Renewable/Alternative

- What are alternative or 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
    - Conservation as an alternative resource

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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.

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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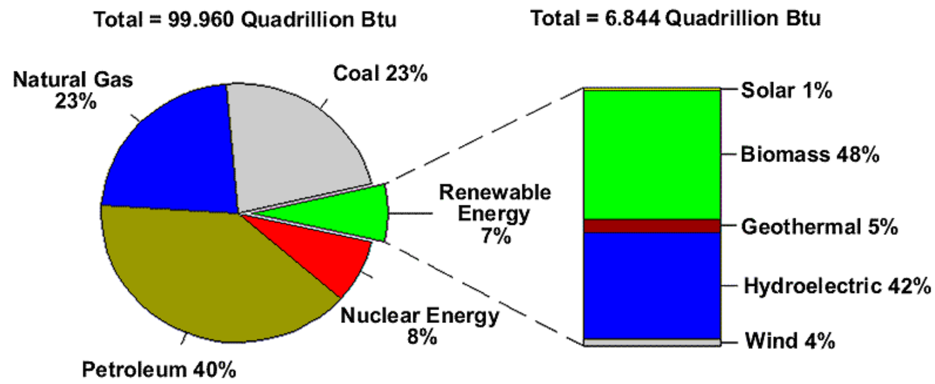
We will be discussing each of the topics covered here tonight in more detail. However, all the issues described here will be pertinent to those discussions. Many alternative energy technologies, such as solar, wind, geothermal, and tidal/wave power have the prospect of using zero cost fuels, but have 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.

US Renewable Use 2006



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

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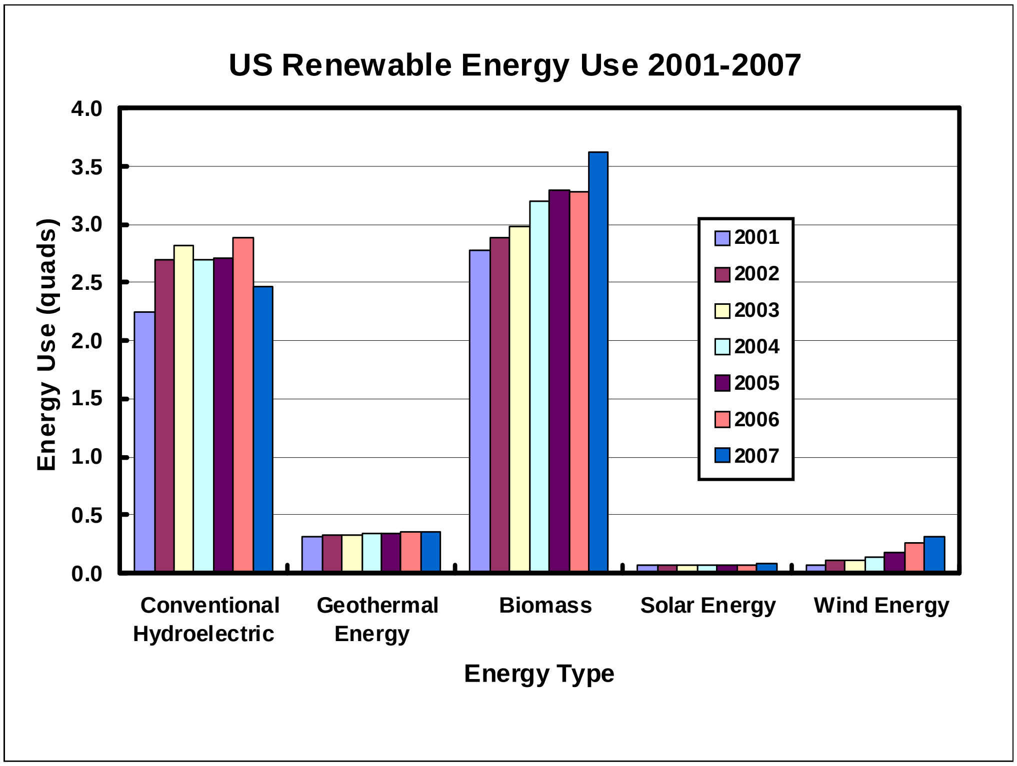
Reference: http://www.eia.doe.gov/cneaf/solar.renewables/page/ prelim_trends /rea_prereport.html accessed February 28, 2008

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.

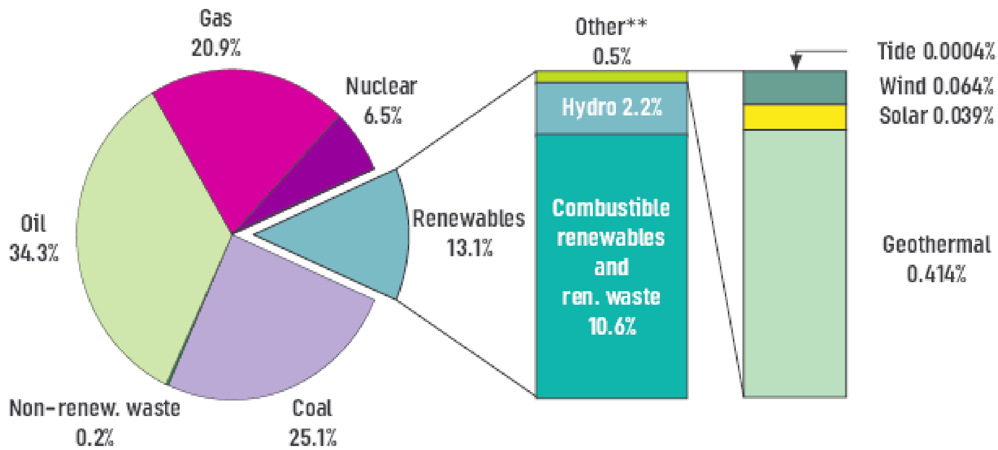
Biomass includes: black liquor, wood/wood waste liquids, wood/wood waste solids, municipal solid waste (MSW), landfill gas, agriculture byproducts/crops, sludge waste, tires, biodiesel, ethanol, losses and coproducts from production of biodiesel and ethanol, and other biomass solids, liquids and gases. 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* Mtoe	Share of Renewables in TPES A %	Share of Renewables in TPES B %
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

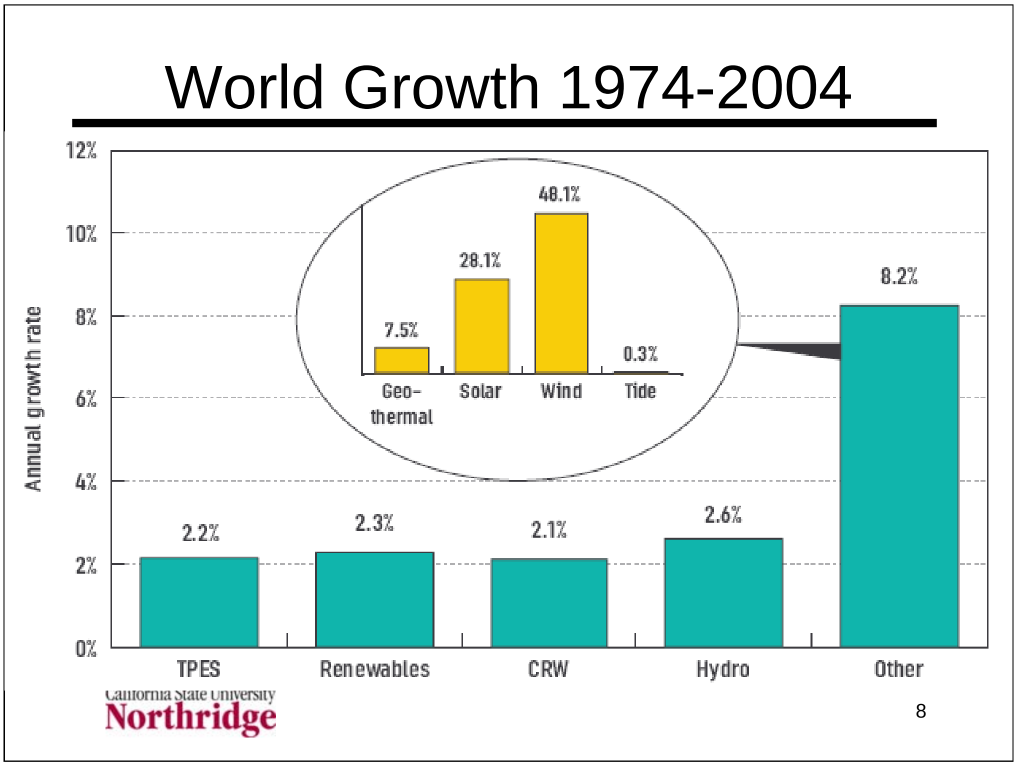
Mtoe = Million tonnes of oil equivalent

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.)



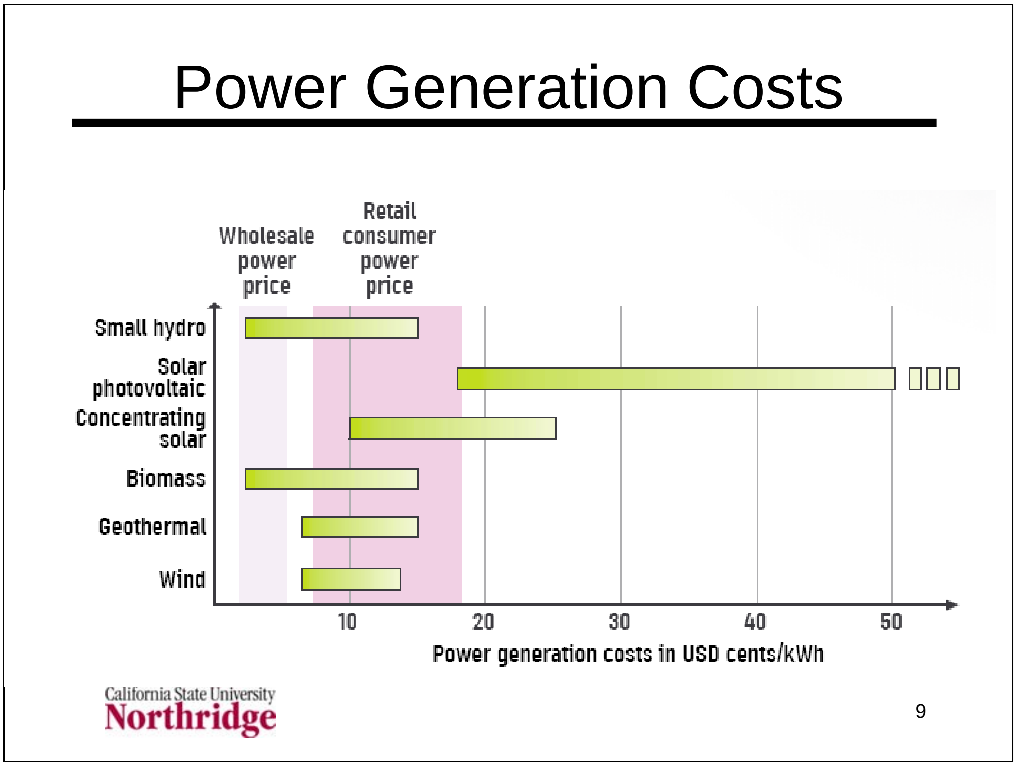
Reference: Pamphlet available from IEA web site; it's URL is http://www.iea.org/textbase/papers/2006/renewable_factsheet.pdf

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.

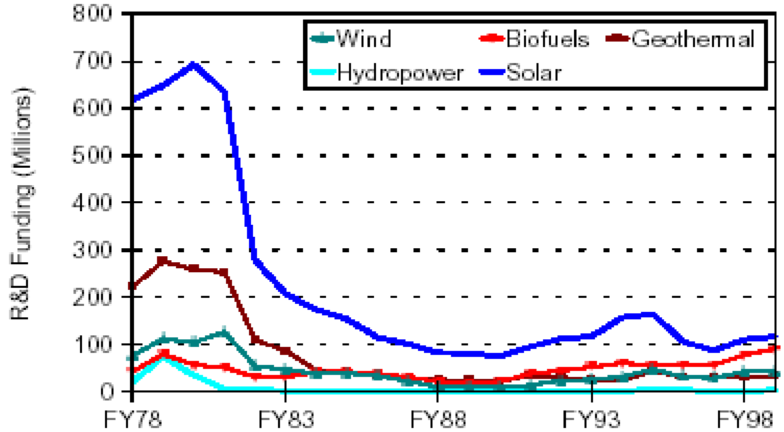


Reference: Pamphlet available from IEA web site; it's URL is http://www.iea.org/textbase/papers/2006/renewable_factsheet.pdf

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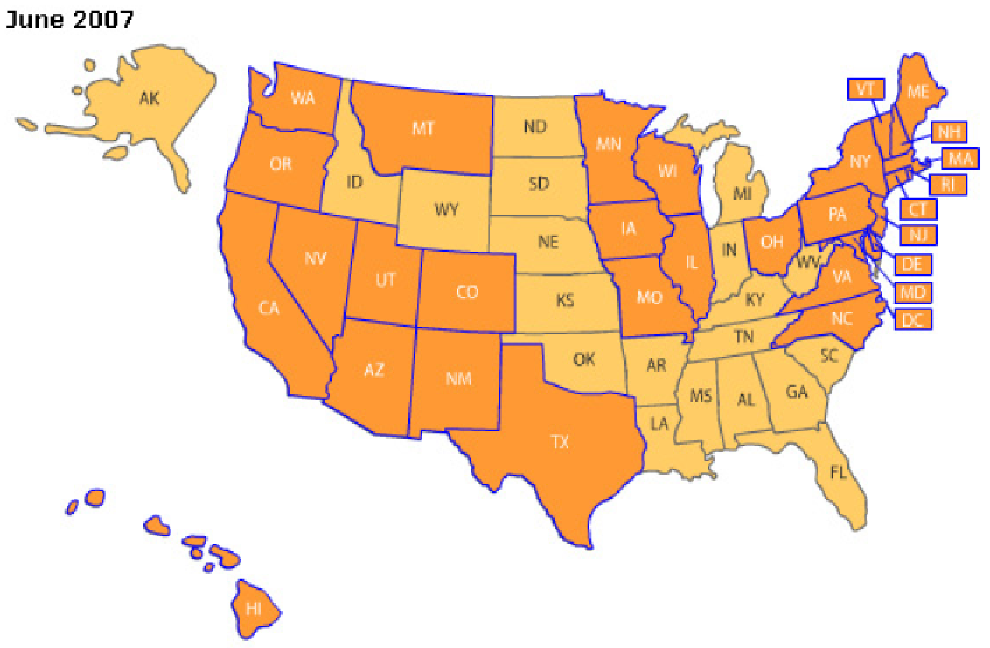
See http://www.dsireusa.org/ (accessed March 2, 2009) a web site entitled Database of State Incentives for Renewables and Efficiency for a list of various incentives programs. The site also contains a limited list of Federal incentives.

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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Annual wind electric energy generated TWh (2007 World total 164.4 of 18,779 TWh)
http://www.eia.doe.gov/emeu/international/contents.html

	1990	1995	2000	2005	2006	2007	2008
United States	2.789	3.164	5.593	17.811	26.589	34.450	52.026
Spain	0.013	0.257	4.491	20.117	22.132	26.134	29.933
India	0.030	0.471	1.600	6.273	8.255	11.070	14.800
China	0.002	0.061	0.584	1.927	3.304	6.430	12.779
United Kingdom	0.009	0.371	0.900	2.759	4.014	5.010	6.756
Denmark	0.580	1.118	4.029	6.283	5.803	6.814	6.582
Italy	0.002	0.009	0.535	2.227	2.822	3.937	6.115
Portugal	0.001	0.015	0.160	1.684	2.779	3.835	5.446
France	0.000	0.005	0.073	0.914	2.080	3.849	5.425
Netherlands	0.048	0.301	0.788	1.964	2.596	3.266	4.046
Australia	0.000	0.007	0.055	0.841	1.627	2.481	3.121
Canada	0.002	0.056	0.251	1.398	2.375	2.873	2.871
Japan	0.000	0.001	0.104	1.666	2.100	2.493	2.773
Ireland	0.000	0.015	0.232	1.056	1.541	1.860	2.290
Austria	0.000	0.001	0.064	1.262	1.664	1.914	1.889
Sweden	0.006	0.094	0.434	0.889	0.938	1.359	1.875
Greece	0.001	0.032	0.428	1.203	1.614	1.727	1.578
New Zealand	0.000	0.001	0.114	0.584	0.592	0.890	1.004
Norway	0.000	0.010	0.029	0.481	0.605	0.855	0.871
Egypt	0.000	0.000	0.130	0.524	0.585	0.789	NA
Poland	0.000	0.001	0.005	0.128	0.243	0.496	0.791
Belgium	0.008	0.009	0.015	0.216	0.348	0.467	0.591
Brazil	0.000	0.000	0.001	0.088	0.225	0.531	0.530
Taiwan	0.000	0.000	0.001	0.086	0.263	0.422	NA
Korea, South	0.000	0.001	0.016	0.124	0.227	0.357	0.362
Turkey	0.000	0.000	0.031	0.056	0.121	0.337	0.757

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.

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. It also has limited resources.

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**. which is made from heavy vegetable oils or food waste.

Agricultural waste can be used for combustion. However, this waste has large transportation costs leading to a large number of small generating facilities.

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

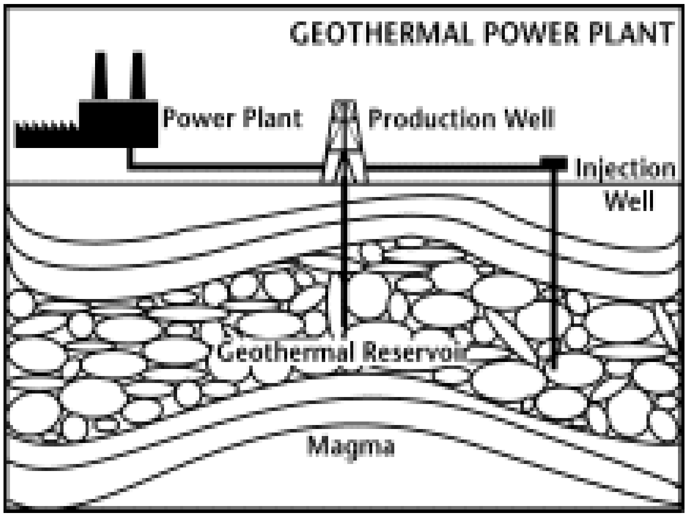
Refuse-Derived Fuel Refuse-derived fuel (RDF) typically consists of pelletized or "fluff" MSW that is the by-product of a resource recovery operation.

Pyrolysis/Thermal Gasification produces gaseous fuels from waste. The process is similar to the ones used to produce gaseous fuels from coal.

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

Fischer-Tropsch liquids are produced from coal or natural gas. They have been used for gasoline and fuel oil.

Geothermal



- Uses energy from under-ground 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.

Alternative and Renewable Energy Resources

Mechanical Engineering 483

Alternative Energy Engineering II

Larry Caretto

February 17, 2010

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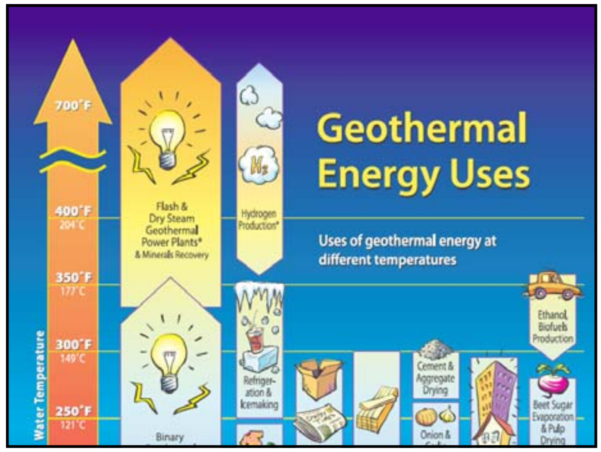
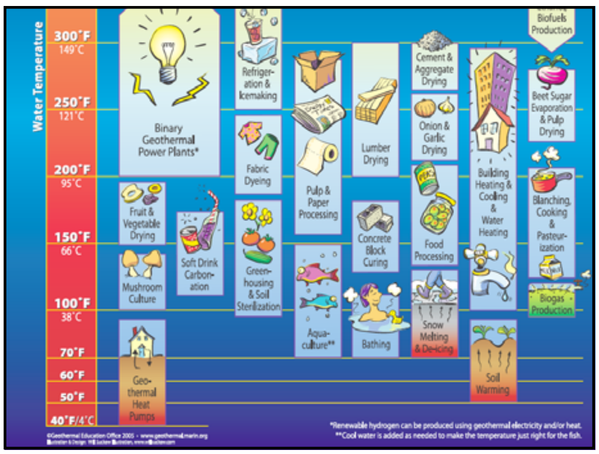
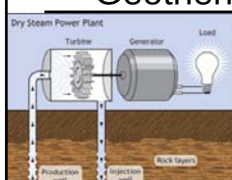
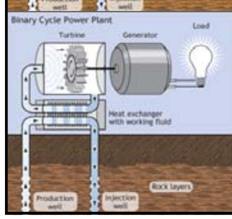


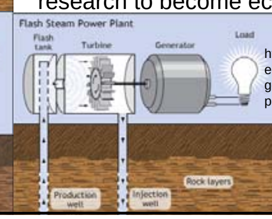


Geothermal Power Plants



- Dry steam preferred, but resource is rate
- Flash steam is most common
- Binary cycle can use largest resource, but needs more research to become economic





http://www1.eere.energy.gov/geothermal/powerplants.html

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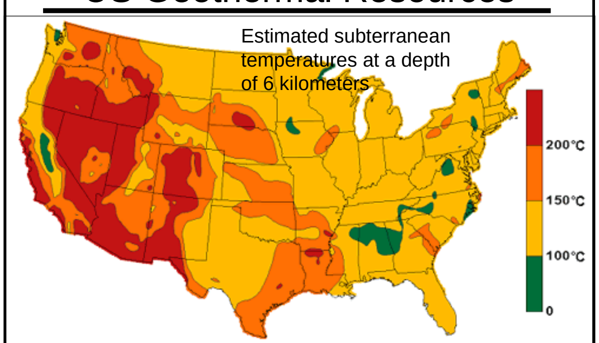
US Geothermal Resources



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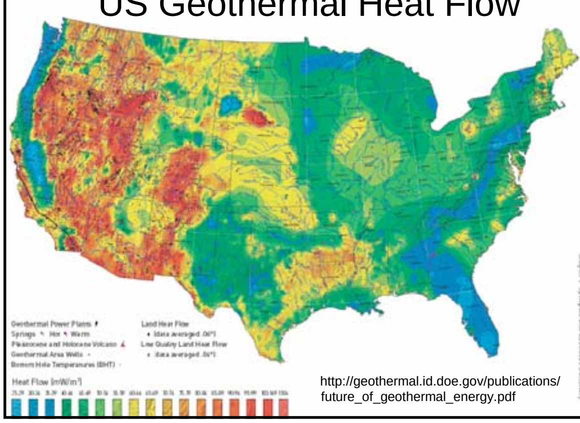
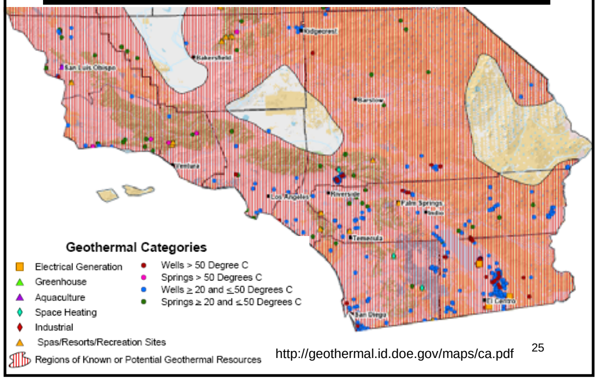
http://www1.eere.energy.gov/geothermal/geomap.html 23

US Geothermal Heat Flow



http://geothermal.id.doe.gov/publications/future_of_geothermal_energy.pdf

CA Geothermal Resources



http://geothermal.id.doe.gov/maps/ca.pdf

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MIT Report

- Future of Geothermal Energy (2006)
  - http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf
- Interdisciplinary assessment of resource, production, and use, focusing on electric power production
  - Enhanced geothermal systems (EGS)
  - Develop technology to use energy from hot rock geothermal energy

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MIT Report II

- States that 100,000 MW_e of geothermal power could be developed over 50 years with additional R&D funding
  - \$300–400 million required over 15 years
- Need commercial demonstration of plants using water injection to hot rock
  - Total public/private investment of \$0.8–1 billion over 15 years
- EGS can be significant by 2050

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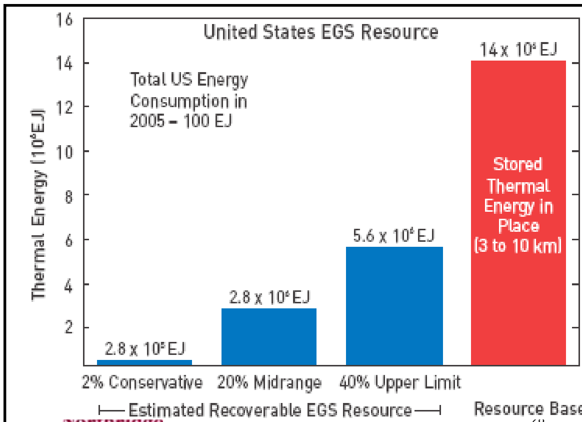

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http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

Size Requirements

Table 1.2 Estimated land area and subsurface reservoir volumes needed for EGS development. Note: Above 100 MW_e, reservoir size scaling should be linear.

Plant size in MW_e	Surface area for power plant and auxiliaries in km^2	Subsurface reservoir volume in km^3
25	1	1.5
50	1.4	2.7
75	1.8	3.9
100	2.1	5.0

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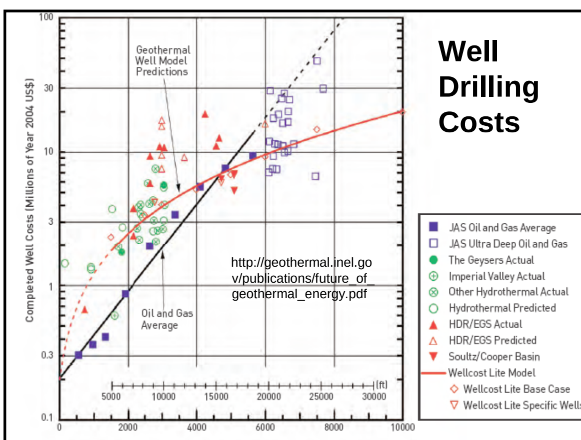
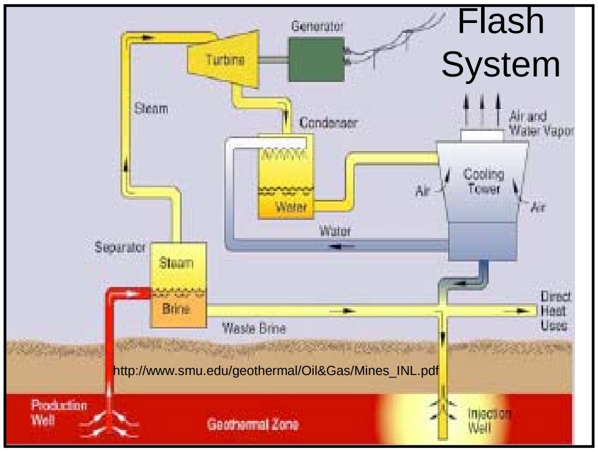
http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf



Well Drilling Costs

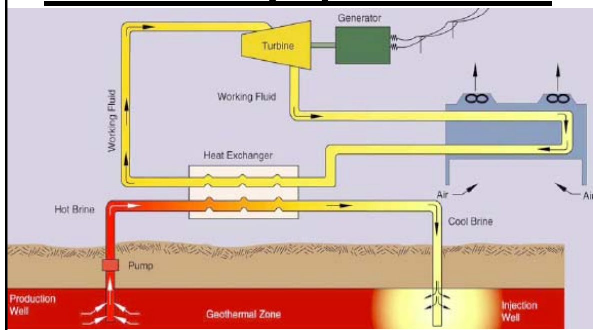
http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

Flash System



http://www.smu.edu/geothermal/Oil&Gas/Mines_INL.pdf

Binary System



California State University Northridge http://www.smu.edu/geothermal/Oil&Gas/Mines_INL.pdf 32

CalEnergy Geothermal Plants

- Located in Imperial Valley
  - Net capacity of 10 plants is 237 MW
    - Power sold to Edison transmitted over Imperial Irrigation District power lines
  - Resource is hot, high-pressure water
  - Flashed to steam in three stages
    - High pressure from ground
    - Standard pressure 8 atm and 340ºF
    - Low pressure 1 atm and 250ºF

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CalEnergy Geothermal Plants II

- Condensed steam from turbine and geothermal water (brine) not flashed to steam is returned to ground
- Crystallizer-clarifier technology used to remove silica from brine during flashing

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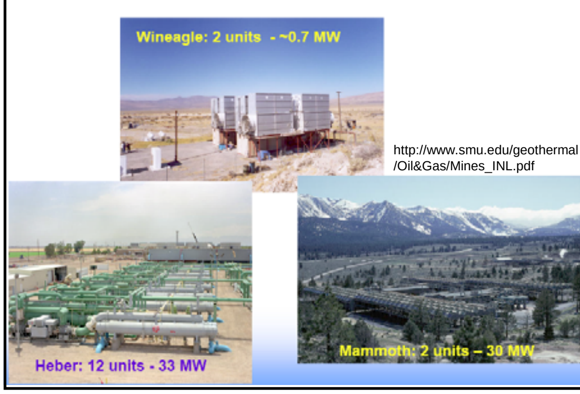
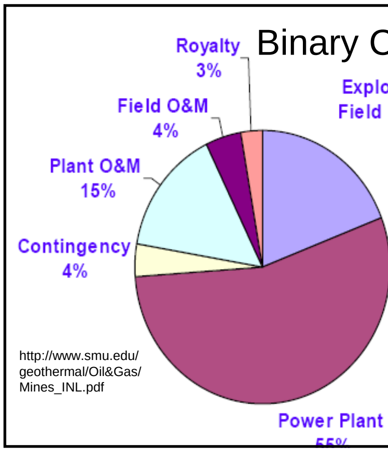
Binary Power Plants



http://www.smu.edu/geothermal/Oil&Gas/Mines_INL.pdf

Binary Cost Estimate



Cost of 8.5¢/kWh estimated with DOE Geothermal Electric Technologies Evaluation Model (GETEM)

http://www.smu.edu/geothermal/Oil&Gas/Mines_INL.pdf

Environmental Effects

- Small to negligible amounts of pollution
- Hydrogen sulfide (H_2S) must be controlled to avoid problems
- At Geysers (California) control system for H_2S produces small amounts of NOx
- Other noncondensable gases (including small amounts of CO_2)
- Footprint smaller than other generation technologies

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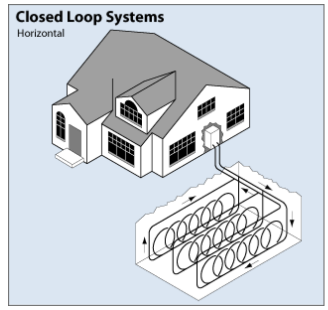
Geothermal Heat Pumps



- Uses nearly constant temperature environment underground for winter heating and summer cooling

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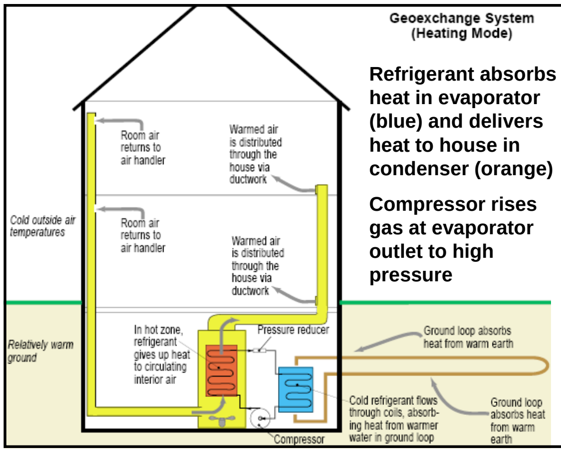
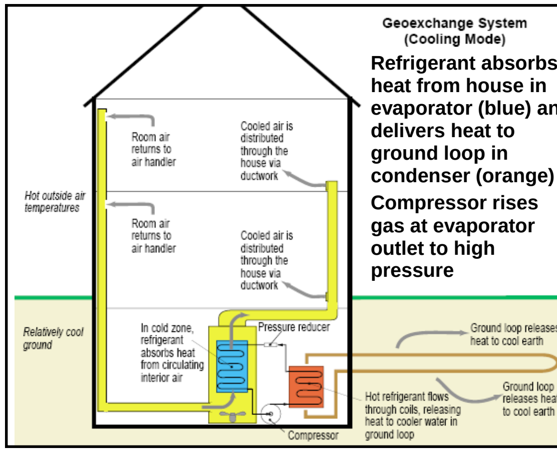


Refrigerant absorbs heat in evaporator (blue) and delivers heat to house in condenser (orange)

Compressor rises gas at evaporator outlet to high pressure



Refrigerant absorbs heat from house in evaporator (blue) and delivers heat to ground loop in condenser (orange)

Compressor rises gas at evaporator outlet to high pressure

Heat Pump Economics

- Air source heat pumps more expensive than conventional gas heating and electric air conditioning
  - Cannot operate at very low air temperature
- Geothermal heat pumps have lower life cycle costs than conventional gas heating and electric air conditioning
  - High first cost, especially if done as retrofit
  - Can generate hot water during summer

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Ocean Energy

- Tidal power – use energy in daily variation of tides
- Wave power – use energy in waves produced by gravitational interactions with the sun and the moon
- Ocean Thermal Energy Conversion – OTEC – concept to use small temperature gradients to run power plants

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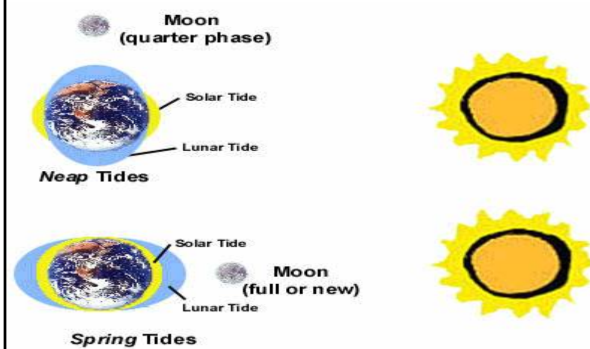
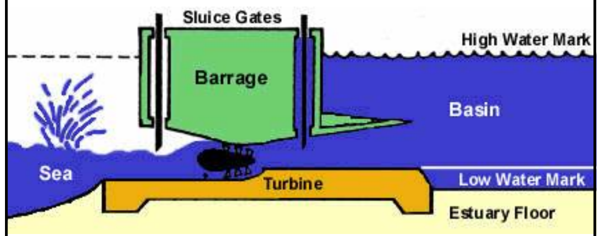
Tidal Patterns



http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/Tidal%20Power.htm

Tidal Barrage



- Bulb-type tidal power turbine
  - As tide comes in, exit gate is closed and entry gates (not shown) allow water in

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http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/Tidal%20Power.htm

Tidal Power Analysis

- Power, $P = \dot{m} g\Delta z = \rho V A g \Delta z$
  - g = acceleration of gravity
  - Δz = elevation difference
  - ρ = water density
  - A = outflow area
  - V = flow velocity
- Ideal velocity from Bernoulli equation, with empirical discharge coefficient, C_d
  - $V = C_d(2g\Delta z)^{1/2}$

$$P = C_d \rho A g \Delta z \sqrt{2g\Delta z}$$

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Tidal Power Possibility

- Only one major plant in existence in La Rance, France
- Limited tidal power sites
- High initial costs
- Various forms: tidal barrages, tidal fences, tidal streams and tidal turbines
- Pilot tidal turbine project in New York East River generates 30 kW with 5 m turbine blade

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La Rance Tidal Power Station

- Dam is 330 m long; basin is 22 km^2; tidal range is 8 m (St. Malo, Brittany)

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La Rance II

- Built 1966
- 24 10-MW bulb-type turbines
- 1966 to 1996 generation was 16 GWh
- 4% of Brittany electricity

http://www.reuk.co.uk/La-Rance-Tidal-Power-Plant.htm 48

Wave Energy

- Various devices sug–gested for capturing energy from ocean waves
  – Ocean Power Tech-nologies buoy shown here is one example
  – Concerns over visual impact and inter-ference with surfers

California State University Northridge 40 kW buoy photo: http://www.oceanpowertechnologies.com/ 49

OPT Devices

- Buoys move up and down with waves
- Vertical motion transferred to a piston
- Piston drives electrical generator
- Electrical power transmitted to shore by subsurface cables
- Video available at OPT link
- http://www.oceanpowertechnologies.com/tech.htm

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Some Examples

- OPT has three demonstration projects with plans to install 1.39 MW in Spain
- Wavegen has wave turbines that can be installed in breakwaters and other ocean structures
  – Chamber transforms wave energy into air pressure that drives turbogenerator
  – One reported test had disappointing results because design changes reduced power
    - http://www.wavegen.co.uk/pdf/LIMPET%20publishable%20report.pdf

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Pelamis Wave Power

- Located in Scotland
  – Device has three articulated cylinders in ocean
  – Waves move different parts at different rates
  – Wave-induced device motion resisted by hydraulic rams that pump high pressure fluid through hydraulic motors that drive generators
    - 140 m long, 3.5 m diameter, 750 kW, capacity factors depend on waves are 25 to 40%
    - 2.25 MW installed off Atlantic coast of Portugal
  – http://www.pelamiswave.com/

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Ocean Thermal Energy

- OTEC uses ocean temperature gradients to drive a power cycle
  – Requires at least 20°C (36°F) temperature difference between surface and deep ocean temperatures
  – Cold temperature must be no deeper than 1000 m (3,280 ft)
  – Distance to shore an obvious issue
    - Operation on slow moving boats a possibility
  – OTEC cannot compete with low fuel costs

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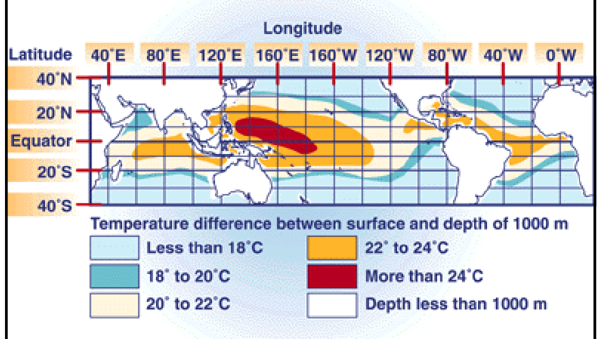
Thermal Energy Conversion Map



http://www.nrel.gov/otec/what.html