NREL
NATIONAL RENEWABLE ENERGY LABORATORY

WindPACT – A Precursor to Wind System COE Modeling

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National Wind
Technology Center

Wind Energy Systems
Engineering Workshop

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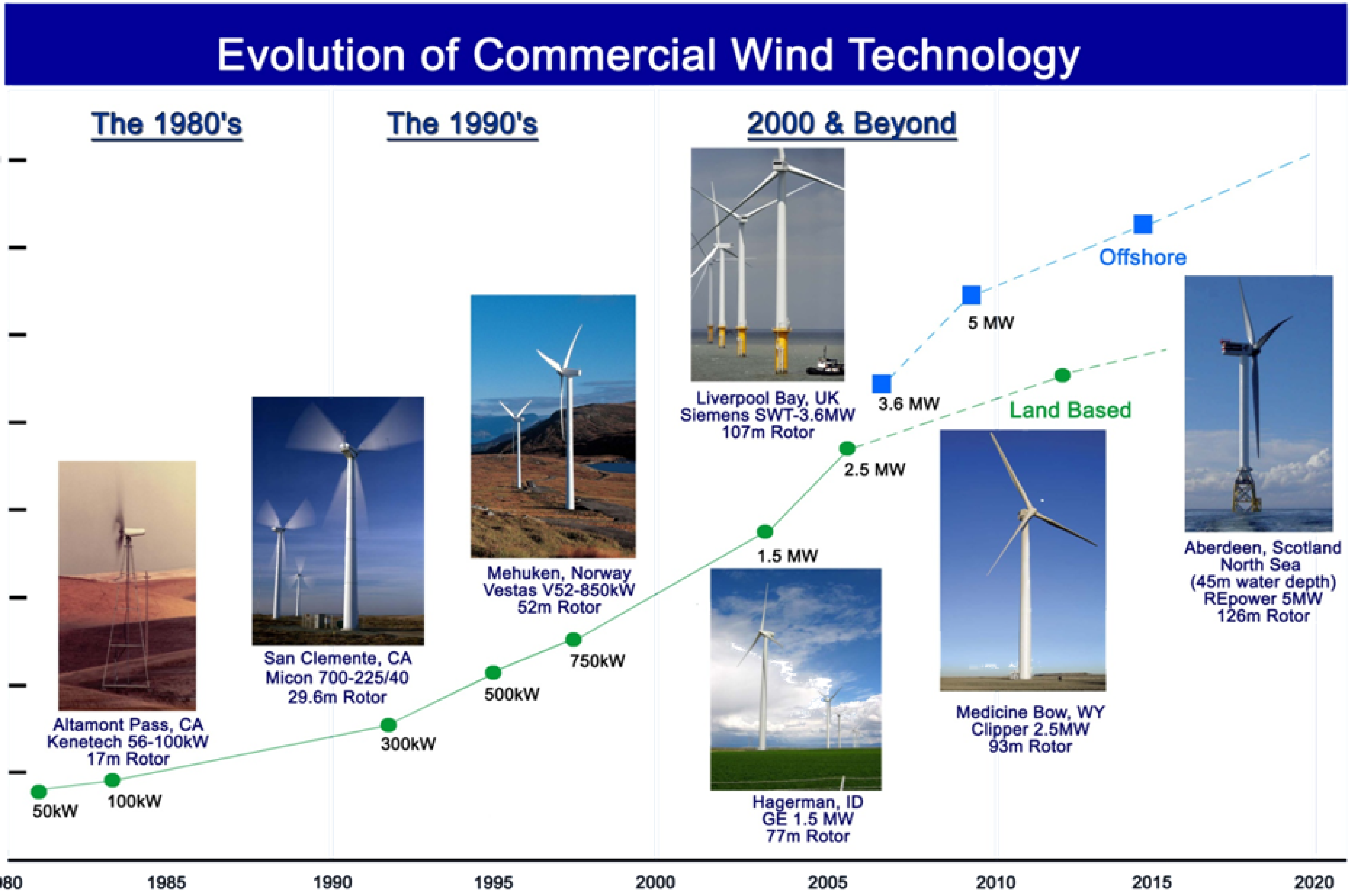
Technology Evolution



WindPACT Motivation

- Turbines growing in mid- to late-90s
  - 600 kW to 750 kW widely deployed
  - 1 MW to 2 MW planned/prototyped
- Motivation for turbine size increases
  - Land use, wind resource issues
  - Future offshore deployments
- Economies of scale observed
  - COE reduction with turbine size
  - Generality across machines, markets?

WindPACT Project Objectives

For next generation utility class turbines …

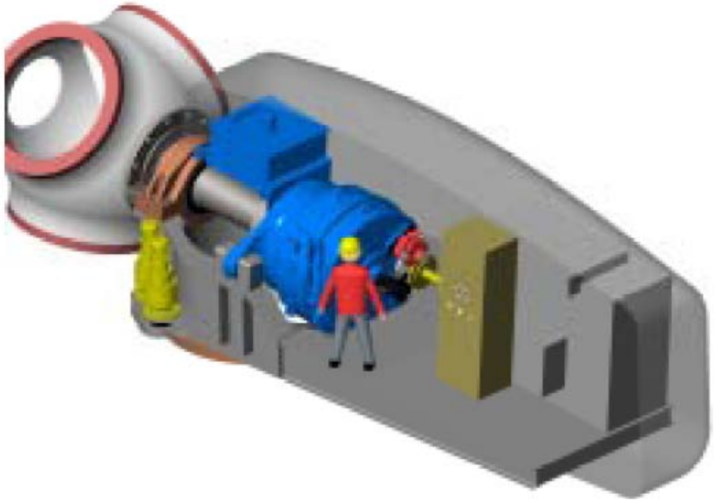
- Reduce COE via technology development
- Project likely wind turbine scale range
- Evaluate, exploit promising advanced concepts
- Identify and address technological roadblocks
- Design, build, test advanced components
- Nonconfidential and transparent
- Transfer technology from labs to industry

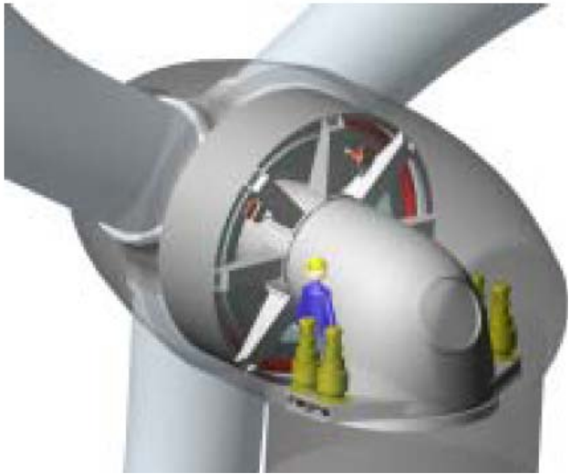
WindPACT Design Studies

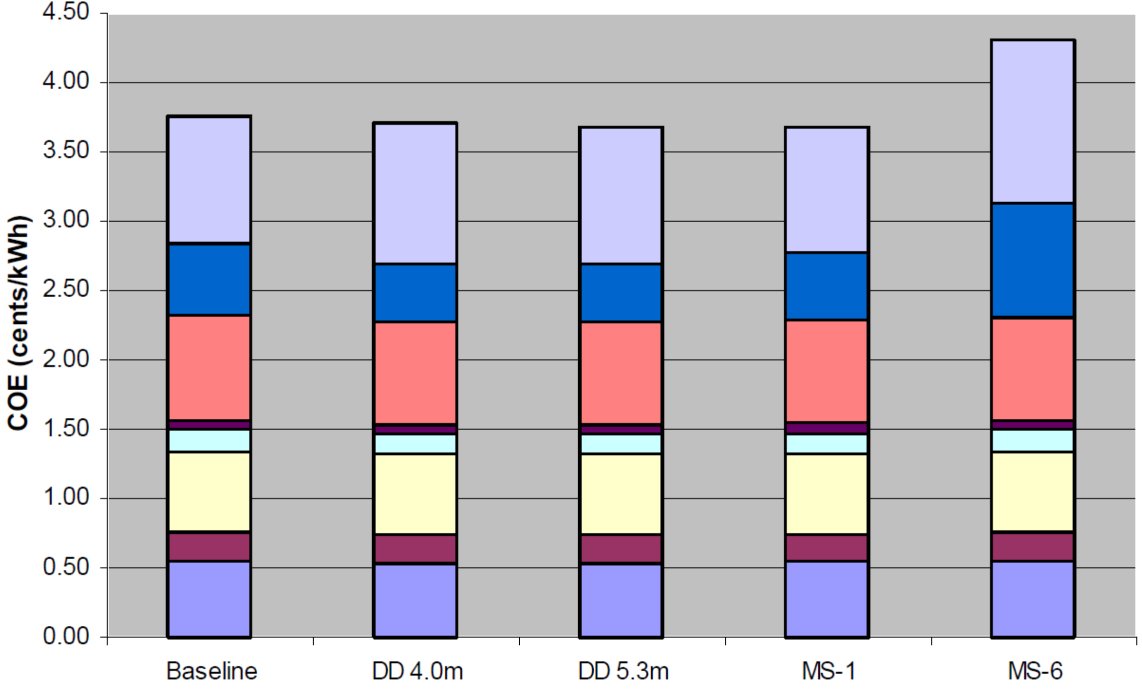
Multi-year WindPACT studies

- Drivetrain/PE studies and validation
- Turbine rotor design and rating study
- Composite blades for 80-120 m rotors
- Blade systems studies and validation
- Turbine rotor and blade logistics
- Self-erecting tower/nacelle feasibility
- Balance of station costs

Drive Train Alternative Design Study







WindPACT Drivetrain/PE

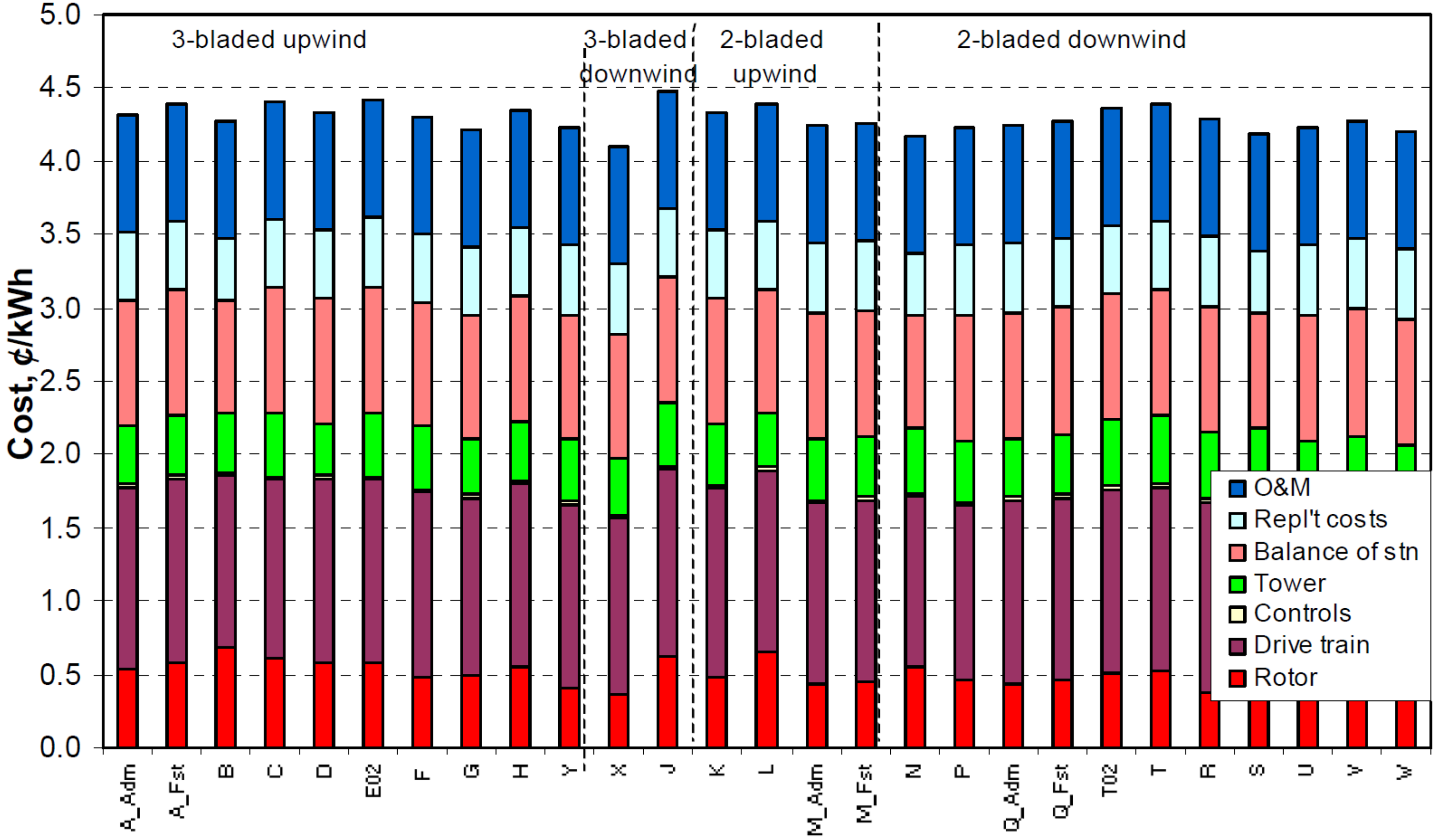
Northern Power Systems

- PMDD generator, integrated PE
- Published study report May 2004
- Completed dynamometer testing 2006

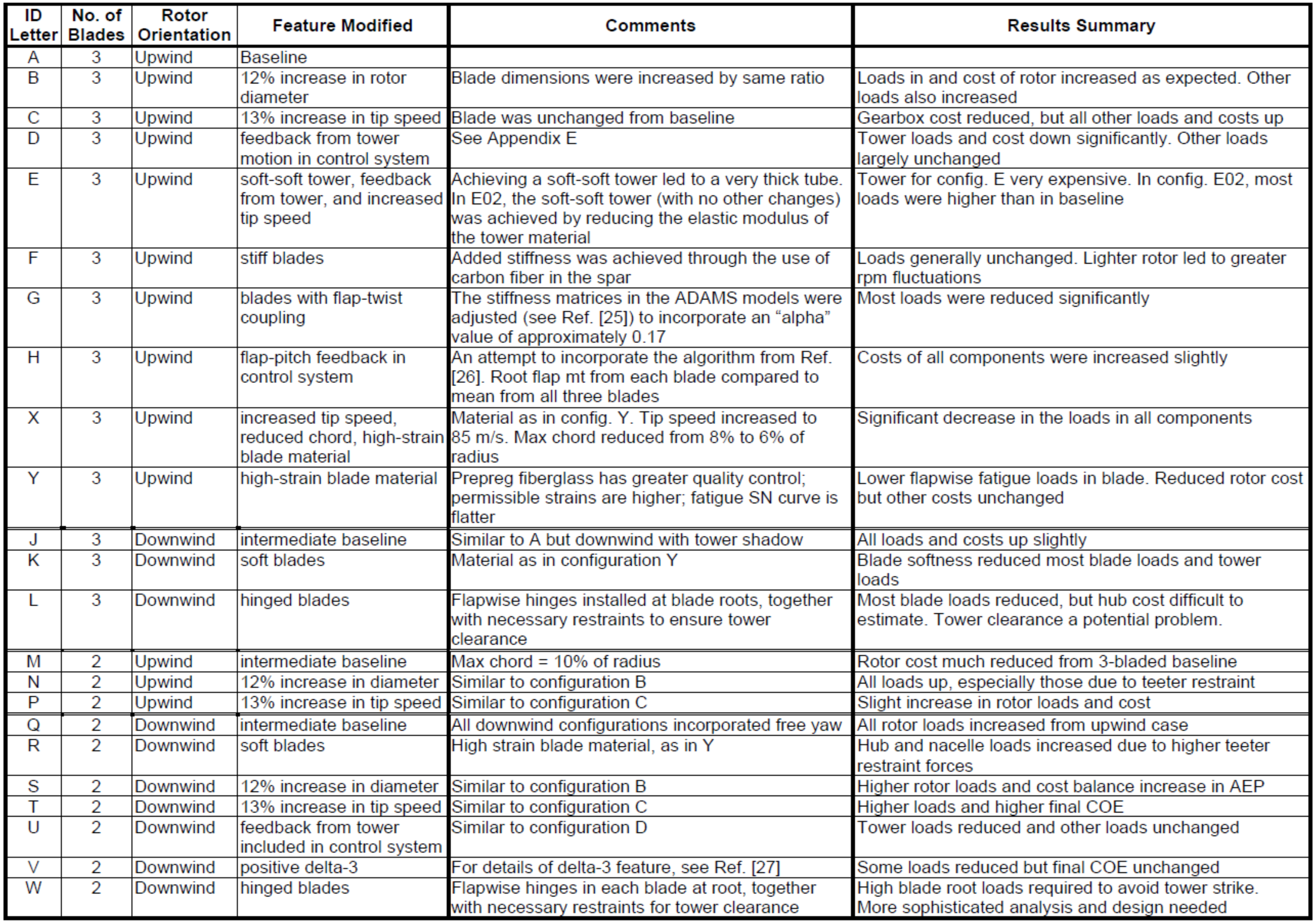
Global Energy Concepts

- Single stage gearbox, med speed generator
- Published study report August 2003
- Completed dynamometer testing 2008

WindPACT Rotor Design Study

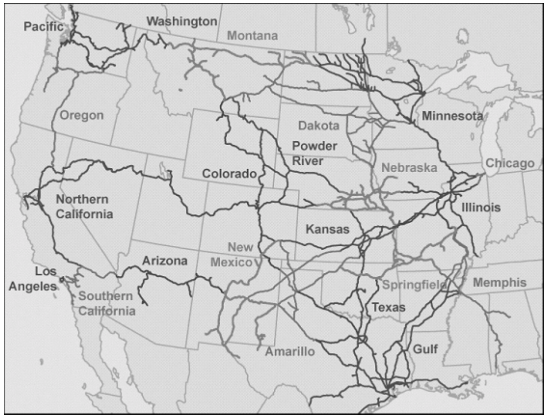


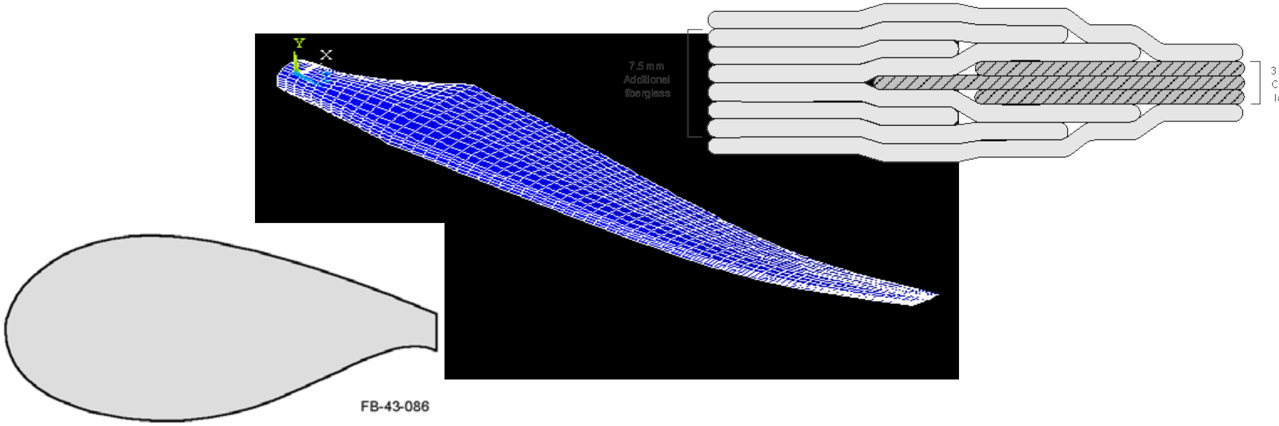
Rotor Design Study Configurations

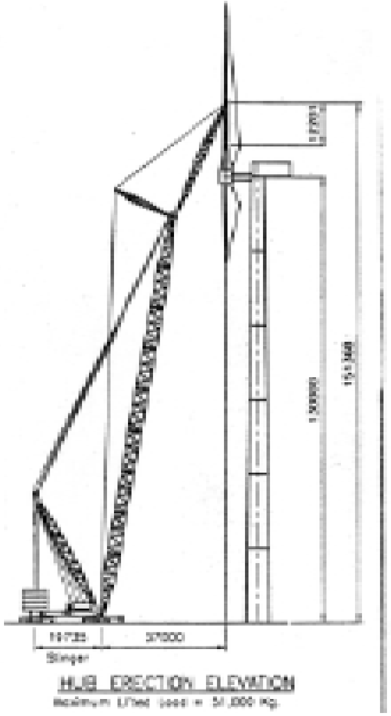


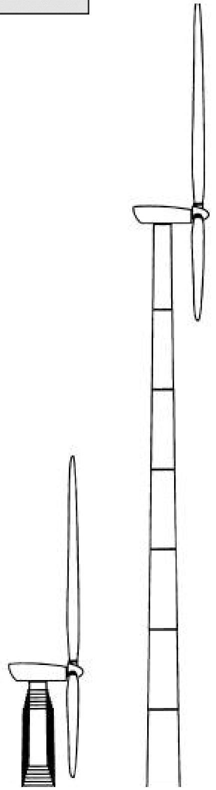
ID Letter	No. of Blades	Rotor Orientation	Feature Modified	Comments	Results Summary
A	3	Upwind	Baseline		
B	3	Upwind	12% increase in rotor diameter	Blade dimensions were increased by same ratio	Loads in and cost of rotor increased as expected. Other loads also increased
C	3	Upwind	13% increase in tip speed	Blade was unchanged from baseline	Gearbox cost reduced, but all other loads and costs up
D	3	Upwind	feedback from tower motion in control system	See Appendix E	Tower loads and cost down significantly. Other loads largely unchanged
E	3	Upwind	soft-soft tower, feedback from tower, and increased tip speed	Achieving a soft-soft tower led to a very thick tube. In E02, the soft-soft tower (with no other changes) was achieved by reducing the elastic modulus of the tower material	Tower for config. E very expensive. In config. E02, most loads were higher than in baseline
F	3	Upwind	stiff blades	Added stiffness was achieved through the use of carbon fiber in the spar	Loads generally unchanged. Lighter rotor led to greater rpm fluctuations
G	3	Upwind	blades with flap-twist coupling	The stiffness matrices in the ADAMS models were adjusted (see Ref. [25]) to incorporate an “alpha” value of approximately 0.17	Most loads were reduced significantly
H	3	Upwind	flap-pitch feedback in control system	An attempt to incorporate the algorithm from Ref. [26]. Root flap mt from each blade compared to mean from all three blades	Costs of all components were increased slightly
X	3	Upwind	increased tip speed, reduced chord, high-strain blade material	Material as in config. Y. Tip speed increased to 85 m/s. Max chord reduced from 8% to 6% of radius	Significant decrease in the loads in all components
Y	3	Upwind	high-strain blade material	Prepreg fiberglass has greater quality control; permissible strains are higher; fatigue SN curve is flatter	Lower flapwise fatigue loads in blade. Reduced rotor cost but other costs unchanged
J	3	Downwind	intermediate baseline	Similar to A but downwind with tower shadow	All loads and costs up slightly
K	3	Downwind	soft blades	Material as in configuration Y	Blade softness reduced most blade loads and tower loads
L	3	Downwind	hinged blades	Flapwise hinges installed at blade roots, together with necessary restraints to ensure tower clearance	Most blade loads reduced, but hub cost difficult to estimate. Tower clearance a potential problem.
M	2	Upwind	intermediate baseline	Max chord = 10% of radius	Rotor cost much reduced from 3-bladed baseline
N	2	Upwind	12% increase in diameter	Similar to configuration B	All loads up, especially those due to teeter restraint
P	2	Upwind	13% increase in tip speed	Similar to configuration C	Slight increase in rotor loads and cost
Q	2	Downwind	intermediate baseline	All downwind configurations incorporated free yaw	All rotor loads increased from upwind case
R	2	Downwind	soft blades	High strain blade material, as in Y	Hub and nacelle loads increased due to higher teeter restraint forces
S	2	Downwind	12% increase in diameter	Similar to configuration B	Higher rotor loads and cost balance increase in AEP
T	2	Downwind	13% increase in tip speed	Similar to configuration C	Higher loads and higher final COE
U	2	Downwind	feedback from tower included in control system	Similar to configuration D	Tower loads reduced and other loads unchanged
V	2	Downwind	positive delta-3	For details of delta-3 feature, see Ref. [27]	Some loads reduced but final COE unchanged
W	2	Downwind	hinged blades	Flapwise hinges in each blade at root, together with necessary restraints for tower clearance	High blade root loads required to avoid tower strike. More sophisticated analysis and design needed

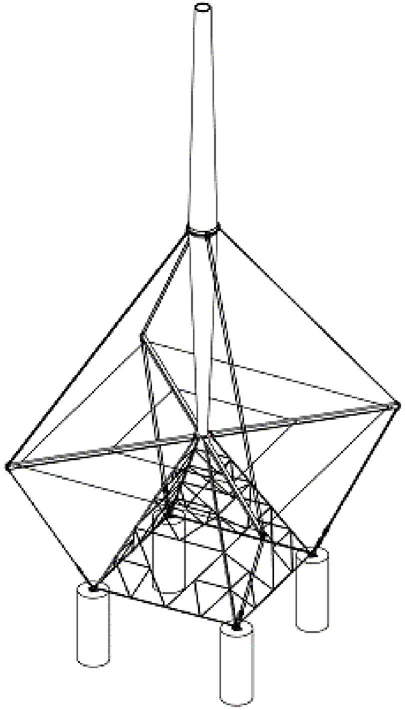
Other WindPACT Design Studies

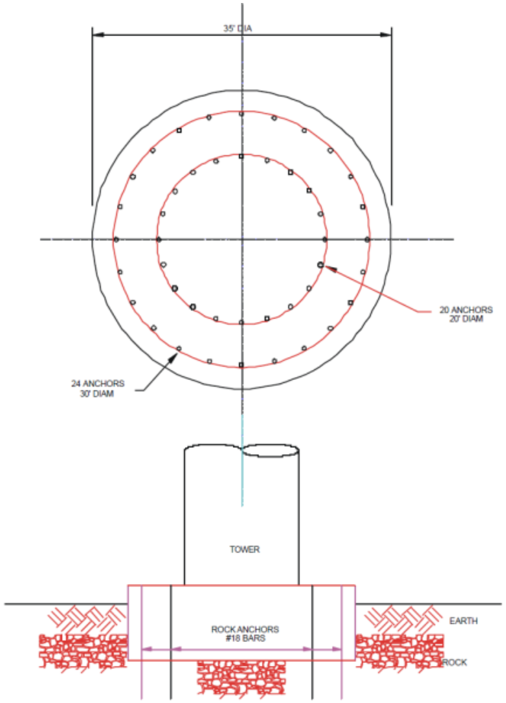






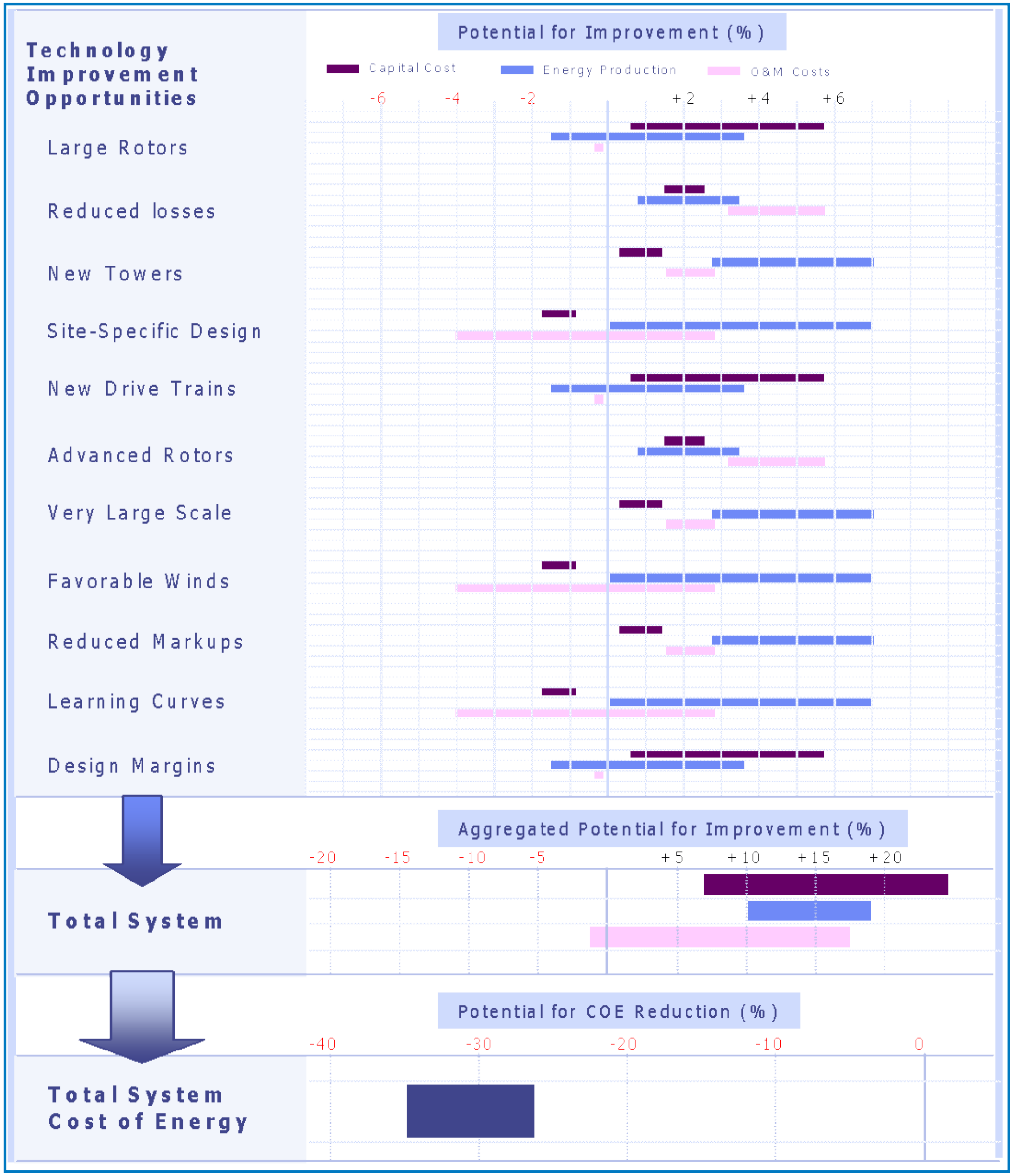






Technology Improvement Opportunities

- COE drivers
  - – Design
  - – Manufacture
  - – Deployment
  - – Operation



TIO Applications

- Pathways Analysis (Schweizer & Cohen)
  - Probabilistic input distributions
  - Correlations between TIOs not explicit
  - Probabilistic system COE distributions
- Annual Turbine Technology Update (ATTU)
  - Detailed subcontractor input data
  - Correlations between TIOs not exhaustive
  - Subcontract and project COE values
- No global systems engineering model

Questions?

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