Renewable Energy Resources

Mechanical Engineering 694C

Seminar in Energy Resources, Technology and Policy

Larry Caretto

October 9, 2002

California State University Northridge

Remind students to turn in project proposals and homework.

Reading for this week is pages 143 to 183 in Fay and Golomb.

Reading for next class is pages 188 to 223 in Fay and Golomb.

Problems for this week, due October 16: 7.2, 7.6, 7.10, and 7.13.

Research assignment for October 16: determine the cost of a solar photovoltaic system for your home and the number of years that it would take to pay back the cost. Consider any applicable tax incentives.

Hand back and discuss homework assignments for September 18 and September 25. (Solutions on web site.)

Main Ideas

- What are renewable resources?
- Solar energy
- Wind energy
- Hydropower
- Other renewable resources
  - Ocean energy
  - Geothermal energy
  - Biomass combustion

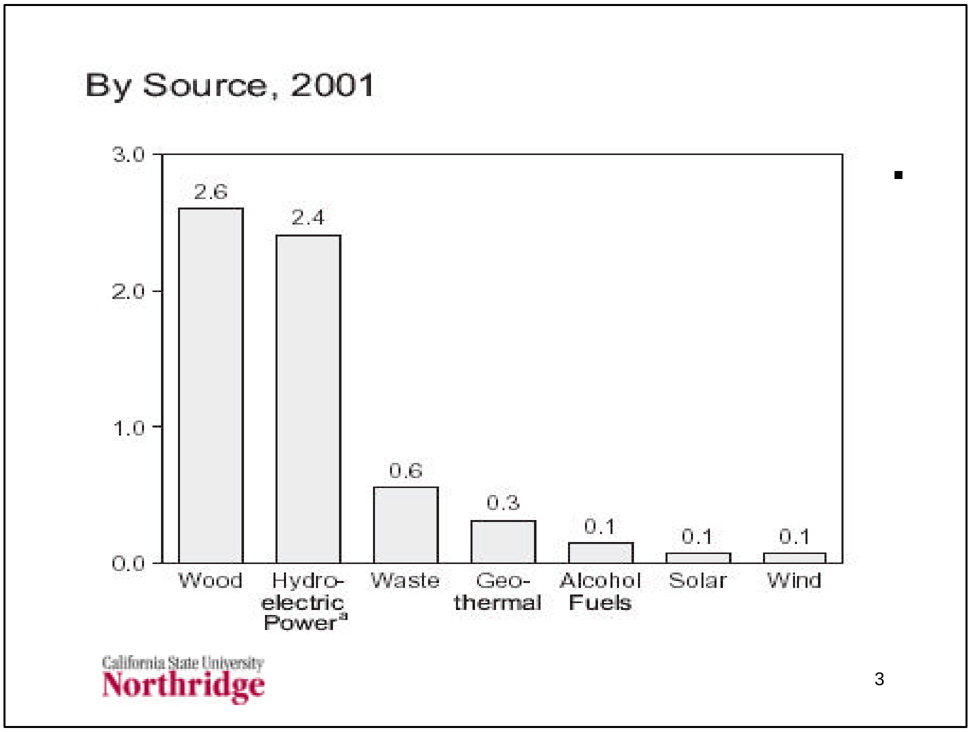
California State University Northridge

2

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 those that can be renewed in short periods of time such as biomass fuels. The latter include alcohols produced form 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.



This chart and the next two charts are taken from the EIA monthly energy review for September 2002. The figures are copied from the electronic version of the report at http://www.eia.doe.gov/emeu/mer/pdf/pages/sec10_2.pdf.

All these figures show the energy use in quads.

Wood category includes wood, wood waste, black liquor, red liquor, spent sulfite liquor, wood sludge, peat, railroad ties, and utility poles.

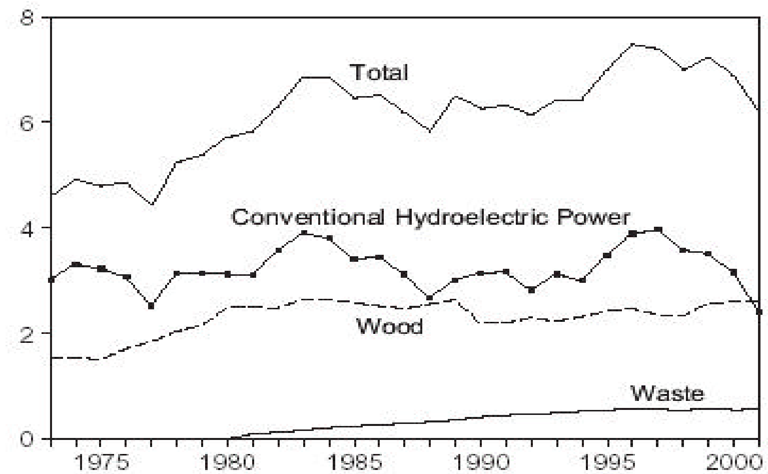
Waste includes municipal solid waste, landfill gas, methane, digester gas, liquid acetonitrile waste, tall oil, waste alcohol, medical waste, paper pellets, sludge waste, solid byproducts, tires, agricultural byproducts, closed loop biomass, fish oil, and straw.

Alcohol fuels category is limited to ethanol blended into motor gasoline.

Solar includes solar thermal and photovoltaic electricity net generation, and solar thermal.

Since the annual energy use in the US is about 100 quads, these resources are seen to provide only a small amount of that total. Solar and wind energies which have received much attention are seen to account for about 0.01% (each) of the total energy use in the US.

Total and Major Sources, 1973-2001

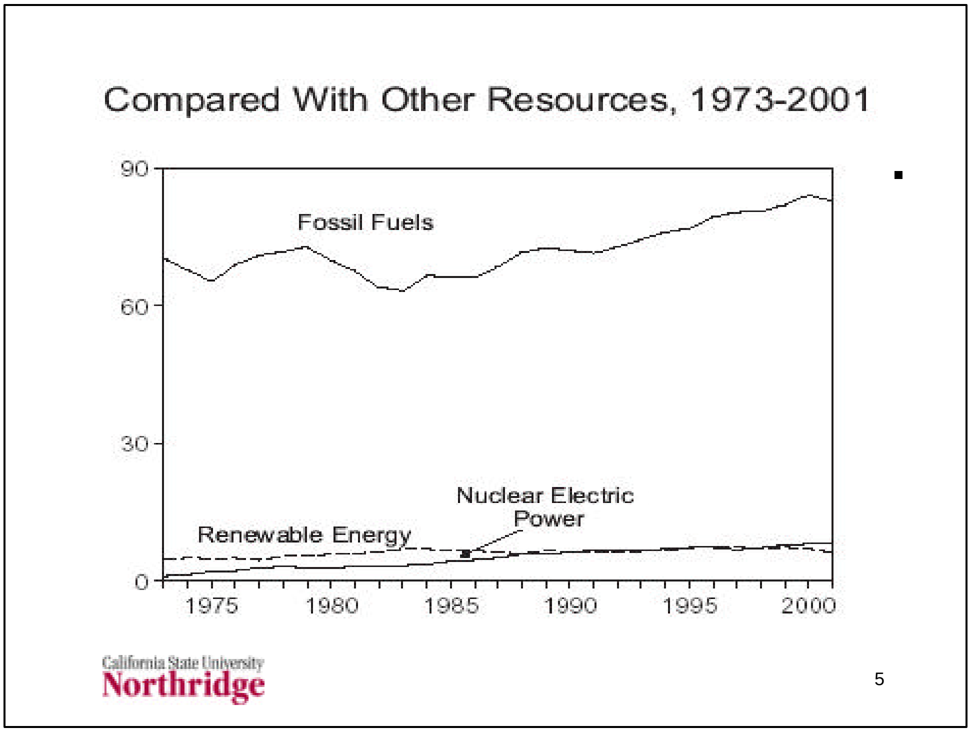


California State University Northridge

4

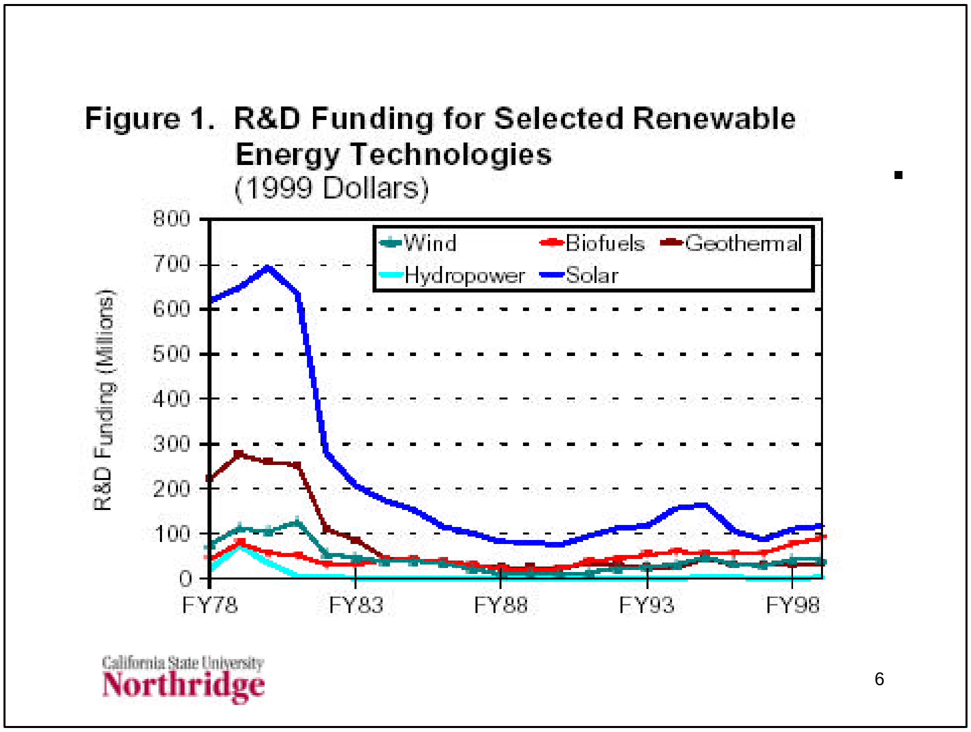
This chart, like the previous one, is taken from the EIA monthly energy review for September 2002. The figures are copied from the electronic version of the report at http://www.eia.doe.gov/emeu/mer/pdf/pages/sec10_2.pdf. The energy use here is shown in quads. Although there has been an increased emphasis on the use of alternative energy resources since the 1973 oil embargo, the actual growth has been quite small. The figures for solar and wind do not even show up on the scale used here.

.



Reference EIA monthly energy review for September 2002.
http://www.eia.doe.gov/emeu/mer/pdf/pages/sec10_2.pdf.

In 2001 all renewable resources contributed 6% of the total energy in the US. Nuclear generation contributed 8% and fossil fuels contributed 85%. (Total does not add due to rounding.)



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

Energy Information Administration/ Renewable Energy 2000: Issues and Trends

The effectiveness of tax credits and production incentives has varied considerably, depending on the amounts and certainty of the incentive. The long-term nature and financial support levels of the PURPA Standard Offer 4 contracts in California, in addition to the Federal and State tax credits, provided reasonable assurance that investors in power plants using renewable resources would make a profit.52 In contrast, the Renewable Energy Production Incentive of EPACT relies upon year-to-year congressional funding, raising the level of uncertainty investors face. It has resulted in only a small amount of additional renewable generating facilities.

Other tax credits (e.g., the residential solar/ wind tax credit) have generally had much less impact, simply because the gap between competitive energy prices and energy production costs is greater than the benefit investors perceive such tax credits are worth.

In the case of alcohol fuels, the impact of the Federal 54 cents per gallon incentive was substantial and immediate. Production of fuel ethanol would no doubt drop sharply if the Federal 54 cents per gallon (of ethanol) incentive were removed and States provided no supports for, or, mandates to use, ethanol.

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.

One reason for this is that although there have been some reductions in the cost of renewable electric generating technologies, these cost reductions have not kept pace with the general declines in cost seen in natural gas-fired generation. These cost reductions, however, have put renewables in a better competitive position, especially given the sharp increases in natural gas prices in 2000.

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

California State University Northridge

7

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

California State University
Northridge

8

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

California State University Northridge

9

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.

State and Local Incentives

- California Energy Commission
  http://www.energy.ca.gov/distgen/incentives/incentives.html
- Southern California Edison
  http://www.scespc.com/sgip.nsf
- Southern California Gas
  http://www.socalgas.com/business/cash_for_you/self_generation.shtml
- LA Department of Water and Power
  http://www.ladwp.com/whatnew/solaroof/solaroof.htm

California State University Northridge

10

There are a variety of incentive programs that are offered by individual states. In California such incentives are typically administered through the California Energy Commission, although some are administered through the state Public Utilities Commission. The direct administration of incentives as tax rebates is handled through the Franchise Tax Board as part of the individual or corporate tax return.

Individual public or private regulated utilities also offer incentives. Such incentives range from a deduction for the cost of solar cells to an offer to purchase excess power from devices such as solar cells. (The latter approach is called “net metering.”)

You can use these web sites, particularly the one at the Califomia Energy Commission to start this weeks assignment to determine how much it would cost you to install a solar photovoltaic system with the incentives that you would receive.

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

California State University
Northridge

11

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

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 Turbines

- Power in incoming air = $\rho V^3 A/2 = P_0$
- Inflow is V_1; outflow is V_2
- For frictionless flow, the actual power = $\rho A(V_1+V_2)(V_1^2-V_2^2)/4$
- Power coefficient, $c_p = P/P_0 = 0.593$ (maximum) when $V_2/V_1 = 1/3$

California State University Northridge

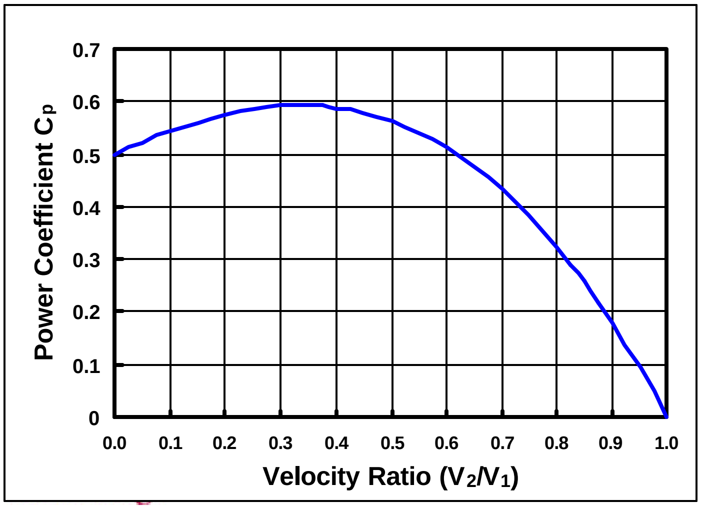
12

The kinetic energy per unit mass in an airflow is $V^2/2$. The mass flow rate through an area, A, is ρVA. The product of the mass flow times the kinetic energy per unit mass gives the power as $\rho V^3A/2$.

If we could reduce the air flow to zero in our wind turbine, we would extract all of this power, except for inefficiencies. However, if the flow were reduced to zero, there would be no flow through the turbine. A simplified analysis, ignoring drag forces, looks at a force momentum balance. The difference in velocity between the inlet and outlet of the wind turbine gives rise to a force on the turbine. The actual power that is produced in the frictionless flow case is given by the equation on the slide.

The computations with the power coefficient are shown in the next slide.

Wind Turbine Power Coefficient



13

From the two equations on the previous slide we can obtain the following equation for the power coefficient, c_p.

$c_p = P/P_0 = [1 + V_2/V_1]\ [1 – (V_2/V_1)^2] / 2$

If we plot this equation we obtain the graph above. This is consistent with the assertion made on the previous chart that the power coefficient is a maximum when the velocity ratio is 1/3.

If we define the velocity ratio, V_2/V_1, as r, our equation for c_p becomes.

$c_p = (1 + r)(1 – r^2)/2 = (1 – r^2 + r – r^3)/2$

Taking the first derivative of this equation and setting the result equal to zero gives.

$dc_p/dr = (–2 r + 1 – 3r^2)/2 = 0$

The roots of this equation are $[2 \pm (4 - 4*(-3)(1))^{1/2}] / [2(-3)] = (2 \pm 4) / (-6)$. We reject the negative root of -1 as not physically realistic and accept the positive root of 1/3. This confirms that the power coefficient is a maximum when the velocity ratio is 1/3.

Setting r = 1/3 in the cp equation gives the result that the maximum value of c_p is 0.59259259259259…

Wind Classes (10 m)

Class	power/area(W/m^2)		Speed(m/s)/(mph)	
	mim	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

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

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)

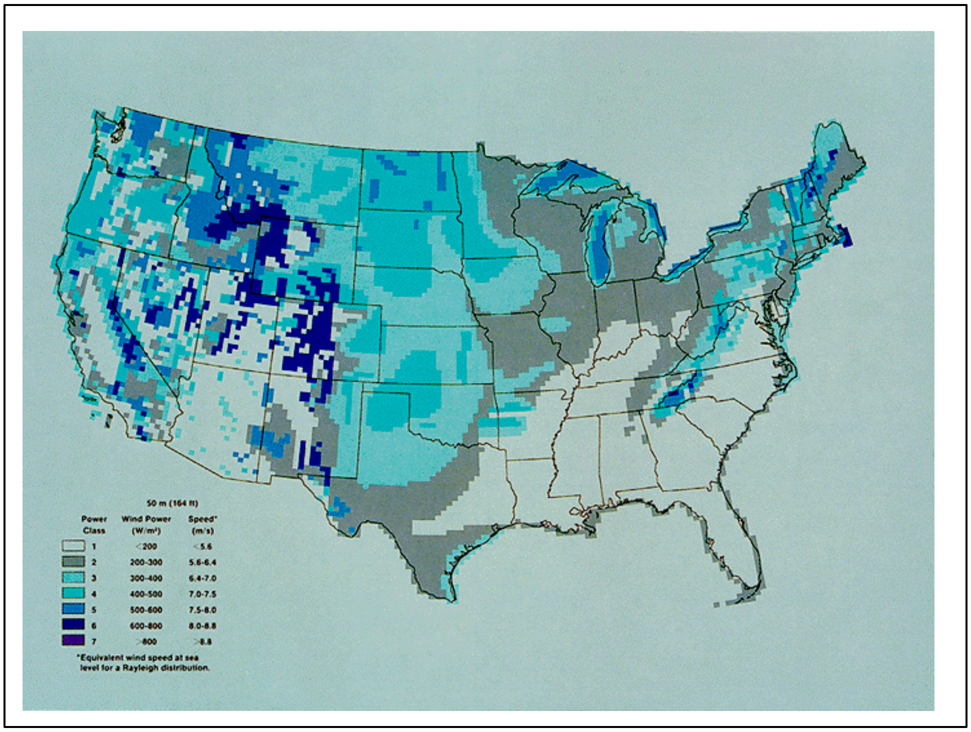
Class	power/area(W/m^2)		Speed(m/s)/(mph)	
	mim	max	min	max
1	0	200	0	5.6/12.5
2	200	300	5.6/12.5	6.4/14.3
3	300	400	6.4/14.3	7.0/15.7
4	400	500	7.0/15.7	7.5/16.8
5	500	600	7.5/16.8	8.0/17.9
6	600	800	8.0/17.9	8.8/19.7
7	800	2000	8.8/19.7	11.9/26.6

California State University
Northridge

15

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

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/chap2/2-06m.html

Seasonal Variations of the Wind Resource

There is considerable seasonal variation in the wind energy resource, with maxima in winter and spring and minima in summer and autumn throughout most of the contiguous United States

In winter, mean upper-air wind speeds are stronger than in any other season over most of the contiguous United States. Class 3 and above wind resource can be found at exposed sites throughout most of the contiguous United States except for the southeastern United States (excluding ridge crests), much of southern Texas, the basins and valleys of the western United States, and heavily forested areas and sheltered valleys and basins of the northeastern United States..

In spring, the mean upper-air flow is weaker than in winter but remains quite strong over most of the contiguous United States, although its strength decreases as spring progresses from March to May. Thus, in spring the wind resource is generally less than in winter on mountain summits and ridge crests (except in the extreme southern part of the Southwest) and exposed coastal areas of the Northwest, Northeast, and Great Lakes.

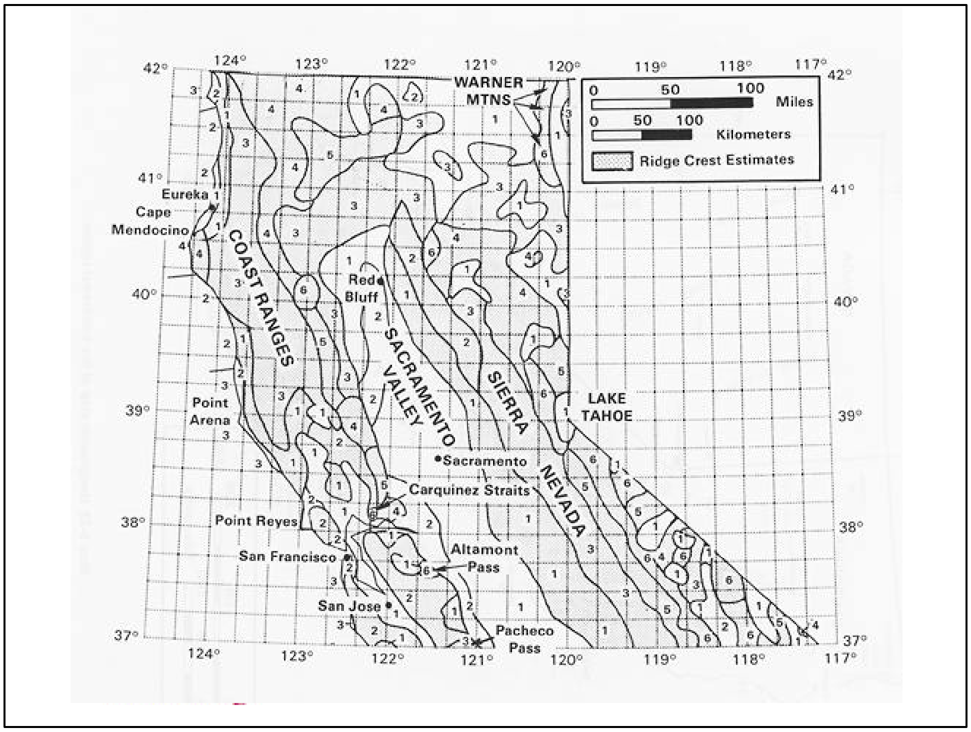
In spring, the coastal regions exhibit the greatest thermal contrasts between land and sea. The combined effects of weakened, but still significant, upper-air flow and regional, thermally induced flow in the coastal areas produce wind powers in the spring that exceed those in winter along much of the California coast and south Texas coast and are comparable to those in winter along much of the southern Atlantic coast, the Gulf coast, and the coastal areas of the western Great Lakes .

In summer, wind speeds aloft diminish, and wind power is at its lowest over most of the United States. Although only class 1 or 2 wind power occurs over much of the contiguous United States, areas of class 3 or higher wind resource occur over much of the northern and southern Great Plains, the Great Lakes, the south Texas coast, the Pacific coast from south central California northward to Oregon, southern Wyoming, the wind corridors in specific areas of California, Oregon, Washington, Montana, and Utah, and exposed mountain summits and ridge crests throughout the West. In the Northeast, class 3 wind power in summer can be found over Cape Cod and Nantucket Island, Massachusetts, and exposed ridge crests in Vermont, New Hampshire, and Maine.

Summer is the season of maximum wind energy in Hawaii, Puerto Rico, the Virgin Islands, and parts of California, Oregon, and Washington. In these regions, specific areas have high wind energy resource in the summer.

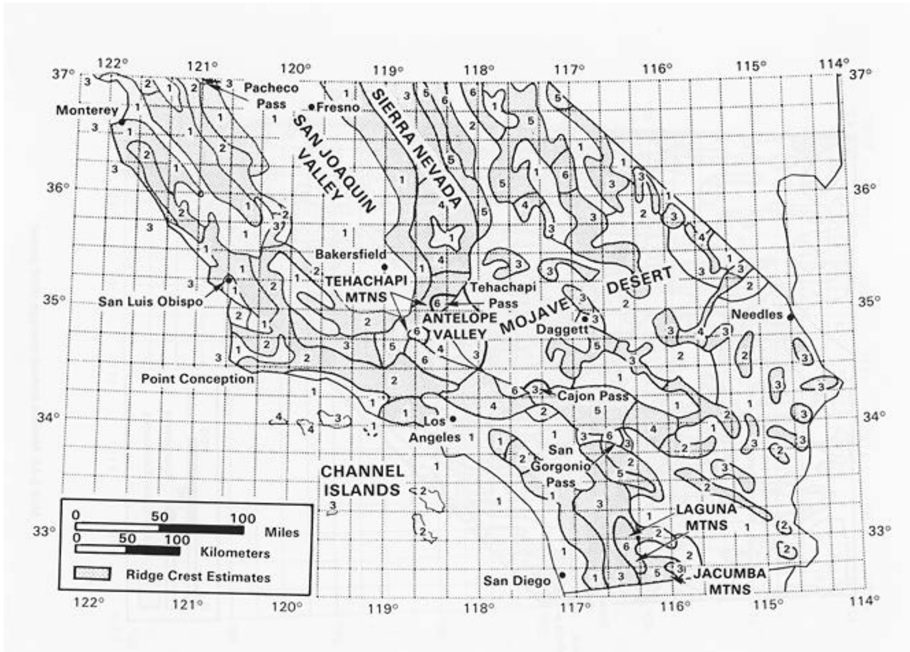
Along the West Coast, class 3 or 4 wind resource occurs at exposed coastal areas from Point Conception, California, north through Oregon. Persistent, strong north-to-northwest winds, which occur during summer along much of the West Coast, are associated with the summer anticyclone (high-pressure system) over the eastern Pacific Ocean.

In autumn, upper-air wind speeds increase as autumn progresses toward winter. Consequently, the mean wind power is considerably greater in November than in September over much of the country. Throughout most of the contiguous United States, the mean autumn wind resource is less than that of spring and winter but greater than that of summer.



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

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 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

Wind Power Efficiency

- Incoming wind has 3,046 kW
- Rotor produces 1,340 kW and delivers 1,297 kW to generator
- Generator produces 1,252 kW of which 1,176 are delivered to grid
- Usual grid loss is about 8%

California State University Northridge

19

This example is taken from Eric Hau's book, *Wind Turbines*, Springer, 2000, Figure 13.2, page 384. It is for a WKA-60 wind turbine. Not shown on the diagram is a power input to the turbine of 34 kW that is taken from the grid. According to Hau, most of this is used for measuring instruments for this experimental installation.

If we assume an air density of 1.2 kg/m^3, and use the 60 m diameter of the WKA-60 to compute the swept area, the equation $P = A\rho V^3/2$ can be solved for the wind velocity. This gives a wind velocity of 12 m/s.

The turbine has a power coefficient of 0.44 to produce the output of 1,340 kW. Bearing and gearbox efficiencies of 99.6% and 97.2% result in the mechanical power of 1,297 delivered to the generator.

The generator efficiency is 96.5% and the power output from the generator has to go through a frequency converter with an efficiency of 97.5%, reactive power compensation and harmonic filters with an efficiency of 98.3%. At this point the power output is 1,200 kW, which is the rated power of the unit. The rated power coefficient of 0.394 is this rated power divided by the input wind power.

Prior to delivery to the grid the power goes through a transformer with an efficiency of 98% resulting in the final 1,176 kW delivered to the grid.

Commercial Wind Turbines

Mfg./ Model	Area (m^2)	Power (kW) at		Power/Area at	
		11.6	*17 m/s*	*11.6*	*17 m/s*
NEG/64	3,217	1,168	1,564	363	486
Ve/V66	3,421	1,161	1,650	339	482
NEG/48	1,824	610	745	334	408
Ve/V47	1,735	569	660	328	380
Zo/Z48	1,810	750	750	414	414

California State University Northridge

20

DOE/EIA report *Renewable Energy 2000: Issues and* Trends, DOE/EIA-0628(2000), February, 2001. http://www.eia.doe.gov/cneaf/solar.renewables/rea_issues/062800.pdf page 77

This chart shows the performance of various wind turbines. The first column shows the manufacturer and the model. The full information for each entry is shown below:

NEG/64 is a NEG Micron Unipower 64 NM 1500C/64 The rotor diameter is 64 m and the rated power output is 1500 kW.

Ve/V66 is a Vestas/V66. The rotor diameter is 66 m and the rated power output is 1,650 kW.

NEG/48 is a NEG Micron Multipower 48 NM 750/48 The rotor diameter is 48.2 m and the rated power output is 750 kW.

Ve/V47 is a Vestas/V47. The rotor diameter is 47 m and the rated power output is 660 kW.

Zo/Z48 is a Zond/Z48 with a rotor diameter of 48 meters and a rated power output of 750 kW.

The power output in kW and the power output divided by the swept area of the rotors (W/m^2) are shown at two different wind speeds 11.6 m/s and 17 m/s. The original reference also has data for wind speeds of 14, 15, and 16 m/s.

Wind Farm Capacity Factors

Loc	MW	Model	kW	H_{hub} m	Area	CF
A	28	Micon	600	55	1631	28.5%
B	19	Vestas	500	40	1408	28.2%
C	25	DOE97	500	40	1134	26.2%
D	25	DOE97	500	40	1134	35.5%
E	80	Zond	750	63	1963	32%
F	107	Zond	750	51	1810	28%

California State University Northridge

21

DOE/EIA report *Renewable Energy 2000: Issues and* Trends, DOE/EIA-0628(2000), February, 2001. http://www.eia.doe.gov/cneaf/solar.renewables/rea_issues/062800.pdf page 79

This chart shows data on some actual wind farm and wind farm designs. In the table, the MW column is the total capacity of the wind farm. The kW column is the maximum power output of the individual wind turbines in the wind farm. The hub height is the elevation of the center of the rotor and CF is the capacity factor. This has its usual definition for power plants. The area represents the swept area of the rotors in square meters.

Individual locations, shown in the Loc column are discussed below.

Loc A is in Denmark. For this location the data shown are averages over different operating periods. The capacity of the farm varied from 27.6 to 28.8 MW and the individual turbines had hub heights ranging from 40 to 70 m and swept areas ranging from 1,452 to 2,810 m^2

Locs C and D are hypothetical wind farm models based on projections made by DOE using best case assumptions about hardware available in 1997.

Wind Energy R&D

- Improved blade aerodynamics
- Variable speed generators extend wind speed range
- Gearless turbines reduce the operating costs
- Lighter tower structures
- Smart controls and power electronics

California State University Northridge

22

Research and development throughout the past 20 years has resulted in a current generation of utility-scale wind turbines, with maximum electricity generating capacity often exceeding 500 kW per turbine, designed for about 120,000 hours of operation over a 20-year lifetime. In the United States, wind farm development activity in 1999 was motivated by the June 1999 expiration of the Federal production tax credit, and dominated by installation of utility-scale turbines manufactured by NEG Micon and Vestas, both Danish firms, and by Zond Energy Systems, a subsidiary of Enron Wind Corporation, a U.S. firm. Research and development for utility-scale turbines has been directed toward increasing the amount of wind energy that a turbine can convert into electricity for the lowest amount of capital investment and the lowest ongoing operating cost.

Following are examples of the R&D efforts that have contributed to current utility-scale turbine technology: Improvements in the aerodynamics of wind turbine blades, resulting in higher capacity factors and an increase in the watts per square meter of swept area performance factor.

Development of variable speed generators to improve conversion of wind power to electricity over a range of wind speeds.

Development of gearless turbines that reduce the on going operating cost of the turbine.

Development of lighter tower structures. A byproduct of advances in aerodynamics and in generator design is reduction or better distribution of the stresses and strains in the wind turbine.

Lighter tower structures, which are also less expensive because of material cost savings, may be used because of such advances.

Smart controls and power electronics have enabled remote operation and monitoring of wind turbines. Some systems enable remote corrective action in response to system operational problems. The cost of such components has decreased.

Turbine designs where power electronics are needed to maintain power quality also have benefited from a reduction in component costs.

In the United States, the Zond Z-750 series turbine represents a very innovative but less gradual design change. Enron Wind Corporation wind farms, which use the Zond Z-750 technology, address the risk of the design innovation with performance contracts that guarantee turbine electricity production, in addition to power curve and reliability guarantees normally included in wind turbine performance contracts. The results of R&D have been incorporated into utility-scale wind turbine design more gradually in Europe, followed by operation in wind farms to assess reliability over time.

Near-term R&D efforts are expected to continue in directions that increase the efficiency with which wind turbines convert wind energy to electricity. For instance, researchers report that further optimization of blade design is possible.42 Taller towers and rotor/generator systems with maximum power ratings exceeding 1 MW will continue to be improved.

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

California State University Northridge

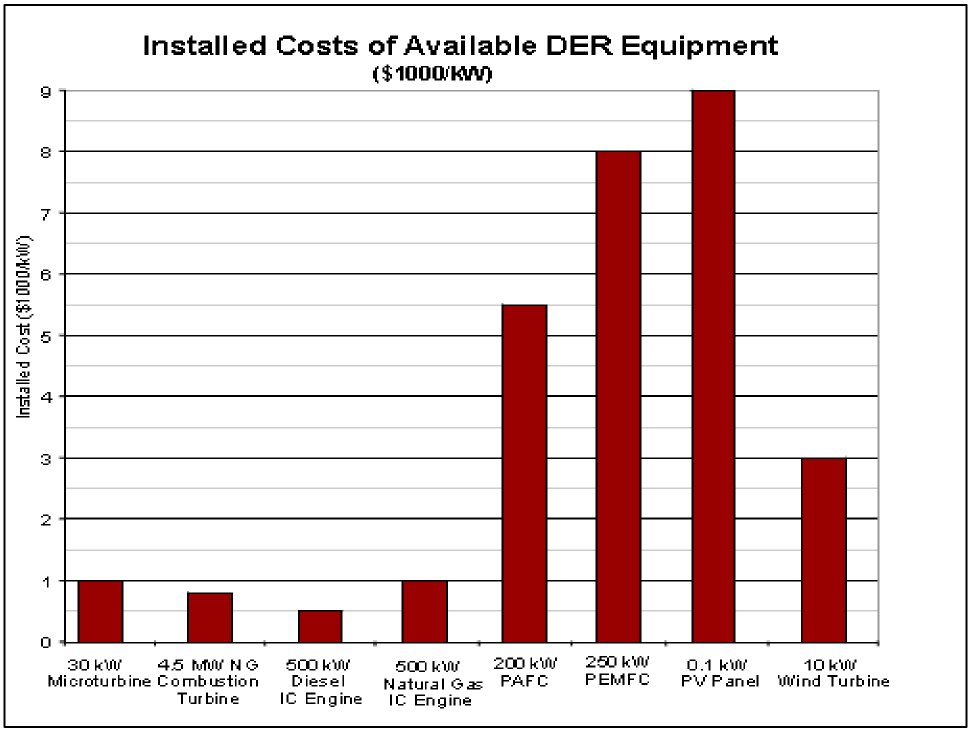
23

These data were taken from the web site of the American Wind Energy Association. They reference 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.

This can be compared with the data in Table 7.7 of the text which estimates a cost of 7.7 cents per kWh for Wind and a cost of 6.8 cents per kWh for hydropower. That same table estimates a cost of 22.8 cents per kWh for solar photovoltaic.

Of course, all cost estimates are affected by assumptions about capital cost, operating costs, and the interest rate used to obtain annualized equivalents of the initial capital cost.

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.



Distributed Energy Resource Costs from California Energy Commission at http://www.energy.ca.gov/distgen/economics/capital.html

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

California State University Northridge

25

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

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.

Check Wind Turbine Costs

- CEC DER cost is $3,000/kW (10 kW)
- Assume 20-year life with 12% return on investment (CRF = 0.13388)
- Annual O&M cost is 1.5% of initial investment ($45/kW)
- Capacity factor is 25%
- Cost is 20.4 cents per kWh

California State University Northridge

26

The exercise on this chart is intended to serve as a check on the cost estimates produced by the California Energy Commission and quoted by the Wind Energy Association.

The capital cost of $3,000/kW for a 10 kW wind generator is taken from the CEC chart on DER capital costs. The assumptions on lifetime and desired return on investment are my own. The factor for the annual operating and maintenance cost is taken from the CEC web site. They quote a range of 1.5% to 2% which is attributed to a biennial inspection. This seems small as it ignores property taxes and labor costs.

The capacity factor is taken from the historical data on wind farms.

Cost per kWh of generated electricity is computed as follows:

[($3,000/kW)(0.13388 $/year/$)

+$45/year/kW] / [(0.25)(24)(365) kWh/kW]

This figure is much larger than the range of 4.0 – 6.0 cents per kWh reported previously.

However, we can consider another set of data on the next slide.

Revised Wind Turbine Costs

- CEC DER low-end cost is $850/kW
- Assume 30-year life with 10% return on investment (CRF = 0.10608)
- Annual O&M cost is 2% of initial investment ($17/kW)
- Capacity factor is 30%
- Cost is 4.1 cents per kWh

California State University
Northridge

27

The calculations here are exactly the same as on the previous slide. However we are using different data for this estimate..

The capital cost of $850 / kW for w wind generator is the low end of the wind turbine range in the DER capital cost table provided by the CEC. The assumptions on lifetime and desired return on investment are my own. These assumptions of a longer lifetime and a smaller ROI have the net effect of reducing the annualized costs by a factor of (1 – 0.10608 / 0.13388) compared to the previous calculations.

The factor for the annual operating and maintenance cost is taken from the CEC web site. They quote a range of 1.5% to 2% which is attributed to a biennial inspection. This seems small as it ignores property taxes and labor costs.

The capacity factor which is taken from the historical data on wind farms, is higher than the value of 25% assumed previously.

In this case the same method for the cost per kWh of generated electricity yields the following result:

[($850/kW)(0.10608 $/year/$)

+$17/year/kW] / [(0.30)(24)(365) kWh/kW]

This figure is just above the low end of the range of 4.0 – 6.0 cents per kWh reported previously.

This chart and the previous one show how there can be a great discrepancy in the reported costs of alternative technologies.

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

California State University
Northridge

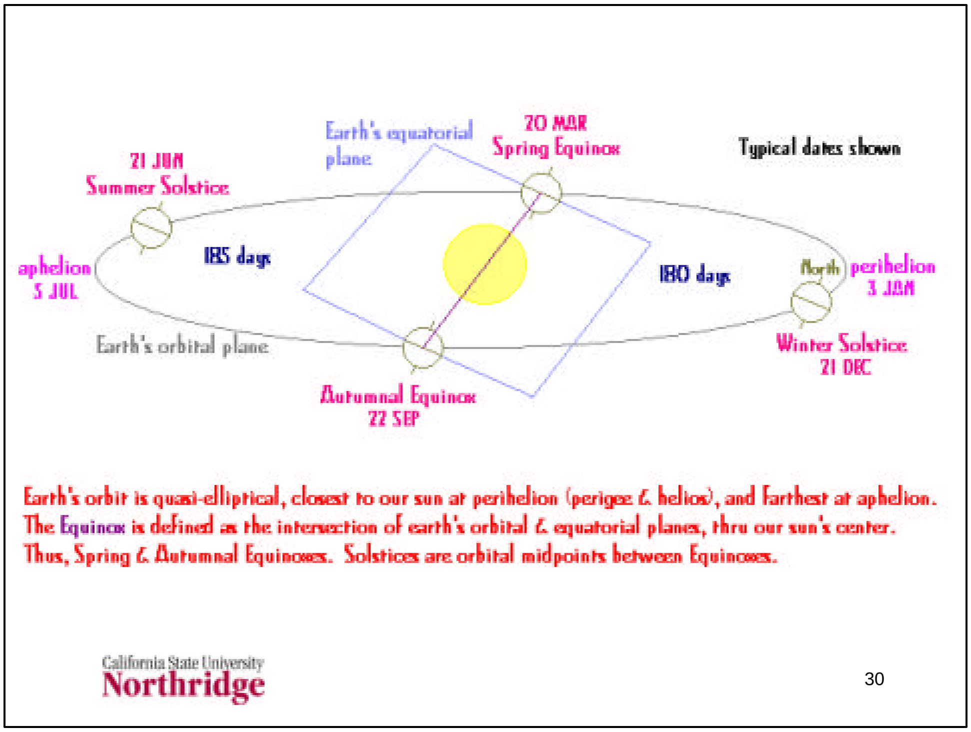
Solar Geometry

- Earth has mildly elliptic orbit around sun
- Earth has tilt of 23.45^o
- Typical analysis uses earth centered coordinate system
- Angle of declination is apparent angle that sun makes with plane through the earth's equator

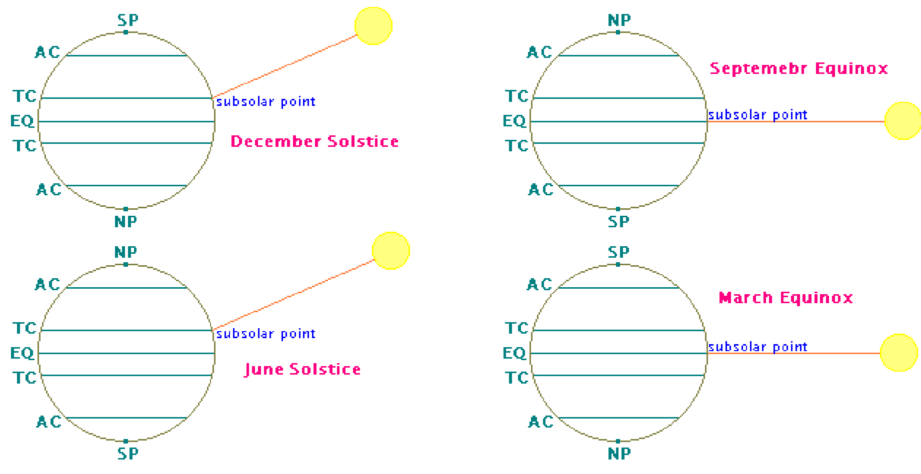
California State University Northridge

29

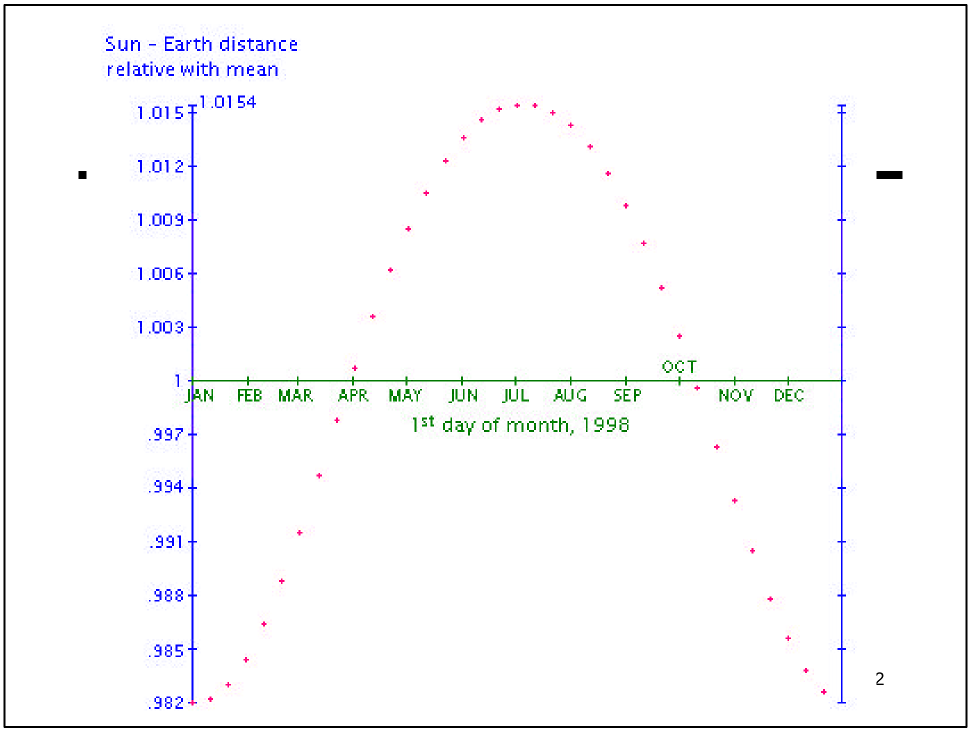
In the Northern hemisphere the angle that the sun makes with the equatorial plane is 23.45^o on the first day of summer (the summer solstice) and -23.45^o on the first day of winter (the winter solstice). The angle is zero on the first day of spring and autumn (the vernal and autumnal equinoxes). Of course this apparent angle is due to the tilt of the earth as it rotates about the sun.



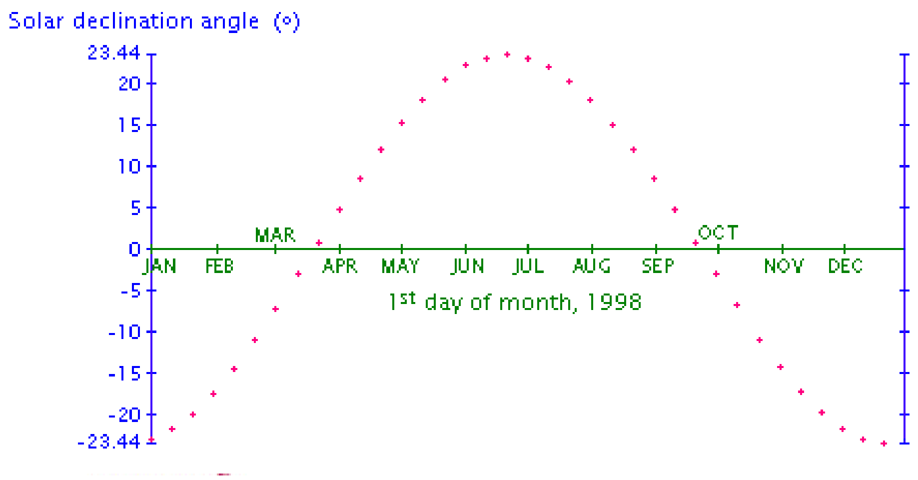
The next series of slides, showing the earth's orbit around the sun, and the impact on the solar angle, is taken from http://www.enter.net/~jbartlo/supp/sungeo.htm

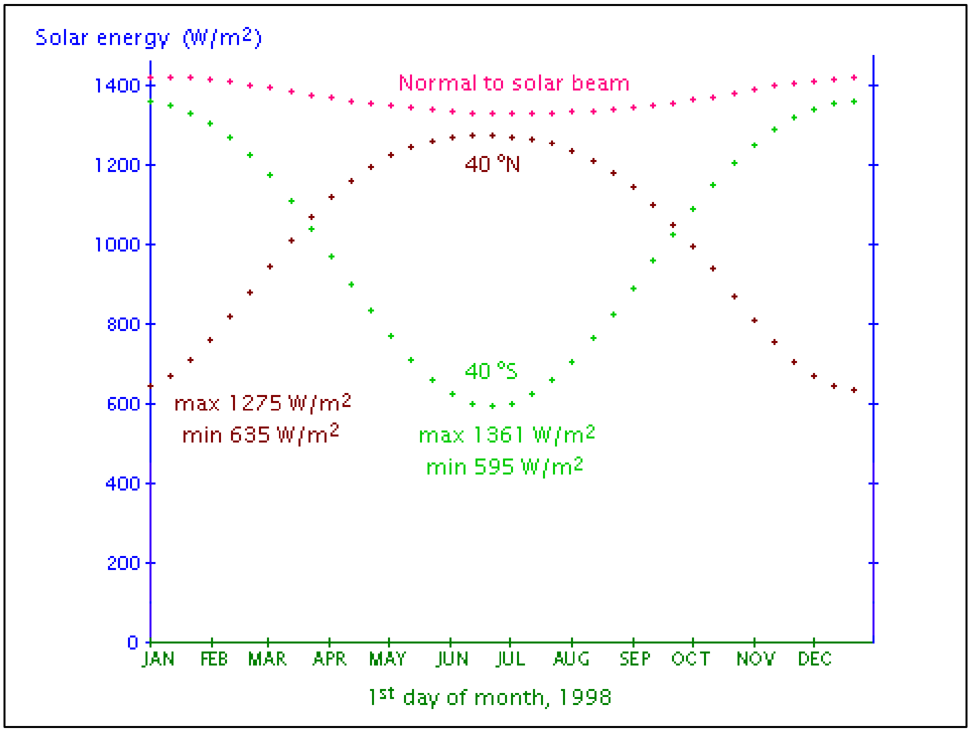


SP
AC
TC
EQ
TC
AC
NP
subsolar point
December Solstice
NP
AC
TC
EQ
TC
AC
SP
Septemebr Equinox
subsolar point
NP
AC
TC
EQ
TC
AC
SP
subsolar point
June Solstice
SP
AC
TC
EQ
TC
AC
NP
March Equinox
subsolar point


Sun - Earth distance
relative with mean
1.0154
1.015
1.012
1.009
1.006
1.003
1
.997
.994
.991
.988
.985
.982
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1st day of month, 1998
2

Solar Declination Angle

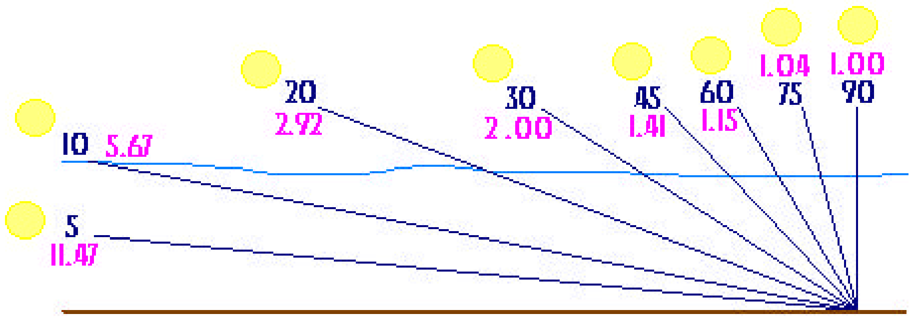




Maximum solar energy flux (normal to solar beam) variation is quite significant, between 1422 W/m2 at perihelion to 1330 W/m2 at aphelion, a 6.7 % annual change. Peak solar energy amount (incident to horizontal) at 40 °N at June Solstice is much less than that at 40 °S at December Solstice, but the reverse is true for minimum amounts at opposite solstices. Such values are for one time of day though. Considering an entire day, most solar energy reaches the South Pole at December Solstice than at any other time and location because day length increases poleward during Summer :

LAT	DD
0	12:06
5	12:23
10	12:41
15	12:59
20	13:19
25	13:40
30	14:03
35	14:29
40	14:59
45	15:34
50	16:19
55	17:19
58	18:06
60	18:47
62	19:38
63	20:11
64	20:51
65	21:47
65.5	22:29
65.7	22:53
65.9	23:34
>= 66	24:00

Daytime duration (DD, hr:min) at various latitudes (LAT, °S) during 22 December 1995 (day of solstice). 24 hour day is less than 66.56° latitude because of atmospheric refraction.



Solar elevation angle (deg) and approximate optical air mass. Optical air mass is amount of atmosphere the solar beam traverses to reach Earth's surface, relative to a beam directly overhead thru standard atmospheric conditions at sea level. Solar elevation angle is never much > 75 deg in most of the United States, but increasing elevation decreases optical air mass.

California State University Northridge

35

Collecting Solar Energy

- Position of sun changes during day and year
- Can have fixed or tracking collectors
  - Track position during day
  - Track position during year
- Compromise is to have fixed collector, facing South tilted at the same angle as the latitude

California State University Northridge

36

Solar Water Heaters

- Used as a source of lower temperature hot water
- May be used to heat swimming pools
- Can also be used as preheater for conventional water heater
- Similar technology may be used for space heating

California State University Northridge

37

Reference: http://www.consumerenergycenter.org/renewable/basics/solarthermal/water.html

More than one-half million solar hot water systems have been installed in the United States, mostly on single-family homes. The majority of these systems are used to heat swimming pools.

Typically, a homeowner relying on electricity to heat water could save up to $500 in the first year of operation by installing a solar water heating system. The savings over time increases due to increasing electricity rates. The average solar heating system pays for itself in four to seven years.

Roof-mounted solar hot water systems are often designed to look like skylights, making them more pleasing in appearance to homeowners and their neighbors.

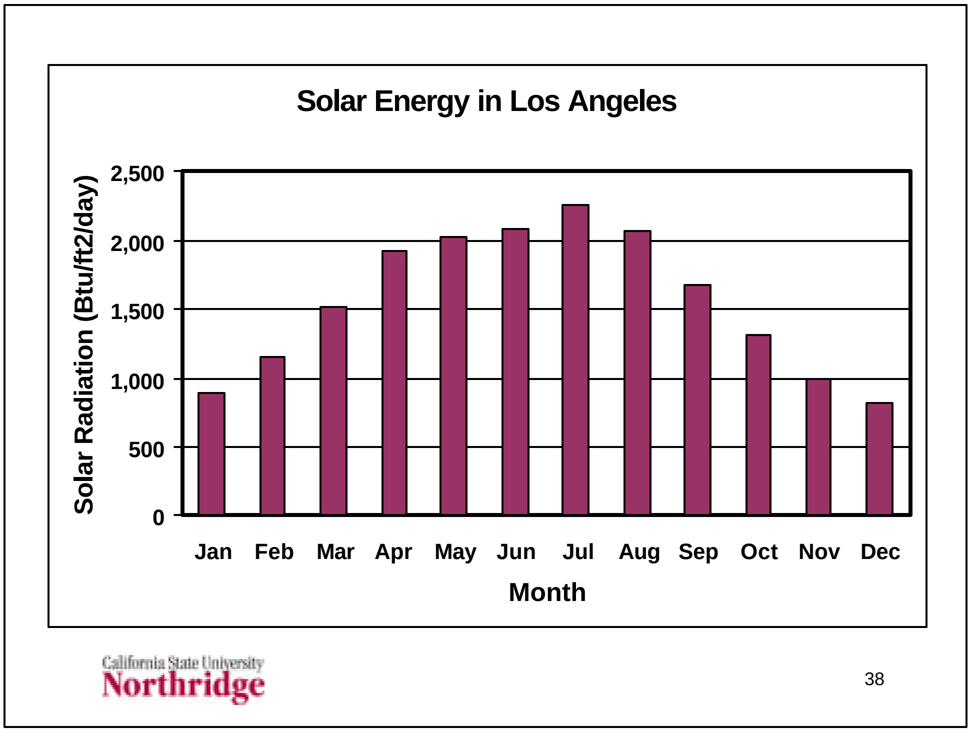
The cost of solar water heating systems declined by 30 percent between 1980 and 1990. Further cost reductions will not be as dramatic, but prices will continue to decrease as demand increases and manufacturers take advantage of economies of scale.

In September 2000, Governor Davis signed Senate Bill 1345 that provided funding for solar water heating systems as well as distributed generation systems. The is being administered by the California Energy Commission. The Program has funded up to $750 per solar water heating system.

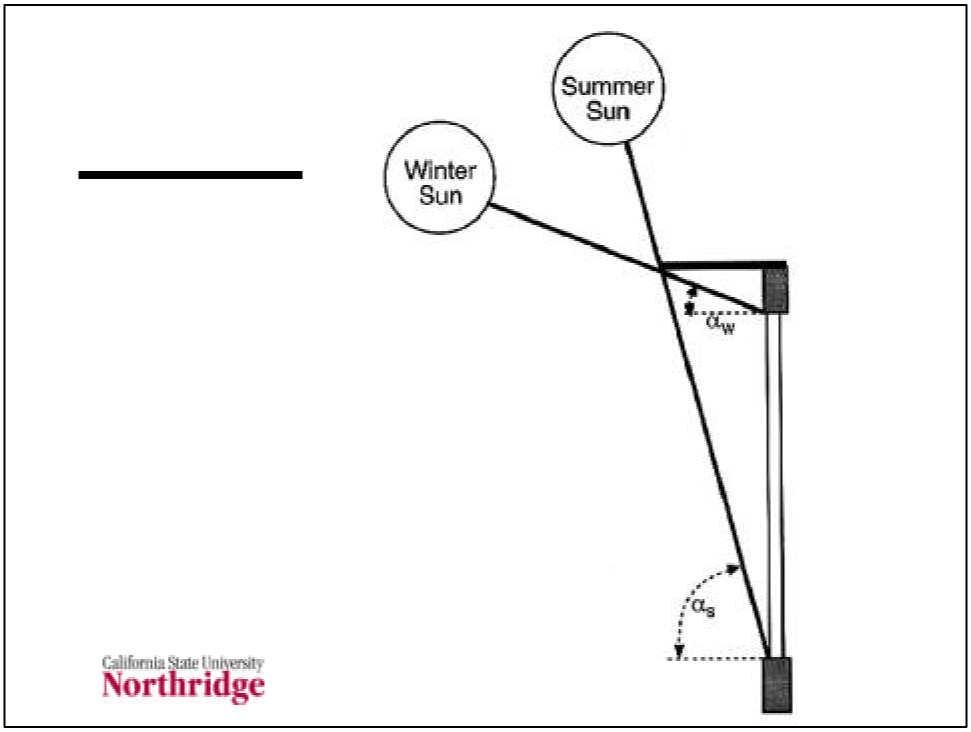
how it works

Cold water from the home's regular water line is being pumped to the roof where it enters the thermal energy collector. Sunlight strikes the collector, and the sun's heat warms the water. The heated water comes back into the home or business.

Inside, the warmed water from the roof is collected in a "solar" tank, which has temperature sensors and other mechanisms. The warm water from the solar system then goes into the regular hot water system. because the regular hot water system (either electric or gas heated) is heating warmer water, you don't have to heat it as much as if it were plain cold water. If no one turns on a hot water tap, the water is circulated back to the roof to be heated even more. During the night, the system can be set up so that water is not pumped to the roof, preventing heat loss to the cool outside air.



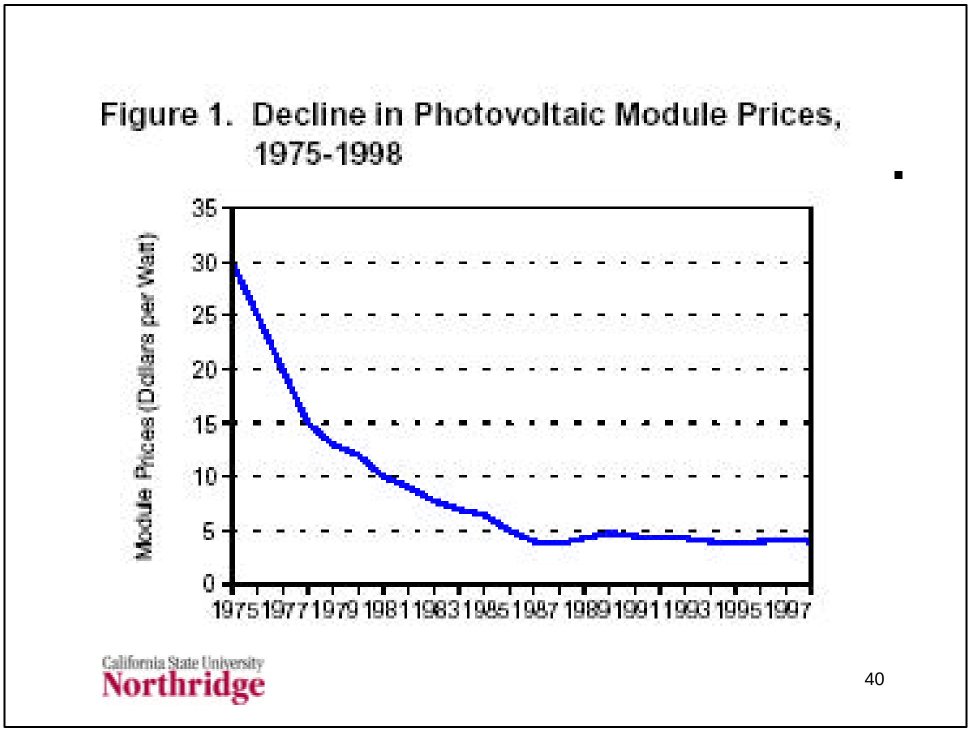
The data for this plot was obtained from http://rredc.nrel.gov/solar/



Reference: http://rredc.nrel.gov/solar/pubs/bluebook/gifs/fig9.gif

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.



Reference: 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

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 implications of this cost for the electricity cost of photovoltaic cells are explored on the next slide.

Photovoltaic Costs

- DOE/EIA data for initial cost $4000/kW
- Assume 20-year life with 13% return on investment (CRF = 0.13388)
- Annual O&M cost is 1% of initial investment ($40/kW)
- Capacity factor is 20%
- Cost is 32.8 cents per kWh

California State University
Northridge

41

This calculation is similar to the ones done previously for wind turbines.

Municipal Solid Waste

- Mass Burn
- Refuse-derived fuel
- Pyrolysis/thermal gasification

California State University
Northridge

42

municipal solid waste power plants Municipal solid waste MSW can be directly combusted in waste-to-energy facilities as a fuel with minimal processing, known as mass burn; it can undergo moderate to extensive processing before being directly combusted as refuse-derived fuel; or it can be gasified using pyrolysis or thermal gasification techniques.

Mass Burn **I**ncoming trucks deposit the refuse into pits, where cranes then mix the refuse and remove any bulky or large non-combustible items (such as large appliances). The refuse storage area can be maintained under lower than atmospheric pressure in order to prevent odors from escaping. The cranes move the refuse to the combustor charging hopper to feed the boiler.

Heat from the combustion process is used to turn water into steam, with the steam then routed to a steam turbine-generator for power generation. The steam is then condensed via traditional methods (such as wet cooling towers or once-through cooling) and routed back to the boiler. Residues produced include bottom ash (which falls to the bottom of the combustion chamber), fly ash (which exits the combustion chamber with the flue gas [hot combustion products]), and residue (including fly ash) from the flue gas cleaning system.

The combined ash and air pollution control residue typically ranges from 20 percent to 25 percent by weight of the incoming refuse processed. This ash residue may or may not be considered a hazardous material, depending on the makeup of the municipal waste.

Refuse-Derived Fuel Refuse-derived fuel (RDF) typically consists of pelletized or "fluff" MSW that is the by-product of a resource recovery operation. Processing removes iron materials, glass, grit, and other materials that are not combustible. The remaining material is then sold as RDF. Both the RDF processing facility and the RDF combustion facility are usually located near each other, if not on the same site.
Pyrolysis/Thermal Gasification Pyrolysis and thermal gasification are related technologies. Pyrolysis heats organic material to high temperatures in the absence of gases such as air or oxygen. The process produces a mixture of combustible gases (primarily methane, complex hydrocarbons, hydrogen and carbon monoxide), liquids and solid residues. Thermal gasification of MSW is different from pyrolysis in that the thermal decomposition takes place in the presence of a limited amount of oxygen or air.

The producer gas which is generated in either process can then be used in boilers or cleaned up and used in combustion turbine/generators. The primary area of research for this technology is the scrubbing of the producer gas of tars and particulates at high temperatures in order to protect combustion equipment downstream of the gasifier and still maintain high thermal efficiency.

Both of these technologies are in the development stage with a limited number of units in operation. The Hyperion Energy Recovery System operated by the City of Los Angeles had a system designed to fire dried sewage sludge in a staged fluidized bed combustor. The resulting gas was then combusted in stages, and the heat was used to turn water into steam, driving a 10 MW steam turbine-generator.

Landifll Gas

- Formed when municipal solid waste is buried
- Gas is about 57% CH_4 and 42% CO_2
- Trace species nitrogen, hydrogen, oxygen
- Smaller amounts of alkanes, aromatics, chlorocarbons, oxygenated compounds, other hydrocarbons and sulfur dioxide.

California State University Northridge

43

Reference: http://www.consumerenergycenter.org/renewable/basics/biomass/landfill.htmldigester

gas & landfill gas

When you bury trash at a landfill, you create on an oxygen-free environment under the capping soil layer. With relatively dry conditions, landfill waste produces significant amounts of gas as it decomposes -- mostly methane. With Californians dumping 33 million tons of waste per year, the total amount of landfill gases produced in California is tremendous.

If these gases were just released to the atmosphere, they could add to global climate change problems. They could also be potentially a fire or explosion hazard if not collected and gotten rid of. So, a good solution to the landfill gas problem is to collect it and burn it to produce electricity.

The gas can be collected by a collection system, which typically consists of a series of wells drilled into the landfill and connected by a plastic piping system. The gas entering the gas collection system is saturated with water, and that water must be removed prior to further processing.

The typical dry composition of the low-energy content gas is 57 percent methane (natural gas), 42 percent carbon dioxide, 0.5 percent nitrogen, 0.2 percent hydrogen, and 0.2 percent oxygen. In addition, a significant number of other compounds are found in trace quantities. These include alkanes, aromatics, chlorocarbons, oxygenated compounds, other hydrocarbons and sulfur dioxide.

After the water is removed, the landfill gas can be used directly in reciprocating engines. Or the carbon dioxide can be removed with further refining and purer methane can be used for electricity generation applications such as gas turbines and fuel cells. For example, Southern California Edison and Los Angeles Department of Water and Power operate a 40 kilowatt phosphoric acid fuel cell using processed landfill gas at a hotel/convention center complex in the City of Industry.

Digestor Gas

- Formed from animal waste
- First step is decomposition into molecules such as sugar
- Next organic acids are formed
- Final product is methane gas that can be burned

California State University Northridge

44

Reference: http://www.consumerenergycenter.org/renewable/basics/biomass/landfill.htmldigester

Digestor Gas

Anaerobic digestion is a biological process that produces a gas principally composed of methane (CH4) and carbon dioxide (CO2) otherwise known as biogas. These gases are produced from organic wastes such as livestock manure, food processing waste, etc.

Anaerobic processes could either occur naturally or in a controlled environment such as a biogas plant. Organic waste such as livestock manure and various types of bacteria are put in an airtight container called digester so the process could occur. Depending on the waste feedstock and the system design, biogas is typically 55 to 75 percent pure methane. State-of-the-art systems report producing biogas that is more than 95 percent pure methane.

The process of anaerobic digestion consists of three steps.

The first step is the decomposition (hydrolysis) of plant or animal matter. This step breaks down the organic material to usable-sized molecules such as sugar. The second step is the conversion of decomposed matter to organic acids. And finally, the acids are converted to methane gas.

At Royal Farms No. 1 in Tulare, Calif., hog manure is slurried and sent to a covered lagoon for biogas generation. The collected biogas fuels a 70 kilowatt (kW) engine-generator and a 100 kW engine-generator. The electricity generated on the farm is able to meet monthly electric and heat energy demand.

Given the success of this project, three other swine farms (Sharp Ranch, Fresno and Prison Farm) have also installed floating covers on lagoons. The Knudsen and Sons project in Chico, Calif., treated wastewater which contained organic matter from fruit crushing and wash-down in a covered and lined lagoon. The biogas produce is burned in a boiler. And at Langerwerf Dairy in Durham, Calif., cow manure is scraped and fed into a plug-flow digester. The biogas produced is used to fire an 85 kW gas engine. The engine operates at 35 kW capacity level and drives a generator to produce electricity. Electricity and heat generated is able to offset all dairy energy demand. That system has been in operation since 1982.

Many anaerobic digestion technologies are commercially available and have been demonstrated for use with agricultural wastes and for treating municipal and industrial wastewater. Where unprocessed wastes cause odor and water pollution such as in large dairies, anaerobic digestion reduces the odor and liquid waste disposal problems and produces a biogas fuel that can be used for process heating and/or electricity generation.