Wind Farm Development

Wind Energy Science, Engineering, and Policy

NSF Research Experience for Undergraduates

Iowa State University, Ames, Iowa
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Photo by David Ausberger

What I will discuss….

- Wind Farm Development Steps
- Wind Resources
- Local Impacts of Wind Generation
- Grid Impacts for Distributed Wind Generation
- Economic Feasibility of Distributed Wind Generation

Wind Farm Development Steps

Photo by David Ausberger

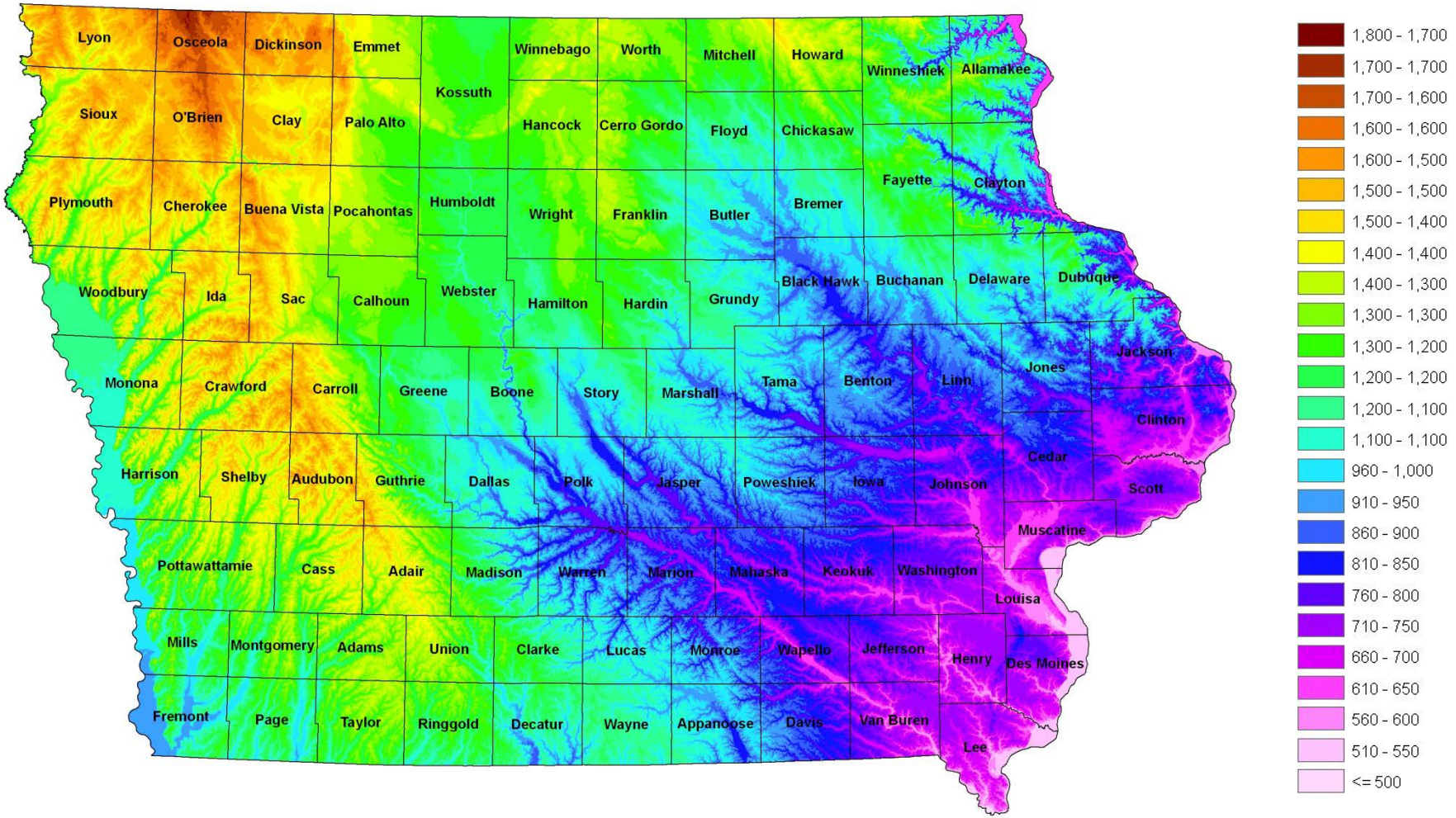
Typical Wind Project Development Process

This is not always a straight-forward process and the steps are not always in this order.
Sometimes the steps are repeated in an iterative fashion to optimize the economics of the project.

Wind Resources

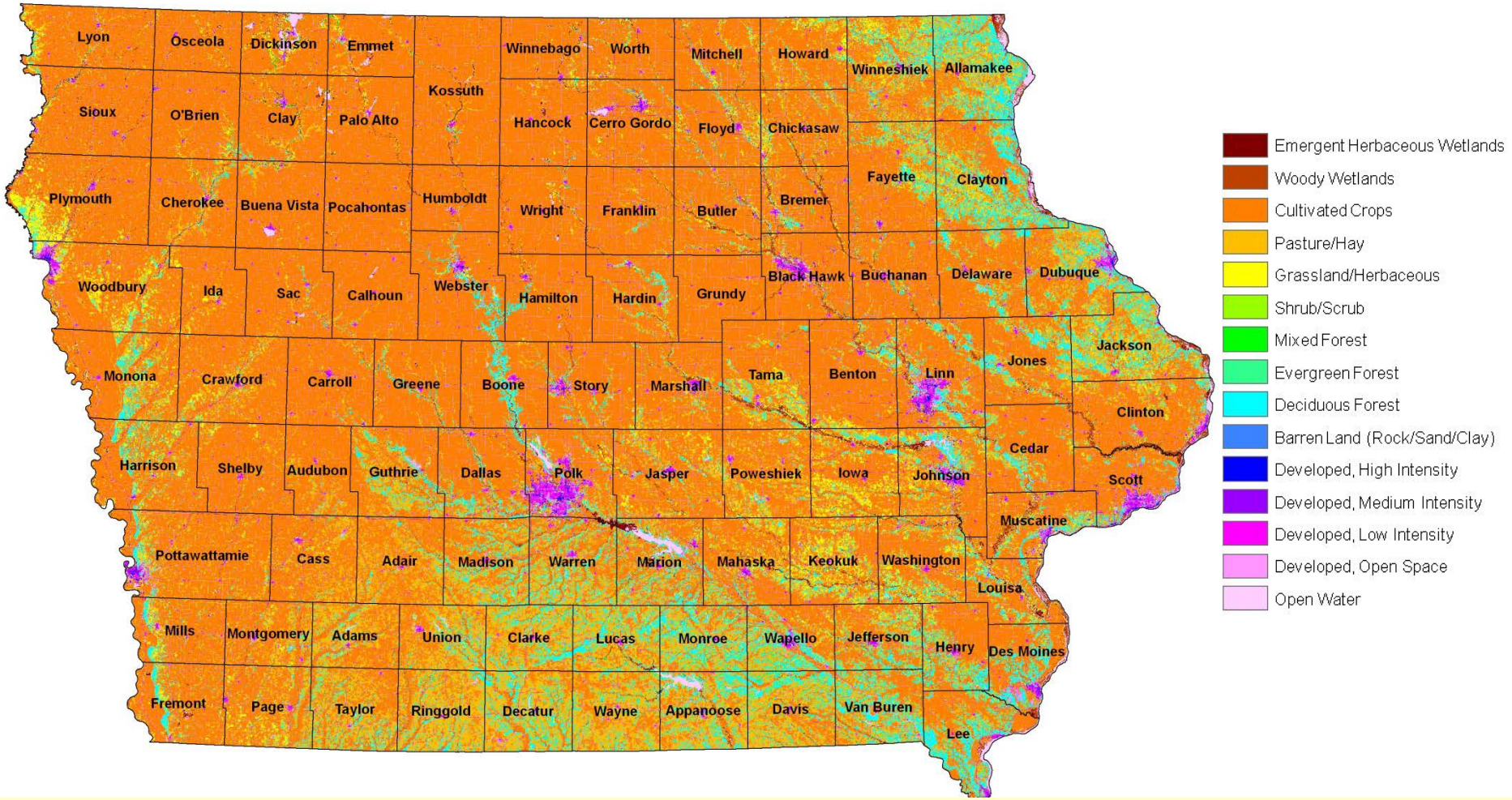
Photo by David Ausberger

Land Elevation in Iowa
in Feet Above Mean Sea Level



This map shows the ground elevation and is based on Digital Elevation Model data released by the United States Geological Survey.

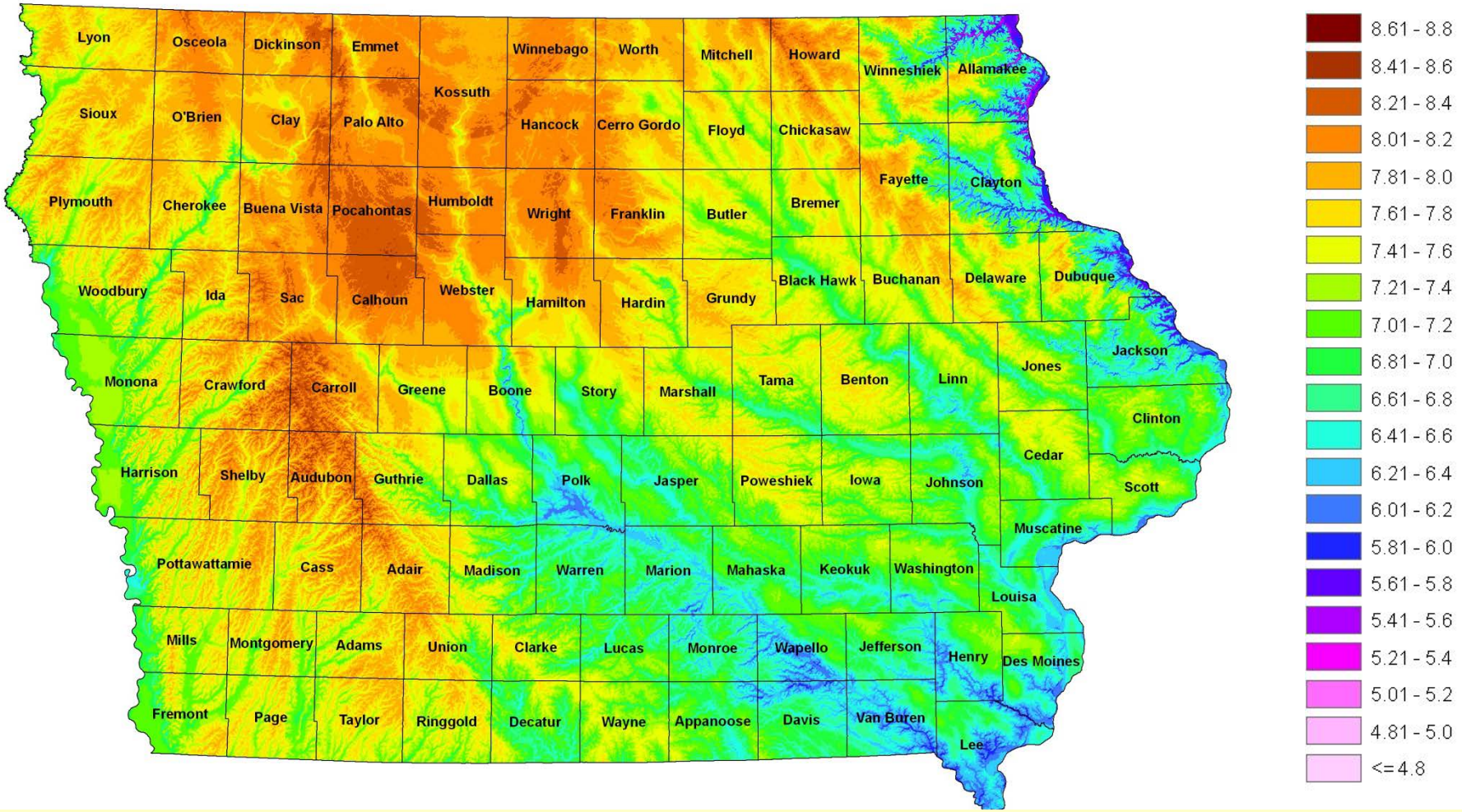
Land Cover in Iowa



Land Cover is converted to surface roughness, which varies from 0.0001 (calm sea) to 3.0 meters (center of city with tall buildings).
Iowa's surface roughness varies from about 0.03 to 1.0 meters.

This map shows the detailed land cover types and is from United States Geological Survey.

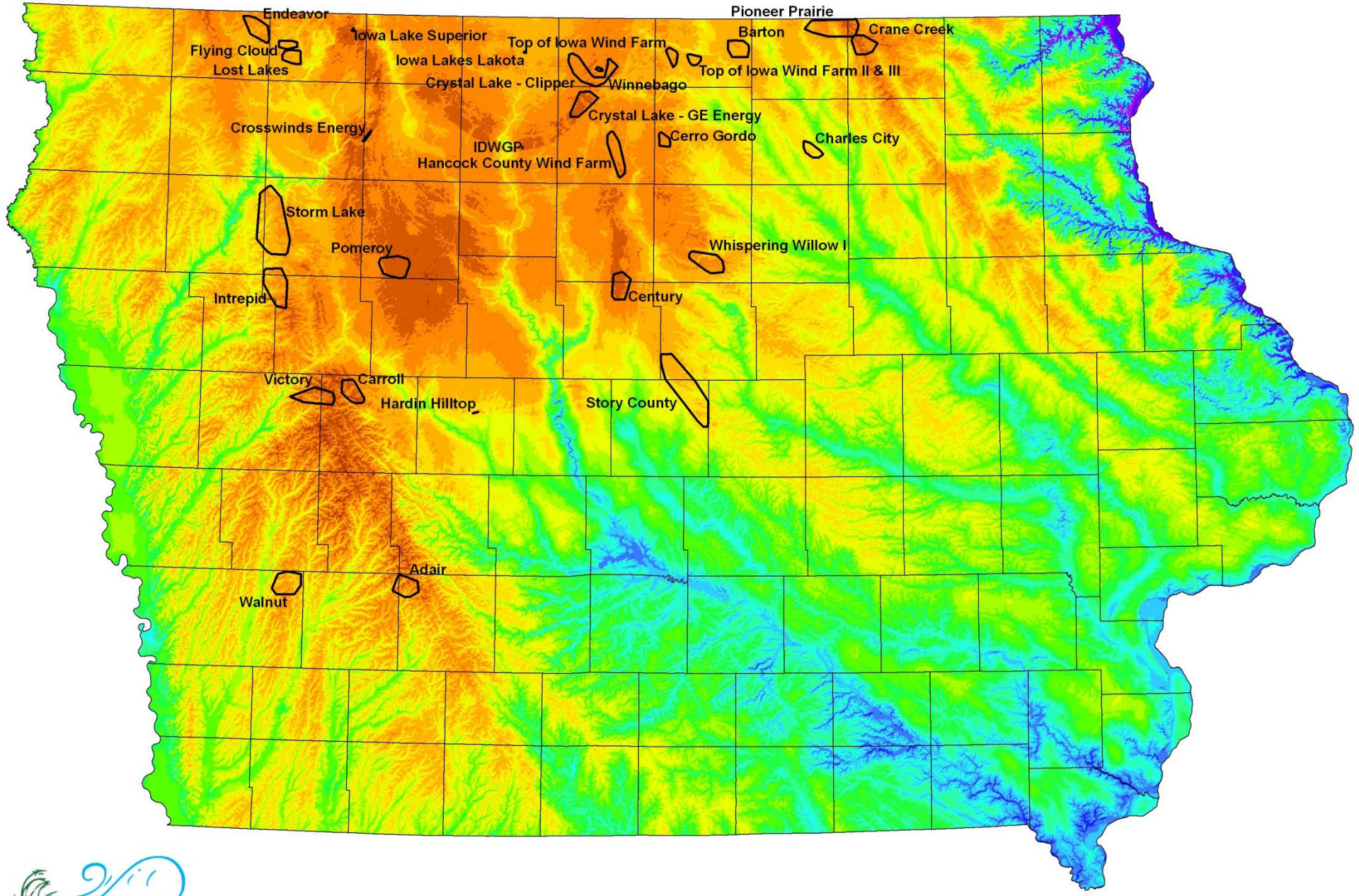
Mean Annual Wind Speed
in Meters per Second at an 80-Meter Height



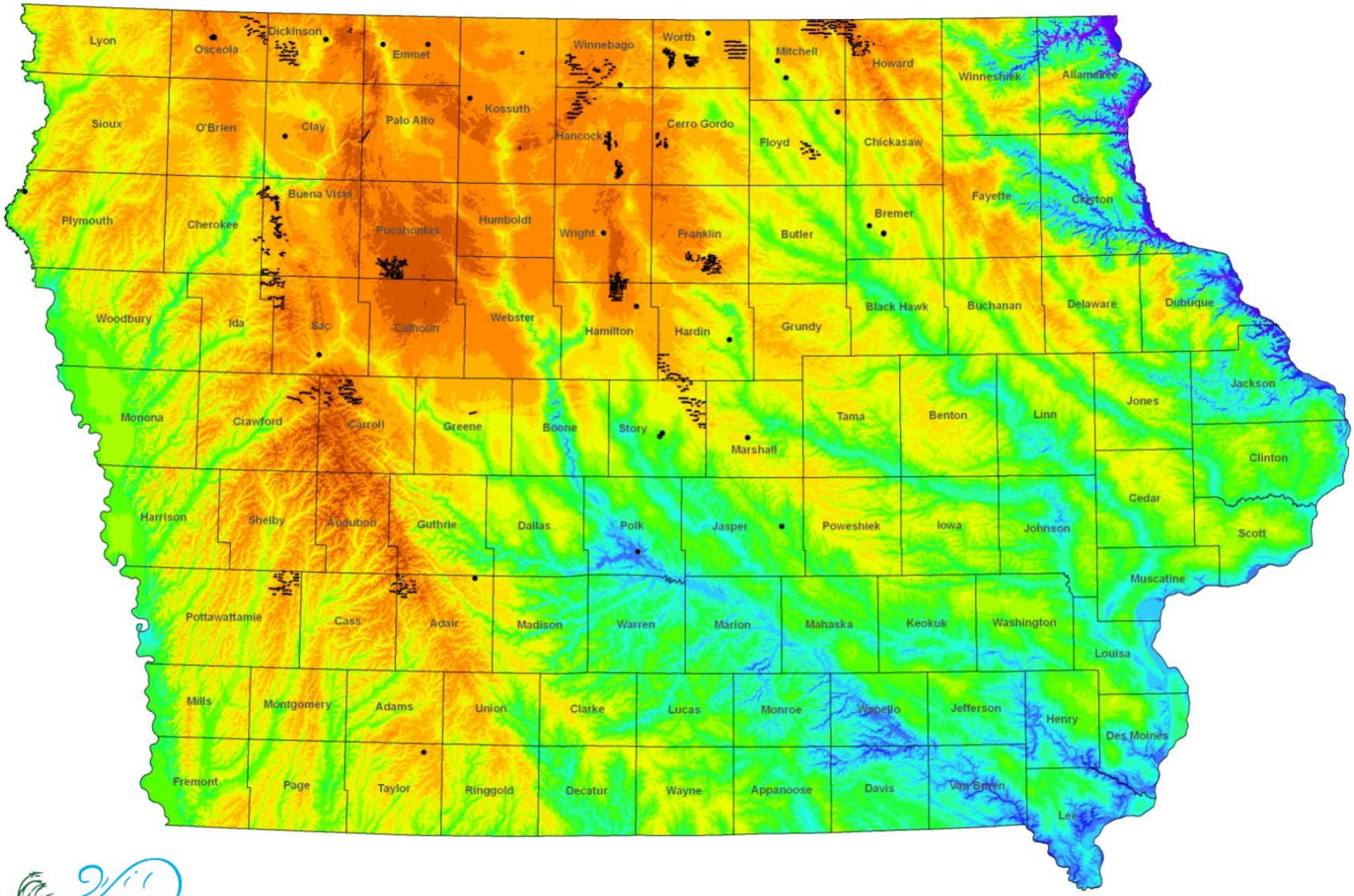
Surface Elevation and Land Cover along with Iowa's weather patterns determine the mean annual wind speed for any one location in Iowa

This is a low-spatial resolution (200-meter) mean annual wind speed map developed by AWS Truewind in 2010 for the Iowa Energy Center.

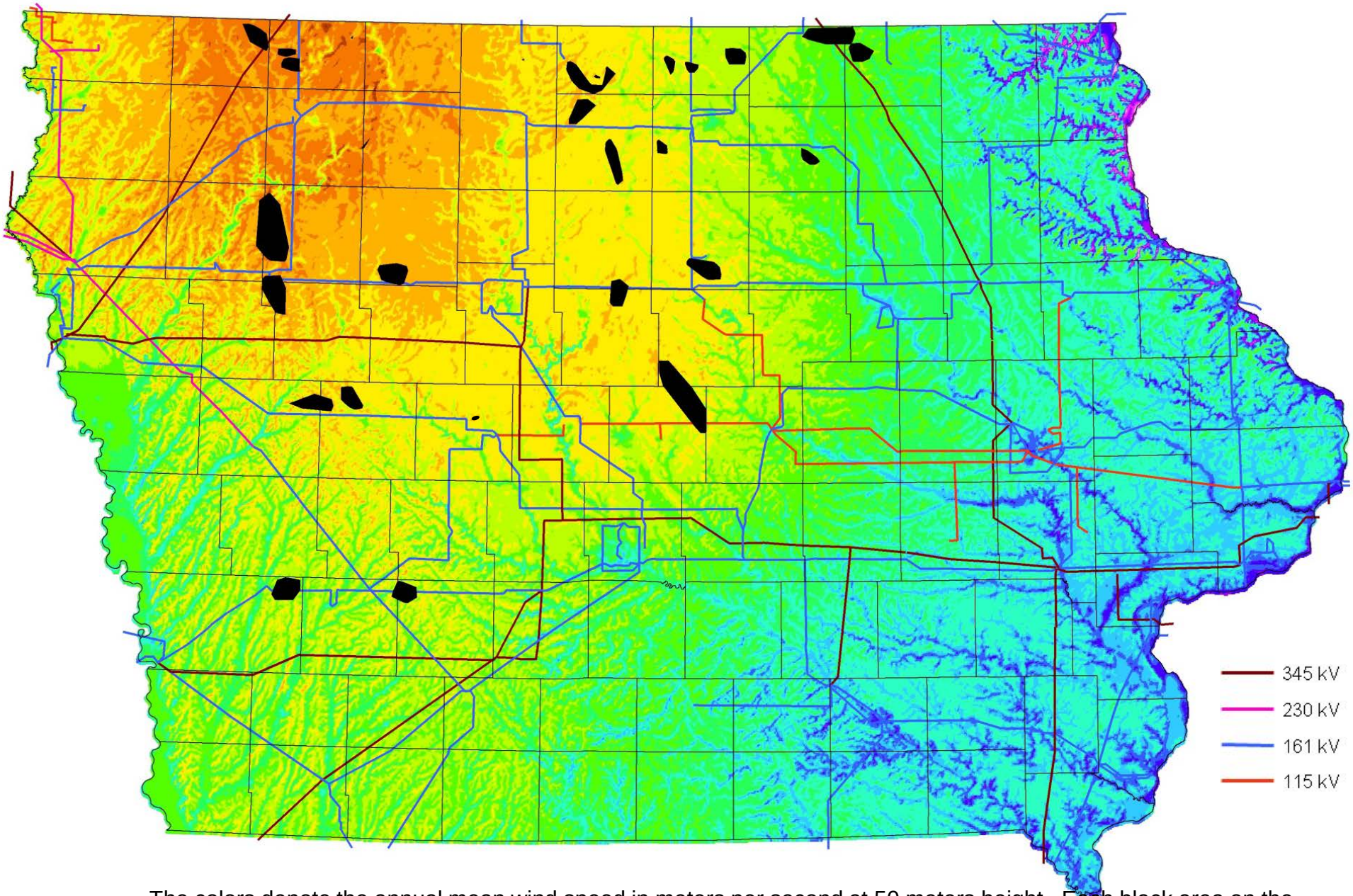
Wind Farms In Iowa



The Location of 2,500+ Large Wind Turbines In Iowa

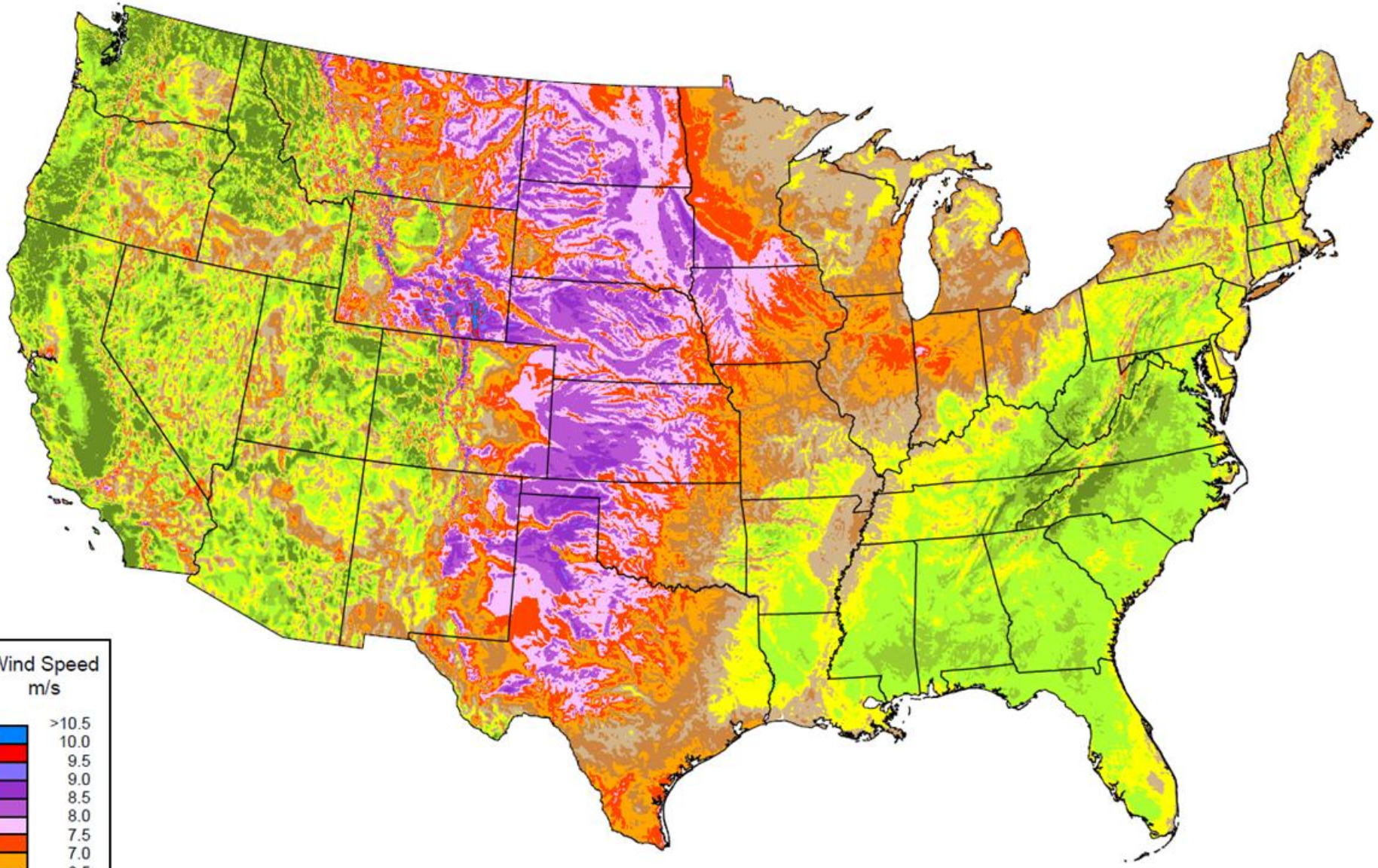


Locations of wind Farms in Iowa and the major high voltage transmission lines.



The colors denote the annual mean wind speed in meters per second at 50 meters height. Each black area on the map represents one or more larger wind turbines. Map by Wind Utility Consulting, PC, July 2010

United States - Annual Average Wind Speed at 80 m



Wind Speed
m/s

>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
< 4.0

Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.

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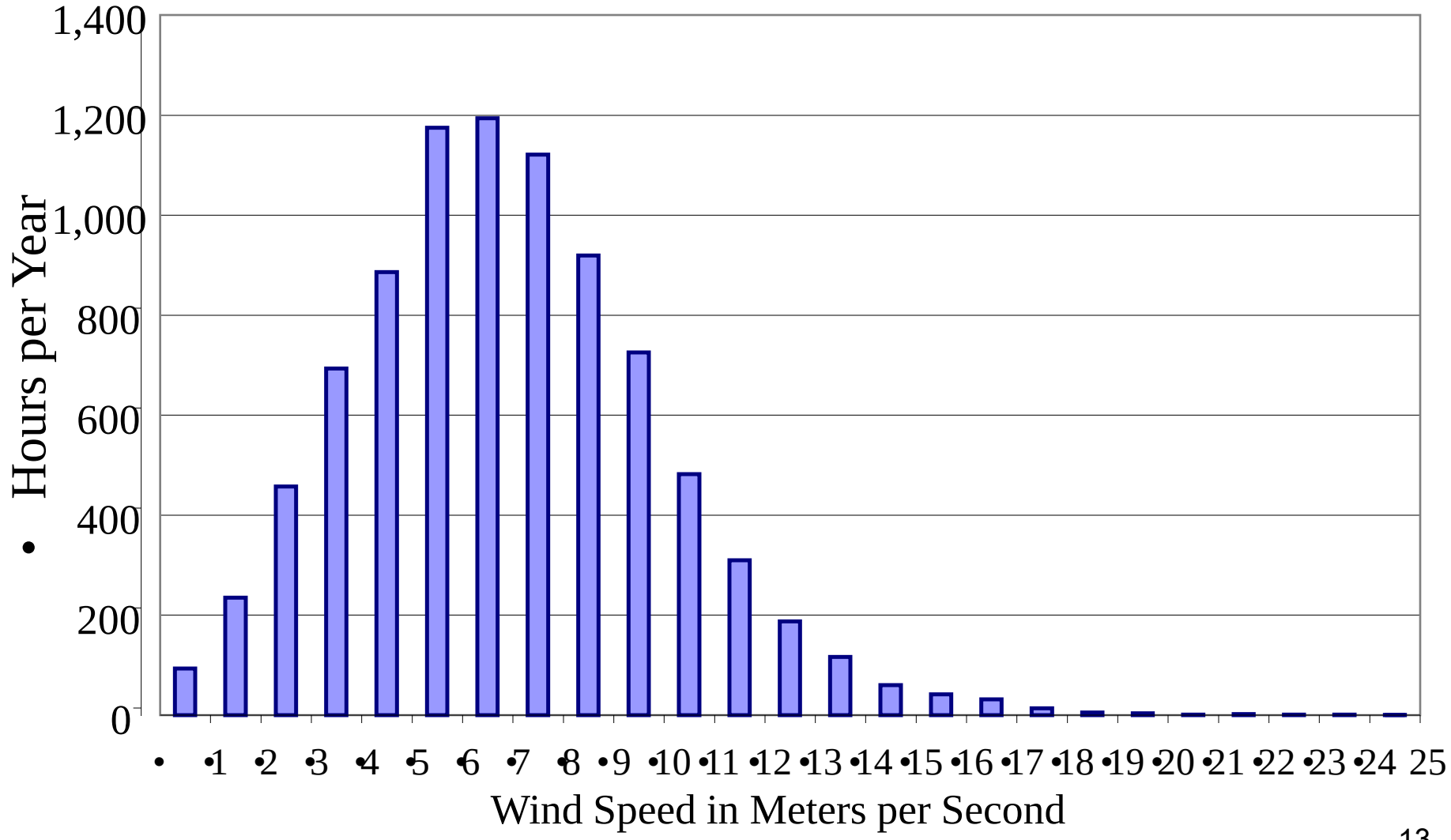
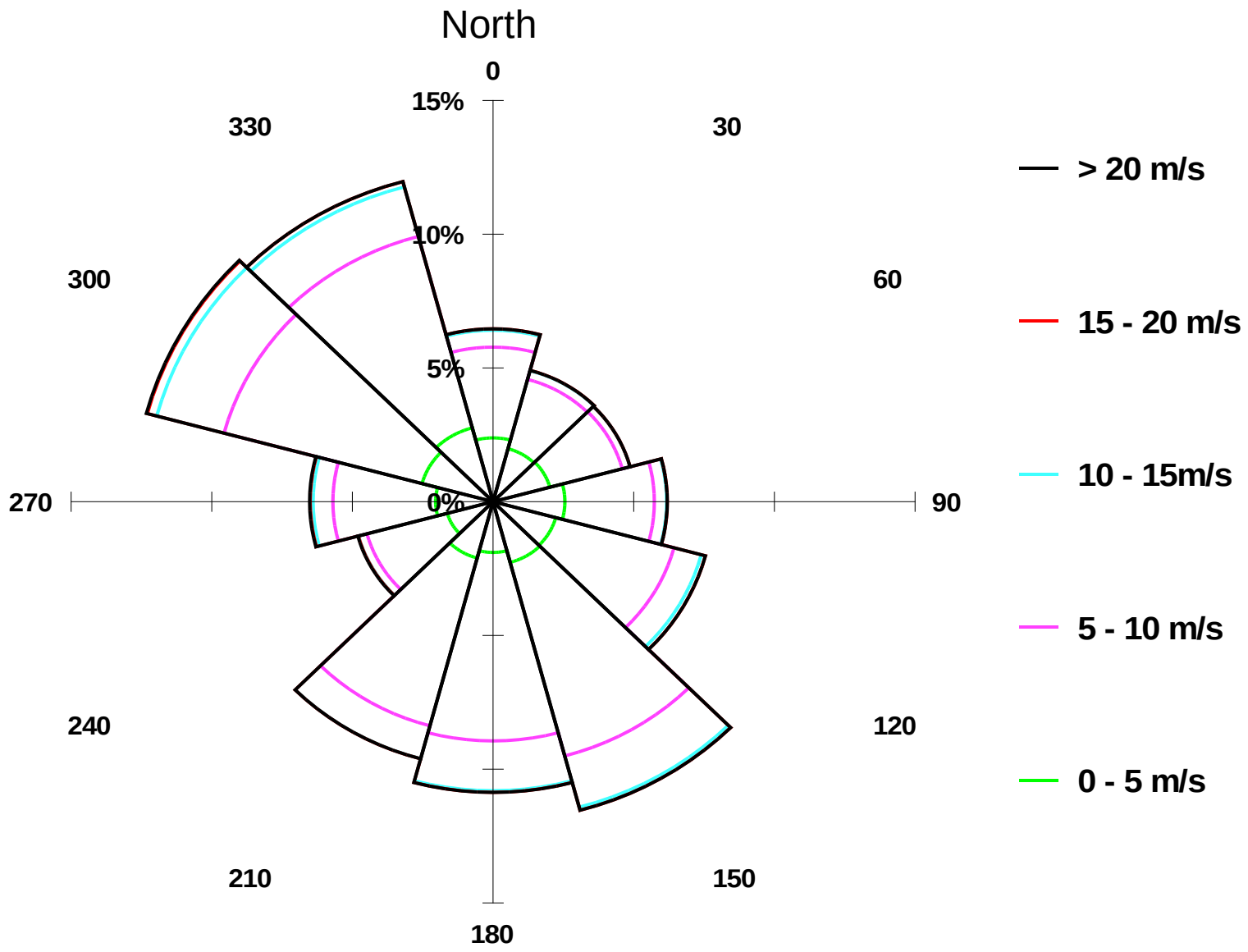
Wind Speed Bin Data

Hours per Year at Various Wind Speeds



Directional Wind Rose

Percentage of Time that the Wind Blows from a Certain Direction



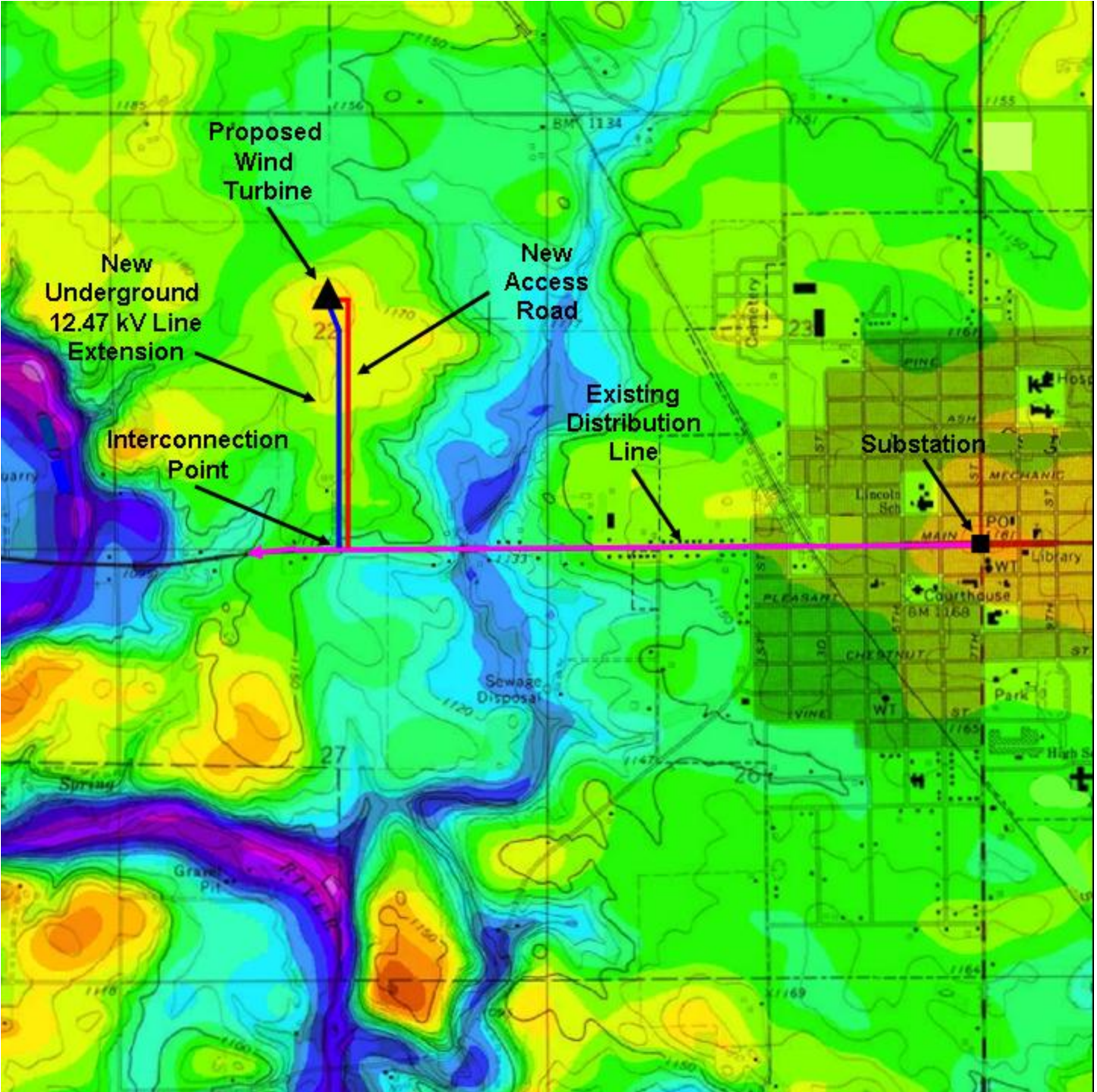
Local Impacts of Wind Generation

Photo by David Ausberger

Local Impacts of Wind Generation

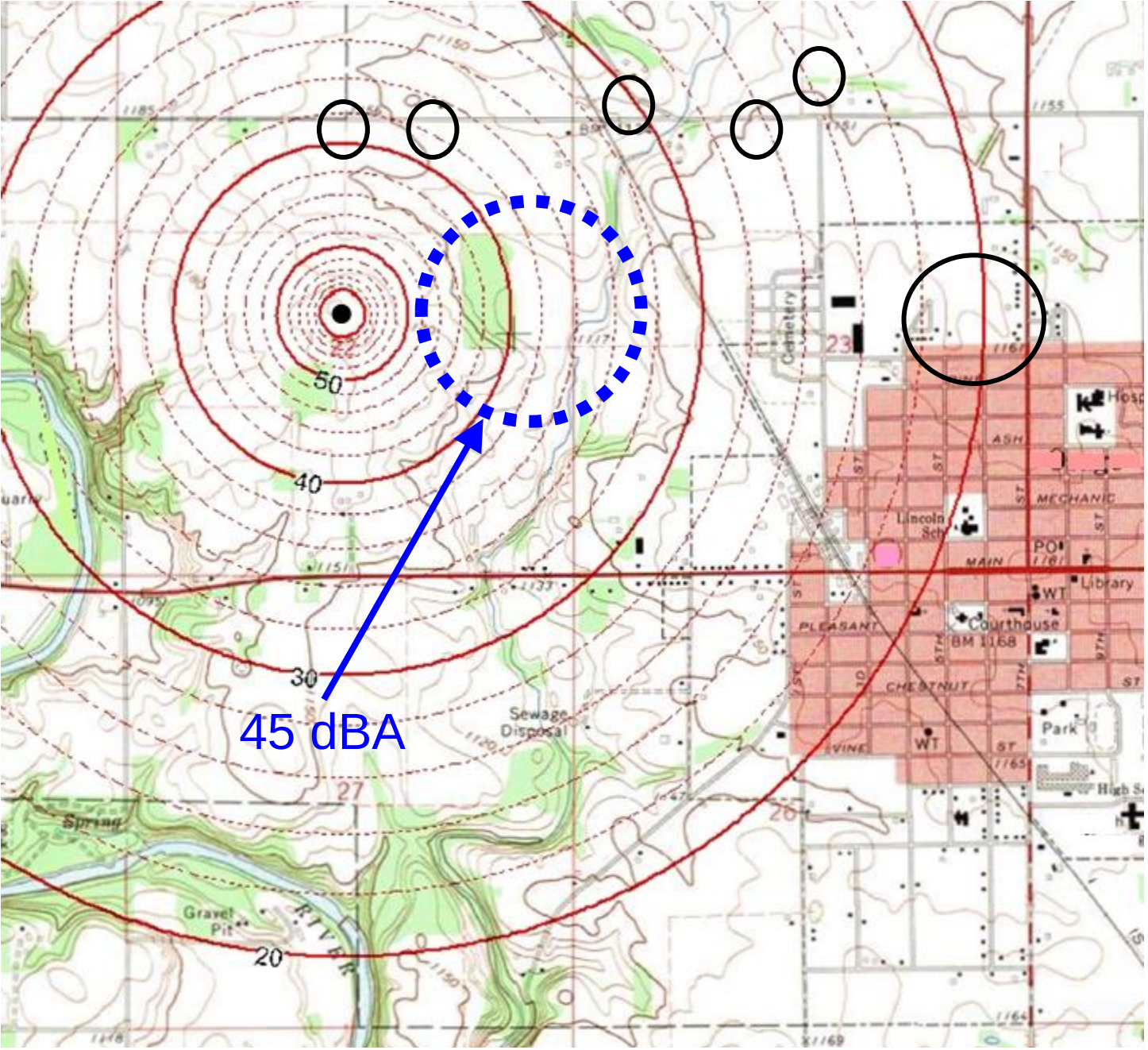
- Keeping an adequate distance from homes, property lines, roads is the key tool for minimizing local area impacts
- Noise levels at neighbors
- Shadow Flicker levels
- Visual Impact of proposed turbines
- Wildlife, wetlands, threatened species impact
- FAA Height restrictions due to nearby airports
- TV, radio, and microwave interference.

An Example of Siting Issues



Estimated Mean Annual Wind Speed in Meters per Second at a 50-Meter (164 feet) Height

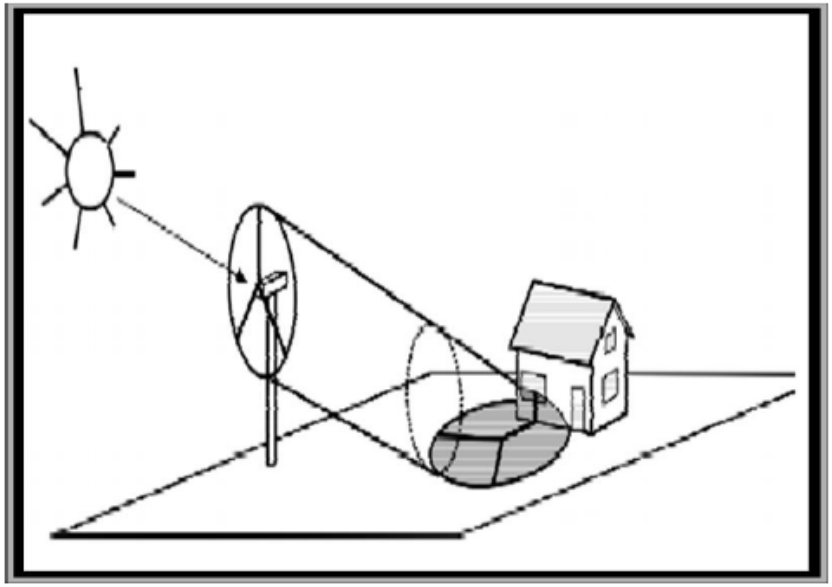
Projected Noise Level



Wind Turbines Add to the Ambient Noise Levels

Shadow Flicker

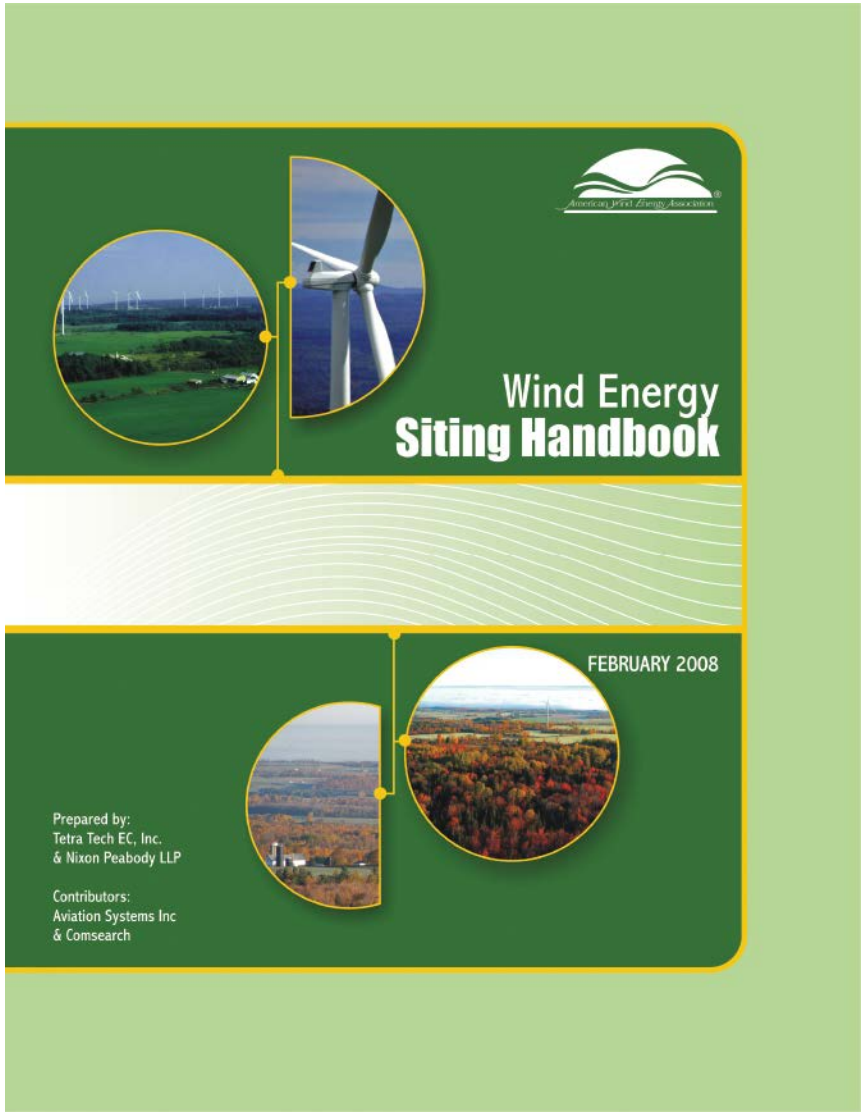
- Shadow flicker is caused when a wind turbine blade passes between the sun and the window of a home or business. As each blade rotates, it can cast a shadow on the window for a brief instant. The flickering shadows from the rotating blades can last from 90 minutes to less than 1 minute per day, depending upon the day of the year and the position of the window with respect to the wind turbine. The typical duration might be 30 minutes.

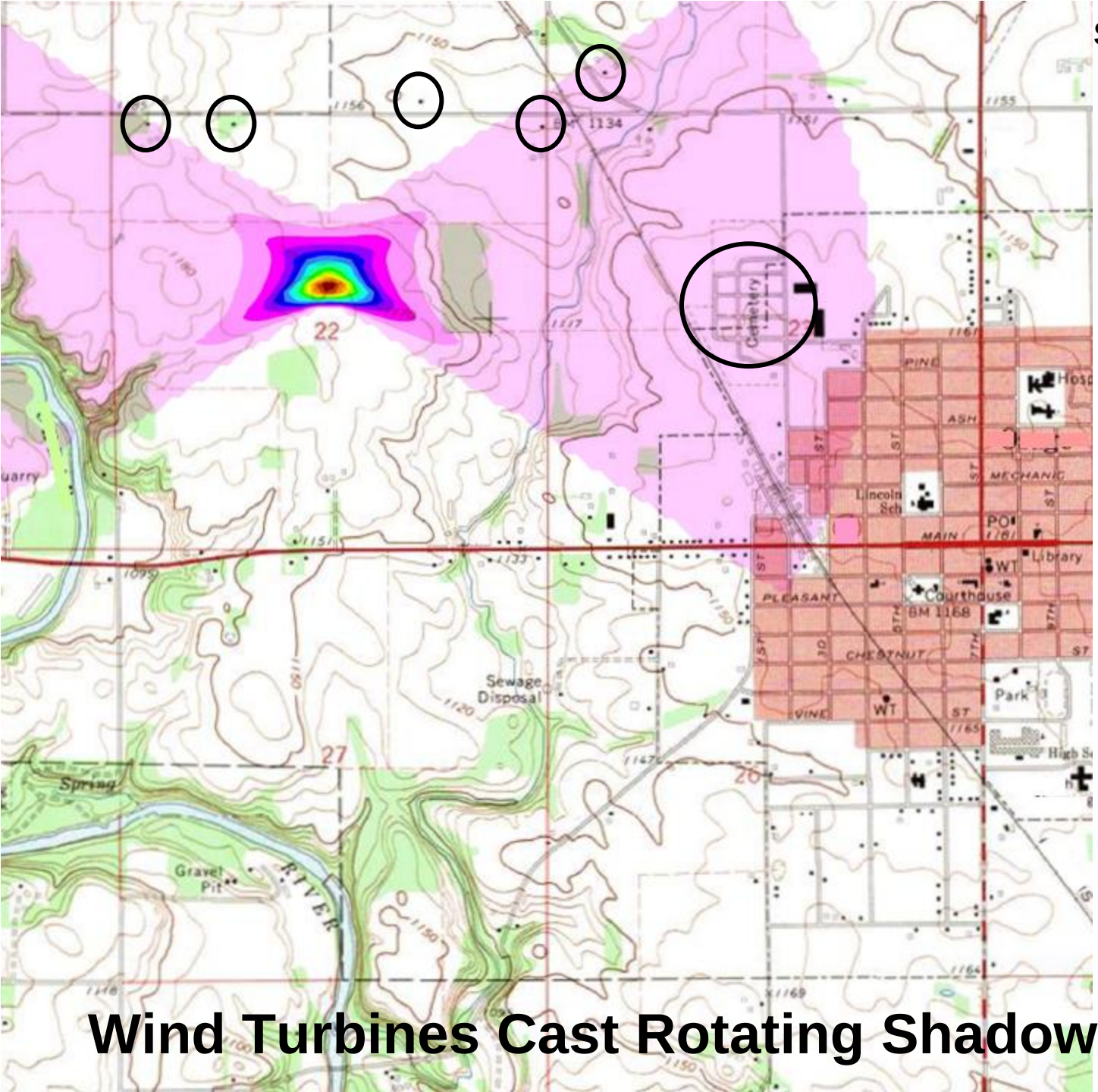


- Shadow flicker does not occur when the sun is obscured by clouds or fog, or when wind turbines are not operating, or when the blades are at a 90º angle to the receptor.

Shadow Flicker Guidelines

- The American Wind Energy Association Siting Handbook states:
  - *"While shadow flicker can be perceived outdoors, it tends to be more noticeable in rooms with windows oriented to the shadows. A wind turbine's shadow flicker impact area does not generally extend beyond 2 kilometers, and high-impact durations (>200 hours per year) are generally located within approximately 300 meters of the turbine."*
- *I recommend levels no higher than 50 hours per year after considering the reduction due to cloud cover.*





Shadow Flicker Levels in Hours per Year Based on No Cloud Cover

- 701 - 750
- 651 - 700
- 601 - 650
- 551 - 600
- 501 - 550
- 451 - 500
- 401 - 450
- 351 - 400
- 301 - 350
- 251 - 300
- 201 - 250
- 151 - 200
- 101 - 150
- 51 - 100
- <= 50

Wind Turbines Cast Rotating Shadows

TV, Radio, Microwave Interference

Analysis of Wind Farm Impacts on Nearby Communication Systems

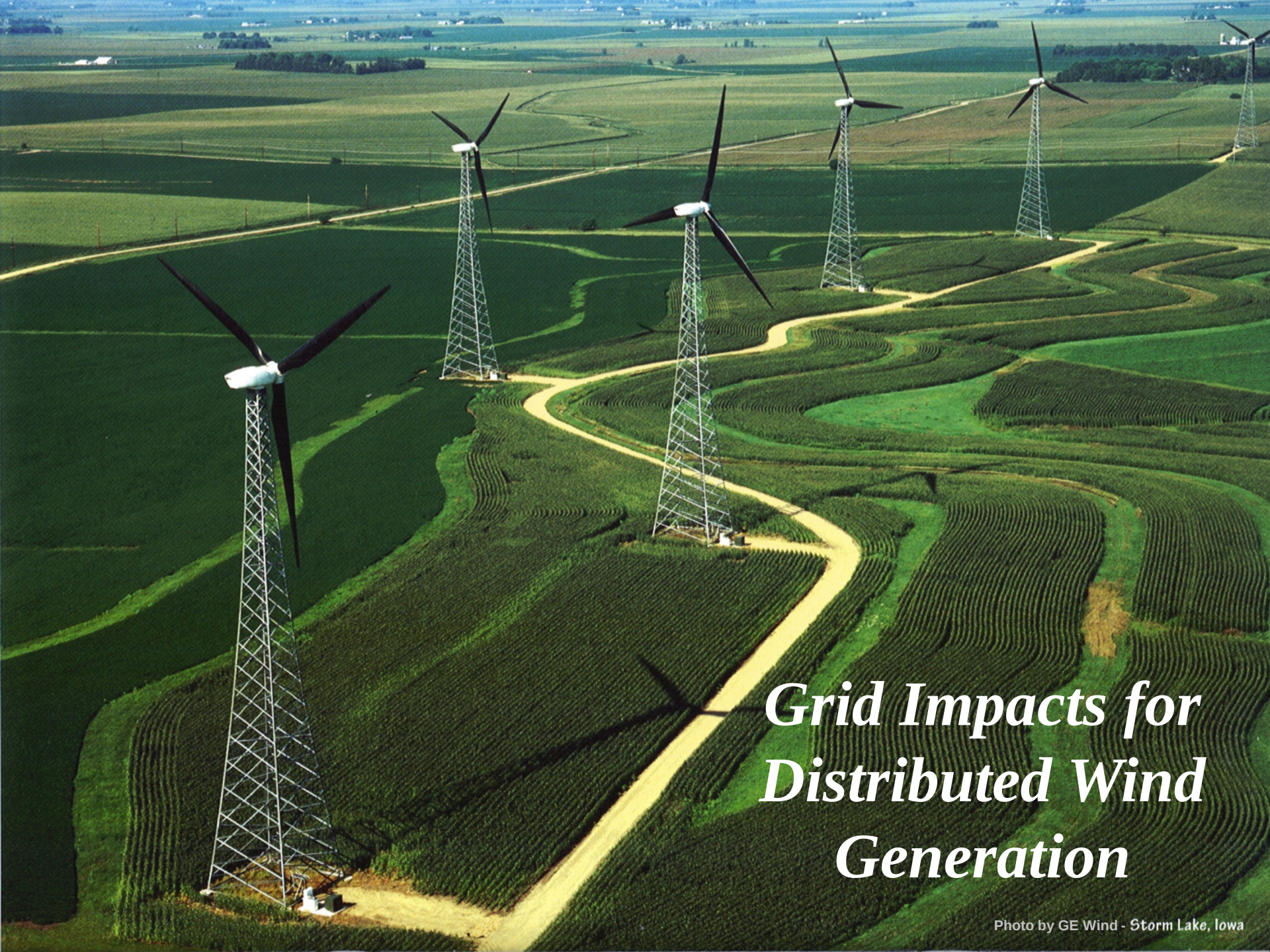
This map shows the location of all microwave transmitters and receivers within a 25 mile radius of the wind farm.

Only one microwave path goes through the wind farm. See the next diagram for a closer look.

Wind Turbine
FCC Site
Microwave Path

Wildlife Impacts

- In a typical Iowa wind farm, three birds are killed per wind turbine per year
- About twice that many bats are killed as birds
- This avian mortality is a very small fraction of other natural avian mortality
- In Iowa, a general rule of thumb is that wind turbine should be sited one mile or more from designated wild life areas


Grid Impacts for Distributed Wind Generation
Photo by GE Wind - Storm Lake, Iowa

Key Grid Interconnection Technical Issues

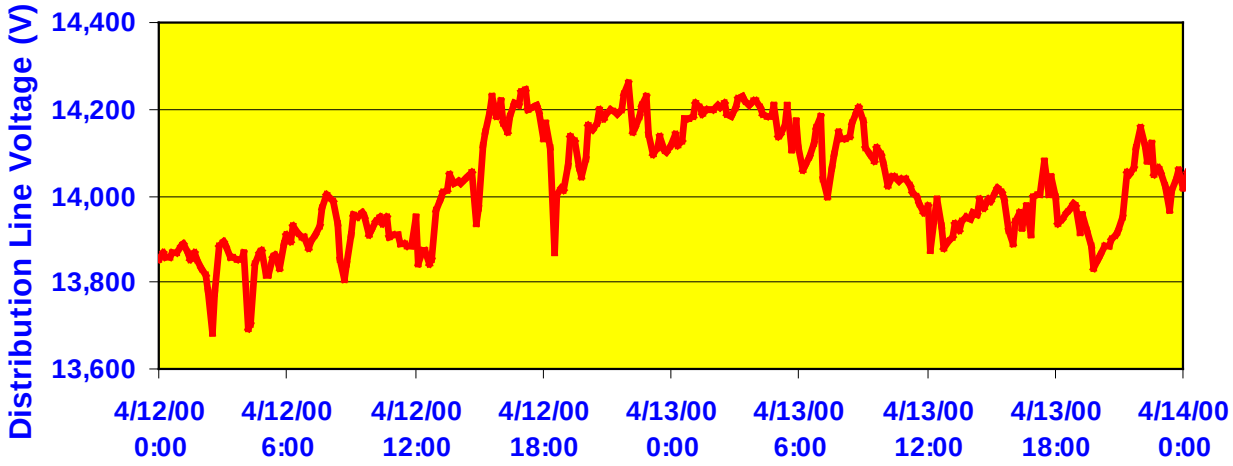
- Relative size of the wind turbine compared to the capability of the distribution grid
  - Voltage level of distribution grid
  - Distance from substation
  - Size of substation transformer
- Protecting the distribution grid and wind turbine during grid disturbances.

Key Technical Operational Issues

- If wind turbine supplied power to owner's facilities
  - Backfeeding
  - Standby or demand charges
- If wind power is sold wholesale to utility
  - Supervisory control and data acquisition for monitoring
  - Forced shutdowns for transmission grid problems.

Power Quality

- When a wind turbine starts up, there are current surges or transients
- These current surges cause the voltage on the distribution system to dip slightly
- Voltage dips can be annoying if they are severe or frequent
- Harmonics are not an issue with larger wind turbines.



Grid Impacts for Distributed Wind Generation

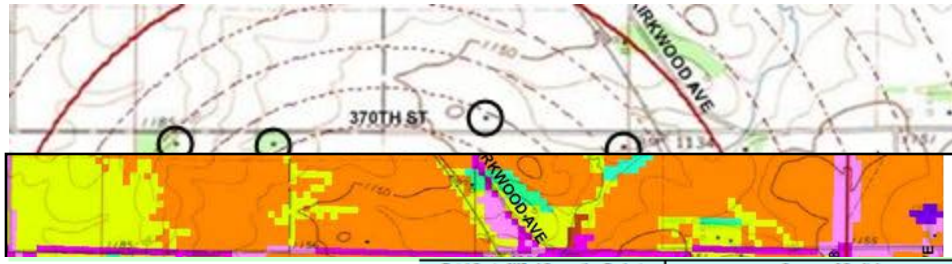
Photo by Donna Sutton

Factors Affecting Wind Project Economics

- The most important and influential factor is the wind speed.
- The second-most important factor is the Power Bill Savings or the Power Purchase Agreement.
- The other important factors affecting the project economics are:
  - Tax credits, grants and incentives
  - Wind turbine costs
  - Interconnection cost
  - Interest rates and ROE.

Key Steps in Feasibility Analysis

- Finding a site
  - Wind speed
  - FAA
  - Impact on Neighbors
  - Environmental Impact
- Electrical Interconnection
- Financial Feasibility
  - Selling price of power
  - Financial structure
  - Income tax benefits
  - Grants, subsidies
  - Financial returns
- Analysis is often an iterative process



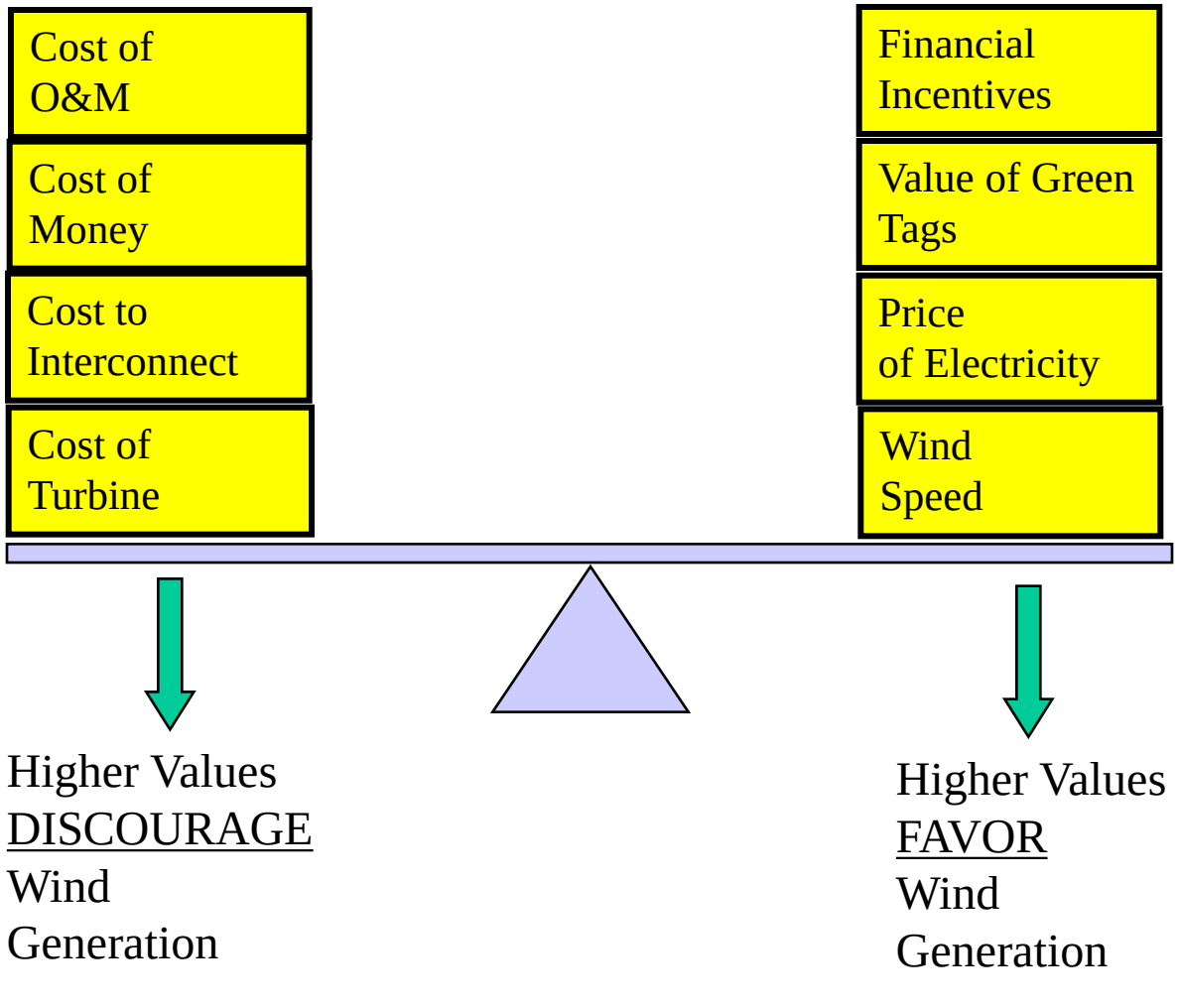
Land Cover Data Around the City of Osage

Total Cost of Wind Generation Project			Sources of Capital			Loan and Other Information	
$ 2,401,750	Wind Turbine, Delivered	$ -	0.0%	Secondary Investor Investment	5.00%	Comm. Loan Interest Rate	
$ 605,000	Balance of Plant	$ 125,156	3.7%	Primary Investor Investment	15	Comm. Loan Term, in years	
$ 85,100	Interconnection, Cable, Roads	$ 500,000	14.7%	USDA / Other Grants	1	Comm. Loan Payments per Yr.	
$ 97,500	Soft Costs (IDC, WC, Eng, Legal	$ 350,000	10.3%	AERLP Loan	10	IDC Loan Term, in years	
$ 159,300	Contingencies	$ 1,520,428	45.0%	Commercial Loan	$ 25,000	Initial Extra Ann. Principal Pmt.	
$ 3,348,506	Total Capital Cost	$ 880,921	26.3%	Bridge Loan			
$ 50,000	Financial Reserves	$ 3,396,506	100.0%	Total Wind Project Cost	2.5%	General Inflation Rate	
$ 3,398,506	Total Wind Project Cost				3.5%	O&M Escalator Rate	
					$0.00000	Production Based Taxes	
					25.0	Property Tax Millage Rate	

Note This Simplified Cash Flow Analysis Assumes a Full Year of Operation the First Year.

Years to Get Primary Investor's Money Back	12	0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Minimum Debt Service Coverage Ratio	1.35	0.24	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
OPERATING REVENUE												
Projected Annual Net Energy Generated	kWh		5,293,037	5,293,037	5,293,037	5,282,451	5,271,865	5,261,278	5,250,692	5,240,106	5,229,520	5,218,934
Rate for Sale of Energy	$ / kWh		$0.0500	$0.0500	$0.0500	$0.0500	$0.0500	$0.0500	$0.0500	$0.0500	$0.0500	$0.0500
Revenue from Sale of Energy to Utility	$		$ 264,652	$ 264,652	$ 264,652	$ 264,123	$ 263,593	$ 263,064	$ 262,535	$ 262,005	$ 261,476	$ 260,947
Rate for Sale of Green Tags	$/kWh		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Revenue from Green Tags	$		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Federal 1603 Treasury Grant (Non Taxable)			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Operating Revenue	$		$ 264,652	$ 264,652	$ 264,652	$ 264,123	$ 263,593	$ 263,064	$ 262,535	$ 262,005	$ 261,476	$ 260,947
EXPENSES												
Maintenance Service Contract	$		$ 25,650	$ 26,548	$ 27,477	$ 28,439	$ 29,434	$ 30,464	$ 31,530	$ 32,634	$ 33,776	$ 34,958
Local Operation Labor	$		$ 5,000	$ 5,175	$ 5,356	$ 5,544	$ 5,738	$ 5,939	$ 6,146	$ 6,361	$ 6,584	$ 6,814
Secondary Investor Management Fee	$		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Property, Business Interruption, & Liability Insurance	$		$ 13,210	$ 13,540	$ 13,878	$ 14,225	$ 14,581	$ 14,945	$ 15,319	$ 15,702	$ 16,095	$ 16,497
	$											
Repair and Replacement Equipment Reserve / Warranty Fund	$		$ 44,000	$ 44,000	$ 44,000	$ 44,000	$ 44,000	$ 44,000	$ 44,000	$ 44,000	$ 44,000	$ 44,000
Decommissioning Escrow	$		$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000
Professional Services / Management	$		$ 5,000	$ 5,125	$ 5,253	$ 5,384	$ 5,519	$ 5,657	$ 5,798	$ 5,943	$ 6,092	$ 6,244
Miscellaneous & Other	$		$ 1,000	$ 1,025	$ 1,051	$ 1,077	$ 1,104	$ 1,131	$ 1,160	$ 1,189	$ 1,218	$ 1,249
Land Lease, Total Dollars	$		$ 7,000	$ 7,175	$ 7,354	$ 7,538	$ 7,727	$ 7,920	$ 8,118	$ 8,321	$ 8,529	$ 8,742
Production or PropertyTaxes	$		$ -	$ 4,173	$ 8,426	$ 12,779	$ 17,167	$ 21,711	$ 26,344	$ 26,577	$ 26,842	$ 27,111
Total Operating Expenses	$		$ 101,860	$ 107,760	$ 113,795	$ 119,977	$ 126,299	$ 132,767	$ 139,395	$ 141,727	$ 144,137	$ 146,616
DEBT SERVICE & NET INCOME												
Beginnig of Year Loan Balance	$		$ 1,520,428	$ 1,432,596	$ 1,336,797	$ 1,240,648	$ 1,144,567	$ 1,047,757	$ 950,214	$ 851,723	$ 752,057	$ 650,979
Normal Principal Portion of Commercial Loan Payment	$		$ 70,831	$ 74,372	$ 78,091	$ 81,996	$ 86,095	$ 90,400	$ 94,920	$ 99,666	$ 104,649	$ 109,882
Extra Principal Payment Made	$		$ 25,000	$ 21,429	$ 17,057	$ 14,286	$ 10,714	$ 7,143	$ 3,571	$ (0)	$ (3,571)	$ (7,143)
Total Principal Portion of Commercial Loan Payment	$		$ 95,831	$ 95,801	$ 95,948	$ 96,281	$ 96,810	$ 97,543	$ 98,492	$ 99,666	$ 101,078	$ 102,739
Interest Portion of Commercial Loan Payment	$		$ 76,421	$ 71,630	$ 66,040	$ 62,042	$ 57,228	$ 52,366	$ 47,511	$ 43,596	$ 37,803	$ 32,549
Total Commercial Loan Pmt. (Based on 1 pmts./year)	$		$ 172,252	$ 167,431	$ 162,788	$ 158,324	$ 154,038	$ 149,931	$ 146,002	$ 143,262	$ 138,881	$ 135,288
End of Year Loan Balance	$		$ 1,432,596	$ 1,336,797	$ 1,240,648	$ 1,144,567	$ 1,047,757	$ 950,214	$ 851,723	$ 752,057	$ 650,979	$ 548,240
AELRP Loan Repayment (Zero Interest)	$		$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000
Bridge Loan Principal Payment	$		$ 892,921	$ -								
Bridge Loan Interest Payment at 7.0% for 14 Months	$		$ 36,461	$ -								
Total Loan Payments	$		$ 1,136,634	$ 202,431	$ 197,788	$ 193,324	$ 189,038	$ 184,931	$ 181,002	$ 177,262	$ 173,881	$ 170,288
Net Cash From Operations			$ (873,042)	$ (45,539)	$ (48,935)	$ (49,178)	$ (51,744)	$ (54,634)	$ (57,853)	$ (56,974)	$ (56,341)	$ (55,957)
Sale of State Production Tax Credit (PTC)	$0.0135		$ 71,456	$ 71,456	$ 71,456	$ 71,313	$ 71,170	$ 71,027	$ 70,884	$ 70,741	$ 70,599	$ 70,456
State PTC Allocated to Secondary Investor	0.0%	-	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
State PTC Allocated to Primary Investor	100.0%	-	$ 71,456	$ 71,456	$ 71,456	$ 71,456	$ 71,313	$ 71,170	$ 71,027	$ 70,884	$ 70,741	$ 70,599
	Pre Flip	Post Flip										
Total Cash Allocated to Secondary Investor	0.0%	0.0%	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Cash Allocated to Primary Investor	100.0%	100.0%	$ (902,598)	$ 25,917	$ 24,521	$ 22,278	$ 19,570	$ 16,536	$ 13,174	$ 13,910	$ 14,400	$ 14,641
Cash Available to Cover Debt Service (Incl. Mngmt Fee, R&R)			$ 270,248	$ 272,347	$ 266,309	$ 259,602	$ 252,600	$ 245,467	$ 238,177	$ 235,183	$ 232,061	$ 228,929
Debt Service Coverage Ratio			0.24	1.35	1.35	1.34	1.34	1.33	1.32	1.33	1.34	1.34

The Overall Economics of Wind Generation is Determined by a Balance of Factors



Financial Pro Forma Economic Analysis

- **Operating Revenues**
  - Revenue or Power Bill Savings
  - Sale of Green Tags
  - Production Incentives
- **Operating Expenses**
  - Operation and Maintenance expense
  - Insurance
  - Property taxes
  - Land Lease (if any)
  - Depreciation
- **Loan payments**
- **Income Tax Calculations**

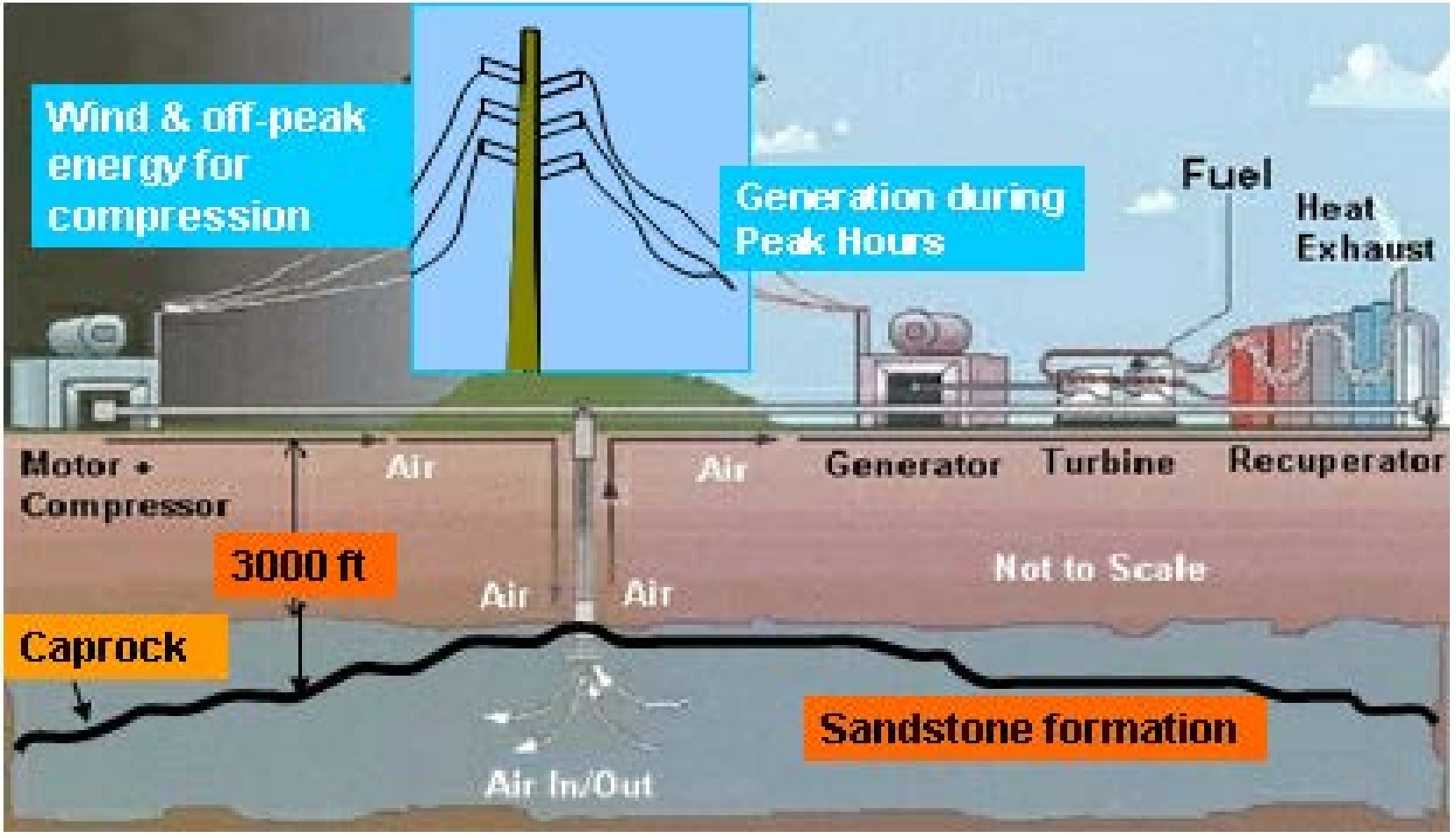
Wind Turbines on the Buffalo Ridge in Southwestern Minnesota

Buffalo Ridge Minnesota from 10,000 feet…… Wind Turbines as Far as the Eye Can See

The Proposed Iowa Stored Energy Park

This power plant would use electricity off-peak to compress air which would be stored underground in an aquifer, much like natural gas is stored near Redfield, Iowa. When electricity is needed during the daytime, the air is released and heated with natural gas to power combustion turbines to generate electricity.

THE IOWA STORED ENERGY PARK



CAPTURING THE POWER OF NATURE

Photo by David Ausberger