بسم الله الرحمن الرحيم

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Postgraduate (Pre-master) Course

Generation of Electrical Power from Renewable Resources

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Why Wind Energy?

Clean, Cheap & Simple

- ***Reduced Greenhouse Gas Emissions***

Do you know ?

1 GW (Fuel Oil) => 4000 Tons CO_2 /hr
1 GW (Natural Gas) => 1500 Tons CO_2 /hr

- ***Reduced Air Pollution***

Do you know ?

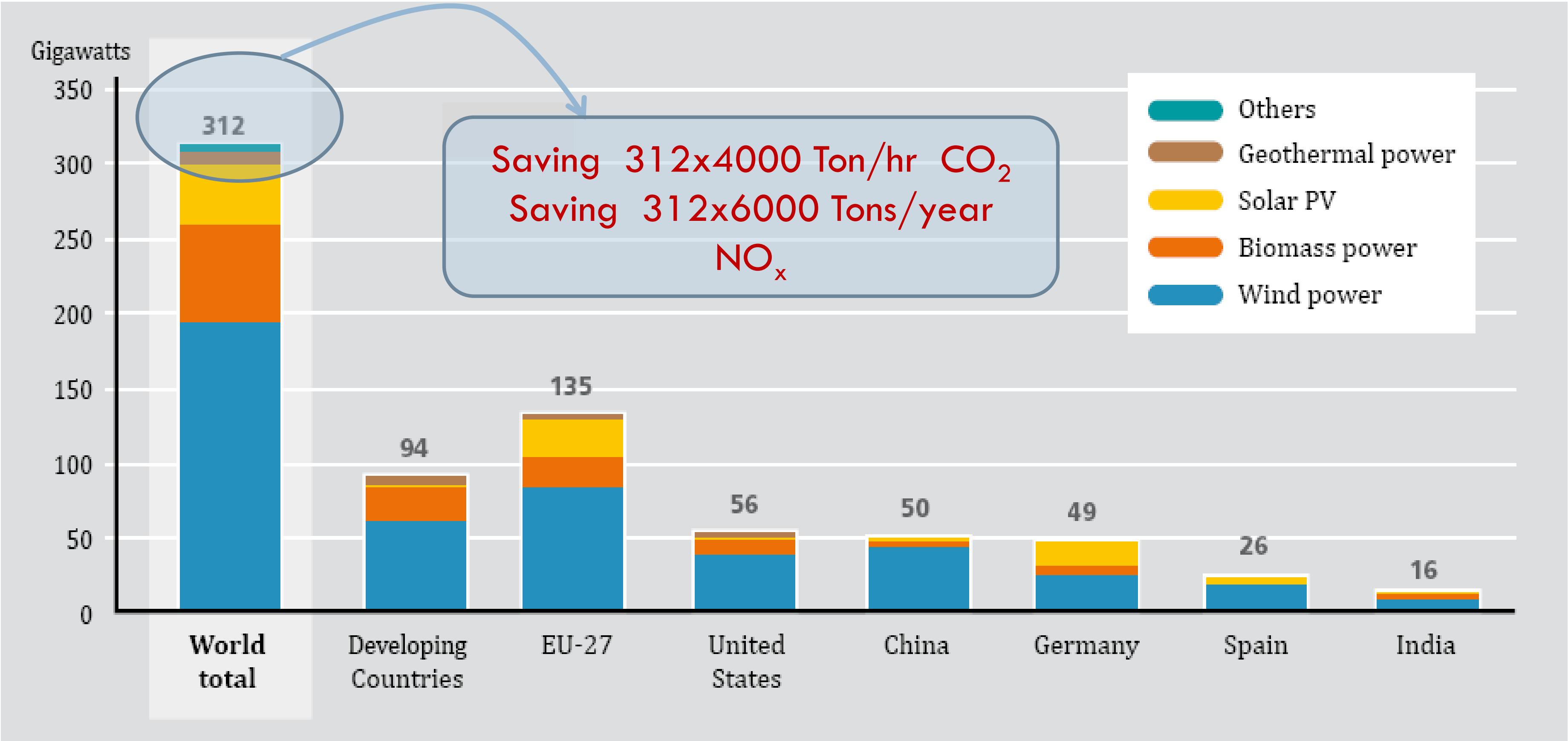
1GW of wind energy ≈ 6,000 tons/year of NO_x emissions

- ***Running cost is very low***

Do you know ?

That wind energy is the so far cheapest renewable energy 6 c/Kw

Renewable Power Capacities, Developing world, EU, and Top five Countries, 2010



* Excluding hydropower

Source: Renewables 2011 GLOBAL STATUS REPORT

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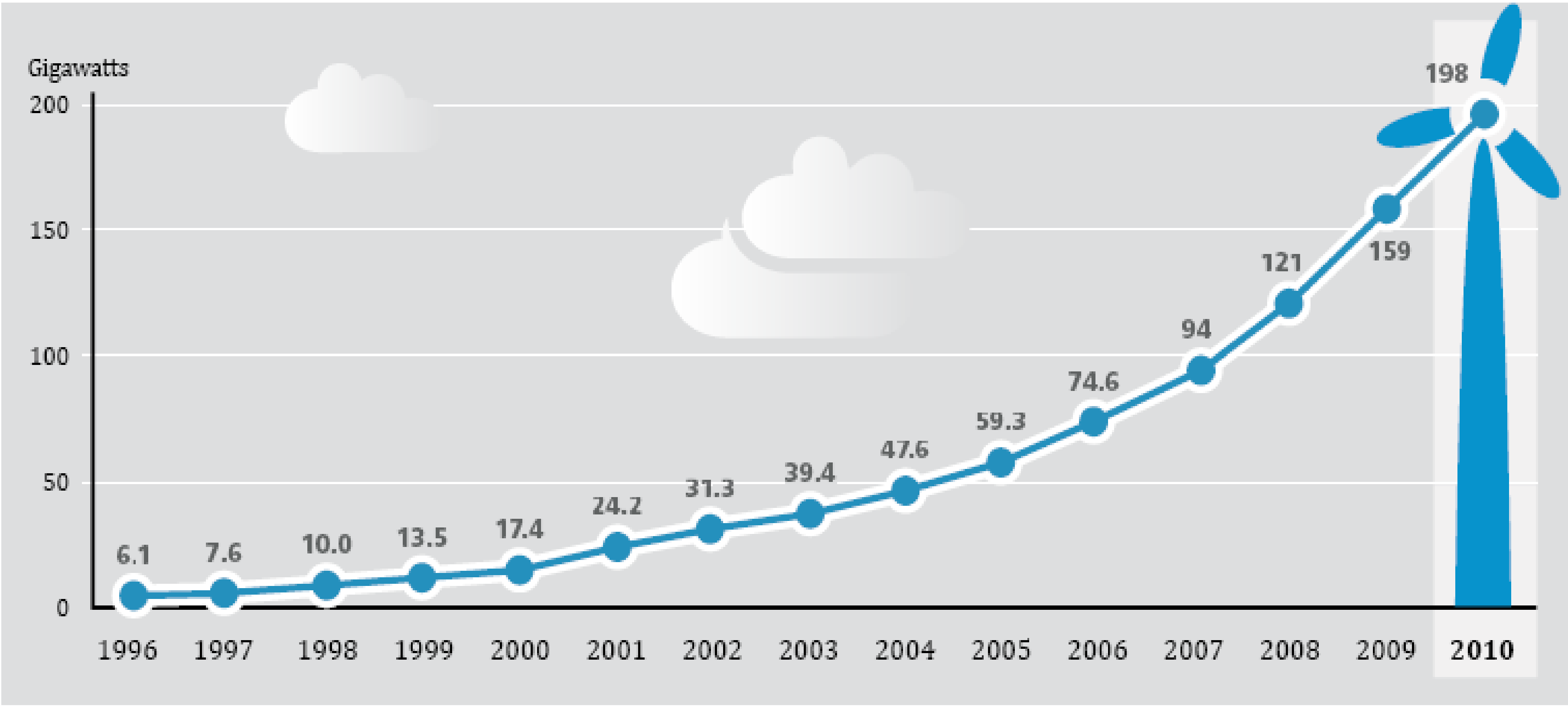
Wind Power, Existing World Capacity, 1996–2010

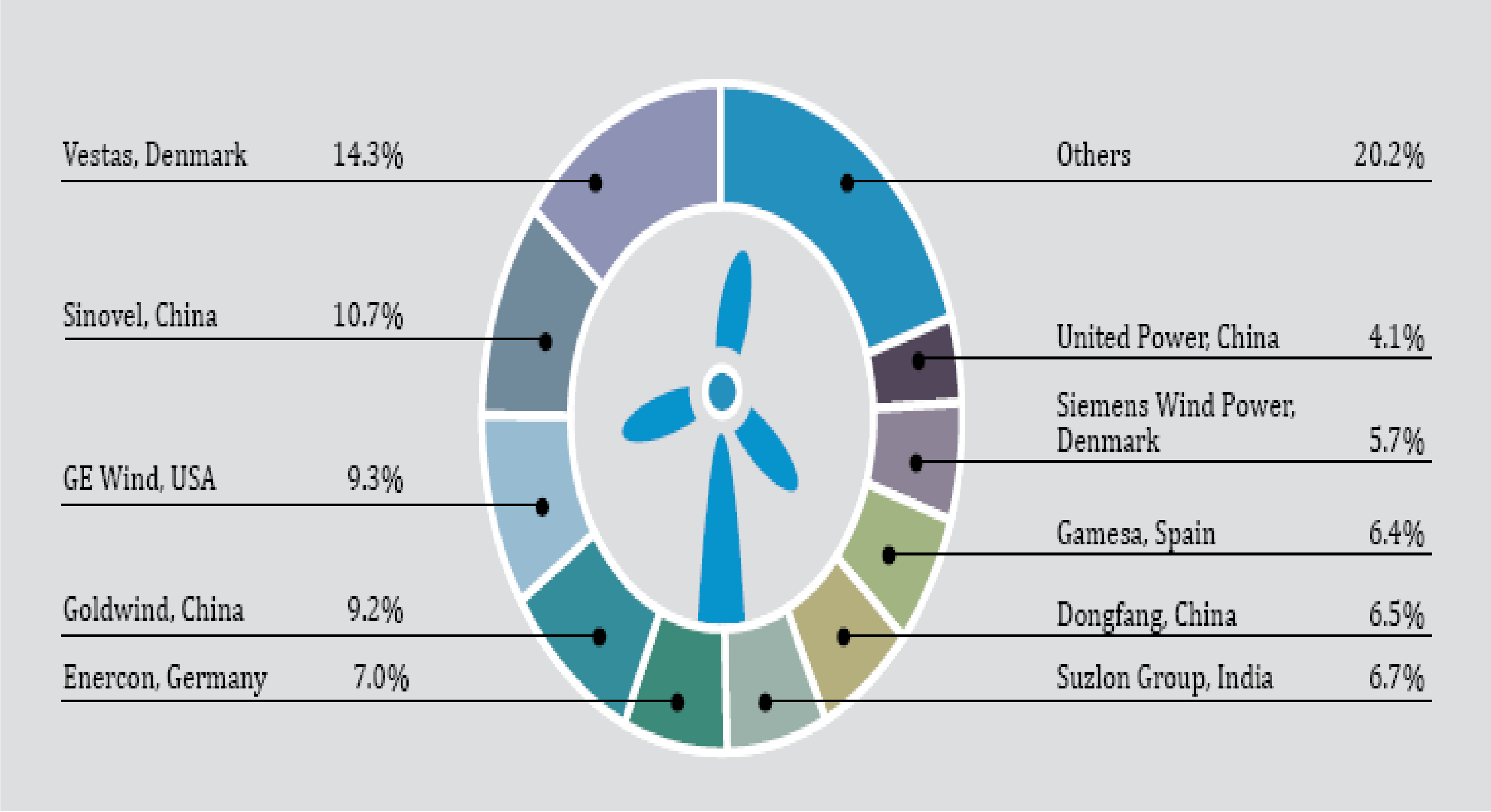


Source: GWEC, WWEA, EWEA, MNRE, BMU,BTM

Added and Existing Wind Power, Top 10 Countries, 2010

Country	Cumulative at end of 2009 (GW)	Added in 2010 (GW)	Cumulative at end of 2010 (GW)
China[1]	17/25.8	14/18.9	31/44.7
United States	35.1	5.1	40.2
Germany	25.7	1.5	27.2
Spain	18.9	1.8	20.7
India	10.9	2.3	13.2
Italy	4.8	0.9	5.8
France	4.6	1.1	5.7
United Kingdom	4.4	0.9	5.3
Canada	3.3	0.7	4
Denmark	3.5	0.3	3.8
World Total	159	39	198

Market Shares of Top 10 wind Turbine Manufacturers, 2010

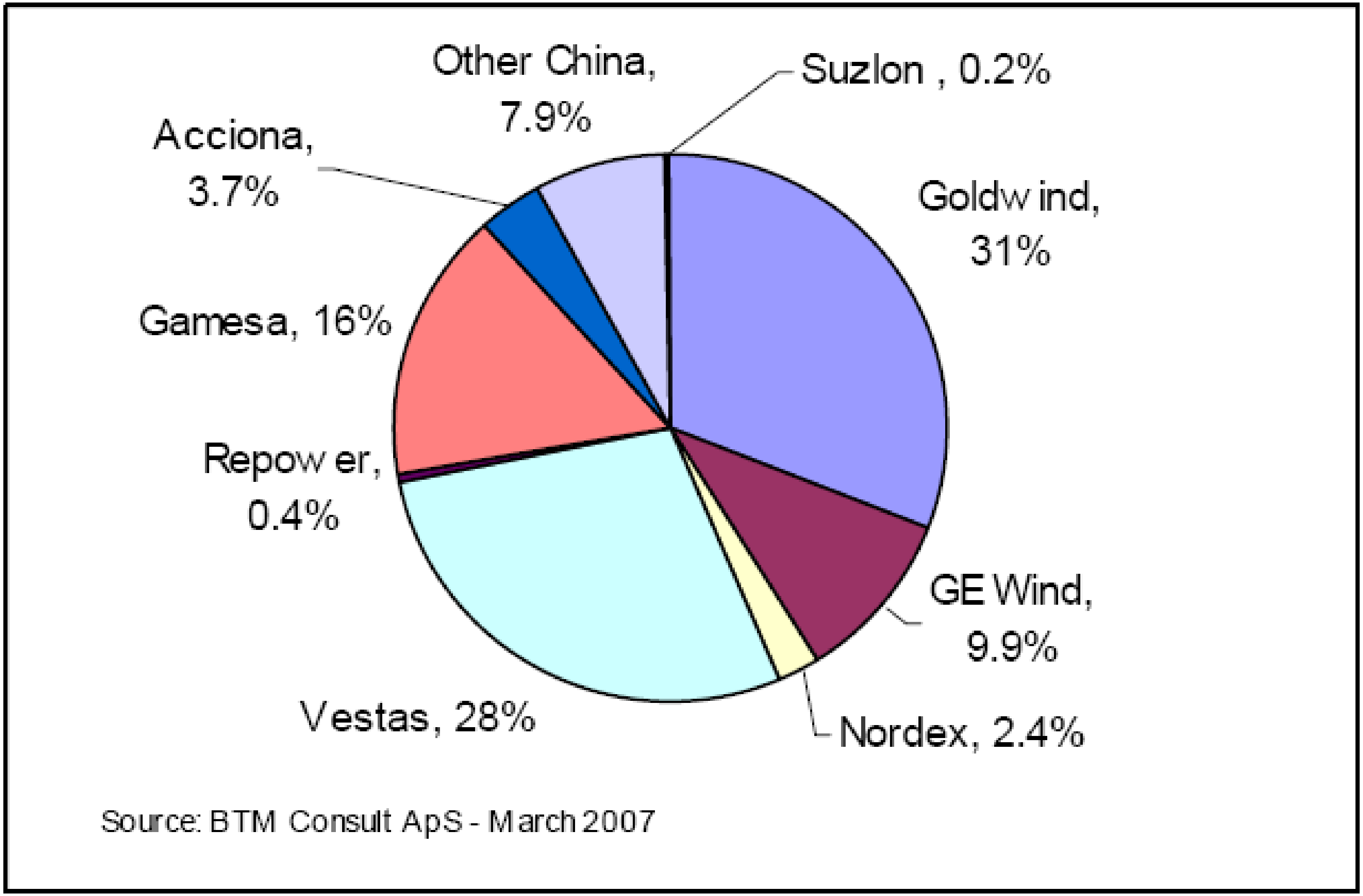


Source: BTM Consult ApS a part of Navigant Consulting

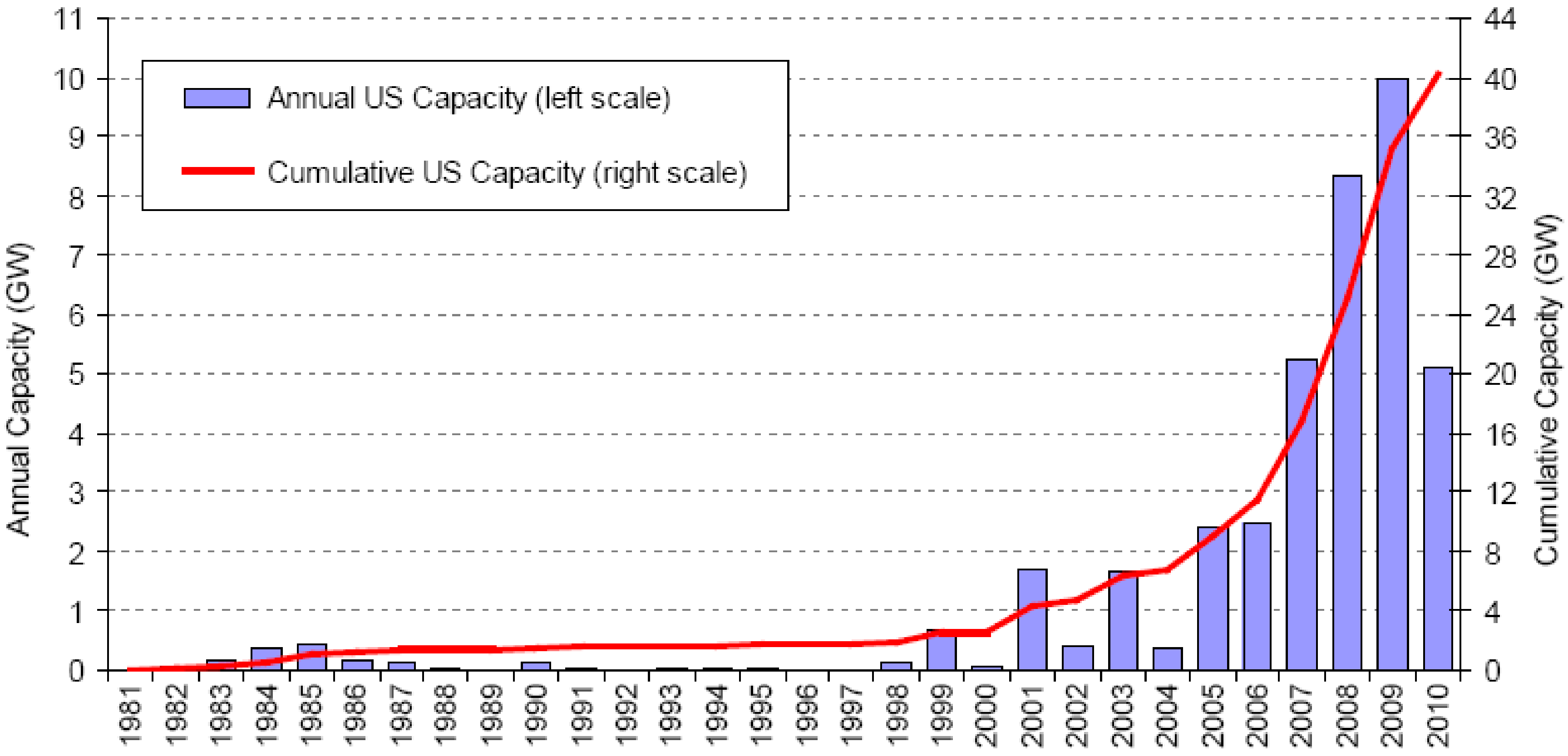
China Targets 2020

Country	Renewables - GW	Hydro-GW	Wind - GW	Biomass - GW	PV/CSP - GW	Thermal GWth
China	362	300	30	30	1.8	210

Market Shares in China, % of 1,337MW Total.

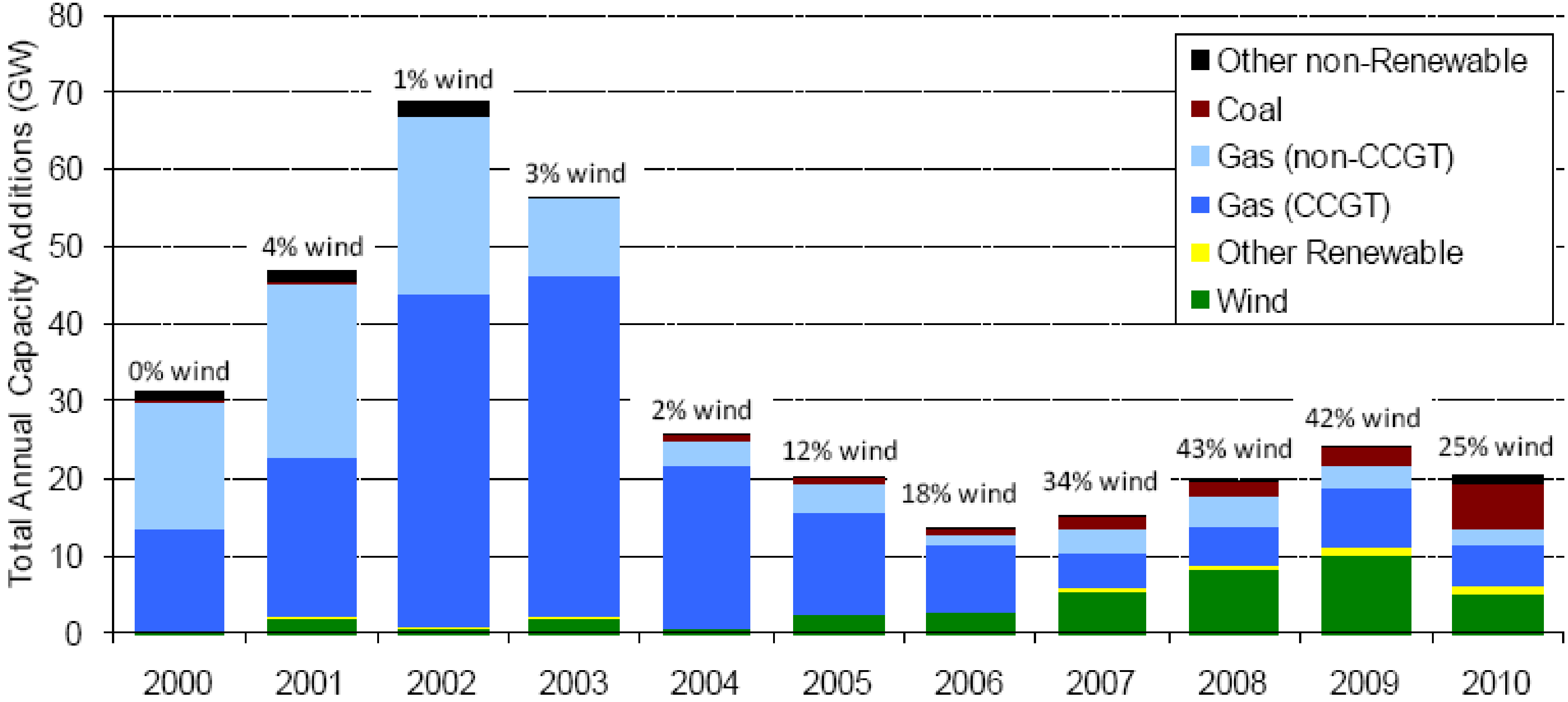


Annual and Cumulative Growth in U.S. Wind Power Capacity



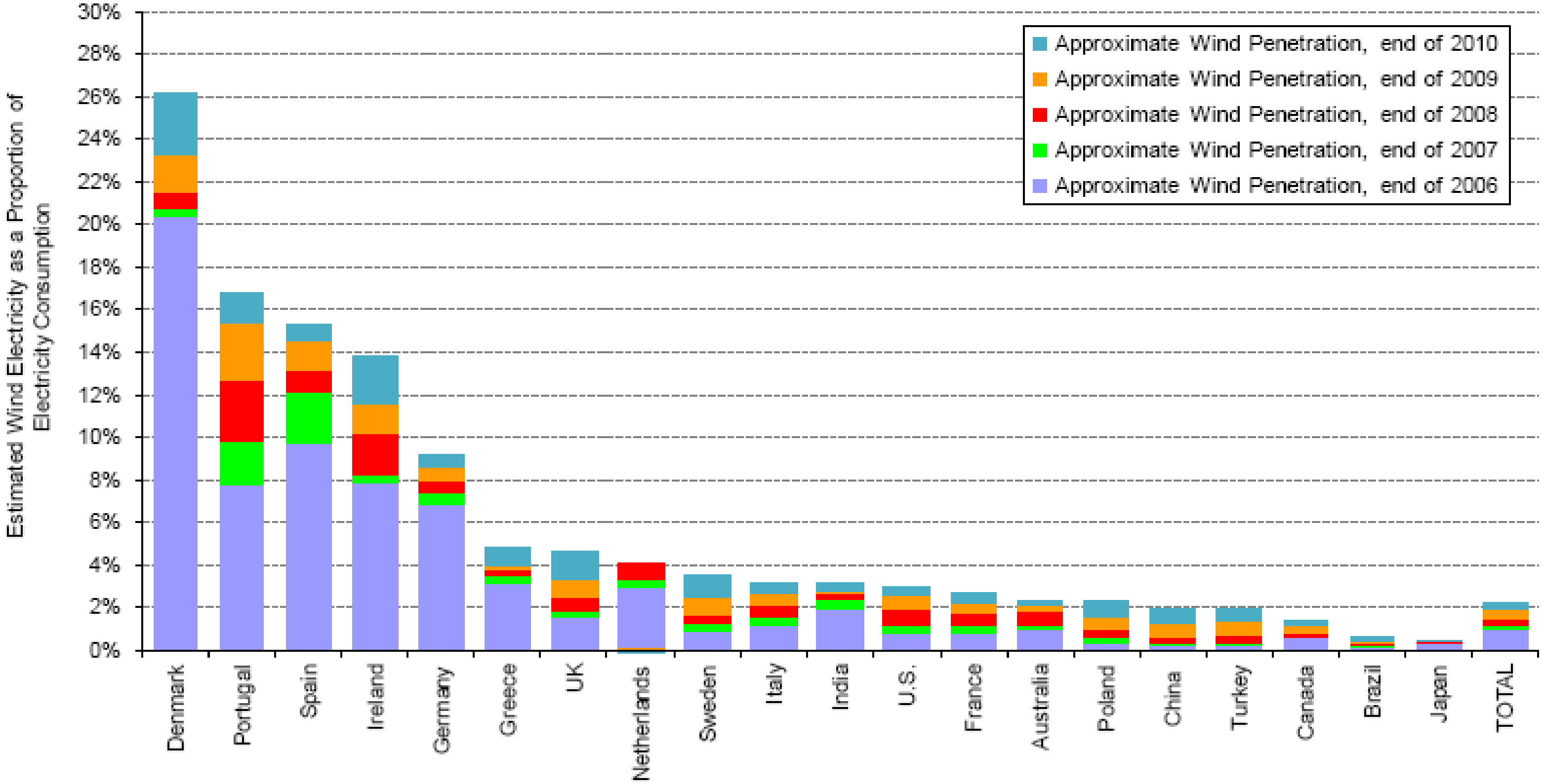
Source: AWEA project database

Relative Contribution of Generation Types in Annual Capacity Additions



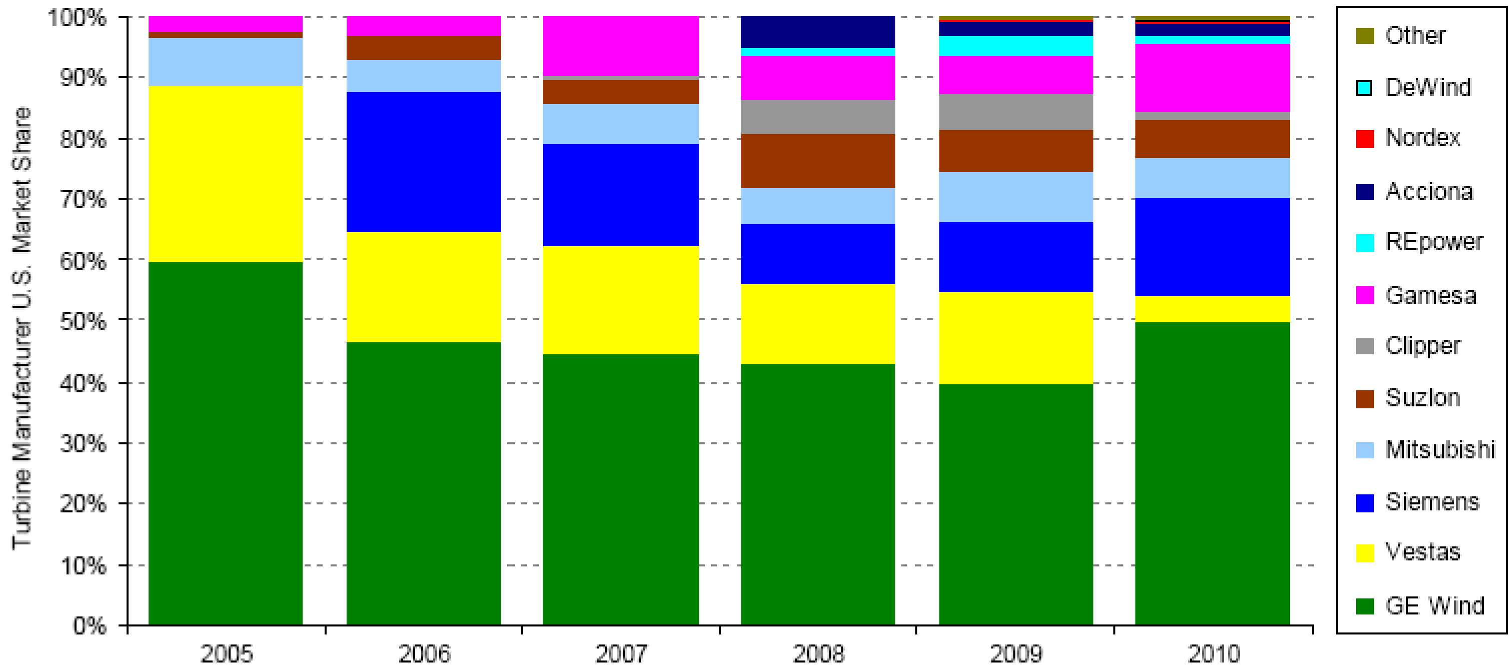
Source: EIA, Ventyx, AWEA, IREC, SEIA/GTM, Berkeley Lab

Approximate Wind Energy Penetration in the Twenty Countries with the Greatest Installed Wind Power Capacity



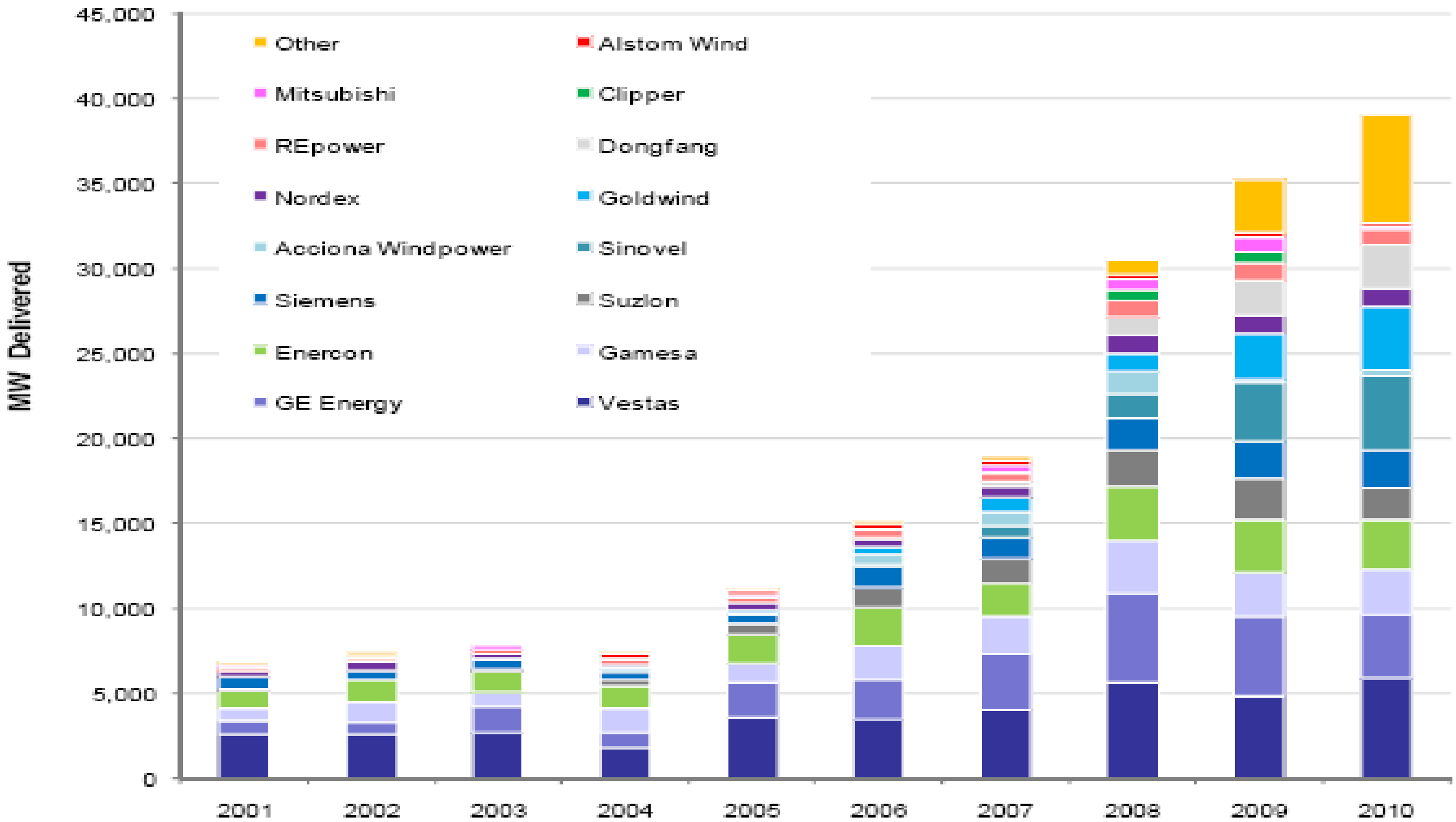
Source: Berkeley Lab estimates based on data from BTM Consult, EIA, and elsewhere

Annual U.S. Market Share of Wind Manufacturers by MW, 2005-2010



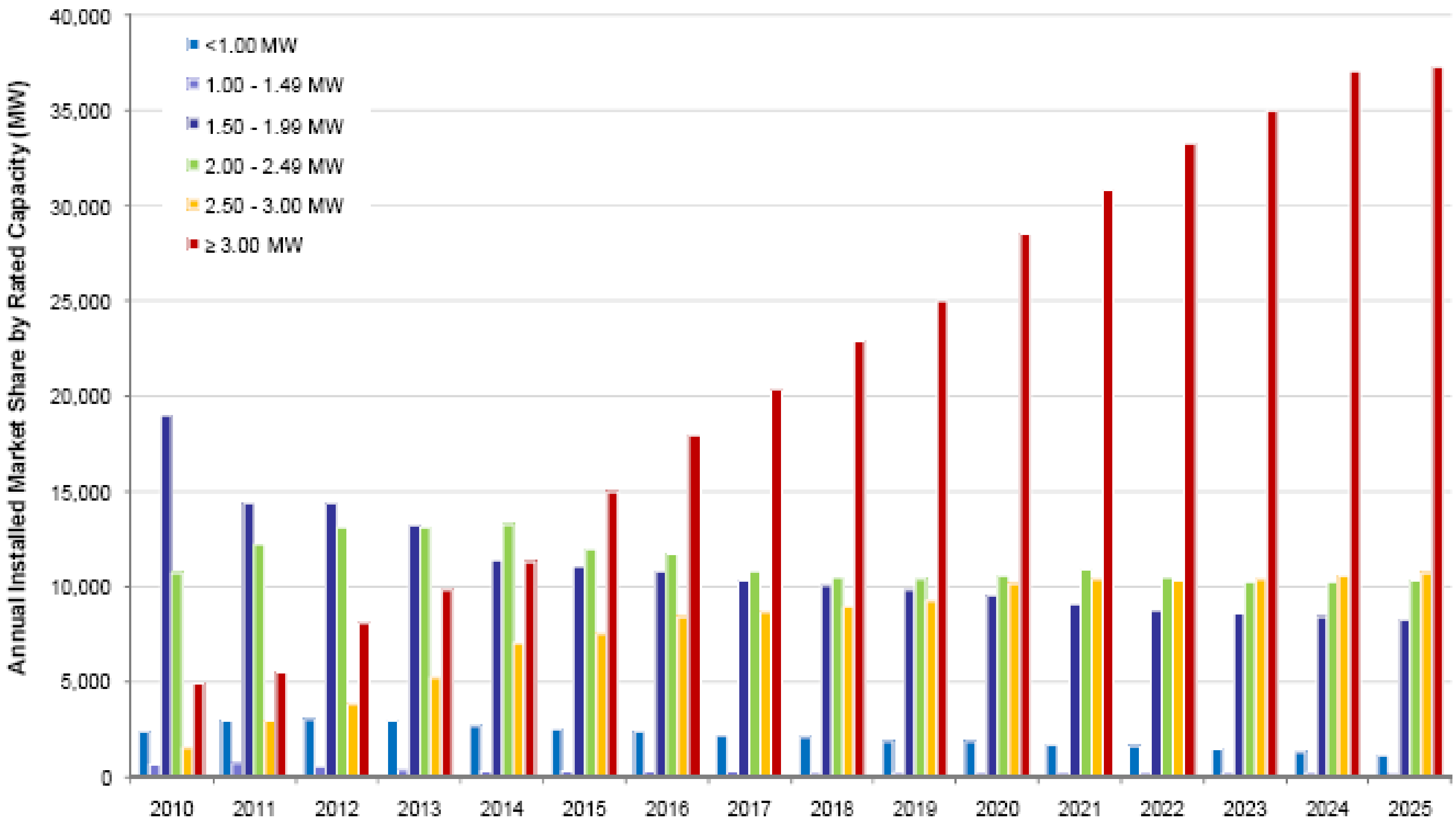
Source: AWEA project database

Global Wind Turbine Market Share, MW Delivered: 2001–2010



Note: Data is based on wind turbine deliveries on an annual basis, and not on wind turbine activations
Source: IHS Emerging Energy Research

Global Annual Wind Installed by Rated Turbine Capacity: 2010–2025



Source: IHS Emerging Energy Research

Wind Turbine Design Concepts

Horizontal axis
3-bladed

(HAWT)

Horizontal axis
2-bladed

Vertical axis

(VAWT)

Wind Turbine Components

GE 1.5 MW
1200-1700 Households

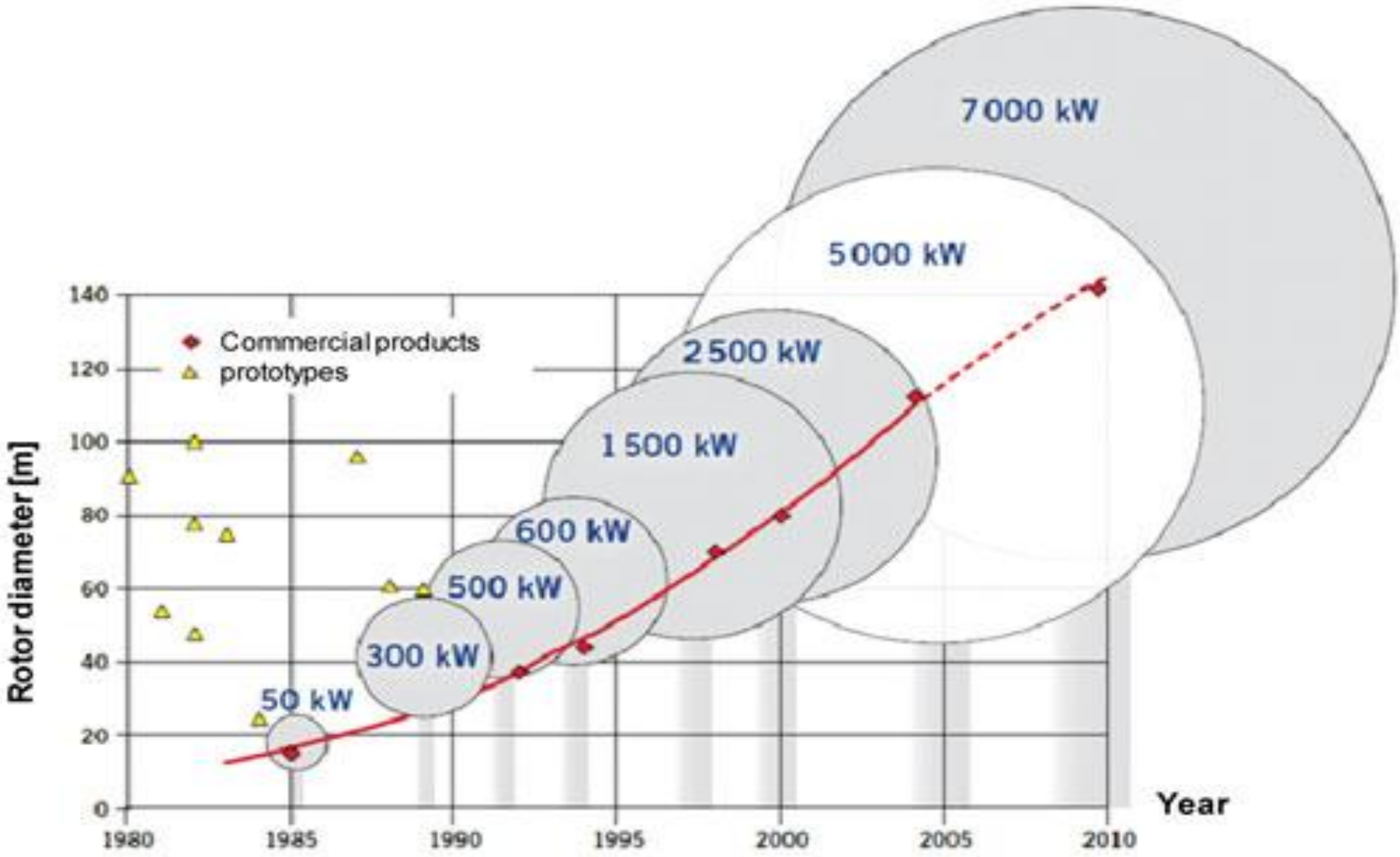
Rotor
35 metric tons
77 meters diameter

Nacelle
52 metric tons

Tower
120+ metric tons
60 to 100 meters

Car (for scale)

Increasing Wind Turbine Capacity



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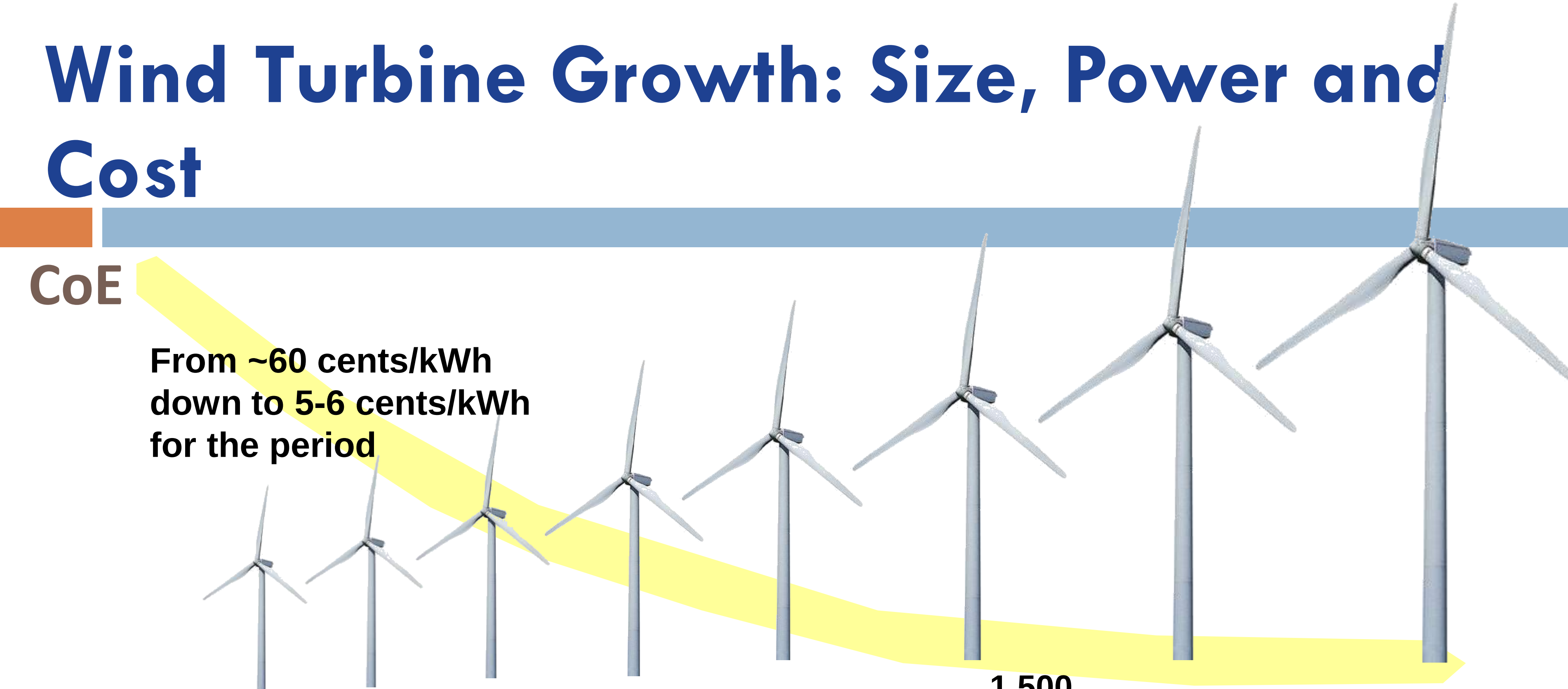
Wind Turbine Growth: Size, Power and Cost



	1981	1985	1990	1996	1999	2001	2005	2010+
Rotor Dia. (m)	10	17	27	40	50	71	88	125+
KW	25	100	225	550	750	1,500	2,500	7,500+

Increased size, improved performance and technology innovation

Wind energy now cost competitive with conventional fuels

Source: Cy Harbourt

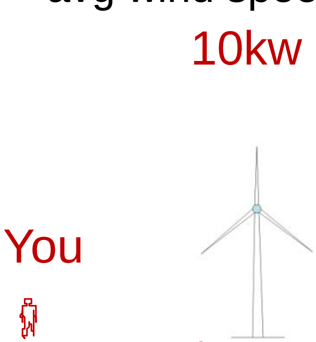
Small vs. Big wind energy

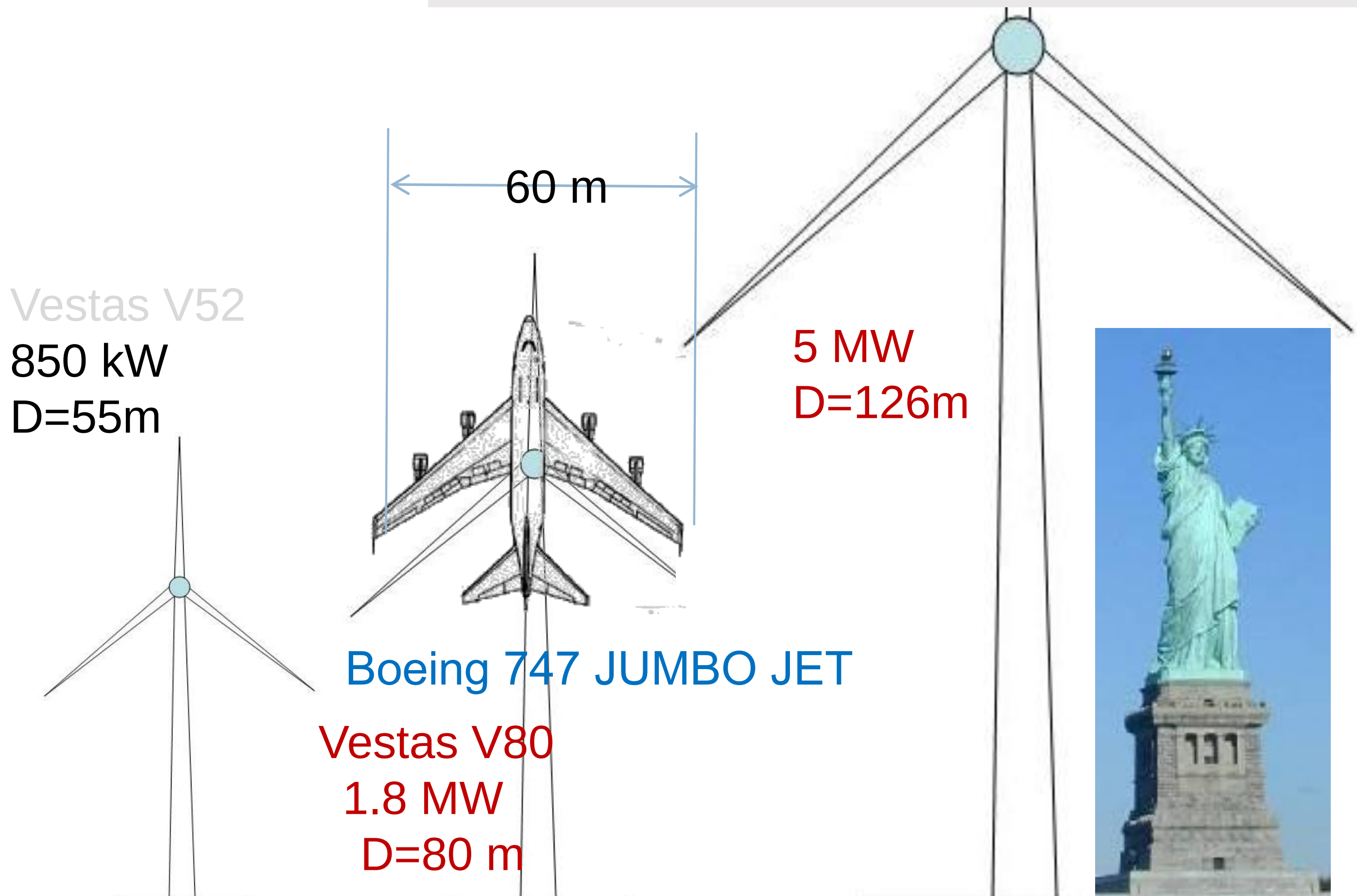
Utility-Scale Wind Power - 850 - 7000 kW

- Owned by utilities, multi-million $ companies
- Installed on wind farms, 10 – 600 MW
- Professional maintenance crews
- >13 mph (6 m/s) avg wind speed

Small Wind Power - 300 W - 250 kW

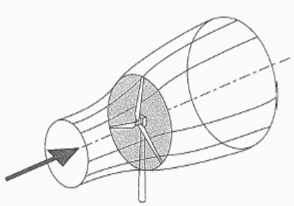
- Individual homes, farms, businesses, etc.
- On the “customer side” of the meter
- Or…off the grid entirely
- High reliability, low maintenance
- >9 mph (4 m/s) avg wind speed

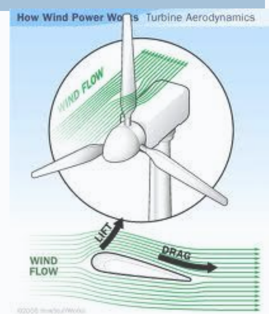


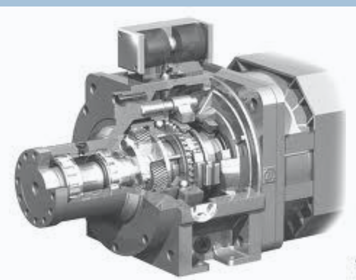


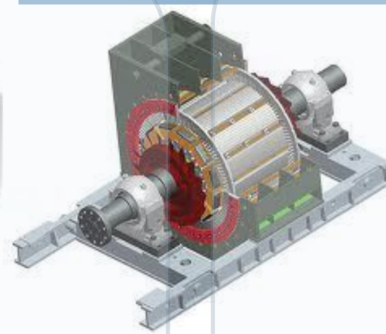
Wind Turbine Principles

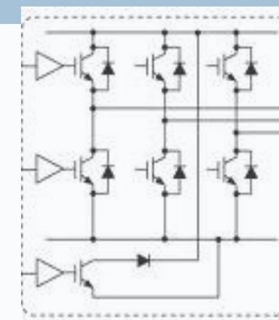
Converting one form of energy to another











Wind Kinetic Energy → Mechanical Energy → Electrical Energy

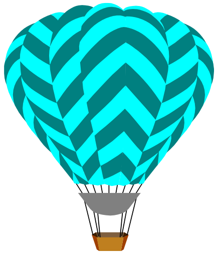
Component	Rotor	Gearbox	Generator	Converter
Efficiency	45-52%	95-97%	97-98%	96-99%

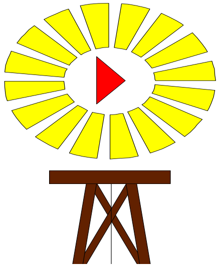
Overall: 42 – 50% Efficient Today… Theoretical Maximum is 59.3%

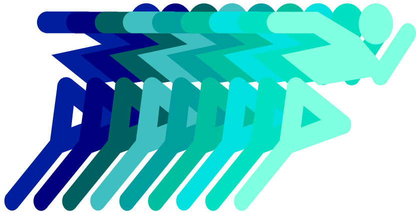
Power in the Wind (W/m^2)

P_{wind} = 1/2 x air density x swept rotor area x (wind speed)^3

ρ **A** **V^3**







Density = P/(R . T)

P - pressure (Pa)
R - specific gas constant (287 J/kgK)
T - air temperature (K)

Area = πr^2

Instantaneous Speed (not mean speed)

kg/m^3	m^2	m/s

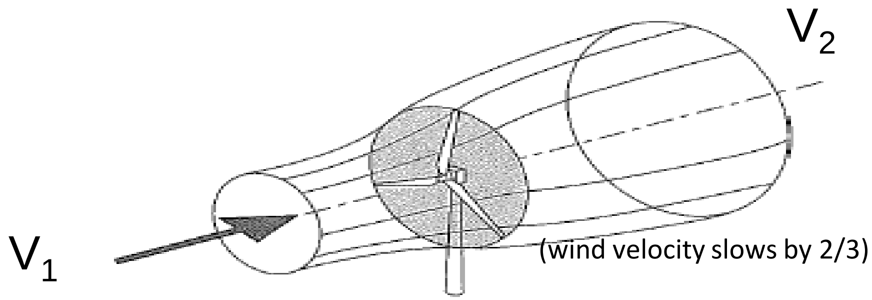
$$P_{wind} = \frac{1}{2}\rho A v^3$$

Power Coefficient $C_p = \frac{P}{P_{wind}}$

Theoretical Maximum is 59.3%

represents how much we can extract power form wind

Wind Turbine Energy Capture



Rotor power

- 10% increase in wind speed translates into 30% more electricity
- 2X the wind speed translates into 8X the electricity

$$P = \tau_{aero} \omega$$

- Wind energy increases with height to the 1/7 power
- 2X the height translates into 10.4% more electricity

- 10% increase in swept diameter translates into 21% greater swept area
- Humid air has higher ρ

Source: *"Wind turbines: Fundamentals, Technologies, Application and Economics"*, Erich Hau, ISBN: 3540570640; (April 30, 2000)

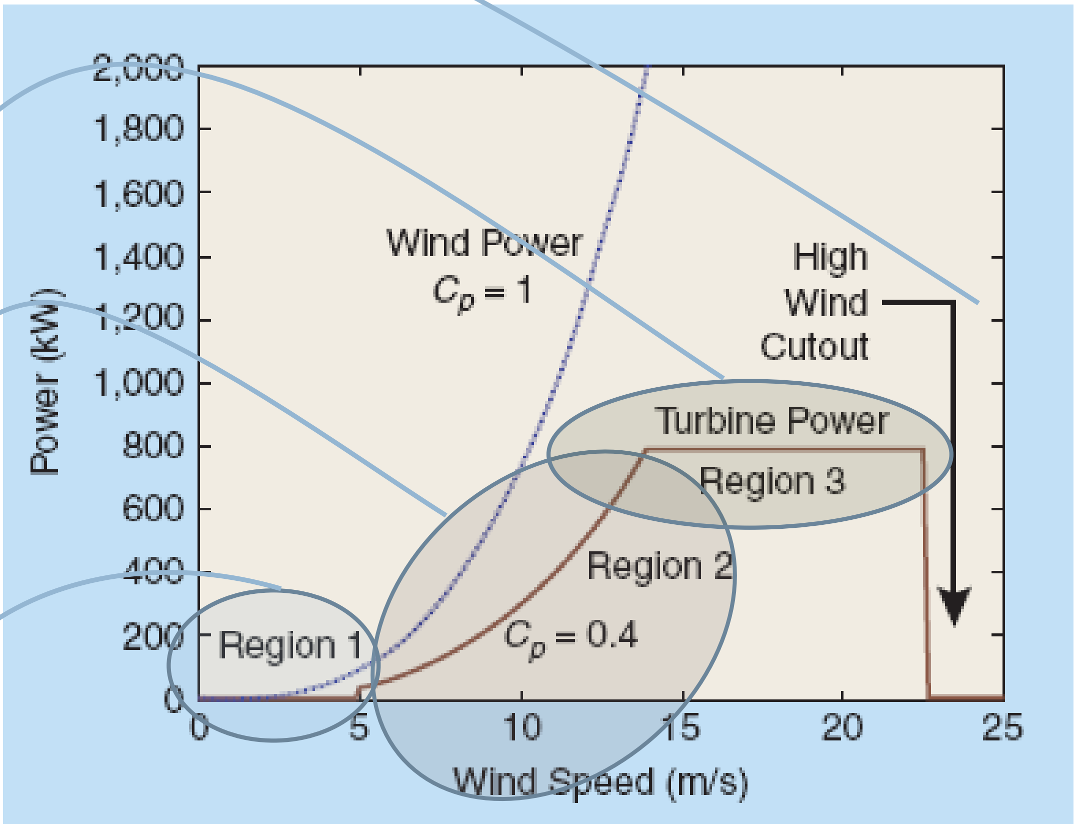
Power Speed Curve

Un Secure Operation
Stop turbine

Power is Maximum
Pitch Control to Regulate Turbine Power and to reduce mechanical stresses

Extract the Maximum Turbine Power
Maximum Power Point Tracking Control is required

Too little Wind Turbine has to stop



Source: IEEE CONTROL SYSTEMS MAGAZINE » JUNE 2006

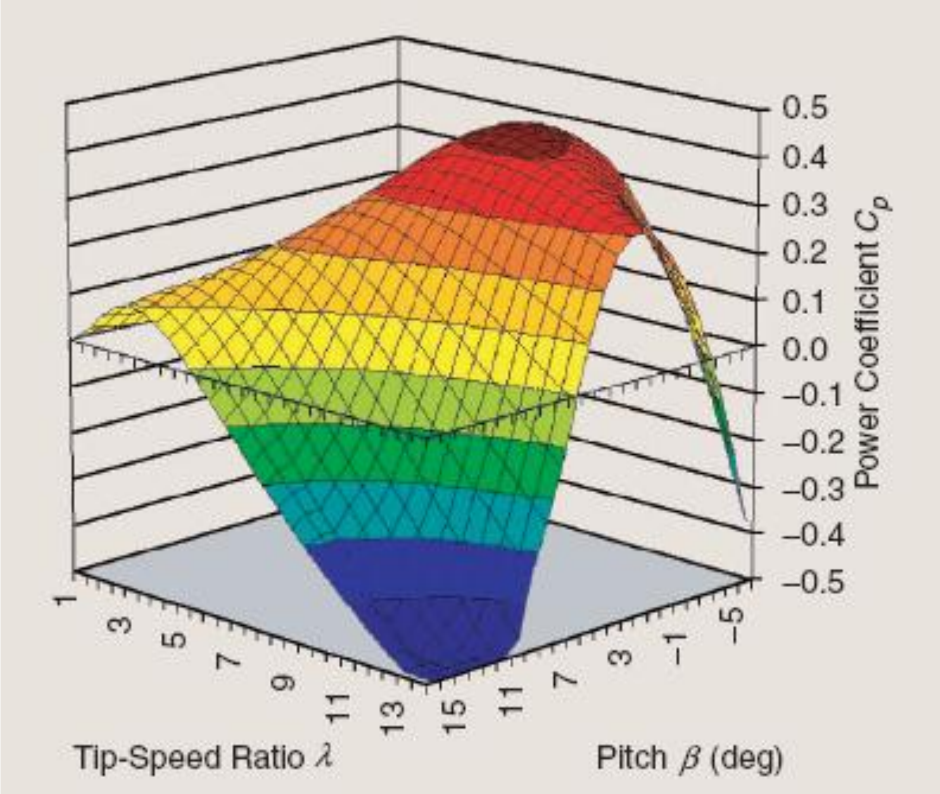
http://www.windpower.org/en/tour/grid/rein.htm

Power Coefficient C_p

The tip-speed ratio

$$\lambda = \omega R / v$$

$$C_p = f(\lambda, \beta)$$



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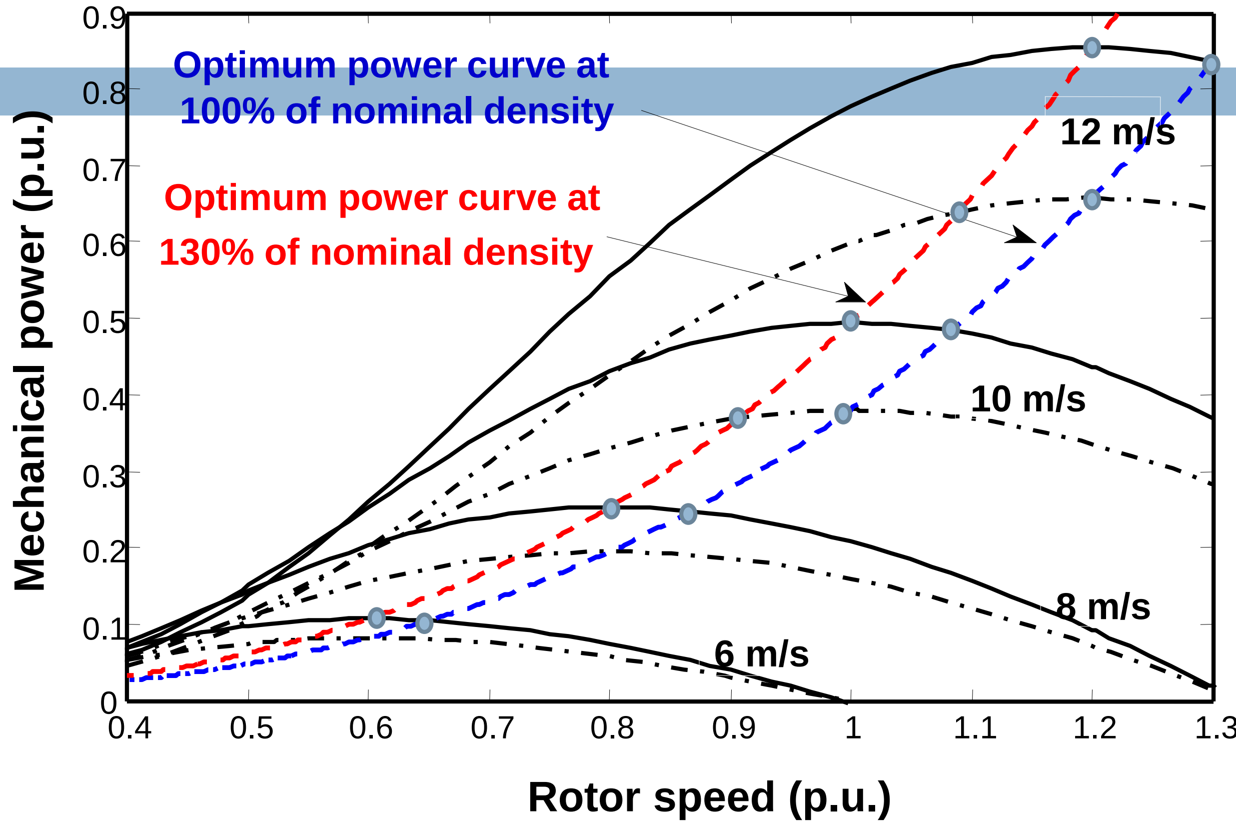
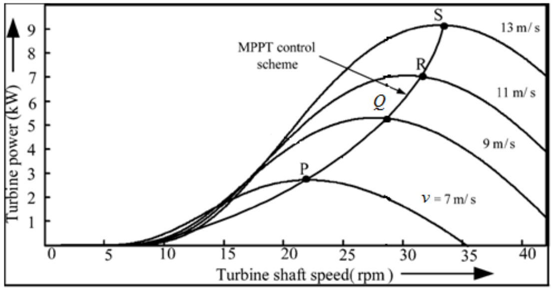

Optimum power curve at
100% of nominal density
Optimum power curve at
130% of nominal density
12 m/s
10 m/s
8 m/s
6 m/s
Mechanical power (p.u.)
Rotor speed (p.u.)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3


MPPT control
scheme
S
R
Q
P
13 m/s
11 m/s
9 m/s
v = 7 m/s
Turbine power (kW)
Turbine shaft speed(rpm)

Thank You

For Your Attention

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