Wind power

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Defination :

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electricity, wind mills for mechanical power, wind pumps for pumping water or drainage, or sails to propel ships.

At the end of 2008, worldwide nameplate capacity of wind-powered generators was 121.2 gigawatts (GW).[1], which is about 1.5% of worldwide electricity usage;[1][2] and is growing rapidly, having doubled in the three years between 2005 and 2008. Several countries have achieved relatively high levels of wind power penetration, such as 19% of stationary electricity production in Denmark, 13% in Spain[3] and Portugal, and 7% in Germany and the Republic of Ireland in 2008. As of May 2009, eighty countries around the world are using wind power on a commercial basis.[2]

Large-scale wind farms are connected to the electric power transmission network; smaller facilities are used to provide electricity to isolated locations. Utility companies increasingly buy back surplus electricity produced by small domestic turbines. Wind energy as a power source is attractive as an alternative to fossil fuels, because it is plentiful, renewable, widely distributed, clean, and produces no greenhouse gas emissions. However, the construction of wind farms is not universally welcomed because of their visual impact and other effects on the environment.

Wind power is non-dispatchable, meaning that for economic operation, all of the available output must be taken when it is available. Other resources, such as hydropower, and standard load management techniques must be used to match supply with demand. The intermittency of wind seldom creates problems when using wind power to supply a low proportion of total demand.[4][5]

History

Medieval depiction of a windmill

Windmills are typically installed in favourable windy locations. In the image, generators in Spain

Humans have been using wind power for at least 5,500 years to propel sailboats and sailing ships, and architects have used wind-driven natural ventilation in buildings since similarly ancient times. Windmills have been used for irrigation pumping and for milling grain since the 7th century AD.

In the United States, the development of the "water-pumping windmill" was the major factor in allowing the farming and ranching of vast areas otherwise devoid of readily accessible water. Windpumps contributed to the expansion of rail transport systems throughout the world, by pumping water from water wells for the steam locomotives.[6] The multi-bladed wind turbine atop a lattice tower made of wood or steel was, for many years, a fixture of the landscape throughout rural America. When fitted with generators and battery banks, small wind machines provided electricity to isolated farms.

In July 1887, a Scottish academic, Professor James Blyth, undertook wind power experiments that culminated in a UK patent[*citation needed*] in 1891.[7] In the United States, Charles F. Brush produced electricity using a wind powered machine, starting in the winter of 1887-1888, which powered his home and laboratory until about 1900. In the 1890s, the Danish scientist and inventor Poul la Cour constructed wind turbines to generate electricity, which was then used to produce hydrogen.[7] These were the first of what was to become the modern form of wind turbine.

Small wind turbines for lighting of isolated rural buildings were widespread in the first part of the 20th century. Larger units intended for connection to a distribution network were tried at several locations including Balaklava USSR in 1931 and in a 1.25 megawatt (MW) experimental unit in Vermont in 1941.

The modern wind power industry began in 1979 with the serial production of wind turbines by Danish manufacturers Kuriant, Vestas, Nordtank, and Bonus. These early turbines were small by today's standards, with capacities of 20–30 kW each. Since then, they have increased greatly in size, while wind turbine production has expanded to many countries.

Wind energy

Further information: Wind

Distribution of wind speed (red) and energy (blue) for all of 2002 at the Lee Ranch facility in Colorado. The histogram shows measured data, while the curve is the Rayleigh model distribution for the same average wind speed. Energy is the Betz limit through a 100 m (328 ft) diameter circle facing directly into the wind. Total energy for the year through that circle was 15.4 gigawatt-hours (GW·h).

The Earth is unevenly heated by the sun, such that the poles receive less energy from the sun than the equator; along with this, dry land heats up (and cools down) more quickly than the seas do. The differential heating drives a global atmospheric convection system reaching from the Earth's surface to the stratosphere which acts as a virtual ceiling. Most of the energy stored in these wind movements can be found at high altitudes where continuous wind speeds of over 160 km/h (99 mph) occur. Eventually, the wind energy is converted through friction into diffuse heat throughout the Earth's surface and the atmosphere.

The total amount of economically extractable power available from the wind is considerably more than present human power use from all sources.[8] An estimated 72 terawatt (TW) of wind power on the Earth potentially can be commercially viable,[9] compared to about 15 TW average global power consumption from all sources in 2005. Not all the energy of the wind flowing past a given point can be recovered (see Betz' law).

Distribution of wind speed

The strength of wind varies, and an average value for a given location does not alone indicate the amount of energy a wind turbine could produce there. To assess the frequency of wind speeds at a particular location, a probability distribution function is often fit to the observed data. Different locations will have different wind speed distributions. The Weibull model closely mirrors the actual distribution of hourly wind speeds at many locations. The Weibull factor is often close to 2 and therefore a Rayleigh distribution can be used as a less accurate, but simpler model.

Because so much power is generated by higher wind speed, much of the energy comes in short bursts. The 2002 Lee Ranch sample is telling;[10] half of the energy available arrived in just 15% of the operating time. The consequence is that wind energy from a particular turbine or wind farm does not have as consistent an output as fuel-fired power plants; utilities that use wind power provide power from starting existing generation for times when the wind is weak thus wind power is primarily a fuel saver rather than a capacity saver. Making wind power more consistent requires that various existing technologies and methods be extended, in particular the use of stronger inter-regional transmission lines to link widely distributed wind farms. Problems of variability are addressed by grid energy storage, batteries, pumped-storage hydroelectricity and energy demand management.[11]

Electricity generation

Typical components of a wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position

In a wind farm, individual turbines are interconnected with a medium voltage (often 34.5 kV), power collection system and communications network. At a substation, this medium-voltage electrical current is increased in voltage with a transformer for connection to the high voltage electric power transmission system.

The surplus power produced by domestic microgenerators can, in some jurisdictions, be fed into the network and sold to the utility company, producing a retail credit for the microgenerators' owners to offset their energy costs.[12][13]

Grid management

Induction generators, often used for wind power projects, require reactive power for excitation so substations used in wind-power collection systems include substantial capacitor banks for power factor correction. Different types of wind turbine generators behave differently during transmission grid disturbances, so extensive modelling of the dynamic electromechanical characteristics of a new wind farm is required by transmission system operators to ensure predictable stable behaviour during system faults (see: Low voltage ride through). In particular, induction generators cannot support the system voltage during faults, unlike steam or hydro turbine-driven synchronous generators. Doubly-fed machines—wind turbines with solid-state converters between the turbine generator and the collector system—generally have more desirable properties for grid interconnection. Transmission systems operators will supply a wind farm developer with a *grid code* to specify the requirements for interconnection to the transmission grid. This will include power factor, constancy of frequency and dynamic behaviour of the wind farm turbines during a system fault.[14][15]

Capacity factor

Worldwide installed capacity 1997–2008, with projection 2009–13 based on an exponential fit. Data source: WWEA

Since wind speed is not constant, a wind farm's annual energy production is never as much as the sum of the generator nameplate ratings multiplied by the total hours in a year. The ratio of actual productivity in a year to this theoretical maximum is called the capacity factor. Typical capacity factors are 20–40%, with values at the upper end of the range in particularly favourable sites.[16] For example, a 1 MW turbine with a capacity factor of 35% will not produce 8,760 MW·h in a year (1 × 24 × 365), but only 1 × 0.35 × 24 × 365 = 3,066 MW·h, averaging to 0.35 MW. Online data is available for some locations and the capacity factor can be calculated from the yearly output.[17][18]

Unlike fueled generating plants, the capacity factor is limited by the inherent properties of wind. Capacity factors of other types of power plant are based mostly on fuel cost, with a small amount of downtime for maintenance. Nuclear plants have low incremental fuel cost, and so are run at full output and achieve a 90% capacity factor. Plants with higher fuel cost are throttled back to follow load. Gas turbine plants using natural gas as fuel may be very expensive to operate and may be run only to meet peak power demand. A gas turbine plant may have an annual capacity factor of 5–25% due to relatively high energy production cost.

According to a 2007 Stanford University study published in the Journal of Applied Meteorology and Climatology, interconnecting ten or more wind farms can allow an average of 33% of the total energy produced to be used as reliable, baseload electric power, as long as minimum criteria are met for wind speed and turbine height.[19][20]

One estimate of the actual capacity factor for the entire fleet of wind turbines in the USA in 2002 is 12.7%[21].

Penetration

Wind energy "penetration" refers to the fraction of energy produced by wind compared with the total available generation capacity. There is no generally accepted "maximum" level of wind penetration. The limit for a particular grid will depend on the existing generating plants, pricing mechanisms, capacity for storage or demand management, and other factors. An interconnected electricity grid will already include reserve generating and transmission capacity to allow for equipment failures; this reserve capacity can also serve to regulate for the varying power generation by wind plants. Studies have indicated that 20% of the total electrical energy consumption may be incorporated with minimal difficulty.[22] These studies have been for locations with geographically dispersed wind farms, some degree of dispatchable energy, or hydropower with storage capacity, demand management, and interconnection to a large grid area export of electricity when needed. Beyond this level, there are few technical limits, but the economic implications become more significant. Electrical utilities continue to study the effects of large (20% or more) scale penetration of wind generation on system stability and economics.[23][24][25][26]

At present, a few grid systems have penetration of wind energy above 5%: Denmark (values over 19%), Spain and Portugal (values over 11%), Germany and the Republic of Ireland (values over 6%). For instance, in the morning hours of 8 November 2009, wind power energy produced covered more than half the electricity demand in Spain during the early morning hours, setting a new record, and without problems for the network [27].

The Danish grid is heavily interconnected to the European electrical grid, and it has solved grid management problems by exporting almost half of its wind power to Norway. The correlation between electricity export and wind power production is very strong.[28]

Intermittency and penetration limits

Main article: Intermittent Power Sources
See also: Wind Power Forecasting

Electricity generated from wind power can be highly variable at several different timescales: from hour to hour, daily, and seasonally. Annual variation also exists, but is not as significant. Related to variability is the short-term (hourly or daily) predictability of wind plant output. Like other electricity sources, wind energy must be "scheduled". Wind power forecasting methods are used, but predictability of wind plant output remains low for short-term operation.

Because instantaneous electrical generation and consumption must remain in balance to maintain grid stability, this variability can present substantial challenges to incorporating large amounts of wind power into a grid system. Intermittency and the non-dispatchable nature of wind energy production can raise costs for regulation, incremental operating reserve, and (at high penetration levels) could require an increase in the already existing energy demand management, load shedding, or storage solutions or system interconnection with HVDC cables. At low levels of wind penetration, fluctuations in load and allowance for failure of large generating units requires reserve capacity that can also regulate for variability of wind generation. Wind power can be replaced by other power stations during low wind periods. Transmission networks must already cope with outages of generation plant and daily changes in electrical demand. Systems with large wind capacity components may need more spinning reserve (plants operating at less than full load).[29][30]

Pumped-storage hydroelectricity or other forms of grid energy storage can store energy developed by high-wind periods and release it when needed.[31] Stored energy increases the economic value of wind energy since it can be shifted to displace higher cost generation during peak demand periods. The potential revenue from this arbitrage can offset the cost and losses of storage; the cost of storage may add 25% to the cost of any wind energy stored, but it is not envisaged that this would apply to a large proportion of wind energy generated. The 2 GW Dinorwig pumped storage plant in Wales evens out electrical demand peaks, and allows base-load suppliers to run their plant more efficiently. Although pumped storage power systems are only about 75% efficient, and have high installation costs, their low running costs and ability to reduce the required electrical base-load can save both fuel and total electrical generation costs.[32][33]

In particular geographic regions, peak wind speeds may not coincide with peak demand for electrical power. In the US states of California and Texas, for example, hot days in summer may have low wind speed and high electrical demand due to air conditioning. Some utilities subsidize the purchase of geothermal heat pumps by their customers, to reduce electricity demand during the summer months by making air conditioning up to 70% more efficient;[34] widespread adoption of this technology would better match electricity demand to wind availability in areas with hot summers and low summer winds. Another option is to interconnect widely dispersed geographic areas with an HVDC "Super grid". In the USA it is estimated that to upgrade the transmission system to take in planned or potential renewables would cost at least $60 billion[35]. Total annual US power consumption in 2006 was 4 thousand billion kW·h.[36] Over an asset life of 40 years and low cost utility investment grade funding, the cost of $60 billion investment would be about 5% p.a. (i.e. $3 billion p.a.) Dividing by total power used gives an increased unit cost of around $3,000,000,000 × 100 / 4,000 × 1 exp9 = 0.075 cent/kW·h.

In the UK, demand for electricity is higher in winter than in summer, and so are wind speeds.[37][38] Solar power tends to be complementary to wind.[39][40] On daily to weekly timescales, high pressure areas tend to bring clear skies and low surface winds, whereas low pressure areas tend to be windier and cloudier. On seasonal timescales, solar energy typically peaks in summer, whereas in many areas wind energy is lower in summer and higher in winter.[41] Thus the intermittencies of wind and solar power tend to cancel each other somewhat. A demonstration project at the Massachusetts Maritime Academy shows the effect.[42] The Institute for Solar Energy Supply Technology of the University of Kassel pilot-tested a combined power plant linking solar, wind, biogas and hydrostorage to provide load-following power around the clock, entirely from renewable sources.[43]

A report from Denmark noted that their wind power network was without power for 54 days during 2002.[44] Wind power advocates argue that these periods of low wind can be dealt with by simply restarting existing power stations that have been held in readiness or interlinking with HVDC. [45] Electrical grids with slow-responding thermal power plants and without ties to networks with hydroelectric generation may have to limit the use of wind power. [44]

Three reports on the wind variability in the UK issued in 2009, generally agree that variability of wind needs to be taken into account, but it does not make the grid unmanageable; and the additional costs, which are modest, can be quantified.[46]

A 2006 International Energy Agency forum presented costs for managing intermittency as a function of wind-energy's share of total capacity for several countries, as shown:

Increase in system operation costs, Euros per MW·h, for 10% and 20% wind share[4]

	10%	**20%**
Germany	2.5	3.2
Denmark	0.4	0.8
Finland	0.3	1.5
Norway	0.1	0.3
Sweden	0.3	0.7

Capacity credit and fuel saving

Many commentators concentrate on whether or not wind has any "capacity credit" without defining what they mean by this and its relevance. Wind does have a capacity credit, using a widely accepted and meaningful definition, equal to about 20% of its rated output (but this figure varies depending on actual circumstances). This means that reserve capacity on a system equal in MW to 20% of added wind could be retired when such wind is added without affecting system security or robustness. But the precise value is irrelevant since the main value of wind (in the UK, worth 5 times the capacity credit value[47]) is its fuel and CO2 savings.

Turbine placement

Good selection of a wind turbine site is critical to economic development of wind power. Aside from the availability of wind itself, other factors include the availability of transmission lines, value of energy to be produced, cost of land acquisition, land use considerations, and environmental impact of construction and operations. Off-shore locations may offset their higher construction cost with higher annual load factors, thereby reducing cost of energy produced. Wind farm designers use specialized wind energy software applications to evaluate the impact of these issues on a given wind farm design.[citation needed]

Wind power density (WPD) is a calculation of the effective power of the wind at a particular location.[48] A map showing the distribution of wind power density is a first step in identifying possible locations for wind turbines. In the United States, the National Renewable Energy Laboratory classifies wind power density into ascending classes. The larger the WPD at a location, the higher it is rated by class. Wind power classes 3 (300–400 W/m^2 at 50 m altitude) to 7 (800–2000 W/m^2 at 50 m altitude) are generally considered suitable for wind power development. There are 625,000 km^2 in the contiguous United States that have class 3 or higher wind resources and which are within 10 km of electric transmission lines. If this area is fully utilized for wind power, it would produce power at the average continuous equivalent rate of 734 GW$_e$. For comparison, in 2007 the US consumed electricity at an average rate of 474 GW,[49] from a total generating capacity of 1,088 GW.[50]

Wind power usage

Further information: Category:Wind power by country and Installed wind power capacity

Installed windpower capacity (MW)[1]

#	Nation	2005	2006	2007	2008	2009
-	European Union	40,722	48,122	56,614	65,255	
1	United States	9,149	11,603	16,819	25,170	33,170
2	Germany	18,428	20,622	22,247	23,903	25,000 [51]
3	China	1,266	2,599	5,912	12,210	22,500
4	Spain	10,028	11,630	15,145	16,740	18,119 [52]
5	India	4,430	6,270	7,850	9,587	11,587
6	Italy	1,718	2,123	2,726	3,537	
7	France	779	1,589	2,477	3,426	4,410
8	United Kingdom	1,353	1,963	2,389	3,288	4,070
9	Denmark	3,132	3,140	3,129	3,164	
10	Portugal	1,022	1,716	2,130	2,862	
11	Canada	683	1,460	1,846	2,369	3,249[53]
12	Netherlands	1,236	1,571	1,759	2,237	
13	Japan	1,040	1,309	1,528	1,880	
14	Australia	579	817	817	1,494	
15	Ireland	495	746	805	1,245	
16	Sweden	509	571	831	1,067	
17	Austria	819	965	982	995	
18	Greece	573	758	873	990	
19	Poland	83	153	276	472	

20	Turkey	20	65	207	433	
21	Norway	268	325	333	428	
22	Egypt	145	230	310	390	
23	Belgium	167	194	287	384	
24	Taiwan	104	188	280	358	
25	Brazil	29	237	247	339	
26	New Zealand	168	171	322	325	
27	South Korea	119	176	192	278	
28	Bulgaria	14	36	57	158	
29	Czech Republic	30	57	116	150	
30	Finland	82	86	110	143	147
31	Hungary	18	61	65	127	
32	Morocco	64	64	125	125	
33	Ukraine	77	86	89	90	
34	Mexico	2	84	85	85	
35	Iran	32	47	67	82	
	Rest of Europe	141	204	233	261	
	Rest of Americas	155	159	184	210	
	Rest of Africa & Middle East	52	52	51	56	
	Rest of Asia & Oceania	27	27	27	36	
	World total (MW)	**59,024**	**74,151**	**93,927**	**121,188**	

There are now many thousands of wind turbines operating, with a total nameplate capacity of 121,188 MW of which wind power in Europe accounts for 55% (2008). World wind generation capacity more than quadrupled between 2000 and 2006, doubling about every three years. 81% of wind power installations are in the US and Europe. The share of the top five countries in terms of new installations fell from 71% in 2004 to 62% in 2006, but climbed to 73% by 2008 as those countries—the United States, Germany, Spain, China, and India—have seen substantial capacity growth in the past two years (see chart).

By 2010, the World Wind Energy Association expects 160 GW of capacity to be installed worldwide,[54] up from 73.9 GW at the end of 2006, implying an anticipated net growth rate of more than 21% per year.

Denmark generates nearly one-fifth of its electricity with wind turbines—the highest percentage of any country—and is ninth in the world in total wind power generation. Denmark is prominent in the manufacturing and use of wind turbines, with a commitment made in the 1970s to eventually produce half of the country's power by wind.

In recent years, the US has added more wind energy to its grid than any other country, with a growth in power capacity of 45% to 16.8 GW in 2007[55] and surpassing Germany's nameplate capacity in 2008. California was one of the incubators of the modern wind power industry, and led the U.S. in installed capacity for many years; however, by the end of 2006, Texas became the leading wind power state and continues to extend its lead. At the end of 2008, the state had 7,116 MW installed, which would have ranked it sixth in the world if Texas was a separate country. Iowa and Minnesota each grew to more than 1 GW installed by the end of 2007; in 2008 they were joined by Oregon, Washington, and Colorado.[56] Wind power generation in the U.S. was up 31.8% in February, 2007 from February, 2006.[57] The average output of one MW of wind power is equivalent to the average electricity consumption of about 250 American households. According to the American Wind Energy Association, wind will generate enough electricity in 2008 to power just over 1% (equivalent to 4.5 million households) of total electricity in U.S., up from less than 0.1% in 1999. U.S. Department of Energy studies have concluded wind harvested in the Great Plains states of Texas, Kansas, and North Dakota could provide enough electricity to power the entire nation, and that offshore wind farms could do the same job.[58][59] In addition, the wind resource over and around the Great Lakes, recoverable with currently available technology, could by itself provide 80% as much power as the U.S. and Canada currently generate from non-renewable resources,[60] with Michigan's share alone equating to one third of current U.S. electricity demand.[61]

China had originally set a generating target of 30,000 MW by 2020 from renewable energy sources, but reached 22,500 MW by end of 2009 and could easily surpass 30,000 MW by end of 2010. Indigenous wind power could generate up to 253,000 MW.[62] A Chinese renewable energy law was adopted in November 2004, following the World Wind Energy Conference organized by the Chinese and the World Wind Energy Association. By 2008, wind power was growing faster in China than the government had planned, and indeed faster in percentage terms than in any other large country, having more than doubled each year since 2005. Policymakers doubled their wind power prediction for 2010, after the wind industry reached the original goal of 5 GW three years ahead of schedule.[63] Current trends suggest an actual installed capacity near 20 GW by 2010, with China shortly thereafter pursuing the United States for the world wind power lead.[63]

India ranks 5th in the world with a total wind power capacity of 9,587 MW in 2008,[1] or 3% of all electricity produced in India. The World Wind Energy Conference in New Delhi in November 2006 has given additional impetus to the Indian wind industry.[54] Muppandal village in Tamil Nadu state, India, has several wind turbine farms in its vicinity, and is one of the major wind energy harnessing centres in India led by majors like Suzlon, Vestas, Micon among others.[64][65]

Mexico recently opened La Venta II wind power project as an important step in reducing Mexico's consumption of fossil fuels. The 88 MW project is the first of its kind in Mexico, and will provide 13 percent of the electricity needs of the state of Oaxaca. By 2012 the project will have a capacity of 3500 MW.

Another growing market is Brazil, with a wind potential of 143 GW.[66] The federal government has created an incentive program, called Proinfa,[67] to build production capacity of 3300 MW of renewable energy for 2008, of which 1422 MW through wind energy. The program seeks to produce 10% of Brazilian electricity through renewable sources.

South Africa has a proposed station situated on the West Coast north of the Olifants River mouth near the town of Koekenaap, east of Vredendal in the Western Cape province. The station is proposed to have a total output of 100 MW although there are negotiations to double this capacity. The plant could be operational by 2010.

France has announced a target of 12,500 MW installed by 2010, though their installation trends over the past few years suggest they'll fall well short of their goal.

Canada experienced rapid growth of wind capacity between 2000 and 2006, with total installed capacity increasing from 137 MW to 1,451 MW, and showing an annual growth rate of 38%.[68] Particularly rapid growth was seen in 2006, with total capacity doubling from the 684 MW at end-2005.[69] This growth was fed by measures including installation targets, economic incentives and political support. For example, the Ontario government announced that it will introduce a feed-in tariff for wind power, referred to as 'Standard Offer Contracts', which may boost the wind industry across the province.[70] In Quebec, the provincially owned electric utility plans to purchase an additional 2000 MW by 2013.[71]. By 2025, Canada will reach its capacity of 55,000 MW of wind energy, or 20% of the country's energy needs.

Annual Wind Power Generation (TW·h) and total electricity consumption(TW·h) for 10 largest countries[1][72][73][74][75][76]

Rank	**Nation**	**2005**				**2006**				**2007**				**2008**				**2009**			
		Wind Energy	Capacity Factor	%	Total Consumption	Wind Energy	Capacity Factor	%	Total Consumption	Wind Energy	Capacity Factor	%	Total Consumption	Wind Energy	Capacity Factor	%	Total Consumption	Wind Energy	Capacity Factor	%	Total Consumption
1	United States	17.8	22.2%	0.4%	4048.9	26.6	26.1%	0.7%	4058.1	34.5	23.4%	0.8%	4149.9	52.0	23.5%	1.3%	4108.6				
2	Germany	27.2	16.9%	5.1%	533.7	30.7	17.0%	5.4%	569.9	38.5	19.7%	6.6%	584.9								
3	Spain	20.7	23.5%	7.9%	260.7	22.9	22.4%	8.5%	268.8	27.2	20.5%	9.8%	276.8	31.4	21.7%	11.1%	282.1	35.8	22.3%	13.4%	266.9
4	China	1.9	17.2%	0.1	2474.7	3.7	16.2%	0.1	2834.4	5.6	10.6%	0.2	3255.9	12.8	12.0%	0.4	3426.8				

				%				%		[77]		%		[78]		%					
5	India	6.3	16.2%	0.9%	679.2	7.6	13.8%	1.0%	726.7	14.7	21.0%	1.9%	774.7								
6	Italy	2.3	15.3%	0.7%	330.4	3.0	16.1%	0.9%	337.5	4.0[79]	16.7%	1.2%	339.9	4.9	15.7%	1.4%	339.5				
7	France	0.9	13.6%	0.2%	482.4	2.2	16.0%	0.5%	478.4	4.0	18.6%	0.8%	480.3	5.6	18.8%	1.1%	494.5				
8	United Kingdom	2.8	24.0%	0.7%	407.4	4.0	23.2%	1.0%	383.9	5.9	28.2%	1.5%	379.8								
9	Denmark	6.6	24.0%	18.5%	35.7	6.1	22.2%	16.8%	36.4	7.2	26.3%	19.7%	36.4	6.9	24.9%	19.1%	36.2				
10	Portugal	1.7	19.0%	3.6%	47.9	2.9	19.3%	5.9%	49.2	4.0	21.2%	8.0%	50.1	5.7	22.7%	11.3%	50.6				
	World total (TW·h)	**99.5**	**19.2%**	**0.6%**	**15,746.5**[80]	**124.9**	**19.2%**	**0.7%**	**16,790**				**17,480**[81]	**260**[1]	**24.5%**[1]	**1.5%**[1]					

[edit] Power Analysis

Due to ever increasing sizes of turbines which hit maximum power at lower speeds[82] energy produced has been rising faster than nameplate power capacity. Energy more than doubled between 2006 and 2008 in the table above, yet nameplate capacity (table on left) grew by 63% in the same period.

Small-scale wind power

This wind turbine charges a 12 V battery to run 12 V appliances.

Small-scale wind power is the name given to wind generation systems with the capacity to produce up to 50 kW of electrical power.[83] Isolated communities, that may otherwise rely on diesel generators may use wind turbines to displace diesel fuel consumption. Individuals may purchase these systems to reduce or eliminate their dependence on grid electricity for economic or other reasons, or to reduce their carbon footprint. Wind turbines have been used for household electricity generation in conjunction with battery storage over many decades in remote areas.

5 kilowatt vertical axis wind turbine

Windmill with rotating sails

Grid-connected wind turbines may use grid energy storage, displacing purchased energy with local production when available. Off-grid system users can either adapt to intermittent power or use batteries, photovoltaic or diesel systems to supplement the wind turbine. In urban locations, where it is difficult to obtain predictable or large amounts of wind energy (little is known about the actual wind resource of towns and cities [84]), smaller systems may still be used to run low-power equipment. Equipment such as parking meters or wireless Internet gateways may be powered by a wind turbine that charges a small battery, replacing the need for a connection to the power grid.

A new Carbon Trust study into the potential of small-scale wind energy has found that small wind turbines could provide up to 1.5 terawatt hours (TW·h) per year of electricity (0.4% of total UK electricity consumption), saving 0.6 million tonnes of carbon dioxide (Mt CO_2) emission savings. This is based on the assumption that 10% of households would install turbines at costs competitive with grid electricity, around 12 pence (US 19 cents) a kW·h.[85]

Distributed generation from renewable resources is increasing as a consequence of the increased awareness of climate change. The electronic interfaces required to connect renewable generation units with the utility system can include additional functions, such as the active filtering to enhance the power quality.[86]

Economics and feasibility

Relative cost of electricity by generation source

See also: Relative cost of electricity generated by different sources

Growth and cost trends

Wind and hydroelectric power generation have negligible fuel costs and relatively low maintenance costs. Wind power has a low marginal cost and a high proportion of capital cost. The estimated average cost per unit incorporates the cost of construction of the turbine and transmission facilities, borrowed funds, return to investors (including cost of risk), estimated annual production, and other components, averaged over the projected useful life of the equipment, which may be in excess of twenty years. Energy cost estimates are highly dependent on these assumptions so published cost figures can differ substantially. A British Wind Energy Association report gives an average generation cost of onshore wind power of around 3.2 pence (between US 5 and 6 cents) per kW·h (2005).[87] Cost per unit of energy produced was estimated in 2006 to be comparable to the cost of new generating capacity in the US for coal and natural gas: wind cost was estimated at $55.80 per MW·h, coal at $53.10/MW·h and natural gas at $52.50.[88] Other sources in various studies have estimated wind to be more expensive than other sources (see Economics of new nuclear power plants, Clean coal, and Carbon capture and storage).

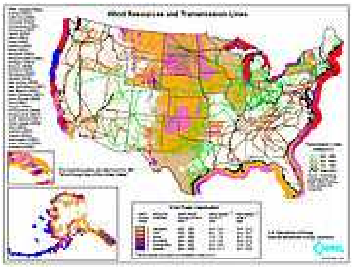
In 2004, wind energy cost a fifth of what it did in the 1980s, and some expected that downward trend to continue as larger multi-megawatt turbines were mass-produced.[89] However, installed cost averaged €1,300 a kW in 2007,[90] compared to €1,100 a kW in 2005.[91] Not as many facilities can produce large modern turbines and their towers and foundations, so constraints develop in the supply of turbines resulting in higher costs.[92] Research from a wide variety of sources in various countries shows that support for wind power is consistently 70–80% among the general public.[93]

Global Wind Energy Council (GWEC) figures show that 2007 recorded an increase of installed capacity of 20 GW, taking the total installed wind energy capacity to 94 GW, up from 74 GW in 2006. Despite constraints facing supply chains for wind turbines, the annual market for wind continued to increase at an estimated rate of 37%, following 32% growth in 2006. In terms of economic value, the wind energy sector has become one of the important players in the energy markets, with the total value of new generating equipment installed in 2007 reaching €25 billion, or US$36 billion.[90]

Although the wind power industry will be impacted by the global financial crisis in 2009 and 2010, a BTM Consult five year forecast up to 2013 projects substantial growth. Over the past five years the average growth in new installations has been 27.6 percent each year. In the forecast to 2013 the expected average annual growth rate is 15.7 percent.[94][95] More than 200 GW of new wind power capacity could come on line before the end of 2013. Wind power market penetration is expected to reach 3.35 percent by 2013 and 8 percent by 2018.[94][95]

Existing generation capacity represents sunk costs, and the decision to continue production will depend on marginal costs going forward, not estimated average costs at project inception. For example, the estimated cost of new wind power capacity may be lower than that for "new coal" (estimated average costs for new generation capacity) but higher than for "old coal" (marginal cost of production for existing capacity). Therefore, the choice to increase wind capacity will depend on factors including the profile of existing generation capacity.

Theoretical potential - World



Map of available wind power for the United States. Color codes indicate wind power density class.

Wind power available in the atmosphere is much greater than current world energy consumption. The most comprehensive study As of 2005[96] found the potential of wind power on land and near-shore to be 72 TW, equivalent to 54,000 MToE (million tons of oil equivalent) per year, or over five times the world's current energy use in all forms. The potential takes into account only locations with mean annual wind speeds ≥ 6.9 m/s at 80 m. The study assumes six 1.5 megawatt, 77 m diameter turbines per square kilometer on roughly 13% of the total global land area (though that land would also be available for other compatible uses such as farming). The authors acknowledge that many practical barriers would need to be overcome to reach this theoretical capacity.

The practical limit to exploitation of wind power will be set by economic and environmental factors, since the resource available is far larger than any practical means to develop it.

Theoretical potential - UK

A recent estimate gives the total potential average output for UK for various depth and distance from the coast. The maximum case considered was beyond 200 km from shore and in depths of 100 - 700 m (necessitating floating wind turbines) and this gave an average resource of 2,000 GWe which is to be compared with the average UK demand of about 40 GWe.[97]

Direct costs

Many potential sites for wind farms are far from demand centres, requiring substantially more money to construct new transmission lines and substations. In some regions this is partly because frequent strong winds themselves have discouraged dense human settlement in especially windy areas. The wind which was historically a nuisance is now becoming a valuable resource, but it may be far from large populations which developed in areas more sheltered from wind.

Since the primary cost of producing wind energy is construction and there are no fuel costs, the average cost of wind energy per unit of production depends on a few key assumptions, such as the cost of capital and years of assumed service. The marginal cost of wind energy once a plant is constructed is usually less than 1 cent per kW·h.[98] Since the cost of capital plays a large part in projected cost, risk (as perceived by investors) will affect projected costs per unit of electricity.

The commercial viability of wind power also depends on the price paid to power producers. Electricity prices are highly regulated worldwide, and in many locations may not reflect the full cost of production, let alone indirect subsidies or negative externalities. Customers may enter into long-term pricing contracts for wind to reduce the risk of future pricing changes, thereby ensuring more stable returns for projects at the development stage. These may take the form of standard offer contracts, whereby the system operator undertakes to purchase power from wind at a fixed price for a certain period (perhaps up to a limit); these prices may be different than purchase prices from other sources, and even incorporate an implicit subsidy.

Where the price for electricity is based on market mechanisms, revenue for all producers per unit is higher when their production coincides with periods of higher prices. The profitability of wind farms will therefore be higher if their production schedule coincides with these periods. If wind represents a significant portion of supply, average revenue per unit of production may be lower as more expensive and less-efficient forms of generation, which typically set revenue levels, are displaced from economic dispatch.[*citation needed*] This may be of particular concern if the output of many wind plants in a market have strong temporal correlation. In economic terms, the marginal revenue of the wind sector as penetration increases may diminish.

External costs

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Most forms of energy production create some form of negative externality: costs that are not paid by the producer or consumer of the good. For electric production, the most significant externality is pollution, which imposes social costs in increased health expenses, reduced agricultural productivity, and other problems. In addition, carbon dioxide, a greenhouse gas produced when fossil fuels are burned, may impose even greater costs in the form of global warming. Few mechanisms currently exist to *internalise* these costs, and the total cost is highly uncertain. Other significant externalities can include military expenditures to ensure access to fossil fuels, remediation of polluted sites, destruction of wild habitat, loss of scenery/tourism, etc.

If the external costs are taken into account, wind energy can be competitive in more cases, as costs have generally decreased because of technology development and scale enlargement. Supporters argue that, once external costs and subsidies to other forms of electrical production are accounted for, wind energy is amongst the least costly forms of electrical production. Critics argue that the level of required subsidies, the small amount of energy needs met, the expense of transmission lines to connect the wind farms to population centers, and the uncertain financial returns to wind projects make it inferior to other energy sources. Intermittency and other characteristics of wind energy also have costs that may rise with higher levels of penetration, and may change the cost-benefit ratio.

Incentives

Some of the over 6,000 wind turbines at Altamont Pass, in California, United States. Developed during a period of tax incentives in the 1980s, this wind farm has more turbines than any other in the United States.[99]

Wind energy in many jurisdictions receives some financial or other support to encourage its development. Wind energy benefits from subsidies in many jurisdictions, either to increase its attractiveness, or to compensate for subsidies received by other forms of production which have significant negative externalities.

In the United States, wind power receives a tax credit for each kW·h produced; at 1.9 cents per kW·h in 2006, the credit has a yearly inflationary adjustment. Another tax benefit is accelerated depreciation. Many American states also provide incentives, such as exemption from property tax, mandated purchases, and additional markets for "green credits." Countries such as Canada and Germany also provide incentives for wind turbine construction, such as tax credits or minimum purchase prices for wind generation, with assured grid access (sometimes referred to as feed-in tariffs). These feed-in tariffs are typically set well above average electricity prices. The Energy Improvement and Extension Act of 2008 contains extensions of credits for wind, including microturbines.

Secondary market forces also provide incentives for businesses to use wind-generated power, even if there is a premium price for the electricity. For example, socially responsible manufacturers pay utility companies a premium that goes to subsidize and build new wind power infrastructure. Companies use wind-generated power, and in return they can claim that they are making a powerful "green" effort. In the USA the organization Green-e monitors business compliance with these renewable energy credits.[100]

Full costs and lobbying

Commenting on the EU's 2020 renewable energy target, Helm (2009) is critical of how the costs of wind power are citied by lobbyists:[101]

For those with an economic interest in capturing as much of the climate-change pork barrel as possible, there are two ways of presenting the costs [of wind power] in a favourable light: first, define the cost base as narrowly as possible; and, second, assume that the costs will fall over time with R&D and large-scale deployment. And, for good measure, when considering the alternatives, go for a wider cost base (for example, focusing on the full fuel-cycle costs of nuclear and coal-mining for coal generation) and assume that these technologies are mature, and even that costs might rise (for example, invoking the highly questionable 'peak oil hypothesis').

A House of Lords Select Committee report (2008) on renewable energy in the UK says:[102]

We have a particular concern over the prospective role of wind generated and other intermittent sources of electricity in the UK, in the absence of a break-through in electricity storage technology or the integration of the UK grid with that of continental Europe. Wind generation offers the most readily available short-term enhancement in renewable electricity and its base cost is relatively cheap. Yet the evidence presented to us implies that the full costs of wind generation (allowing for intermittency, back-up conventional plant and grid connection), although declining over time, remain significantly higher than those of conventional or nuclear generation (even before allowing for support costs and the environmental impacts of wind farms). Furthermore, the evidence suggests that the capacity credit of wind power (its probable power output at the time of need) is very low; so it cannot be relied upon to meet peak demand. Thus wind generation needs to be viewed largely as additional capacity to that which will need to be provided, in any event, by more reliable means

Helm (2009) says that wind's problem of intermittent supply will probably lead to another dash-for-gas or dash-for-coal in Europe, possibly with a negative impact on energy security.[101]

Environmental effects

Main article: Environmental effects of wind power

Livestock ignore wind turbines,[103] and continue to graze as they did before wind turbines were installed.

Compared to the environmental effects of traditional energy sources, the environmental effects of wind power are relatively minor. Wind power consumes no fuel, and emits no air pollution, unlike fossil fuel power sources. The energy consumed to manufacture and transport the materials used to build a wind power plant is equal to the new energy produced by the plant within a few months of operation. Garrett Gross, a scientist from UMKC in Kansas City, Missouri states, "The impact made on the environment is very little when compared to what is gained." The initial carbon dioxide emission from energy used in the installation is "paid back" within about 9 months of operation for offshore turbines.

Danger to birds and bats has been a concern in some locations. However, studies show that the number of birds killed by wind turbines is negligible compared to the number that die as a result of other human activities, and especially the environmental impacts of using non-clean power sources. Fossil fuel generation kills around twenty times as many birds per unit of energy produced than wind-farms.[104] Bat species appear to be at risk during key movement periods. Almost nothing is known about current populations of these species and the impact on bat numbers as a result of mortality at windpower locations. Offshore wind sites 10 km or more from shore do not interact with bat populations. While a wind farm may cover a large area of land, many land uses such as agriculture are compatible, with only small areas of turbine foundations and infrastructure made unavailable for use.

Aesthetics have also been an issue. In the USA, the Massachusetts Cape Wind project was delayed for years mainly because of aesthetic concerns. In the UK, repeated opinion surveys have shown that more than 70% of people either like, or do not mind, the visual impact. According to a town councillor in Ardrossan, Scotland, the overwhelming majority of locals believe that the Ardrossan Wind Farm has enhanced the area, saying that the turbines are impressive looking and bring a calming effect to the town.[105]

Finally, noise has also been an important disadvantage. With careful implanting of the wind turbines, along with use of noise reducing-modifications for the wind turbines however, these issues can be easily adressed.

Wind Power: How We Got Here

I saw an article in *Mother Earth News* that was shamelessly supporting wind power (a topic I know something about), so I contacted the writer. My question to him was: *what scientific information do you have that proves that wind power does what it is supposed to do?*
After several amusingly evasive correspondences, he finally conceded that he had none. In a desperate attempt to defend this untenable position he then said that *no proof was needed*!
In exploring this unexpected line of thought with this reportedly knowledgeable individual, it became quite clear to me that he did not have a big-picture concept of what is going on

here. But since this deficiency is clearly shared by many other people, let's do a quick review as to how we have arrived at our current electrical energy predicament...

The first practical use of electricity, in the late 1800s, is generally attributed to Thomas Edison (a founder of General Electric). Of course there were actually dozens of people who contributed to making commercial electricity a reality. And there were a LOT of formidable hurdles to overcome.

One of the initial primary issues was: *where was this electricity going to come from*? For the first hundred years or so, there were six over-riding concerns about commercial electricity

generators:

1 - could they provide *large amounts* of electricity?
2 - could they provide *reliable* and *predictable* electricity?
3 - could they provide *dispatchable*1 electricity?
4 - could they service one or more of the *grid demand elements*2?
5 - could their facility be *compact*3?
6 - could they provide *economical* electricity?

1 *Dispatchable* means a source can generate higher or lower amounts of power *on-demand*, i.e. on a *human-defined* schedule.

2 *Grid Demand Elements* = *Base Load* (the minimum amount of steady rate electric power required 24/7) + *Load Following* (regulation of power output in response to moment-tomoment changes in system demand, so as to maintain the system within predetermined limits) + *Peak Load* (the maximum load during a specified period of time).

3 *Compact* is the ability to site an electrical facility on a relatively small and well-defined footprint, preferably near high demand, e.g. cities. This would save on transmission lines which are extremely expensive, unsightly, and produce power loss.

The implementation of these has resulted in the most successful grid system on the planet.

I would like to avoid getting too technical here, but the primary goal of all of these efforts was to achieve *capacity*. To ensure reliability at the lowest cost, grid operators consider capacity in several ways as they evaluate electricity sources — but the most important is *Capacity Value.* The layperson's definition of this is: "the percentage of a machine's rated capacity that grid operators can be confidant will be in available during upcoming times of greatest demand." Knowing this accurately is the key to reliable system grid performance.

Back to our history. Many options were proposed to satisfy these six criteria. To maximize public benefit, each was individually and *scientifically* vetted (*before* being put on the grid) to ascertain whether the suggested source would comply with all of the needed conditions.

Over time, what resulted from these assessments was that we selected the following sources to provide commercial electricity for us: hydroelectric, coal, nuclear, natural gas, and oil.

(Oil is *by far* the smallest source, as only about 1% of U.S. electricity comes from that.)

Note that each of these current sources meet ALL of the above six essential criteria — and if they don't (like oil now being more expensive) then they get replaced, by other conventional sources that do meet all criteria.

As a result, today, and a hundred years from now, these sources can provide ALL of the electrical needs of our society — *and continue to meet all six criteria.*

It's important to also note that ALL of the primary conventional sources use home-grown energy. Regarding our electrical energy sources, we have *always* been energy independent!

So what's the problem?

Ahhh, the problem is that a new element has been recently added to the list of requirements: *environmental impact* — and the current number one environmental impact consideration is *greenhouse gas emissions* (e.g. CO2).

So why has this joined the Big Six? It is a direct result of the current debate on Global Warming. Note the word *debate*. This is not yet a scientifically resolved matter (though some would like to have you think so). In response to intense political pressure, our government has acquiesced to these forces to make emissions an *additional* criterion. Having the government step in and mandate that utility companies change the principles that have been the foundation of our electrical supply system for a hundred years is a bit disconcerting... Transforming such a successful system based on a position that is not yet scientifically resolved is *seriously* disturbing. That's concern #2. And there's more — much more. Concern #3 is that this new standard for electrical supply sources now has taken priority *over ALL THE OTHER SIX!* Concern #4 is that this newboy- on-the-block has in reality become the *ONLY benchmark of importance* — the other six have essentially been put aside, and are now given only lip service. In this unraveling of sensibility there is one final incredible insult to science (concern #5): alternative sources of commercial electricity that *claim* to meet this new super-criteria (to make a consequential impact on CO2) don't even have to prove that they actually do it! I know that this is a lot to absorb here. Maybe you want to take a moment to let the profound impact of these latest developments sink in...

Just in case you think I am not being accurate here, we'll look at the environmental poster child: *wind power*. Let's examine each of the six time-tested criteria, then the new one...

1 - Does industrial wind power provide large amounts of electricity?

Yes, it could. However, its effectiveness from most perspectives is inferior. For instance (because of the wide and unpredictable fluctuations of wind), it only produces, on average, about 30% of it's nameplate power. Another example of its dilutedness is that it takes over *one thousand times* the amount of land for wind power to produce a roughly equivalent amount of energy as does a nuclear facility.

2 - Does industrial wind power provide *reliable* and *predictable* electricity?

NO. Despite the wind industry's absolute best efforts it is not reliable or predictable *compared to the standards set by our other conventional electrical sources*. What's worse is that when power is really needed (e.g. hot Summer afternoons) wind is usually on vacation. Compare its performance to a car (windmobile) run solely by wind power.

3 - Does industrial wind power provide *dispatchable* electricity?

NO. Again, due to its unpredictability, wind can not be counted on to provide power *ondemand*,

i.e. on a human-defined schedule.

4 - Does industrial wind power provide one or more of the *grid demand elements*?

NO. It certainly can not provide *Base Load* power, which is what is needed to supply an underlying 24/7 demand. It can not provide *Load Following,* which is in response to moment-to-moment changes in system demand. It can not reliably provide *Peak Load*, which is needed maximums during specified periods of time (like hot Summer afternoons when lots of air conditioners are on, and the wind is usually still).

5 - Is industrial wind power *compact*?

NO. As mentioned above, to even approximate the nameplate power of a conventional facility, like nuclear, takes something like *a thousand times* the amount of area. Wind promoters are desperately trying to convince gullible politicians that it can have some real capacity value. Their tinkertoy "solution" is to try to connect multiple wind farms spread over vast areas (often several states). In addition to being speculative, all of this, of course, completely undermines the objective to be a *concentrated* power source.

And another "feature" of wind power is that most of the windiest sites (and available land) are a LONG way from where the electricity is needed. This will result in *thousands* of miles of huge unsightly transmission towers and cables, at an *enormous* expense to ratepayers — most of it completely unnecessary. Kite flying will be a thing of the past.

6 - Does industrial wind power provide *economical* electricity?

NO. It is artificially subsidized WAY more than any conventional power source. A 2008 US Energy Information Administration report concluded that just *some* of the federal subsidies for wind energy amount to $23+ per megawatt-hour. By contrast, normal coal receives 44¢ per megawatt-hour, natural gas 25¢, hydroelectric 67¢, and nuclear power $1.59. In addition to these, there are significant state subsidies and mandates. And, as of this writing, there are some 200 bills pending before Congress to add *more* incentives!

And now let's add the latest rule dejour:

7 - Does industrial wind power make a *consequential reduction of CO2*?

NO! No independent scientific study has ever shown that wind power saves a meaningful amount of CO2. In fact, the most independent scientific study done (by the National Academy of Sciences) says the opposite. Their 2007 report concludes that (assuming the *most optimistic conditions*) the U.S. CO2 savings by 2020 will amount to only 1.8%. An earlier EIA report said 1.3%. *These are trivial quantities!*

What about the critical factor of *Capacity Value*? The result of the above deficiencies is that wind power has a Capacity Value of about 10%. Compare this to the conventional sources, where essentially all of them have a Capacity Value over 90%: *a stunning disparity.*

Huh? How can this *possibly* be? How could the U.S. be on the path to spend over a TRILLION dollars on an electrical source that fails five out of six of our historically important criteria, *AND has no scientific proof that it even meets this new emissions criterion?*

It's all about the money. Lobbyists for businesses, and parties who want a piece of this TRILLION+ dollars (e.g. T. B. Pickens), are leaving no stone unturned. Environmentalists who have taken their eye off the ball are promoting this palliative non-solution. Politicians eager to be seen as "green" (a current fad) are saying yes to everything the color of money.

Wind power proponents typically try to rationalize away its serious shortcomings saying that things will "get worked out" *mañana*. What essentially is happening though, is that our politicians are trying to pound a square peg into a round hole. Zero wind power is appropriate until after these significant problems are resolved — as some may *never* be.

Another consideration is that after understanding wind power's inherent electrical generation defects, it might put some other issues into perspective. For instance, it is entirely legitimate to be concerned about bird and bat mortality, noise intrusions, flicker effect, property devaluation, etc. But what if they were "fixed" — *would wind power then be OK?*

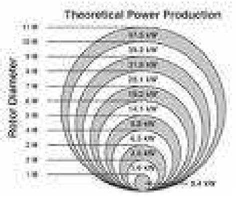
Let's say that (to help with some of these issues) a conscientious town's ordinance required a one mile separation of wind turbines from all houses. *Is wind power then an "acceptable"* *source for providing us commercial electricity?* The fact is that this excellent regulation would in *no way* address the fundamental electrical grid limitations of wind power identified above. Wind power will not be acceptable until all seven criteria are met.

Does wind power's abysmal failure mean that all "renewables" are a similar scam? NO. Each proposed new power source needs to be objectively evaluated, *independently*. For example, based on MIT's 2007 report, industrial Geothermal holds significant promise.

In any case, this profound turn of events in how we select our sources of electrical power (by abandoning our successful and time-tested criteria) is having, and will continue to have, incalculable negative impacts on every person on the planet.

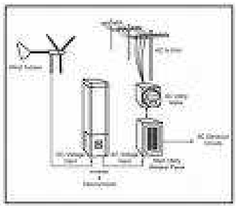
There is a solution — and it will cost a lot less that a Trillion dollars. 90% of what we do spend should be on improving the conventional sources that already "work." The remaining amount could go towards exploring new options that (by definition) would have to meet or exceed conventional sources (i.e. the six criteria). Then add conservation.

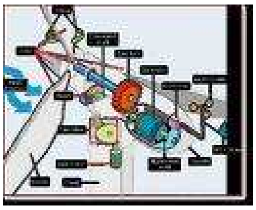
Conventional

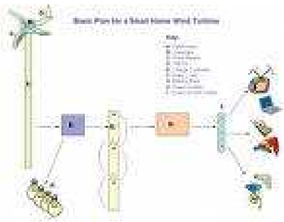


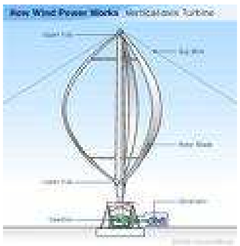
Offshore wind

Verticle Axial wind


Wind Turbine




Basic Plan for a Small Home Wind Turbine
Key


How Wind Power Works
Vertical-axis Turbine
Guy Wire
Rotor Blade

Modern