Wind Energy: State-of-the Art and Future Trends

Southwest Renewable Energy Conference

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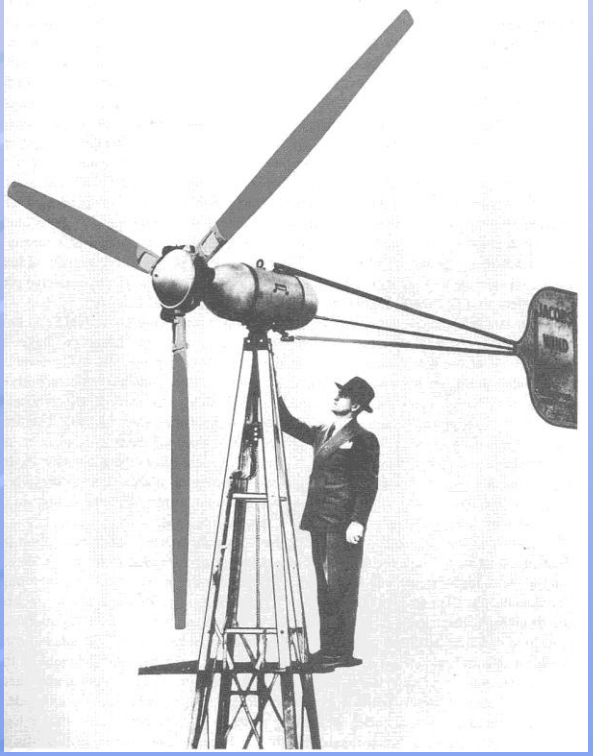
Overview

- Recent History
- Wind Turbines Today
- Economics and Wind Energy Development
- Future Trends

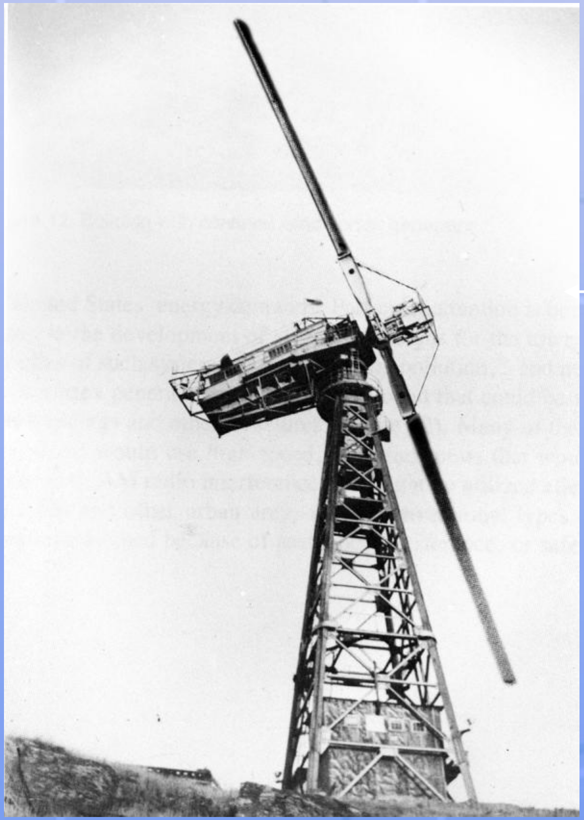
Historically Important Small Wind Turbines

Traditional Water Pumping Windmill



Jacob's Wind Generator, 1930's

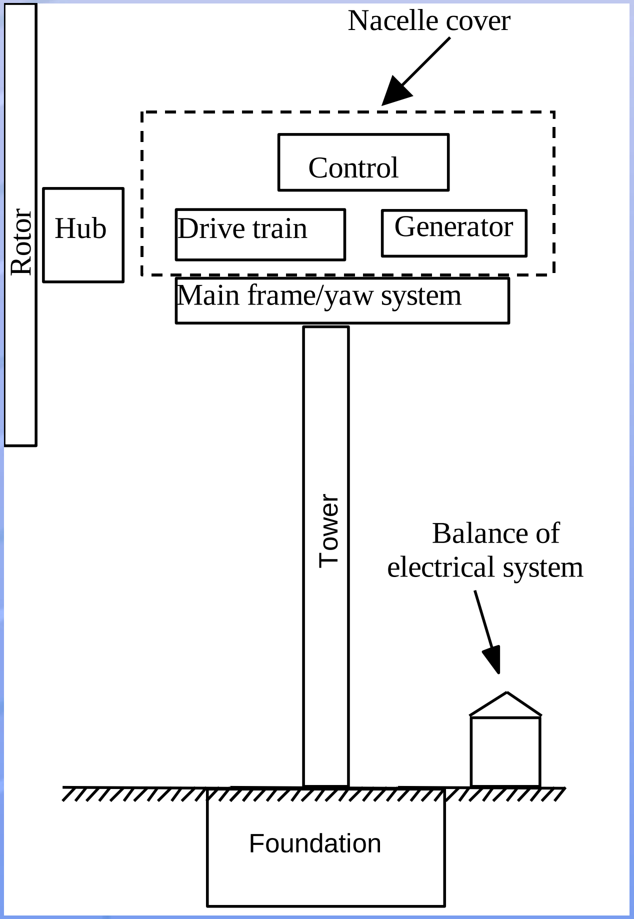
Historically Important Large Wind Turbines



Smith-Putnam, VT, 1940's

Gedser, Denmark, 1950's

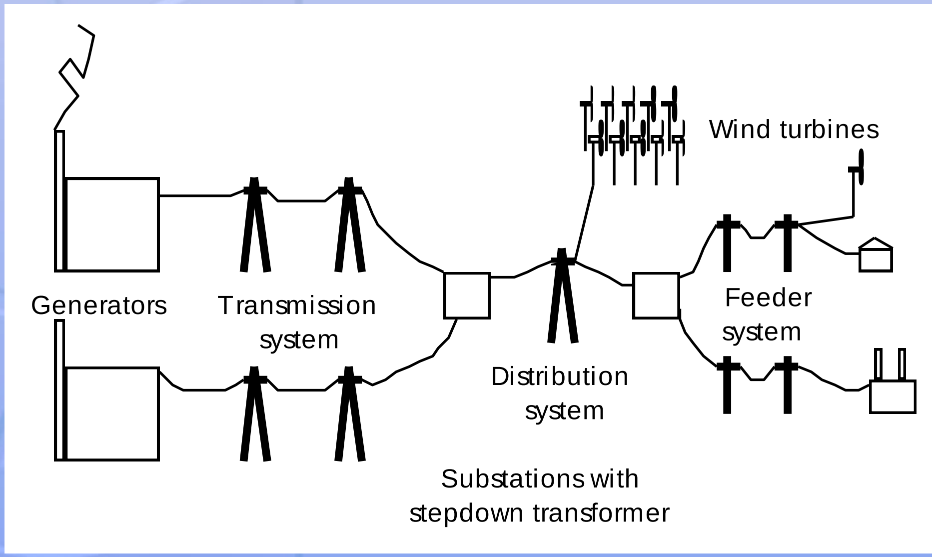
Modern Wind Turbine



Hull, MA 2003

Wind Farm

Palm Springs, CA, 2001

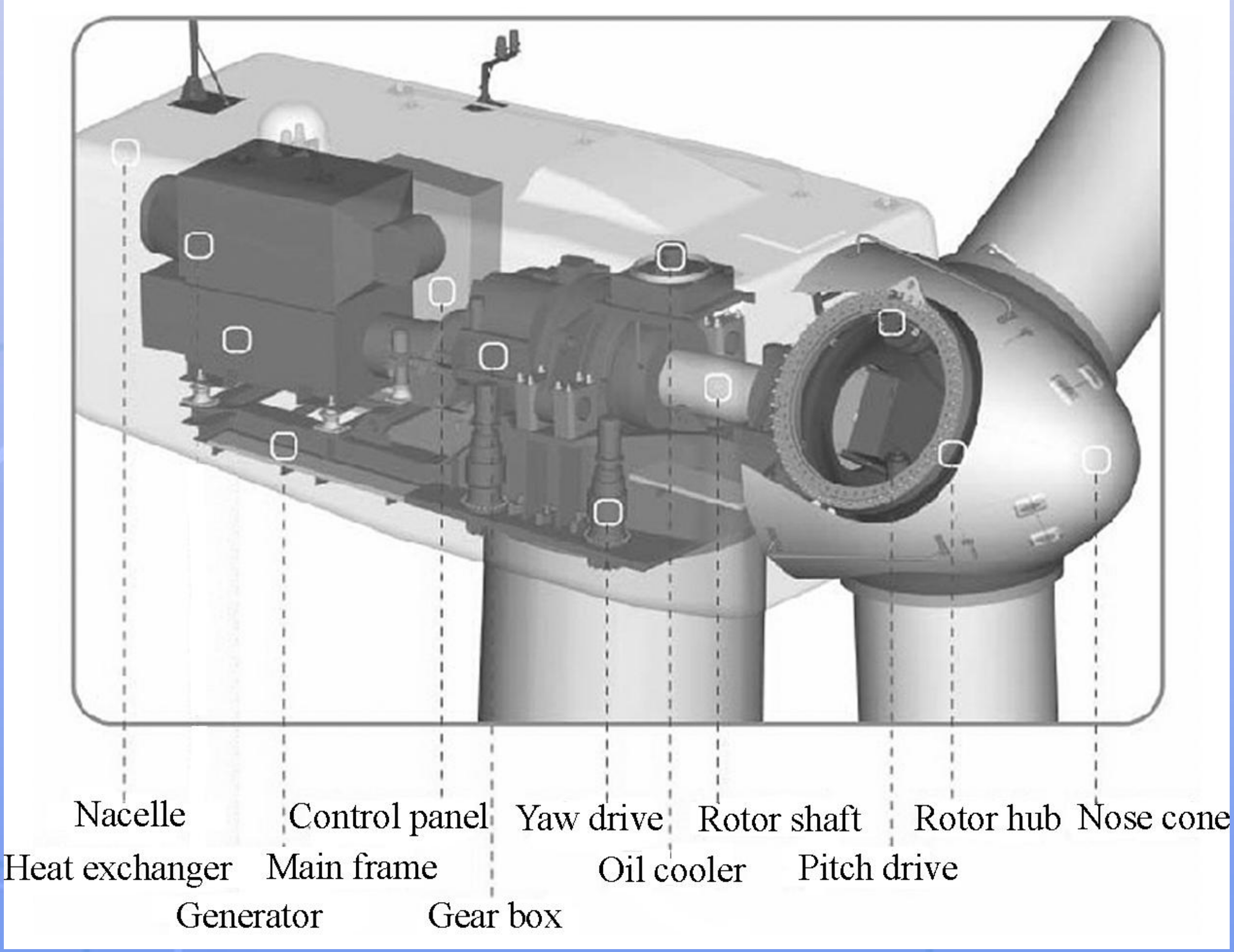


Utility Grid with Wind Farm

Wind Turbine Topology Options

- **Axis orientation**: Horizontal/Vertical
- **Power control**: Stall/Variable Pitch/Controllable Aerodynamic Surfaces/Yaw Control
- **Yaw Orientation**: Driven Yaw/Free Yaw/Fixed Yaw
- Rotor Position: Upwind of Tower/Downwind of Tower
- **Type of Hub**: Rigid/Teetered/Hinged blades/Gimbaled
- Design Tip Speed Ratio
- **Solidity** (Relative Blade Area)
- **Number of Blades**: One, Two, Three
- **Rotor Speed**: Constant/Variable

Turbine Components

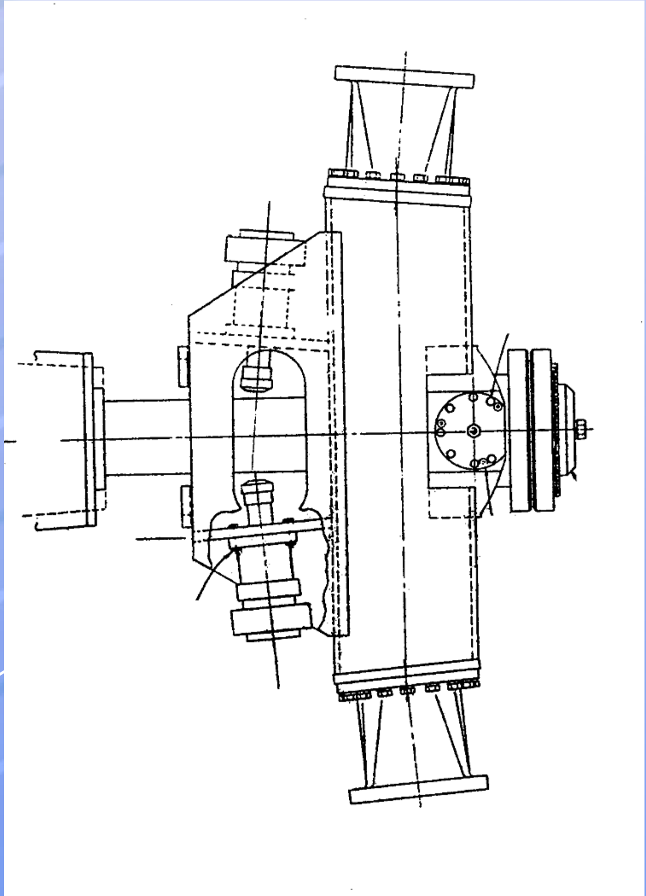


Wind Turbine Subsystems and Components

- Rotor
- Drive Train
- Yaw System
- Main Frame
- Tower
- Control System

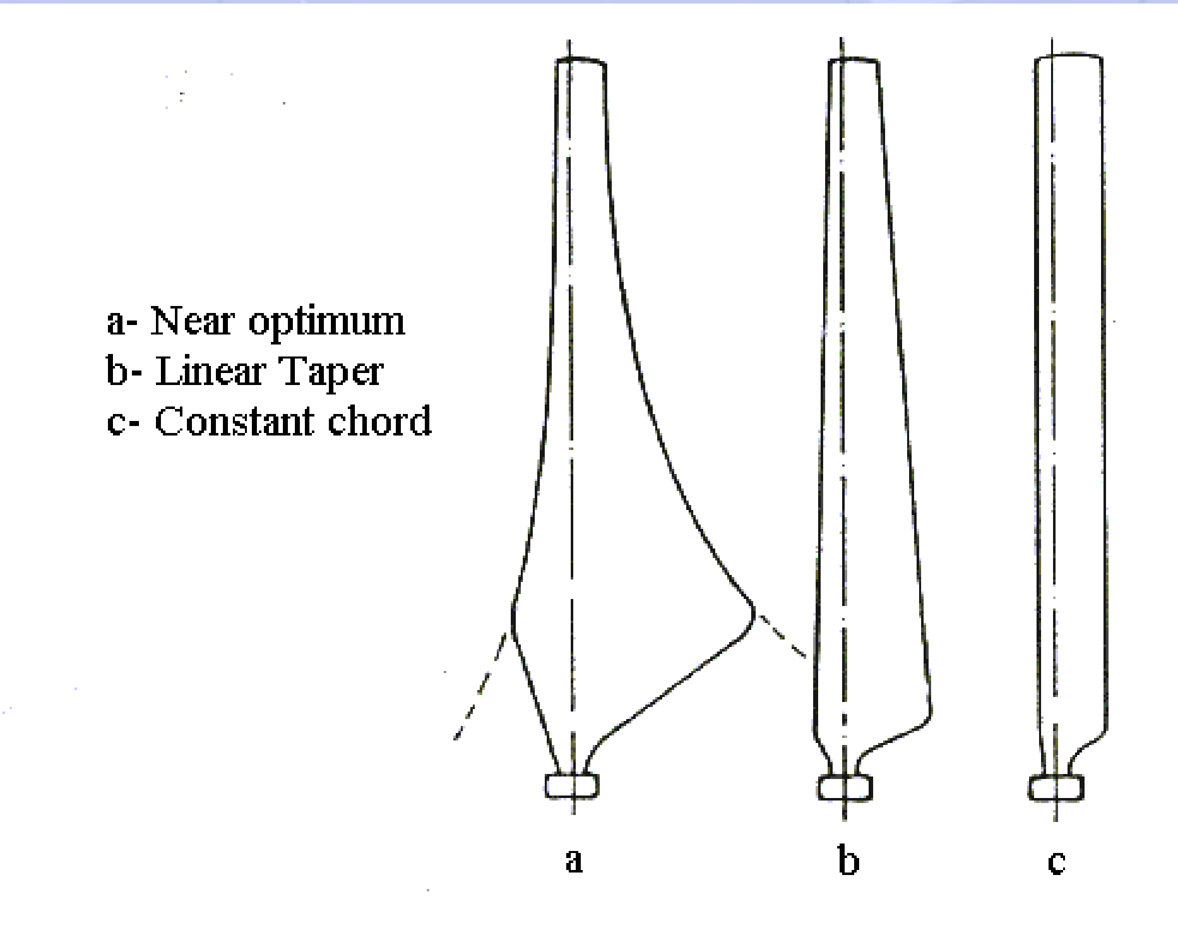
Rotor: Hub

- Hub connects the blades to the main shaft
- Usually made of steel
- Types
  - Rigid
  - Teetered
  - Hinged



Hub of 2 Blade Turbine

Blades



Some Planform Options

Drive Train: Main Shaft

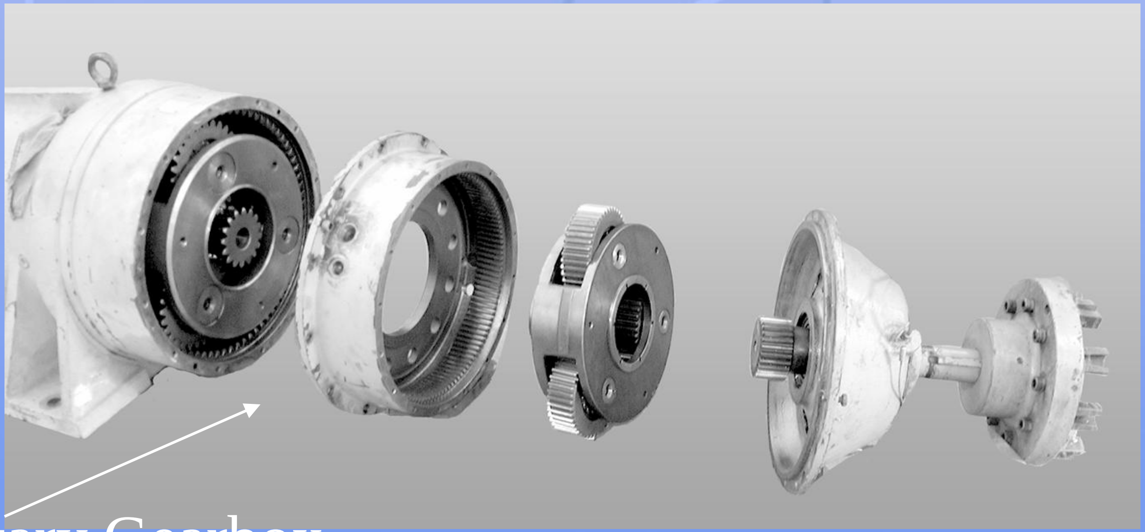
- Main Shaft is principal rotating element, transfers torque from the rotor to the rest of the drive train.
- Usually supports weight of hub
- Made of steel

Drive Train

- Generator
  - Converts mechanical power to electricity
- Couplings
  - Used to Connect Shafts, e.g. Gearbox High Speed Shaft to Generator Shaft

Drive Train: Gearbox

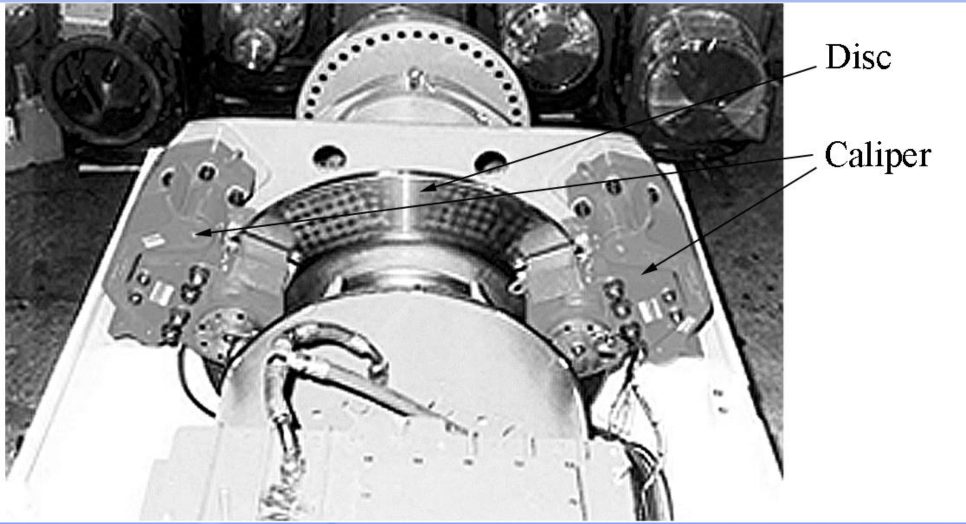
- Gearbox increases the speed of generator input shaft
- Main components: Case, Gears, Bearings
- Types: i) Parallel Shaft, ii) Planetary



Typical Planetary Gearbox (exploded view)

Drive Train: Mechanical Brake

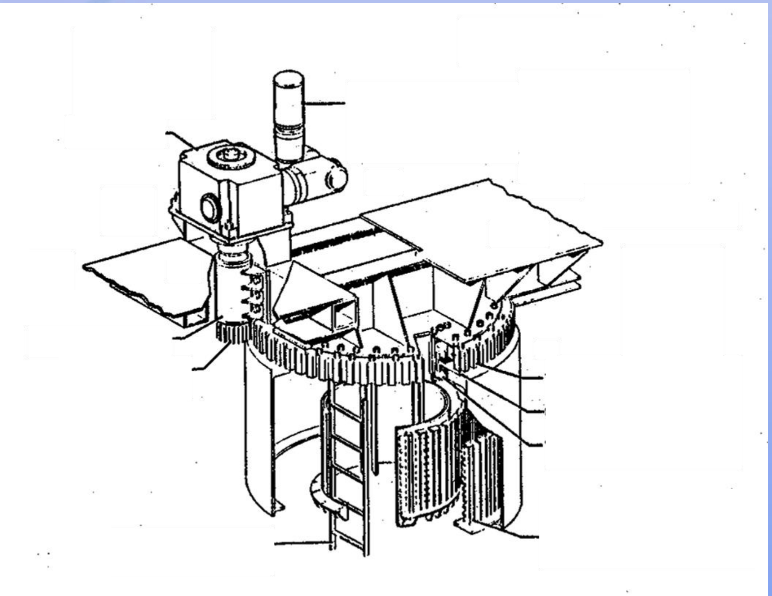
- Mechanical Brake used to stop (or park) rotor
- Usually redundant with aerodynamic brakes
- Types:
  - Disc
  - Clutch
- Location:
  - Main Shaft
  - High Speed Shaft
- Design considerations:
  - Maximum torque
  - Length of time required to apply
  - Energy absorption



Disc Brake

Yaw System

- The Yaw System orients the turbine to the wind
- Types
  - Active Yaw (Upwind turbines)
    - Employs motor and gearing
    - May Need Yaw Brake to Prevent Excess Motion
  - Free Yaw (Downwind turbines)
    - Relies on wind forces for alignment
    - May Need Yaw Damper or Power Cable "Unwinder"



Yaw Drive

Main Frame

- The Main Frame is the platform to which the other principal components are attached.
- Provides for proper alignment among those components
- Provides for yaw bearing and ultimately tower top attachment
- Usually made of cast or welded steel

Nacelle Cover

- The nacelle cover is the wind turbine housing
- Protects turbine components from weather
- Reduces emitted mechanical sound
- Often made of fiberglass

Tower

- Raises turbine into the air
- Ensures blade clearance
- Types
  - Free standing lattice (truss)
  - Cantilevered pipe (tubular tower)
  - Guyed lattice or pole.

Installation of Tubular Tower

Success of Modern Turbines

- Experience
  - California, Europe
- Computers (intelligence)
  - Design, monitoring, analysis, control
- Materials
  - Composites
- Design standards
  - Specification of conditions
  - Ensure safety & reliability

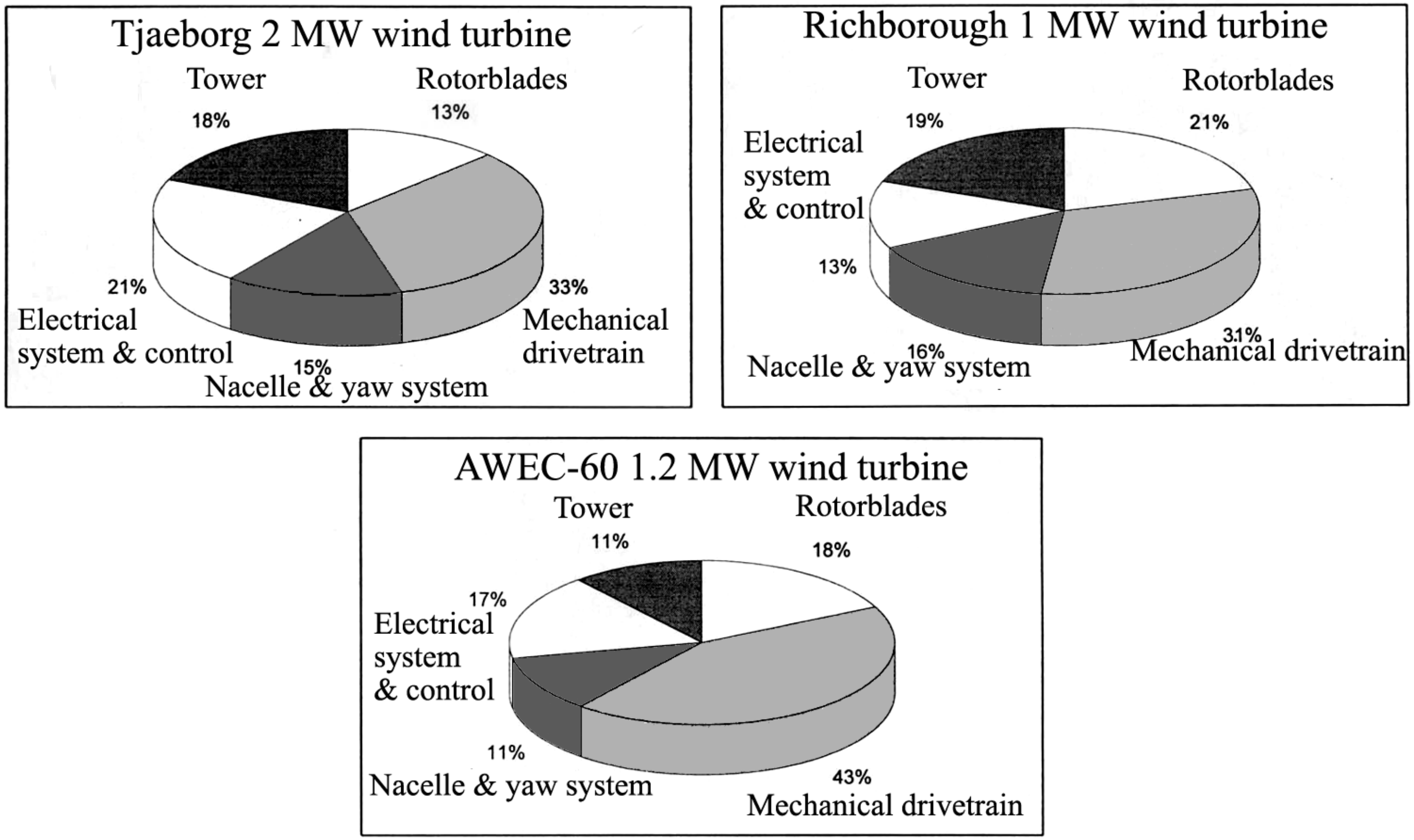
Cost of Energy

- Cost of energy (COE), $/kWh
- COE = (C*FCR+O&M)/E
- Depends on:
  - Installed costs, C
  - Fixed charge rate, FCR – fraction of installed costs paid each year (including financing)
  - O & M (operation & maintenance)
  - Annual energy production, E

Typical Costs

- Wind
  - Size range: 500 W- 2,000 kW
  - Installed system: $900-1500/kW
  - COE: $0.04 – 0.15/kWh

Typical Component Costs



Typical Energy Production

- Use 'Capacity Factor' (CF)
  - CF = Actual Energy/Maximum Energy
  - E = CF x Rated Power x 8760 (kWh/yr)
- Typical Range:
  - CF = 0.15 - 0.45
  - CF ideally > 0.25

Efficiencies

- Rotor: ~85% of theoretical
- Gearbox: ~97%
- Generator: ~95%
- Power electronics: ~92-95%

Challenges

- Installation, maintenance of very large turbines
- Transmission from windy areas to load centers
- Fuel production (hydrogen by electrolysis)
- Public acceptance

Example: Transportation Challenges

Is this the way to move large turbines?

Future

- Larger turbines
- Improvements in design details
- More sophistication
  - Example: self-diagnosis and correction
- Improved power electronics
- Effective use of high wind ites
  - Great plains
  - Offshore
- Designs for lower wind sites

Future (2)

- Focus on complete system
- Transmission
- High value applications
- Energy storage
- Fuel creation (hydrogen)
  - Wind+Turbine -> Electricity
  - Electricity + Water -> H_2 (+O_2)