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

![Pie chart showing cost distribution]

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

- 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)
Key Messages

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

Baseline

Direct Drive

Multi-Gen

Single Stage
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