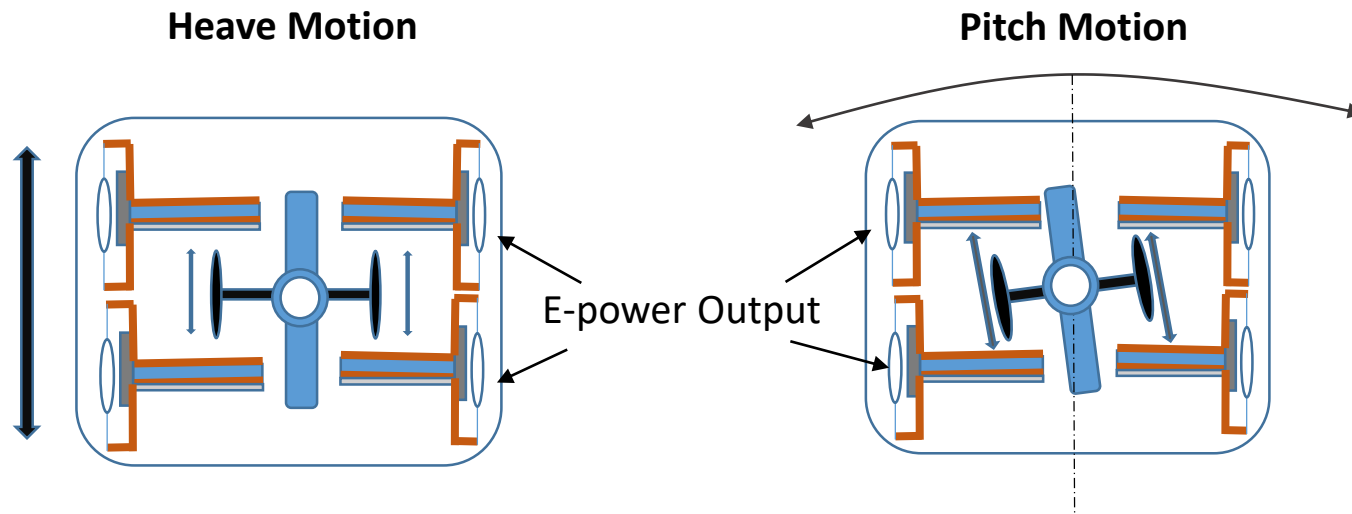
Some Representative Designs and Devices Using Piezoelectric Elements (stacked disk and d_{33})



The device can be deployed as a single unit harvester or an array harvester having several units connected in an optimally designed form to increase utilization efficiency of ocean waves.

Some Representative Designs and Devices Using Piezoelectric Elements (oscillation/bending)

Balance-like physical pendulum harvester



The device can also be deployed as a single unit harvester or an array harvester having several units connected in an optimally designed form to increase utilization efficiency of ocean waves.



Advantages of Using Piezoelectric Polymers for Energy Conversion

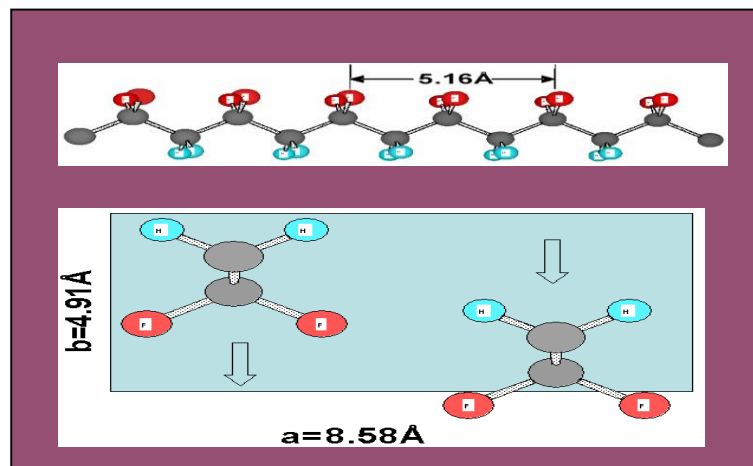
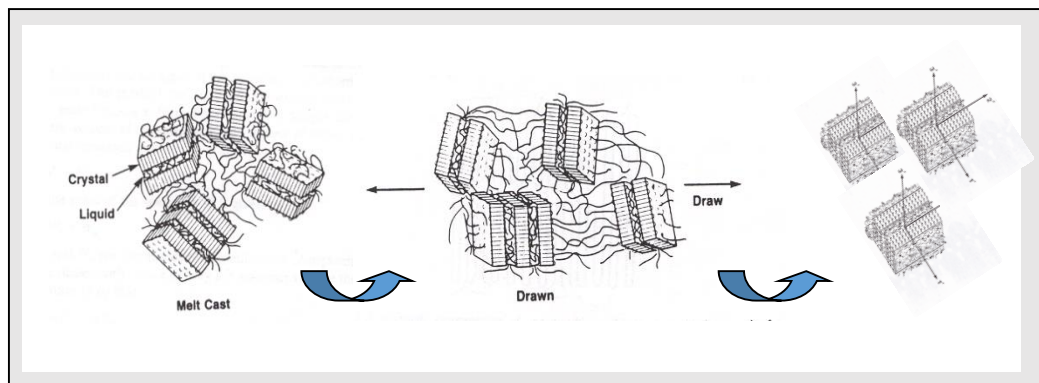
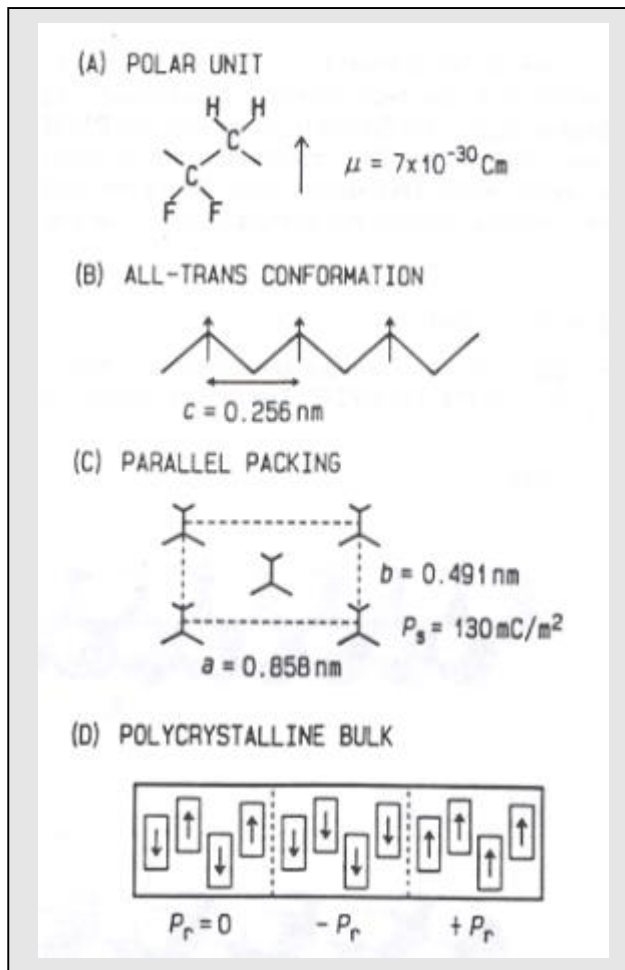
- Simplicity (from four steps to one or two steps)
- Low cost (less system building and maintenance requirements)

Plus

- More design options since both d_{33} and d_{31} can be utilized
- Light weight and good processing properties
- Electrical and mechanical toughness

A Piezoelectric Polymer: PVDF (or PVF₂)

Poly(vinylidene fluoride)

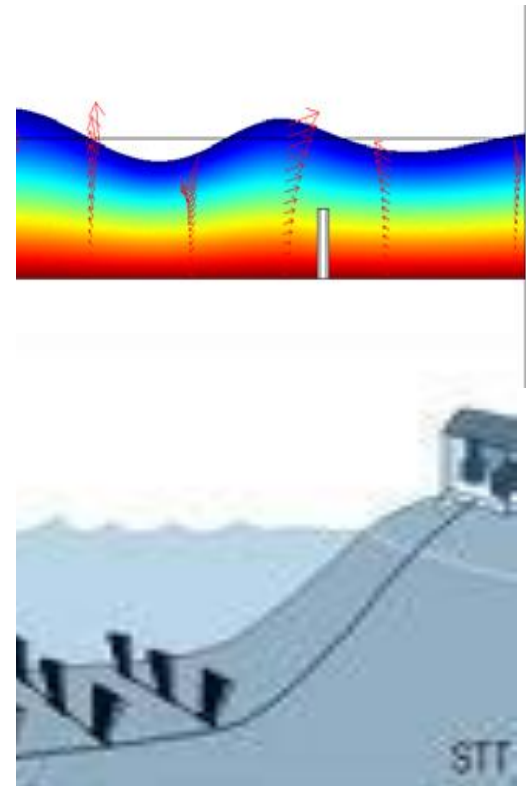
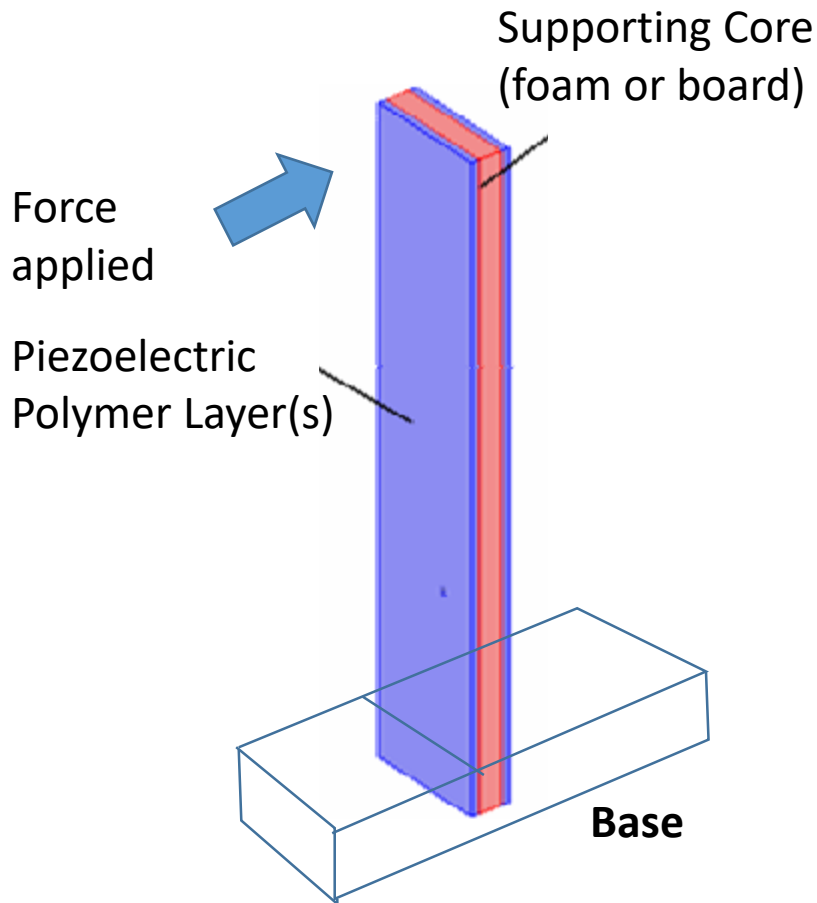


“Applications of Ferroelectric Polymers” by M. E. Lines, A. M. Glass, and T. T. Wang, (Springer, 1992)

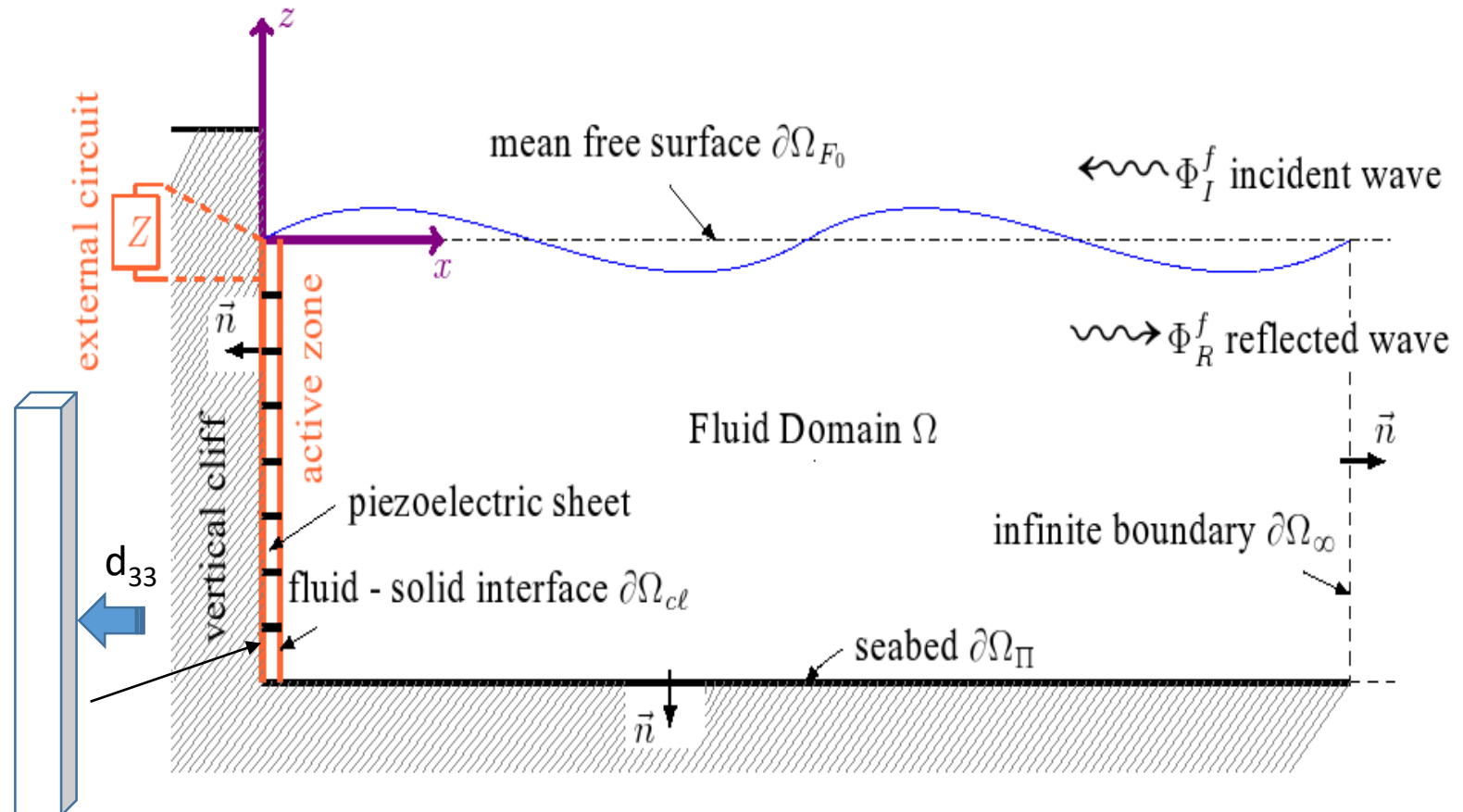
“Ferroelectric Properties of Vinylidene Fluoride Copolymers” T. Furukawa, Phase Transitions V.18, 143-211 (1989).



A Piezoelectric PVDF Film Based Ocean Energy Converter Using Complex Piezoelectric property

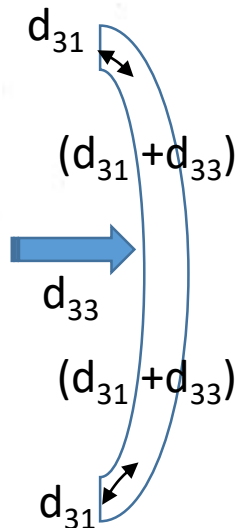
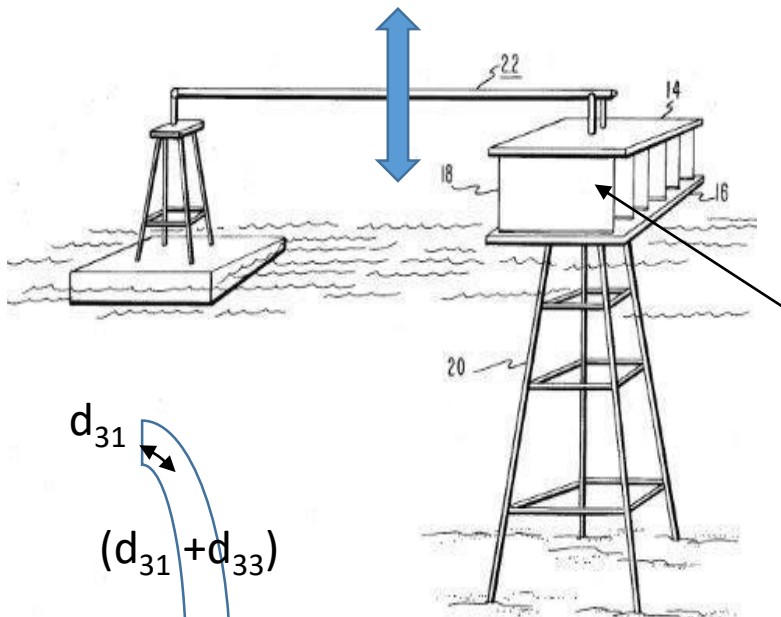


A Piezoelectric PVDF Film Based Ocean Energy Converter Using d_{33}

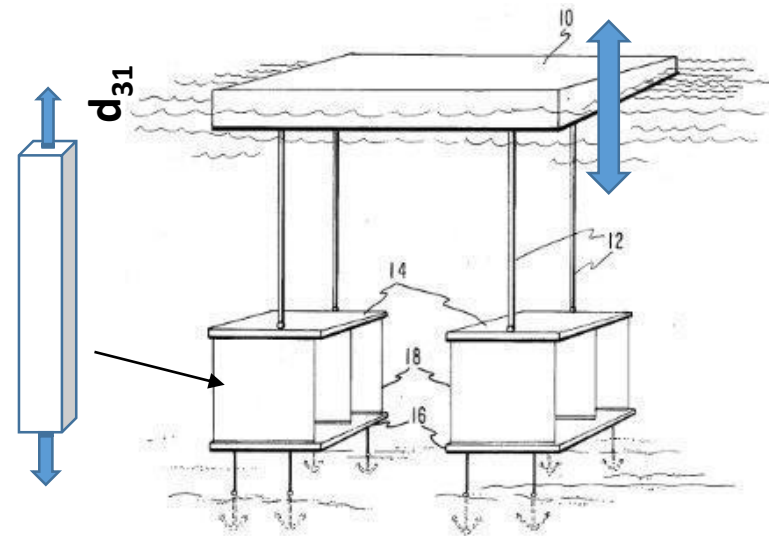




Piezoelectric PVDF Film Based Ocean Energy Converters Using d_{31} and Complex Piezoelectric Property



When the films are pushed by water stream, the complex piezoelectric properties are utilized.



Ocean wave energy conversion using piezoelectric material members (US Patent 4685296 A)



Challenges

Irregular Characteristic in the Following Ocean Wave Properties:

Low frequency

Varying frequency

Not moving in a single direction

Varying force

Varying wavelength

Varying amplitude

Conversion Efficiency

Multistep conversions

Conversion efficiency of systems (ocean wave to standard mechanical motion, mechanical motion to electrical output)

Conversion efficiency of piezoelectric materials

Associated Technologies:

Storage materials and devices

Long distance transmission

Regulated distribution



Concluding Remarks

- Ocean Mechanical Energy is a very promising renewable resource for electrical power generation.**
- Piezoelectric materials provide a technical route for potential simple technology with improved efficiency**
- Piezoelectric polymer demonstrated electromechanical properties that should provide more technical options in designing piezoelectric material-based ocean wave power generation.**
- Applications of piezoelectric polymers in the ocean wave power generation technologies may be adopted to the Disaster Mitigation and Sustainable Engineering Based on Smart Materials and Structures**



Thank you very much!

