

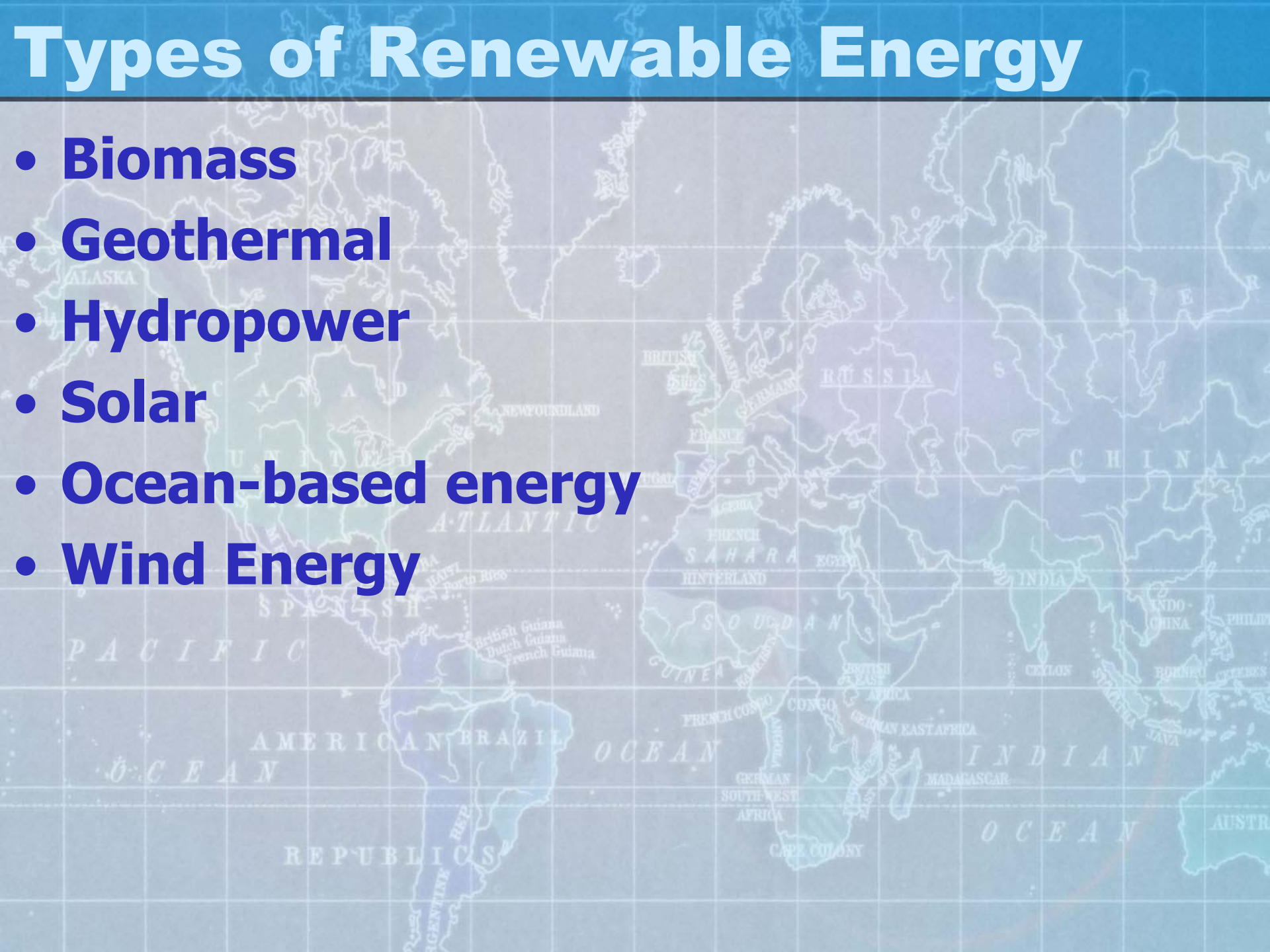


Sustainable Energy

Lecture 9: Introduction to Renewable Energy

Types of Renewable Energy

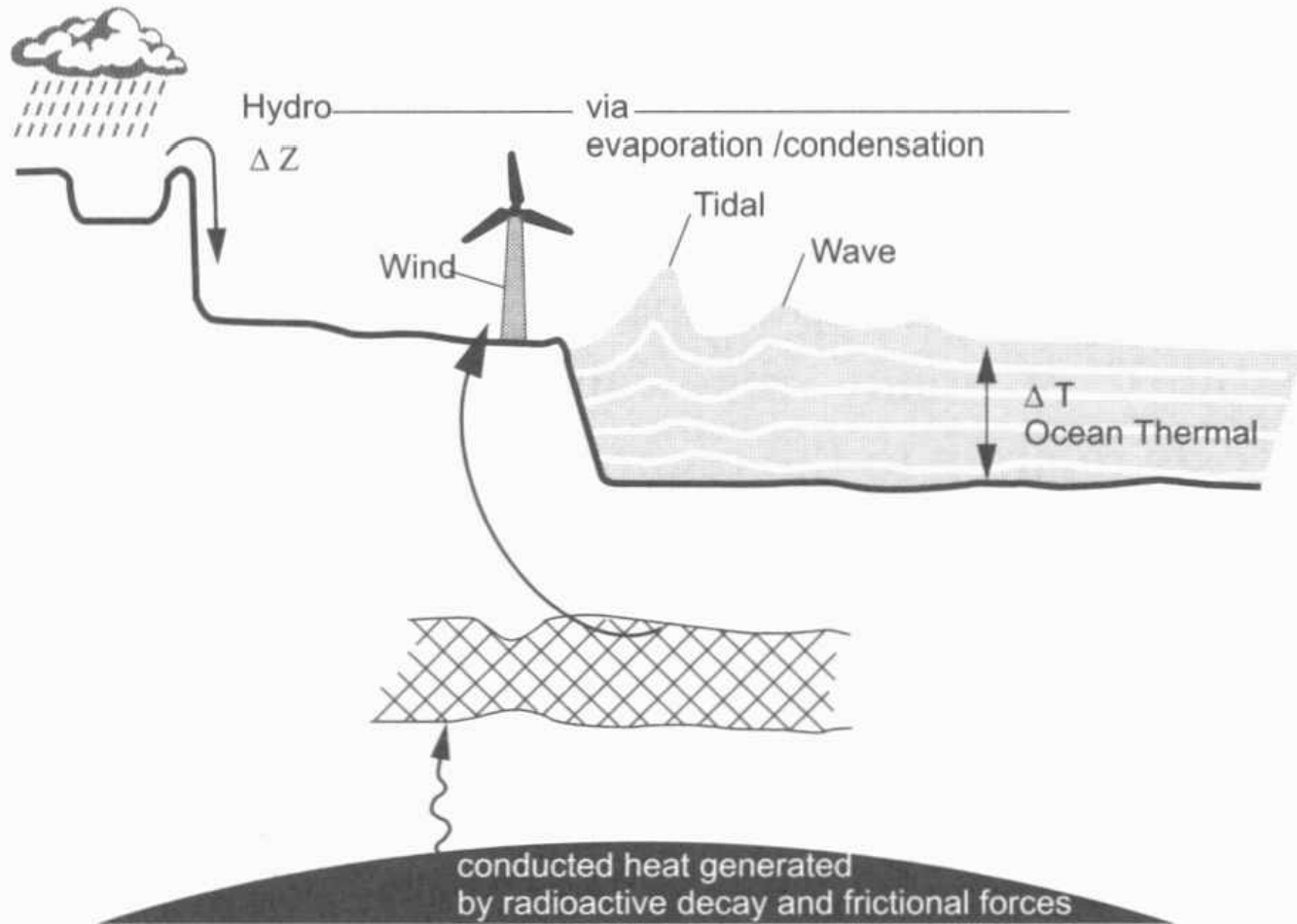
- Biomass
- Geothermal
- Hydropower
- Solar
- Ocean-based energy
- Wind Energy



Historical Notes

- Each renewable energy type is tied to one of three primary energy sources:
 - Solar radiation
 - Gravitational forces
 - Radioactive decay
- Renewable energy has been used since ancient times:
 - Sailing ships
 - Anasazi cave dwellings used passive solar.
 - Hot springs
 - Hydropower/Niagara Falls (please see www.niagarafrontier.com/power.html)

Renewable energy sources



Origins of Renewable Energy

Table 9.1. Renewable Energy Types and Energy Transfer Processes

(See also Goldenberg et al. (1987), Twidell and Weir (1986), and Johannson et al. (1993))

Primary Energy Source	Energy Transfer Process	Renewable Energy Type
Solar Radiation/ Photon flux	absorption on semi-conductor surface → conversion to electrons via photoelectric effect → conversion to electricity;	photovoltaic (PV)
	absorption on surfaces → conversion to thermal energy;	solar thermal
	differential absorption on the earth's land surfaces and oceans → conversion to kinetic energy;	wind, waves
	selective absorption of light energy to drive photosynthesis → conversion of CO ₂ and H ₂ O to glucose → further metabolically driven conversions to carbohydrates, fats, and proteins;	biomass energy, bio fuels
	solar heat absorption → water evaporation → heat loss to the atmosphere → water condensation → rain → PE in water storage	hydro (solar)
Gravitational forces and planetary motion	PE and KE contained in stored water;	hydro (solar)
	dissipative forces induce periodic KE changes in ocean	tidal
Gravitational forces and friction	Stored and generated thermal energy in the earth's crust transported to surface by conduction and fluid convection, enhanced by tectonic plate motion;	geothermal
Nuclear energy	radioactive decay of isotopes deposits energy in the earth's interior (e.g., K, U, Th)	geothermal

Historical notes continued....

- Only about 10% of the world's energy is currently provided by renewable sources.
- Current issues with renewable energy:
 - Low energy density
 - Low capture efficiency
 - Storage issues
 - Costs relative to fossil fuels
 - Potential environmental impacts

Resource Assessment

- **Plenty of renewable energy is potentially available to satisfy current energy demands.**
- **Current energy consumption doesn't exceed 400 quads/year.**
- **Many renewable sources easily cover this demand on a theoretical level.**

Worldwide Renewable Energy

Table 9.2. Worldwide Resource Bases for Renewable Energy: Fluxes and Stored Energy*

Resource	Energy Type	Total Flux TW (quads/yr)	Net Stored Energy TW-yr (quads)**
Solar	land flux	27,000	0
	ocean flux	53,000	0
	total flux	89,000 (2.7×10^6)	0
Wind	kinetic energy (land)	100 (3,000)	0
Waves	kinetic energy (ocean), gravity	200 (6,000)	0
Biomass	photosynthesis	30 (900)	750 (22,400)
Hydro	latent evaporative heat	40,000 (1.2×10^6)	80,000 (2.4×10^6)
Tides	gravitational forces between the moon and earth	> 3 (90)	3 (90)
Geothermal			
– hydrothermal	convection	~2.5 (75)	1.710^5 (5.1×10^6)
– geopressed and – magma			
– hot dry rock	conduction	≥ 30 (900)	$3.3 \cdot 10^6$ (1×10^8)
All fossil fuels	chemical reaction enthalpies or heats ***	10 (300)	$\geq 360,000$ (1.1×10^7)

*estimates based on information provided by Armstead and Tester (1987), Grubb (1990), and Armstead (1983); US figures based in part on USGS estimates (e.g., see Muffler and Guffanti (1978), Sass (1993)).

**1 quad = 3.35×10^{15} Btu

***does not include any energy stored from the solar greenhouse effect, e.g., in atmospheric CO₂, H₂O, or CH₄.

The importance of storage

- **Some renewable energy types have their own storage capacity: hydropower and biomass.**
- **Energy storage systems will be necessary for expansion of solar, wind and wave power.**
- **Technology will play an important role in the development and propagation of these technologies as a result.**
- **People will have to be trained to install, maintain and operate these systems just as people are trained now to run fossil fuel and nuclear technologies.**
- **The importance of hydrogen as an energy carrier may depend on the use of renewable energy for its production.**

Environmental Impacts

- All renewable energy types/technologies have environmental impacts.
- Full life cycle analysis will allow comparison of different forms of renewable energy.
- Consideration of the environmental costs of operating fossil fuel technologies is making many renewable technologies economically feasible.
- Externalities like the costs of the environmental impacts of climate change have finally sobered many people in the energy industry.
- The general public is now demanding change and will not accept inflated prices for renewable alternatives.

The Future of Renewable Energy

- **Renewable energy is attractive because of three characteristics:**
 - **RE provides abundant energy sources.**
 - **RE does not deplete the earth's natural resources.**
 - **RE has little, if any, environmental impacts compared to conventional technologies.**
- **The recent surge in oil prices has revived the interest in using renewable energy in the US and elsewhere.**
- **Educational programs are now being developed at many institutions of higher learning to increase awareness and provide training for the next generation of energy technology....renewable energy.**