Site Selection and Energy Assessments for a Financeable Project

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Outline

Photo by David Parsons, courtesy of DOE/NREL

- Site Selection
- Wind Characteristics
- Measuring the Resource
- Energy Estimates and Uncertainty Analysis
- Conclusions

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Site Selection

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Siting Considerations

- Location, location, location
- Accessibility
  - Resource assessment
  - Construction
  - Operations
- Transmission access
  - Capacity on lines
  - Right-of-way to line
- Construction compatibility
  - Lay-down areas
  - Subassembly areas
  - Crane access and mobility

Photo by Waverly Light & Power, courtesy of DOE/NREL

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Siting Considerations (Cont.)

- Location, location, location
- Electricity market
  - Pricing and price security
  - Market structure
  - Market access
- Environmental compatibility
  - Avian
  - Endangered species
  - Erosion
- Cultural compatibility
  - Noise
  - Visual impact
  - Culturally significant location
- Exposure to wind resource

Photo by Corey Babcock, courtesy of DOE/NREL

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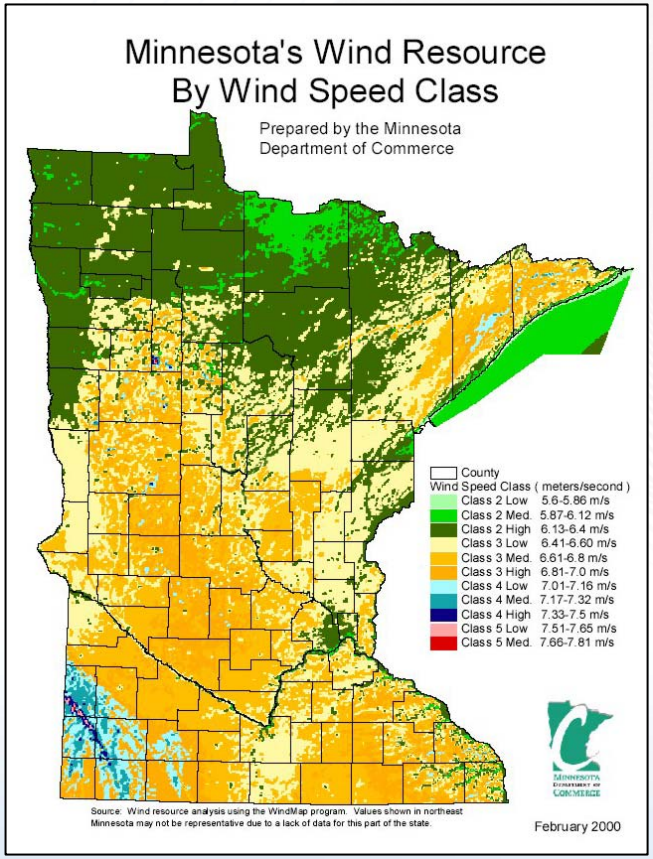
Locating Windy Sites

- Wind maps
- Regional wind atlases
- Biological indicators
- Environmental monitoring data
- Local knowledge
- Geographic/social references
- Proprietary localized wind maps



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Wind Characteristics

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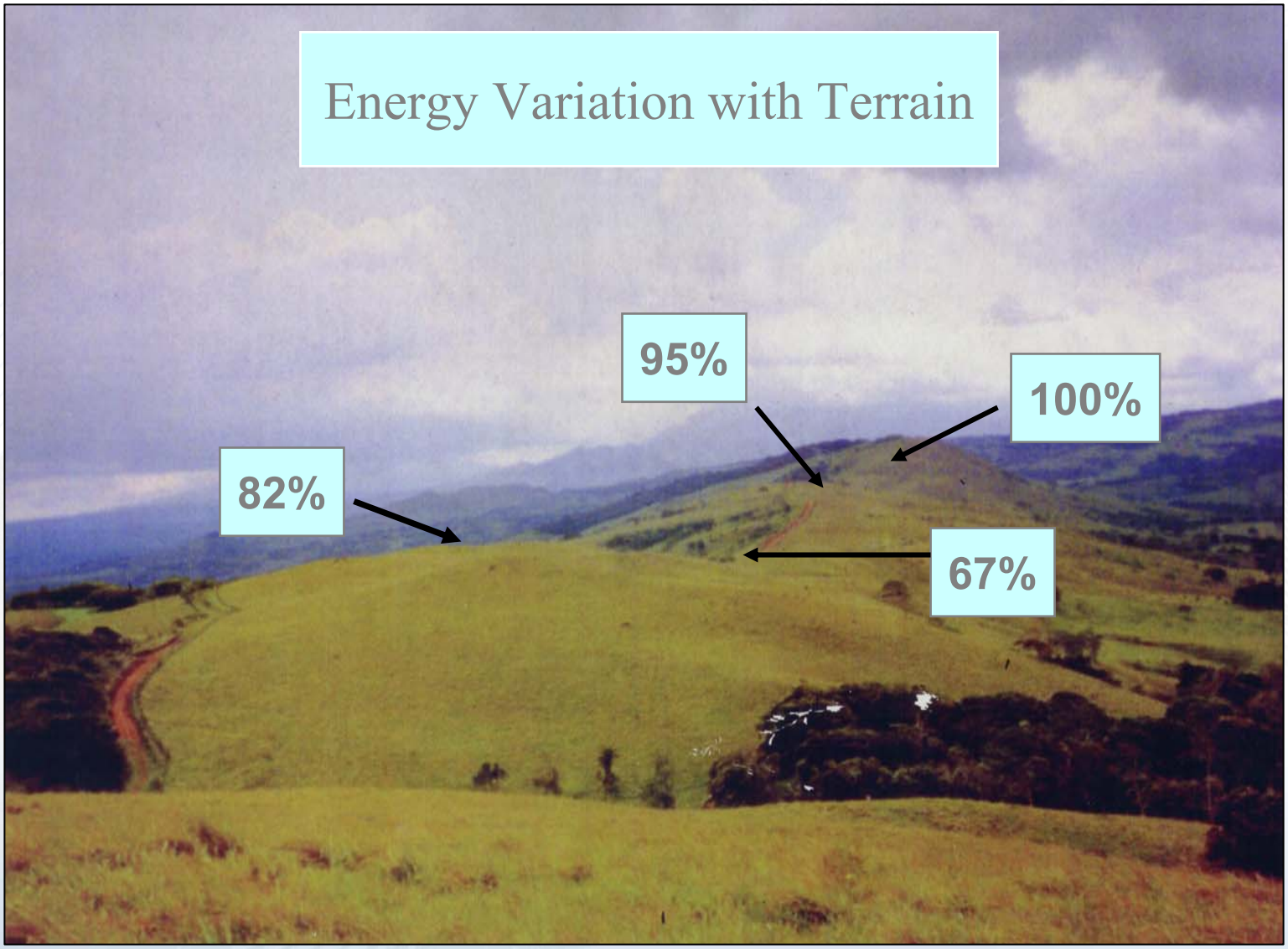
Energy Variation with Terrain



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Winds Change with Height–Shear

- Measurements from low levels are extrapolated upwards

$$[v_2 = v_1 * (h_2/h_1)^{\alpha}]$$

α= Wind Shear Exponent

- Typical shear exponent: 0.14
- Range from 0.1 to 0.3 is common

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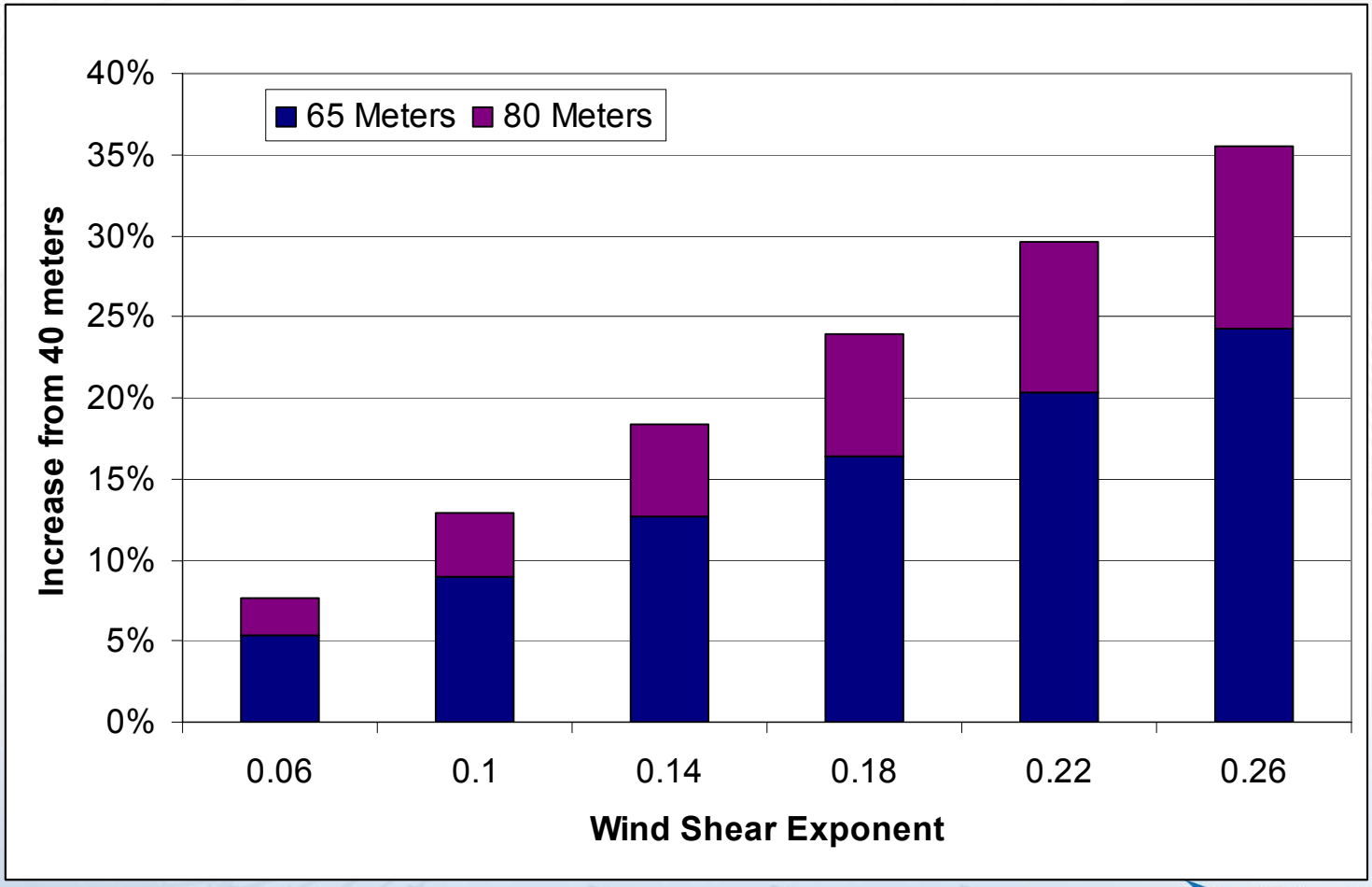
Shear Example

Increase in Wind Energy with Height



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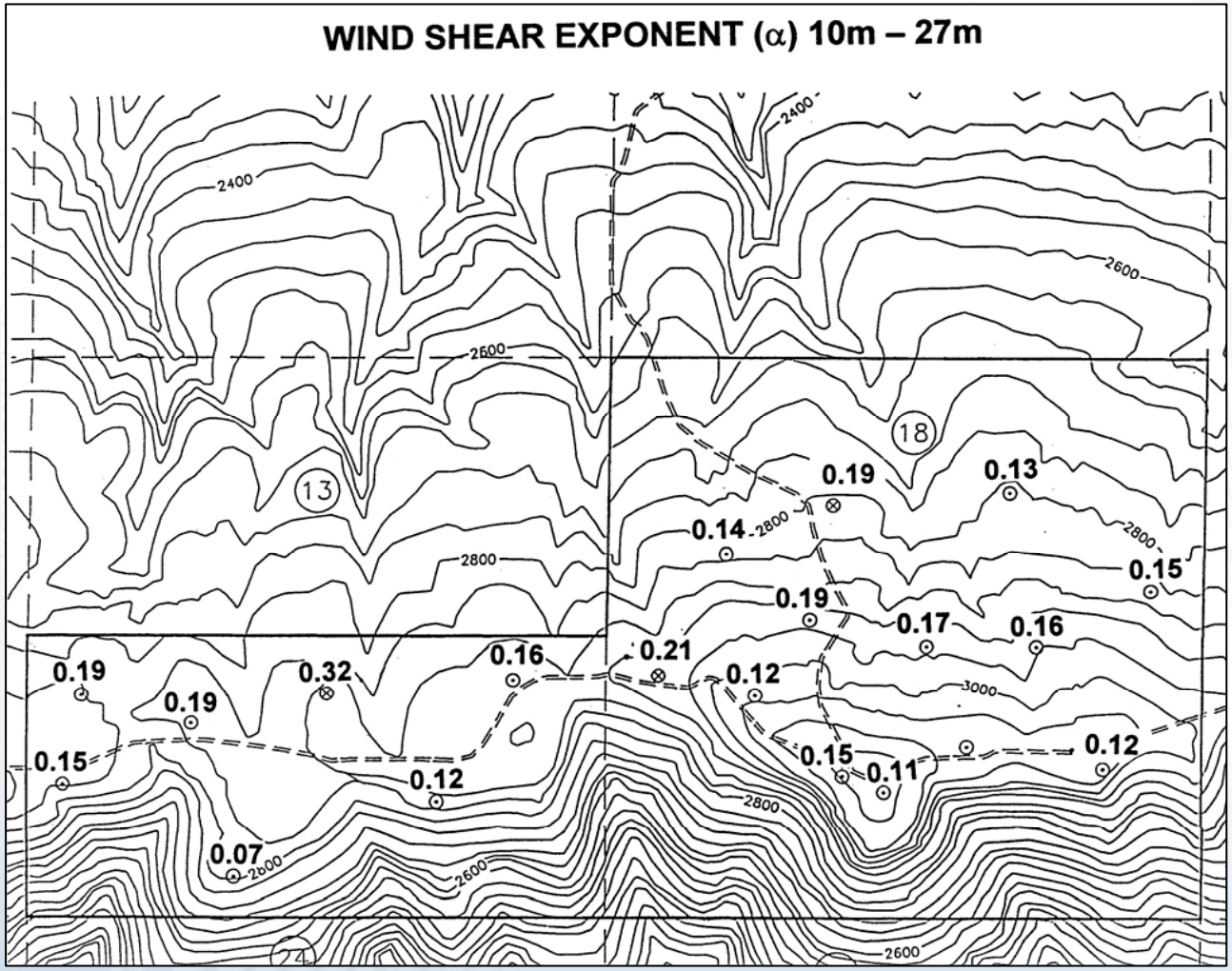
Shear



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Site Characterization

- For energy projections
- For turbine suitability and operations strategies
  - Maximum slopes
  - Turbulence levels
  - Shear characteristics
  - Environmental extremes
  - Directional characteristics

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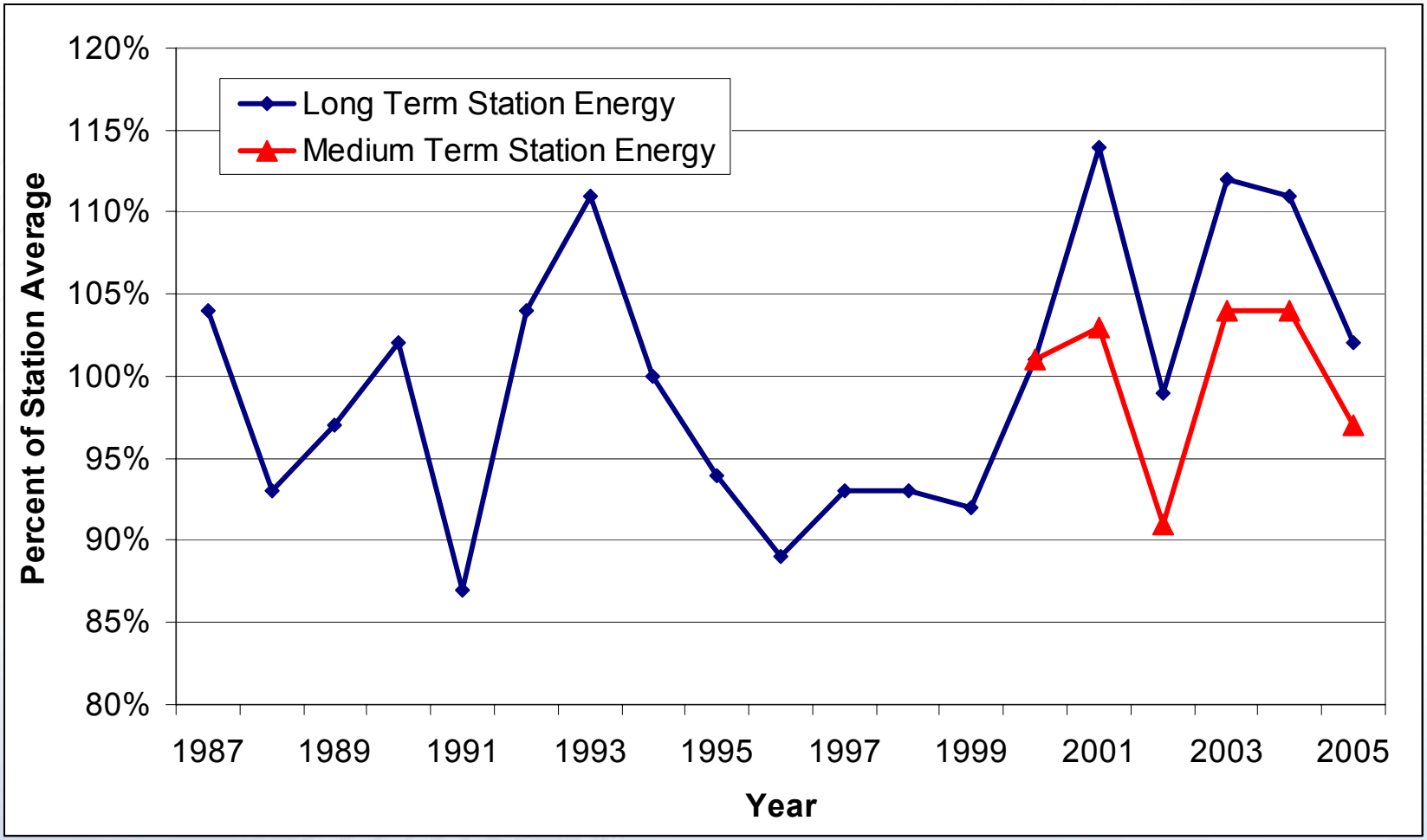
Interannual Variations



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Measurement

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Tubular Guyed Towers

- Limited height
  - Historically 40 meters
  - 50 & 60 meters recently
- Low cost
- Widely used
- Minimal impact on data

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Guyed Lattice Towers

- Over 100 meters
- More expensive
- More impact on data
- Uses
  - Limited quantity height measurement
  - Long-term site met data
  - Power curve measurement

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Communications Towers

- Usually significant effect on data
- Uses
  - Regional resource assessment
  - Long-term references
  - Shear data

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SODAR

- Developing technology
- Supplements other data
- Understand how SODAR campaign relates to overall resource characteristics

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Equipment

- Instruments
  - Anemometer
    - Type?
    - Calibrate?
    - Heated?
    - Cost
  - Wind vane
  - Logger
  - Data transmission
- Mounting

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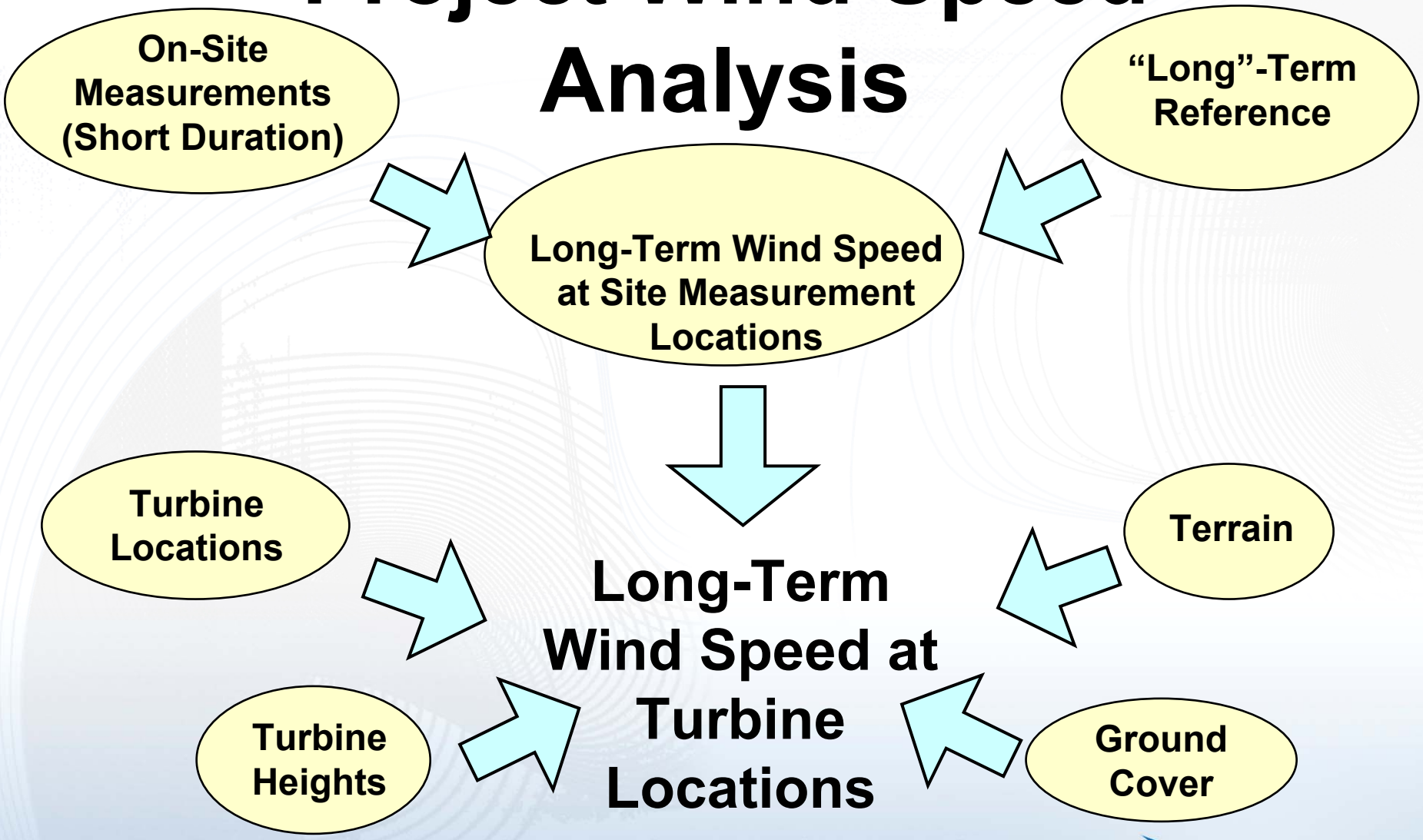
Project Wind Speed Analysis



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Analysis Techniques

- Experiential Assessment of the Data
  - Widely practiced in the U.S.
  - Experience required
  - Subjectivity depends on amount of data
  - Data intensive
  - Characterize the prospective turbine locations
- Computer Modeling
  - Several widely used software packages
  - Similar results from all
  - Experience required
  - Best suited to benign terrain
  - May require less wind data
- Combination

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Data Validation and Analysis

- Tower shadow
- Icing
- Failed sensors
- Normalize for period of record
- Shear patterns
- Directional patterns
- Turbulence intensity

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Data Quantity Requirements

Depends on:

- Purpose
  - Site acquisition decision
  - Financing
- Site characteristics
  - Terrain
  - Vegetation
  - Seasonal variability
  - Atmospheric physics
- Project size
- Analysis methods
- Long-term reference
- Risk tolerance

Photo by Neil Kelley, courtesy of DOE/NREL

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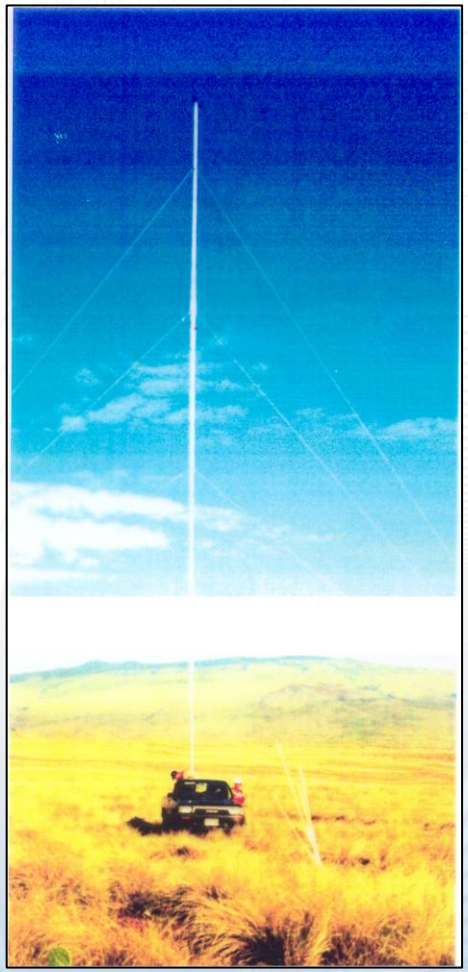
Best Practices for Wind Assessments



- Anemometers located where they represent conditions experienced by turbines
- Data measured at hub height
- High-quality data essential
- High-quality equipment and mounting
- Trained personnel
- Frequent equipment inspections
- Thorough data analysis
- No substitute for long-term, on-site data (one year or more)

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Energy Estimates and Uncertainty Analysis

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Calculating Turbine Output

Wind Speed (m/s)	WTG Power (kW)	Wind Speed Distribution	Wind Speed Distribution (Hours)	Annual Energy Production (kWh)
1	0	5.8%	508	0
2	0	10.7%	937	0
3	0	13.7%	1,200	0
4	1	14.9%	1,305	1,305
5	6	14.2%	1,244	7,464
6	12	12.2%	1,069	12,828
7	18	9.7%	850	15,300
8	26	7.0%	613	15,938
9	32	4.7%	412	13,184
10	39	3.0%	263	10,257
11	46	1.7%	149	6,854
12	52	1.0%	88	4,576
13	57	0.5%	44	2,508
14	62	0.2%	18	1,116
15	66	0.1%	9	594
16	68	0.0%	0	0
17	70	0.0%	0	0
18	71	0.0%	0	0
19	71	0.0%	0	0
20	70	0.0%	0	0
21	69	0.0%	0	0
22	67	0.0%	0	0
23	65	0.0%	0	0
24	64	0.0%	0	0
25	63	0.0%	0	0
Total		0.994	8,709	91,924

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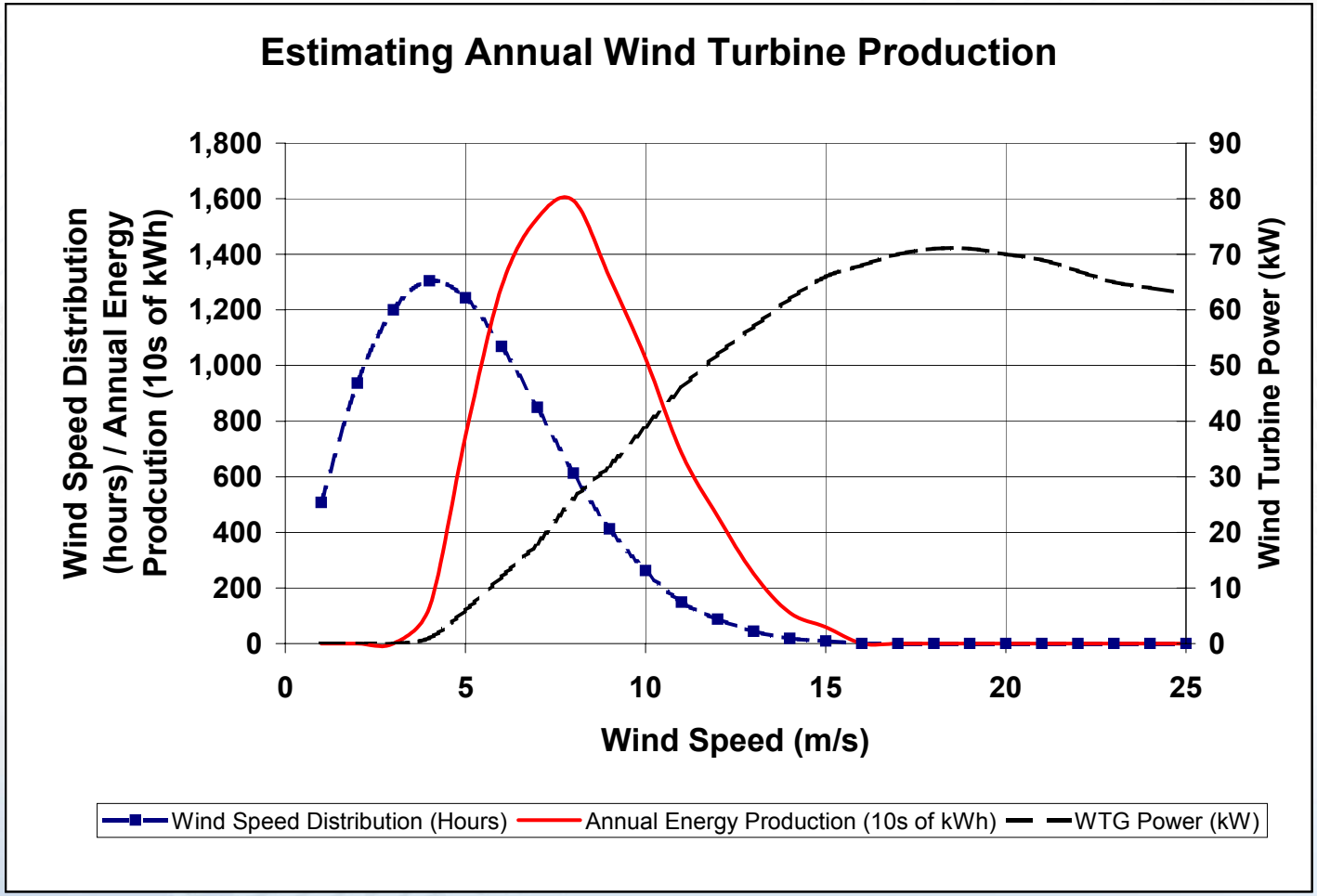
Calculating Turbine Output



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Wind Turbine Performance

Small & Medium Wind Turbines

- 10% - 25% Capacity Factor
- 10 kW WTG @ 12% Cap Factor ==> 10,500 kWh/year

Large Wind Turbines

- 25% - 40% Capacity Factor
- 1.5 MW WTG @ 35% Cap Factor ==> 4,600,000 kWh/year

CF = Annual Energy Production / (Rated Power * 8,760 hours/year)

Annual Energy Production (AEP) = CF * Rated Power * 8,760 hours/year)

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Calculating Capacity Factor (Examples)

<u>Example #1</u>

Rated Power = 10 kW

CF = 12%

What is the AEP?

AEP = 12% * 10 kW * 8,760 hours/year = 10,500 kWh/year

<u>Example #2</u>

Rated Power = 1,500 kW

CF = 35%

What is the AEP?

AEP = 35% * 1,500 kW * 8,760 hours/year = 4,600,000 kWh/year

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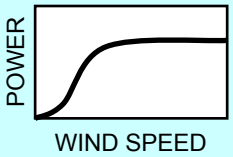
Net Energy Calculations

WIND SPEED
- Terrain effects
- Wind direction
- Multiple heights
- Hours/years at each wind speed
- Hub height

WIND TURBINE POWER OUTPUT



Adjust for air density

GROSS ENERGY PRODUCTION

ARRAY EFFECTS
- Wind turbine spacing
- Wind turbine orientation
- Wind turbine characteristics

AIRFOIL SOILING
- Bugs
- Dirt
- Icing
- Aging

CONTROL
- "Off-yaw"
- Start – Stops
- High-wind cut-outs (gusts)
- Turbulence

AVAILABILITY
- Utility outages
- Station outages
- Wind turbine failure
- Scheduled maintenance

PARASITIC LOSSES
- Power handling/ conditioning
- Station energy consumption

NET ENERGY

Representative Uncertainty Elements

- Wind speed measurements
  - Mounting
  - Instruments
  - Records
- Is measurement period representative?
- Turbine performance
- Mechanical availability
- Losses
  - Array
  - Weather
  - Transmission
  - Etc.
- Correlations to long-term reference

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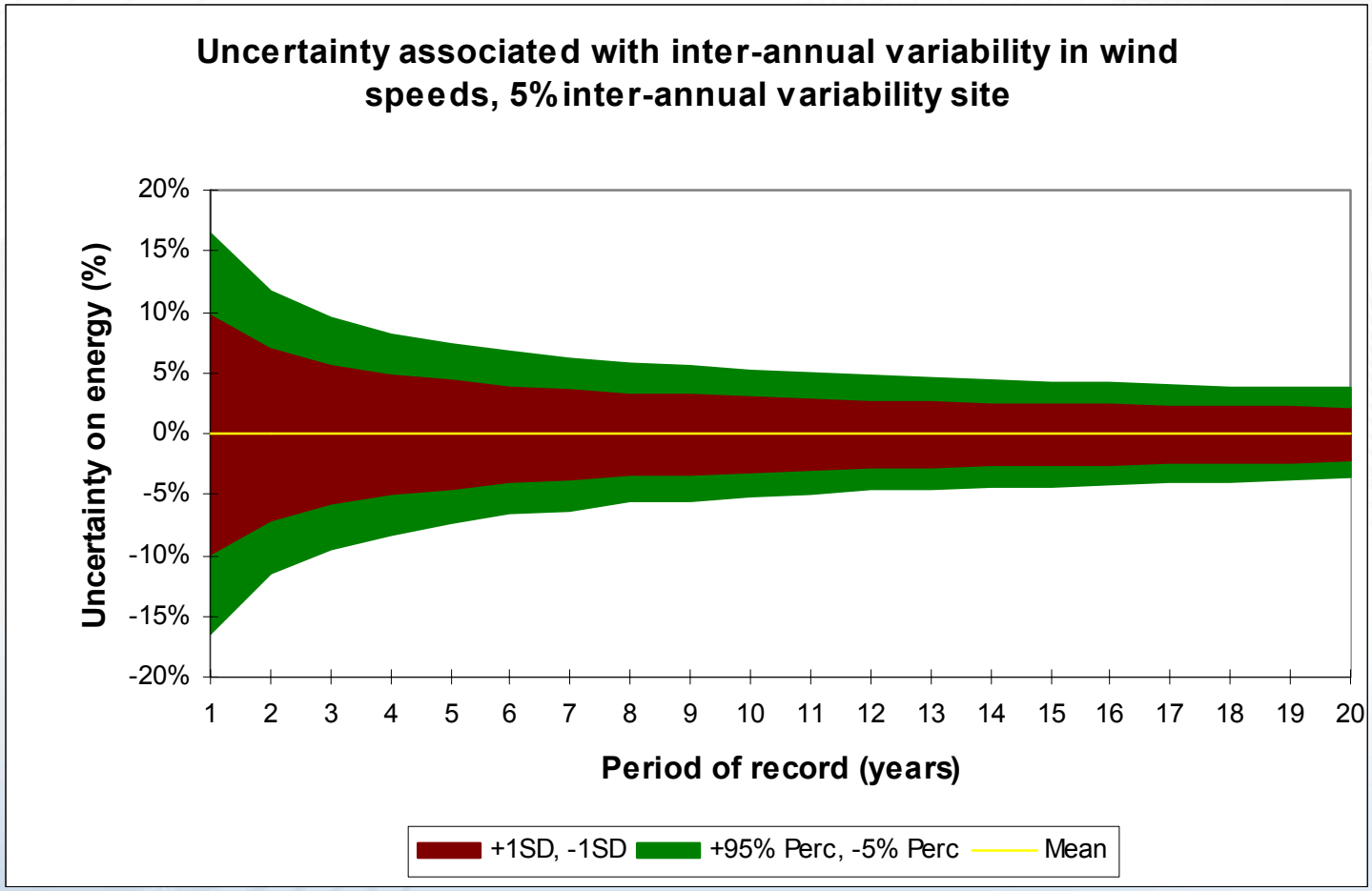
Long-Term Wind Speed Uncertainty



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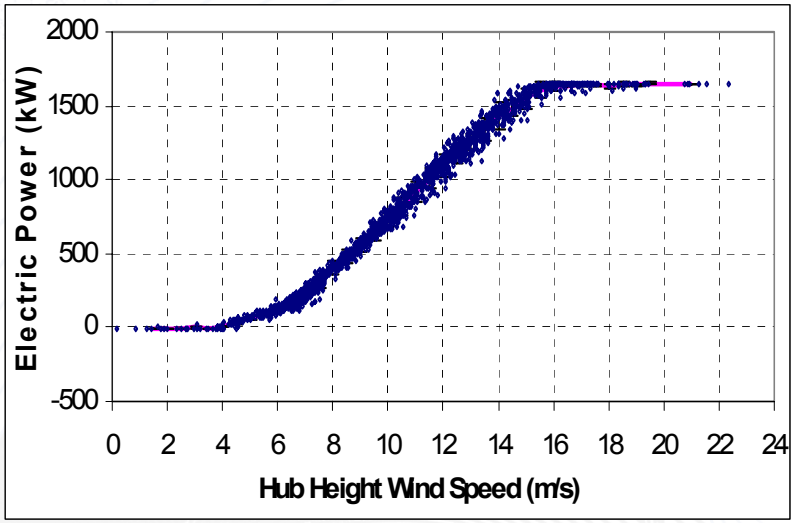
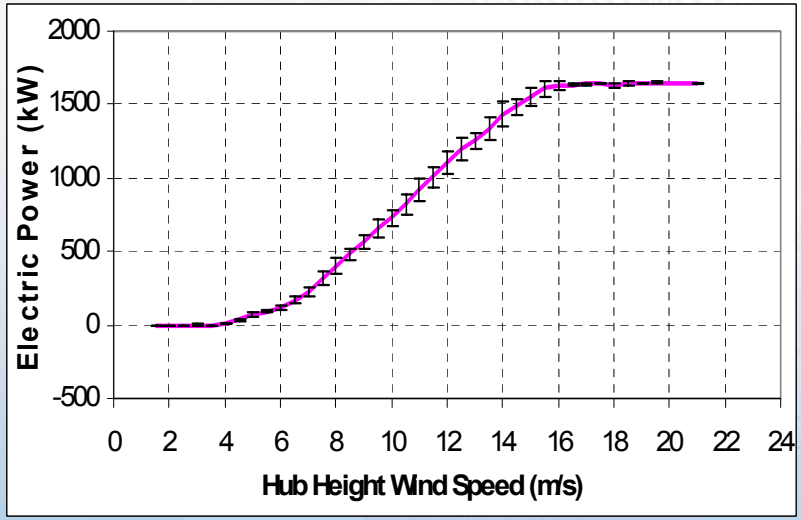
Power Curve Uncertainty





- Instrumentation
- Reference wind speed uncertainty
- Atmospheric condition variations

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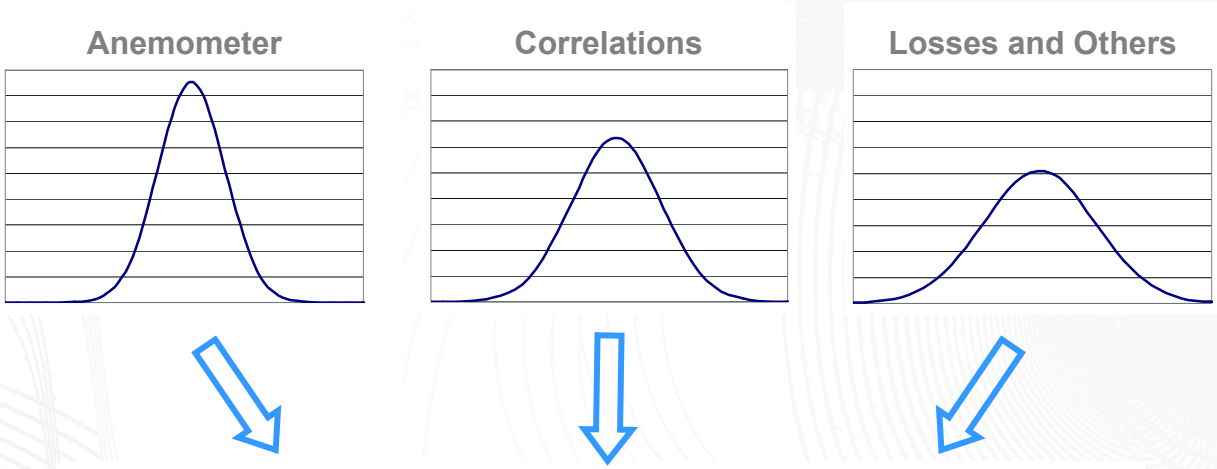
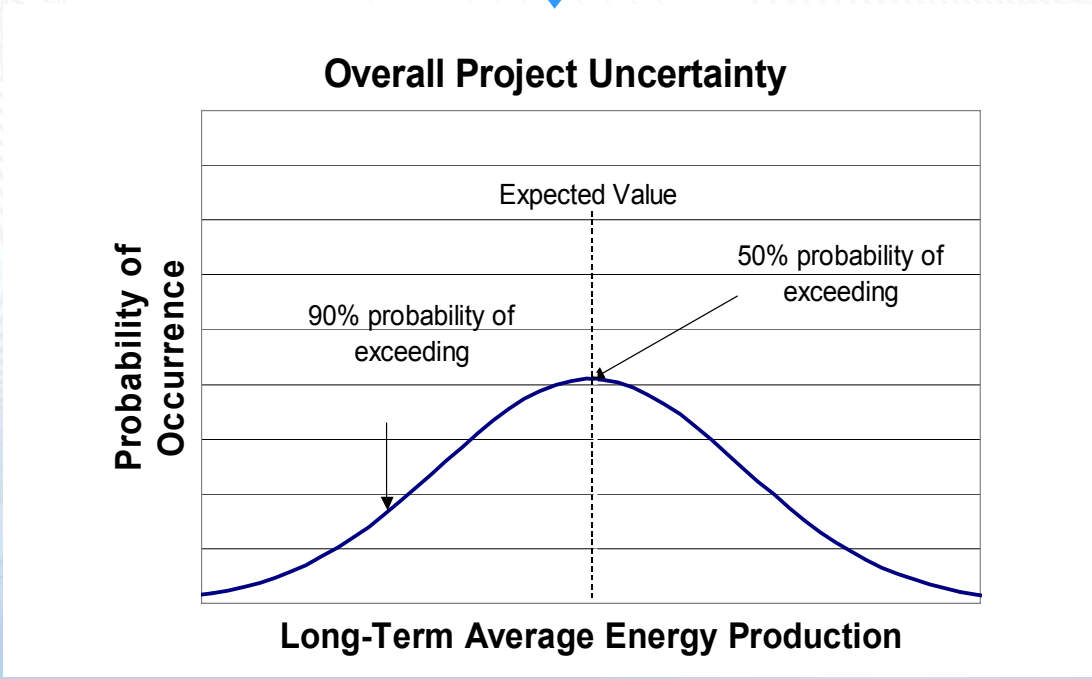
Uncertainty Analysis

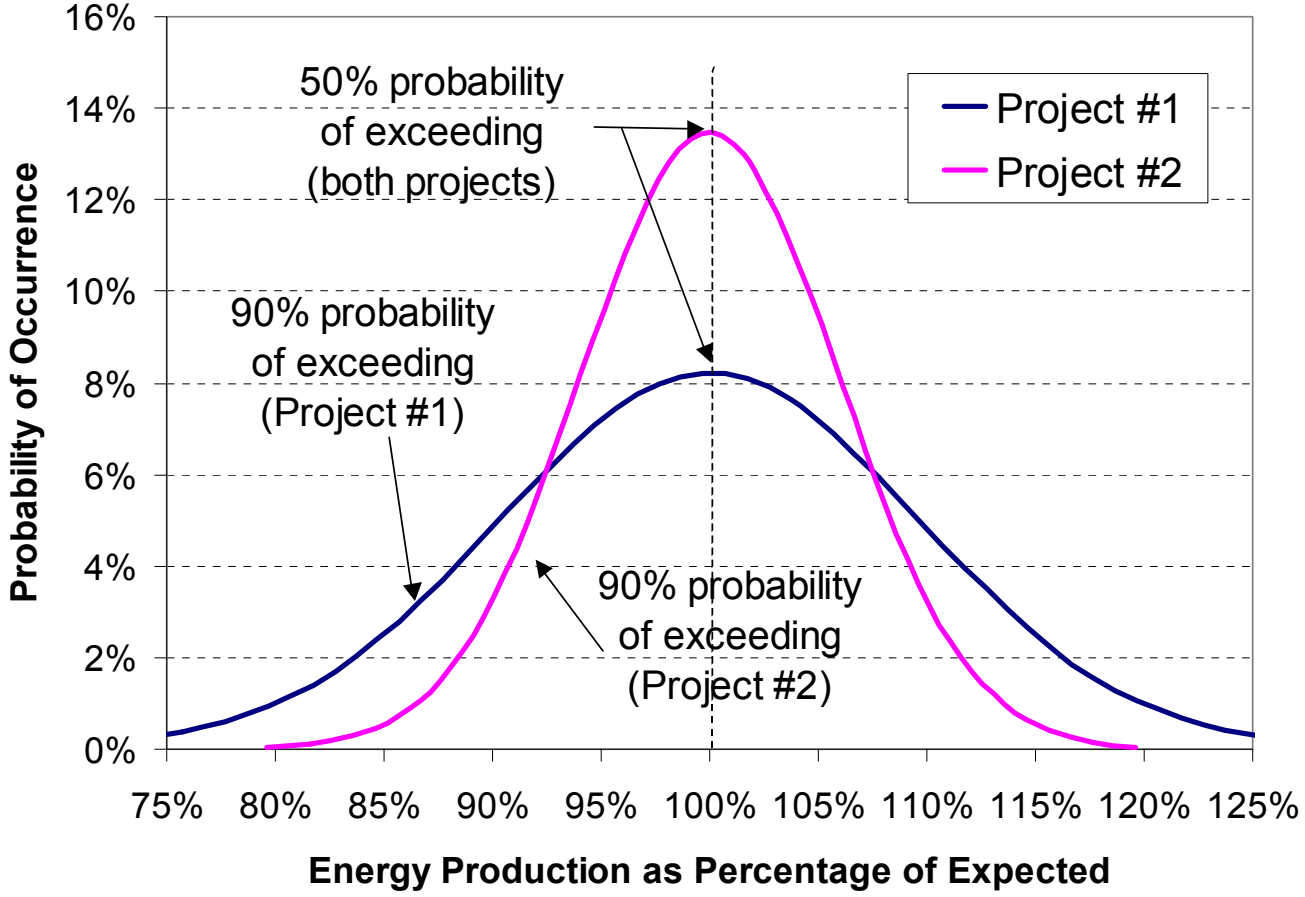
- Uncertainty associated with each element of analysis
- Actual performance has 50% probability of exceeding analyst's best estimate, and 50% probability of being below best estimate
- Variability of some elements well defined, others subjective





Representative Uncertainty Results

Two Projects – Different Site Characterization



Reducing Uncertainty Increasing Financeability

- Sufficient on-site data to fully characterize seasonal variations and terrain effects
- 10-minute turbulence and shear data
- Hub-height data
- A LONG term reference
- Well documented anemometry
- Multiple analysis methods
- Detailed well documented analysis

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Conclusions

- Consider non-wind issues prior to beginning on-site measurements
- Heed the lessons of the past
- Increase financeability by reducing uncertainty

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