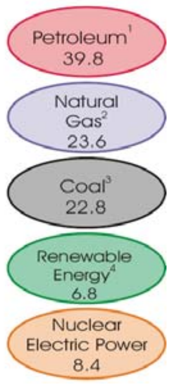
U.S. Energy Consumption

Quadrillion (10^{15}) Btu



39.8 QBtu petrol

+ 23.6 QBtu natural gas

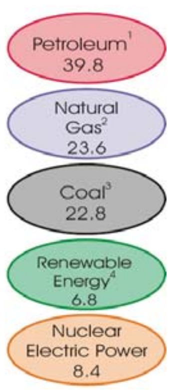
+ 22.8 QBtu coal

+ 6.8 QBtu renewable

+ 8.4 QBtu nuclear

= 101.4 QBtu total = 29.7 trillion kWh (Annual)

U.S. Energy Consumption



106 kWh/day per person

63 kWh/day per person

61 kWh/day per person

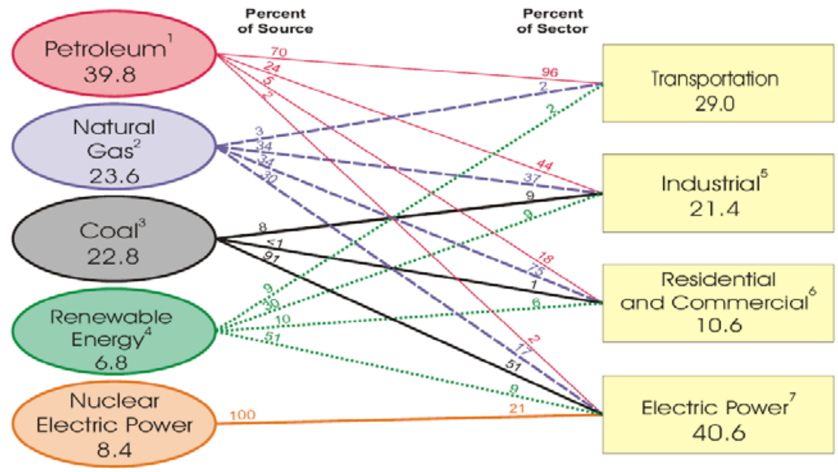
18 kWh/day per person

22 kWh/day per person

Total = 270 kWh/day per person

U.S. Primary Energy Consumption by Source and Sector, 2007

(Quadrillion Btu)



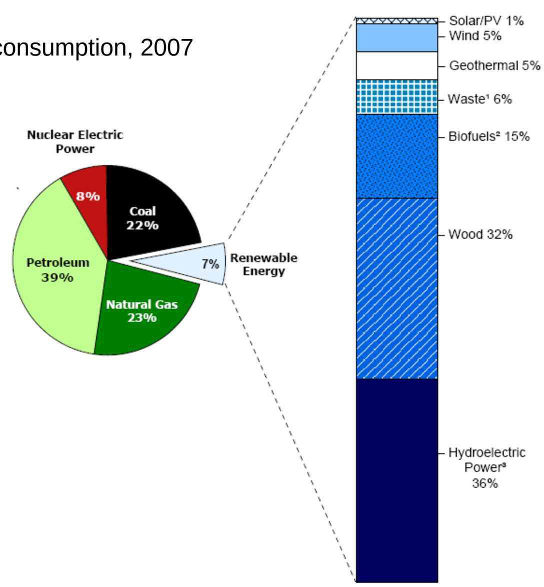
[1] Does not include 0.6 quadrillion Btu of fuel ethanol, which is included in "Renewable Energy."
[2] Excludes supplemental gaseous fuels.
[3] Includes less than 0.1 quadrillion Btu of coal coke net imports.
[4] Conventional hydroelectric power, geothermal, solar/PV, wind, and biomass.
[5] Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
[6] Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
[7] Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.

Note: Sum of components may not equal 100 percent due to independent rounding.

Sources: Energy Information Administration, *Annual Energy Review 2007*, Tables 1.3, 2.1b-2.1f and 10.3.

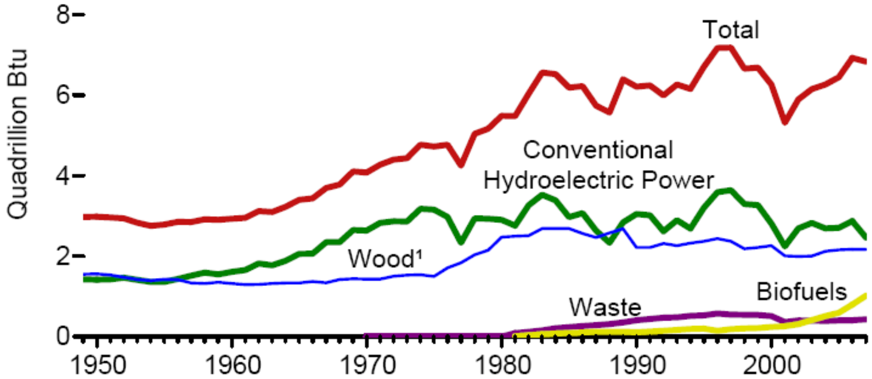
Our Renewables Today

U.S. Energy consumption, 2007



Source: Energy Information Administration / Annual Energy Review 2007

Renewable Energy Total Consumption and Major Sources



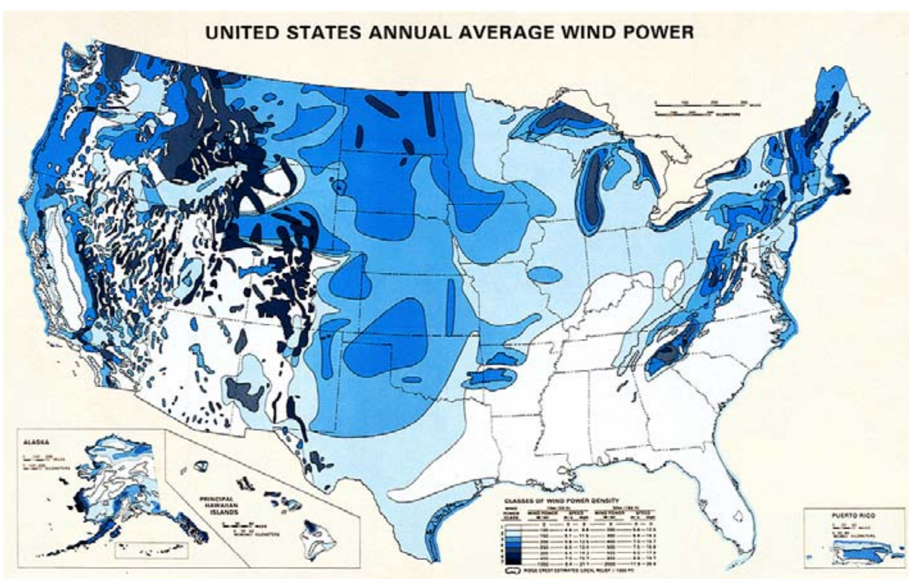
Total renewable energy consumption generally followed the pattern of hydroelectric power output, which was the largest component of the total for most of the years shown. In 2007, hydroelectric power accounted for 36 percent of the total. Wood was the next largest source of renewable energy, followed by biofuels, waste, geothermal, wind, and solar/photovoltaic.

California utilities are mandated to supply 20% of electricity from qualified renewable sources (wind, solar, bio/waste, geothermal, and small hydro) by 2015. Contributions from these sources have been stuck in the range of 10-11% since 2000. The 20% mandate appears to be a major challenge.

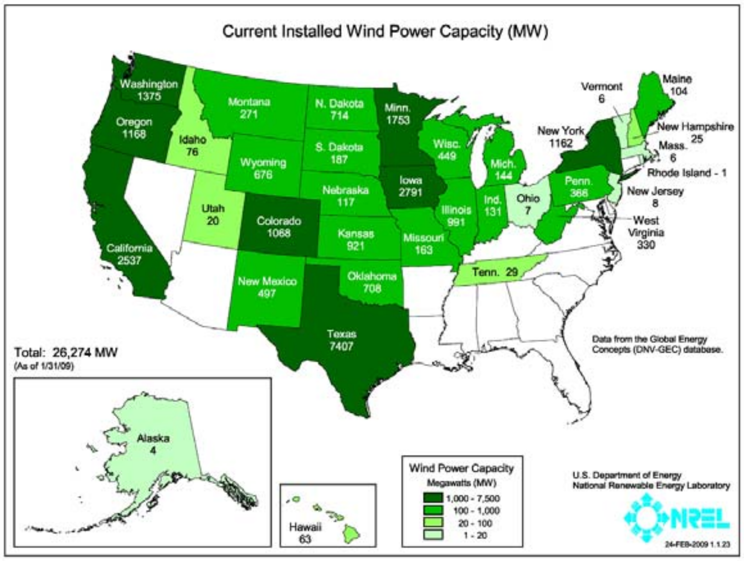
Wind

In 2007, 319 trillion Btus of energy were produced by windmills = 0.85 kWh/day per person.

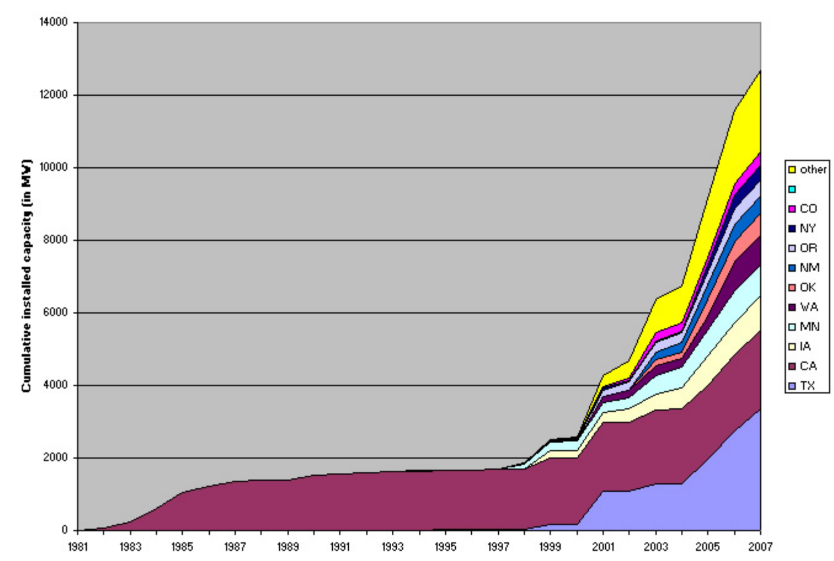
Wind



Wind


Current Installed Wind Power Capacity (MW)
Washington 1375
Oregon 1168
Idaho 76
Montana 271
N. Dakota 714
Minn. 1753
S. Dakota 187
Wyoming 676
Wisc. 449
Mich. 144
Nebraska 117
Iowa 2791
Utah 20
Colorado 1068
Kansas 921
Illinois 991
Ind. 131
Ohio 7
California 2537
Missouri 163
New Mexico 497
Oklahoma 708
Tenn. 29
Texas 7407
Vermont 6
Maine 104
New York 1162
New Hampshire 25
Mass. 6
Rhode Island - 1
Penn. 366
New Jersey 8
West Virginia 330
Total: 26,274 MW
(As of 1/31/09)
Data from the Global Energy Concepts (DNV-GEC) database.
Alaska 4
Hawaii 63
Wind Power Capacity
Megawatts (MW)
1,000 - 7,500
100 - 1,000
20 - 100
1 - 20
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
24-FEB-2009 1.1.23

Wind


Cumulative installed capacity (in MV)
14000
12000
10000
8000
6000
4000
2000
0
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
other
CO
NY
OR
NM
OK
VA
MN
IA
CA
TX

Wind

With a wind of 6 m/s (strong, force 4 wind) and the top of the line technology, wind farms can generate 2 W/m^2 of flat ground.

Put wind farms on 5% of the country

= 1500 m^2 per person

= 3000 W

= 72 kWh/day per person

Wind

Wind turbines kill birds.

So do cars. So do cats.

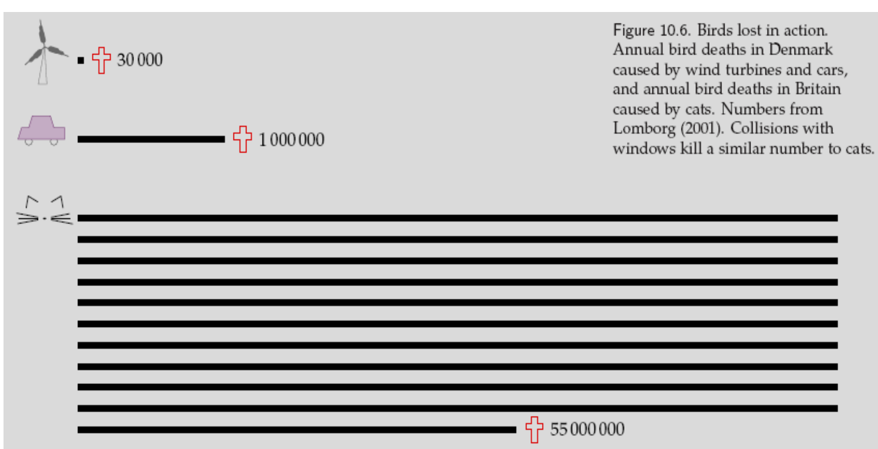


Figure 10.6. Birds lost in action. Annual bird deaths in Denmark caused by wind turbines and cars, and annual bird deaths in Britain caused by cats. Numbers from Lomborg (2001). Collisions with windows kill a similar number to cats.

Source: http://www.withouthotair.com/

Wind

The typical windmill of today has a rotor diameter of around 54 metres centred at a height of 80 metres; such a machine has a "capacity" of 1MW. The "capacity" or "peak power" is the *maximum* power the windmill can generate in optimal conditions. Usually, wind turbines are designed to start running at wind speeds somewhere around 3 to 5m/s and to stop if the wind speed reaches gale speeds of 25m/s. The actual average power delivered is the "capacity" multiplied by a factor that describes the fraction of the time that wind conditions are near optimal. This factor, sometimes called the "load factor" depends on the site; a typical load factor for a *good* site is 30%. In the Netherlands, the typical load factor is 22%; in Germany, it is 19%.

Assuming a load factor of 33%, an average power of 72 kWh/day per person requires an installed capacity of 2710 GW. As of 1/31/09 the U.S. had an installed capacity of 26.3 GW. At the end of 2006, Denmark had an installed capacity of 3.1GW; Germany had 20.6GW. The world total was 74 GW (wwindea.org).

Solar Thermal

Incoming solar energy at the top of the atmosphere (global avg) = 342 W/m^2.

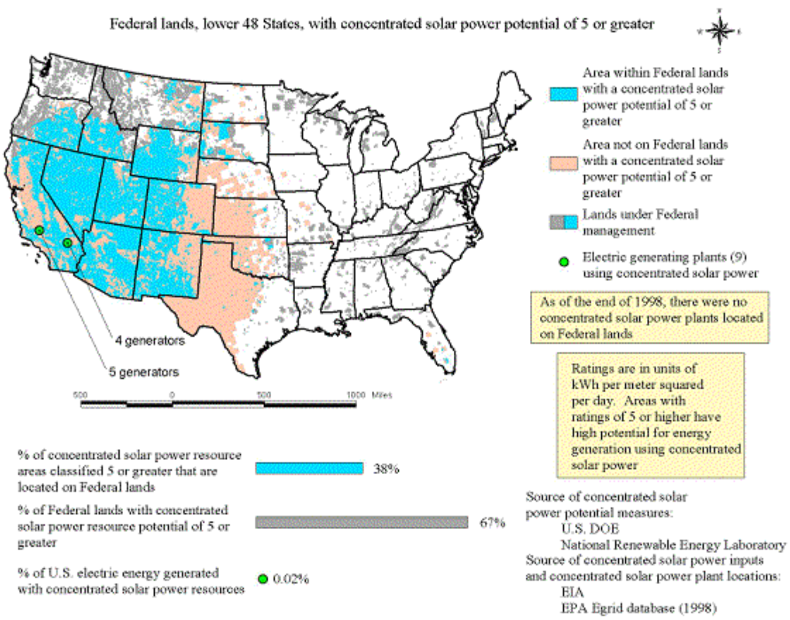
On average about 50% of this reaches the surface = 171 W/m^2 = 4.1 kWh/day per m^2.

The amount at any location depends on latitude, season, time of day, and cloud cover.

In North Africa the annual average is about 5.5 kWh/day.

In the U.S. it is between 3 and 5.5 kWh/day.

Solar Thermal



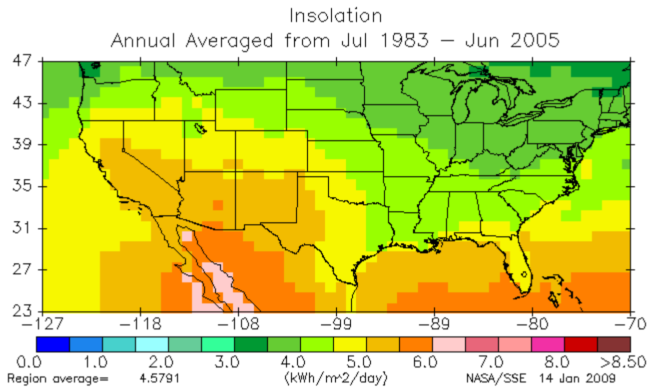
Solar Thermal

Using sunlight to heat water through rooftop pipes.

Assume 126,316,181 housing units in U.S. (2006 census).
Avg. home size 2300 sq ft (in 2004). Assume half homes 2-storey.
Approx rooftop area in U.S. per person = 628 sq ft = 58 m^2.
Assume quarter faces south and 20% has other use.
Available area = 12 m^2 south facing roof per person.

Solar Thermal

Incoming solar energy over U.S. = 3.5 – 5.5 kWh/m² per day

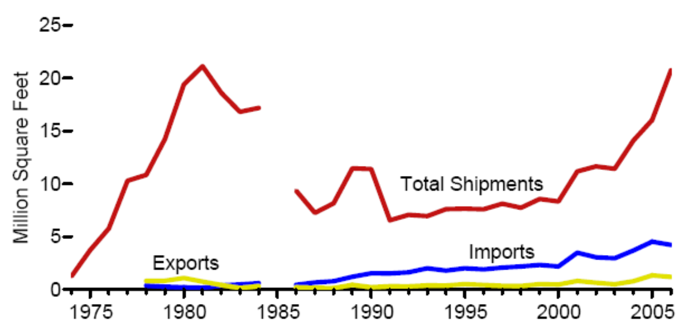


=

Assume panels are 50% efficient at turning radiation into heat.

Provides 50% x 12 m^2 x 4.6 kWh/day/m^2 = 28 kWh/day per person (hot water).

Solar Collector Shipments and Trade



Notes: • Data were not collected for 1985. • Shipments include all domestically manufactured collectors plus imports.

"Shipments of solar collectors grew strongly in the 1970s and reached a peak of 21 million square feet in 1981. Uneven performance was recorded over the next decade, followed by a mild upward trend during the 1990s and a bump up in 2001 and again in 2004 through 2006. Imports reached a record level of 4.5 million square feet in 2005."
EIA, Renewable Energy Report, 2007.

Solar – Rooftop Photovoltaics

Convert sunlight into electricity.
Typical solar panels have an efficiency of ~10%; expensive ones 20%.

Assume 12 m^2 usable south facing roof per person.
Provides 20% x 12 m^2 x 4.6 kWh/m^2 = 11 kWh/day per person

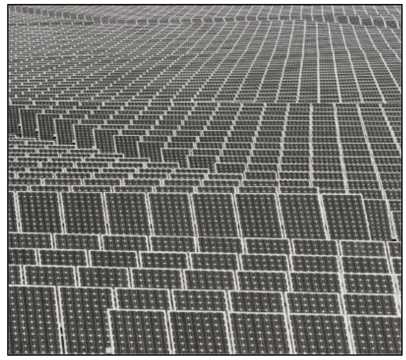
Solar – Rooftop Photovoltaics

Two solar warriors enjoying their photovoltaic system, which powers their electric cars and home. The array of 120 panels (300W each, 2.2m^2 each) has an area of 268m^2, a peak output (allowing for losses in DC-to-AC conversion) of 30.5 kW, and an average output – near Santa Cruz – of 5 kW (19W/m^2).

Photo by Kenneth Adelman. www.solarwarrior.com

PV Farm

Cover the countryside in PC panels!



World's largest PV farm (Spain). Peak capacity 20 MW.
120,000 solar panels, 100 hectares (247 acres).
Average output = 3.8 W/m^2 = 0.09 kWh/day per m^2.

PV Farm

Cover the countryside in PV panels!

US's largest PV farm (Nellis Air Base, Nevada). Peak capacity 15 MW.
70,000 solar panels, 140 acres. ($100 million).
Output = 6 W/m^2 = 0.14 kWh/day per m^2.

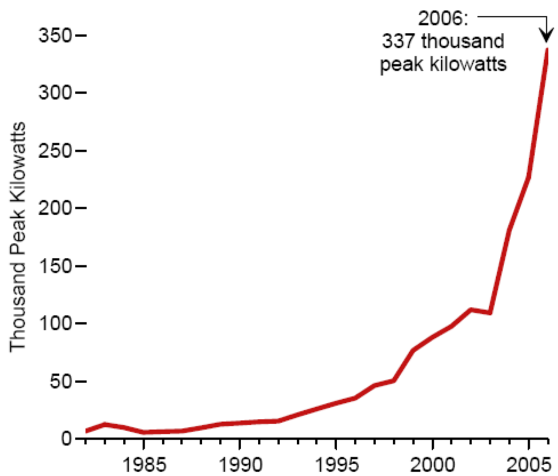
PV Farm

In 2007, the U.S. produced 80 TBtu from solar/PV = 0.2 kWh/day per person

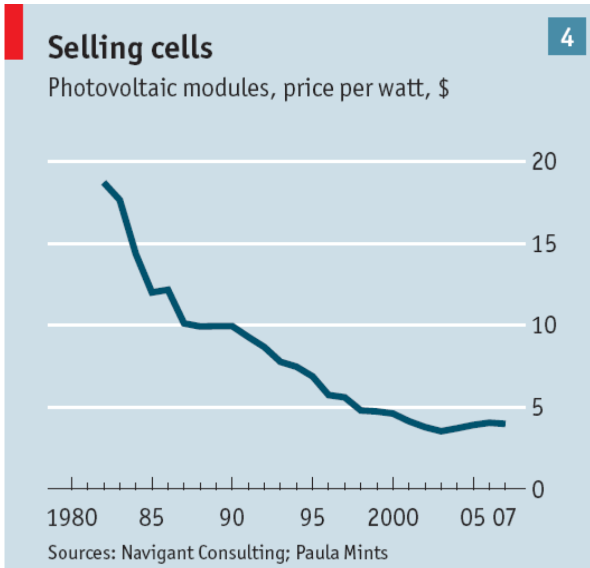
Assume panels are 10% efficient at turning radiation into electricity.
10% x 4.8 kWh/day/m^2 = 0.48 kWh/day/m^2.
This is 4x as efficient as today's leading Solarpark in Bavaria, Germany.
Cover 1% of our area with PV panels: 300 m^2 x 0.48 kWh/day/m^2
Provides 144 kWh/day per person

Photovoltaic Cell and Module Shipments,

Total Shipments, 1982-2006



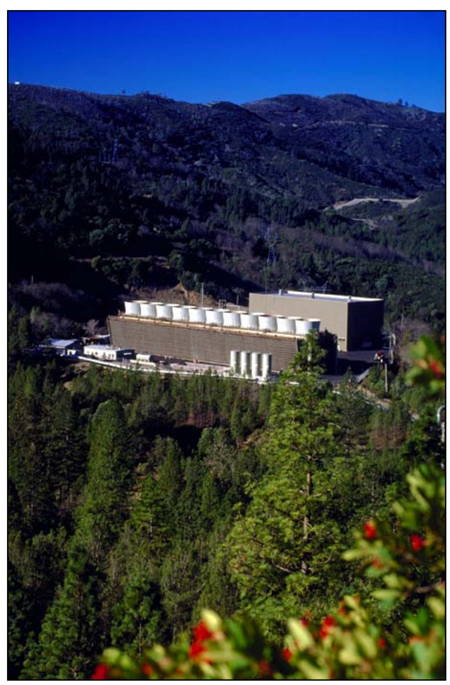
Photovoltaic Cell Cost



The Economist, June 2008

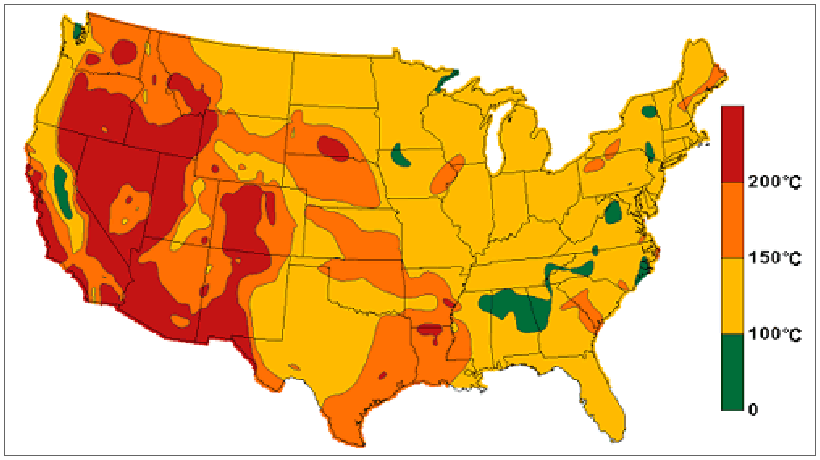
Geothermal Energy

Wells are drilled down to depths of 5 – 10 km and rocks are fractured by pumping down water. A second well is drilled down to the fracture zone and water is pumped down one well, and up the other as superheated water or steam. At the surface this is used to generate electricity.



Geyser's power plant in Sonoma, CA

Geothermal Energy



The geothermal resources map of the United States below shows the estimated subterranean temperatures at a depth of 6 kilometers.

Geothermal Energy

Geothermal Energy

In 2007, 353 trillion Btus of energy were generated from geothermal

= 0.94 kWh/day per person

So currently we get about

1 kWh/day per person

Possible?

Researchers at MIT say that there is 1.9e20 Btu recoverable

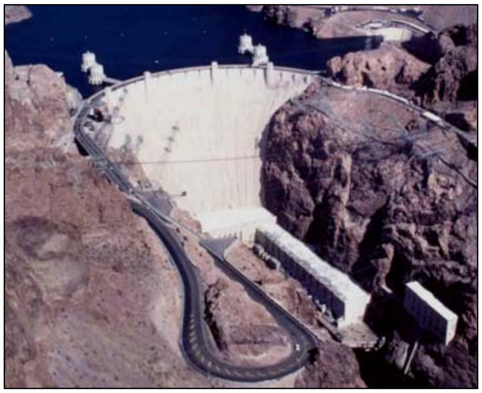
For $1 billion over 40 years they estimate about 100 Gigawatts available at a similar price to coal

= 8 kWh/day per person

Hydroelectric Power

In 2007, 2463 trillion Btus of energy were generated from hydroelectric power plants in the U.S.

= 6.5 kWh/day per person



Hoover Dam, NV

Hydroelectric Power

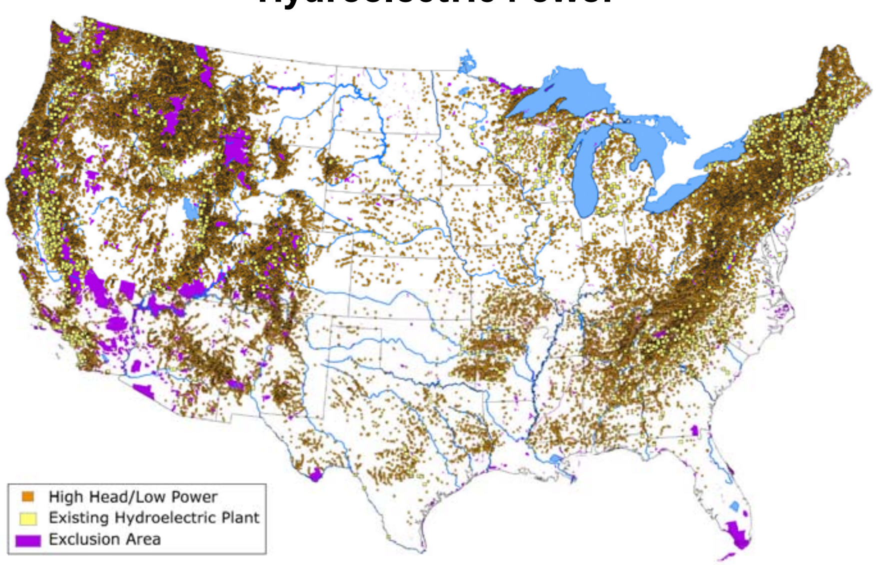
Advantages to hydroelectric power:

Relatively low operations and maintenance costs
The technology is reliable and proven over time
It's renewable - rainfall renews the water in the reservoir, so the fuel is almost always there

Hydroelectric power is not perfect, though, and does have some disadvantages:

High investment costs
Hydrology dependent (precipitation)
Inundation of land and wildlife habitat
Loss or modification of fish habitat
Fish entrainment or passage restriction
Changes in reservoir and stream water quality
Displacement of local populations

Hydroelectric Power



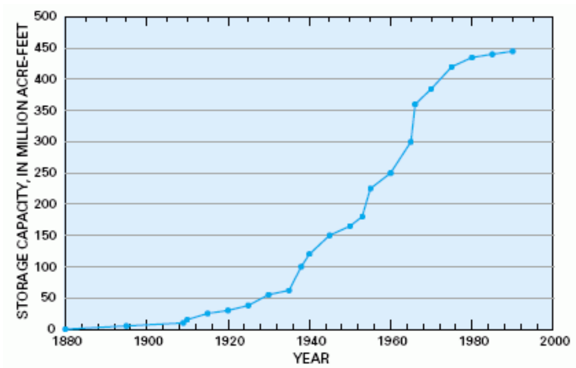
http://www.nationalatlas.gov/articles/people/IMAGES/energy_hydromap_lrg.gif

Hydroelectric Power

Most of the good spots for hydropower have already been taken.

In early part of century, half our electricity was from hydroelectric power. Now only 10% of our electricity, and 2.5% of all our energy.

Very expensive – high construction costs, needs lots of land.



Potential: probably close to zero.

Source: http://ga.water.usgs.gov/edu/wuhy.html

BioEnergy/BioFuels

"All of a sudden, you know, we may be in the energy business by being able to grow grass on the ranch and have it harvested and converted into energy. That's what's close to happening."

George W. Bush, February 2006

4 ways to get energy from plants

1. Grow specially chosen plants and burn them in a power station to produce electricity.
2. Grow specially chosen plants (oil-seed rape, sugar cane, corn) and turn them into ethanol or biodiesel and burn it in vehicles.
3. Burn by-products including methane from landfills.
4. Grow plants and eat them.

BioEnergy/BioFuels

In 2007 the U.S. consumed 1449 trillion Btu of energy from biofuels (not including wood).

Approx. 30% of this came from waste (landfills).

The rest came from corn and other biomass used to produce fuel ethanol and biodiesel.

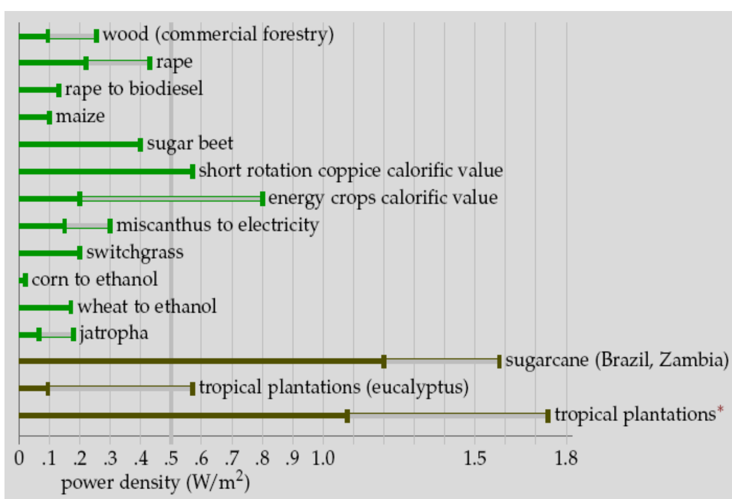
40% of the energy was lost in the production process (not including electricity and transportation)

2007 Biofuel energy (ethanol + biodiesel) = 988 TBtu
= 2.6 kWh/day per person

2007 energy from waste = 1.1 kWh/day

BioEnergy/BioFuels

Efficiency of plants at turning sunlight into energy (carbohydrates):



BioEnergy/BioFuels

Best crops, ~ 0.5 W/m^2

18% of the U.S. land is arable (CIA, World Factbook)

But according to http://www.nemw.org/farmland.htm, 40% of U.S. land is "farmed". (This includes range land.)

So, cover 40% of land with crops = 12,000 m^2 per person

40% loss in production process

Net yield ~ 86.4 kWh/day per person

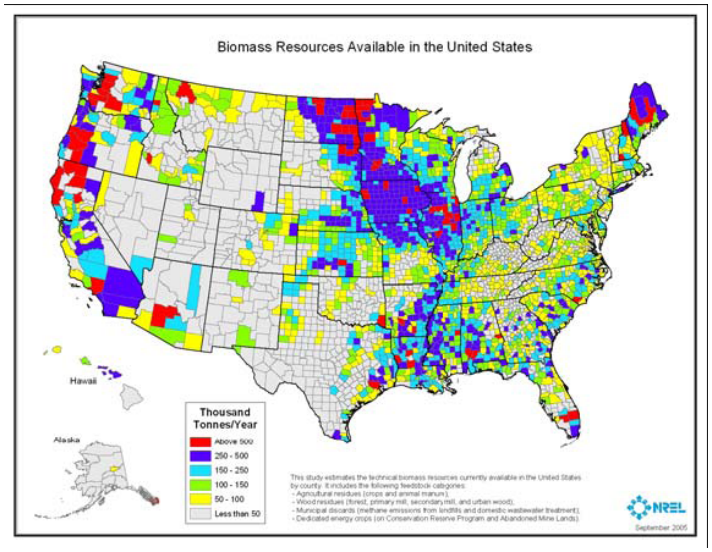
or 40 kWh/day if we assume 18% arable land

But what about land needed to grow food?

Let's assume we need at least half of this for food.

Net yield ~ 20 kWh/day per person

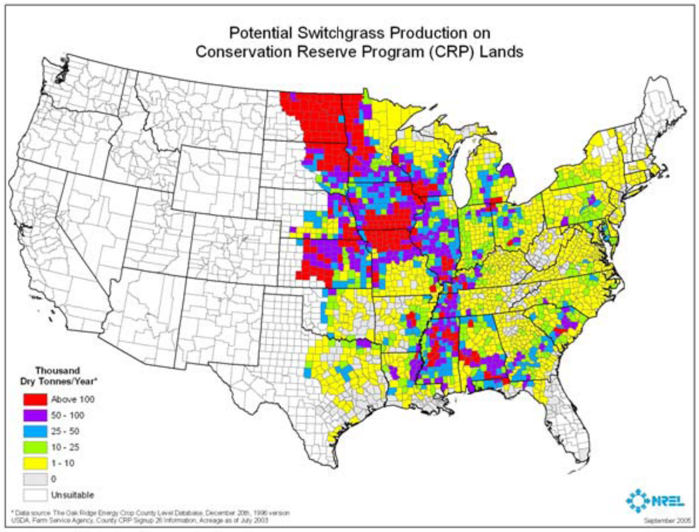
BioEnergy/BioFuels



"A Geographic Perspective on the Current Biomass Resource Availability in the United States" by A. Milbrandt

http://www.nrel.gov/docs/fy06osti/39181.pdf

BioEnergy/BioFuels



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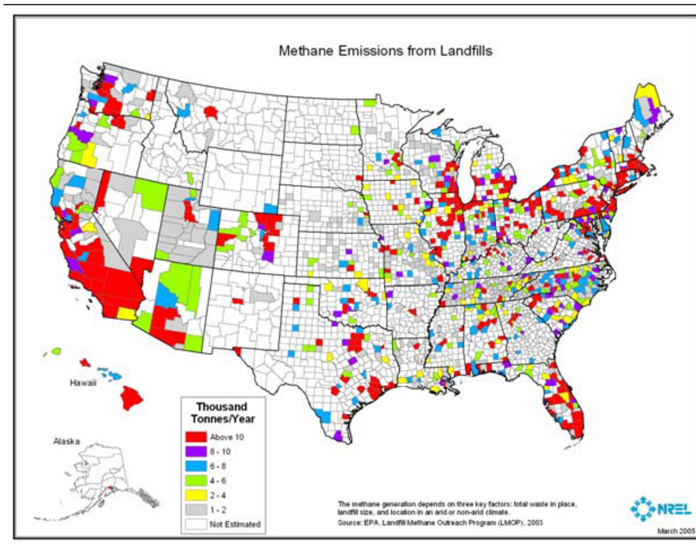

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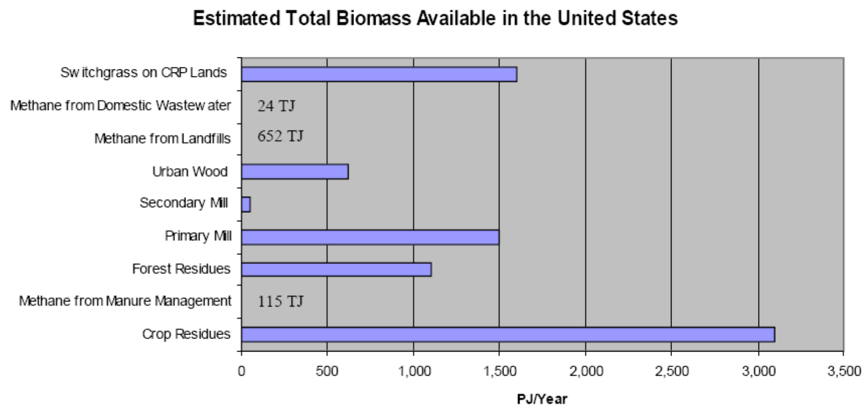
BioEnergy/BioFuels



"A Geographic Perspective on the Current Biomass Resource Availability in the United States" by A. Milbrandt

http://www.nrel.gov/docs/fy06osti/39181.pdf

Renewable Energy 6.8

U.S. Energy Consumption

		2007	Potential?
	Wind	0.9 kWh/day	72 kWh/day
	Solar thermal		28 kWh/day
			OR
	Solar roof	0.2 kWh/day	11 kWh/day
	PV farm		144 kWh/day

Renewable Energy[4] 6.8

U.S. Energy Consumption

		2007	Potential?
	Geothermal	1 kWh/day	8 kWh/day
	Hydroelectric	6.5 kWh/day	6.5 kWh/day
	Biofuel	3.7 kWh/day	20 kWh/day
	Wood	5.7 kWh/day	5.7 kWh/day
	TOTAL	12.3 kWh/day	284 kWh/day!!

> current energy use, 270 kWh/day

U.S. Energy Consumption

We can meet our current energy needs if we:

- cover all south-facing roofs with solar
- install windmills on 5% of land (7x current world's total)
- grow biofuels on half our arable land
- install PV farms on 1% of U.S. land
- invest $1 billion or more in new geothermal wells

We might also want to consider:

- reducing our energy use (by half)
- investing in nuclear energy