Introduction to Alternative Energy Systems

Lecture # 1

Some Common Energy Units

joule (J)	The amount of work or energy exerted when a force of one newton causes a displacement of one meter	The energy needed to maintain a flow of 1 ampere for 1 second at a potential of 1 volt in electrical applications
calorie (cal)	The energy needed to raise the temperature of 1 gram of water by 1 ºC 1 cal = 4.184 J	In nutrition, a unit called the kilocalorie, also known as the diet calorie, is frequently mentioned. This unit is equivalent to 1000 cal, and is the amount of heat energy required to raise or lower one kilogram (1 kg) of pure liquid water by 1º C or 1º K. When the label on a package of food says that a serving contains 200 calories, it means that the sample would yield 200 kcal (not 200 cal) of heat energy if subjected to complete combustion.
British Thermal Unit (BTU)	The energy needed to raise the temperature of 1 pound of water by 1 ºF 1 BTU = 1055 J	The unit used extensively in engineering applications. Heating and cooling units (air conditioners) are rated in BTU units

Energy Units are Usually Large Quantities

Prefix	*Symbol*	*Value*
Kilo	k	10^3 (thousand)
Mega	M	10^6 (million)
Giga	G	10^9 (billion)
Tera	T	10^{12} (trillion)
Peta	P	10^{15} (quadrillion)
Exa	E	10^{18} (quintillion)

The following factors can be used to convert some energy units

- **1 J = 0.2388 cal**
  1 cal = 4.1868 J
  1 BTU = 1.055 kJ = 0.252 kcal
- **<u>WEC (World Energy Council) Standard Energy Units</u>**
  1 tonne of oil equivalent (toe) = 42 GJ (net calorific value) = 10 034 Mcal
  1 tonne of coal equivalent (tce) = 29.3 GJ (net calorific value) = 7 000 Mcal
- **<u>Volumetric Equivalents</u>**
  1 barrel = 42 US gallons = 158.9 liters = 0.1589 m3
  1 cubic meter = 35.315 cubic feet = 6.2898 barrels
- **<u>Representative Average Conversion Factors</u>**
  1 tonne of crude oil = approx. 7.3 barrels
  1 tonne of natural gas liquids = 45 GJ (net calorific value)
  1 000 standard cubic metres of natural gas = 36 GJ (net calorific value)
  1 tonne of uranium
  (light-water reactors, open cycle) = 10,000 – 16,000 toe
  1 tonne of peat = 0.2275 toe
  1 tonne of fuelwood = 0.3215 toe
  1 kWh (primary energy equivalent) = 3.6 MJ
  1 Therm of natural gas = 100,000 BTU

World Primary Energy Consumption Excluding Biomass and Others for 2002

Source: BP 2003

Solid fuels	**100,395 PJ**
Liquid fuels	**147,480 PJ**
Natural gas	**95,543 PJ**
Hydroelectric power	**24,792 PJ**
Nuclear power	**25,564 PJ**
TOTAL	**393,773 PJ**

Let us assume the current world energy consumption to be approximately 400 EJ

Fossil Fuel Reserves

- **OIL RESERVES**

  The estimated oil reserve worldwide, as of 2002, is about 1.05×10^{12} Barrel of oil. The world consumption of oil in 2002 was about 2.76×10^{10} Barrel of oil. Hence, the world reserves will last less than 40 years.

- **US NATURAL GAS RESERVES**

  US reserves in 2002 was 5.19×10^{12} m^3

  US consumption in 2002 was 6.68×10^{11} m^3

  The US reserves of natural gas will last for 7.8 years.

- **WORLDWIDE NATURAL GAS RESERVES**

  World reserves in 2002 was 1.55×10^{14} m^3

  World consumption in 2002 was 2.54×10^{12} m^3

  The world reserves of natural gas will last for 61 years.

Reserves – Cont.

- **COAL RESERVES**

  The world's reserve of coal in 2002 was 9.8×10^{11} tons

  The US reserve of coal in 2002 was 2.7×10^{11} tons

  The world coal reserves may last about 200 years.

- **WORLDWIDE URANIUM RESERVES**

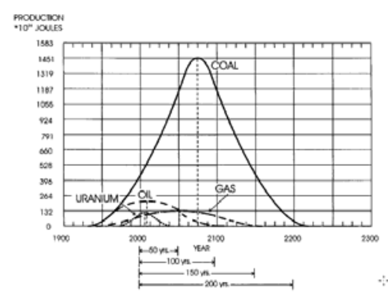
  Uranium reserves in 2002 was

  1.57 Mt at the processing price of \$40/kg

  5.67 Mt at the processing price of \$130/kg

  Less than 6 % of the world primary energy is currently provided by nuclear power. Suppose that **ALL WORLD ENERGY** is supplied by nuclear power at the least expensive processing methods. Therefore, the uranium reserves may last **ONLY 2 YEARS.**

Energy Depletion Curves



Energy Consciousness

We take energy for granted until that is not available...

Energy – Historical Perspectives

- Since humankind's beginning, the ability to harvest and convert energy has been a means of survival.
- When the industrial revolution in Europe caused an evolution of society and areas of larger population density, people realized that factors such as comfortable housing and energy could be important to the development of a country.
- Fossil fuels became essential products of a modern society, and new strategies were developed to guarantee their uninterrupted supply
- Since then, our population has grown—and so has its demands for industrial goods. On a planet of unaltered size and resources, this has had predictable consequences. Bloody wars, new frontiers, international agreements, and optimized use of resources are a few of the results. With the exhaustion of the planet's energy resources, the continuation of such effects can be easily foreseen.

Energy – Historical Perspectives – Cont.

- Long ago, the need to generate large amounts of electrical energy and the realization that larger power plants were more efficient than smaller ones encouraged the construction of huge power plants.
- Examples can be found in Itaipu Binational in Brazil, Guri in Venezuela, Sayano-Shushensk in Russia, and Churchill Falls in Canada. A more recent example is the plan for construction of the largest hydropower plant in China, Three Gorges Dam (18 GW).
- Some of these areas are affected by immense floods, massive power transmission lines and towers, air pollution, modified waterways, devastated forests, large population densities, and wars.
- Because of this trend of development, distances to energy sources were increasing, material capacities were reaching their limits, fossil reserves were being exhausted, and pollution was becoming widespread. New alternatives must be devised if humanity is to survive today and for centuries to come.

Renewable Sources of Energy

- Earth receives solar energy as radiation receiving it in a quantity that far exceeds humankind's use. The sun powers the evapotranspiration cycle, power in hydro schemes—the largest source of renewable electricity today.
- Organic matter that makes up plants is known as biomass, and biomass can be used to produce electricity, transportation fuel, and chemicals.
- Hydrogen can also be extracted from many organic compounds, as can water. Hydrogen is the most abundant element on Earth, but it does not occur naturally in a gas. It always combines with other elements, such as with oxygen to make water. Once separated from another element, hydrogen can be burned as a fuel or converted into electricity.
- Research has made renewable energy more affordable today than it was 25 years ago.
- Wind energy has declined from 40/kwh to less than 5 cents.
- PV energy dropped from more than $ 1/kwh in 1980 to nearly 20 cents/kwh today.

Energy Categories

	Fossil	Renewable
Conventional	Coal Oil Gas	Wood Hydro Human/Animal
Alternative	Oil Shale Tar Sands	Wind Solar Biomass Wave/Tide Ocean Current Geothermal

- Sustainable means using less than it is renewed

Energy Categories - Cont.

- Conventional energies are from wood, coal, oil, and hydro
- Alternative energy is nonconventional
- Sustainable energy has a usage rate less than the rate that can be maintained;
- Renewable energy is sustainable indefinitely, unlike long-stored energy from fossil fuels that will be depleted
- Biomass combustion is also renewable, but emits CO_2 and pollutants
- Nuclear energy is not renewable, but sometimes is treated as though it were because of the extremely long depletion period

What's Renewable Energy?

- Renewable energy systems transform incoming solar energy and its primary alternate forms (wind and river flow), usually without pollution-causing combustion
- This energy is "renewed" by the sun and is "sustainable"
- Renewable energy from wind, solar, or ocean energy emits no pollution or carbon dioxide (although the building of the components does)
- Biomass can be heated with water under pressure to create synthetic fuel gas (synfuel); can add grass or brush to coal burners.

What's Renewable Energy? – Cont.

- A renewable energy source cannot run out and causes so little damage to the environment that its use does not need to be restricted.
- No energy system based on mineral resources is renewable because, one day, the mineral deposits will be used up. This is true for fossil fuels and uranium.
- Fuel combustion produces "greenhouse gases" that are believed to lead to climate change (global warming), thus combustion of biomass is not as desirable as other energy forms
- For example, the sunlight that falls on the United States in one day contains more than twice the energy the country normally consumes in a year. California has enough wind gusts to produce 11% of the world's wind electricity.

Drawbacks to Renewable Energy Development

- Even though renewable power plant does not release air pollution or use fossil fuels, it still has an effect on the environment.
- Solar thermal energy uses large tracts of land, and this affects natural habitat.
- Environment is also affected when buildings, roads, transmission lines, and transformers are built.
- Fluid often used for solar thermal are toxic.
- Solar or photovoltaic cells are produced using toxic chemicals.
- Toxic chemicals are used in batteries.

Kyoto Protocol

- At the International Climate Convention in Kyoto (1997), it was agreed that the developed nations of the world must reduce their greenhouse gas emissions.
- The European Union (EU) committed to reducing emissions of carbon dioxide (CO2) by 8% from 1990 levels by the year 2010.

Country	Emission Reduction (%)
Australia	-8
Canada	+6
Croatia	+5
European Community	+8
Hungary	+6
Iceland	-10
Japan	+6
New Zealand	0
Norway	-1
Poland	+6
Russian Federation	0
Switzerland	+8
Ukraine	0
U.S.A.	+7

- The United States was to reduce emissions by 7% and Japan by 6%. These agreements are laid down in the Kyoto Protocol and aim for a society that uses renewable energies, not fossil fuels.

Nuclear Energy

- Atomic energy does not emit greenhouse gases. However, nuclear energy is not renewable.
- Uranium ore is needed to feed nuclear power stations, and one day uranium, like fossil fuels, will have been used up.
- Nuclear energy produces radioactivity. Although nuclear energy emits less carbon dioxide, it releases life-threatening radioactive substances into the environment.
- Nuclear energy is not CO2-free

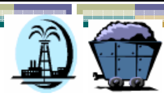
  Although nuclear power stations emit little CO2, the entire nuclear energy chain produces at least a third as much carbon dioxide as a modern gas-fired power station does.
- Nuclear energy is expensive

  Nuclear energy costs more per KW/hour than the alternatives. Added to this, the energy recovery time is very long compared to other energy sources. It takes a great deal of energy to produce nuclear energy.

Entire Cycle of Energy for CO2 Emissions

Renewable Source	Emissions of CO_2/kWh (in grams)
Waste Incineration	600
Biogasifier	-3800
Biomass	-4000
Photovoltaic Cells	120
Wind Turbine	10
Hydraulic Power Station	25
Nuclear Power Station	55
Gas-Fired Power Station	400
Coal-Fired Power Station	1160

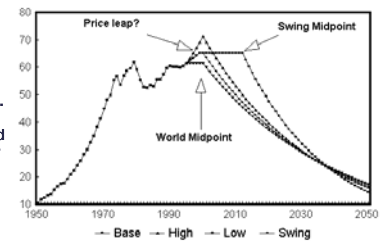
The Eventual Decline of Fossil Fuels



- Millions of years of incoming solar energy were captured in the form of coal, oil, and natural gas; current usage thus exceeds the rate of original production (0.02%)
- Coal may last 230 years; estimates vary greatly; not as useful for transportation due to thermal losses in converting to convenient liquid "synfuel"
- We can conserve energy by reducing loads and through increased efficiency in generating, transmitting, and using energy
- Efficiency and conservation will delay an energy crisis, but will not prevent it.

The Hubbert Curve Predicts Fossil Fuel Decline

- Dr. M. King Hubbert, geophysicist, published his prediction that the US oil peak would be reached in 1970. Later, others predicted the World oil peak would occur in the first decade of the 21st Century.
- Past the production peak, oil prices will increase as extraction becomes more difficult and the price is bid up.



Indicators of Renewable Energy Technologies

Renewable Energy Technology		Volatility (approx. time variation)	Resource Availability	Range of Generation Cost (EU ¢/kWh)	Preferred Voltage Level of Grid Connection (kV)
Biogas		year	high	5.18~26.34	1.30
Biomass		year	high	2.87~9.46	1.30, except co-firing
Geothermal electricity		year	low: country-specific	3.34~6.49	10.110
Large hydro power	Run-of-river power plants	months	low	2.53~16.37	220.380
	Storage power plants	months	low	not considered	220.380
Small hydro power		months	high	2.69~24.93	10.30
Landfill gas		year	low	2.50~3.91	1.30
Sewage gas		year	medium	2.85~6.24	1.30
Photovoltaics		days, hours, seconds	high	47.56~165.32	<1
Solar thermal electricity		days, hours, seconds	low: country-specific	12.48~66.97	1.30
Tidal		12 hours	high	not considered	10.380
Wave		weeks	high	9.38~45.16	10.380
Wind	On-shore	hours, minutes	low: country-specific	4.63~10.80	30.380
	Off-shore	hours, minutes	low: country-specific	6.09~13.39	110.380

Intensity and Frequency Characteristics of Renewable Sources

System	Major Periods	Major Variables	Power Relationship	Comment	Approximate Time Variation
Direct sunshine	24 h, 1 y	solar beam radiance $G_b^* \ (W/m^2)$, beam angle from vertical q_z	$P \propto G_b \cos\theta_z$; $P_{max} \cong 1kW/m^2$	daytime only, highly fluctuating	hours to seconds
Diffuse sunshine	24 h, 1 y	cloud cover, perhaps air pollution	$P < \sim 300W/m^2$	significant energy, however	day
Biofuels	1 y	soil condition, solar radiation, water, plant species, wastes	stored energy $10MJ/kg$	many variations, linked to forestry and agriculture	year
Wind	1 y	wind speed u_o nacelle height above ground z, height anemometer mast h	$P \propto u_o^3$ $\frac{u_z}{u_h} = (\frac{z}{h})^b$	highly fluctuating $b \approx 0.15$	minutes to hours for wind farms
Wave	1 y	reservoir height H_s wave period T	$P \propto H_s^2 T$	high power density $\approx 50kW/m$ across wave front	week
Hydro	1 y	reservoir height H water volume flow rate	$P \propto HQ$	established resource	months
Tidal	12 h, 25 min	tidal range R; contained area A; estuary length L; depth h	$P \propto R^2 A$	enhanced tidal range if $L/\sqrt{h} \approx 36000 m^{1/2}$	12 h
Geothermal	none	temperature of aquifer or rock formation, hence temperature difference from ambient	$P \propto (\Delta T)^2$	very few suitable locations for electricity generation	none

Solar Energy Intensity

- **Energy sunlight (1372 W/m^2) is filtered through the atmosphere and is received at the surface at ~1000 watts per square meter or less; average is 345 W/m^2**
- **Air, clouds, and haze reduce the received surface energy**
- **Capture is from heat (thermal energy) and by photovoltaic cells yielding direct electrical energy**

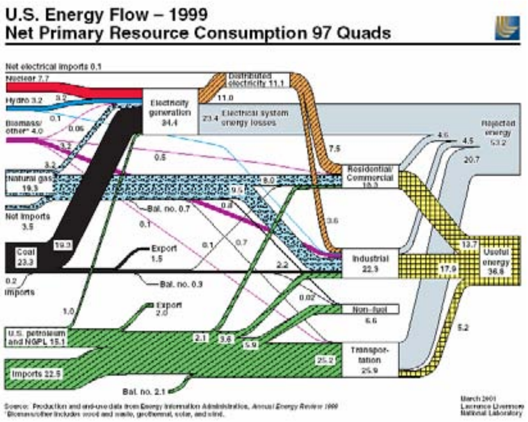
- Solar "constant" varies with sun and measurement accuracy

Calculation of Electricity Generation Costs

- **Annual running costs are split into fuel costs and operation and maintenance (O&M) costs.**
- **Fuel costs are a function of the fuel price of the primary energy carrier and efficiency. O&M costs must refer to electricity output.**

$$C = C_{var} = C_{fuel} + \widetilde{C}_{O\&M} - R_{heat} = \frac{p_{fuel}}{\eta_{el}} + \frac{C_{O\&M}}{H} \cdot 1000 - p_{heat}\frac{\eta_{heat}}{\eta_{el}} \cdot \frac{H_{heat}}{H_{el}}$$

$$C = C_{var} + \frac{C_{fix}}{q_{el}} = (C_{fuel} + \frac{C_{O\&M}}{H_{el}} \cdot 1000 - R_{heat}) + \frac{1000 \cdot I \cdot CRF}{H_{el}}$$



How Much Solar Energy Strikes Earth?

The Sun gives off 3.90x10²⁶ Watts

The Earth intercepts energy equal to a disk equal to the Earth's diameter

Earth's radius is 3,393,000 meters

Earth's solar interception area is (3.14)(3,393,000)^². This equals 3.62x1013 m²

The amount of power crossing Earth's orbit is 1388 watts / m²

Therefore: the Earth intercepts 5.02x10¹⁶ watts

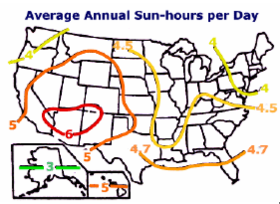
Therefore, the Earth intercepts 50 quadrillion watts of solar power each day.

Variations in Surface Energy Affect Potential Capture

- **A flat-plate absorber aimed normal to the sun (directly at it) will receive energy diminishing according to the amount of atmosphere along the path (overhead air mass Ξ 1)**
- **The received energy varies around the World due to local cloud attenuation.**
- **For example in Arizona, direct normal radiation is 5.0 to 5.5 kWh/(m^2 - day)**
- **In USA, daily solar energy varies from <3.0 to 7.0 kWh/(m^2 - day)**

Solar Energy: Thermal

- **Low-temperature extraction of heat from ground; ~70° F to 80° F**
- **Water heating for home and business; ~90° F to 120° F**
- **High-temperature process-heating water for industry; ~200° F to 400° F**
- **Solar thermal power plants; ~1000° F**

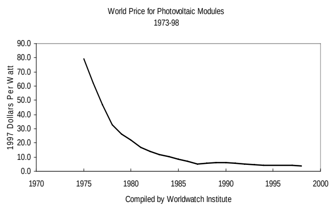


Arizona has higher sunlight irradiation than Florida

From www.energy.ca.gov/education

Solar Energy: Photovoltaic Sunlight to Electricity

- Photovoltaic cells can extract about 15% of incoming solar energy; theoretical is about 21%; $/W is the key
- Low voltage direct current is produced at about 0.55 volt per cell; clusters are connected for ~16 volts output for charging a 12 volt system
- Arrays of cells (modules) can be fixed or can track the sun for greater energy gain
- Storage is required unless the energy is inverted to 120 Vac to synchronously drive the utility grid



PV prices are falling, though still relatively expensive compared to wind or fossil utility power

Roof-Top Solar Array Computations

- Find the south-facing roof area; say 20 ft * 40 ft = 800 ft^2
- Assume 120 Wp solar modules are 26 inches by 52 inches; 9.4 ft^2/120 watt; 12.78 W/ft^2
- Assume 90% of area can be covered, 720 ft^2, ~9202 W and that there are 5.5 effective hours of sun/day; 51 kWh/day
- The south-facing modules are tilted south to the latitude angle
- 76 modules would fit the area, but 44 would provide an average home with 30 kWh/day and cost ~$17600 for modules alone, ~one mile of powerline

Siemens Solar SM110

Maximum power rating, 110 W

Minimum power rating, 100 W

Rated current. 6.3 A

Rated voltage, 17.9 V

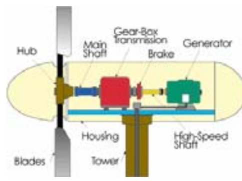
Short circuit current, 6.9 A

Open circuit voltage, 21.7 V

Wind Energy

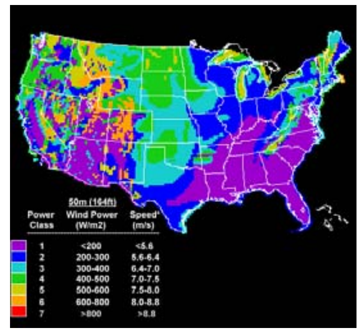
- Wind energy results from uneven heating of the atmosphere
- Wind resources vary greatly worldwide, even within a few miles
- Power is proportional to the wind speed cubed

Ref.: www.freefoto.com/pictures/general/ windfarm/index.asp?i=2



Wind Energy in Practice

- Early Twentieth Century saw wind-driven water-pumps commonly used in rural America, but the spread of electricity lines in 1930s (REA) caused their decline
- Favorable California tax incentives resulted in major U.S. wind farms
  - Altamonte Pass
  - Tehachapi
  - San Gorgonio Pass
- Other turbines are located in Dakotas, Iowa, Texas, WA, OR, KS, Minnesota, Wyoming, Iowa, Vermont, NY, VA, etc.



www.nrel.gov/wind/usmaps.html

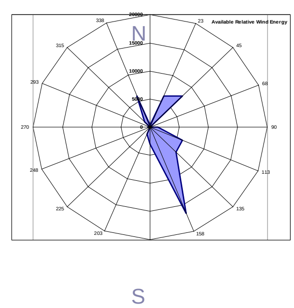
Wind Energy is Higher in the Great Plains

- High average wind speeds in the Rocky Mountain Region (300 to 1000 W/m^2) and the Great Plains States (200 to 250 W/m^2)
- Coastal Florida has Class 2 wind energy (160 to 240 W/m^2) per the PNNL Wind Energy Atlas — sufficient to investigate but marginal for major wind energy systems

Nat'l Wind Tech. Center (NWTC) F. Leslie, 2003

Predominant Wind Energy Direction Determines the Site Selected

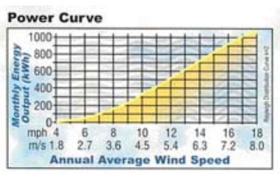
- The energy rose is the cube of the wind speed rose (flower-like)
- In Palm Bay, Florida, this day's wind data sample shows the main wind direction at 150 degrees azimuth
- Several years of data are averaged to get a useful sample; >5 years is desirable
- In obstructed areas, the site selection is critical to obtain the maximum wind energy



Energy Is Proportional to Wind Speed Cubed

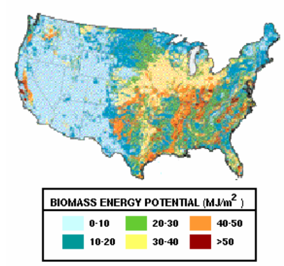
- Recall that the average wind power is based upon the average of the speed cubed for each occurrence
- The wind energy varies from trivial to disastrous!
- Precautions are needed to protect the turbine

Turbines must be turned automatically out of destructive winds to protect them. Some turn sideways, while others rotate vertically. Another way is to drag flaps from the tip of the blades. Most turbines reject power when the wind speed exceeds 30 mph.



Bioenergy (From Biomass)

- Direct firing, cofiring, and gasification are forms of biopower
- Ethanol can be made from grain or soybeans, and methanol can be made from cellulose
- Liquid fuels are essential for transportation vehicles due to high energy density
- May be intentionally grown (coppicing) such as poplar trees or might use waste byproducts
- Biomass can serve as a bridge from fossil fuels, although it is an inefficient producer of energy

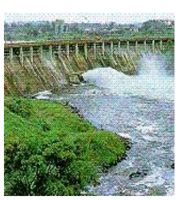


Annual photosynthetic energy fixed by a single species typical of local land cover. Assumes typical management practices (including irrigation).

www.seco.cpa.state.tx.us/.../ re_renew_maps_bio_poten.htm

Hydroelectric Energy (Dams)

- The solar distillation of ocean and surface waters and ground moisture produces rain that stores potential energy above sea level
- The impoundment of this water energy has long been used for generation of electricity
- Hydro dams were commonplace in the 1930's, but many have fallen into disuse and were removed
- Once installed, these systems produced low cost electricity



World's largest storage dam, Uganda's Owen Falls Dam. The hydroelectric station at the dam supplies most of the electricity requirements of Uganda, and parts of Kenya. (Photo:Faculty of Engineering, Kasetsart University, Thailand)

Newhalem WA Gorge Plant; photo: Leslie, 2002

Hydroelectric Energy (continued)

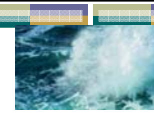
- Most useful sources have been exploited years ago
- Dams are under attack by environmentalists who want water unhindered for fish passage, recreation, and for endangered species
- Small scale hydropower still has a lot of potential for growth.

Large Hydroelectric Plants

The energy from Itaipu represent for Brazil and Paraguay:
In the year 2000 the production from Itaipu supplied almost one quarter (more precisely 24.25%) of the electric energy demand in Brazil and 93.57% of the electric energy consumed in Paraguay.

Power of Itaipu:
The installed capacity of Itaipu is 14 **14,000 MW.**

Ocean Energy



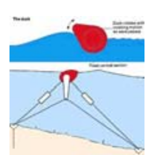
- **The tidal gravitational forces and thermal storage of the ocean provide a major energy source**
- **Wave action adds to the extractable surface energy, but is less than tidal energy**
- **Major ocean currents (like the Gulf Stream) may be exploited to extract energy with underwater rotors similar to wind turbines**
- **Offshore winds are unhindered and strong**

Ocean Energy: Tidal Energy

- **Tides are produced by gravitational forces of the moon and sun and the Earth's rotation (24 hour, 50 minute period)**
- **Existing and possible sites:**
  - France: Rance River estuary 240 MW station
  - England: Severn River
  - Canada: Passamaquoddy in the Bay of Fundy (1935 attempt failed; not economically practical)
  - California: high potential along the northern coast
- **Environmental, economic, and esthetic aspects have delayed implementation**

Ocean Energy: Wave Energy

- **Salter "ducks" rock up and down as the wave passes beneath it. This oscillating mechanical energy is converted to electrical energy**
- **A Wavegen, wave-driven, air compressor or oscillating water column (OWC) spins a Wells turbine to produce electricity regardless of flow direction**

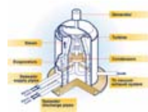


Ref.: www.fujita.com/archive-frr/ TidalPower.html

Source: Wave Energy paper. IMechE, 1991 and
European Directory of Renewable Energy (Suppliers and Services) 1991

Ocean Energy: OTEC (Ocean Thermal Electric Conversion)

- Hawaii has the research OTEC system http://www.hawaii.gov/dbedt/ert/pubs.html
- OTEC requires some 40°F temperature difference between the surface and deep waters to extract energy
- Open-cycle plants vaporize warm water and condense it using the cold sea water, yielding potable water and electricity from turbine-driven alternators
- Closed-cycle units evaporate ammonia at 78°F to drive a turbine and an alternator

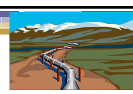


Geothermal Energy

- First electricity from geothermal produced in Italy in 1903 in Larderello (southern Tuscany)
- Active geysers supply steam or hot water for heating in The Geysers, California (824 MWe)
- "Hot, dry rock" (HDR) offers potential for injecting water and using the resultant steam to spin a turbine
- At a lower thermal level, an air conditioner can extract heat from the ground for winter heating or insert energy into the ground to gain a more efficient cooling sink

www.eren.doe.gov/geothermal/ geysers20.html

Energy Transmission



- Electricity and hydrogen are energy carriers, not natural fuels
- Electric transmission lines lose energy in heat (~2 to 5% as design parameter)
- Line energy flow directional analysis can show where new energy plants are required
- Hydrogen is made by electrolysis of water, cracking of natural gas, or from bacterial action (lab experiment level)
- Pipelines can transport hydrogen without appreciable energy loss
- A 40-ton truck delivering H2 and tapping the load as fuel could travel 800-miles --- and arrive empty [The Hydrogen Hallucination - The 'Freedom Fuel' Leaves Us in Chains", Energy Central, ***9.25.03***]

Energy Storage

- Renewable energy is often intermittent, and storage allows alignment with time of use.
- Compressed air, flywheels, weight-shifting (pumped water storage) are developing
- Batteries are traditional for small systems and electric vehicles; grid storage alternative
- Energy may be stored financially as credits in the electrical "grid"
- "Net metering" provides the same cost a sale dollars to the supplier; 37 states' l needed in Florida

www.strawbilt.org/systems/ details.solar_electric.html

Energy in Transportation

- Air and ground transportation require energy-dense fuels (liquids) and fueling infrastructure
- Fixed natural gas energy plants compete with CNG for cars and trucks
- Research is on-going with hydrogen based fuel cell powered cars.

Compressed natural gas car

Energy in Transportation

- Brazil has a biomass program since 1974 => The Pro-Alcohol Program, the first massive ethanol program for fueling cars.
- Brazilian car makers are "flex fuel" cars, which can be powered by gasoline or sugar-based ethanol, or a mixture of both.
- The Pro-Alcohol is soothing public concerns about air pollution and Brazilian oil reserves. Total imported oil in Brazil is less than 20%.

São Paulo City has 7.7 million of cars

Each alcohol powered car keeps 29 jobs in the sugar-cane plantation industry

Distributed Generation (DG)

- Distributed generation (DG) is the application of small generators, typically 1–10 MW, scattered throughout a system to provide electrical energy closer to consumers. Current DG power sources include hydropower, wind, photovoltaics, diesel, fuel cells, and gas turbines. Renewable and other generators located downstream in a distribution network and involving small, modular electricity generation units close to the point of consumption are defined in this book as DG.
- Distributed generation occurs when power is generated (converted) locally and might be shared with or sold to neighbors through the electrical grid
- Distributed generation avoids the losses that occur in transmission over long distances; energy used nearby
- Varying wind and sunshine averages across several houses, blocks, cities, or states
- Supply is robust, but precautions are required to protect electricity workers when main base-load power is out and system may feed back into powerlines

Generic Trades in Energy

- Energy trade-offs are required to make rational decisions
- PV is expensive ($5 per watt for hardware + $5 per watt for shipping and installation = $10 per watt) compared to wind energy ($1.5 per watt for hardware + $5 per watt for installation = $6 per watt total)

Ref.: www.freefoto.com/pictures/general/windfarm/index.asp?i=2

Ref.: www.energy.ca.gov/education/story/story-images/solar.jpeg

Photo of FPL's Cape Canaveral Plant by F. Leslie, 2001

Transmission and Distribution

T&D

- The thickness, and hence cost, of conducting cable is inversely proportional to the voltage of power.
- Therefore, high voltages are preferred for electricity supply along transmission and sub-transmission lines. The practical limits relate to safety issues, especially sparking and insulation at high voltage.

In practice,

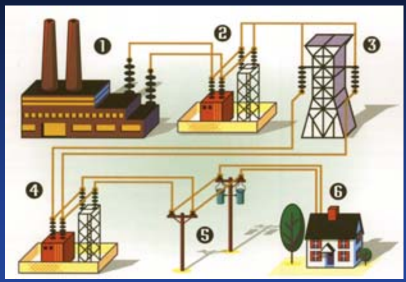
- Voltage of long-distance transmission is 50–750 kV
- Local area distribution is 6–50 kV
- Supply to consumers is 100–500 V.
- Internally, in equipments, it is 3–48 V

Grid electricity is converted from the primary source by:

- Moving wires in magnetic fields (Faraday effect)
- Photovoltaic generation with sunlight (photovoltaic effects)
- Chemical transformations, e.g., in fuel cells and batteries (electrochemical effects)

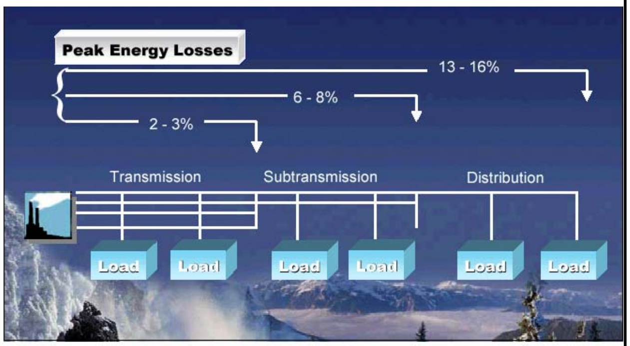
How electricity gets to you

conectiv



When electricity leaves a power plant (1), its voltage is increased at a “step-up” substation (2). Next, the energy travels along a transmission line to the area where the power is needed (3). Once there, the voltage is decreased, or “stepped-down,” at another substation (4), and a distribution power line (5) carries the electricity until it reaches a home or business (6).

– EEI, Getting Electricity Where It’s Needed, May 2000



Injection of RE Power

- The implementation of a small renewable energy system is probably going to be at the power distribution level.
- Medium and large renewable energy systems may be implemented at the transmission level by utilities
- Discussion of terminology : Generation, Transmission and Distribution

Transmission / Distribution Lines

- ROLE: Minimize i^2R losses in system
- Transmission: 69, 138, 230, 500, 765 kV
- Distribution: 4 - 34.5 kV (12-13.8 kV common)

Interconnected RE Systems

- Depend on voltage and frequencies in different countries

Standards for Voltage and Frequency in Several Countries

Country	Voltage (V)	Frequency (Hz)
Australia	230	50
Brazil	110/220	60
Canada	120	60
China	220	50
Cyprus	240	50
Egypt	220	50
France	230	50
Guyana	240	60
South Korea	220	60
Mexico	127	60
Japan	100	50 and 60
Russian Federation	220	50
Spain	230	50
Taiwan	110	60
United Kingdom	230	50
United States	120	60

Interconnected RE Systems

- Depend on voltage and frequencies in different countries.
- Depend on regulation
- Protection and reliability are concerns
- It may be required to have power electronic circuits (PV, fuel cells, small wind, small hydro) or maybe possible to be connected directly (wind and hydro) with electrical generators without power electronics
- For electrical generators without power electronics there might be a need to supply reactive power if the generator is an induction machine.

Frequency of an Electrical Generator

$$f = \frac{p}{120} n$$

- Where n is the rpm and p is the number of magnetic poles
- Examples

  Power Generation (1900)

  12 pole machine running at 250 rpm (first machine used for Niagara Falls).

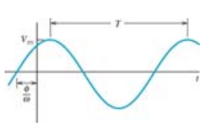
  Industrial Drives (1920)

  10 pole machine running at 200 rpm (low frequency generation providing ac supply for series dc motors).

Interconnected Electrical Generators

- **In USA, until 1940s the generators were not interconnected**
- **What happens when they are interconnected ?** **DISCUSSION**
- **Why they became interconnected after 1940s ?** **DISCUSSION**

Sinusoidal Sources



$$v(t) = V_m \sin(\omega t + \phi)$$

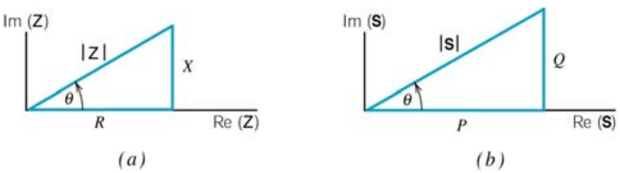
$$V_{rms} = V_m \sqrt{(\cos^2 \omega t)_{avg}} = V_m \sqrt{\frac{1}{2}} = \frac{V_m}{\sqrt{2}}$$

- **T is period of oscillation**
- **f = 1/T (frequency)**
  - Units of Hertz
  - Cycles per second
- **$\omega = 2\pi f$**
  - Angular frequency
  - Radians per second
- **ϕ = phase angle**
  - Offset from zero
  - May be degrees or rads

Power Factor

- **Typically, *average power*, *watts*, also called *real power* is represented by the following equation:**
  - P_{avg} = VI cos ϕ = VI x Power Factor
  - Where ϕ is the phase angle between V and I
- **Therefore, the power factor is identical to:**
  - cos ϕ
  - PF = cos ϕ
- **This definition of power factor is valid only for sinusoidal voltages and currents**
- **When there are harmonics, the total harmonic distortion must be considered.**
  - Such issues will be discussed on the lecture about inverters

Complex Power



(a) **The impedance triangle where Z = R + jX**
The complex power triangle where S = P + jQ

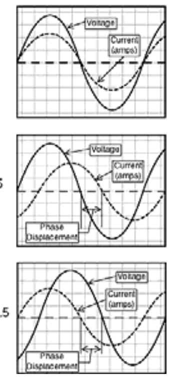
Resistive and Reactive Loads

Displacement Power Factor

Resistive Load — Power Factor = 1
Current is in time with Voltage — Unity

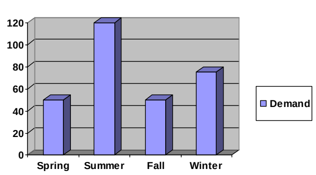
Reactive Load (inductive) — Power Factor = .5
Current flows after Voltage — Lagging

Reactive Load (capacitive) — Power Factor = .5
Current flows before Voltage — Leading



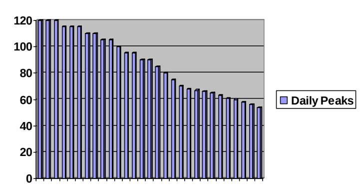
Load

- Climate and the time of season impact the demand for heating, cooling and lighting.
- The mix of customer base determines the end-use form of energy demanded and the peak time of day.
- The type of energy conversion equipment owned by consumers also has an impact on the relative demand for different types of energy at different times of the day and year, for example as recorded by the figure, with demand in kW.

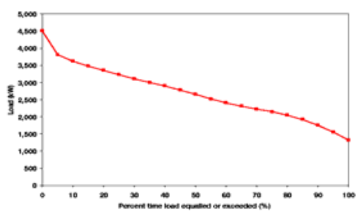


Load – Cont.

- The previous figure does not reveal any data on *average* demand during the seasons.
- It only reports the highest instantaneous level of demand (the peak) in each season.
- The next figure displays daily peaks in decreasing order of magnitude.



- If the RES is connected to a central–grid, we may assume that the grid absorbs all of the energy production, and the load does not need to be specified.
- On the other hand if the system is connected to an isolated–grid, then the portion of the energy that can be delivered depends on the load on the grid.
- A load–duration curve may be specified by twenty one values L_0, L_5, ... , L_{100} defining the load on the load–duration curve in 5% increments L_k represents the load that is equalled or exceeded k % of the time.



Energy Demand

- Daily energy demand is calculated by integrating the area under the load duration curve over one day. A simple trapezoidal integration formula is used. The daily demand, D_d, expressed in kWh is therefore calculated as:

$$D_d = \sum_{k=1}^{20} \left(\frac{L_{(k-1)} + L_k}{2} \right) \frac{1}{100} 24$$

where

L expressed in kW.

D = The annual energy demand that is obtained by multiplying the daily demand by the number of days in a year, 365: $D=365D_d$

- The average load factor $\bar{L}$ is the ratio of the average daily load (Dd/24) to the peak load (L_0):

$$\bar{L} = \frac{D_d / 24}{L_0}$$

Energy Production

- The energy production will depend on:
  - **Source availability**
  - **The load (load–duration curve)**
  - **Efficiencies/losses.**
- The calculation involves comparing the daily renewable energy available to the daily load–duration curve.

Evaluation of Losses

- It is important to evaluate the losses for small renewable energy systems
- Wiring is a major factor of losses
- Voltage drops should be limited to less than 2% whenever possible, the following equation is useful:

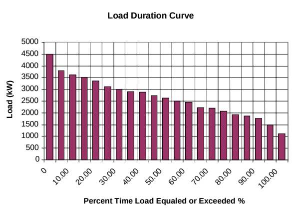
$$\frac{V_{load}}{V_{source}} = \frac{1}{1 + \left(\frac{R_{wire}}{R_{load}} \right)} = \frac{1}{1 + \text{resistivity} * \left(\frac{\frac{\text{lenght}}{\text{Area}}}{R_{load}} \right)}$$

- The copper resistivity can be assumed at room temperature to be :

$$\rho = 1.673 \times 10^{-8} \Omega m$$

Load Duration Curve

- **If the RES system is connected to an isolated-grid, then the portion of the energy that can be delivered depends on the load on the grid.**
- **A load-duration curve may be specified by twenty one values L0, L5, ... , L100 defining the load on the load-duration curve in 5% increments Lk represents the load that is equalled or exceeded k % of the time.**



Energy Production

- The energy production will depend on:
  - **Source availability**
  - **The load (load–duration curve)**
  - **Efficiencies/losses.**
- The calculation involves comparing the daily renewable energy available to the daily load–duration curve.

Interaction of Environment and Electric Energy

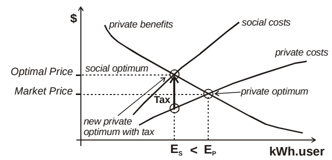
- Such interaction, through an economic analysis, sometimes binds incompatible perspectives.
- Electric energy is not found in nature directly (only on lightening and statics).
- Electric energy has to be converted from fossil fuels (oil, coal and natural gas), nuclear power, hydropower (large scale renewable) and small-scale renewable sources as wind and solar.
- Non-renewable sources have a very high energy density at the expenses of generating wastes and pollutant by-products.
- The valuation of costs associated with pollution and resource depletion must be taken in consideration to estimate the social costs against the social benefits of energy production.

Private Benefits

- The figure shows the demand of energy for a kWh consumed by users. The private cost i.e. supply is indicated in the figure with a private optimum at energy.
- There are costs not included under utilities perspectives: some losses may happen and affect people. Perhaps, landscape has been transformed to give space for a coal thermal plant, or pollution transformed the perceived impact of the environment on people.
- Accumulated carbon dioxide may have been increased due to loss of land area including beaches and wetlands, thinning of species and forest area with heat waves, droughts and disruption of water supplies.
- Climate change is very hard to quantify as social costs, but surely represents a curve to be considered to find an optimal social cost for an energy investment

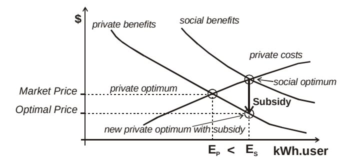
Private Benefits – Cont.

- One way to have an ecosystem market oriented policy is to raise the price of the energy with a pollution tax, as indicated by the arrow. A pollution tax looks like a simpler procedure to make consumers buy less of the "pollution creating source" at tight regulatory government guidelines
- If all private benefits are captured by social benefits, the new intersection represents a new equilibrium point representing a compromise between the society's need for energy and the one's desire to keep a resilient ecosystem.



Social Benefits

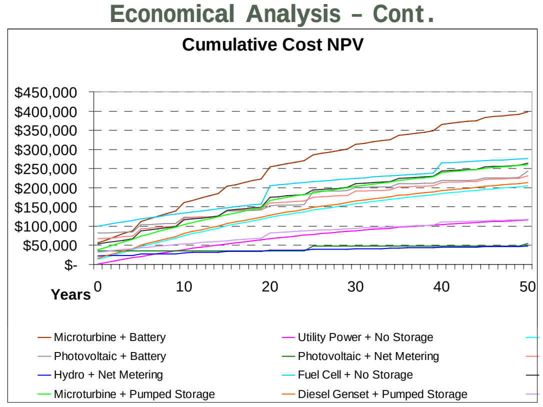
- Green energy could be fostered by encouraging private investors in small distributed energy, for example, small more efficient hydropower plants, CHP and combining agricultural processing machines with local energy production.
- Provisions for hybrid systems incorporating hydro, solar and wind installations will make each technology capable of complementing or circumventing the gaps in power generation.
- The arrow indicates a subsidy that lowers the costs, through tax rebate, or offering payments for green power investments and purchase of on-site generated power.



Economical Analysis

- Initial capital costs, periodic capital costs, and annual operating costs must be gathered for each of the generation and energy storage alternatives.
- These costs must be entered into a spreadsheet in today's dollars.
- Periodic capital costs and annual operating costs must be projected into the future using a Price Inflation Rate.
- Actual expenditures must be summed for each year to determine the costs for that particular year.
- Yearly expenditures must be discounted back to today's dollars using the Discount Rate.
- A cumulative cost Net Present Value (NPV) must be calculated by adding each year's NPV to the sum of the prior year's NPVs. The Cumulative Cost NPV can be plotted on a common chart.

Economical Analysis – Cont.



Economical Analysis – Cont.

- Price Inflation Rate and the Discount Rate chosen for the analysis have a significant impact on the final results. Increasing the Price Inflation Rate tends to increase the general slope of the individual NPV lines, while increasing the Discount Rate tends to flatten the general slope of the individual NPV lines. Increasing the Discount Rate tends to place more weight on the initial capital costs, while decreasing the Discount Rate places more emphasis on the annual operating and periodic capital costs.

- Selection of a preferred energy generation and storage combination may be accomplished by simply selecting the number of years over which the combinations are to be evaluated, and select the combination with the lowest Cumulative Cost NPV at that point in time. This analysis assumes that no revenues are generated, therefore the analysis is performed based on lowest NPV cost over the evaluation period.