Renewable Energy Resources – an Overview
Part II

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Electricity production from renewables

Diagram:
- Solar Derived Energy
- HYDRO
- CLEAN RENEWABLE FUELS
- OCEAN ∆T
- THERMAL COLLECTOR
- WIND
- GEO- THERMAL
- POWER PLANT
- ELECTRICITY
- SOLAR CELLS
Biomass

- Biomass is organic material that made from plants and animals (micro-organisms).
- Biomass contains stored energy from the sun: Plants absorb the sun's energy through photosynthesis. The chemical energy in plants (in the form of glucose or sugar) gets passed on to animals and people that eat them.
Biomass Energy

- The most common form of biomass is wood. Wood was the main source of energy until the mid-1800s.
- Biomass can be used to make an energy-rich gas or biogas - like natural gas.
- Biomass can also be turned into a fuel like gasoline - corn and wheat can be made into ethanol.
- Biomass can also be used to make electricity. Many towns, instead of putting the garbage in landfills, they burn it to make electricity.
- Landfills can be a source of energy. Anaerobic bacteria that live in landfills decompose organic waste to produce methane gas.
As of 2011, over 550 landfills have operating gas to energy projects in the United States.

Source: http://www.eia.gov/biogas/
Biomass energy from animal waste

Some farmers produce biogas in large tanks called "digesters" where they put manure and bedding material from their barns. Some cover their manure ponds to capture biogas.
Biomass in Nevada:
CC Landfill Energy LLC: 12 MW
Locate biomass power plants in the US

https://www.eia.gov/state/maps.php
Electricity production from renewables

Diagram showing the flow of energy from solar radiation to electricity: Direct Solar Radiation to Solar Derived Energy to Hydro to Clean Renewable Fuels to Thermal Collector to Ocean ΔT to Wind to Geothermal to Power Plant to Electricity.
Hydropower relies on the water cycle. Herein:

- Solar energy heats water on the ocean surface, causing it to evaporate.
- This water vapor condenses into clouds and falls back onto the surface as precipitation (rain, snow, etc.).
- The water flows through rivers back into the oceans, where it can evaporate and begin the cycle over again.
Hydropower

- The amount of available energy in moving water is determined by its flow rate or fall.
- Water flows through a pipe, or *penstock*, pushes against and turns blades in a turbine to spin a generator to produce electricity.
Hydropower 101: See Video Links Below

http://energy.gov/eere/videos/energy-101-hydroelectric-power
Power of a hydro power generator

- Ideal case:
  \[ P = 9.81QH_G \]

- When friction losses in the penstock and in the turbine-generator:
  \[ P = 9.81\eta QH_N = \eta Q(gpm)H_N(ft)/5.3 \]

  - P: Power (W)
  - Q: flow rate (m³/s)
  - H_G: gross head (m)
  - \(\eta\): turbine-generator efficiency
  - H_N: net head (m) ( = gross head – head loss). Head loss depends on the type of pipe material, diameter, flow rate, and length.
Hydropower is the renewable energy source that produces the most electricity in the United States. It accounted for 7.5% of total U.S. electricity generation in 2017.

Most hydropower is produced at large facilities built by the federal government.

- Only a small percentage of all dams in the United States produce electricity.
- Most dams were constructed solely to provide irrigation and flood control.
Locate hydro power plants in the US

https://www.eia.gov/state/maps.php
Small Hydro Power Plants in Northern Nevada

- **Fleish**: 2.3 MW
- **Hooper**: 0.8 MW
- **Truckee Irrigation District**: 4.0 MW
- **Verdi**: 2.2 MW
- **Washoe**: 2.2 MW

Pelton Turbine
Pumped-Storage Hydro

- Used in bulk power storage applications where water is pumped up at night and released during the day.
- Locate pumped hydro storage systems in the US.
  - https://www.eia.gov/state/maps.php
Electricity production from renewables

- Solar Derived Energy
- OCEAN ΔT
- GEO- THERMAL
- HYDRO
- CLEAN RENEWABLE FUELS
- THERMAL COLLECTOR
- SOLAR CELLS

Direct Conversion

Indirect Conversion

Direct Conversion

Indirect Conversion
Ocean Power

- Energy can be extracted from the power of the waves, from the tide, or from ocean currents.
Ocean power – technology development status

Thousand of concepts and patents on ocean energy conversion technology are being pursued today.

- Laboratory scale model testing
- Short-term proof of concept tests in natural waters
- Long-term full scale prototypes in natural waters

Hundreds

A Few Dozen

A Few
Solar energy creates uneven temperatures and pressures across the globe. This results in wind blowing from high pressure to low pressure areas. When wind comes in contact with the ocean surface, it creates waves.

Power of a wave per meter of distance along the ridge of the wave (under ideal sinusoidal conditions):

\[ P = \frac{\rho g^2 H^2 T}{64\pi} \]

- \( \rho \): sea water density (kg/m\(^3\))
- \( g \): grav. accel. (m/s\(^2\))
- \( H \): wave height (m)
- \( T \): wave period (s)
4 Ways to Harness Power from Ocean Waves: attenuators, terminators, point absorbers, and overlapping devices

**Attenuators**: multi-segment floating structures oriented parallel to the direction of the waves. The differing heights of waves along the length of the device causes flexing where the segments connect. This motion is resisted by hydraulic rams which in turn drive electrical generators.

Source: Pelamis Wave Power
Oscillating water column is a form of terminator in which water enters through a subsurface opening into a chamber with air trapped above it. The wave action causes the captured water column to move up and down like a piston to force the air though an opening connected to a turbine.
A point absorber is a floating structure with components that move relative to each other due to wave action (e.g., a floating buoy inside a fixed cylinder). The relative motion is used to drive electromechanical or hydraulic energy converters.

Source: Ocean Power Technologies
Ocean Power - Waves

- An overtopping device has reservoirs that are filled by incoming waves to levels above the average surrounding ocean. Gravity causes it to fall back toward the ocean surface. The energy of the falling water is used to turn hydro turbines.

Source: Wave Dragon, Danmark
Ocean currents flow in complex patterns affected by the wind, water salinity and temperature, topography of the ocean floor, and gravitational forces exerted by the moon and sun.

While ocean currents move slowly relative to typical wind speeds, they carry a great deal of energy because of the density of water (837 times denser than air). \[ P = \frac{1}{2} \rho A v^3 \]

Many industrialized countries are pursuing ocean current energy. Technical challenges include prevention of marine growth buildup, and corrosion resistance.
The tides are the result of the gravitational attraction between the earth and the moon as well as the earth and sun. The strength of the tide is greatly dependent on the earth-moon system.

Depending on the location and time of year, one can experience two equal tidal cycles (semidiurnal), one tidal cycle (diurnal) or two unequal tidal cycles (mixed tide).

Enormous volumes of water rise and fall with the tides each day, and many coastal areas can take advantage of this free energy.

Tidal power plant in Brittany, France (240 MW)
Marine and Hydrokinetic Energy 101: See Video Link Below

Electricity production from renewables

- GEO
- THERMAL
- HYDRO
- WIND
- OCEAN ΔT
- GEOTHERMAL
- CLEAN RENEWABLE FUELS
- THERMAL COLLECTOR
- SOLAR CELLS
- POWER PLANT
- ELECTRICITY
Geothermal energy is generated in the Earth's core. Temperatures hotter than the sun's surface are continuously produced inside the Earth by the slow decay of radioactive particles. The Earth has a number of different layers:

- A solid inner core and an outer core made of magma (melted rock)
- The mantle, made up of magma and rock, surrounds the core and is about 1,800 miles thick.
- The crust is the outermost layer of the Earth, the land that forms the continents and ocean floors. The crust is 15 - 35 miles thick.
Naturally occurring large hydrothermal resources are called **geothermal reservoirs**. Most geothermal reservoirs are deep underground. But geothermal energy sometimes finds its way to the surface in the form of **volcanoes, hot springs** and **geysers**.

In some cases, geothermal energy is used directly to heat city districts by digging wells and pumping the heated water or steam to the surface. For example, district heating system provides heat for 95% of the buildings in Reykjavik, Iceland.
Dry steam plants use steam piped directly from a geothermal reservoir to turn the generator turbines. The first geothermal power plant was built in 1904 in Tuscany, Italy.

Flash steam plants take high-pressure hot water from deep inside the Earth and convert it to steam to drive the generator turbines. When the steam cools, it condenses to water and is injected back into the ground to be used over and over again.
Geothermal Energy 101: See Video Link Blow

http://energy.gov/eere/videos/energy-101-geothermal-energy
Geothermal Resource of the United States
Locations of Identified Hydrothermal Sites and Favorability of Deep Enhanced Geothermal Systems (EGS)

Favorability of Deep EGS
- Most Favorable
- Least Favorable
- N/A*
- No Data**
- Identified Hydrothermal Site (≥ 90°C)

* Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources.
** Source data for deep EGS includes temperature at depth from 3 to 10 km provided by Southern Methodist University Geothermal Laboratory (Blackwell & Richards, 2009) and analyses (for regions with temperatures ≥150°C) performed by NREL (2009).

This map was produced by the National Renewable Energy Laboratory for the US Department of Energy, October 13, 2009. Author: Billy J. Roberts

www.nrel.gov/gis
## Top Counties with Geothermal Resources

<table>
<thead>
<tr>
<th>Country</th>
<th>Geothermal electricity production GWh/yr</th>
<th>Country</th>
<th>Geothermal direct use GWh/yr*</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>16 603</td>
<td>China</td>
<td>20 932</td>
</tr>
<tr>
<td>Philippines</td>
<td>10 311</td>
<td>United States</td>
<td>15 710</td>
</tr>
<tr>
<td>Indonesia</td>
<td>9 600</td>
<td>Sweden</td>
<td>12 585</td>
</tr>
<tr>
<td>Mexico</td>
<td>7 047</td>
<td>Turkey</td>
<td>10 247</td>
</tr>
<tr>
<td>Italy</td>
<td>5 520</td>
<td>Japan</td>
<td>7 139</td>
</tr>
<tr>
<td>Iceland</td>
<td>4 597</td>
<td>Norway</td>
<td>7 000</td>
</tr>
<tr>
<td>New Zealand</td>
<td>4 055</td>
<td>Iceland</td>
<td>6 768</td>
</tr>
<tr>
<td>Japan</td>
<td>3 064</td>
<td>France</td>
<td>3 592</td>
</tr>
<tr>
<td>Kenya</td>
<td>1 430</td>
<td>Germany</td>
<td>3 546</td>
</tr>
<tr>
<td>El Salvador</td>
<td>1 422</td>
<td>Netherlands</td>
<td>2 972</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>1 131</td>
<td>Italy</td>
<td>2 762</td>
</tr>
<tr>
<td>Turkey</td>
<td>490</td>
<td>Hungary</td>
<td>2 713</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>450</td>
<td>New Zealand</td>
<td>2 654</td>
</tr>
<tr>
<td>Russia</td>
<td>441</td>
<td>Canada</td>
<td>2 465</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>310</td>
<td>Finland</td>
<td>2 325</td>
</tr>
</tbody>
</table>

Source: OECD/IEA
Geothermal in Nevada:
Current Capacity: 385 MW (+ 150 MW in construction or development stage).

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beowawe Power</td>
<td>17.7</td>
</tr>
<tr>
<td>Brady Geothermal Project</td>
<td>24.0</td>
</tr>
<tr>
<td>Clayton Valley 1</td>
<td>53.5</td>
</tr>
<tr>
<td>Desert Peak Geothermal Project #2</td>
<td>25.0</td>
</tr>
<tr>
<td>Dixie Meadows</td>
<td>51.0</td>
</tr>
<tr>
<td>Faulkner 1</td>
<td>49.5</td>
</tr>
<tr>
<td>Galena 2</td>
<td>13.0</td>
</tr>
<tr>
<td>Galena 3</td>
<td>26.5</td>
</tr>
<tr>
<td>Homestretch</td>
<td>2.1</td>
</tr>
<tr>
<td>Jersey Valley Geothermal Project</td>
<td>22.5</td>
</tr>
<tr>
<td>McGinness Hills</td>
<td>48.0</td>
</tr>
<tr>
<td>Richard Burdette Generation Facility</td>
<td>26.0</td>
</tr>
<tr>
<td>Soda Lake I</td>
<td>3.6</td>
</tr>
<tr>
<td>Soda Lake II</td>
<td>19.5</td>
</tr>
<tr>
<td>Steamboat Hills</td>
<td>14.6</td>
</tr>
<tr>
<td>Steamboat IA</td>
<td>2.0</td>
</tr>
<tr>
<td>Steamboat II</td>
<td>13.4</td>
</tr>
<tr>
<td>Steamboat III</td>
<td>13.4</td>
</tr>
<tr>
<td>Stillwater 2</td>
<td>47.2</td>
</tr>
<tr>
<td>(Photovoltaic Addition 22.0 MW)</td>
<td></td>
</tr>
<tr>
<td>Tuscarora (aka Hot Sulfur Springs 2)</td>
<td>32.0</td>
</tr>
</tbody>
</table>

Source: NV Energy Website
Locate geothermal power plants in the US

https://www.eia.gov/state/maps.php
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Direct Conversion

Indirect Conversion

Direct Solar Radiation

Direct Conversion
Wind Power … Inland and Offshore
Largest wind turbine generator to date:

- Manufacturer: Vestas
- Rated power: 9.5 MW,
- Rotor diameter: 164m.
Growth in Wind Energy Production

Global cumulative installed wind capacity 2001-2016

<table>
<thead>
<tr>
<th>Year</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>23,900</td>
</tr>
<tr>
<td>2002</td>
<td>31,100</td>
</tr>
<tr>
<td>2003</td>
<td>39,431</td>
</tr>
<tr>
<td>2004</td>
<td>47,620</td>
</tr>
<tr>
<td>2005</td>
<td>59,091</td>
</tr>
<tr>
<td>2006</td>
<td>73,957</td>
</tr>
<tr>
<td>2007</td>
<td>93,924</td>
</tr>
<tr>
<td>2008</td>
<td>1,20,696</td>
</tr>
<tr>
<td>2009</td>
<td>1,59,052</td>
</tr>
<tr>
<td>2010</td>
<td>1,97,956</td>
</tr>
<tr>
<td>2011</td>
<td>2,38,110</td>
</tr>
<tr>
<td>2012</td>
<td>2,82,850</td>
</tr>
<tr>
<td>2013</td>
<td>3,18,697</td>
</tr>
<tr>
<td>2014</td>
<td>3,69,862</td>
</tr>
<tr>
<td>2015</td>
<td>4,32,680</td>
</tr>
<tr>
<td>2016</td>
<td>4,86,790</td>
</tr>
</tbody>
</table>
Installed Wind Capacity by Country (MW)

New Installed capacity by country in 2015 (MW)

- China: 30,753 MW (48.5%)
- United States: 8,598 MW (13.5%)
- Germany: 6,013 MW (9.5%)
- Brazil: 2,754 MW (4.3%)
- India: 2,623 MW (4.1%)
- Canada: 1,506 MW (2.4%)
- Poland: 1,266 MW (2.0%)
- France: 1,073 MW (1.7%)
- United Kingdom: 975 MW (1.5%)
- Turkey: 956 MW (1.5%)
- Rest of the world: 6,950 MW (11.0%)

Installed capacity by country in 2015 (MW)

- China: 145,362 MW (34.1%)
- United States: 74,471 MW (17.5%)
- Germany: 44,947 MW (10.5%)
- India: 27,151 MW (6.4%)
- Spain: 23,025 MW (5.4%)
- United Kingdom: 13,603 MW (3.2%)
- Canada: 11,205 MW (2.6%)
- France: 10,358 MW (2.4%)
- Italy: 8,958 MW (2.1%)
- Brazil: 8,715 MW (2.0%)
- Rest of the world: 58,275 MW (13.7%)
Locate wind energy plants in the US

https://www.eia.gov/state/maps.php
Wind Power in Nevada:
Spring Valley Wind (Pine County): 152 MW
Wind turbines

- Horizontal axis wind turbines (HAWT) are the most popular compared to vertical axis wind turbines (VAWT).
- 3 blades used to minimize power pulsations (if < 3) and aerodynamic interference (if > 3).
- The aerodynamic blades produce a lift force along the blade which produces a mechanical torque on the turbine shaft.
Wind Energy 101: See Video Link Below

Wind and Turbine Power

- Power of the wind: \( P_w = \frac{1}{2} \rho A v_w^3 \)
- Where \( \rho \) is the air density, \( A \) is turbine sweep area, and \( v_w \) is the wind speed.

- Power extracted by the turbine: \( P_t = c_p P_w \)
  where \( c_p \) is the turbine performance coefficient.

- The theoretical maximum value of \( c_p \) (derived from the conservation of mass and energy) is \( 16/27 \approx 60\% \).

- In practice \( c_p \) is less than the above value and its varies with the tip speed ratio: \( \lambda = \frac{\omega r}{v_w} \)
  where \( \omega \) is the rotor speed, \( r \) is the rotor radius and \( v_w \) is the wind speed.
A typical $c_p - \lambda$ curve is shown below and is unique to a particular turbine design. Modern wind turbine design can reach 70-80% of the theoretical limit.

To extract maximum power, the turbine must be operated at the peak of the curve (*peak power tracking*).

For a given wind speed $v_w$ and the $c_p - \lambda$ characteristics, the turbine power can be calculated as a function of shaft speed.
Turbine Power

- For a given turbine $c_p$, the turbine power can be graphed as a function of the wind speed as shown below.
- The figure shows the cut-in speed (around 3-4 m/s), rated speed (around 12.5 m/s), and shut down speed (around 25 m/s).
- Turbines are typically designed to withstand wind speeds of up to 50 m/s (180 km/hr)
Average Power in the Wind

The average power in the wind is proportional to the average of the cube of the wind velocity, **not** the cube of the average wind speed.

\[ P_{\text{avg}} = \left( \frac{1}{2} \rho A v^3 \right)_{\text{avg}} = \frac{1}{2} \rho A (v^3)_{\text{avg}} \neq \frac{1}{2} \rho A (v_{\text{avg}})^3 \]

Example: Calculate the cube of the average value and the average of the cube of the wind if

\[ v(t) = V_M \mid \sin t \mid \]

Ans: \((v_{\text{avg}})^3 = \frac{8}{\pi^3} V_M^3 \approx 0.26 V_M^3\), \( (v^3)_{\text{avg}} = \frac{4}{3\pi} V_M^3 \approx 0.42 V_M^3 \)
Wind intermittency: Important Issue

Wind output can drop 113 MW in 10 minutes, and increase 106 MW in 10 minutes.

Source: NREL
End of Part II

- See posted homework assignment.