# Research Opportunities in Wind Turbine Drive Trains

Stanford University Global Climate and Energy Project

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# Commercial Wind Turbines

- Power
  - ~1-3 Megawatts
- Rotor
  - ~55-90 meters diameter
- Nacelle
  - 65-85,000 pounds
  - 100 -150,000 pounds
- Tower
  - 60-80 meters
  - 160-300,000 pounds

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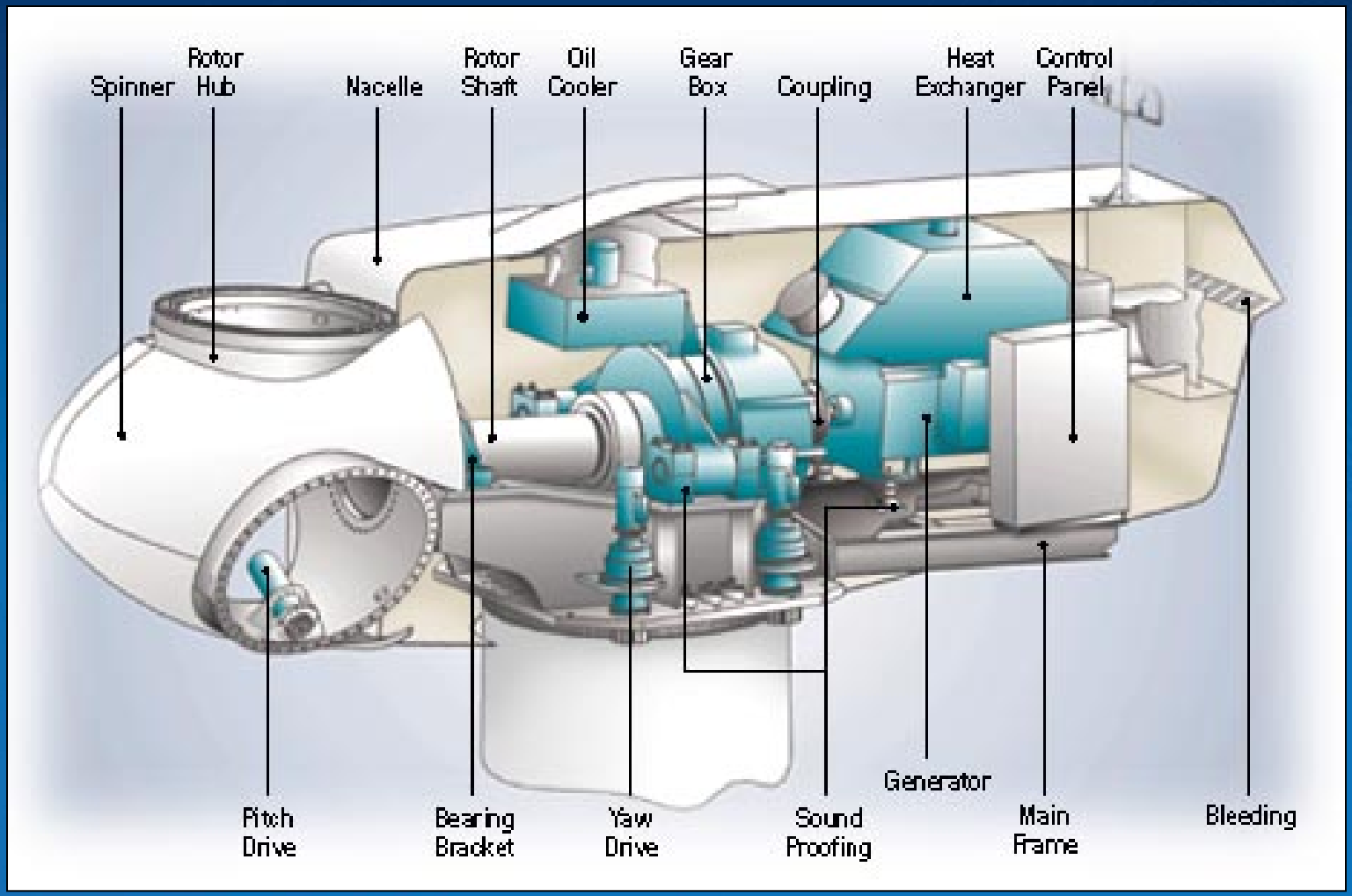
# Mechanical Systems

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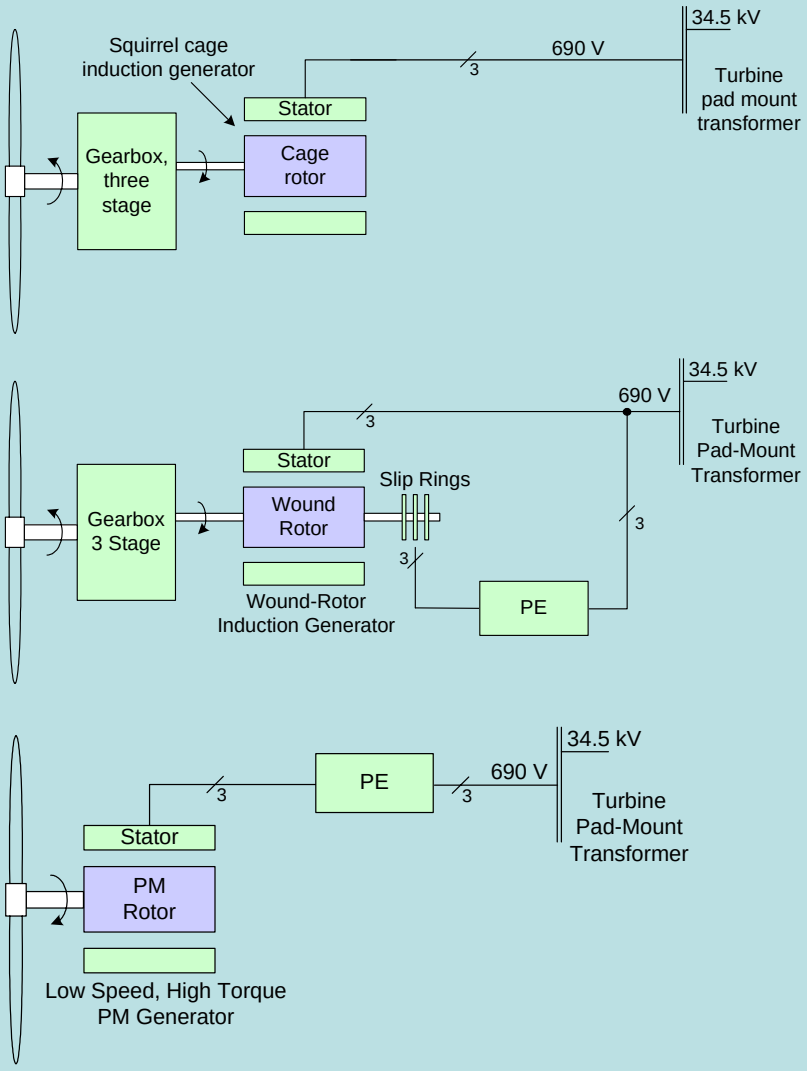
# Power Electrical Systems




**Cage-rotor induction machine**

- **Constant speed**

**Wound-rotor induction machine**

- **Variable speed**
- **Partial-power conversion**

**Synchronous machine**

- **Variable speed**
- **Full-power conversion**

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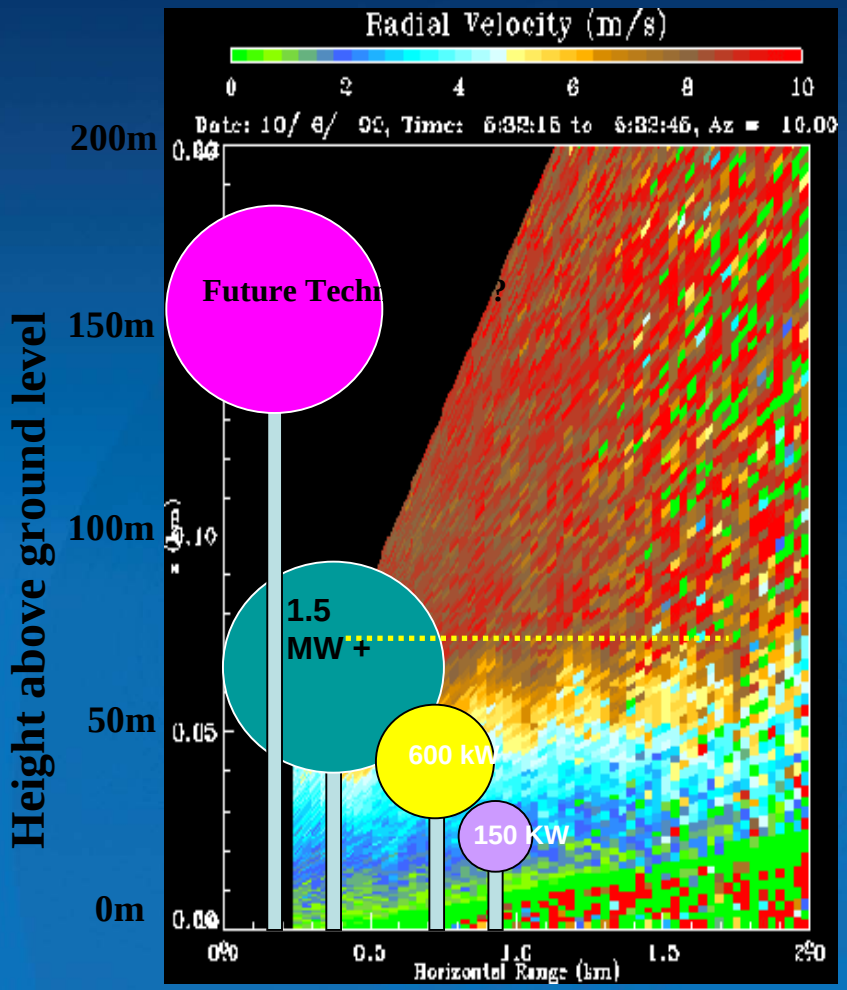
# Design Environment




- Variable/uncontrollable wind environment
- Temperature extremes
- Precipitation and humidity
- Lightning
- Highly vibratory
- Poor accessibility
- 5-6,000 hours per year for 20+ years

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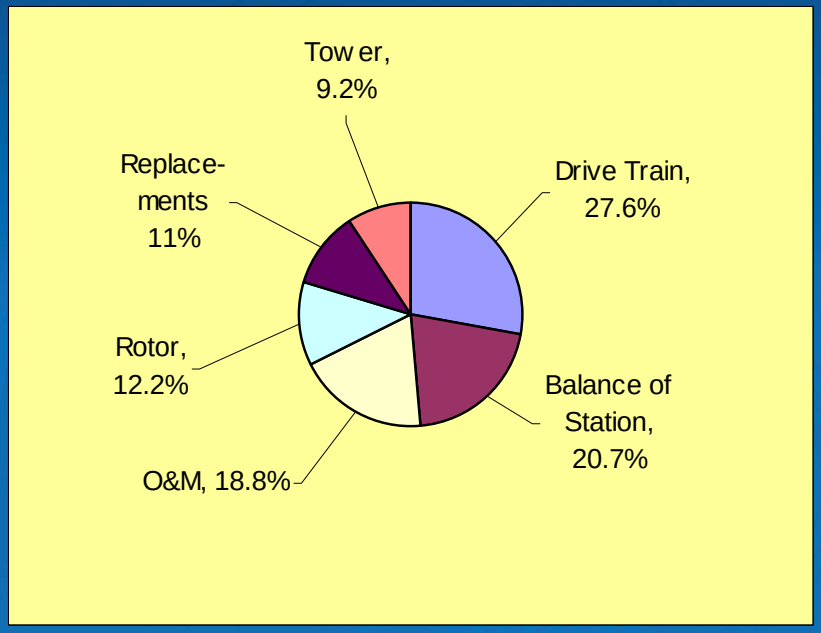
# Cost of Energy (COE)
## Typical Cost Distribution - 1.5 MW Turbines




$$COE = \frac{FCR \cdot ICC + LRC + O\&M}{AEP}$$

**FCR = fixed charge rate (1/yr)**

**ICC = initial capital cost ($)**

**LRC = levelized replacement cost ($/yr)**

**AEP = annual energy production (kWh/yr)**

**O&M = annual ops and maintenance ($/yr)**

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# Key Messages

- Large-scale complex equipment
- Adverse conditions
- Uncertain loads
- Cost of energy is critical
  - Initial cost
  - Energy production
  - O&M
  - Risk

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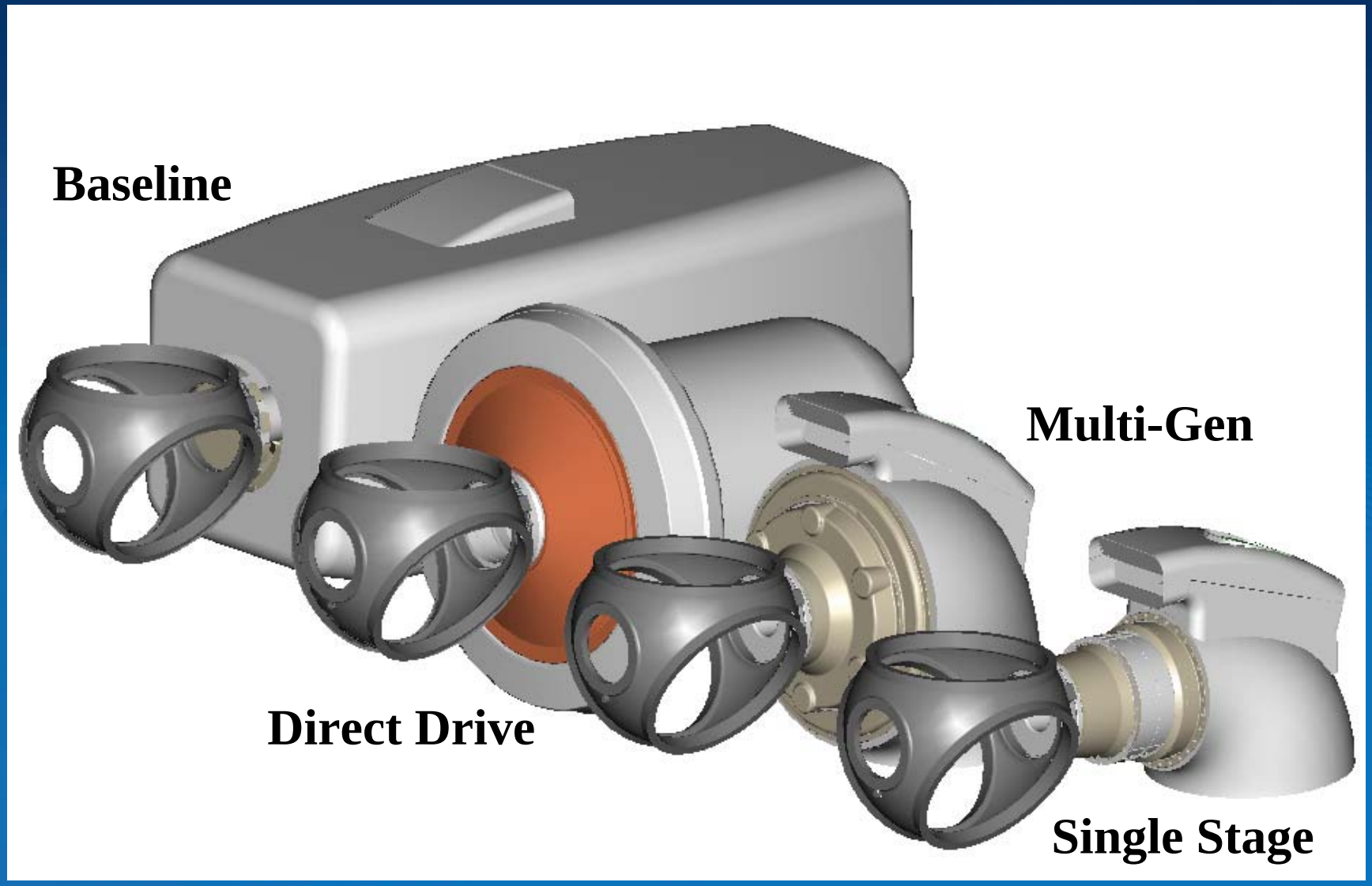
# Mechanical Challenges

- Reducing initial cost
  - Integrated topologies
  - Advanced materials
- Understanding premature failures
  - Rolling-element bearings
  - Gear micro-pitting
- Reducing O&M costs
  - Condition monitoring
  - Facilitating component replacement
  - Improving reliability and predictability

# Power Electrical Challenges

- Reducing initial cost
  - Switching technologies
- Improving low wind speed energy capture
  - Efficient low-speed/power operation
- Improving reliability
  - Environmental robustness
- Grid interconnection concerns
  - VAR support and power quality
  - Fault tolerance (ride-through)

# Solutions Under Investigation

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# Opportunities – Mechanical System

- Understanding loads
  - Turbine motion influences
  - Drive line ‘double-ended’ torsion
  - Internal gear and bearing dynamics
  - Understanding inflow and its interaction with system
- Tribology and wear
  - Understanding gear wear mechanism
  - Effect of dynamic loads on lubricant film
- Refining design methodologies
  - Verifiable and transparent bearing/gear rating methods
- Reducing Loads
  - Higher speeds
  - Controls

# Opportunities – Reducing O&M

- Condition monitoring
  - Defining run/replace alarm levels
- Reduce replacement costs
  - Innovative modular designs
- Reduce skill levels
  - Self-diagnostics and remote monitoring
- Improve reliability
  - Eliminate premature failures

# Opportunities – Power/Electrical

- Increase generator efficiencies
  - Permanent-magnet/synchronous machines
- Improve power electronic efficiencies
  - Higher voltage systems
  - Alternative switching topologies
- Increase speed range
  - More power with same torque
- Lower power electronic costs
  - Especially for high-power drives

# Conclusions

- Many opportunities in multiple disciplines
- Active programs in many areas but heavily limited resources
- Industry has near- and long-term needs
- Collaboration and coordination welcome and could have high impact