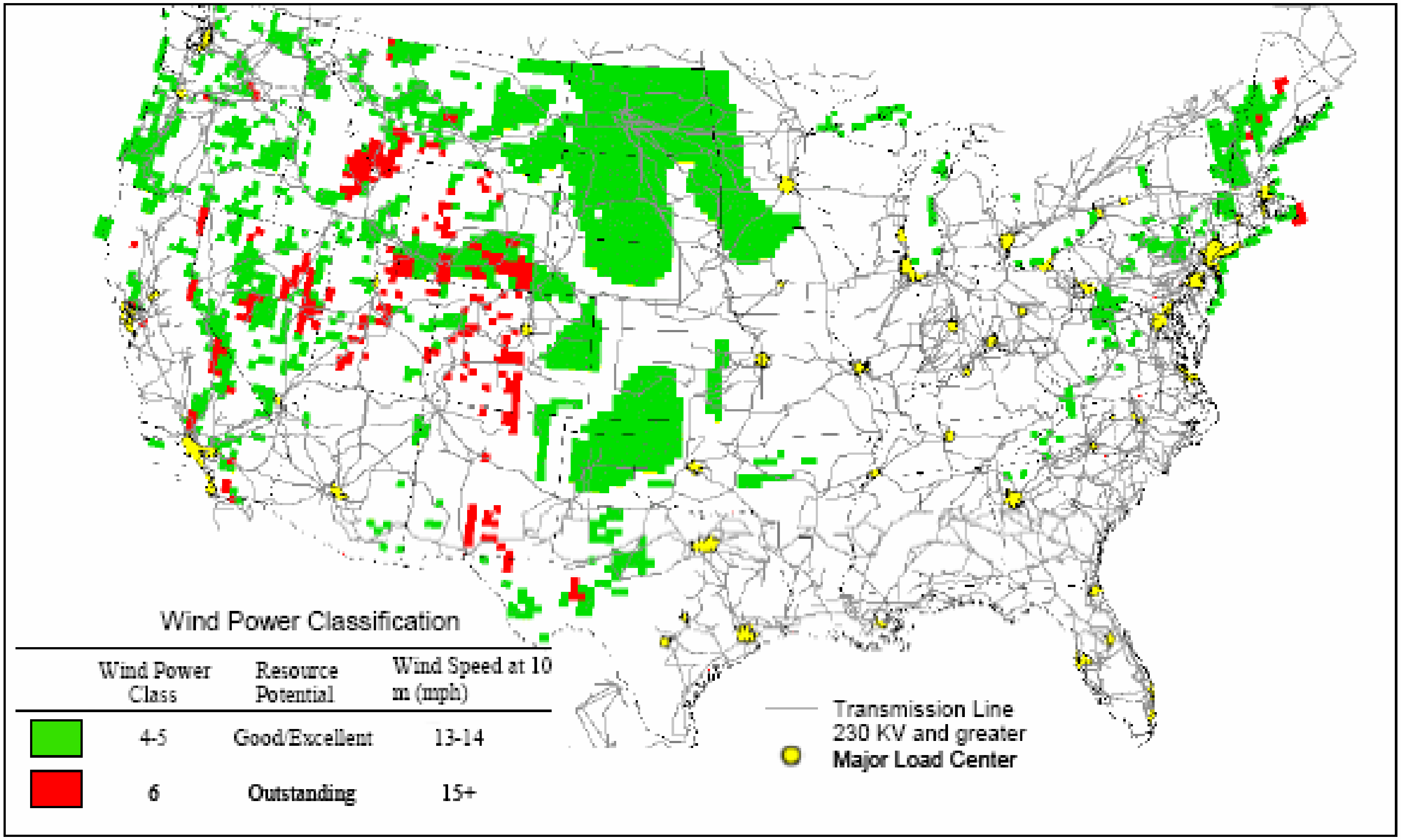
Low Speed Wind Turbines

Current Applications and
Technology Development

Why low wind speed turbines?

- Easily accessible prime class 6 sites are disappearing.
- Many class 6 sites are located in remote areas without easy access to transmission lines.
- Without advances in technology to make low wind speed sites more cost effective, wind energy may plateau in the near future.



On average, class 4 wind sites are 100 miles from a major load center compared to 500 miles for class 6 wind sites.

Available Wind Power

- The amount of energy that a wind turbine can produce is dependant on the wind regime where it is located and the efficiency with which it captures the wind.
- The wind regime is defined by three characteristics:
  - the average wind velocity,
  - the Weibull distribution of the wind velocity,
  - and the shear (and turbulence) of the wind at the turbine location.

Wind Classes and Power Density

Classes of wind power density at 10 m and 50 m [(a)].

Wind Power Class*	10 m (33 ft) Wind Power Density (W/m^2)	10 m (33 ft) Speed [(b)] m/s (mph)	50 m (164 ft) Wind Power Density (W/m^2)	50 m (164 ft) Speed [(b)] m/s (mph)
	0	0	0	0
1				
	100	4.4 (9.8)	200	5.6 (12.5)
2				
	150	5.1 (11.5)	300	6.4 (14.3)
3				
	200	5.6 (12.5)	400	7.0 (15.7)
4				
	250	6.0 (13.4)	500	7.5 (16.8)
5				
	300	6.4 (14.3)	600	8.0 (17.9)
6				
	400	7.0 (15.7)	800	8.8 (19.7)
7				
	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Rayleigh speed distribution of equivalent mean wind power density at sea level

Wind Turbine Power Capture

$$P = \eta_t \eta_g \frac{1}{2} \rho_a C_p V^3 \pi \frac{D^2}{4}$$

η_t = drivetrain eff.

η_g = generator eff.

ρ_a = air density

V = wind velocity

D = rotor diameter

C_p= power coeff. (max=0.59)

Economic Considerations

- Cost of Energy (COE) is largely based on capital cost rather than efficiency since the fuel is free.
- The cost of a wind turbine can be modeled by the weight of the components.
- The loads experienced by the turbine drive the section modulii of components, which drive the weight, which drive the cost.

Design and Economic Drivers

- The most important design drivers are:
  - Rated torque: $$Q_R = \frac{1}{16}\rho_a C_p \pi \frac{V_R^3}{V_T} D^3$$
  - Extreme thrust on the rotor: $$T_R = \frac{1}{8}\rho_a (0.85 * V_{EX})^2 C_D S \pi D^3$$
  - Weight of the blades and rotor.
  - Aerodynamic forces.
  - Fatigue.
  - Stiffness (avoiding natural frequencies).

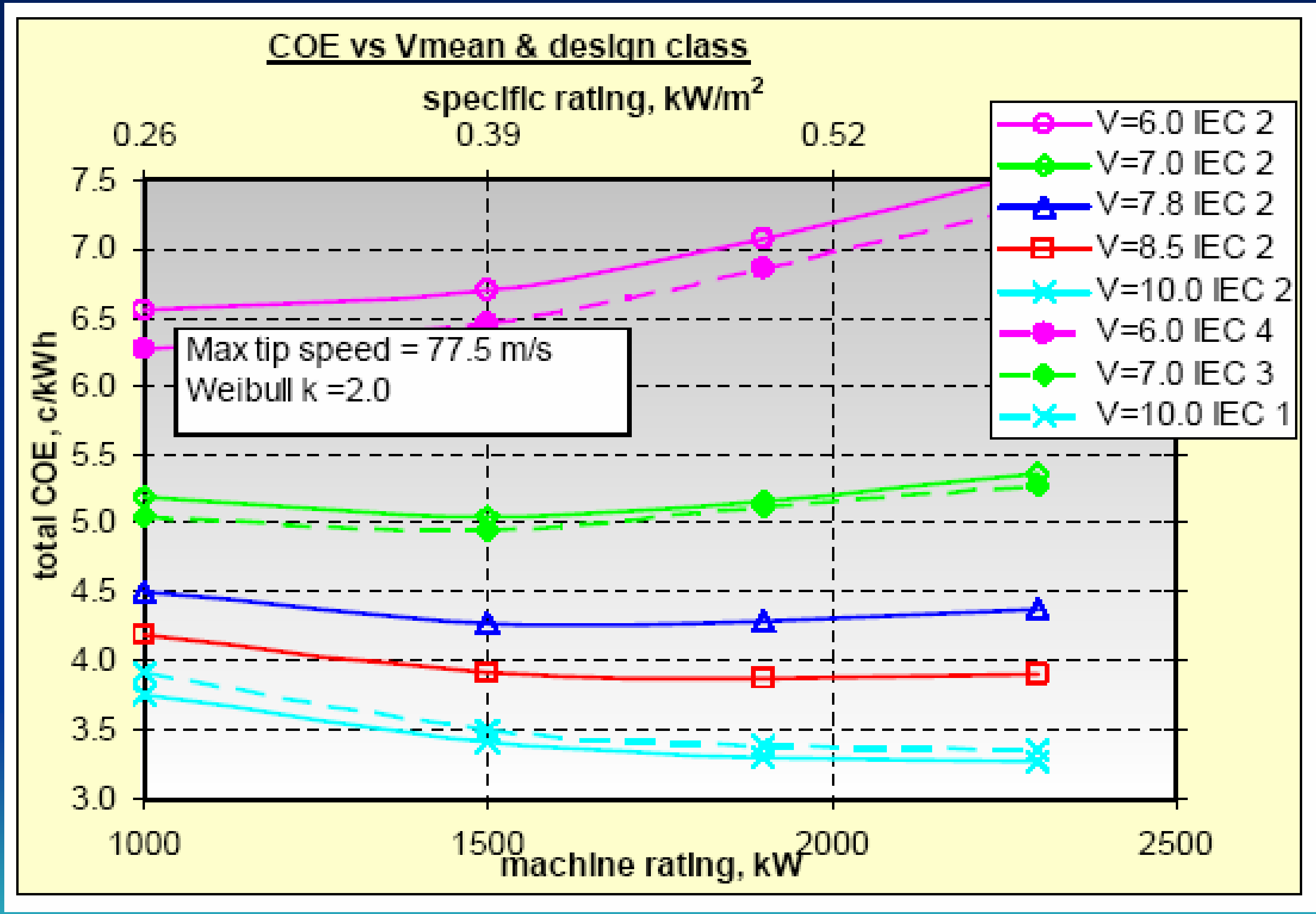
Specific Rating

- Specific Rating Definition:

$$\textit{Specific Rating} = \frac{\textit{Generator Rating}}{\textit{Rotor Swept Area}}$$

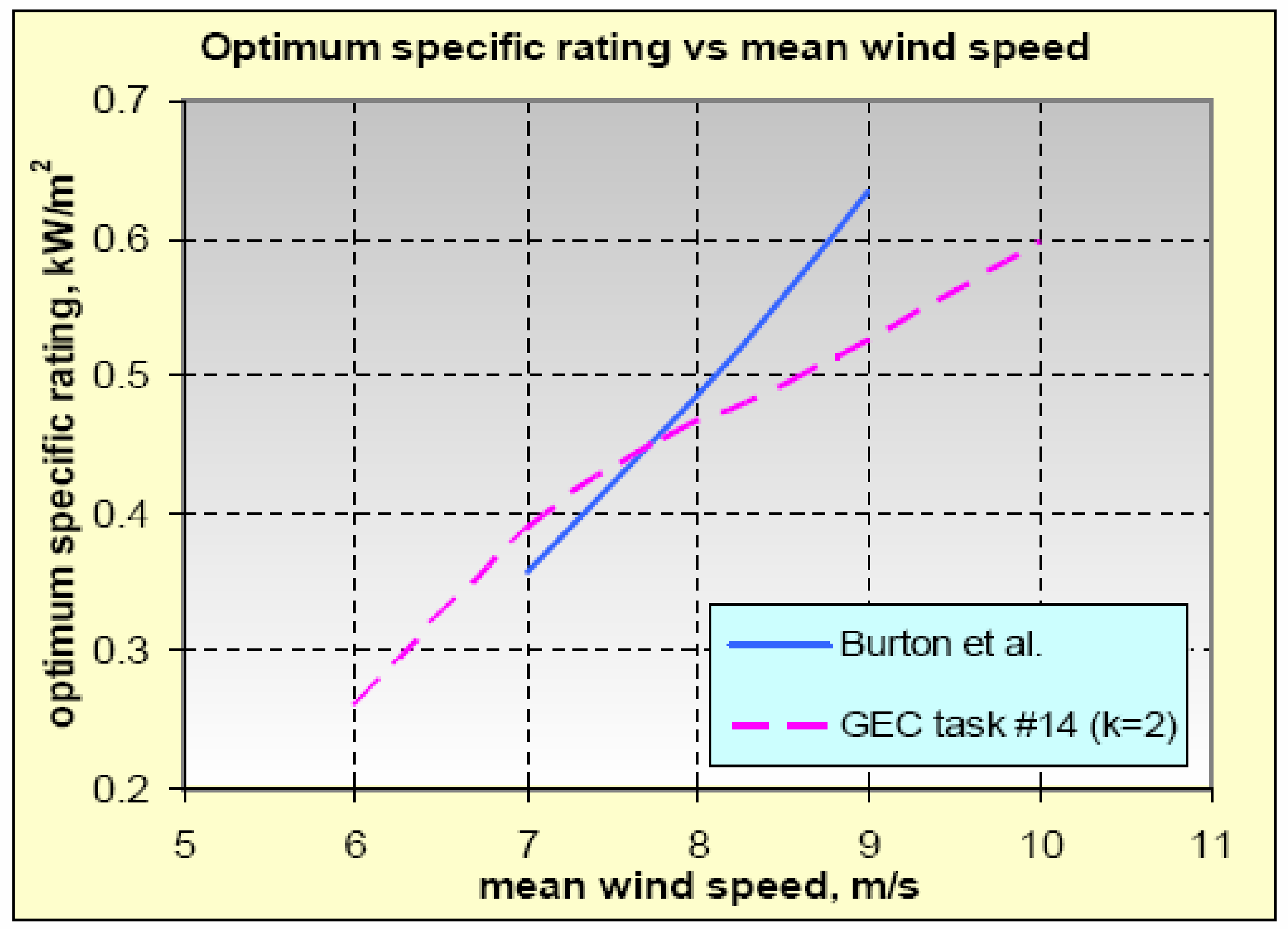
- The specific rating is the key parameter to tailor a turbine for a specific wind regime.
- Wind turbine cost models have been created by the NREL and others to find the specific rating for a given wind speed which provides the lowest COE.

Optimal Specific Rating vs. Ave. Wind Speed (NREL Study)

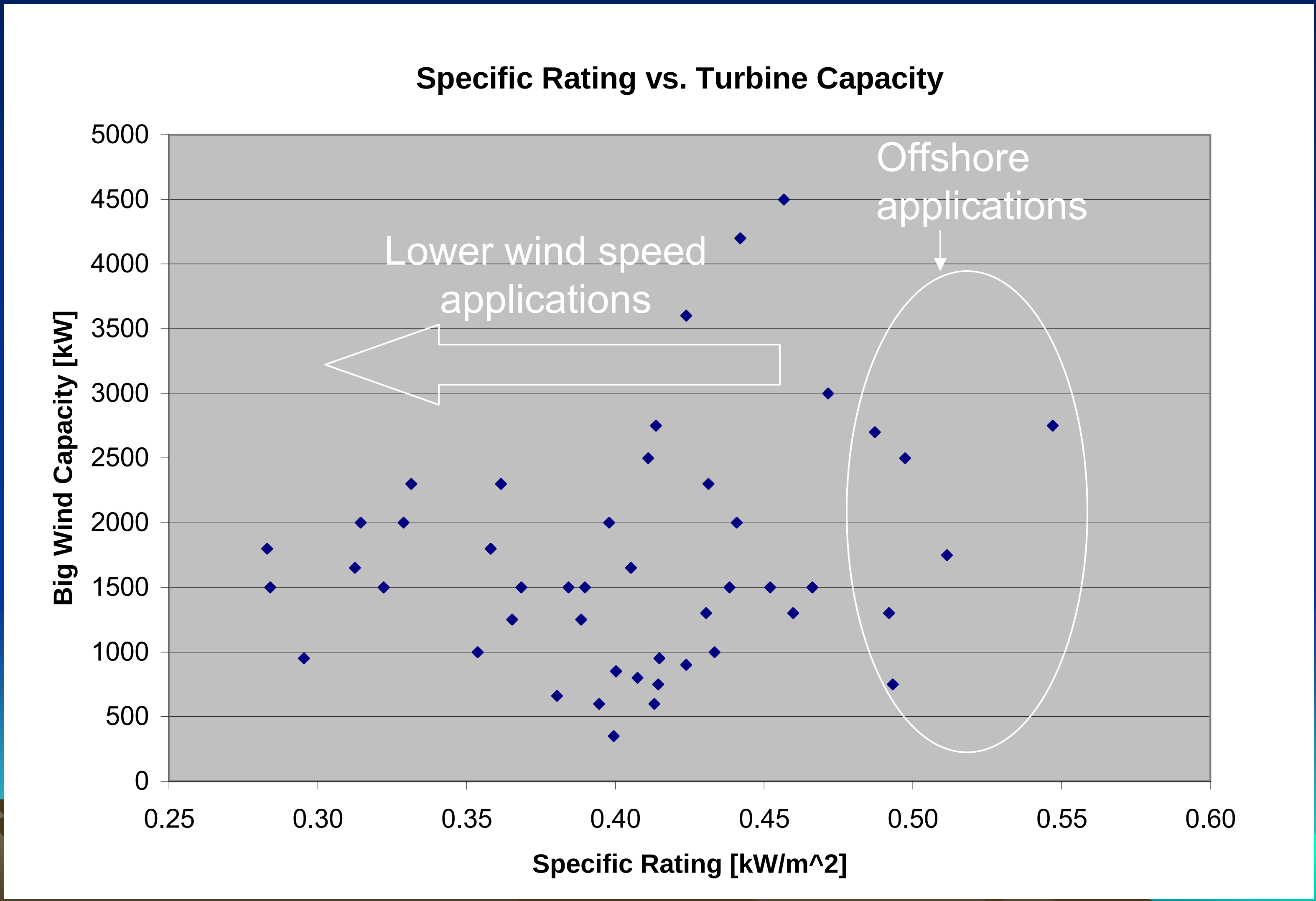


Study done for a 70 meter rotor with maintenance and replacement costs reflecting effects rotor diameter

Optimal Specific Rating vs. Average Wind Speed



Current Commercial Turbine Specific Ratings



Achieving a Lower Specific Rating

- Increasing the rotor diameter.
  - Advantages:

Increased diameter.	Greater energy capture.
Increased tower height. *(height = 1.3 * Rotor Diameter)*	Greater energy capture.
Operating at higher capacity in lower wind speeds.	Greater generator efficiency.
Lower Cut-in wind velocity.	Greater energy capture.

Achieving a Lower Specific Rating

- Disadvantages to a larger rotor:

Increased rotor diameter.	Increased rotor cost and weight.
Increased tower height. (*height = 1.3 * Rotor Diameter)*	Increased tower and foundation costs.
Increased rated torque.	Increased drivetrain component size and weight.
Increased extreme thrust.	Increased weights of bearings, bedplate tower and foundation.
Increased component size and cost.	Increased O&M and replacement costs.

Achieving a Lower Specific Rating

- Decreasing the generator capacity:
  - Advantages:

Smaller generator.	→	Decreased generator weight and cost.
Operating at higher capacity in lower wind speeds.	→	Greater generator efficiency.
Decreased tower head mass.	→	Decreased foundation and tower costs.
Decreased PE system rating.	→	Decreased PE system costs.

Achieving a Lower Specific Rating

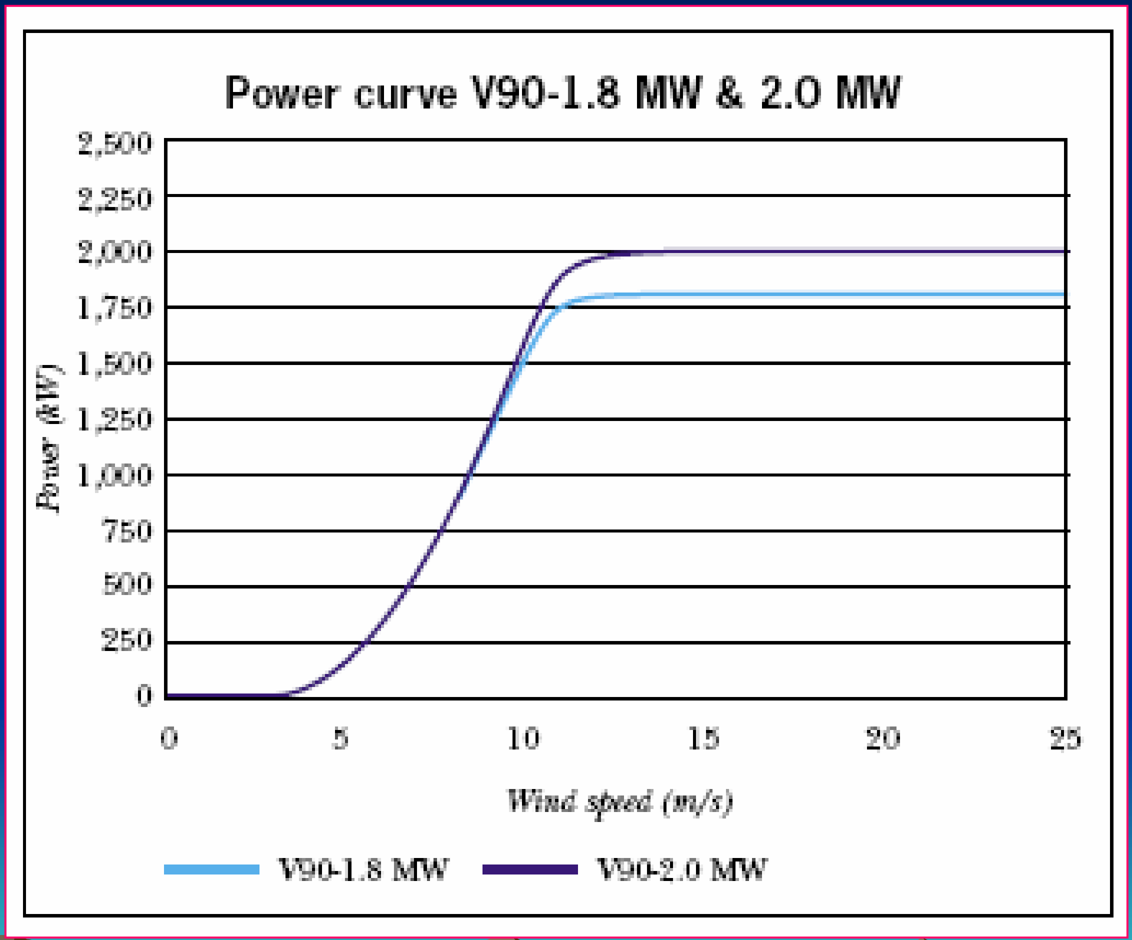
- Disadvantages to a smaller generator capacity:

Lower rated wind speed. → Lower energy capture.

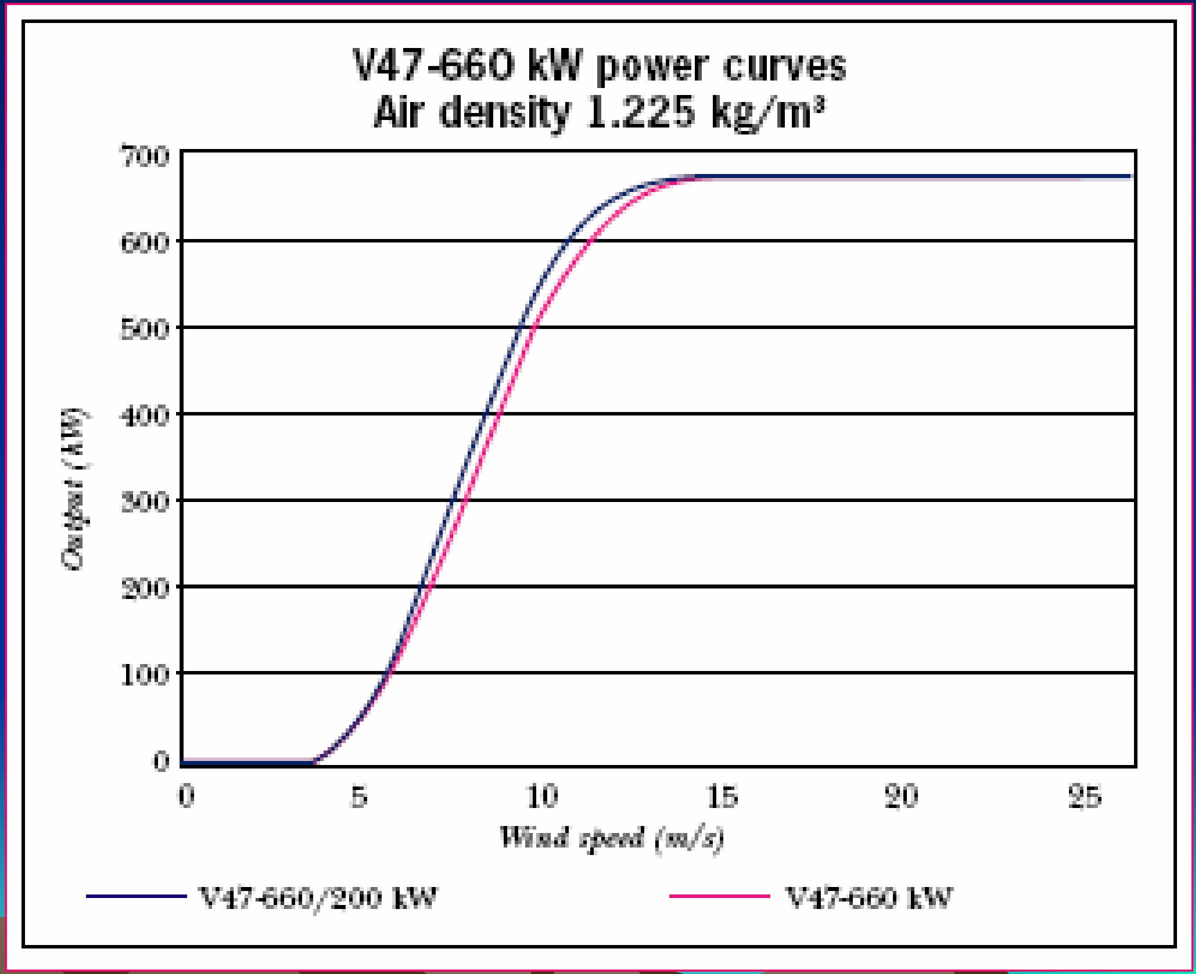
Specific Rating Options

- Most turbine manufactures offer multiple specific ratings for a turbine e.g.:
  - GE 1.5 and 2.X
  - NEG Micon NM72, NM82
  - Nordex N60/62, S70/77
  - Vestas V80, V90
- These turbines employ either multiple rotor sizes and/or multiple generator sizes for the same turbines.

Multiple Specific Rating Offerings



Multiple Generator Systems



Low Wind Speed Turbines

Research and Technology Development

DOE LWST Research Program

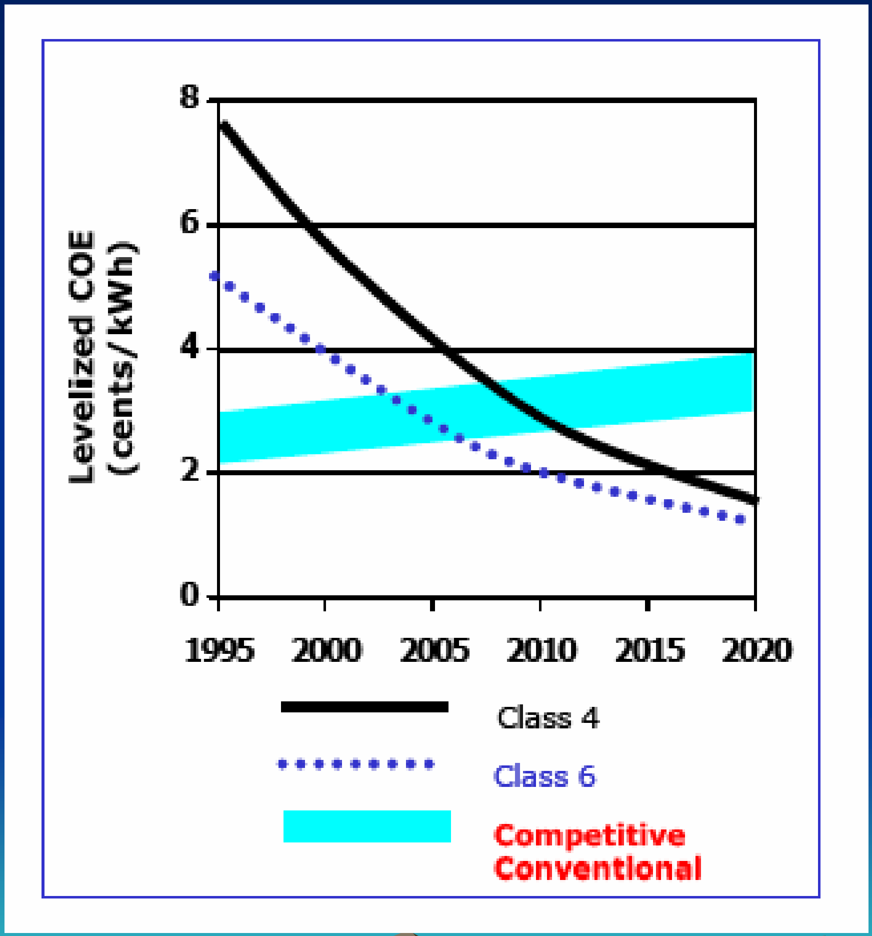
- Targeted sites are Class 4: 5.8 m/s measured at a 10-meter height.
- Targeting levelized cost of energy of 3¢/kWh by 2010.
- Work largely based on WindPACT Program:
  - The Wind Partnerships for Advanced Component Technology (WindPACT) was started in 1999 to been assist industry in lowering the cost of energy by designing and testing innovative components.
  - These components are expected to be primary constituents of the low-wind-speed turbine.

Current COE vs. Targeted COE

- Current COE (with favorable finance)
  - Class 6 sites: 4 ¢/kWh*
  - Class 4 sites: 5-6 ¢/kWh*
- Target COE
  - Class 6 sites: 3 ¢/kWh by 2004
  - Class 4 sites: 3 ¢/kWh by 2010

* 2002 prices w/o 1.7 ¢/kWh subsidy

DOE Targeted COE Reduction for Wind



How will COE be reduced?

- COE reductions will come from each turbine subsystem:
  - Advanced rotors and controls -15%±7%
  - Advanced drive train components -10%±7%
  - New tower concepts -2% ±5%
  - Better availability and reduced losses -5% ±3%
  - Manufacturing improvements -7% ±3%
  - Region and site tailored designs -5% ±2%

Advanced Materials and Rotor Designs

- Rotor costs represent ~15% of wind turbine initial capital costs (ICC)
- Current rotor blades are already pushing the envelope of manufacturing methods and materials.
- Rotor blade will use carbon fibers and fabrics to avoid cubic weight increase with diameter increase.
- Better manufacturing processes will improve mean material properties (e.g. fiber alignment, void reduction) without compromising stiffness.

Advanced Materials and Rotor Designs

- Lower solidity – will reduce weight, loads, and ultimately COE.
- Higher speeds – will reduce COE through load reduction.
- Longer blades – will capture more wind.
- Improvements to rotor blade manufacturing and materials coupled with decreased costs will benefit LWST blades greatly since they are necessarily larger than those of turbines in high wind speed regimes.

High Efficiency Drive Train Components

- With nacelle, the drive train components represent up to 40% of ICC of the wind turbine.
- Integrating low cost permanent magnet generators will reduce ICC.
- Reducing gearbox size and complexity will reduce ICC and O&M costs.

Electrical System

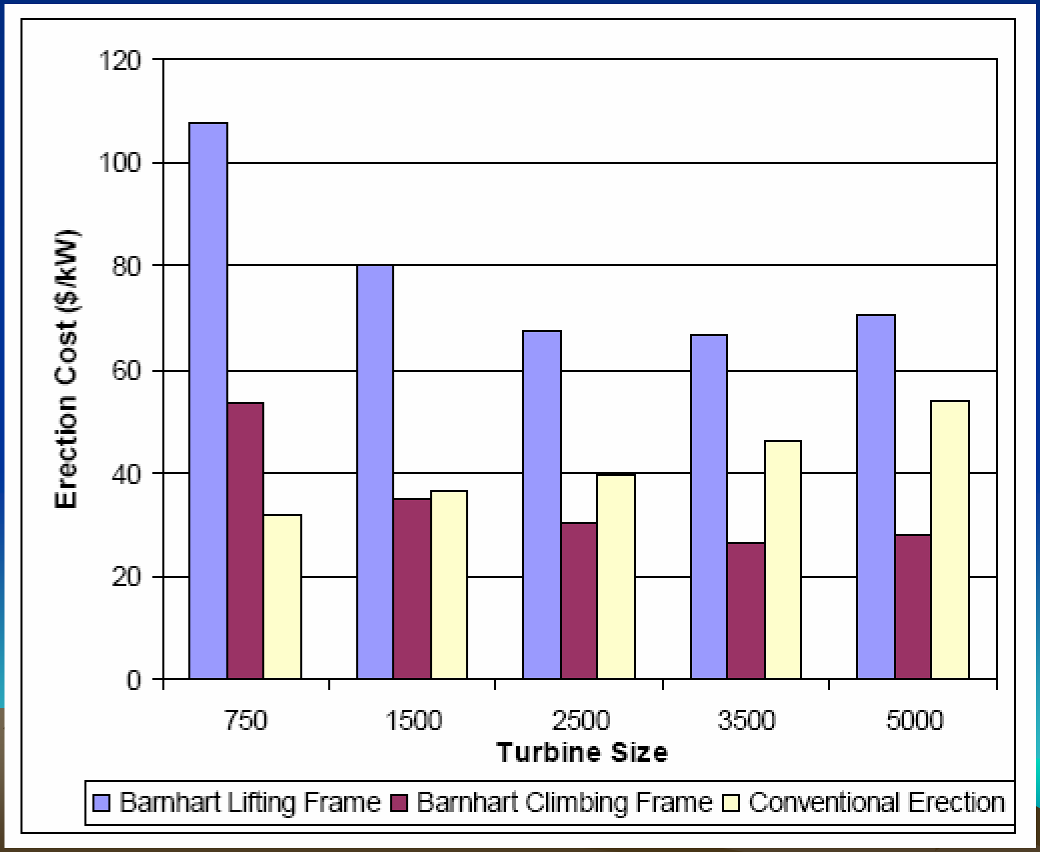
- The cost of power electronics has been on a decreasing trend in cost.
- Variable speed wind turbines use power electronics to convert a variable frequency generator output to a constant frequency.
- With reductions in power electronic costs, variable speed wind turbines will look more attractive compared to fixed speed wind turbines in terms of COE.

Tower Improvements

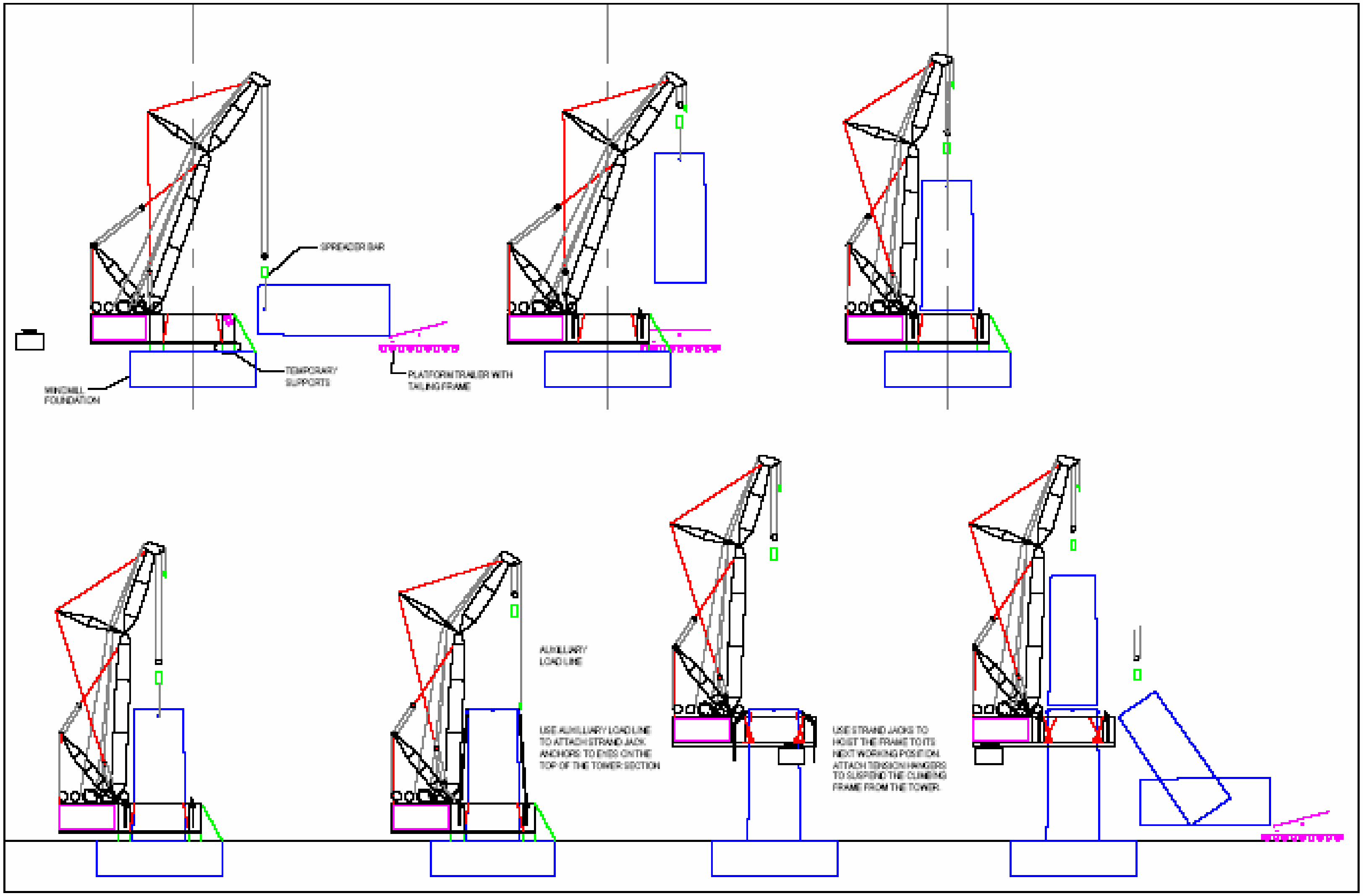
- Tower, foundation and installation represent ~15-20% of ICC.
- Self-erecting towers will avoid the use of large cranes and installation of crane pads.
- Tower motion feedback controls will provide load alleviation and will lower COE.
- Taller towers will enhance energy capture in low wind speed sites and high wind shear sites.

Self-Erecting Tower Concepts

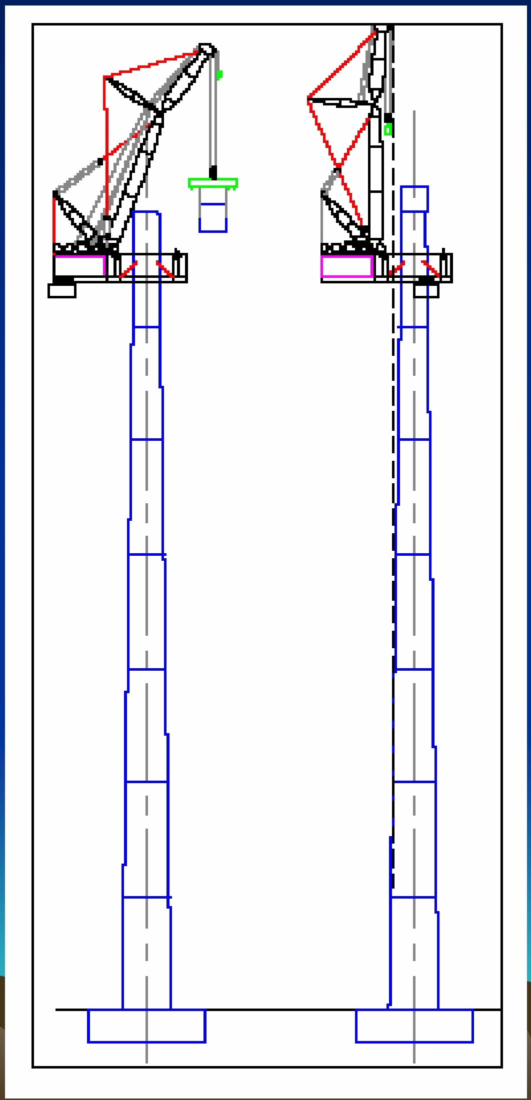
- The climbing frame concept was the only concept that reduced COE (for ≥1.5 MW)



Climbing Frame w/ Counterweight

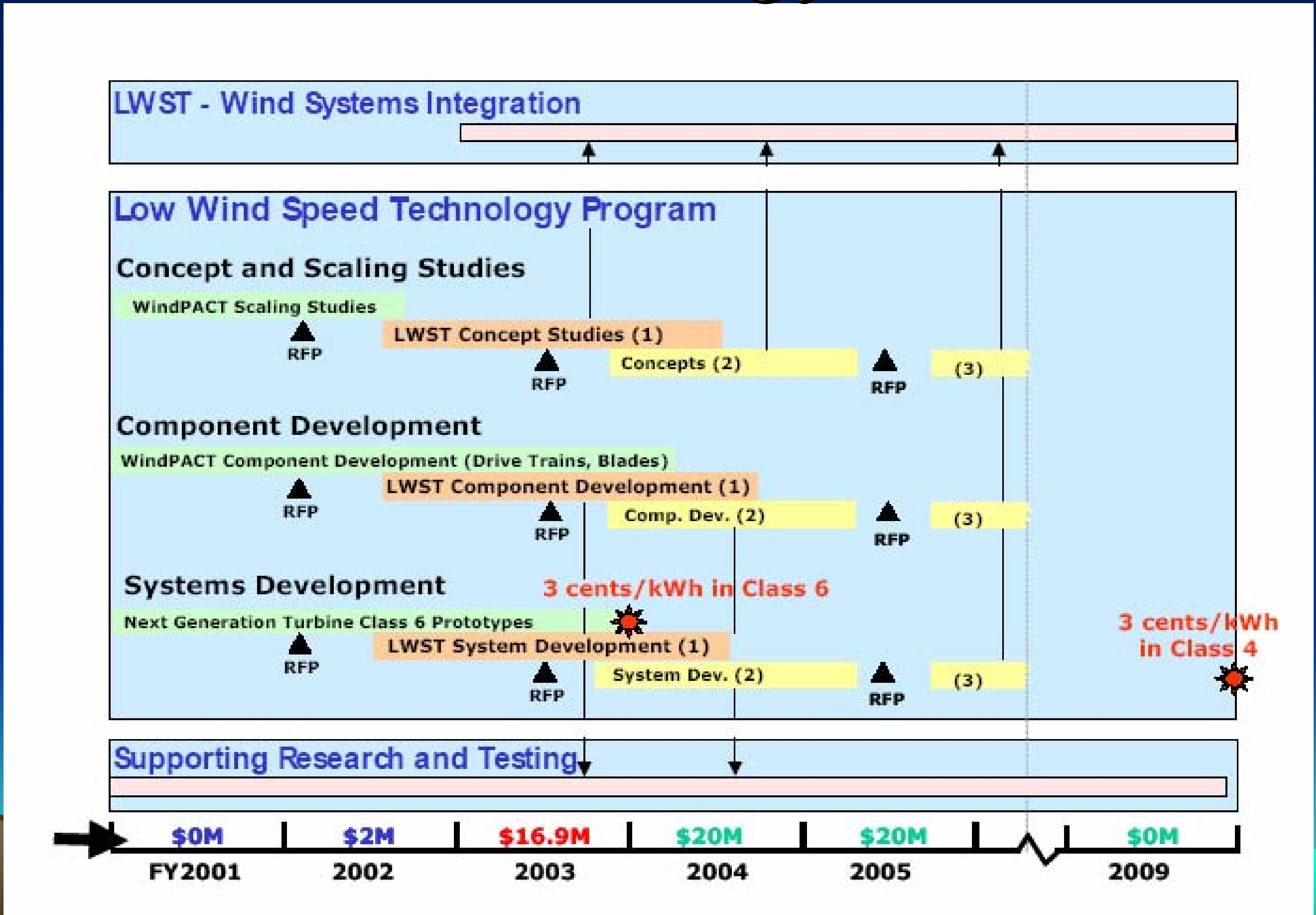


Climbing Frame w/ Counterweight



- Frame equipped with strand jacks to move frame up each section.
- Cables connected to a set of eyes at the top of each section.
- Moveable counterweight to balance boom and section loads.
- Can lift frame at 1 ft/min.

DOE Wind Energy Timeline



Drivetrain Concepts

- Baseline: Modular three-stage gearbox driving a wound-rotor induction generator using a PE system with a 1/3 rating of the generator
- Integrated baseline: An integrated version of the baseline drive train that uses a stressed-skin structural nacelle to eliminate the bedplate. (-5% COE reduction)
- Single PM: A single-stage gearbox drives a single PM synchronous generator. All of the generator's electrical output processed by PE system. (-13%)
- Multi-PM: A single-stage gearbox with multiple output shafts driving PM synchronous generators. All electrical output from the generators is processed, combined, and coupled to the utility grid by PE systems. (-11%)
- Multi-induction: A two-stage gearbox with multiple output shafts that drive a number of squirrel-cage induction generators. The electrical output from the generators is interfaced to the utility grid without a variable speed PE system. (-9%)

Self-Erecting Tower Concepts

- Investigated tower height impacts and design concepts:
  - Telescoping Tower
  - Tower-climbing devices
  - Jack-up devices
  - Lifting through secondary structures