Introduction to Renewable Energy Resources

Mechanical Engineering 496ALT

Alternative Energy

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March 3, 2009

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Project proposals due tonight!

Homework due March 5.

Assigned reading for tonight – Chapter 9 on renewable energy technologies

Assigned reading for Thursday, March 5 and Tuesday, March 10 – Chapter 13 on solar energy

Main Ideas

- What are renewable resources?
- What are common factors to consider in their analysis
  - Solar energy
  - Wind energy
  - Other renewable resources
    - Ocean energy (tides, waves and temperatures)
    - Geothermal energy
    - Hydropower
  - Biomass fuels

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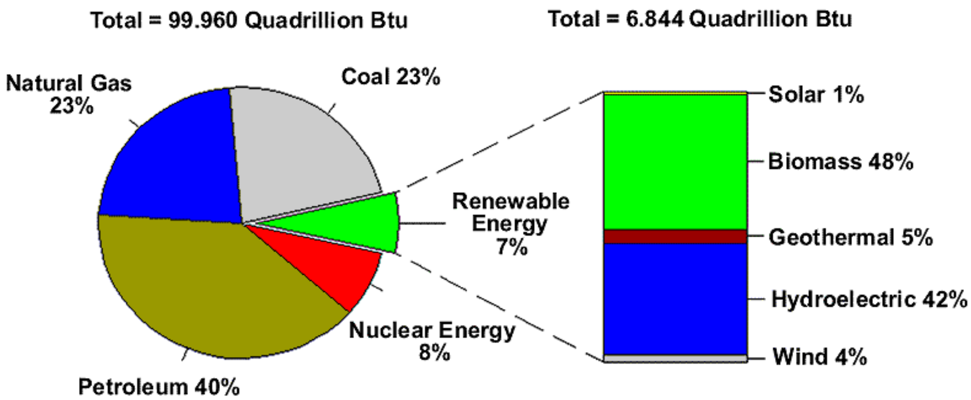
The general theory of fossil fuels is that they were formed over millions of years from decay of organic material from dead plants and animals. In this sense, fossil fuels are renewable resources; they just take millions of years to renew themselves.

The general definition of renewable resources are those that are readily available in nature, such as solar energy and wind energy. It also includes resources that can be renewed in short periods of time such as biomass fuels. The latter include alcohols produced from agricultural products that can be used as a transportation fuel, municipal solid waste, agricultural waste, and crops grown for fuel use.

Hydroelectric power is also considered a renewable resource under this definition, however “new” technology is focused on the development of smaller hydroelectric projects.

US Renewable Use 2006



- Solar + geothermal + wind = 10% of renewables = 0.7% of total energy

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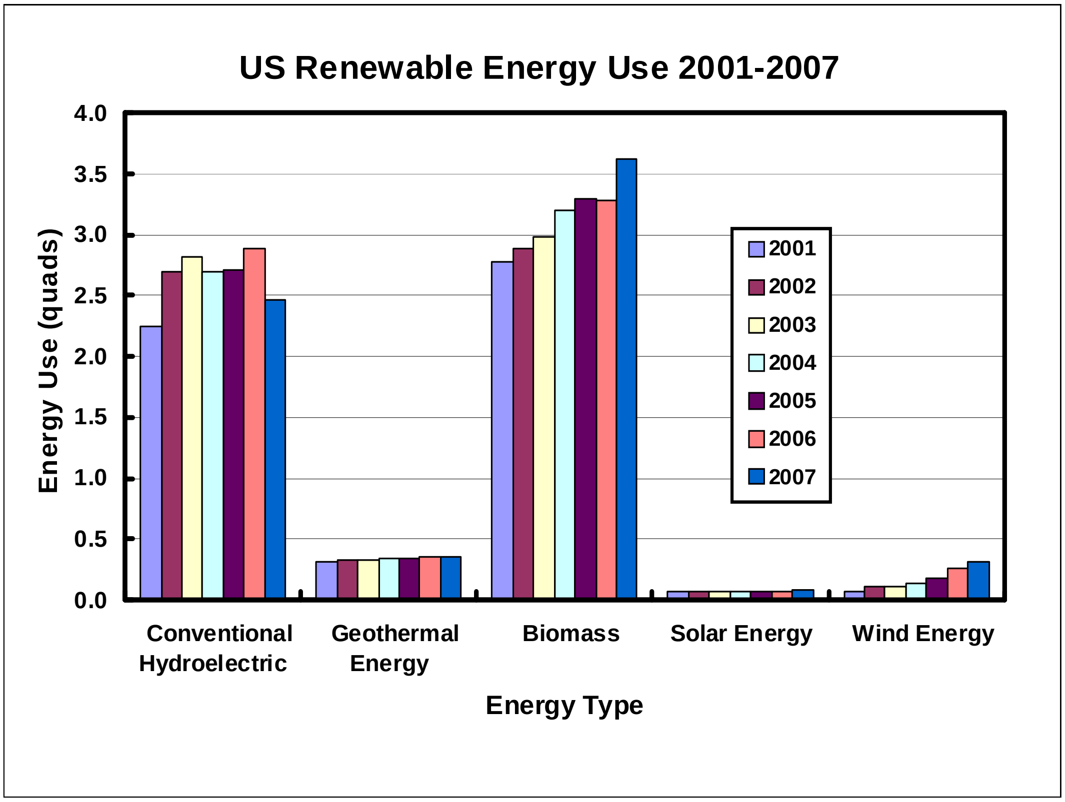
Reference: http://www.eia.doe.gov/cneaf/solar.renewables/page/prelim_trends /rea_prereport.html accessed February 28, 2008

This shows the contribution of various energy sources to the total US supply in 2005. Renewable energy contributed only 6% and the majority of at contribution came from biomass and conventional hydroelectric. Although these are renewable fuels, they are not really new. Hydroelectric power does not have a great potential for expansion. Although biomass has many proponents, there are many concerns about its use and the overall impact of biomass fuels on land use and food supply.

Solar and wind account for 5% of 7% or about 0.35% of the US total energy use. Geothermal has about the same use as solar and wind combined, but as the next chart shows, its growth is relatively flat compared to wind.



Plotted from data in spreadsheet on renewable consumption downloaded from http://www.eia.doe.gov/cneaf/solar.renewables/page/prelim_trends/rea_prereport.html on March 2, 2009.

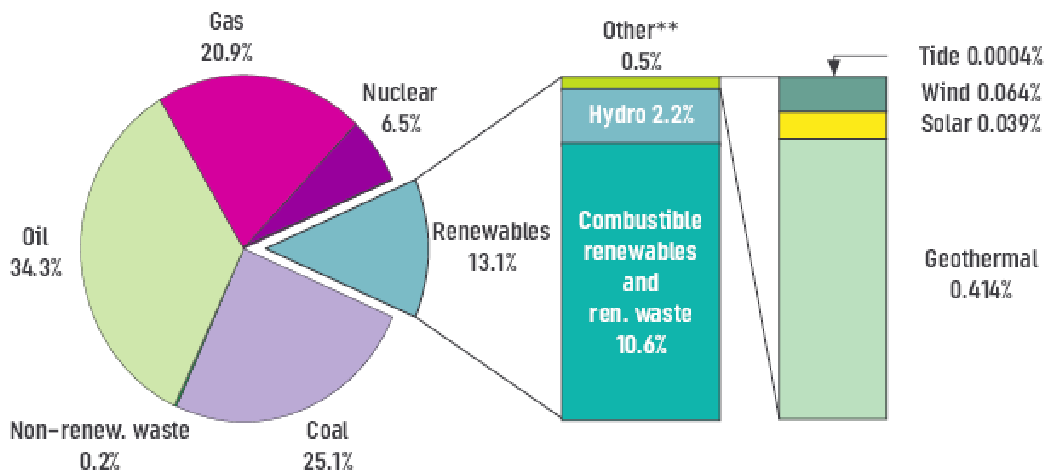
Biomass includes: black liquor, wood/wood waste liquids, wood/wood waste solids, municipal solid waste (MSW), landfill gas, agriculture byproducts/crops, sludge waste, tires, biodiesel, ethanol, losses and coproducts from production of biodiesel and ethanol, and other biomass solids, liquids and gases. The growth in biomass is due, in large part, to the use of alcohol fuels for motor vehicles.

Solar includes solar thermal and photovoltaic electricity net generation.

Since the annual energy use in the US is about 100 quads, the data in quads shown here can be interpreted as a percent of the total energy consumption supplied by renewable sources. This slide also shows that solar and wind energies, which have received much attention, are seen to account for about 0.1% to 0.2% of the total energy use in the US.

Wind has the highest relative growth rate among alternative energy sources (although it is still quite small in an absolute sense) because it is cost competitive with conventional energy sources, especially when there is a tax incentive known as the Production Tax Credit (PTC) of 1.5 ¢/kWh.

World Renewable Use 2004



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Reference: Pamphlet available from IEA web site; it's URL is http://www.iea.org/textbase/papers/2006/renewable_factsheet.pdf accessed February 29, 2008.

The majority of the renewable energy sources are from combustion; these typically include combustion of wood and waste as well as the use of biofuels. Conventional hydro makes up the second largest portion. This is the same ranking as in the US, but the combustible renewals are a larger fraction of the total for the world than in the US. The world use of solar energy and wind energy is 0.105% of the world total, which is less than in the the figure of 0.3% for the US.

Virtually all the tidal energy comes from a single source: the 240 MW tidal power station in La Rance, France.

World Renewables 2004	TPES*	Share of Renewables in TPES	
		A	B
	Mtoe	%	%
Africa	586.0	49.0	1.4
Latin America	485.5	28.9	10.9
Asia	1289.4	31.8	2.4
China	1626.5	15.4	1.9
Non-OECD Europe	104.3	10.6	4.8
Former USSR	979.3	3.0	2.2
Middle East	479.8	0.7	0.5
OECD	5507.9	5.7	2.7
World	11058.6	13.1	2.7

TPES = total primary energy supply

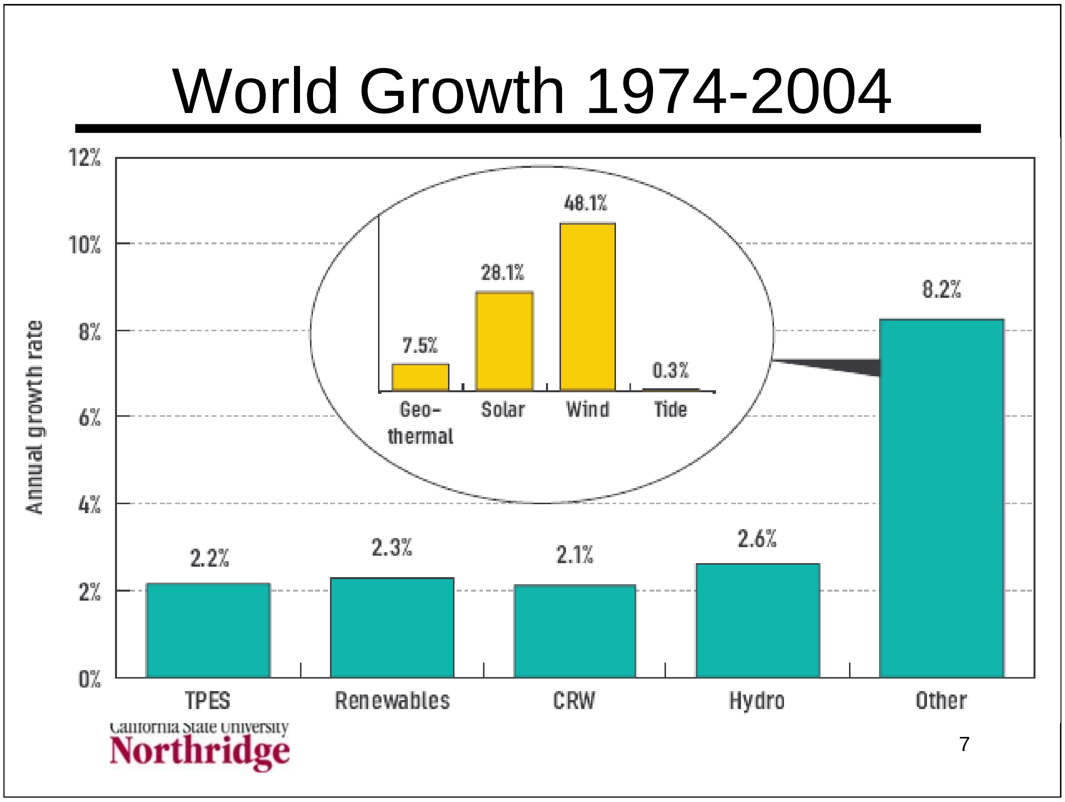
Mtoe = Million tonnes of oil equivalent

A is share of total renewables

B is share of renewables excluding combustion renewables and waste

Reference: Pamphlet available from IEA web site; it's URL is http://www.iea.org/textbase/papers/2006/renewable_factsheet.pdf

The major part of renewable energy in the world is from combustion of wood and waste. Note that hydroelectric power is included in the B share. Hydroelectric power makes a major contribution to the large B share for Latin America. (The reference from which these data are taken has data for individual countries. Paraguay has 111.1% of its TPES from B renewables.)



Reference: Pamphlet available from IEA web site; it’s URL is http://www.iea.org/textbase/papers/2006/renewable_factsheet.pdf

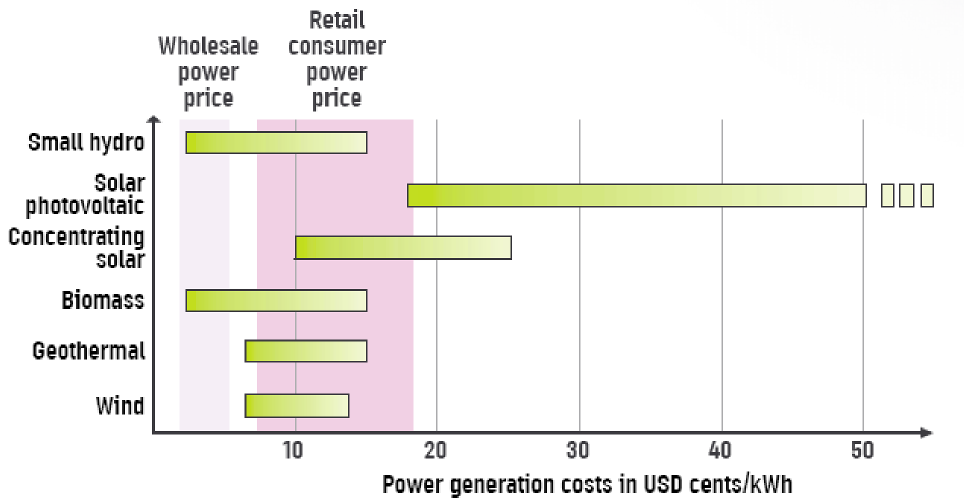
Legend:

TPES = Total Primary Energy Supply

CRW = Combustion Renewables and Waste

The growth rates shown in this chart are the percent per year for the thirty-year period from 1974 to 2004. Although the percentage growth in “Other” or “New” renewables has been quite large, it is a percentage growth of a very small amount for each of these components in 1974.

Power Generation Costs



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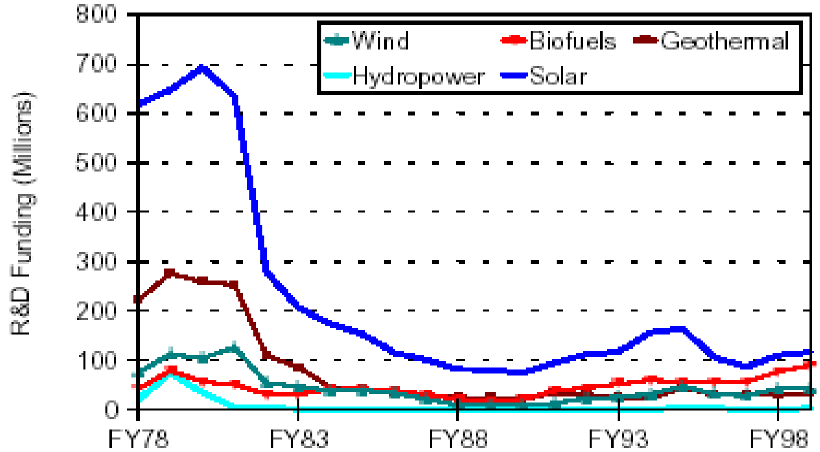
Reference: Pamphlet available from IEA web site; it’s URL is http://www.iea.org/textbase/papers/2006/renewable_factsheet.pdf

The worldwide consumer cost of electricity shown on this chart is somewhat greater than that in the US. The costs for renewables shown here, the generation cost, is generally not competitive with that for wholesale power generation. The exceptions are small hydro and biomass. However, the upper range of the costs for these technologies are well above the range for wholesale power.

Small hydro and biomass are the most cost competitive. Geothermal and wind are next. A limited number of geothermal resources, such as the Geysers in Lake, County, California, are currently cost-competitive.

- **Figure 1. R&D Funding for Selected Renewable Energy Technologies** (1999 Dollars)



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Direct quote from conclusion on pages 16 and 17 of DOE/EIA report *Renewable Energy 2000: Issues and* Trends, DOE/EIA-0628(2000), February , 2001. Downloaded from the web site http://www.eia.doe.gov/cneaf/solar.renewables/rea_issues/062800.pdf in 2001. A similar chart was not available in the current report on renewable energy accessed March 5, 2007 at the web site http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea.pdf

"The cost of photovoltaic and wind electricity generation has declined consistently over the past 20 to 25 years. Federal renewable energy R&D, though inconsistently funded, has been undertaken continuously during this time. **Although available data are insufficient to establish a quantifiable relationship between R&D funding and renewable energy cost reduction, the data suggest that such benefits have occurred.** Together, the Federal and State incentives, mandates, and support programs, including R&D, have been effective when measured by growth in electric generating capacity and electricity generation, or, in the transportation sector with growth in ethanol production. However, they failed to ensure the future self-sustainability of renewable facilities that would substantially contribute to the overall energy security policy of the era in which the incentives were created." (Emphasis added)

Federal Incentives

- Energy Tax Act of 1978
- Crude Oil Windfall Profits Act of 1980
- Economic Recovery Tax Act of 1981
- Surface Transportation Assistance Act of 1982
- Tax Equity and Fiscal Responsibility Act of 1982

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1978 **Energy Tax Act of 1978** (ETA) (P.L.95-618) Residential energy (income) tax credits for solar and wind energy equipment expenditures: 30 percent of the first $2,000 and 20 percent of the next $8,000. Business energy tax credit: 10 percent for investments in solar, wind, geothermal, and ocean thermal technologies; (in addition to standard 10 percent investment tax credit available on all types of equipment, except for property which also served as structural components, such as some types of solar collectors, e.g., roof panels). In sum, investors were eligible to receive income tax credits of up to 25 percent of the cost of the technology. Percentage depletion for geothermal deposits: depletion allowance rate of 22 percent for 1978-1980 and 15 percent after 1983.

1980 **Crude Oil Windfall Profits Tax Act of 1980** (WPT) (P.L.96-223) Increased the ETA residential energy tax credits for solar, wind, and geothermal technologies from 30 percent to 40 percent of the first $10,000 in expenditures. Increased the ETA business energy tax credit for solar, wind, geothermal, and ocean thermal technologies from 10 percent to 15 percent, and extended the credits from December 1982 to December 1985. Expanded and liberalized the tax credit for equipment that either converted biomass into a synthetic fuel, burned the synthetic fuel, or used the biomass as a fuel. Allowed tax-exempt interest on industrial development bonds for the development of solid waste to energy (WTE) producing facilities, for hydroelectric facilities, and for facilities for producing renewable energy.

1981 **Economic Recovery Tax Act of 1981** (ERTA) (P.L.97-34) Allowed accelerated depreciation of capital (five years for most renewable energy-related equipment), known as the Accelerated Cost Recovery System (ACRS); public utility property was not eligible. Provided for a 25 percent tax credit against the income tax for incremental expenditures on research and development (R&D).

1982 **Tax Equity and Fiscal Responsibility Act of 1982** (TEFRA) (P.L.97-248) Canceled further accelerations in ACRS mandated by ERTA, and provided for a basis adjustment provision which reduced the cost basis for purposes of ACRS by the full amount of any regular tax credits, energy tax credit, rehabilitation tax credit.

1982-1985 **Termination of Energy Tax Credits** In December 1982, the 1978 ETA energy tax credits terminated for the following categories of non-renewable energy property: alternative energy property such as synfuels equipment and recycling equipment; equipment for producing gas from geopressurized brine; shale oil equipment; and cogeneration equipment. The remaining energy tax credits, extended by the WPT, terminated on December 31, 1985.

Federal Incentives (cont'd)

- Tax Reform Act of 1986
- Energy Policy Act (EPAct) of 1992
- Energy Conservation Reauthorization Act of 1999
- Tax Relief Extension Act of 1999
- Energy Policy Act of 2005 (EPAct 2005)
- 2007 Energy Act
- 2009 Stimulus Package (HR 1)
    - American Recovery and Reinvestment Act of 2009

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Tax Reform Act of 1986 (P.L.99-514) Repealed the standard 10 percent investment tax credit. Eliminated the tax-free status of municipal solid waste (MSW) powerplants (WTE) financed with industrial development bonds, reduced accelerated depreciation, and eliminated the 10 percent tax credit (P.L.96-223). Extended the WPT business energy tax credit for solar property through 1988 at the rates of 15 percent for 1986, 12 percent for 1987, and 10 percent for 1988; for geothermal property through 1988 at the rates of 15 percent for 1986, and 10 percent for 1987 and 1988; for ocean thermal property through 1988 at the rate of 15 percent; and for biomass property through 1987 at the rates of 15 percent for 1986, and 10 percent for 1987. (The business energy tax credit for wind systems was not extended and, consequently, expired on December 31, 1985.) Public utility property became eligible for accelerated depreciation.

Energy Policy Act of 1992 (EPACT) (P.L.102-486) Established a permanent 10 percent business energy tax credit for investments in solar and geothermal equipment. Established a 10-year, 1.5 cents per kilowatthour (kWh) production tax credit (PTC) for privately owned as well as investor-owned wind projects and biomass plants using dedicated crops (closed-loop) brought on-line between 1994 and 1993, respectively, and June 30, 1999. Instituted the Renewable Energy Production Incentive (REPI), which provides 1.5 cents per kWh incentive, subject to annual congressional appropriations (section 1212), for generation from biomass (except municipal solid waste), geothermal (except dry steam), wind and solar from tax exempt publicly owned utilities and rural cooperatives. Indefinitely extended the 10 percent business energy tax credit for solar and geothermal projects.

1999 **Tax Relief Extension Act of 1999** (P.L. 106-170) Extends and modifies the production tax credit (PTC in EPACT) for electricity produced by wind and closed-loop biomass facilities. The tax credit is expanded to include poultry waste facilities, including those that are government-owned . All three types of facilities are qualified if placed in service before January 1, 2002. Poultry waste facilities must have been in service after 1999. A nonrefundable tax credit of 20 percent is available for incremental research expenses paid or incurred in a trade or business.

1978 **Energy Tax Act of 1978** (ETA) (P.L.95-618) Excise tax exemption through 1984 for alcohol fuels (methanol and ethanol): exemption of 4 cents per gallon (the full value of the excise tax at that time) of the Federal excise tax on "gasohol" (gasoline or other motor fuels that were at least 10 percent alcohol (methanol and ethanol))

1980 **Crude Oil Windfall Profits Tax Act of 1980** (WPT) (P.L.96-223) Extended the gasohol excise tax exemption from October 1, 1984, to December 31, 1992. Introduced the alternative fuels production tax credit. The credit of $3 per barrel equivalent is indexed to inflation using 1979 as the base year, and is applicable only if the real price of oil is bellow $27.50 per barrel. The credit is available for fuel produced and sold from facilities placed in service between 1979 and 1990. The fuel must be sold before 2001. Introduced the alcohol fuel blenders' tax credit; available to the blender in the case of blended fuels and to the user or retail seller in the case of straight alcohol fuels. This credit of 40 cents per gallon for alcohol of at least 190 proof and 45 cents per gallon for alcohol of at least 150 proof but less that 190 proof was available through December 31, 1992. Extended the ETA gasohol excise tax exemption through 1992. Tax-exempt interest on industrial development bonds for the development of alcohol fuels produced from biomass, solid waste to energy producing facilities, for hydroelectric facilities, and for facilities for producing renewable energy.

Incentives for alcohol fuels

- Forgives 5.4 cents per gallon (gallon of gasoline) of federal gasoline tax for fuels with at least 10% alcohol not from fossil fuel sources
- This is a subsidy of 5.4/0.1 = 54 cents per gallon of alcohol for a fuel with exactly ten percent alcohol
- Mandated fractional biofuel use in Energy Policy Acts of 2005 and 2007
  - Increasing requirement to 36% by 2022

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1982 **Surface Transportation Assistance Act** (STA) (P.L. 97-424) Raised the gasoline excise tax from 4 cents per gallon to 9 cents per gallon, and increased the ETA gasohol excise tax exemption from 4 cents per gallon to 5 cents per gallon. Provided a full excise tax exemption of 9 cents per gallon for “neat” alcohol fuels (fuels having an 85 percent or higher alcohol content).

1984 **Deficit Reduction Act of 1984** (P.L.98-369) The STA excise tax exemption for gasohol was raised from 5 cents per gallon to 6 cents per gallon. Provided a new exemption of 4.5 cents per gallon for alcohol fuels derived from natural gas. The alcohol fuels “blenders” credit was increased from 40 cents to 60 cents per gallon of blend for 190 proof alcohol. The duty on alcohol imported for use as a fuel was increased from 50 cents to 60 cents per gallon

1986 **Tax Reform Act of 1986** (P.L.99-514) Reduced the tax exemption for “neat” alcohol fuels (at least 85 percent alcohol) from 9 cents to 6 cents per gallon. Permitted alcohol imported from certain Caribbean countries to enter free of the 60 cents per gallon duty. Repealed the tax-exempt financing provision for alcohol-producing facilities.

1990 **Omnibus Budget Reconciliation Act of 1990** (P.L. 101-508) Allows ethanol producers a 10 cent per gallon tax credit for up to 15 million gallons of ethanol produced annually. Reduced the STA gasohol excise tax exemption to 5.4 cents per gallon.

1992 **Energy Policy Act of 1992 (EPACT)** (P.L. 102-486) Provides: (1) a tax credit (variable by gross vehicle weight) for dedicated alcohol-fueled vehicles; (2) a limited tax credit for alcohol dual-fueled vehicles; and (3) a tax deduction for alcohol fuel dispensing equipment.

1998 **Energy Conservation Reauthorization Act of 1998** (ECRA) (P.L. 105-388) Amended EPACT to include a credit program for biodiesel use by establishing Biodiesel Fuel Use Credits. An EPACT-covered fleet can receive one credit for each 450 gallons of neat (100 percent) biodiesel purchased for use in vehicles weighing in excess of 8500 lbs (gross vehicle weight (GVW)). One credit is equivalent to one alternative fueled vehicle (AFV) acquisition. To qualify for the credit, the biodiesel must be used in biodiesel blends containing at least 20 percent biodiesel (B20) by volume. If B20 is used, 2,250 gallons must be purchased to receive one credit.

Transportation Equity Act for the 21st Century (TEA-21) (P.L. 105-178) Maintains, through 2000, the 5.4 cent per gallon (of gasoline) excise tax exemption for fuel ethanol set by the Omnibus Budget Reconciliation Act of 1990 (P.L. 101-508). Extends the benefits through September 30, 2007, and December 31, 2007, but cuts the ethanol excise tax exemption to 5.3, 5.2, and 5.1 cents for 2001-2002, 2003-2004, and 2005-2007, respectively, and the income tax credits by equivalent amounts. The exemption is eliminated entirely in 2008.

Renewable Portfolio Standard

- An RPS is a requirement that electricity producers in a state or other area have a fixed percentage of their generation as renewable energy
- California RPS is to increase by 2% per year (starting in 2003) to reach 20% by 2010
- Governor and PUC working on goal of 33% by 2020

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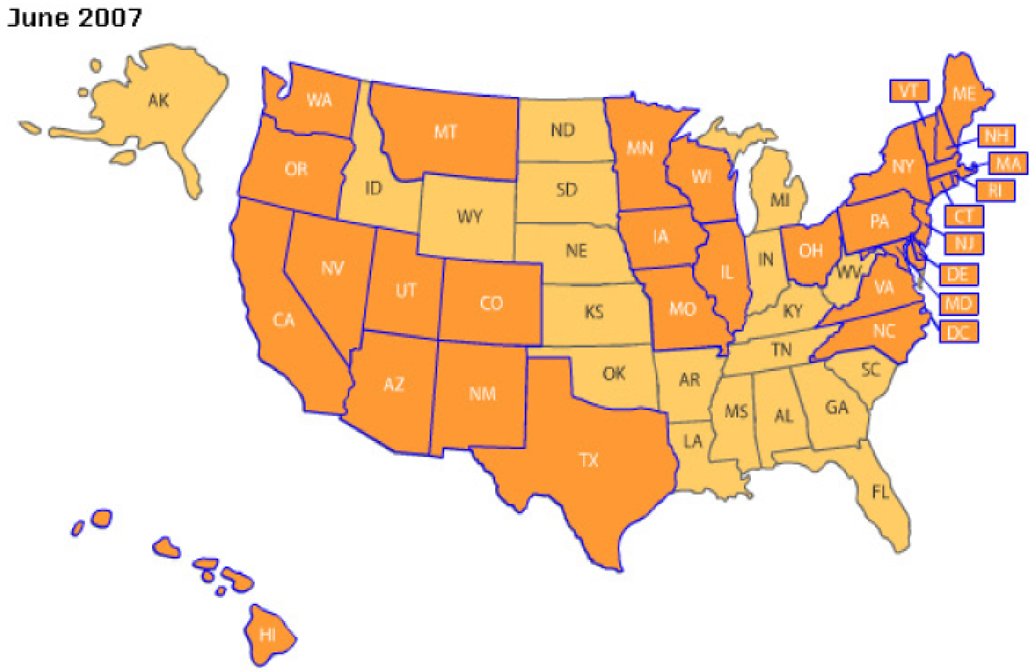
See http://www.dsireusa.org/ (accessed March 2, 2009) a web site entitled Database of State Incentives for Renewables and Efficiency for a list of various incentives programs. The site also contains a limited list of Federal incentives.

Renewables include Solar Thermal Electric, Photovoltaics, Landfill Gas, Wind, Biomass, Hydroelectric, Geothermal Electric, Municipal Solid Waste, Anaerobic Digestion, Tidal Energy, Wave Energy, Ocean Thermal, Fuel Cells using Renewable Fuels

The California Public Utilities Commission (PUC) is responsible for implementing the RPS for investor-owned utilities (IOU) and municipal utilities are required to implement their own renewable portfolio.

RPS States



Map and data table downloaded March 2, 2009 from http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm,

State, Required RPS Amount, Deadline for amount

Arizona 15% 2025	**California** 20% 2010	**Colorado** 20% 2020
Connecticut 23% 2020	**District of Columbia** 11% 2022	
Delaware 20% 2019	**Hawaii** 20% 2020	**Iowa** 105 MW
Illinois 25% 2025	**Massachusetts** 4% 2009	**Maryland** 9.5% 2022
Maine 10% 2017	**Minnesota** 25% 2025	**Missouri***11% 2020
Montana 15% 2015	**New Hampshire** 16% 2025	
New Jersey 22.5% 2021	**New Mexico** 20% 2020	**Nevada** 20% 2015
New York 24% 2013	**North Carolina**12.5% 2021	**Oregon** 25% 2025
Pennsylvania 18% 2020	**Rhode Island** 15% 2020	**Texas** 5,880 MW 2015
Utah* 20% 2025	**Vermont*** 10% 2013	**Virginia***12% 2022
Washington 15% 2020	**Wisconsin** 10% 2015	

*Denotes states with voluntary RPS

Wind Energy

- Use of advanced wind turbines to generate electricity from wind
- Depends on consistent availability of high-speed winds
- Advanced designs of wind turbines provide high conversion efficiencies
- Basic aerodynamics in blade design
- Probabilistic analysis of wind distribution to determine average energy generated

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Direct quote from conclusion on pages 16 and 17 of DOE/EIA report *Renewable Energy 2000: Issues and* Trends, DOE/EIA-0628(2000), February , 2001. Available on the web at http://www.eia.doe.gov/cneaf/solar.renewables/rea_issues/062800.pdf (accessed September 2001)

Table 1. United States Wind Energy Capacity by State, 1998, and New Construction, 1999 and 2000
(Megawatts)

State	**Existing 1998**	**New Construction 1999**	**2000**
Alaska	*	.58	.10
California	1,487	290.33	208.50
Colorado	0	16.0	0 0
Hawaii	20	0	39.75
Iowa	*	237.45	0.60
Kansas	0	1.5	0 0
Maine	0	0	6.10
Massachusetts	* 0	7.5	0
Michigan	1	0	0
Minnesota	129	139.56	32.00
Nebraska	0	1.32	0
New Mexico	0	0.66	0
New York	0	0 1	8.15
Oregon	25	0	0
Pennsylvania	0	0	26.17
South Dakota	0	0	0.75
Tennessee	0	0	1.98
Texas	34	145.82	25.10
Utah	0	0	.23
Vermont	1	0	5.00
Wisconsin	0	21.7	8 0
Wyoming	1	71.25	28.12
Total	**1,698**	**926.24**	**395.05**

Wind Classes (10 m)

Class	power/area(W/m^2)		Speed(m/s)/(mph)	
	min	max	min	max
1	0	100	0	4.4/9.8
2	100	150	4.4/9.8	5.1/11.5
3	150	200	5.1/11.5	5.6/12.5
4	200	250	5.6/12.5	6.0/13.4
5	250	300	6.0/13.4	6.4/14.3
6	300	400	6.4/14.3	7.0/15.7
7	400	1000	7.0/15.7	9.4/21.1

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This chart and the next one are taken from the Wind Energy Resource Atlas of the United States, available at http://rredc.nrel.gov/wind/pubs/atlas (Accessed March 6, 2007)

The classification of an area into a given class depends on its average power density in watts per square meter. This is the average of the cube of the wind speed. This can be different from the cube of the average wind speed as shown in the table below, taken form the same source.

Table 1-2 Comparison of annual average wind power at three sites with identical wind speeds.

Site	**Annual Average Wind Speed (m/s)**	**Annual Average Wind Power Density (W/m2)**	**Wind Power, Class (at 10 m)**
Culebra, Puerto Rico	6.3	220	4
Tiana Beach, New York	6.3	285	5
San Gorgonio, California	6.3	365	6

The higher wind powers, for a given average speed, come from a more consistent wind pattern. When there are large fluctuations in the wind flow, there can still be a high average speed, but the average of the speed cubed is smaller.

The classification of various areas in the US in terms of their annual average wind power density is based on a measure of the wind speeds over a multiyear period.

The different wind classes are based on the wind speeds at two elevations, 10 m (33 feet) and 50 m (164 ft.). The classifications for 50 m are shown on the next chart.

Areas that are potentially suitable for wind power development are those of wind class three and above.

Wind Classes (50 m)

Class	power/area(W/m^2)		Speed(m/s)/(mph)	
	min	max	min	max
1	0	200	0	5.6/12.5
2	200	300	5.6/12.5	6.4/14.3
3	300	400	6.4/14.3	7.0/15.7
4	400	500	7.0/15.7	7.5/16.8
5	500	600	7.5/16.8	8.0/17.9
6	600	800	8.0/17.9	8.8/19.7
7	800	2000	8.8/19.7	11.9/26.6

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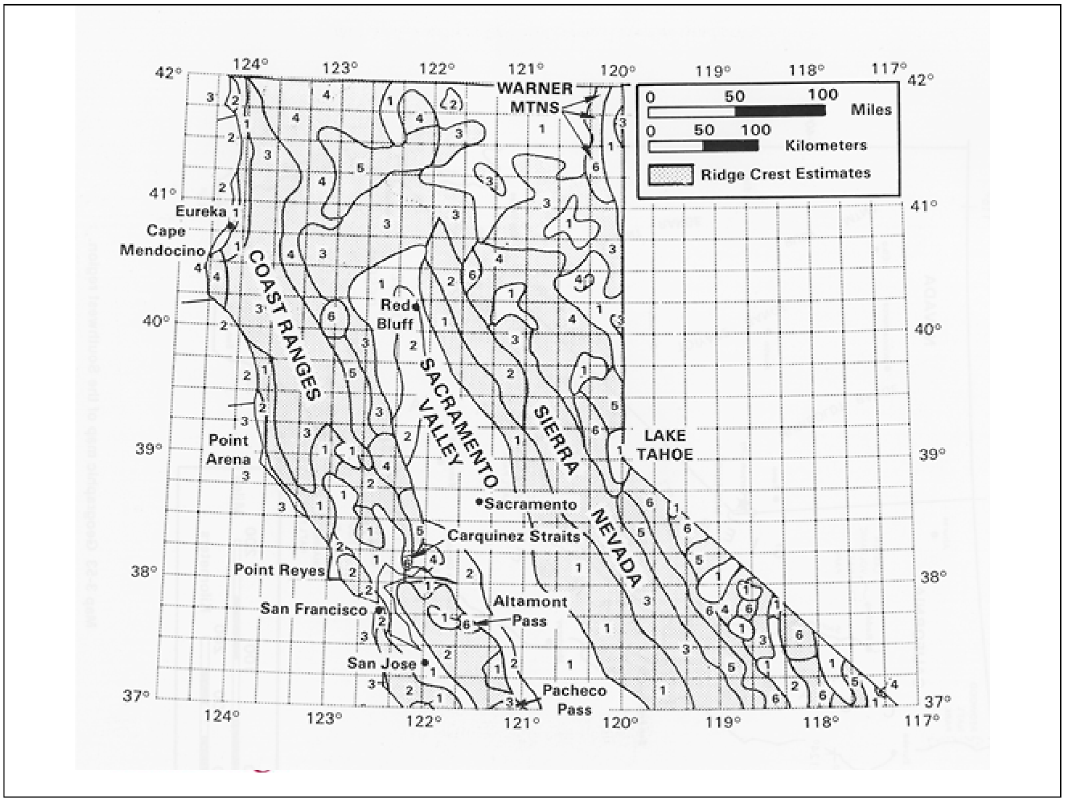
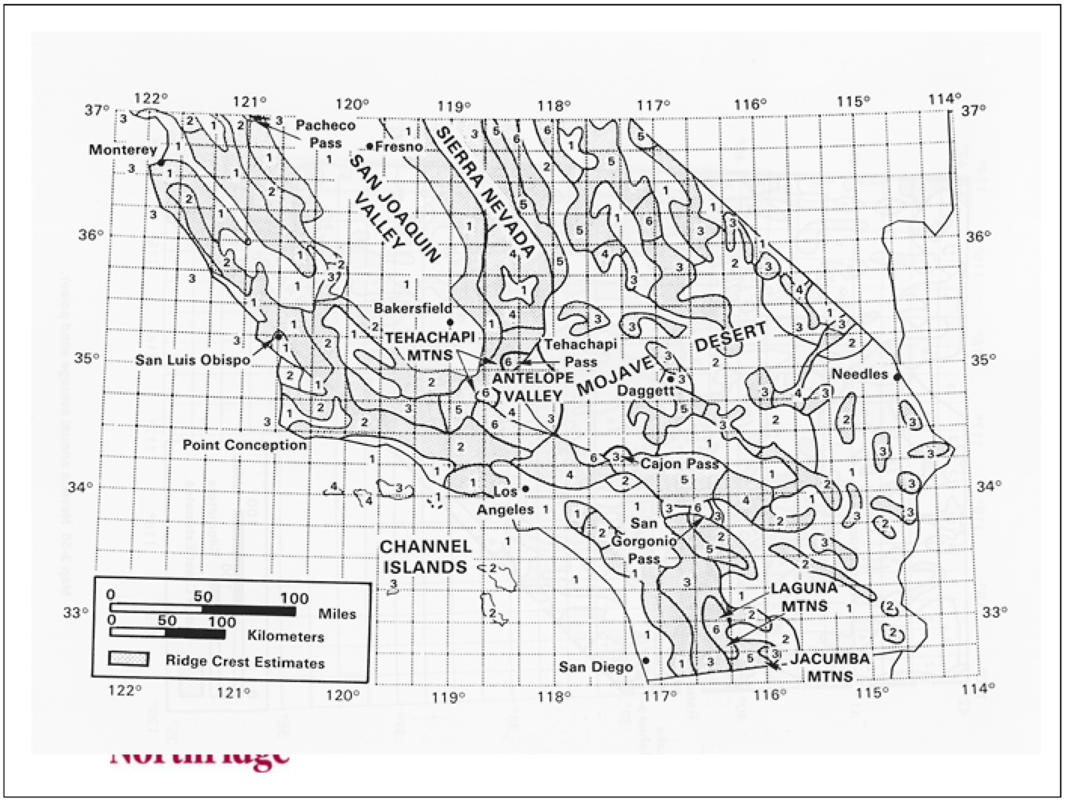
Reference: Wind Energy Resource Atlas of the United States, available at http://rredc.nrel.gov/wind/pubs/atlas/tables/1-1T.html (Accessed March 6, 2007)

These data show that the same wind class produces higher power densities resulting from higher velocities at the elevation of 50 m compared to the elevation of 10 m. The general equation for the velocity profile at the planetary surface is that the velocity is proportional to the elevation to the 1/7th power.



Reference: Wind Energy Resource Atlas of the United States, available at http://rredc.nrel.gov/wind/pubs/atlas/maps/chap3/3-54m.html (Accessed March 6, 2007)

You may have seen the various wind farms located in California. This chart and the next one show that the most significant ones, in the Altamont Pass and the Coachella Valley (on next page) are located in class 6 wind areas.



Reference: Wind Energy Resource Atlas of the United States, available at http://rredc.nrel.gov/wind/pubs/atlas/maps/chap3/3-55m.html (Accessed March 6, 2007)

You may have seen the various wind farms located in California. This chart and the next one show that the most significant ones, in the Altamont Pass (on last page) and the Coachella Valley are located in class 6 wind areas.

Solar Energy

- Used to provide heat in solar collectors
- Direct conversion to electricity via photovoltaic cells
- Focusing solar collectors produce high temperatures that can drive steam power cycles
- Collectors can be fixed or tracking
  - Simplest is fixed, facing south, with tilt equal to latitude

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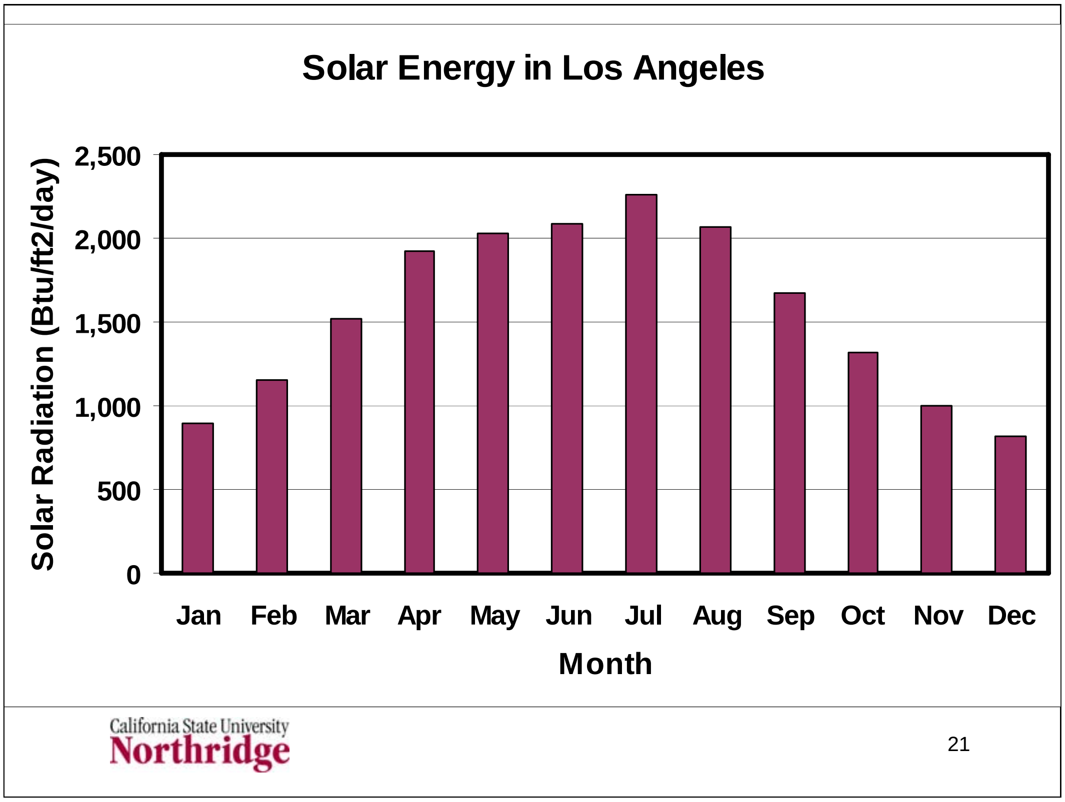
Solar energy is available only during daylight hours and provides much more energy during summer months than during winter months. Although much of the early application of solar energy is for domestic heating purposes (heating water for household use and for swimming pools, heating room air) the temporal profile of solar energy is similar to the demands for electricity, which are higher in the summer than the winter and are higher during the day than at night. Thus there has been much research and development projects on using solar energy for electricity generation.

Solar electricity can be generated directly by photovoltaic cells. However, the cost of electricity produced by such cells is currently greater than the cost of producing high temperature heat from solar collectors and using this heat to generate steam in a conventional power generation cycle.

Because the orientation of the sun changes during the day and during the year, the most solar energy can be captured if the collector is mounted on two axes to follow the sun throughout the year. However, such tracking is expensive and most home solar collectors use a fixed orientation and tilt. The best position for maximizing solar collection year-round is a south facing collector tilted at the angle of the local latitude. Other fixed orientations can be used to optimize collection for a particular season.

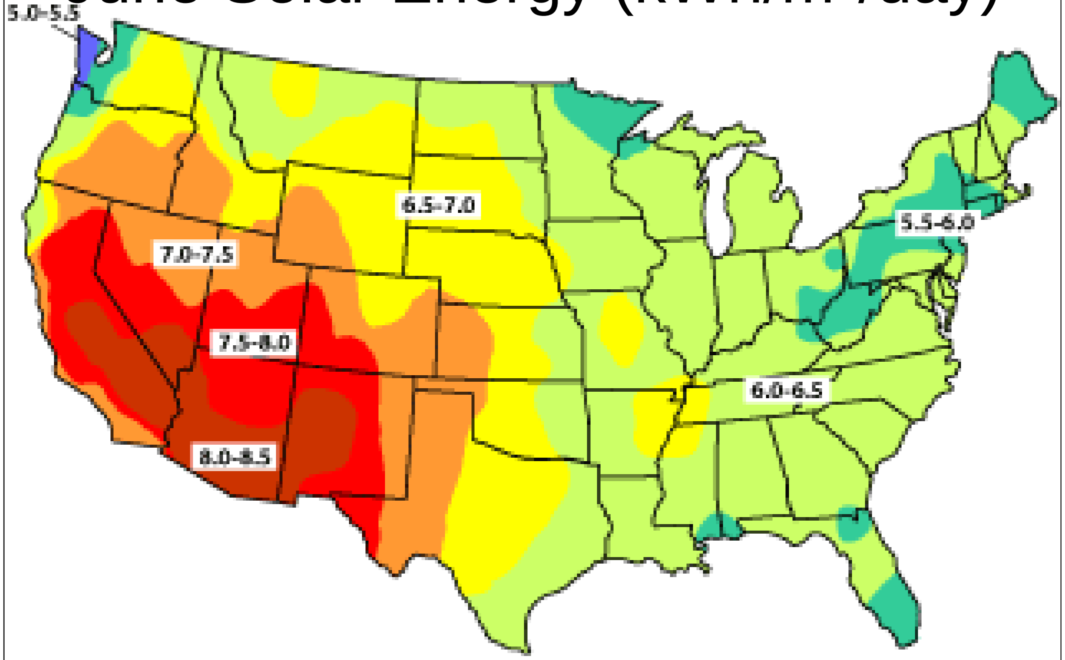


The data for this plot was obtained from http://rredc.nrel.gov/solar/ site accessed on March 6, 2007. The data are located at the URL http://rredc.nrel.gov/solar/old_data/nsrdb/bluebook/data/23174.SBF

Data are also available from the NREL web site for the solar radiation on various types of solar collectors.

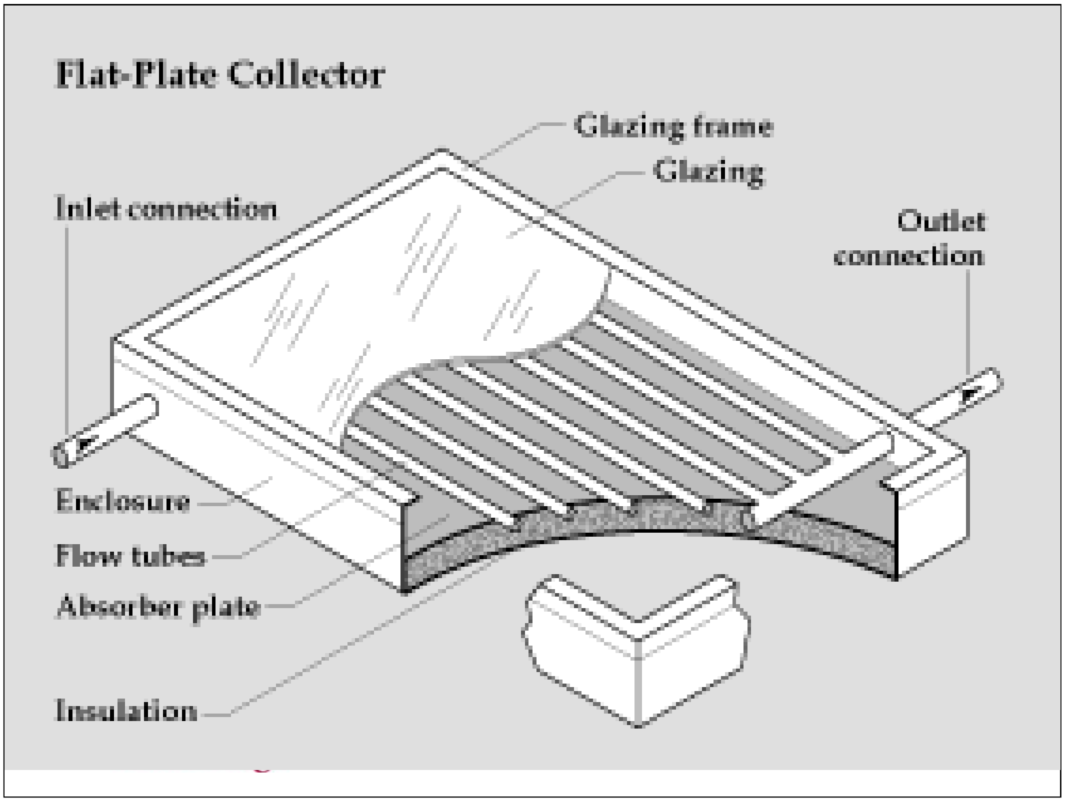
The latitude and longitude reported for the weather station 33.93^o North and 118.40^o West place the weather station at LAX, just at the corner of Sepulveda and Imperial. These data are like to underestimate the solar radiation available in valley areas of Los Angeles.

June Solar Energy (kWh/m²/day)



Reference: http://www1.eere.energy.gov/solar/pv_cell_light.html (accessed March 1, 2009)

This represents the average power received during one day in June on one square meter of surface area for a horizontal surface. These data are based on a thirty-year record that accounts for the different amounts of cloud cover during that period.

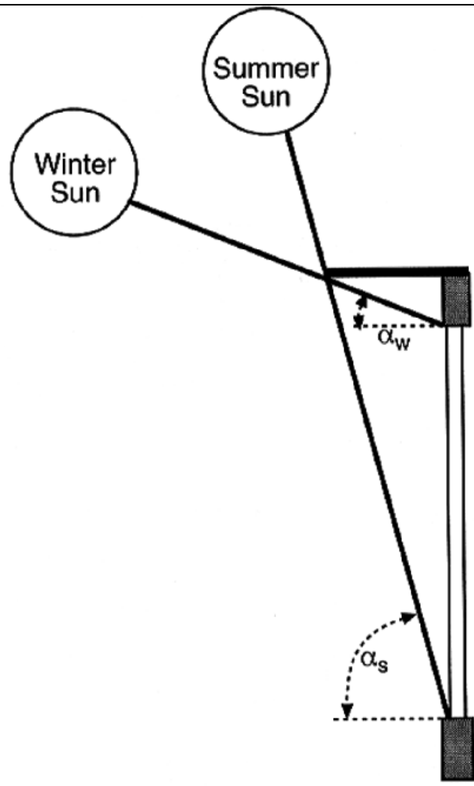


Reference: (accessed March 6, 2007)
http://www1.eere.energy.gov/solar/sh_basics_collectors.html#flatplate

This collector is used for providing household hot water. Other forms of solar collectors are used for heating air and for providing heated water for swimming pools. The differences in these collectors are basically the final temperature of the water leaving the collector. This requires differences in the design to improve the efficiency of the overall heat transfer.

The design of solar thermal collectors is based on a balance of solar energy in minus convection heat losses from the collector to the atmosphere. The difference between these two is the net energy transferred to the fluid circulating in the collector that provides useful heat.

Because convection losses are proportional to the difference in temperature between the collector and the atmosphere, the higher the desired temperatures from the collector, the greater the losses from the collector will be.



Passive

- Passive solar is design of buildings to make best use of natural sunlight

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Reference: http://rredc.nrel.gov/solar/pubs/bluebook/gifs/fig9.gif (accessed March 6, 2007).

This figure illustrates the use of passive solar heating. In this approach, buildings are designed to make optimum use of solar input in the winter when heating is required and reduce the solar input during the summer.

This diagram shows how an overhang can reduce the amount of summer heat entering a window while allowing the winter heat to enter.

Shingles?

- shingles are coated with PV cells made of amorphous silicon to look like regular shingles

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Reference: http://www1.eere.energy.gov/solar/photovoltaics.html (accessed March 6, 2007)

Photovoltaic cells provide the simplest use of solar energy, transforming the solar light directly into electricity. However, the cost of these cells remains high. An alternative approach is to develop less efficient, but much less costly solar cells. In this way the total cost per kWh could be reduced although it would take more area to get the same electrical input.

Note that solar photovoltaic cells produce DC power so it is necessary to have an inverter to convert the DC to AC for household use.

LA Photovoltaic Costs

- Based on solar industry web site: http://www.findsolar.com/
- LADWP area using 860 kWh/month
  - Supply 50% of electricity on average
- Recommendation: 3.11 kW of peak power requires 311 ft^2 roof area
- Installed cost: $25,000; ($9,000 after rebates and incentives)
- Savings $23,000 over 25 years

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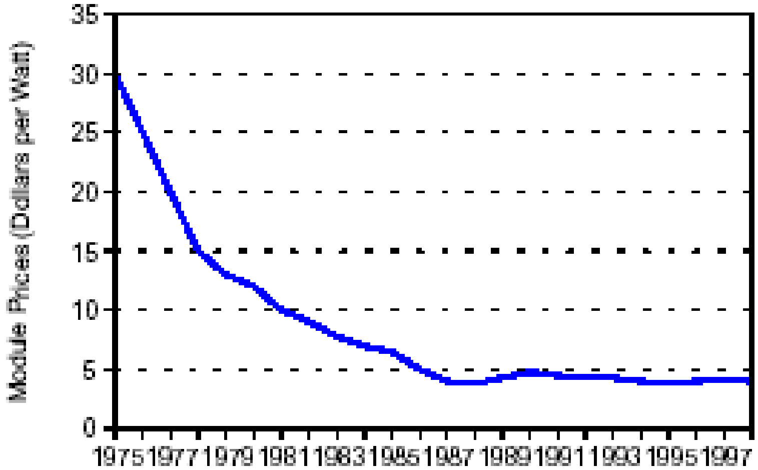
This web site, accessed March 2, 2009, was originally accessed by following a link from a Department of Energy web site. After entering your location (resolved by zip code for solar data) and your utility, you are asked to input your electricity use. The site then recommends a unit size and an estimated cost. (Previous versions of the calculator gave a range that was typicall several thousand dollars; the current version gives only a midpoint.)

The LADWP rebate increases if the solar unit manufacturer is located in Los Angeles. The rebate is computed using a calculator developed by the National Renewable Energy Lab (NREL). The calculator is on-line, but it is not intuitive and I gave up after several attempts. (It appears that part of my problem is that the calculator uses a pop-up window that my browser settings do not like.

If you select 100% of your electricity from the solar system the size and cost doubles to 6.22 kW of peak power and $50,000. The cost after rebates and incentives raises by more than double (to $33,000) due to capping of the rebates based on system size. The 25 year savings is $67,000. All savings are based on an estimated inflation rate of 4% for electricity costs.

The LADWP web site for solar incentives (accessed March 6, 2007) is http://www.ladwp.com/ladwp/cms/ladwp000787.jsp. The linked site, http://mapserve2.nrel.gov/website/LA_PVWatts/viewer.htm, for the rebate calculator was also accessed March 2, 2009.

- **Figure 1. Decline in Photovoltaic Module Prices, 1975-1998**



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Reference: DOE/EIA report *Renewable Energy 2000: Issues and* Trends, DOE/EIA-0628(2000), February , 2001. Accessed at http://www.eia.doe.gov/cneaf/solar.renewables/rea_issues/062800.pdf in September 2001.

Although there was a significant decrease in the cost of photovoltaic cells between 1975 and 1988, the cost has been static since then. Furthermore, the cost of $4,000 per kW is still quite high.

The solar PV cost estimation tool for homeowners located on the web site, http://www.findsolar.com/ind (accessed February 29, 2008), which was described on the previous notes page, gives the installed cost of an solar PV array as $9/watt ±20%. Two-thirds of this cost (or $6,000/watt ±20%) is for the PV module.

Comparative Costs

- Coal 4.8 – 5.5 cents/kWh
- Gas 3.9 – 4.4 cents/kWh
- Hydro 5.1 – 11.3 cents/kWh
- Biomass 5.8 – 11.6 cents/kWh
- Nuclear 11.1 – 14.5 cents/kWh
- Wind 4.0 – 6.0 cents/kWh
- Wind (with PTC) 3.3 – 5.3 cents/kWh

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These data were taken from a fact sheet on the web site of the American Wind Energy Association. The URL for the fact sheet is http://www.awea.org/pubs/factsheets/Cost2001.PDF. (accessed March 6, 2007)

The fact sheet references a 1996 California Energy Commission report, *Energy Technology Status Report* in which all costs are expressed in 1993 dollars. The costs are levelized over a typical lifetime, usually 30 years, assuming that operation starts in calendar year 2000.

In this chart PTC is an abbreviation for the Producer Tax Credit. This shows the impact that incentives can have on the total cost of generated electricity.

These cost estimates are somewhat dated, but they were one source I could find for comparing the levelized costs of electricity production from various conventional forms of power generation.

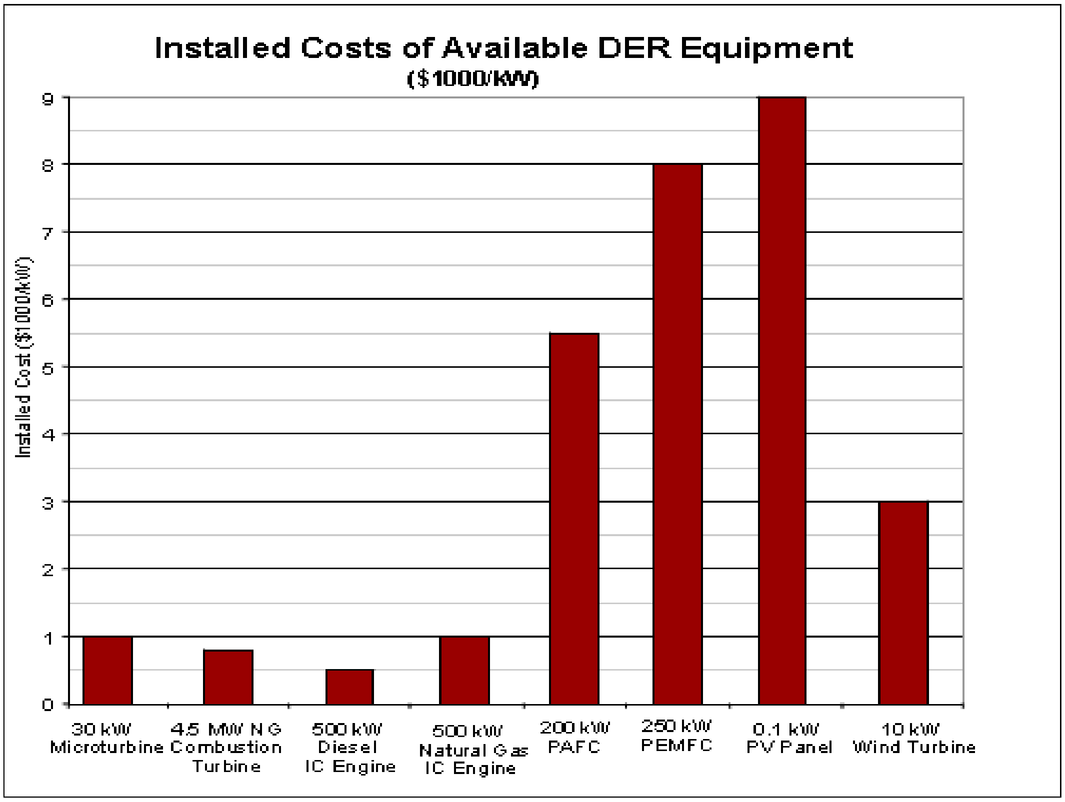

Chart and text below copied from California Energy Commission web site http://www.energy.ca.gov/distgen/economics/capital.html (accessed March 6, 2007) DER is an abbreviation for distributed energy resources

The capital costs for DER technologies can vary significantly even within the same technology, depending on size, power output, performance, fuel type, etc.

Microturbine costs represent early commercial production costs and will likely decrease as production levels increase.

Combustion turbines are a mature technology with high production levels. Larger turbines generally cost less per kW than smaller turbines.

Reciprocating engines are a mature technology with high production volume, therefore costs are relatively low. Larger reciprocating engines cost more per kW than smaller engines because they are manufactured in smaller quantities.

Stirling engine manufacturers target lower costs (~$2000) if higher production volumes are achieved. The high costs reported in the table refer to low production and prototype engines, primarily for space programs.

Fuel cells are in varying stages of development and production, as represented by the large range in capital costs.

Photovoltaic systems are a relatively mature technology. The photovoltaic systems vary in cost by system type and system size.

Wind turbine costs also vary with the size of the project. Lower costs (ie $800/kW) are associated with large utility scale wind farms. Residential size wind turbines can range in price from $2,500-$3,500/kW.

Installation costs will also vary widely within a given technology, especially for less mature technologies. Installation costs are often approximately 30% of the capital cost, but can reach as high as 100% for highly customized applications.

The total installed cost of the DER technology is the sum of the capital cost and installation costs. The total installed cost may include the power generation module, the power conditioning unit, balance of plant equipment, installation, general facilities and engineering fees, project and process contingencies, and owner costs.

Capital Cost Ranges ($/kW)

• Microturbine	700 - 1100
• Combustion Turbine	300 - 1000
• IC Engine	300 - 800
• Stirling Engine	2,000 - 50,000
• Fuel Cell	3,500 - 10,000
• Photovoltaic	4,500 - 6,000
• Wind Turbine	800 - 3,500

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These capital cost ranges are taken from the same CEC web page as the chart on the previous slide: http://www.energy.ca.gov/distgen/economics/capital.html (accessed March 6, 2007).

These show the extreme ranges that are encountered depending on the kind of technology used. Typically larger sizes of equipment will have smaller costs on a $/kW basis.

Renewable Fuels

- Naturally occurring materials either used directly or converted to other fuels
  - Wood
  - Alcohol fuels from corn, cellulose, sugar
  - Biodiesel from natural oils
- Waste products
  - Direct incineration of waste
  - Conversion of waste to other fuels
  - Solids and gases produced by waste

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Direct combustion of wood has long renewal time

Alcohol fuels for automobile and truck engines can be made from a variety of natural sources but are not economical without government subsidy. They are more common than **biodiesel**.

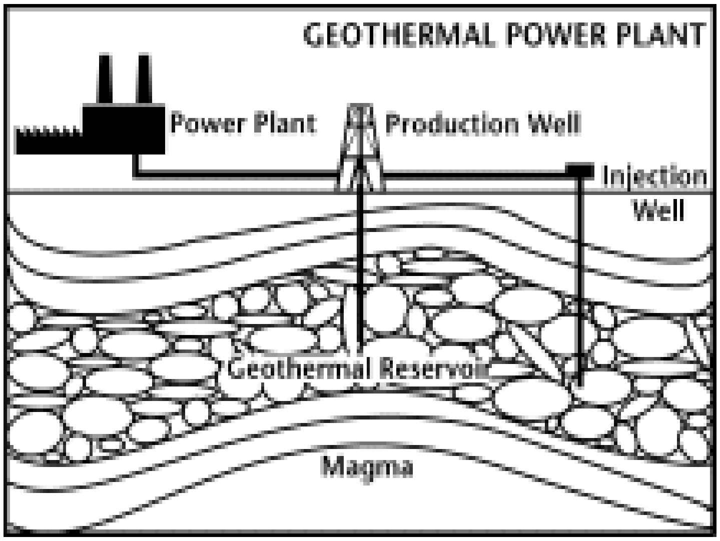
Municipal solid waste power plants directly burn municipal solid waste (MSW) with minimal processing and some amount of pilot fuel

Refuse-Derived Fuel Refuse-derived fuel (RDF) typically consists of pelletized or "fluff" MSW that is the by-product of a resource recovery operation.

Pyrolysis/Thermal Gasification produces gaseous fuels from waste

Animal and human waste can be converted to methane gas in anerobic digestion plants

Geothermal



- Uses energy from underground hot water
- Site specific

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References:
http://www.eia.doe.gov/cneaf/solar.renewables/page/geothermal/geothermal.html (accessed March 7, 2007)

http://www.eia.doe.gov/kids/energyfacts/sources/renewable/geothermal.html (accessed March 7, 2007)

Geothermal energy is contained in underground reservoirs of steam, hot water, and hot dry rocks. As used at electric generating facilities, hot water or steam extracted from geothermal reservoirs in the Earth's crust is supplied to steam turbines at electric utilities that drive generators to produce electricity. Moderate-to-low temperature geothermal resources are used for direct-use applications such as district and space heating. Lower temperature, shallow ground, geothermal resources are used by geothermal heat pumps to heat and cool buildings.

There are limited opportunities for geothermal energy, but where it occurs it is economical to use. At the end of 2004 there were 43 plants producing geothermal energy in the US, most of those at one location in California – the Geysers in Lake County.

The capital of Iceland, Reykjavik, is heated mostly by geothermal energy.

http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf (accessed February 29, 2008) is a comprehensive report prepared by an MIT committee (chaired by J. W. Tester, the senior author of our textbook.)

General Issues

- Cost
- Future technology development
- Incentives to provide experience with using the technologies
- Environmental effects – usually a benefit, but with some biomass fuels there are environmental problems
- Global warming
- Availability of the resource

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We will be discussing each of the topics covered here tonight in more detail. However, all the issues described here will be pertinent to those discussions. Many alternative energy technologies, such as solar, wind, geothermal, and tidal/wave power have the prospect of using zero cost fuels, but have high initial investment costs. All of these sources do not use any combustion and are valued as a way to reduce the emissions of CO_2.

The resources mentioned above also have availability issues. Solar is available only during daytimes in skies that are not overcast. To be usable, a wind turbine must be located in a high wind area. Natural geothermal areas are limited, but hot rocks can be “mined” to produce geothermal energy; the cost of such production may be excessive, however. Wave energy is limited to costal areas and the methods for extracting it efficiently are not well developed.

The successful use of these alternative technologies requires cost reductions or such increases in the cost of fossil fuels that their present higher costs will become favorable in comparison.