The Nuts and Bolts of Wind Energy

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What is Wind?


Cornered
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RENEWABLE ENERGY SOURCES
HARVESTING THE WIND
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What is Wind?

- **Wind is a byproduct of solar energy**
- **Approximately 2% of solar energy reaching the earth is converted to wind**
- **Wind results from**
  - **uneven heating & cooling of earth**
  - **creates atmospheric pressure gradients**
  - **gradients force air movement from areas of high pressure to low pressure**

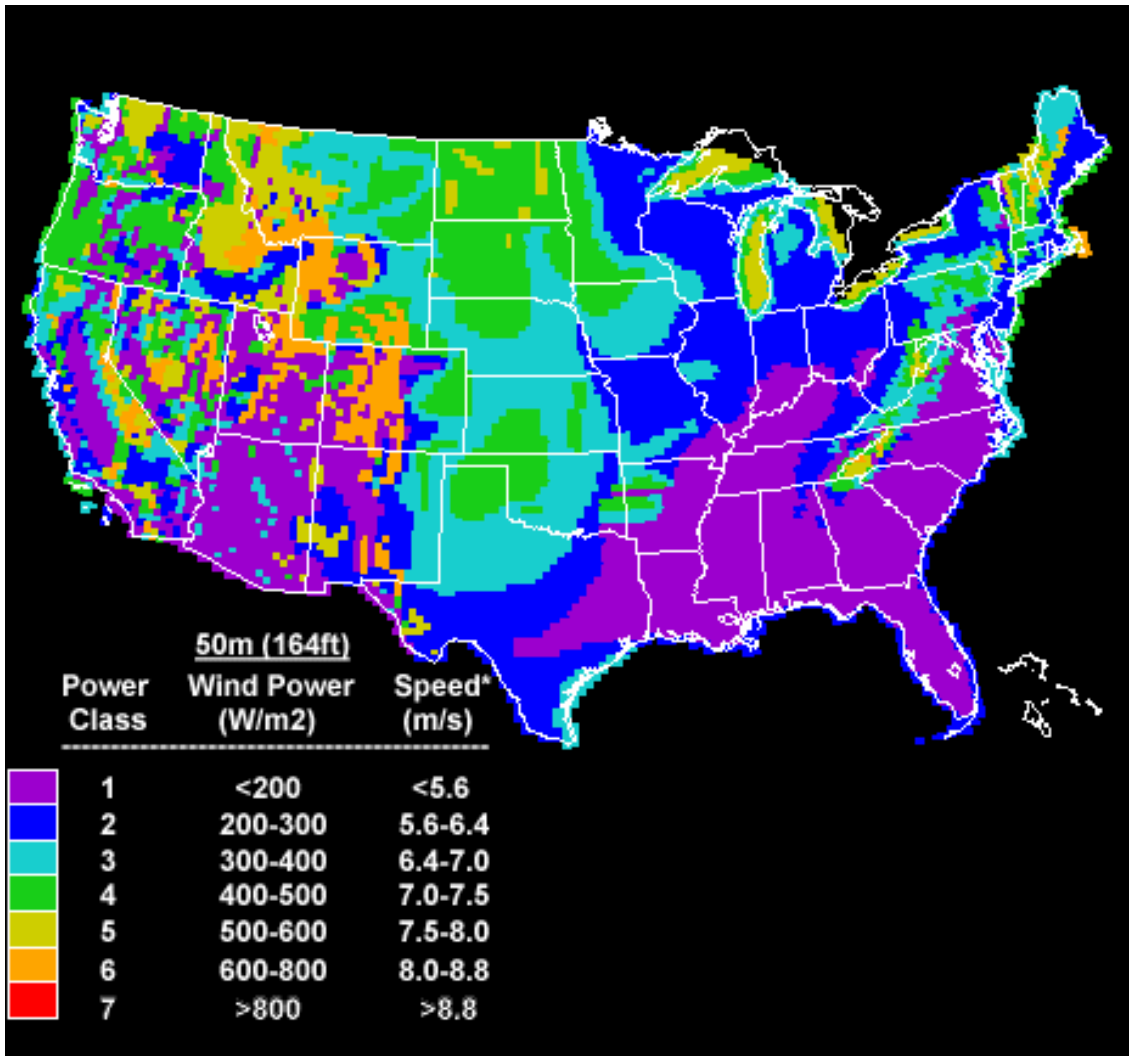
Physics of Wind Power

- **Power = $\frac{1}{2}\rho A v^3 \eta$**
  - **ρ = specific gravity of air**
    - function of air temperature and elevation
  - **A = cross sectional area of swept blades**
  - **v = wind velocity**
    - function of height above ground
      - $V_2 = V_1 (H_2 / H_1)^{0.2}$
  - **η = loss factor**
    - function of wind direction relative to turbine orientation
    - function of ground turbulence effects
    - function of turbine design

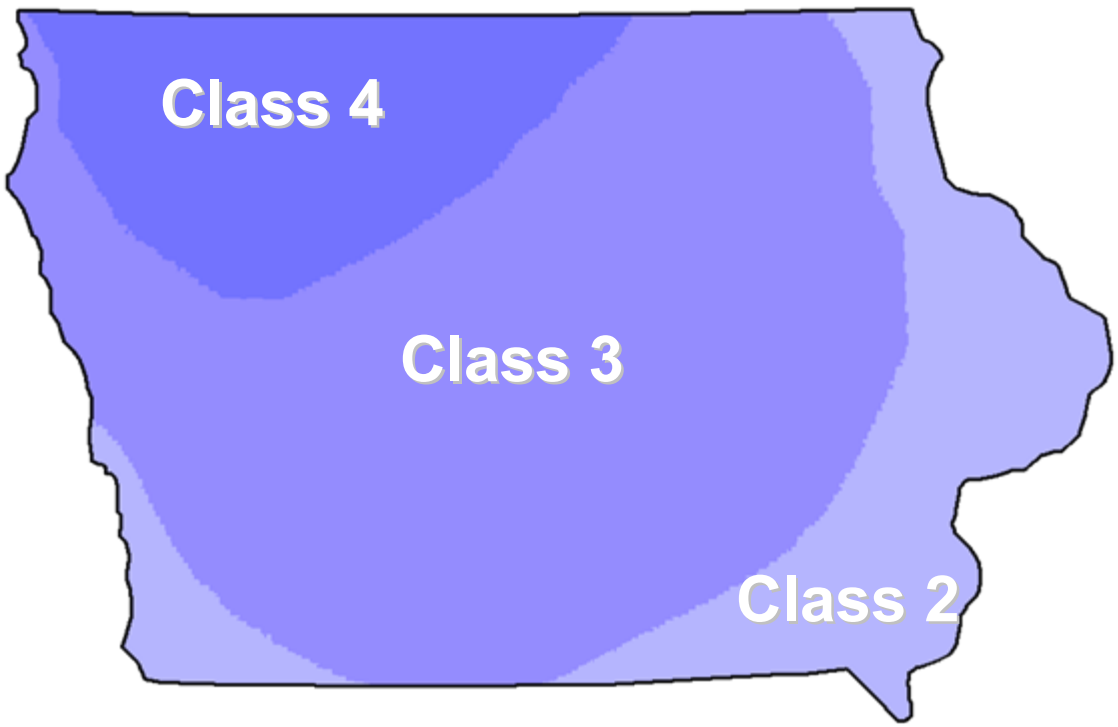
Wind Velocity vs. Power

Velocity 1 (mph)	Velocity 2 (mph)	% Power Increase
7	10.1	300
10	12.6	100
15	16	21
15	17	46
15	18	73

U.S. Wind Resources



NREL Wind Power Classes



Class	mps	mph
1	0.5.6	0-12.5
2	5.6-6.4	12.5-14.3
3	6.4-7.0	14.3-15.7
4	7.0-7.5	15.7-16.8
5	7.5-8.0	16.8-17.9
6	8.0-8.8	17.9-19.7

From Elliott et al., 1987, *Wind Energy Resource Atlas for the United States*, National Renewable Energy Laboratory.

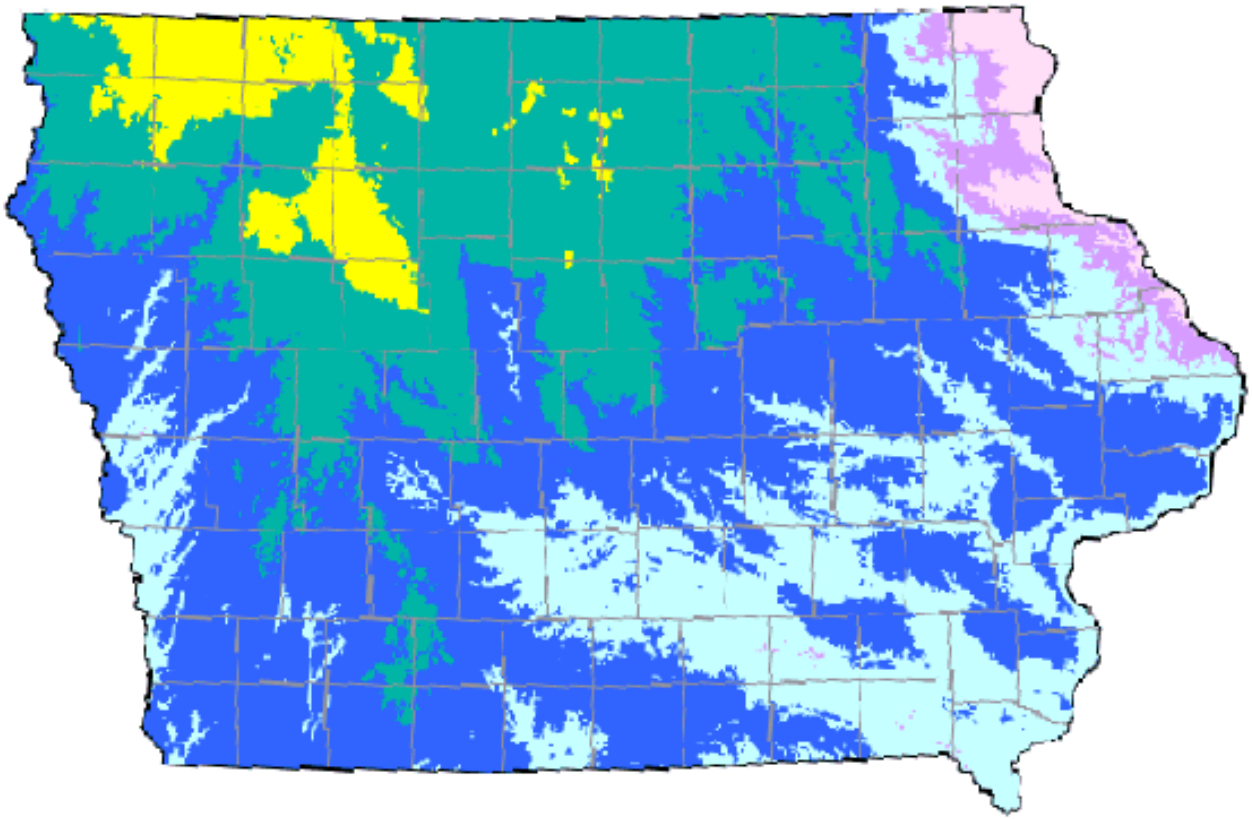
IEC Wind Assessment Study

- **Study Parameters**
  - 2.5 years (1994-97) of data at 60-minute interval
  - 3 years (1997-99) of data at 10-minute interval
  - 14 permanent monitoring stations; 2 mobile stations; 7 NWS airport stations
  - GIS-based computer model
- **Study Investigators**
  - Iowa Wind Energy Institute
  - Brower & Company

IEC Wind Assessment Study

Estimated Average Annual Wind Speeds

Typical average wind speeds on well exposed sites at 50 m above ground



MPH		m/s
>19.0		>8.5
17.9-19.0		8.0-8.5
16.8-17.9		7.5-8.0
15.7-16.8		7.0-7.5
14.5-15.7		6.5-7.0
13.4-14.5		6.0-6.5
12.3-13.4		5.5-6.0
<12.3		<5.5

Iowa Energy Center

This map was generated from data collected by the Iowa Wind Energy Institute under Iowa Energy Center Grant No. 93-04-02. The map was created using a model developed by Brower & Company, Andover, MA.

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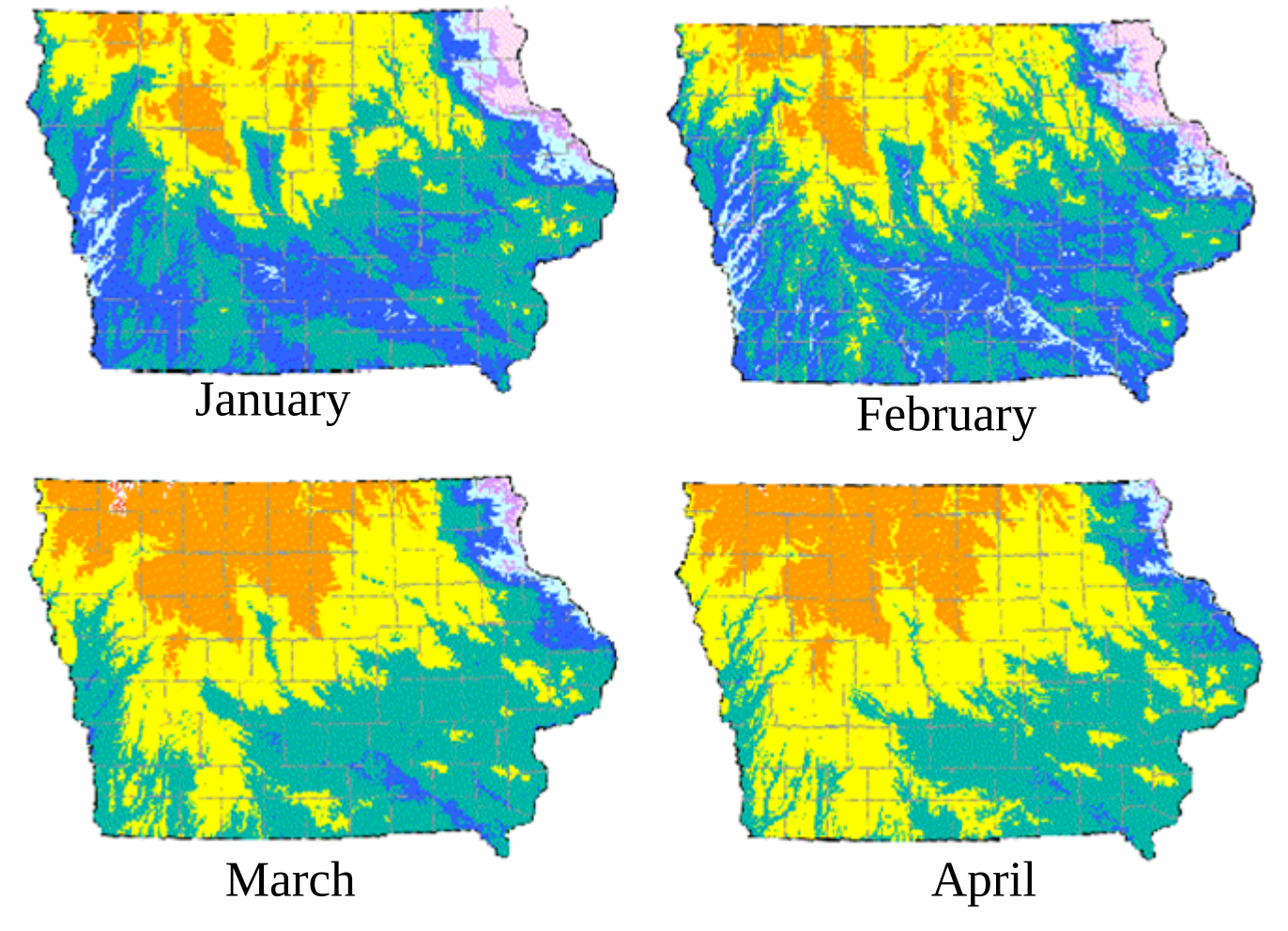
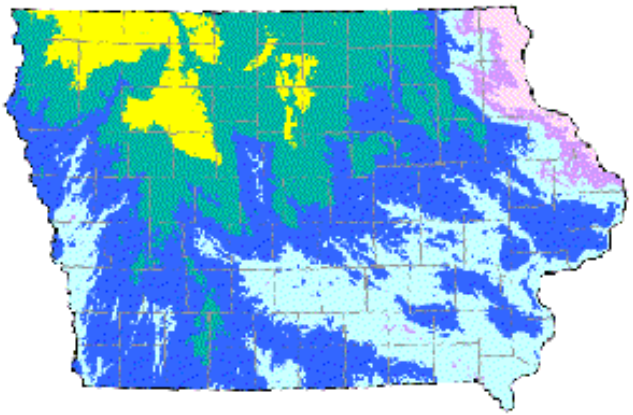
IEC Wind Assessment Study



IEC Wind Assessment Study



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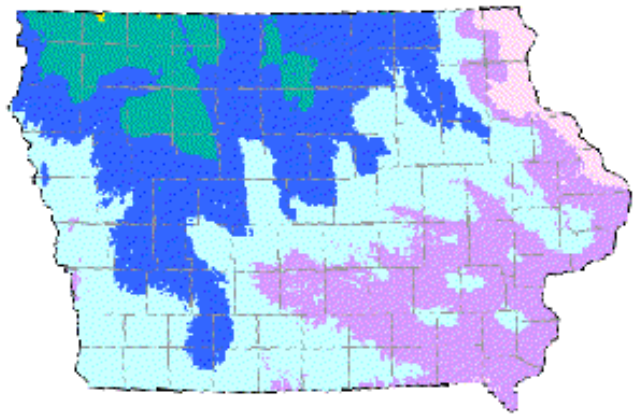

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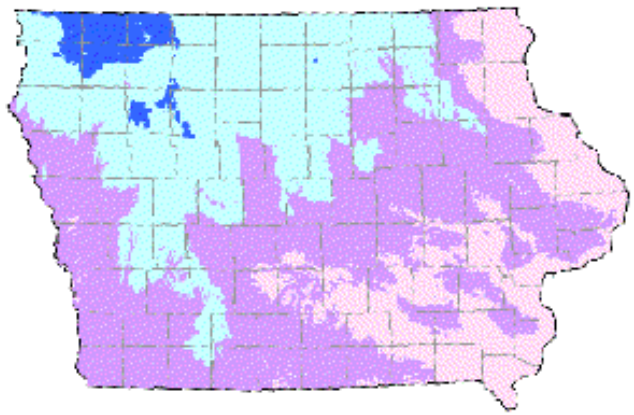

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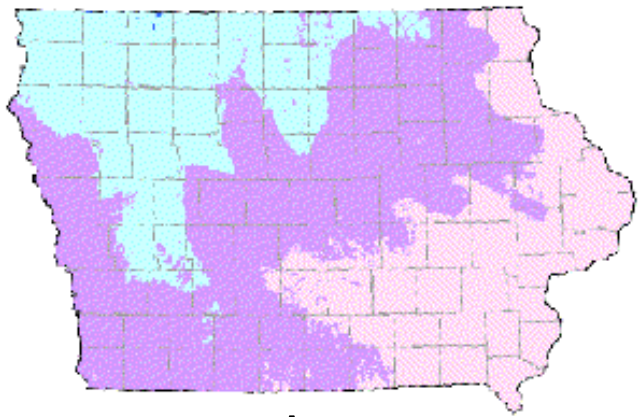

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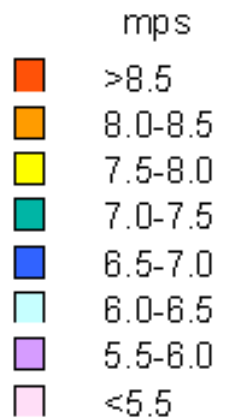
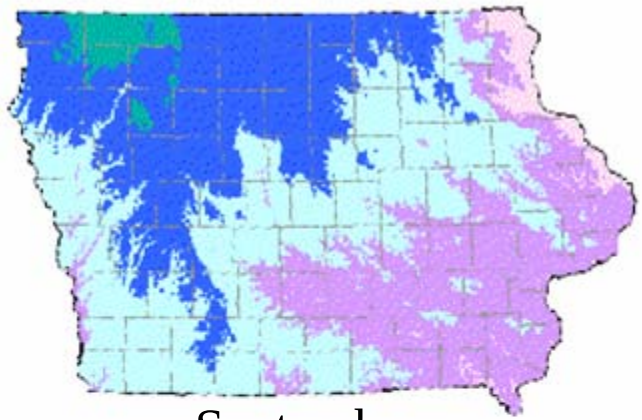


IEC Wind Assessment Study



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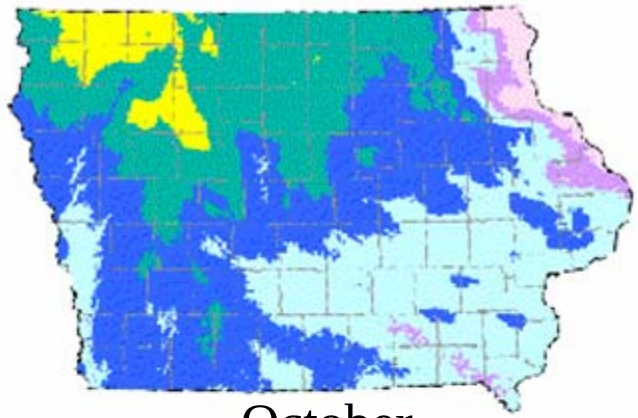
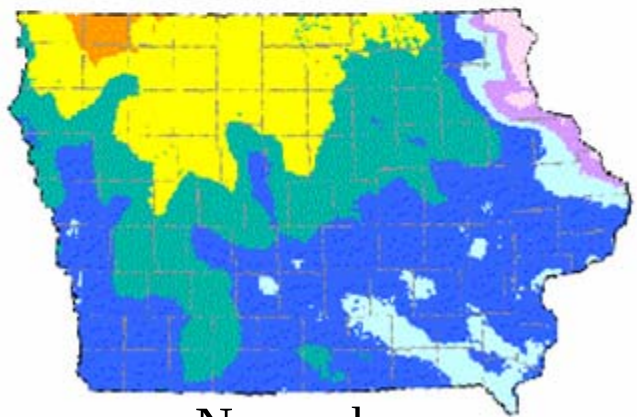


October



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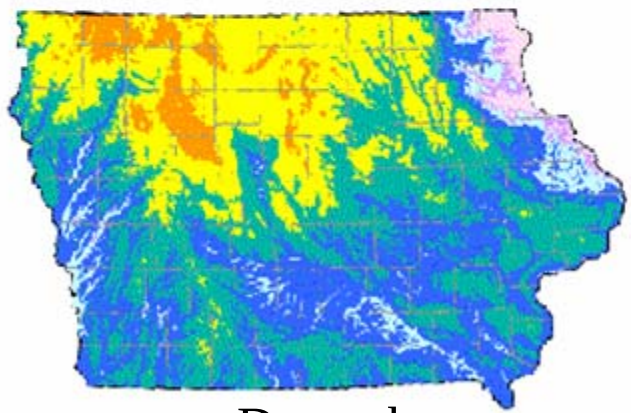

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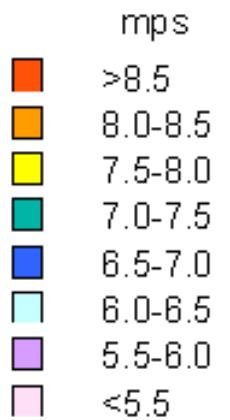
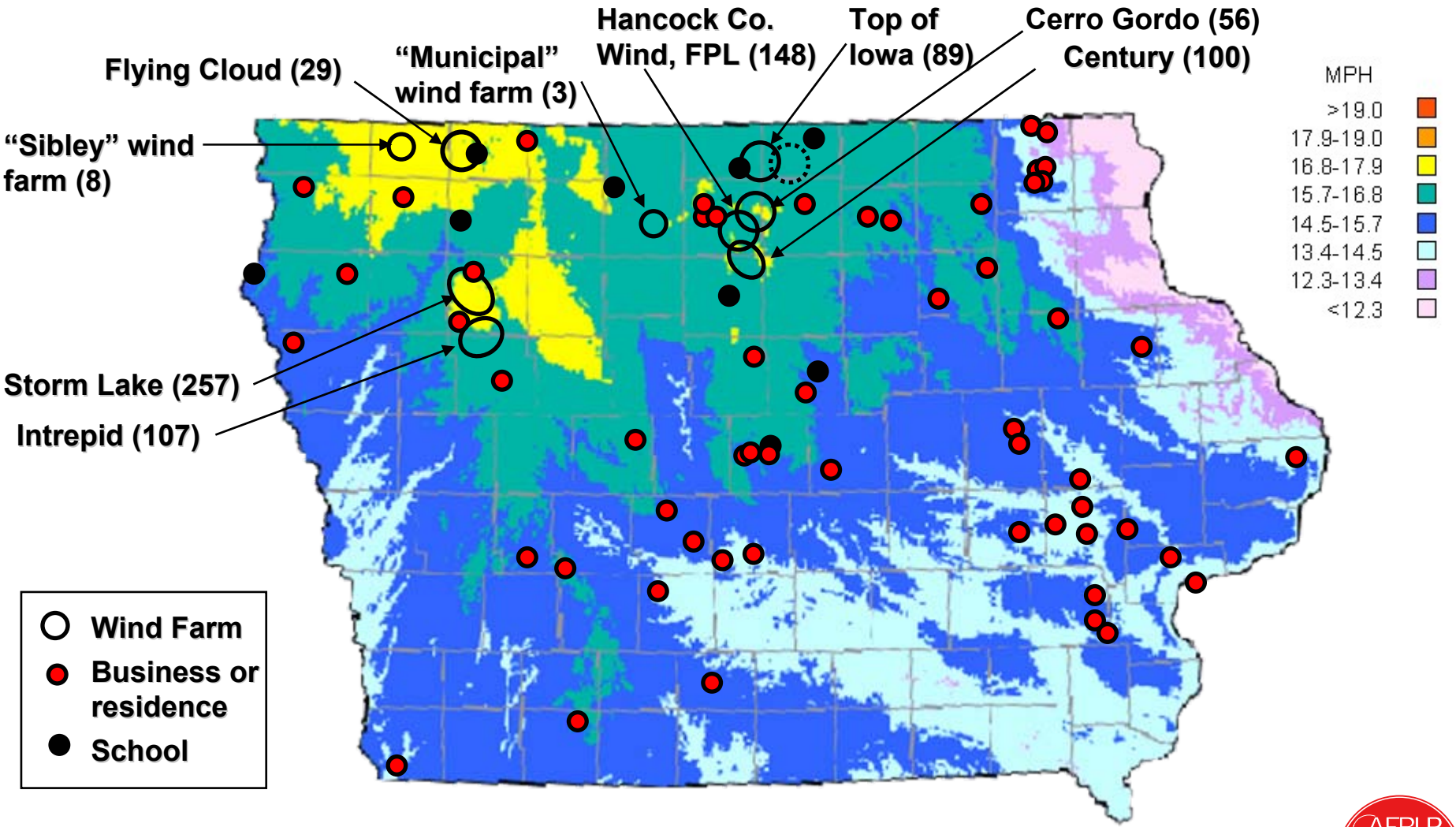


Status of Wind Energy in Iowa

Wind Facts

- Iowa is the nation's 10th windiest state and ranks 3rd in total wind energy generation behind California and Texas
- Approximately 782 MW installed capacity
- Approximately 50 MW under construction
- Approximately 130 MW planned capacity
- ~ 814 existing utility-scale turbines (>50 kW)
- Many farm/residential units

Wind Speed vs. Turbine Locations



Wind Turbine Site Considerations

- **Highest general elevation**
- **On a ridge line perpendicular to prevailing winds**
- **Flat or gently rolling ground**
- **Low height ground cover**
- **No significant wind breaks/obstructions**
- **Proximity to airport(s) and utility grid**
- **Zoning and safety issues**

Wind Development Planning

- **Identify a champion to lead the effort**
- **Perform a feasibility study**
  - **Evaluate energy load profile**
  - **Evaluate energy efficiency opportunities**
  - **Evaluate wind resources (macro level)**
- **Complete micro-site resource assessment**
- **Complete project design**
- **Negotiate with electric utility**
  - **Interconnection agreement**
  - **Power Purchase contract**
- **Finance project**
- **Bid and Construct**

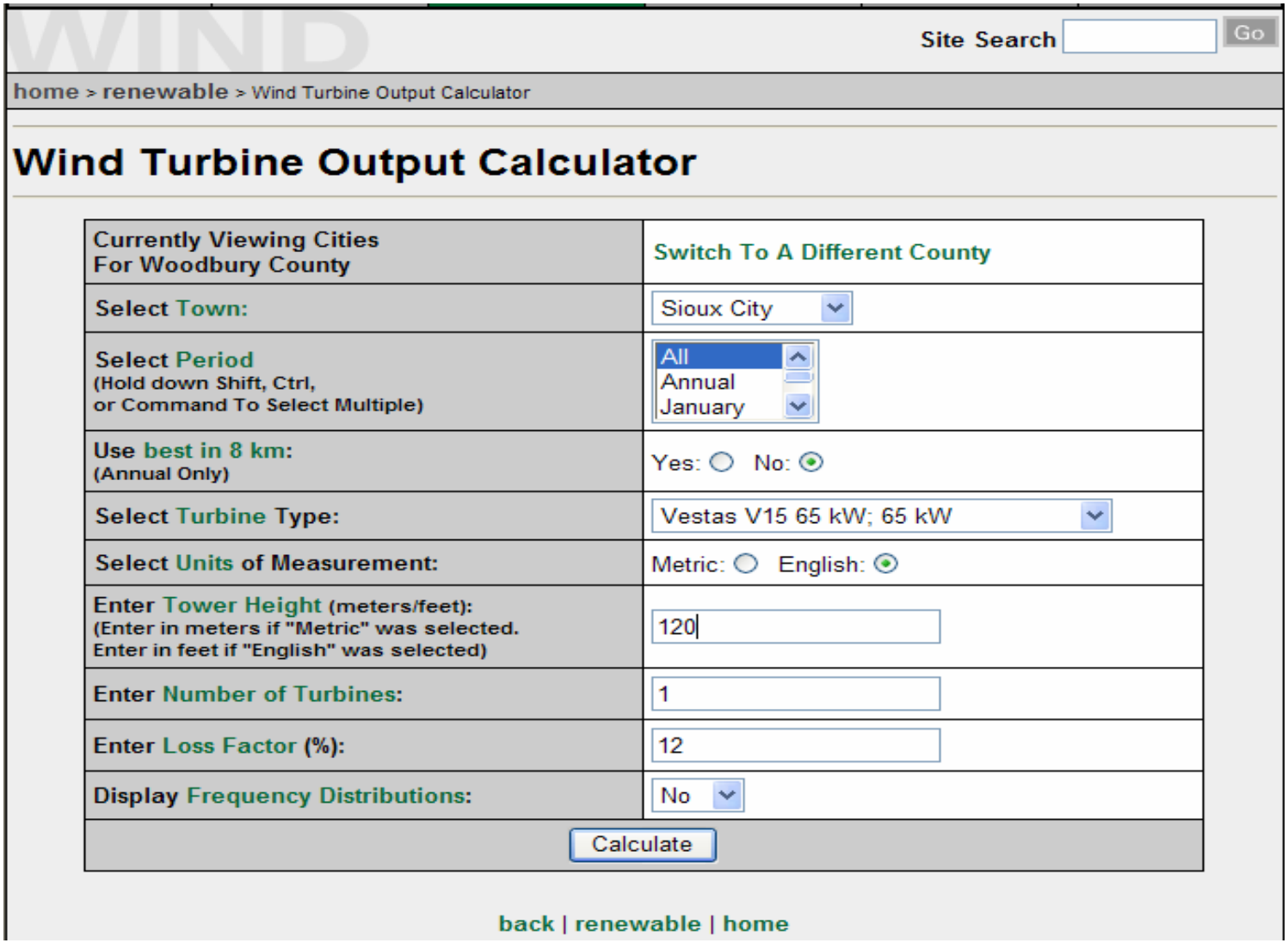
Key Elements For Wind Development

- **Location, Location, Location**
  - **Within a good wind regime**
  - **Close proximity to utility grid**
  - **Favorable terrain features**
  - **Permitting and "good neighbor" barriers**
    - Urban vs. Rural
    - Tower height restrictions
    - Noise and liability considerations
- **Power Consumer vs. Power Supplier Viewpoint**
  - **Retail vs. wholesale vs. avoided cost value of power**
  - **Load profile consistent with wind turbine generation**
- **Favorable Utility Contracts**
  - **Interconnection and Power Purchase Agreements**
  - **Net Metering**
- **Favorable Financing Package**
  - **Property and production tax credits**
  - **Grants and loans**

IEC Wind Calculator

- **Demonstrate monthly variation in wind speeds**
- **Use with turbine power curve to help determine if site has minimum required wind resource**
- **Estimate electricity production for a given site under varying conditions**
  - **different turbine models**
  - **turbine hub heights**
  - **loss factors**
- **Model will not account for local obstructions**
  - **these must be determined on a case-by-case basis**

Wind Turbine Calculator Input



Site Search Go

home > renewable > Wind Turbine Output Calculator

Wind Turbine Output Calculator

Currently Viewing Cities For Woodbury County	Switch To A Different County
Select Town:	Sioux City
Select Period (Hold down Shift, Ctrl, or Command To Select Multiple)	All Annual January
Use best in 8 km: (Annual Only)	Yes: ○ No: ◉
Select Turbine Type:	Vestas V15 65 kW; 65 kW
Select Units of Measurement:	Metric: ○ English: ◉
Enter Tower Height (meters/feet): (Enter in meters if "Metric" was selected. Enter in feet if "English" was selected)	120
Enter Number of Turbines:	1
Enter Loss Factor (%):	12
Display Frequency Distributions:	No
Calculate	

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Wind Turbine Calculator Output

Site Search

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Wind Turbine Output Results

	Average Speed (mph)	Air Density *	Average Wind Power Density (W/m2)	Capacity Factor (%)	Estimated Output for Period (kWh)
Annual	13.81	1.221	242	21.66	123,658
Jan	14.45	1.277	266	24.51	11,371
Feb	14.47	1.273	280	24.83	10,437
Mar	15.43	1.239	316	27.49	13,141
Apr	15.5	1.211	333	27.36	12,955
May	13.77	1.182	229	20.75	10,400
June	13.11	1.162	192	18.12	8,933
July	11.97	1.150	137	13.82	7,123
Aug	12	1.153	135	13.74	7,058
Sep	12.98	1.169	177	17.37	8,516
Oct	13.96	1.204	224	21.30	10,477
Nov	14.39	1.243	279	24.15	11,139
Dec	14.34	1.274	274	24.40	11,344

City: Sioux City **Turbine:** Vestas V15 65 kW **Tower Height:** 120 feet

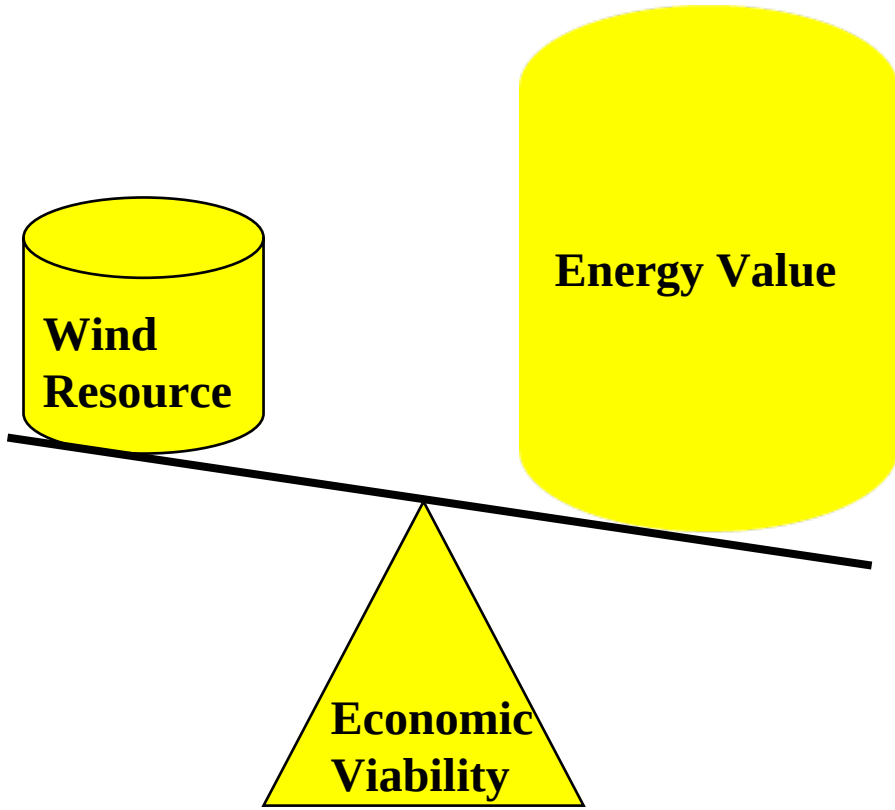
* Air densities are estimated from standard atmospheric densities corrected for the monthly average surface temperature and the elevation above sea level.

Wind Energy Costs

- **Capital costs are declining**
  - technology advancements
  - economies of scale
  - utility scale wind farms are competitive with new fossil fuel power plants ($0.041 - 0.045/kWh)
- **Installed costs**
  - small/residential (< 10 kW) - $2,500 - $3,800/kW
  - medium/commercial (10 – 300 kW) - $3,000 - $2,000/kW
  - large/utility scale (600 – 1,650 kW) - $1,500 - $900
- **Maintenance costs**
  - $0.005 - $0.01/kWh
  - increases with age of turbine

Wind Power Economic Viability

- **Economic viability is a function of:**
  - wind resource (mph)
  - value of energy ($/kWh)
- **Multiple scenarios**
  - high wind resource + high energy value
  - high wind resource + low energy value
  - low wind resource + high energy value
  - average wind resources + average energy value
- **Cost-to-Benefit Analysis**



Renewable Energy Financing

- **Alternate Energy Revolving Loan Program**
  - Zero-interest financing through Iowa Energy Center
- **Energy Bank Program**
  - Low-interest financing via Iowa Dept. of Natural Resources Energy Bureau
- **Federal wind production tax credit**
  - 1.9 cent/kWh inflation adjusted production tax credit for electricity produced by turbine owner
- **Federal Renewable Energy Production Incentive (REPI)**
  - 1.5 cent/kWh energy payment for local/state government entities
- **Local sales and property tax incentives**
- **USDA Grants – Renewable Energy Systems and Energy Efficiency Improvements Program**
  - Farm and Rural Investment Act of 2002
  - 25% cost share ($2,500 minimum and $500,000 maximum)
  - Annual solicitation
- **Iowa Wind Energy Production Tax Credit**

Alternate Energy Revolving Loan Program

AERLP Funds

- up to 50% of the financed project cost
- $250,000 maximum
- 0% interest rate
- 20 year maximum term
- negotiated repayment schedule
- repayments revolved back into fund for further loans

Lender Funds

- matching funds not less than AERLP
- market rate interest rate
- loan term not less than AERLP term
- repayment collection & distribution to AERLP

For More Information

- **Iowa Energy Center's Web site**

  http://www.energy.iastate.edu

- **Contact Energy Center**

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