Wind Power

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Outline

• The Wind Resource
• Turbine Design
• US Wind Industry
• Wind Farm Development
• The Future
The Wind Resource
United States - Wind Resource Map

Wind Power Classification

- **Wind Power Class**
  - 2: Marginal
  - 3: Fair
  - 4: Good
  - 5: Excellent
  - 6: Outstanding
  - 7: Superb

- **Resource Potential**
  - 200 - 300 W/m²
  - 300 - 400 W/m²
  - 400 - 500 W/m²
  - 500 - 600 W/m²
  - 600 - 800 W/m²
  - 800 - 1600 W/m²

- **Wind Power Density at 50 m**
  - 2: 5.6 - 6.4
  - 3: 6.4 - 7.0
  - 4: 7.0 - 7.5
  - 5: 7.5 - 8.0
  - 6: 8.0 - 8.8
  - 7: 8.8 - 11.1

- **Wind Speed at 50 m**
  - 2: 12.5 - 14.3
  - 3: 14.3 - 15.7
  - 4: 15.7 - 16.8
  - 5: 16.8 - 17.9
  - 6: 17.9 - 19.7
  - 7: 19.7 - 24.8


Indian Reservations and Alaska Native Village Areas

U.S. Department of Energy
National Renewable Energy Laboratory

Wind speeds are based on a Weibull k value of 2.0

DM Heimiller 31-MAY-2001 1.2.8
North Dakota: The “Saudi Arabia” of Wind

- Enough wind potential to supply 1/3 of the electricity consumption of the lower 48 states.
- No major load centers – need to transmit power to remote locations
- Potential to become a clean fuel supplier to Minneapolis & Chicago:
  
  \textit{Electricity (through power transmission lines)}

  \textit{Hydrogen (through pipelines)}

Wind Resources & Infrastructure Challenges
Power in the Wind

Power = Work / t

= Kinetic Energy / t

= \( \frac{1}{2} mV^2 / t \)

= \( \frac{1}{2} (\rho A d)V^2/t \)

= \( \frac{1}{2} \rho A V^2 (d/t) \)

= \( \frac{1}{2} \rho A V^3 \)

Power in the Wind = \( \frac{1}{2} \rho A V^3 \)
Maximum Power

Power in the Wind = $\frac{1}{2}\rho AV^3$

- Swept Area - $A = \pi R^2 \text{ (m}^2\text{) Area of the circle swept by the rotor.}$

- Power from a Wind Turbine Rotor $= C_p \frac{1}{2} \rho AV^3$

- Betz limit (air can not be slowed to zero) $C_p < 59%$

- Generator Losses
Sizes and Applications

Small (≤10 kW)
- Homes
- Farms
- Remote Applications (e.g. water pumping, telecom sites, icemaking)

Intermediate (10-250 kW)
- Village Power
- Hybrid Systems
- Distributed Power

Large (250 kW - 2+MW)
- Central Station Wind Farms
- Distributed Power
Small Wind Turbines are Different

- Large Turbines (600-1800 kW)
  - Installed in Windfarms, 10 - 100 MW
  - Provide Low Cost Power to the Grid
  - $< 1,000/kW
  - Require 6 m/s (13 mph) Average Wind

- Small Turbines (0.3-50 kW)
  - Installed Off-Grid or at On-Grid Facilities
  - $2,000-6,000/kW
  - Designed for Reliability / Low Maintenance
  - Require 4 m/s (9 mph) Average

1,500 kW Wind Turbine
10 kW Wind Turbine
The Evolution of Commercial U.S. Wind Technology

1980s
- Structurally stiff
- 3 bladed – upwind yaw-driven
- Constant speed and 2 speed
- Stall regulated/tip brakes or full-span pitch controlled
- Fiberglass blades
- Geared transmission
- Induction generator
- Steel truss or tube tower

1990s
- Structurally stiff
- 3 bladed – upwind yaw-driven
- Variable speed and constant speed
- Special airfoils – NREL
- Stall regulated and pitch controlled
- Planetary transmission
- Induction generator
- Large size to reduce COE

Future Innovation
- Scale to larger size
- Advanced blade materials and manufacturing
- Low speed direct drive generators
- Custom power electronics (high efficiency)
- Feedback control of drive train and rotor loads
- More flexible structurally
- O&M reduction features

HOW A TURBINE CHANGES WIND ENERGY TO ELECTRICITY

NEG MICON: Nacelle & Hub Cross Section

- Lightning rod
- Wind sensors
- Radiator
- Generator
- High speed shaft
- Gearbox
- Nacelle frame
- Air intake
- Disc brake
- Nacelle cover
- Main shaft
- Service crane
- Main bearing
- Spinner
- Yaw motor
- Tower (top)
Energy Production Terms

- **Power in the Wind** = $\frac{1}{2} \rho A V^3$
- **Betz Limit** - 59% Max
- **Power Coefficient** - $C_p$
- **Rated Power** - Maximum power generator can produce.
- **Capacity factor**
  - Actual energy/maximum energy
- **Cut-in** wind speed where energy production begins
- **Cut-out** wind speed where energy production ends.

![Typical Power Curve]
US Wind Industry
Growth of Wind Energy Capacity Worldwide

Sources: BTM Consult Aps, March 2001
Windpower Monthly, January 2002
Wind Farm Development: Driving Factors

- Wind Resource
- Proximity to Transmission Lines/Substations with excess capacity
- State Policy Provisions
  - property/sales tax,
  - permitting and review,
  - subsidies and incentives
  - renewable power purchase mandates
- Utility green power programs and customer demand
- Federal Policy
  - renewal of production tax credit
  - potential purchase mandates
Why Worth County IA – Good Location to Demand Centers

2000 POPULATION DISTRIBUTION IN THE UNITED STATES

Top of Iowa – Wind Farms

One dot = 75,000 people

Prepared by Geography Division, U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau
Why Worth County IA – About the best Non-Firm Transmission available

Top of Iowa Wind Farms

CHRONIC CONSTRAINTS LIMITING ECONOMIC TRANSACTIONS (AFC LIMITS)
Mandated Market Demand

States with Renewable Portfolio Standards

NV: 15% by 2013, solar 5% of total annually
MN: 3.6% by 2002 and 4.8% by 2012
WI: 2.2% by 2011
IA: 2% by 2011
ME: 30% by 2000
MA: 4% by 2009
CT: 13% by 2009
NJ: 6.5% by 2012
PA: varies by utility

CA: 20% by 2017
AZ: 1.1% by 2007, 60% solar
NM: 10% by 2011
TX: 2.2% by 2009

MREC Current Area of Interest

800 MW
400 MW
13 States
Payback

12 mph is class 3 wind power
14 mph is class 5 wind power

Net metering only
50% buy-down and net metering

Electric rate (¢/kWh)
Simple payback (years)
Economic Development Opportunities

- Land Lease Payments: 2-3% of gross revenue $2500-4000/MW/year
- Local property tax revenue: 100 MW brings in on the order of $1 million/yr
- 1-2 jobs/MW during construction
- 2-5 permanent O&M jobs per 50-100 MW,
- Local construction and service industry: concrete, towers usually done locally
- Investment as Equity Owners: production tax credit, accelerated depreciation
- Manufacturing and Assembly plants expanding in U.S. (Micon in IL, LM Glasfiber in ND)
Wind Farm Development
Development Process:

- **Site prospecting**
  - Simultaneously taking first cut at everything
- **Land rights (leases, easements)**
- **Site investigation**
  - Wind measurement, analysis (2 years unless strongly correlated)
  - Environmental study
    - Sound, avian, viewshed, other issues (lightning, erosion, other flora, fauna)
  - Cultural issues (artifacts, land use, religious concerns, historic structures)
  - Geotechnical
- **Permitting**
- **PPA negotiation**
- **Engineering**
- **Financing**
- **Construction and Operation**
Project Development Cycle

- Operation
- Construction
- Engineering
- Sales Agreement
- Permitting
- Resource Measurement
- Land Rights

Years:
- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35
BUILDING A WIND FARM

Build Accesses & Dig Foundation Holes
BUILDING A WIND FARM

Bury Underground Cable & Build Substation
BUILDING A WIND FARM
Installs Foundation
BUILDING A WIND FARM

Deliver Turbines
BUILDING A WIND FARM

Install First Section
BUILDING A WIND FARM

Install Second Section
BUILDING A WIND FARM

Install Third Section & Nacelle
BUILDING A WIND FARM

Install Rotor
BUILDING A WIND FARM

Install Rotor
The Future

- With an eye for Florida
Utgrunden offshore project
Middlegrunden offshore project
Proposed Site

Cotuit – 6.0 Miles
Point Gammon – 4.7 Miles
Oak Bluffs - 9.3 Miles
Edgartown – 8.9 Miles
Nantucket - 13.8 Miles
The Iowa Stored Energy Plant (ISEP)

3 Proven Technologies

1. Renewable wind energy
2. Aquifer storage of gas
3. Combustion turbine
3. Combustion turbine (simple cycle)

- Air compressor
- Combustor
- Turbine
- Generator

Natural Gas
12,000 BTU/kWh
The Alabama CAES plant

Alabama Electric Cooperative
McIntosh Power Plant
Aerial View
Wind-Hydrogen System Concept

Wind-Hydrogen Forms a Green Energy Cycle and is Technically Feasible
Offshore Wind - Onshore H₂ Production (Long Island)

500 MW
~ $1200/kW
η ~ 45%

150 kV AC sub-sea cable
~ $1.2 MM/mile
η ~ 98%

8 miles

220 MW
~ $1000/kW
η ~ 75%

220 MW
~ $1000/kW
η ~ 75%

150 kV AC sub-sea cable
~ $1.2 MM/mile
η ~ 98%

356,400 gal/day

Water Consumption
356,400 gal/day

4950 kg/hr, 25 bar

4950 kg (150 MWh)
~ $100/kWh
η ~ 99%

350 bar

6 MW
η ~ 80%

4950 kg/hr, 25 bar

6 MW
η ~ 80%

- 98 trucks (180 kg/truck)
- 60,000/truck
η ~ 85% (40 miles)

H₂ production:
100,980 kg/day
@ $4.15/kg

H₂ production:
118,000 kg/day
@ $3.5/kg

NOTE: Assuming trucks are powered by H₂