WIND ENERGY

• An indirect form of **solar energy** stored in kinetic form

• Induced chiefly by the **uneven heating** of the earth's crust by the sun.

Uses: (1) **Home owners** may generate electricity, charge batteries, sell excess power to utility (2) Large, modern turbines in **wind farms** can produce electricity for utilities (3) **Remote villages** can generate power, pump water, grind grain, meet their basic energy needs.

Topics - Wind Energy

- Wind Energy, Its Uses and History
- Global Wind Resource Potential
- Basic Principles of Operation & Components
- Power Output and Maximum Efficiency
- Types of Wind Mills and Examples
- Cost of Wind Power (Capital, O&M, Levelized)
- Applicability, Advantages, Disadvantages
- Environmental Impact & Risks

Global Wind Resource

- **Wind** is the movement of air in response to pressure differences within the atmosphere, caused primarily by uneven heating by the sun on the surface of the earth, exerting a force which causes air masses to move from a region of high pressure to a low one.
- About **1.7 million TWh** of energy each year is generated in the form of wind over the earth's land masses, much more over the globe as a whole. Only a small fraction can be harnessed to generate useful energy because of **competing land use**.
- A 1991 estimate puts the realizable global wind power potential at **53,000 TWh per year**.

National Wind Resources

US, UK and China have vast wind resource potential. With only 6% of total land area available for wind, US could generat about 500,000 MW. Present US capacity is 2,500 MW. Philippine capacity stood at 10 kW (Pagudpud) and 120 MW is being planned for Ilocos Norte by PNOC.

National Wind Resources and Installed Capacity

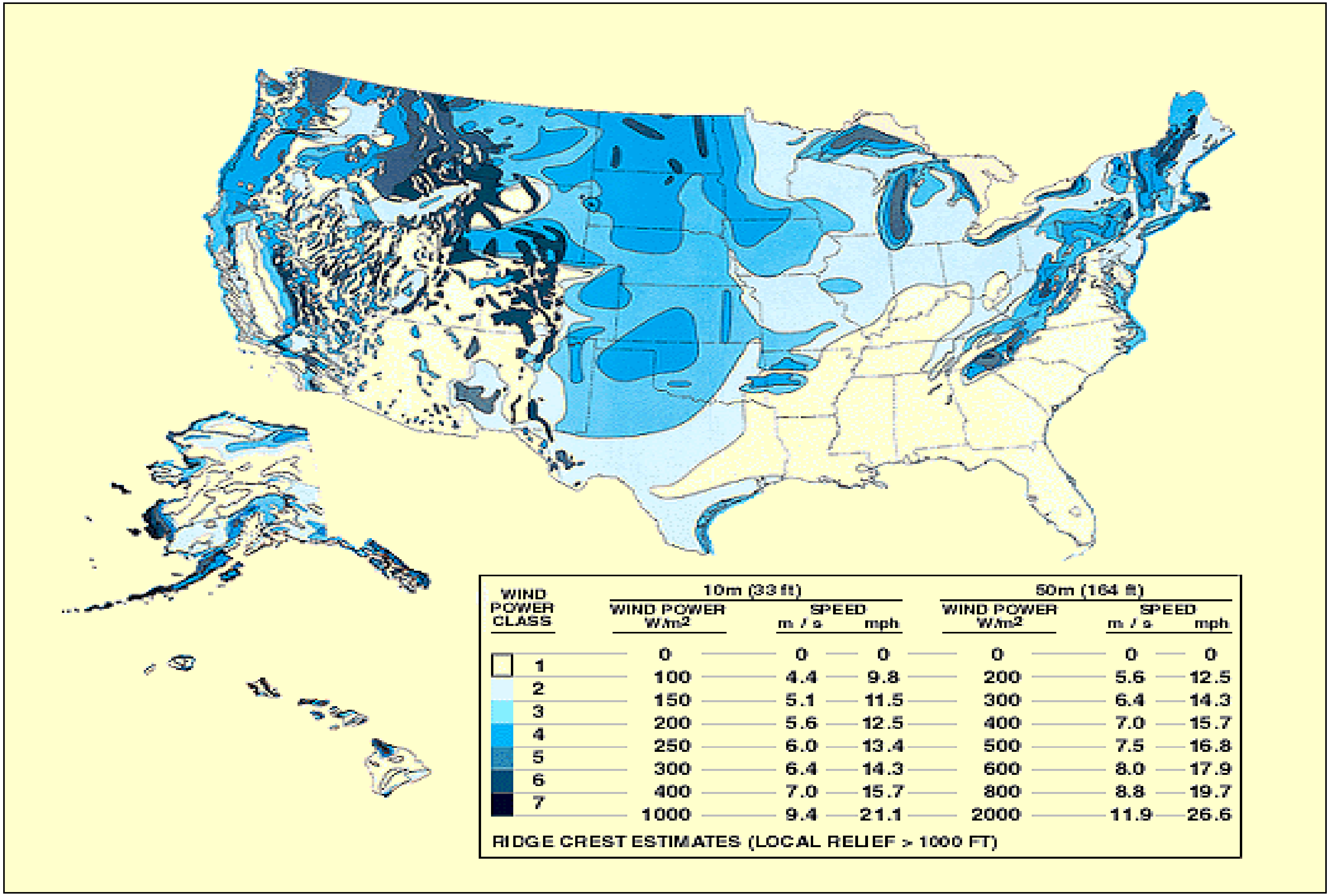
Country	Potential Installed Capacity, MW	Installed Capacity (MW)		Remarks
		1996	1998	
Germany	n.a.	1,136	2,874	US capacity:
US	500,000	1,770	1,884	1999 - 2,502 MW
Denmark	n.a.	614	1,450	2000 - 2,554 MW
India	20,000	565	968	2001 - 4,258 MW
Spain	n.a.	145	834	
Netherlands	n.a.	259	363	
UK	223,000	193	334	
China	253,000	36	224	
Swden			150	
Canada			83	
Philippines	76,000		120	Ilocos Norte (proposed)
			10 kW	Pagudpud (actual)
World Total	20,000 MW by 2001	6,000	12,000	2,590 MW installed in 1998

SOURCE: Paul Breeze, "Power Generation Technologies"
American Wind Association, "The Most FAQ About Wind Energy", 2002

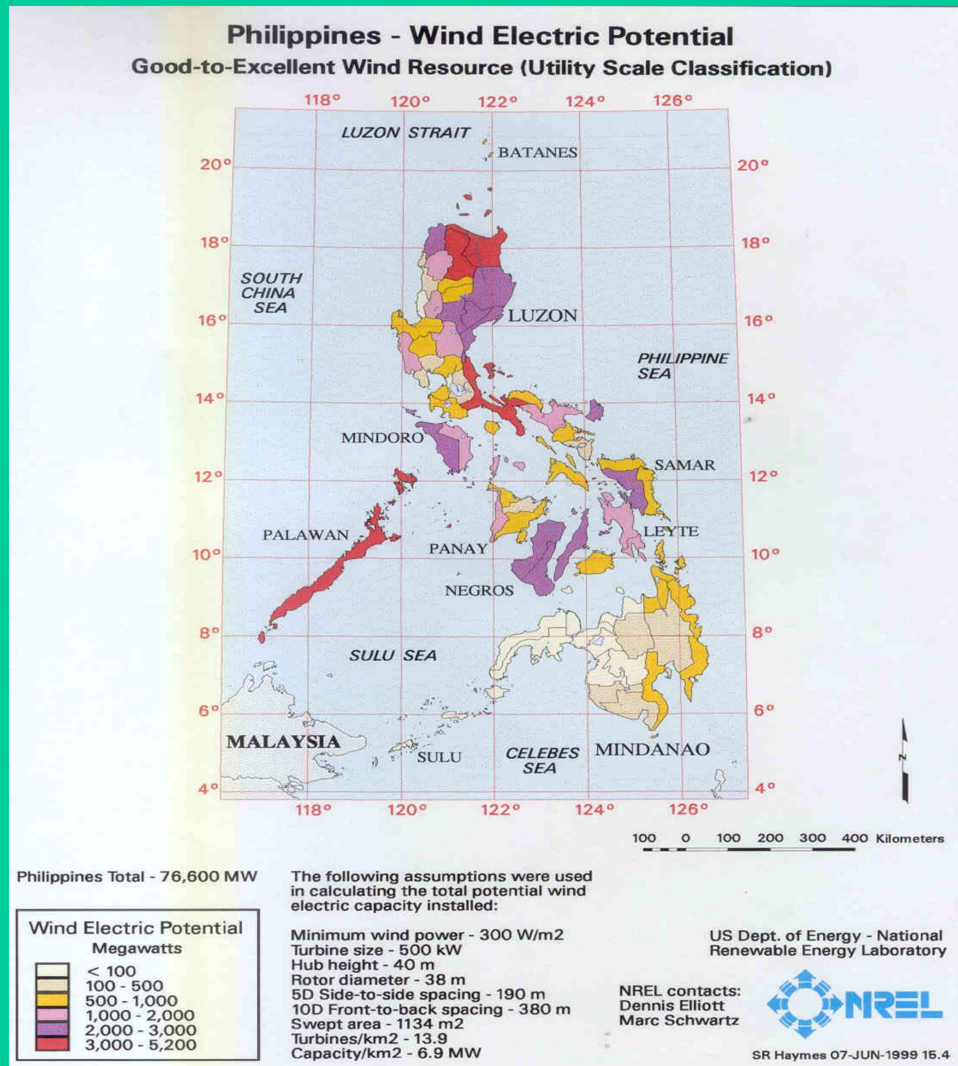
Philippine Wind Energy

- Philippines has vast potential for wind energy development. Wind Mapping Project of PCIERD-DOST, DOE and NREL estimated the country's potential for wind power at about **76,600 MW.**
- Ilocos Norte was estimated to have a combined potential of **80 MW**. Northern Luzon most attractive with average annual wind of 5.39 m/s.
- **10-kW** wind turbine generator of PCIED has been supplying the power needs of 23 households in a small fishing village in Pagudpud, Ilocos Norte.
- PNOC-EDC is establishing a **120-MW** Wind Power Project in Ilocos Norte in 3 phases of 40 MW each.

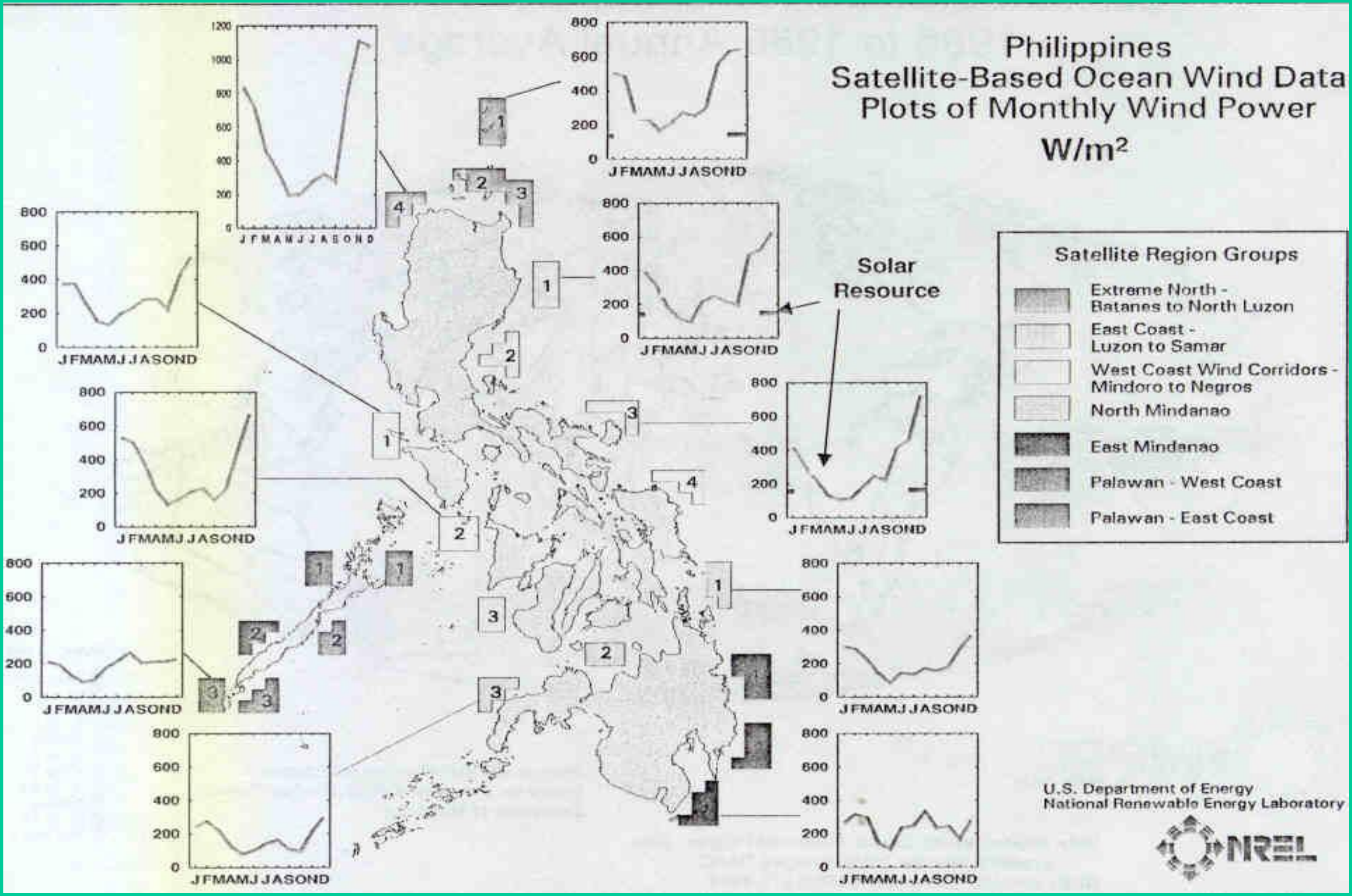
US Wind Potential – Wind Map



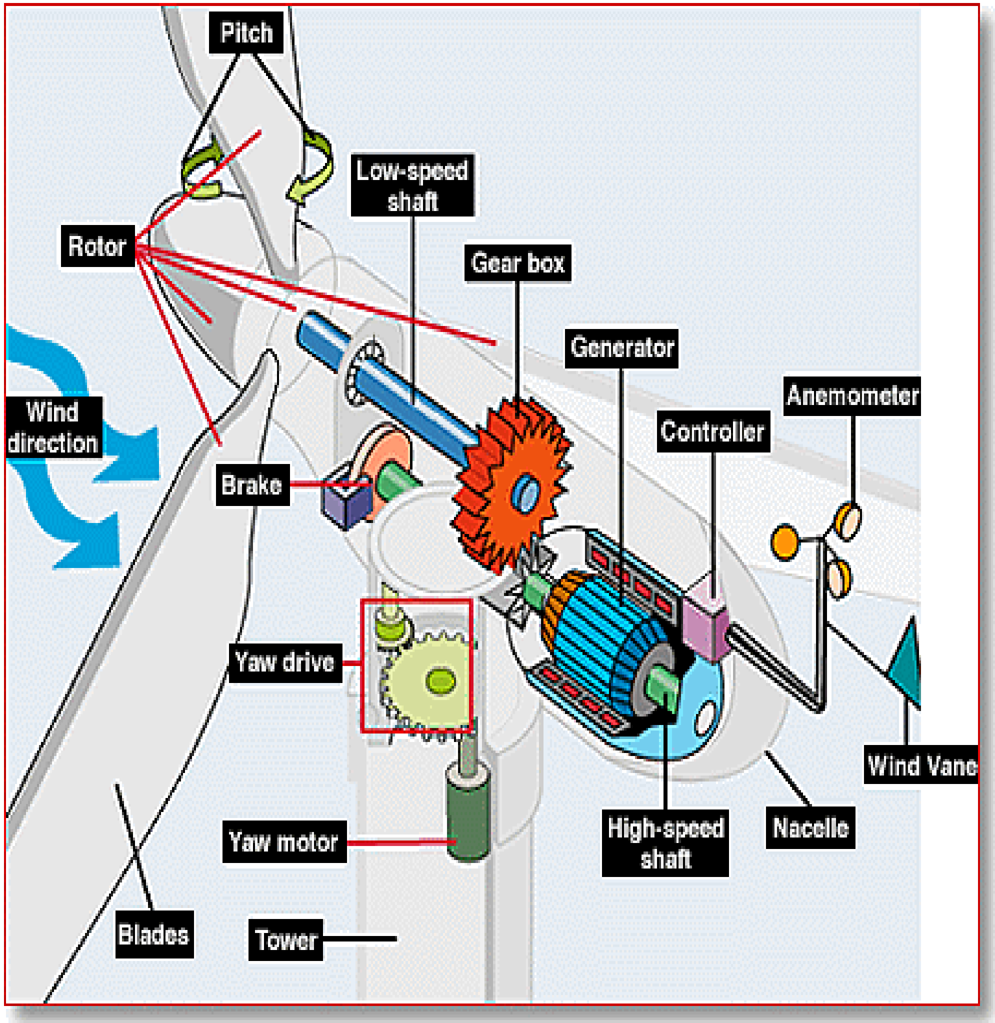
Philippine Wind Potential



Philippine Monthly Wind Power

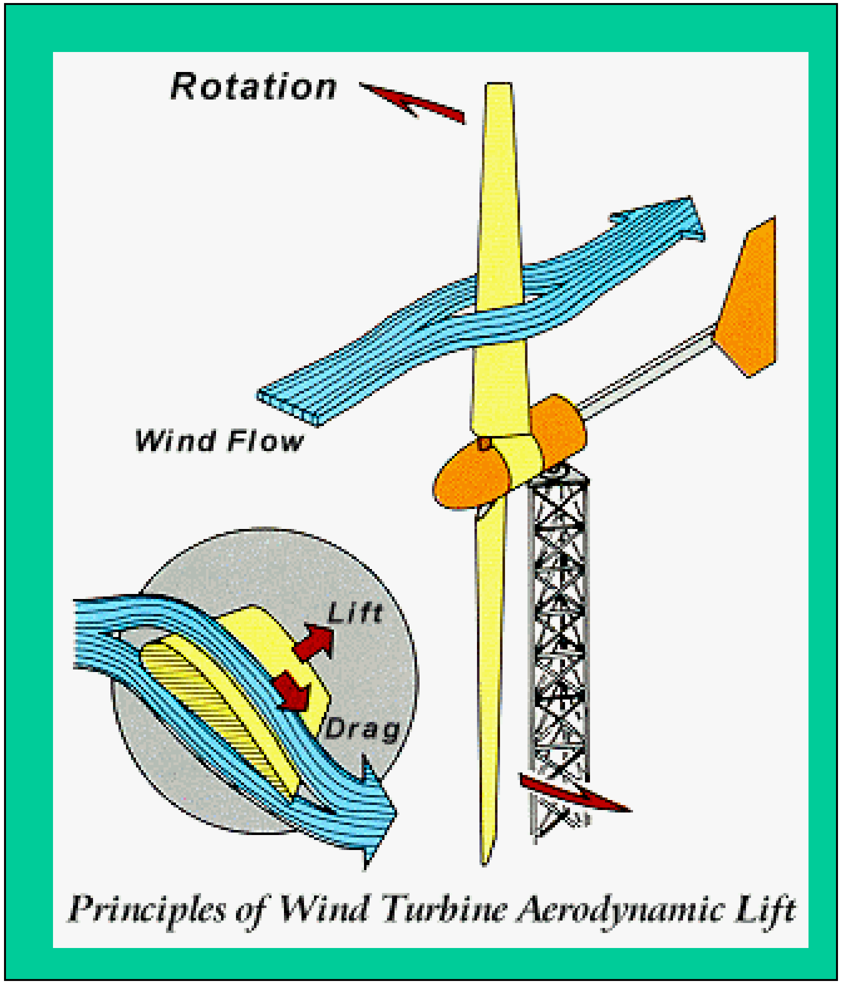


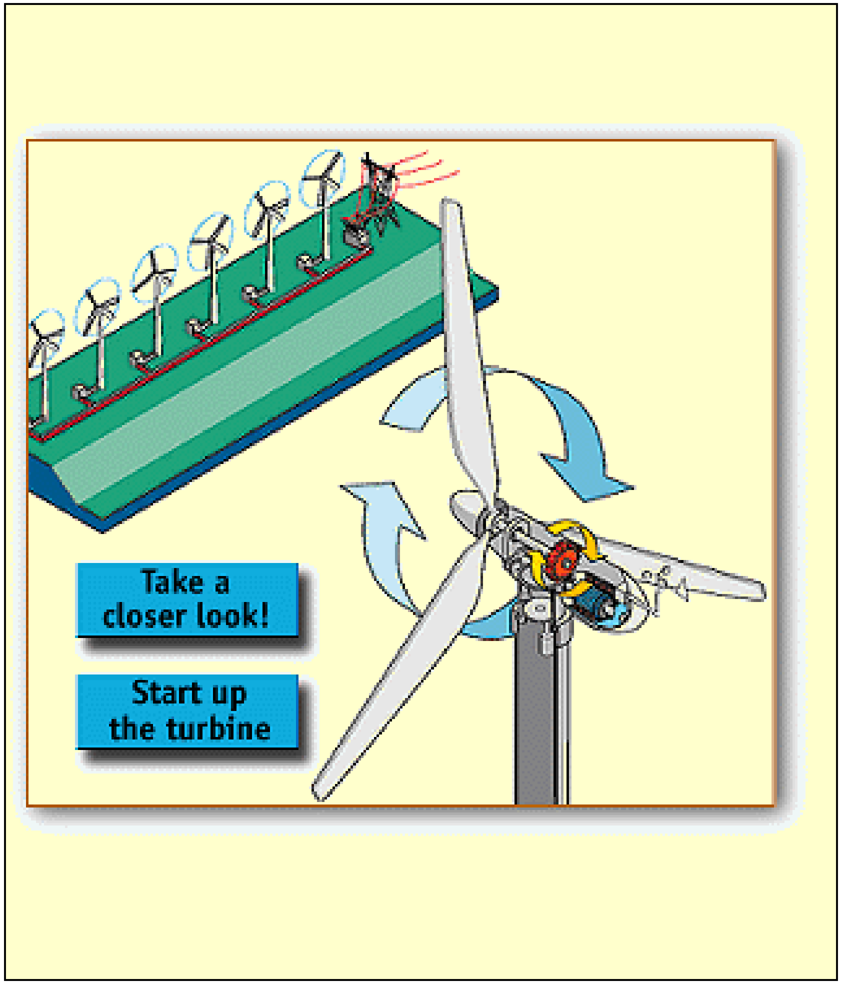
Basic Principles and Components of a Modern Wind Turbine



- Turbine rotor captures the wind energy and converts it into mechanical energy fed via a gearbox to a generator
- Gearbox / generator housed in an enclosed nacelle with the turbine rotor is attached to its front
- Combined rotor and nacelle mounted on a tower fitted with a yawing system keeps the turbine rotor facing into the wind always

Wind Turbine Aerodynamic Lift





Total Power Output of Wind Turbines

Total power output of a wind turbine is proportional to the incoming wind velocity raised to the 3rd power:

$$P_{tot} = m\ KE = m\ V_i^2 / (2\ g_c) \qquad \text{Watt = J/s}$$

$$= (1 / 2\ g_c)\ \rho\ A\ V_i^3$$

where	m = mass flow = $\rho\ A\ V_i$	kg/s
	ρ = density	kg/m^3
	A = cross-sectional area	m^2
	V_i = incoming velocity	m/s
	g_c = conversion factor	= 1.0 $kg/(N\ s^2)$

Ideal or Maximum Theoretical Efficiency of Wind Turbines

Maximum power is obtained by differentiating turbine power equation P with respect to exit velocity V_e and equating to zero:

$$P = (1 / 4\, g_c)\, \rho\, A\, (V_i + V_e)\, (V_i^2 - V_e^2) \qquad \text{Watt} = \text{J/s}$$

Solving for optimum exit velocity Ve yields:

$$V_{e,opt} = (1/3)\, V_i \qquad \text{m/s}$$

$$P_{max} = (8 / 27\, g_c)\, \rho\, A\, V_i^3 \qquad \text{Watt} = \text{J/s}$$

Ideal efficiency therefore that could not be more than 60%:

$$EFF_{max} = P_{max} / P_{tot} = (8/27) / (1/2) = 0.5926$$

Types of Modern Wind Turbines

- **Vertical-Axis Windmills** – early machines known as *Persian windmills*; evolved from ship sails made of canvas or wood attached to a large horizontal wheel; when used to grind grain into flour, they were called windmills.
- **Horizontal-Axis Windmills** –first designs had sails built on a post that could face into any wind direction, and were called *post mills*; evolved throughout the Middle Ages and was used for grinding grain, drainage, pumping, saw-milling.

Examples of Wind Turbines

Shown below are examples of a horizontal-axis and vertical-axis wind turbines.

Australia

California, USA

Cost of Wind Power

- Cost of wind power (EIA, 1996):

Resource type	Intermittent, predictable
Capacity factor	20 – 44 %
Real levelized cost (1998$)	4 – 6 cents / kWh
Construction lead time	1 – 3 years
Overnight capital cost	$857 / kW
Fixed O&M costs	$0.256 / kW / year
Variable O&M, $/kWh	nil

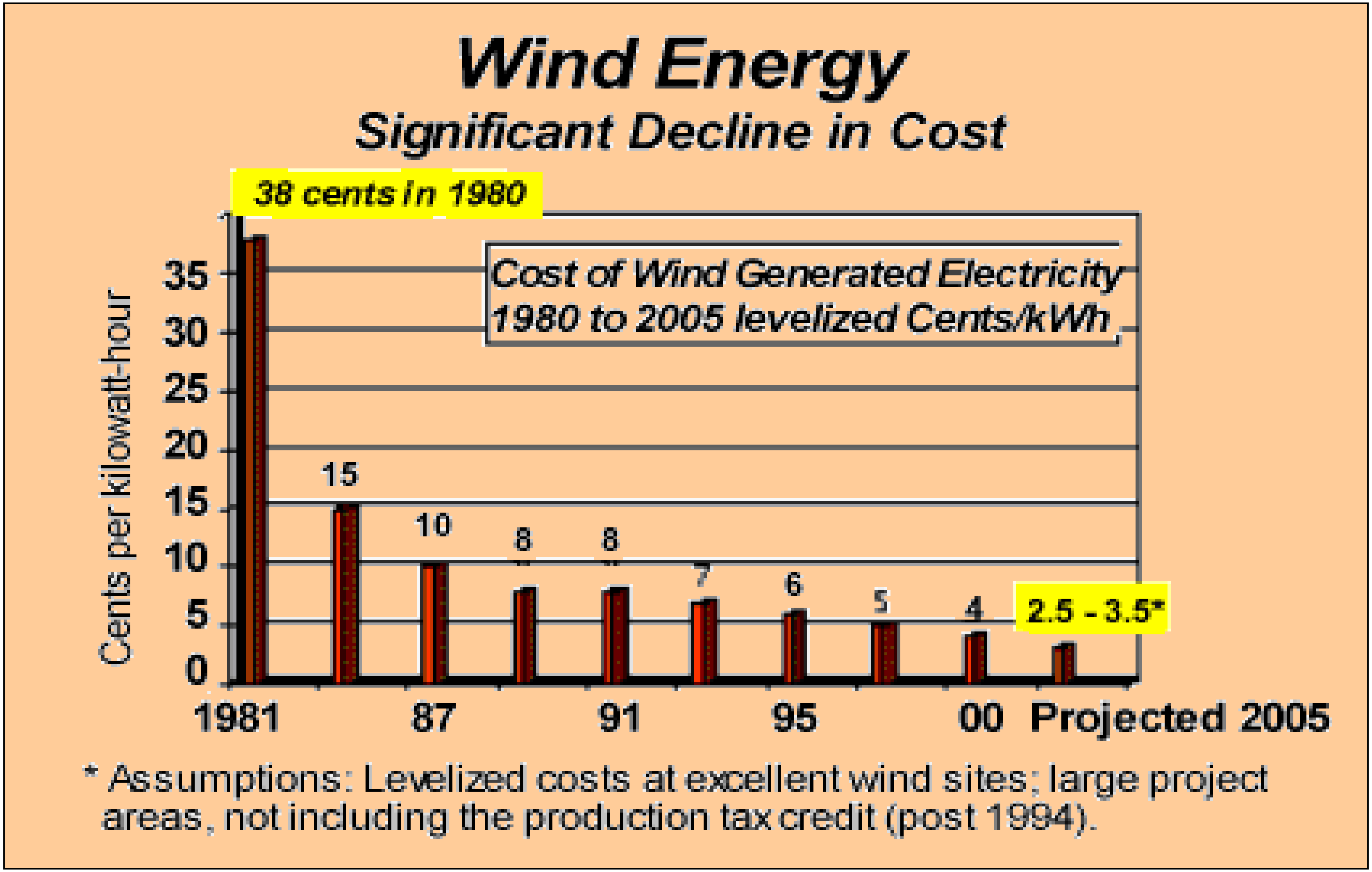
- Availability factor of 90% and load factor of 30-40%, sometimes higher at 45% during favorable wind patterns; because of this 1/3 average load factor, a wind farm would be 2.5 times as large as a conventional power plant of same rating and 80% load factor.
- Cost of generating wind power in US (EPRI) - $0.05/kWh
- Competitive tender bids in UK – as low as $0.032/kWh

Cost of Philippine Wind Power

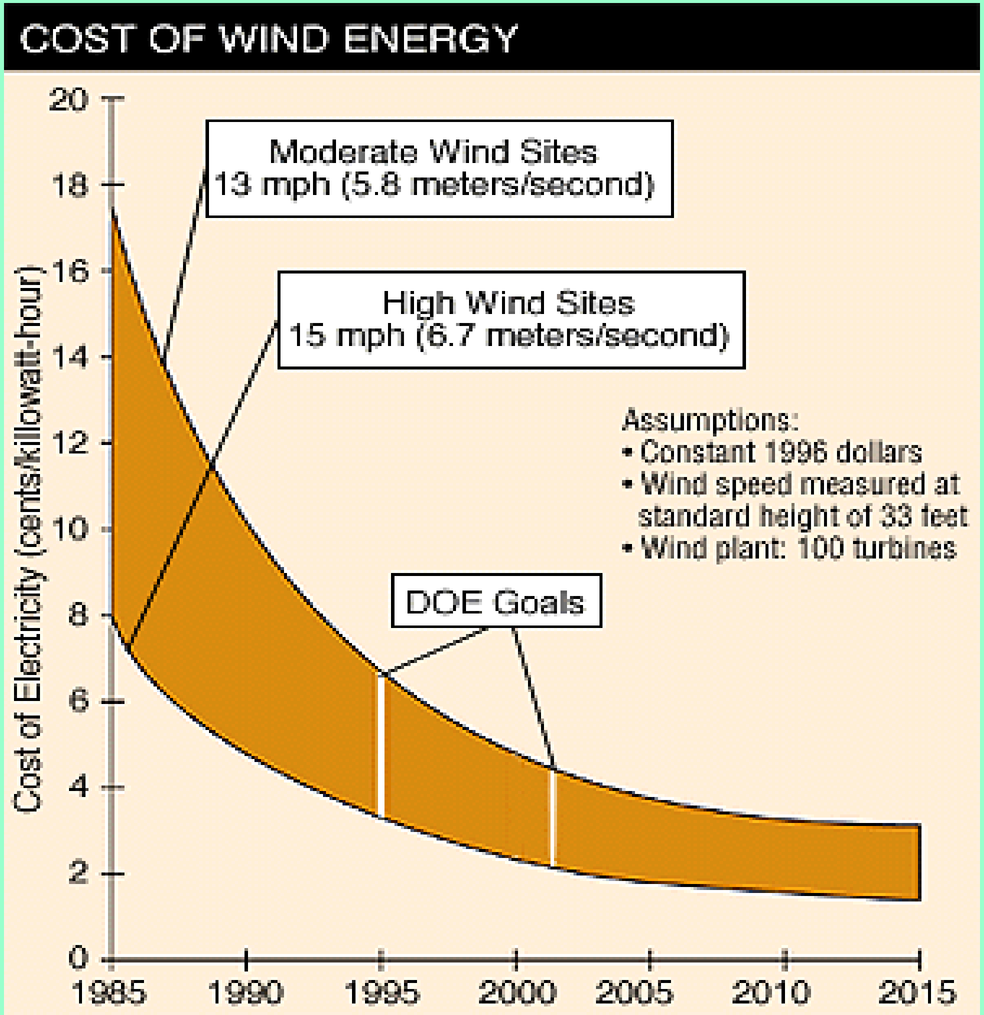
Proposed 120 MW wind farm in Pagudpud, Ilocos:

- 1st phase of 40 MW will cost $54 million for 56 units of 750-kW wind turbine generators and 43.5 km transmission system
- Selling price to electric coop would be P2.50/kWh below the NPC grid price of P3.00/kWh
- 2nd and 3rd phases will cost lower at $36 and $30 million, respectively, for each 40 MW.

Historical Cost of Wind Power



Future Cost of Wind Power



Applicability of Wind Power

- Economics of wind power depend strongly on **wind speed raised to the 3rd power;** double the wind speed and energy increases 8 times; actual wind turbines, however, do not yield that much extra power
- Wind speed also varies with **height** ; the higher the turbine is raised above the ground, the better wind regime it will find; a 50m tower can capture 20% more energy than 30m:

$$V_i = V_o \, (H_i \, / \, H_o)^{\alpha}$$

- **Economic cut-off wind speed** - 6.5m/s at 25m above ground and 7.0m/s at 45m above ground level
- Wind speed-height equation makes **higher sites more attractive**, such as hilly and mountainous sites
- Offshore wind speeds are higher and smoother over surface water than land areas, making **offshore wind attractive**

Advantages of Wind Power

- **Home owners** (250W-25kW) - generate their own electricity, charge batteries, and in some cases, sell excess electricity to the utility, a practice called "*net metering*"
- **Hybrid systems** – used with other technologies like photovoltaic panels, batteries and diesel generators for round-the-clock renewable power and reliable back-up power; cost-effective at remote, cold sites
- **Remote villages** (< 100kW) - wind turbines can power small grids, charge batteries, grind grain or pump water, thus improving their quality of life
- **Wind farms** (> 200kW) - large wind turbines can operate together to produce green power - clean and renewable electricity for utilities; income to rural farmers - $55/acre
- **Distributed generation –** building power plants where power is needed and feeding into distribution rather than transmission systems helps improve the network

Disadvantages of Wind Power

- **Not steady or reliable -** its production does not coincide with demand, hence, it may have to be stored in batteries during off-peak hours or have to be hybrid with other reliable back-up power like diesel generators.
- **Higher capital and O&M costs** - although the cost of wind energy from wind has dropped by 85% over the last 20 years, the need to hybrid wind turbines with other technologies to make it a reliable and stable system tend to increase its capital and operating costs
- **Some doubts on structural integrity to protect investment -** tropical climate of the Philippines which is regularly visited by typhoons with speeds over 100-300 kph, may affect structural integrity of the system even at "*stowed position*" to withstand such sustained winds over a few hours and sudden wind gusts

Environmental Impact

- **Green power technology** - because wind has only minor impacts on the environment and produces no air pollutants or greenhouse gases - fights global warming
- A 1 MW wind farm in UK will **prevent the production** of 2,200 mt of CO_2, 30 mt of SO_2 and 10 mt of NO_X each year based on UK's generation mix in 1990.
- **Aesthetics and visual impacts –** elements that influence visual impacts include the spacing, design and uniformity of the turbines.
- **Birds and other living resources –** likely to be affected by the wind turbines as they fly their migration routes.
- **Noise –** wind turbines produce some low level frequency noise when they operate.
- **TV/radio interference –** older turbines with metal blades caused interference; modern composites have reduced this

Risks

- **Risk associated with the reliability of the wind power resource –** should be *minimal* if an adequate feasibility study has been performed on the site, otherwise, the wind will not blow as it was expected; while the strength of the wind on a particular day and site could not be predicted, wind is normally reliable over longer periods – a windy site will not turn into a windless site.
- **Risk attached to the use of wind power equipment –** while the industry is now well established and many design features have been proven, development is continuous and that always carries a *certain risk*; wind turbines are becoming larger while experience with them is limited; it is vital to obtain historical performance data to establish its reliability for commercial operations

WISCONSIN WIND PROJECT

In 1998, two wind turbines were built on a farm near Green Bay to generate 1,200 kW of electricity at full capacity and 30 mph winds to electrify 450 homes. Historical wind speeds indicate project average of around 13.6 mph.

Wisconsin Wind Project				
Item	**Units**	**Details**	**Units**	**Remarks or SI units**
Project Manager		Wisconsin Public Service Corporation		
Total Cost	$	2,100,000	$/kW	1,750
Rated Power Output (2 units)	kW	1,200		2 x 600 kW
Design Wind Speed	mph	30	m/s	13.4
Average Wind Speed (5 yrs, 110 ft)	mph	13.6	m/s	6.1
Cut-in Wind Speed	mph	6.7	m/s	3.0
Cut-out Wind Speed	mph	44.7	m/s	20.0
Survival Wind Speed	mph	125	m/s	55.9
	kph	201		
Wind Direction		60 % W, 40% SW		
Annual Energy Production	kWh	3,261,126		Average Power, kW
Average Capacity Factor	%	31.0	kW	372.3
Expected Life of Turbine	yrs	20		
Sponsors		Wisconsin Electric Power Co., etc.		
Site Location		Breen Bay, Wisconsin, USA		
Land Area (leased)	acres	2.4	ha	1.0
Elevation	ft	986	m	300.5
Site Description		Agricultural use		
Grid Interconnection	kV	24.9		