Lecture 14

Hydroelectricity, Geothermal, Tidal and Wave Energies
Hydroelectricity

- Well established
- Produces energy reliably for over a century
- $\frac{1}{6}$th of world’s annual electrical output
- Over 90% of electricity from renewables
Hydroelectricity
Hydroelectric Energy

- Video
Main Components & Definitions

- Effective load: the height through which the water falls
- Flow rate: cubic meters per second of water flow
- Turbo-generator: a rotating turbine driven by the water and connected by a common shaft to the rotor of the generator
Fish and Hydroelectric Systems

- Fish ladders – a series of stepped pools with constant downward flow to attract the fish which leap up from pool to pool.
- Round Towers

http://pnwsalmonrun.wordpress.com/salmon-fun-facts/
Hydroelectric Energy Potential

Globally

- Gross theoretical potential 4.6 TW
- Technically feasible potential 1.5 TW
- Economically feasible potential 0.9 TW
- Installed capacity in 1997 0.6 TW
- Production in 1997 0.3 TW
  
  (can get to 80% capacity in some cases)

Source: WEA 2000
## National Hydro Contributions

<table>
<thead>
<tr>
<th>Country</th>
<th>Output, average over 4 years (1999-2002) TWh/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>345</td>
</tr>
<tr>
<td>Brazil</td>
<td>288</td>
</tr>
<tr>
<td>USA</td>
<td>264</td>
</tr>
<tr>
<td>China</td>
<td>231</td>
</tr>
<tr>
<td>Russia</td>
<td>167</td>
</tr>
<tr>
<td>Norway</td>
<td>129</td>
</tr>
<tr>
<td>Japan</td>
<td>91</td>
</tr>
<tr>
<td>India</td>
<td>76</td>
</tr>
<tr>
<td>Sweden</td>
<td>74</td>
</tr>
<tr>
<td>France</td>
<td>74</td>
</tr>
</tbody>
</table>
Calculating Stored Potential Energy

Potential Energy = \( m \cdot g \cdot h \)

where,
- \( m \), mass of stored water (kg)
- \( h \), height (m)
- \( g \), 9.8 m/s\(^2\) acceleration due to gravity
Advantages and Disadvantages

- Does not release CO$_2$
- Does not produce toxic chemical compounds
- Does not produce radioactivity
- Does not cause fires
- Flood control and irrigation
- Very high efficiency (80%)
- Little waste heat
- Low cost per KWh
- Can adjust KWh output to peak loads
- Recreation dollars

- Displacement of people
- Dams failures have killed many thousands
- Fish are endangered species;
- Sediment buildup
- Dam failure
- Changes watershed characteristics
- Alters hydrological cycle
Ideal Power Station

1) Constant availability
2) A reserve energy store to compensate for variations in input
3) No correlation in input variations between power stations
4) Rapid response to changing demand
5) An input which matches annual variation in demand
6) No sudden and/or unpredictable changes in input
7) A location which does not require long transmission lines
Pumped Storage

- Hydroelectric systems respond quickly to sudden surge in demand
- The surplus power from coal-fired plants could be used to increase the stored energy by pumping water up to the reservoir.
- Designed generators can run “backwards” as an electric motor, therefore perform the reverse process.
- Very efficient, nearly 80 percent can be retrieved.
- Pumped storage of 80GW out of the 420GW total hydro capacity in the thirty countries.
Economics

- Expected lifetime of the machinery is 20-25 years, external structures 50-100 years.
- Front end loading
- Civil Engineering costs vary from site to site
- $2000-4000 per kWh development cost
- Refurbishment and up-grading of older plant, a third per “new” kW
Geothermal
Geothermal energy

- The only form of renewable energy that is independent of the sun.
- One or more boreholes are drilled into the reservoir, the hot fluid flows or is pumped to surface and is then used in conventional steam turbines or heating equipment.
Geothermal Energy

- Video
Geothermal Energy Potential

By 2000 world electrical power generating capacity from geothermal resources had reached almost 8GW. About a further 16 GW thermal is also being harnessed in non-electrical direct use applications, typically space heating, agriculture and a variety of industrial processes.
Geothermal Energy

**Advantages**
- very high efficiency
- low initial costs since you already got steam
- 200°C at 10km depth

**Disadvantages**
- non-renewable (more is taken out than can be put in by nature)
- highly local resource

**Cost**
- 1985: $0.15/kWh
- 2002: $0.05 – 0.08/kWh
Geothermal Energy

- Not renewable, but share many with true renewable resources
- Natural energy flow rather than a store of energy like fossil or nuclear flues.
- Declined temperatures in some producing steam fields
- Heat is being mined on a non-sustainable bases
- Lifetime of 20-30 years
# Geothermal Power Generation

<table>
<thead>
<tr>
<th>Nation</th>
<th>2000 (MW)</th>
<th>2005 (est MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indonesia</td>
<td>589.5</td>
<td>1987.5</td>
</tr>
<tr>
<td>Italy</td>
<td>785</td>
<td>946</td>
</tr>
<tr>
<td>Japan</td>
<td>546.9</td>
<td>566.9</td>
</tr>
<tr>
<td>Mexico</td>
<td>755</td>
<td>1080</td>
</tr>
<tr>
<td>New Zealand</td>
<td>437</td>
<td>437</td>
</tr>
<tr>
<td>Philippines</td>
<td>1909</td>
<td>2673</td>
</tr>
<tr>
<td>USA</td>
<td>2228</td>
<td>2376</td>
</tr>
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</table>

Boyle, Renewable Energy, Power for Sustainable Future, p. 343
Energy from the Oceans

Currents

Tides

Thermal Differences (Ocean Thermal Energy Conversion)

Waves

Ken Pedrotti, UCSC
Energy from the Oceans

- Video

Differences between tidal, hydro and wave energies?

- Hydropower is derived from the hydrological climate cycle, powered by solar energy, harnessed via hydroelectric dams.

- Tidal energy is the result of the interaction of the gravitational pull of the moon.

- Wave energy is caused by the action of the wind over water, the wind in turn being the result of the differential solar heating of air over land and sea.
Energy from the Oceans

**Advantages**
- large energy flow
- steady flow for decades

**Disadvantages**
- enormous engineering effort
- extreme conditions (corrosion, storm, transmission)
- extremely high cost
- damage to coastal environments
Tidal Energy Conversion

Figure 1. Tidal power (barrage) generation.
# Tidal Energy Projects

<table>
<thead>
<tr>
<th>country</th>
<th>location</th>
<th>power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>operational</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>La Rance</td>
<td>240</td>
</tr>
<tr>
<td>Canada</td>
<td>Annapolis Royal</td>
<td>20</td>
</tr>
<tr>
<td>China</td>
<td>Jiangxia</td>
<td>3.9</td>
</tr>
<tr>
<td>Russia</td>
<td>Kislaya Guba</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>proposals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>Bay of Fundy, Cumberland Basin</td>
<td>1400</td>
</tr>
<tr>
<td>China</td>
<td>Various</td>
<td>1000</td>
</tr>
<tr>
<td>Russia</td>
<td>Mezan Bay and Tigur</td>
<td>28000</td>
</tr>
<tr>
<td>Korea</td>
<td>Siwha and Garolim</td>
<td>740</td>
</tr>
<tr>
<td>India</td>
<td>Khambat</td>
<td>1800</td>
</tr>
<tr>
<td>Australia</td>
<td>Secure Bay and Cape Keraudren</td>
<td>600</td>
</tr>
<tr>
<td>Argentina</td>
<td>San Jose/Neuvo</td>
<td>600</td>
</tr>
<tr>
<td>UK</td>
<td>Severn and Mersey</td>
<td>9300</td>
</tr>
</tbody>
</table>

Kerr, Phil Trans. R. Soc. A 2007
Areas Appropriate for Traditional Tidal Power


http://www.window.state.tx.us/specialrpt/energy/renewable/ocean.php
Tidal Current Turbine Technology

- Clean Current (h-axis, shrouded rotor)
- GCK (vertical-axis, Gorlov helical rotor)
- Lunar Energy (h-axis, shrouded rotor)
- Marine Current Turbines (h-axis, open rotor)
- Open Hydro (h-axis, open rotor, rim-drive)
- Ponte de Archimeda
- SeaPower (vertical axis, Savonius rotor)
- SMD Hydrovision (h-axis, open rotor)
- UEK (h-axis, shrouded rotor)
- Verdant Power (h-axis, open rotor)
Wave Energy Conversion Devices

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*Oscillating water column (OWC)*. Power is extracted by an air turbine (figure 18). Most prototypes to date are of this type.

*Buoyant moored, on or below surface*. Power extraction method varies (e.g. from the motion of the device relative to the seabed).

*Hinged contour devices*. Power is extracted from the motion of the joints.
UK Wave Energy Assessment

<table>
<thead>
<tr>
<th>location</th>
<th>total resource (TWh)</th>
<th>recoverable energy (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>shoreline</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td>nearshore</td>
<td>100–140</td>
<td>2.1</td>
</tr>
<tr>
<td>offshore</td>
<td>600–700</td>
<td>50</td>
</tr>
</tbody>
</table>
World Annual Mean Wave Energy

kW/m

Kerr, Phil Trans. R. Soc. A 2007
U.S. Wave and Current Energy Potential

U.S. Annual Electric Power Generation by fuel type in 2004 was 3,971 Terawatt-Hours (TWh)

- Coal: 49.8%
- Nuclear: 19.9%
- Natural Gas: 17.9%
- Petroleum: 3.0%
- Other Renewables: 2.3%
- Hydroelectric*: 6.5%
- Other: 0.2%
- Other Gases: 0.4%

* Note: Hydroelectric includes generation from pumped-storage facilities after subtracting energy used for pumping

U.S. conventional hydro-electric generation in 2004 was ~260 TWh/yr

Wave and current generation potential

- Offshore wave 250-260 TWh/yr if 15% utilized
- Tidal, river, and ocean currents TBD but maybe half of wave

Credible potential to meet nearly 10% of national demand
Total flux into all regions with mean wave power density >10 kW/m is 2,100 TWh/yr

Extracting 15% of total flux and converting to electricity at 80% efficiency would yield 252 TWh/yr
Figure 4. Example short-term variability in wave characteristics
Source: US Army Corps of Engineers
Wave Energy Conversion Technology

- Able Technologies - Electricity Generation Wave Pump
- Artificial Muscles Inc
- AquaEnergy Group, Finevera - AquaBuOY
- AWS Energy - Archimedes Wave Swing
- Ecofys - Wave Rotor
- OceanLinx (Energetech) - Uiscebeathae
- Independent Natural Resources Inc - SeaDog™
- Ocean Power Delivery - Pelamis
- Ocean Power Technologies - PowerBuoy®
- Oregon State University – Direct Drive Point Absorbers
- Renewable Energy Holdings - Cylindrical Energy Transfer Oscillator (CETO)
- Wavebob Ltd - Wavebob WEC
- Wave Dragon Ltd - Wave Dragon
- Wave Energy - Sea Wave Slot-Cone Generator
- Wave Star Energy - Wave Star
Oscillating water column device: Oceanlinx.

Attenuator: Pelamis

Overtopping device: Wave Dragon
Santa Cruz Wave Pump - 1898

Operated 1898 – 1910
Solved a need – how to water local wagon roads to keep dust down
A ‘new 1910” technology put the Armstrong Brothers out of business
Environmental Impact

- Little potential for chemical pollution. At most, they may contain some lubricating or hydraulic oil, which will be carefully sealed from the environment.
- They have little visual impact except where shore-mounted.
- Noise generation is likely to be low – generally lower than the noise of crashing waves.
- They should present a small hazard to shipping.
- They should present no difficulties to migrating fish.
- Floating schemes, since they are incapable of extracting more than a small fraction of the energy of storms, will not significantly influence the coastal environment.