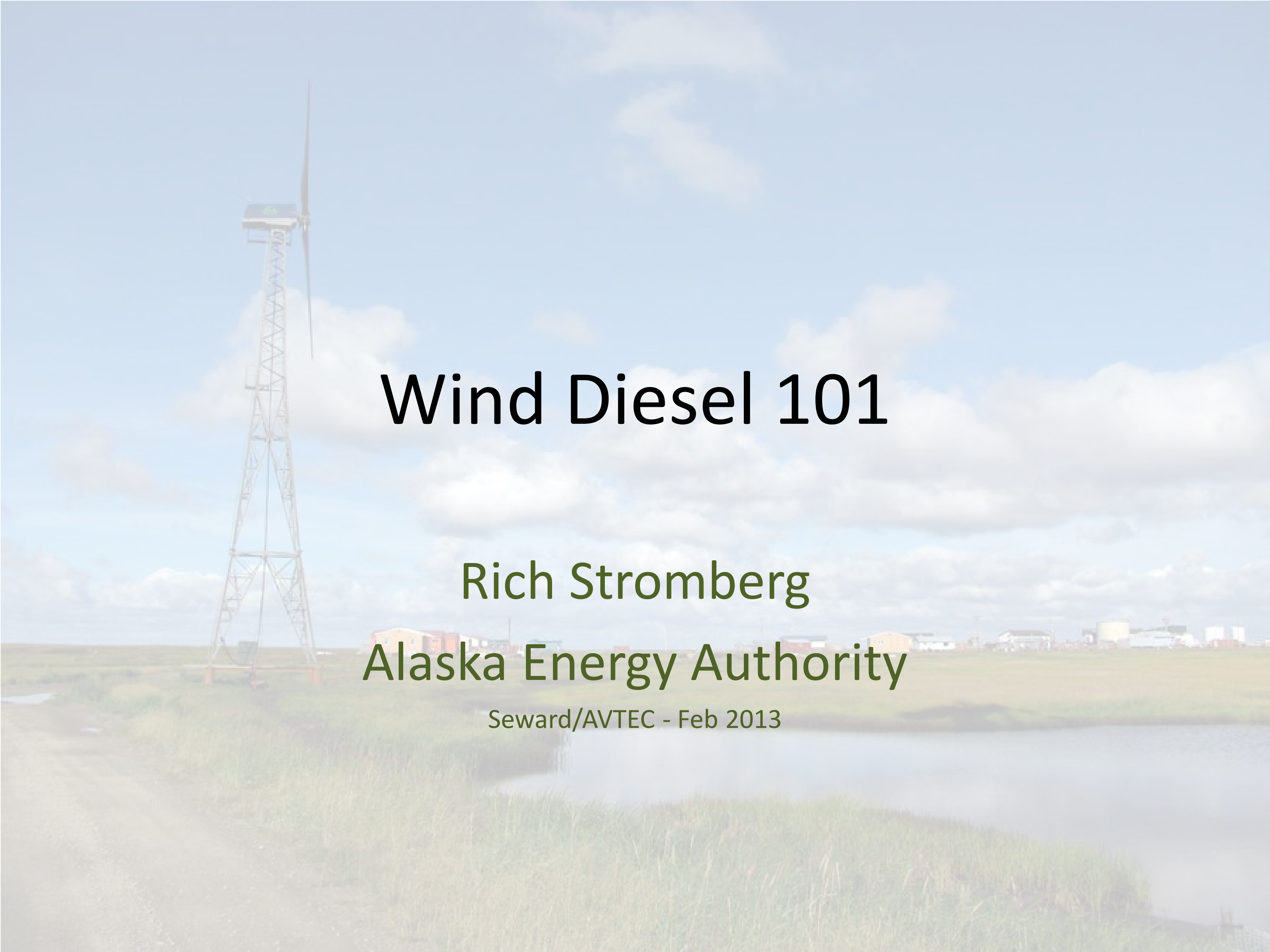


Wind Diesel 101

Rich Stromberg

Alaska Energy Authority

Seward/AVTEC - Feb 2013

AEA Wind Program Values

http://www.akenergyauthority.org/programwind.html

- Involve the local community throughout all aspects of the project to increase local ownership.
- Be kind when judging our predecessors. They didn’t have the benefit of the hindsight we now possess.
- Make data-driven decisions.
- Admit when we’re wrong.
- Approach problems and projects holistically. Developed integrated solutions.
- There is great opportunity to increase cost savings and learning when we improve existing wind systems.
- Think and plan for the long term.
- Understand that wind energy isn’t always the best solution.

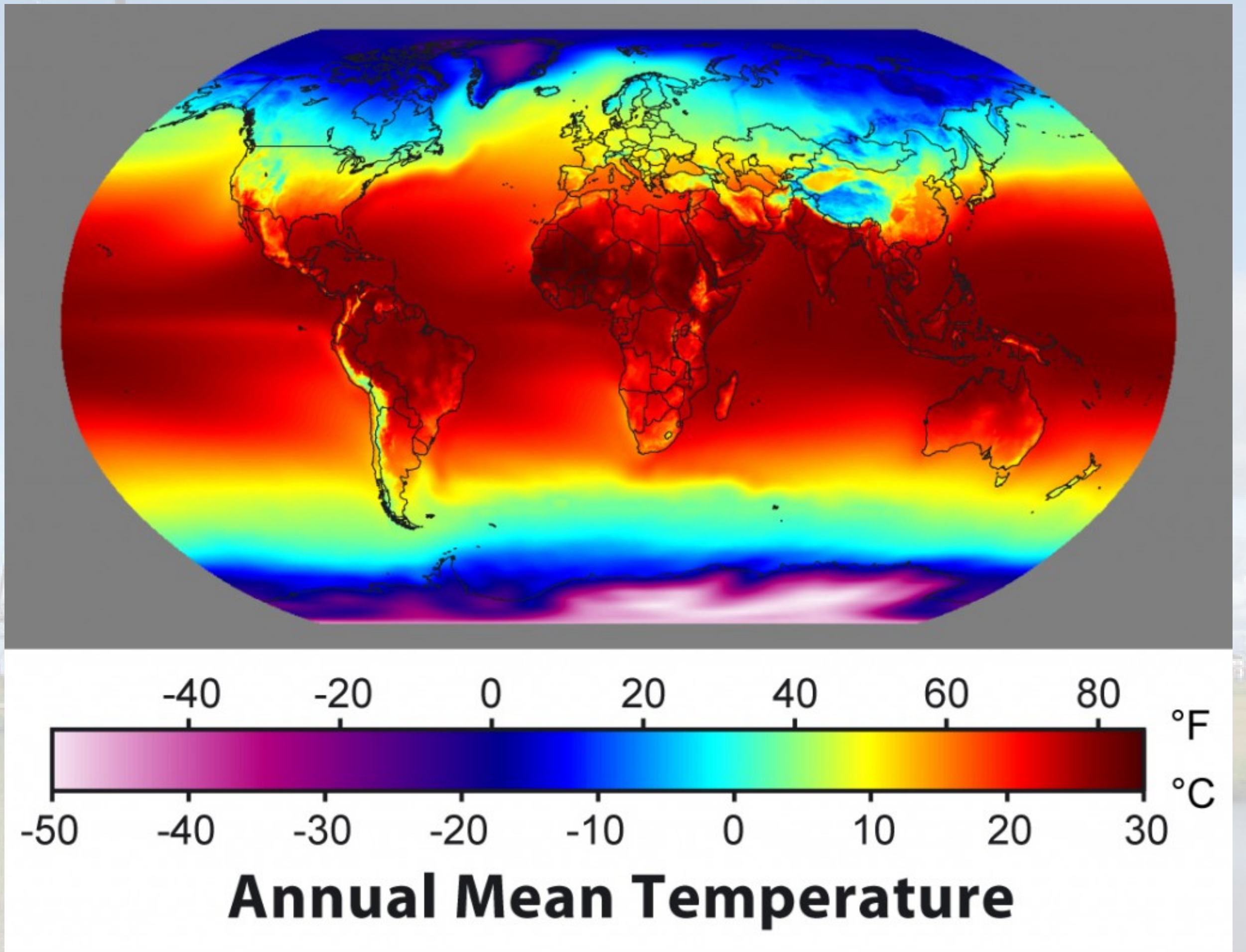
This will be on the test!

First Law of Thermodynamics: Energy can be changed from one form to another, but it cannot be created or destroyed.

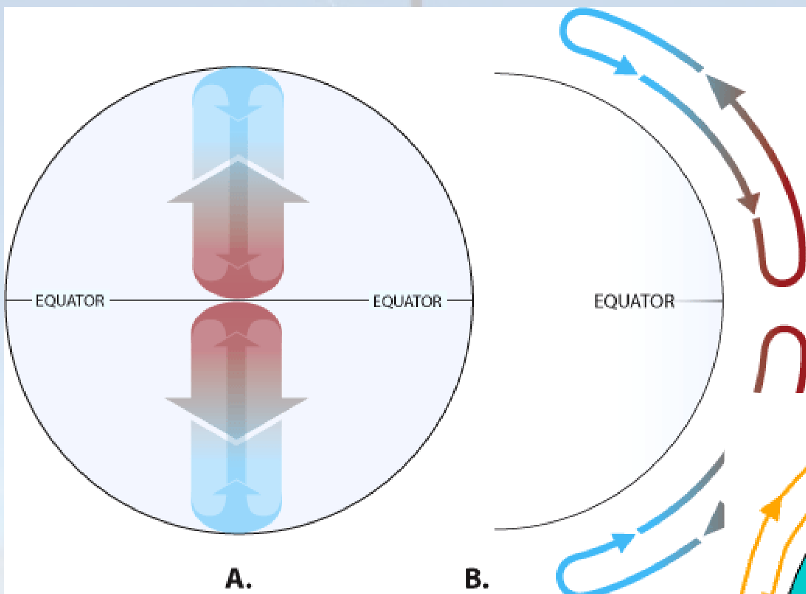
Everything we do with village energy systems is based on these two concepts.

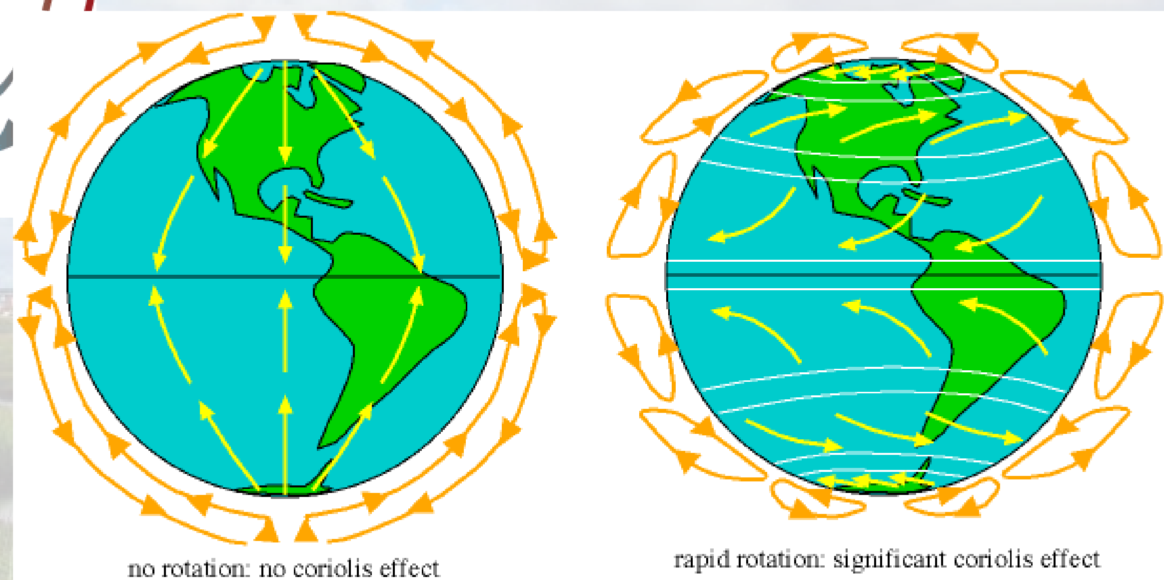
An important facet of the Second Law of Thermodynamics (which deals with entropy): In the process of energy transfer, some energy will dissipate as heat.

What makes the wind?



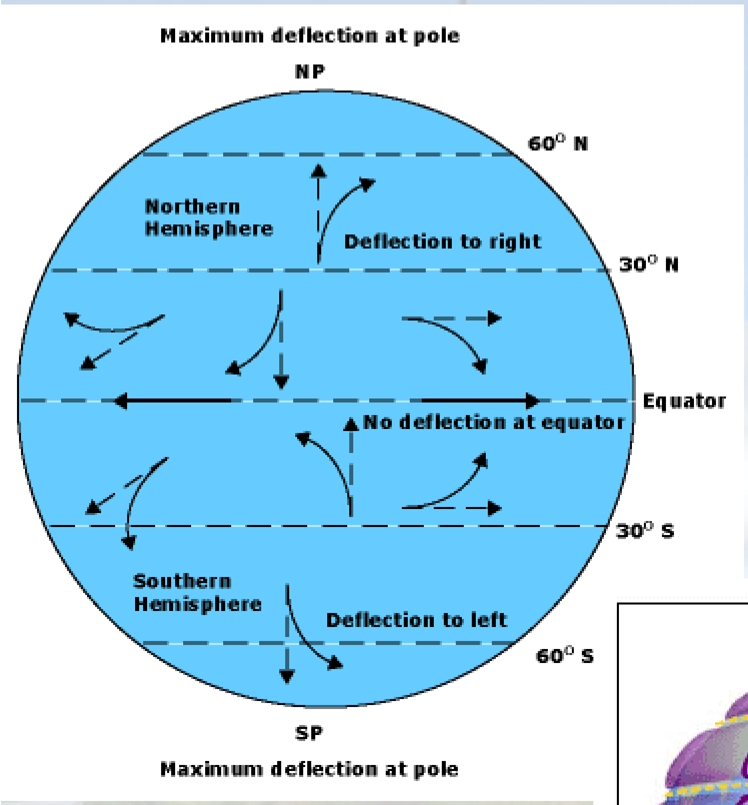
What makes the wind?

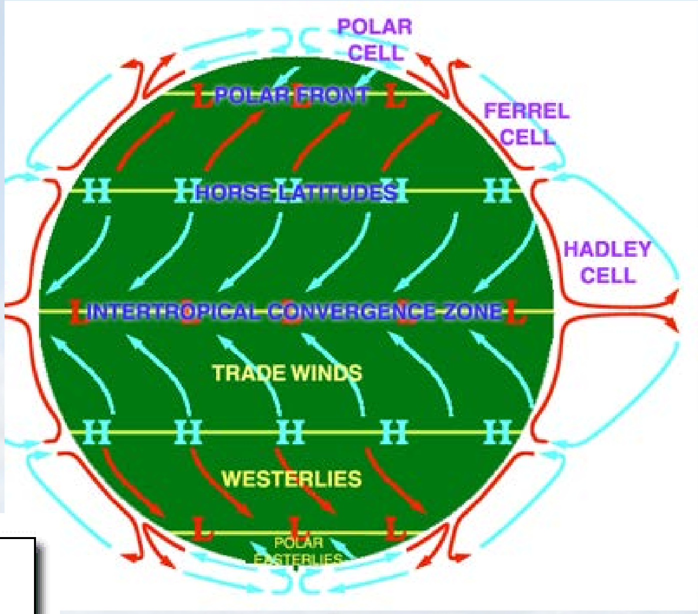


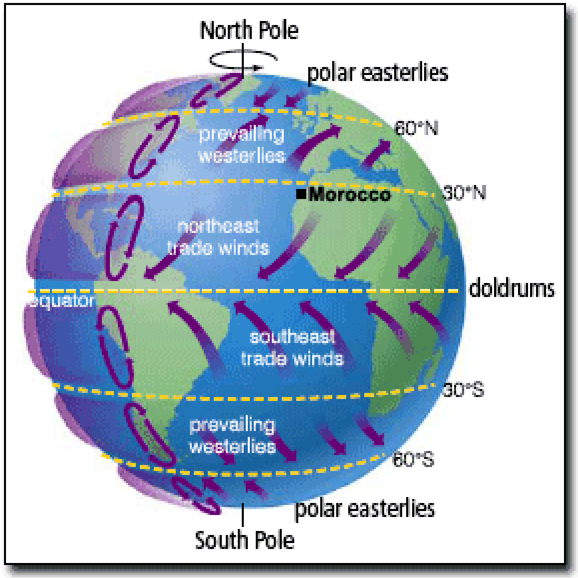


On a planet with little or no rotation, the global air circulation pattern is very simple. On a planet with rapid rotation, the coriolis effect creates large-scale eddies with belts of wind and belts of calm.

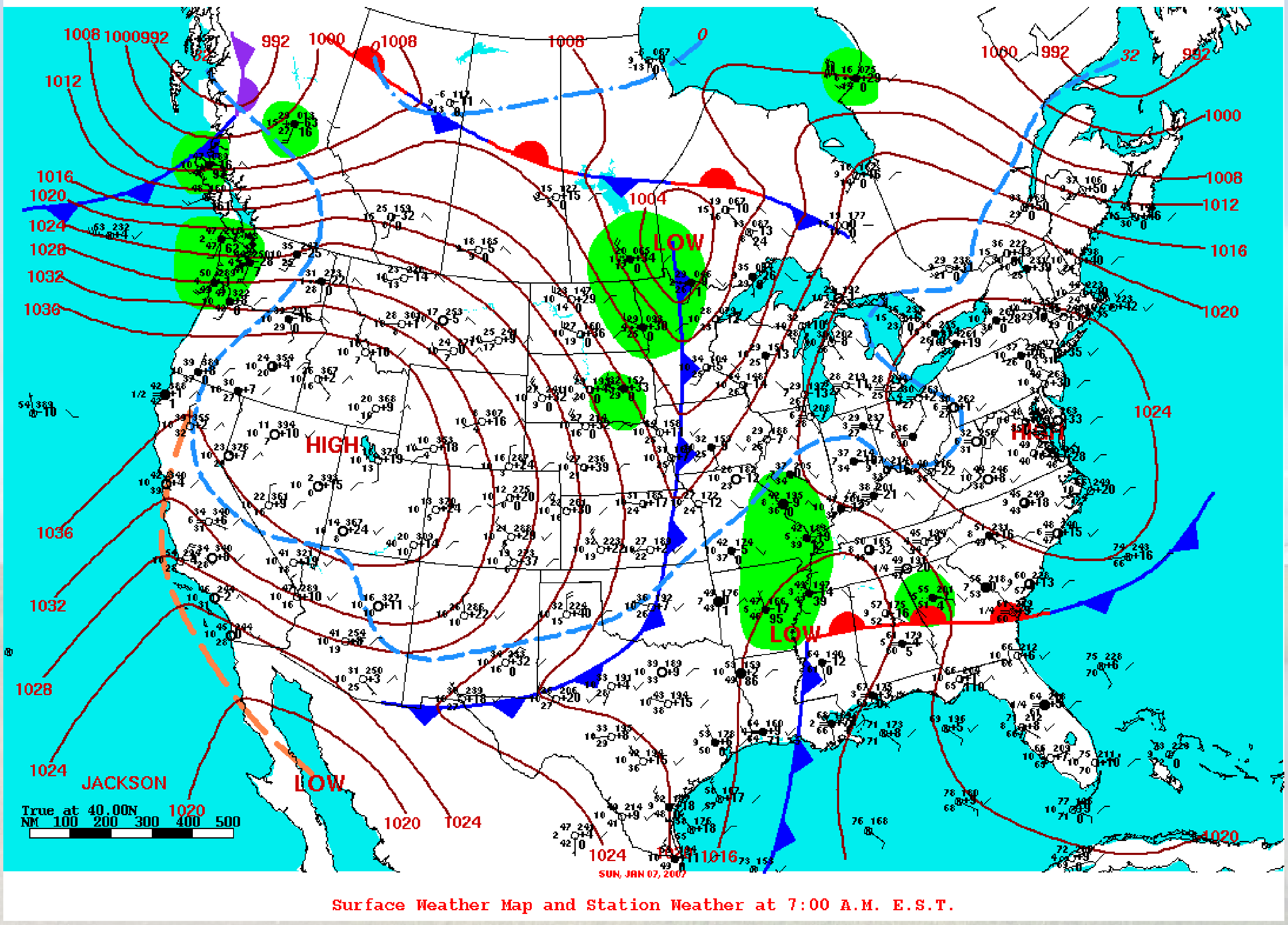
Global Wind Patterns





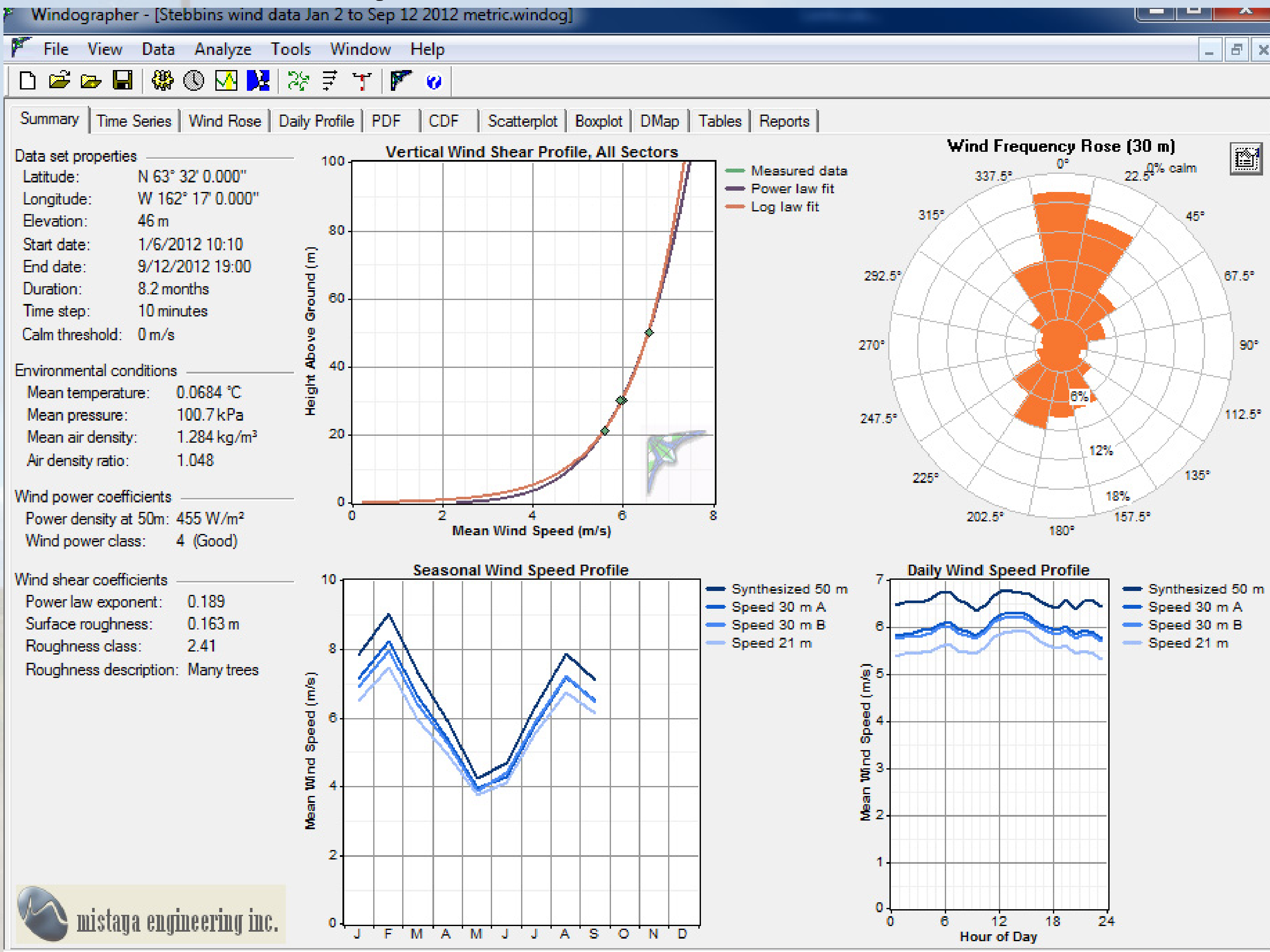


Zooming in, winds become more complex and variable.



Zooming in, winds become more complex and variable.

Zooming in, winds become more complex and variable.



How windy is it, really?

- **Anecdotal weather data or observations can be deceptive. For example:**
  - A few windy days get some people wanting to install wind turbines.
  - It only takes one rainy day for people to think that fire danger is reduced.
  - A short cold spell can fool us into not seeing an overall warming trend.
  - Our bodies can sense the weather, but we need to collect data to understand the long-term climate.
- **What matters is the wind speed throughout the course of an entire year.**

How windy is it, really?

- The formula for wind power is:

Power = 0.5 x Rotor Swept Area x Air Density x Velocity^3

- Thus, doubling the wind speed from 3 meters/sec to 6 meters/sec increases the power by 8X.
- 7 meters/sec wind speed adds another 58% increase in wind power over 6 meters/sec.

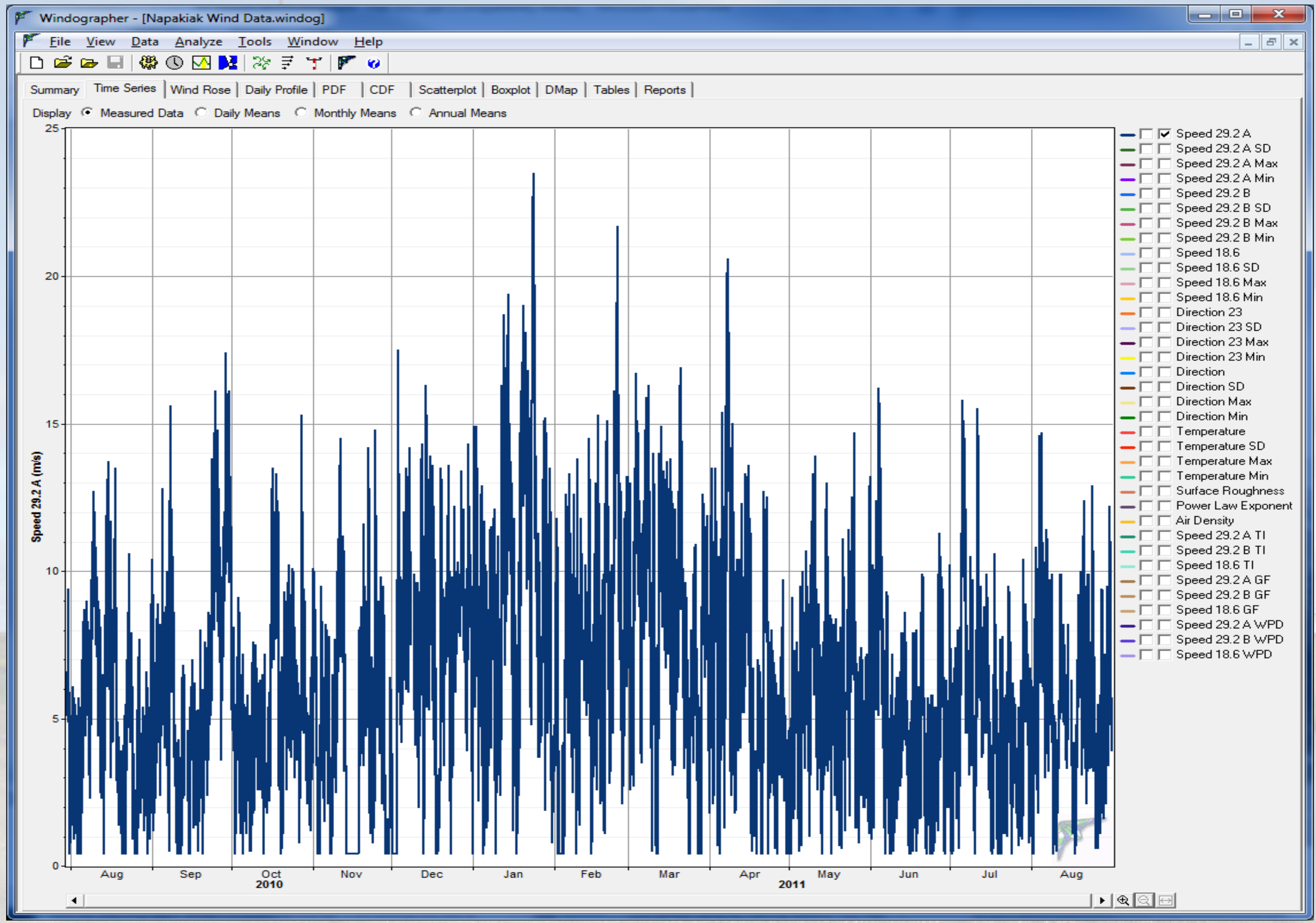
How windy is it, really?

- **Measure the wind for a minimum of one year.**

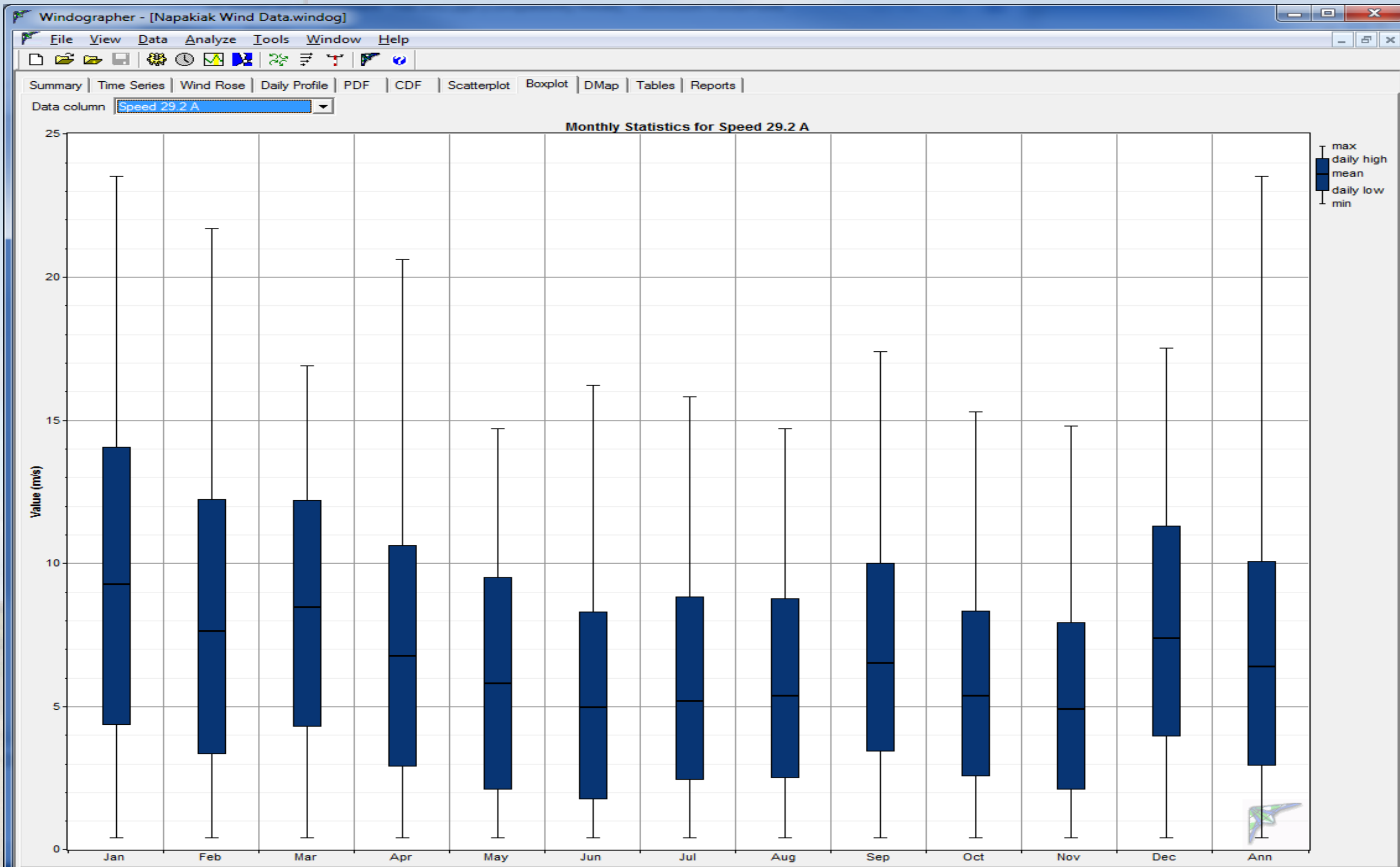
How windy is it, really?

- Met towers require a permit from the FAA and consultation with US Fish & Wildlife, State Historic Preservation Office and possibly other agencies.

What the raw data shows



Summarize data into information



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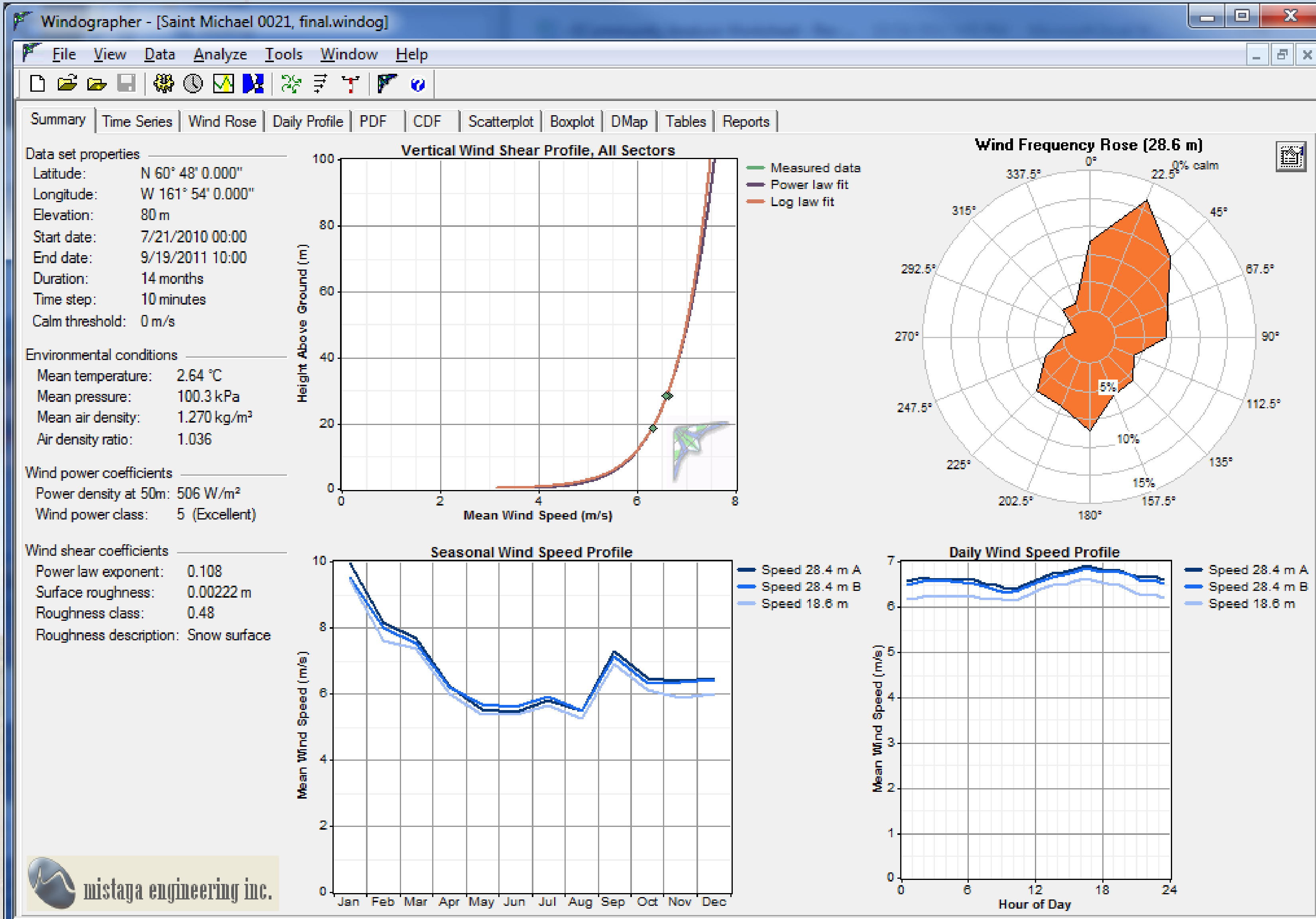
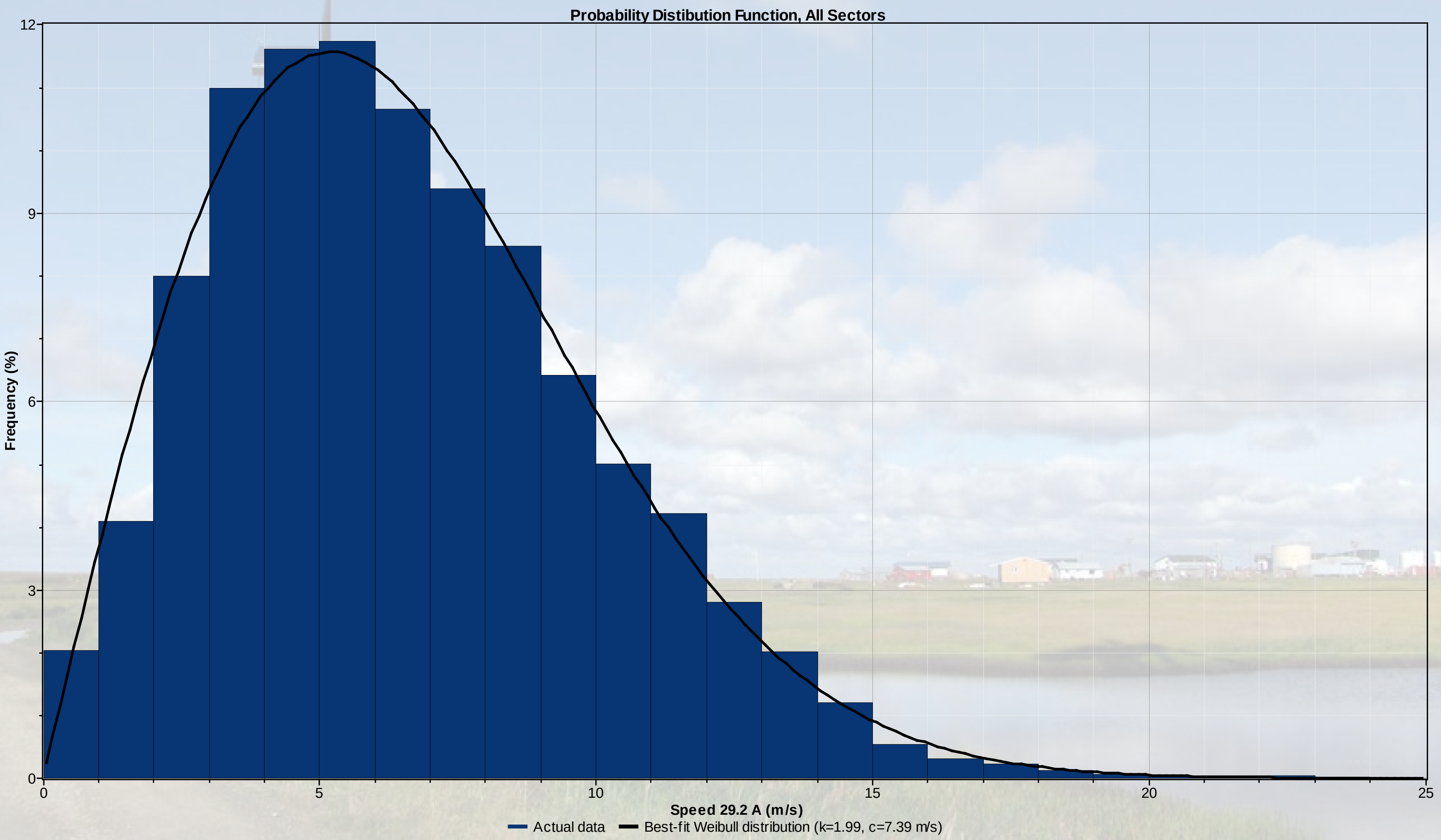
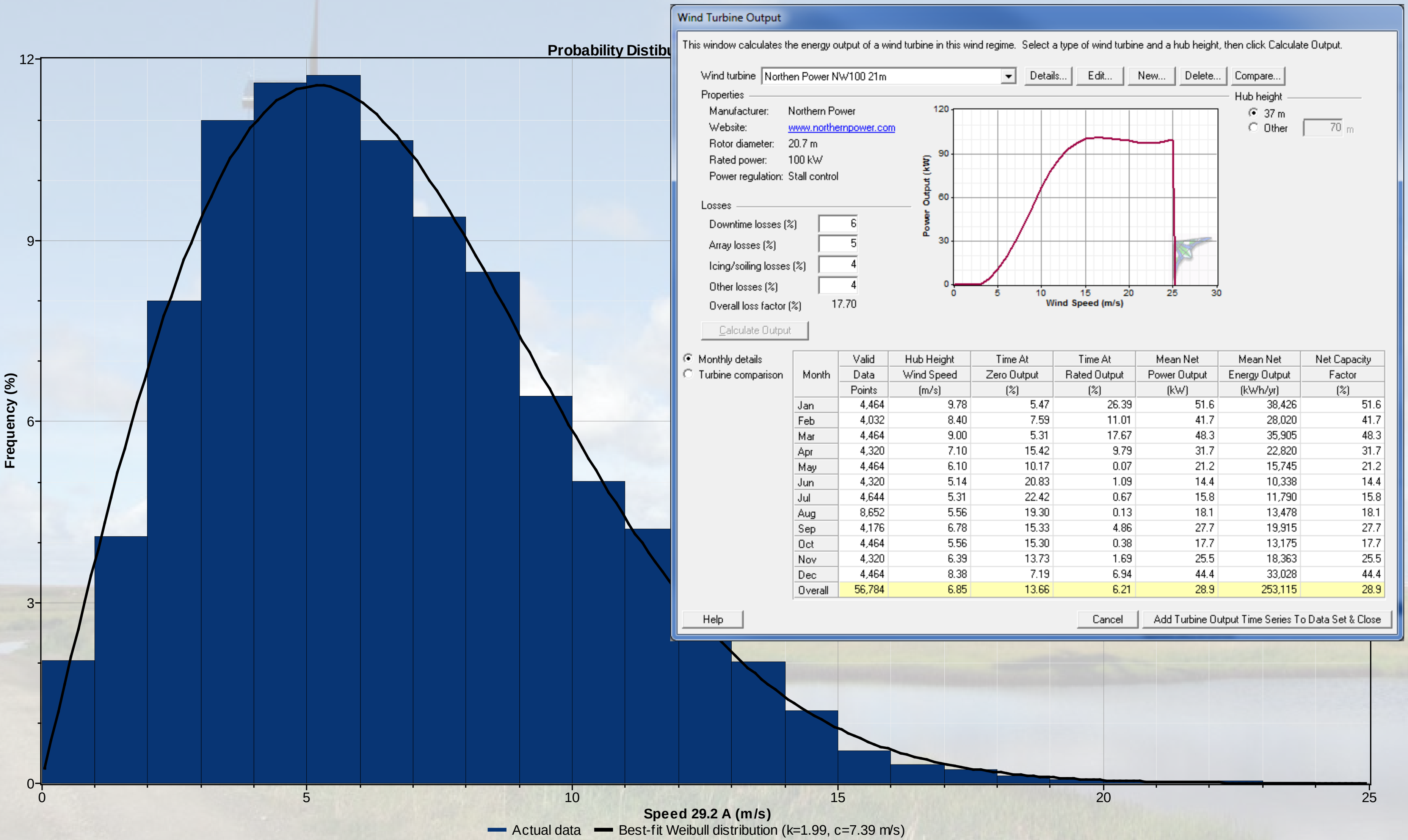


Shape of the wind distribution

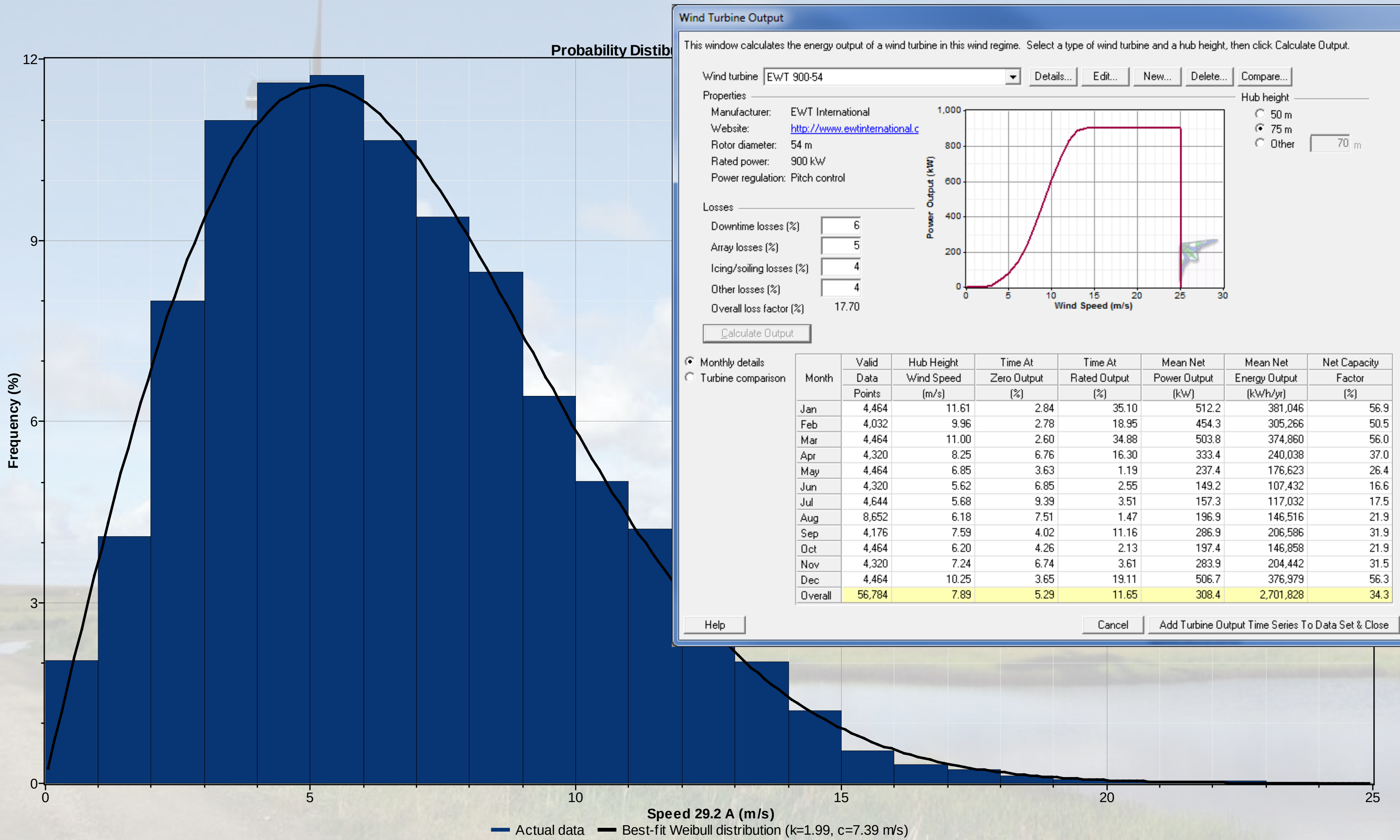


Wind distribution vs. turbine power curve



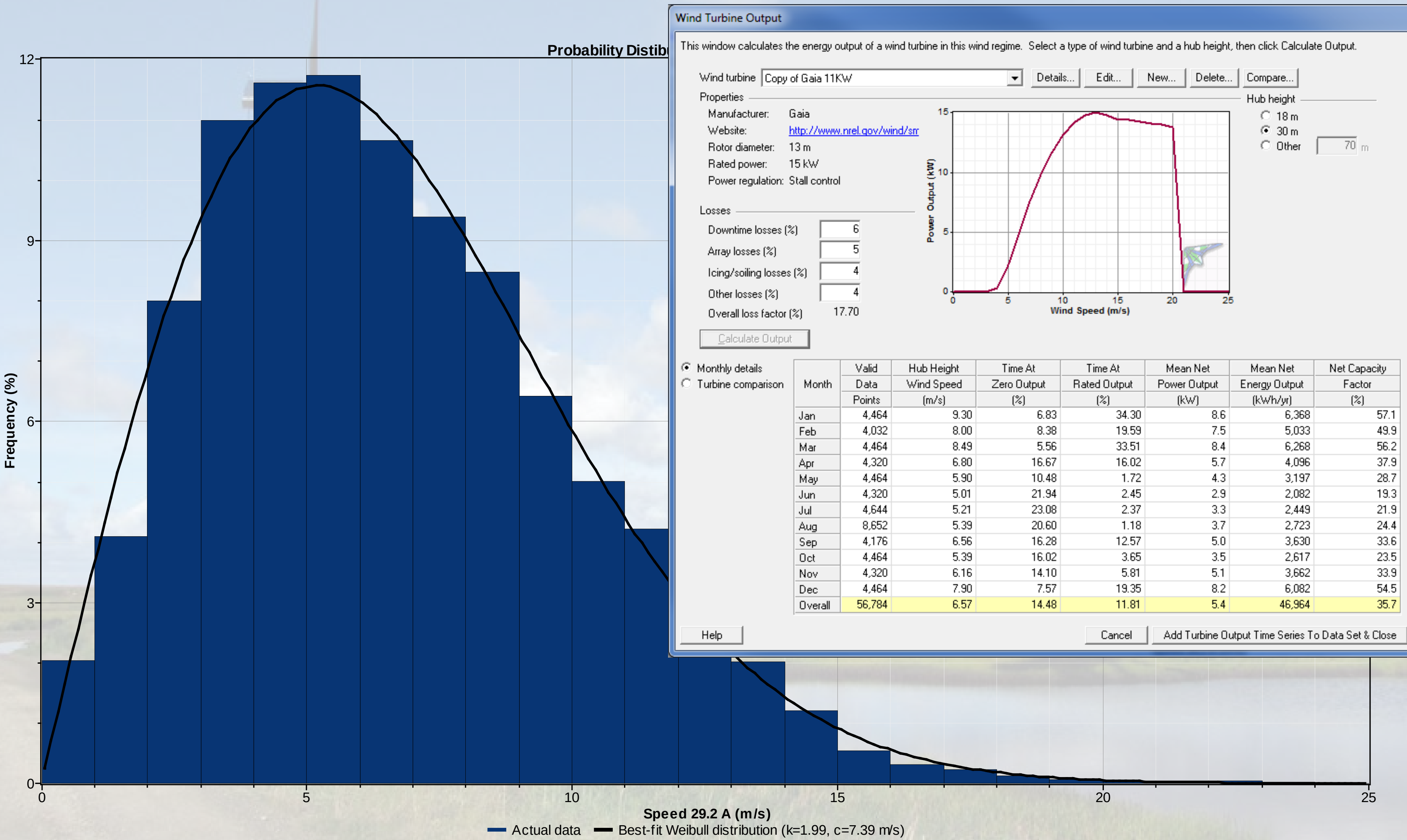
Month	Valid Data Points	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Jan	4,464	9.78	5.47	26.39	51.6	38,426	51.6
Feb	4,032	8.40	7.59	11.01	41.7	28,020	41.7
Mar	4,464	9.00	5.31	17.67	48.3	35,905	48.3
Apr	4,320	7.10	15.42	9.79	31.7	22,820	31.7
May	4,464	6.10	10.17	0.07	21.2	15,745	21.2
Jun	4,320	5.14	20.83	1.09	14.4	10,338	14.4
Jul	4,644	5.31	22.42	0.67	15.8	11,790	15.8
Aug	8,652	5.56	19.30	0.13	18.1	13,478	18.1
Sep	4,176	6.78	15.33	4.86	27.7	19,915	27.7
Oct	4,464	5.56	15.30	0.38	17.7	13,175	17.7
Nov	4,320	6.39	13.73	1.69	25.5	18,363	25.5
Dec	4,464	8.38	7.19	6.94	44.4	33,028	44.4
Overall	56,784	6.85	13.66	6.21	28.9	253,115	28.9

Wind distribution vs. turbine power curve



Month	Valid Data Points	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Jan	4,464	11.61	2.84	35.10	512.2	381,046	56.9
Feb	4,032	9.96	2.78	18.95	454.3	305,266	50.5
Mar	4,464	11.00	2.60	34.88	503.8	374,860	56.0
Apr	4,320	8.25	6.76	16.30	333.4	240,038	37.0
May	4,464	6.85	3.63	1.19	237.4	176,623	26.4
Jun	4,320	5.62	6.85	2.55	149.2	107,432	16.6
Jul	4,644	5.68	9.39	3.51	157.3	117,032	17.5
Aug	8,652	6.18	7.51	1.47	196.9	146,516	21.9
Sep	4,176	7.59	4.02	11.16	286.9	206,586	31.9
Oct	4,464	6.20	4.26	2.13	197.4	146,858	21.9
Nov	4,320	7.24	6.74	3.61	283.9	204,442	31.5
Dec	4,464	10.25	3.65	19.11	506.7	376,979	56.3
Overall	56,784	7.89	5.29	11.65	308.4	2,701,828	34.3

Wind distribution vs. turbine power curve



Month	Valid Data Points	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Jan	4,464	9.30	6.83	34.30	8.6	6,368	57.1
Feb	4,032	8.00	8.38	19.59	7.5	5,033	49.9
Mar	4,464	8.49	5.56	33.51	8.4	6,268	56.2
Apr	4,320	6.80	16.67	16.02	5.7	4,096	37.9
May	4,464	5.90	10.48	1.72	4.3	3,197	28.7
Jun	4,320	5.01	21.94	2.45	2.9	2,082	19.3
Jul	4,644	5.21	23.08	2.37	3.3	2,449	21.9
Aug	8,652	5.39	20.60	1.18	3.7	2,723	24.4
Sep	4,176	6.56	16.28	12.57	5.0	3,630	33.6
Oct	4,464	5.39	16.02	3.65	3.5	2,617	23.5
Nov	4,320	6.16	14.10	5.81	5.1	3,662	33.9
Dec	4,464	7.90	7.57	19.35	8.2	6,082	54.5
Overall	56,784	6.57	14.48	11.81	5.4	46,964	35.7

Wind Classifications

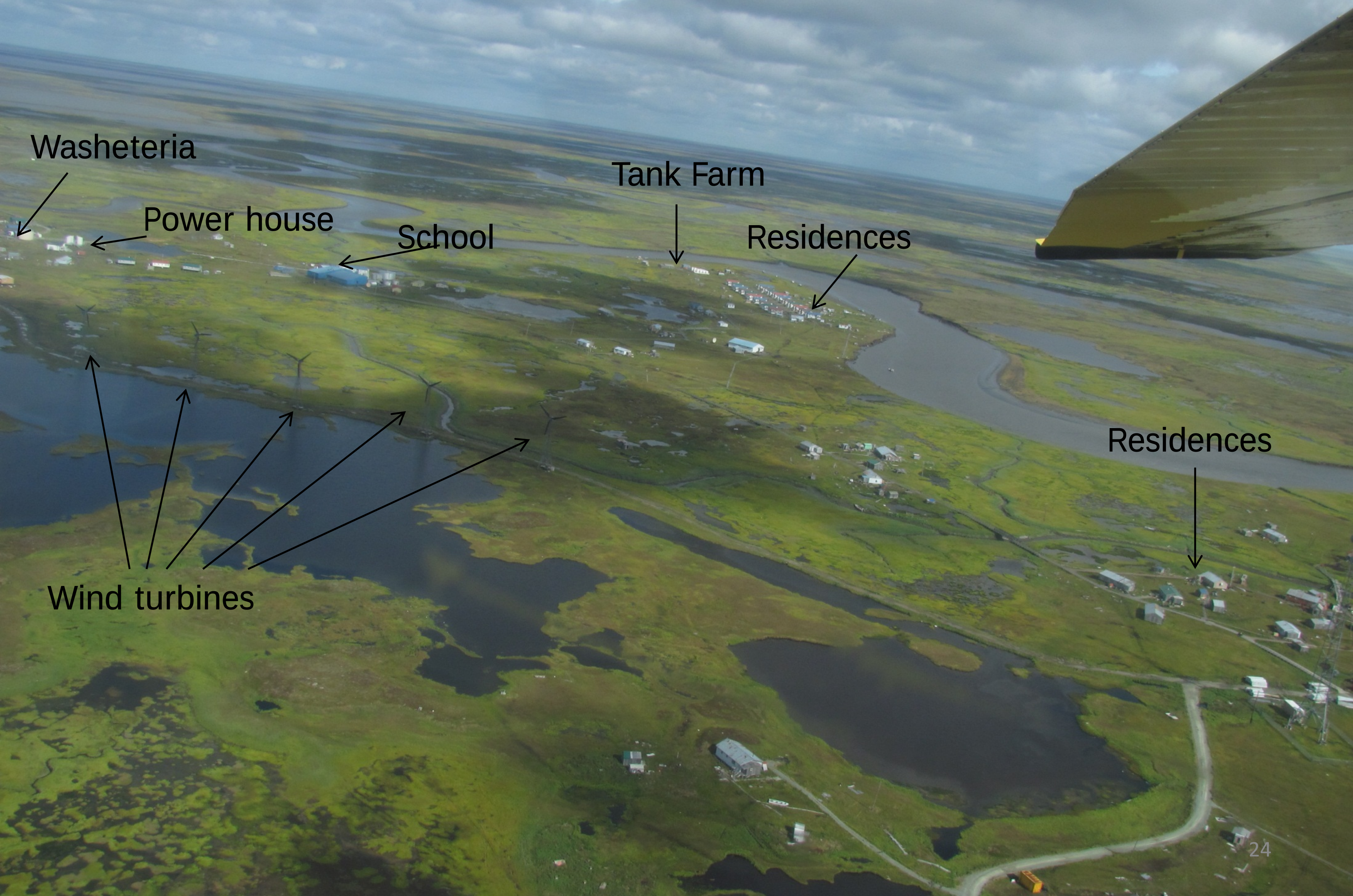
- Class 1/Poor: Pursue options other than wind
- Class 2/Marginal: High costs of development in rural Alaska prevent an economical project.
- Class 3/Fair: A large project on the Railbelt may be cost effective. Remote village projects may have a payback longer than the 20-year life of wind turbines.
- Class 4/Good: A well-designed project will have a payback of 15-20 years.
- Class 5/Excellent: A well-designed project will have a payback of 12-15 years.
- Class 6/Outstanding: A well-designed project will have a payback of 10-12 years, but damaging high-wind events may be a concern.
- Class 7/Superb: Project developer may want to use a smaller rotor or find a sheltered site to protect turbines from periodic damaging winds.

Harnessing the wind's energy

- Kinetic energy in the wind is converted into rotation of the main turbine shaft as air moving across the rotor creates lift, turning the rotor and main shaft.
- Early forms of wind turbines/mills may have used the principle of drag instead of lift, but lift is more efficient.

Wind turbine drive train

A Typical Remote Alaska Village



Wind-Diesel system challenges

- The design and integration of power systems is a complex matter and although the models make it look simple, it is never that easy.
- By their nature renewable generation are stochastic (uncontrolled) and vary with the resource.
- The amount of variation and thus the amount of system control to handle the variation depends on the
  - Renewable resource being used
  - The load
  - Power system design

Can your existing electrical distribution system support wind technology?

- Do you have newer diesel gensets with fast, electronic injection controls or mechanical governors?
- Are your gensets sized so that you can run at optimum fuel efficiency both when the wind is blowing and when it's calm?
- Are your distribution lines, transformers and meters up to code?
- Are your phases balanced?

- If you can't answer "yes" to all of these questions, you could save more money by fixing your existing power system.

Different Integration Issues

There are two general types of integration issues – mechanical and electrical

- Mechanical: The connecting of different devices within the power system and making them work together.
- Electrical: Insuring that the power system power quality is sufficient to meet the needs of the customers

Building Design and Space

Adding new equipment can take up a lot of space

- Switch gear
- Grid stability equipment
- Control boxes
- Spare parts

Building design may be problematic

- Heating
- Layout
- Living arrangements

Making Sure the Equipment Can Talk

- Supervisory Control
- Component Controls
  - Diesels
  - Wind turbines
  - System stability devices
- Controlled thermal loads
  - May be installed in other buildings
  - Switching speed
  - Outside control

Upgrading Diesel Controls

Diesels will need to operate in an automatic fashion, which may require the upgrading of the diesel controls, but allow for manual operation if needed

- Automatic startup and synchronization
- Load sharing
- Speed control

Retrofit of existing diesel units can be complicated

- Age of unit
- Governor design
- Fuel system
- Compatibility, such as generator pitch
- Space constraints within the power house and on the
- diesels themselves

Plant Synchronization

In many older (and smaller) plants only one diesel is run at a single time.

Allowing more than one diesel to operate can be quite a problem, even following the addition of new controls

- Governor design
- Generator compatibility – pitch
- Fuel system feed and return lines
- Cooling system configuration and pumping

Automated start and control capabilities will likely result in more diesel starts, most unattended, which may require the revamping of the diesel start system and starter battery.

Cooling System

Current diesel plants have many different types of cooling systems – some integrated, some not, but all provide primary heat to the power plant and sometimes other buildings as well.

In almost all cases the operation of the diesels provide more than enough heat for the plants needs, but in high penetration systems we would like to shut off the diesels

- Plant goes from heat surplus to heat deficit.
- To allow fast starting of the diesel engines, diesels in fast start mode must be kept warm

May require revamping of the cooling systems

- Implementation of electric boilers to allow use of wind energy
- Allow specific engine cooling systems to be separated
- Better energy management
- Different or conflicting pumping requirements.
- Heat efficiency of plant buildings may need to be considered

Integration of System Electronics

Integration of a power system means that the plant must insure high Power Quality during and following the change

- Variable renewable penetration of system
- Power flow questions
- Voltage variation on feeder lines
- Level of technology/control existing in diesel plant

If at any time you are not producing enough power, power system will collapse

Types of Power Quality

- System stability - reliable power: Having power when you should have it.
  – Unscheduled blackouts
  – System failures
  – Voltage and frequency within acceptable limits
  – System power factor not overtaxing power system
- The level of harmonic distortion -is the power being delivered usable?
  – Changing structure of the power
  – Sub-cycle quality of the power

System Stability

Driven by maintaining system voltage, frequency and reactive power supply.

- Voltage: Currently uses an active controller on the diesel. Alternatives are synchronous condensers or a battery bank and solid state or rotary power converter.
- Frequency: A balance of power supply and demand, controlled by the throttle of the diesel. Can be solved through the use of dump loads or power converters.
- Power Factor: Balancing active and reactive power as needed by the inductive motors and electronics on the system. Capacitor banks, motors or advanced solid state power converters.

Supply Side Options

Options that affect only the power system as seen from the grid

- Dump Loads: Fast acting resistors to balance the generation and load.
- Dispatchable loads: Block heaters to use excess energy.
- Synchronous Condenser: Provides reactive power and controls voltage.
- Advanced power converters and small battery bank: Used to assist in managing power flows, power smoothing.
- Active renewable control: Control power output of the renewable device.

Demand Side Options

Control options that can be completed on the grid
side to support system power quality

- Distinction between critical and non critical loads
  – Dispatchable loads like resistance heating
  – Loads shedding where non-critical loads
  – Protection of sensitive loads
- Installation of capacitors to smooth out rapid system fluctuations and partially correct systems power factor.
  – Replacing large inefficient loads

Penetration

Instantaneous Penetration:
– Voltage and frequency control
– Reactive power

Instantaneous Penetration = Wind Power Output (kW)/Primary Electrical Load (kW)

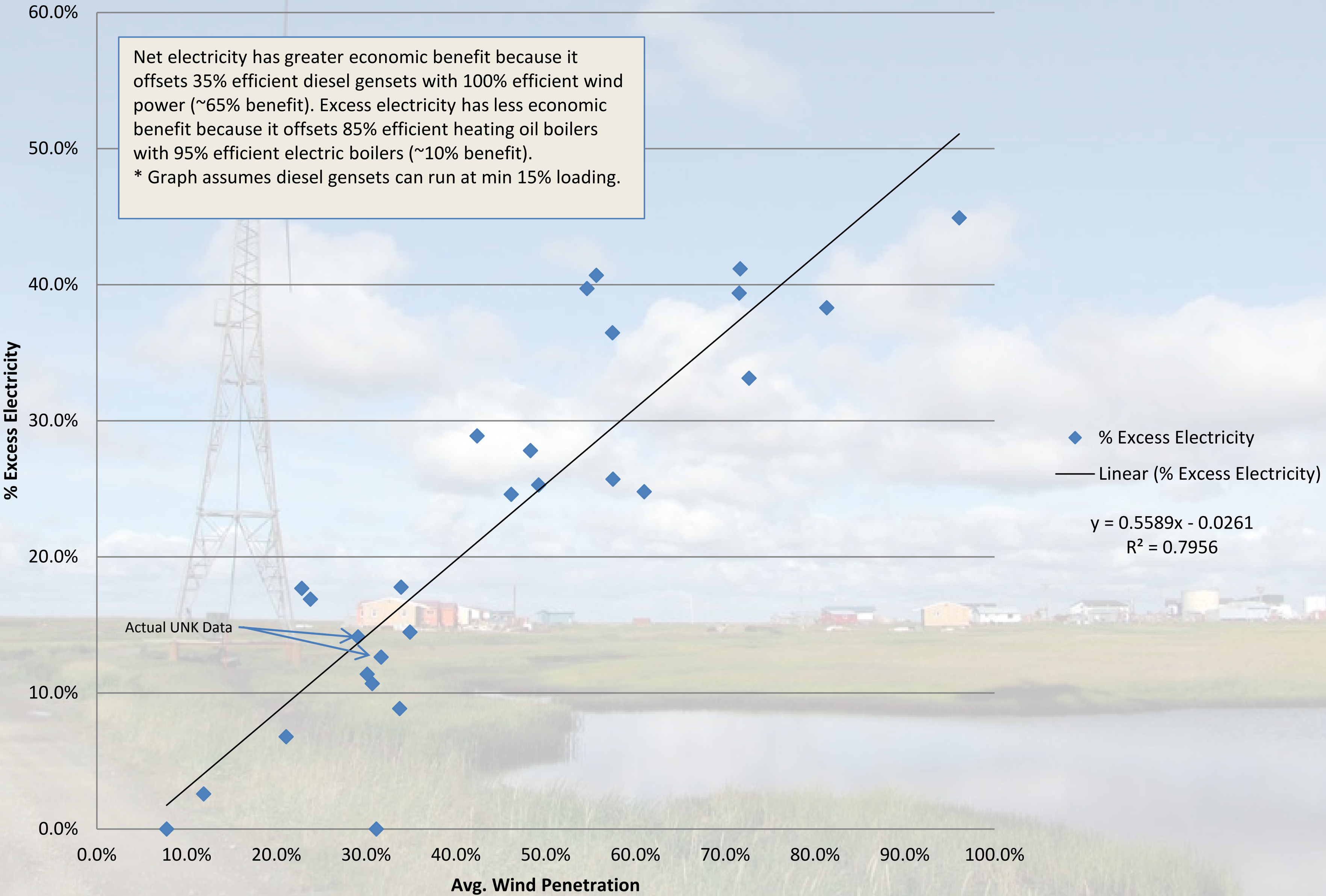
Average Penetration: (generally a month or a year)
– Total energy savings
– Loading on the diesel engines
– Spinning reserve losses/efficiencies

Average Penetration = Wind Energy Produced (kWh)/Primary Energy Demand (kWh)

Old Wind Penetration Classes

Penetration Class	Operating Characteristics	Penetration	
		Instantaneous	Average
LOW	• Diesel runs full-time • Wind power reduces net load on diesel • All wind energy goes to primary load • No supervisory control system	< 50%	< 20%
MEDIUM	• Diesel runs full-time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading or wind generation is curtailed • Requires relatively simple control system	50% – 100%	20% – 50%
HIGH	• Diesels may be shut down during high wind availability • Auxiliary components are required to regulate voltage and frequency • Requires sophisticated control system	100% – 400%	50% – 150%

Excess Electricity vs. Wind Penetration Level - Alaska Village Systems

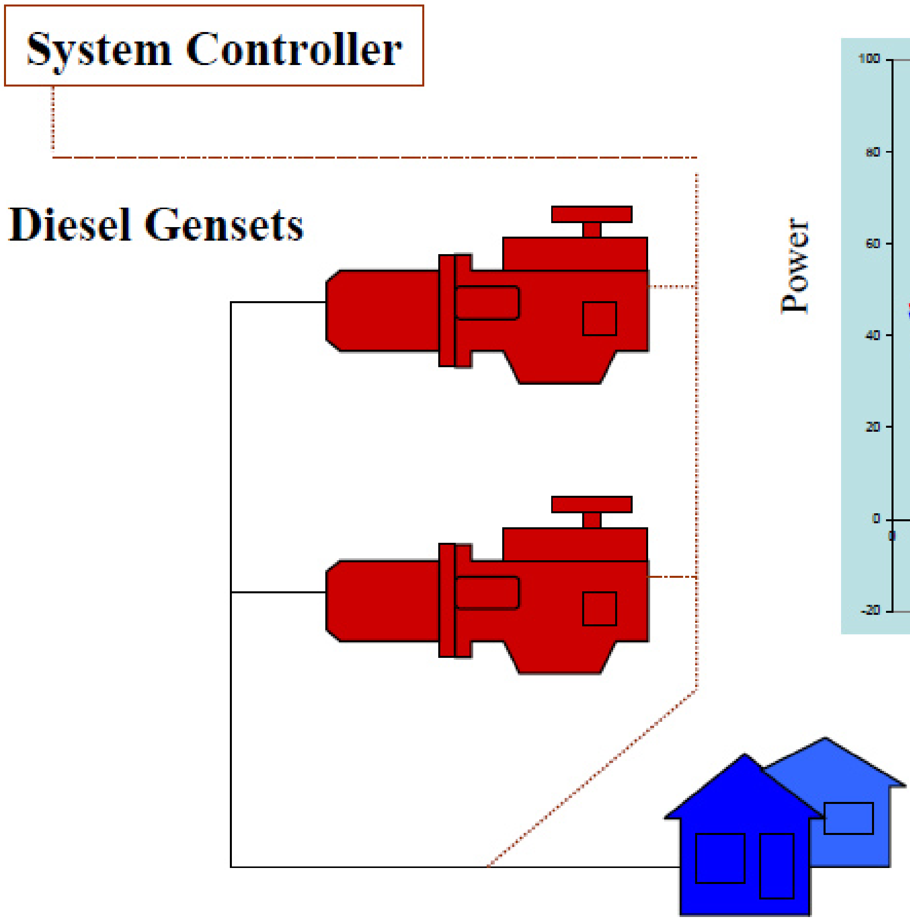


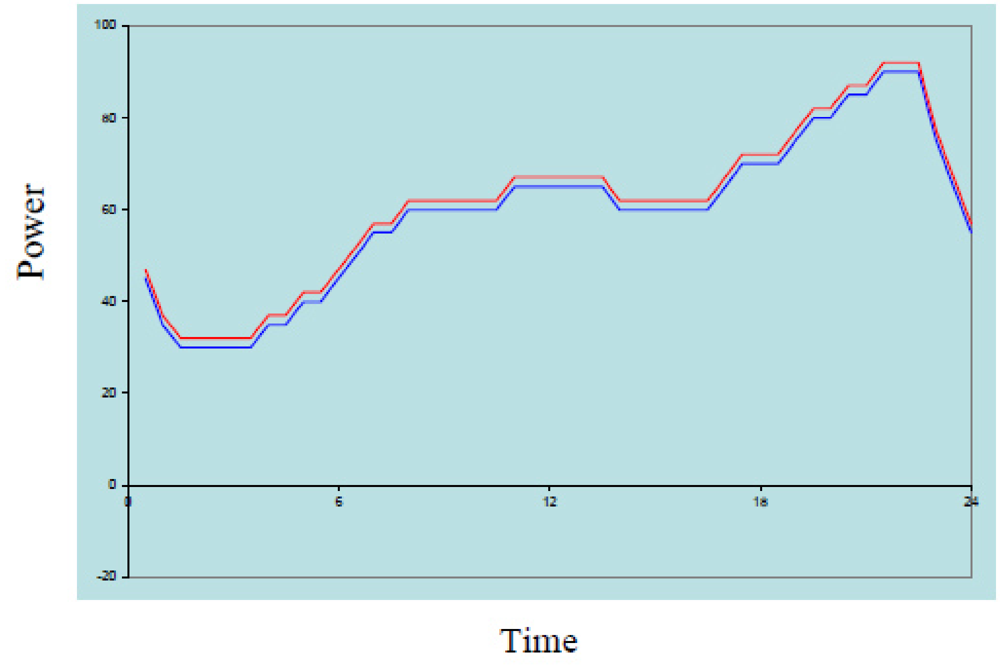
New Wind Penetration Classes

Penetration Class	Operating Characteristics	Instantaneous Penetration	Average Penetration
Very Low	Diesel runs full time Wind power reduces net load on diesel All wind energy goes to primary load No supervisory control system	<60%	<8%
Low	Diesel runs full time At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading or wind generation is curtailed. Requires relatively simple control system	60% - 120%	8%-20%
Medium	Diesel runs full-time At medium to high wind power levels, secondary loads are dispatched to insure sufficient diesel loading. More complex secondary load control system is needed to ensure that heat loads do not become saturated during extended windy periods.	120%-300%	20%-50%
High	Diesels may be shut down during high wind availability Auxiliary components are required to regulate voltage and frequency Requires sophisticated control system	300%-900%	50%-150%

Exact numbers are not sacrosanct.

Diesel Only Power System

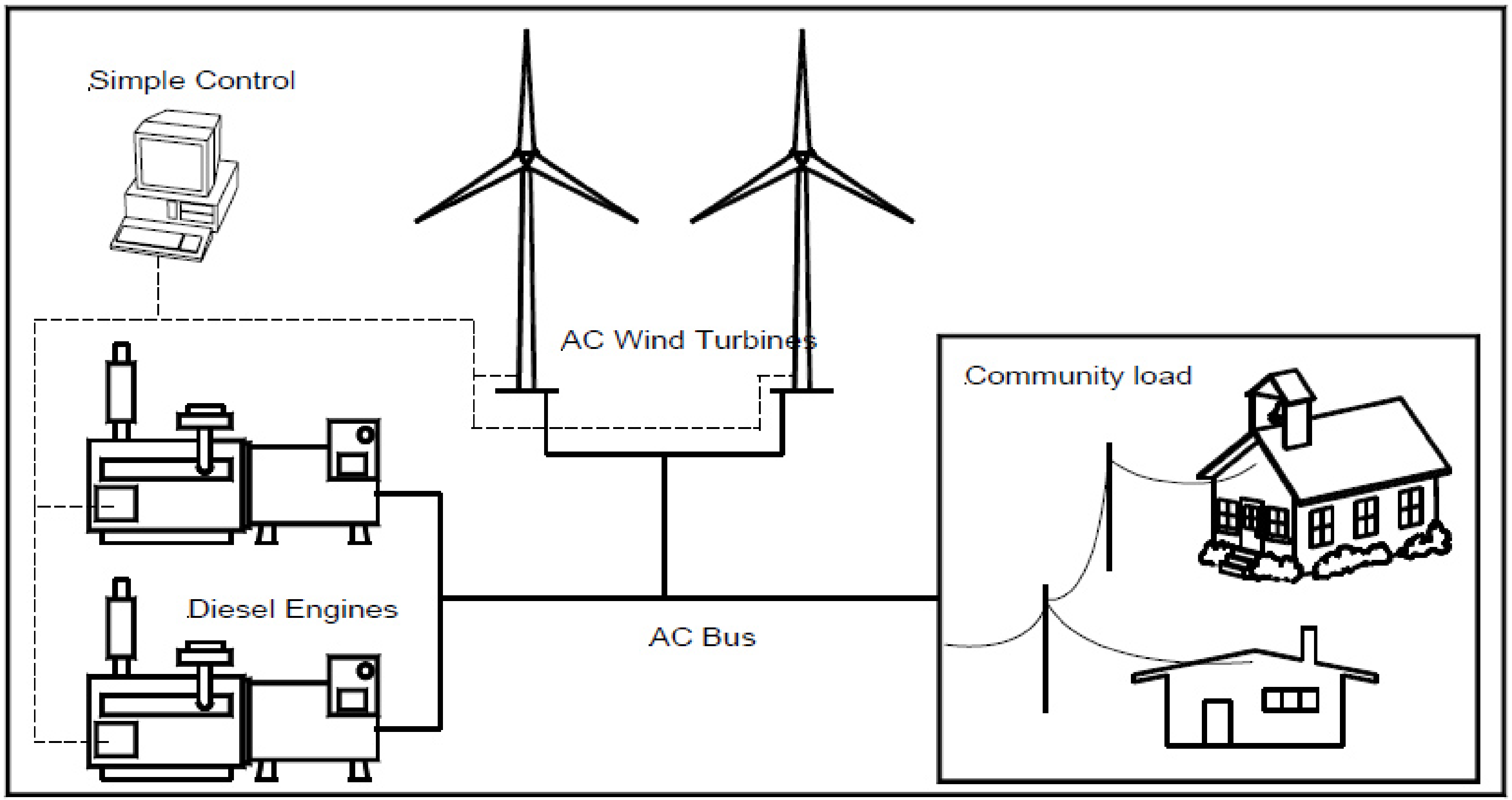




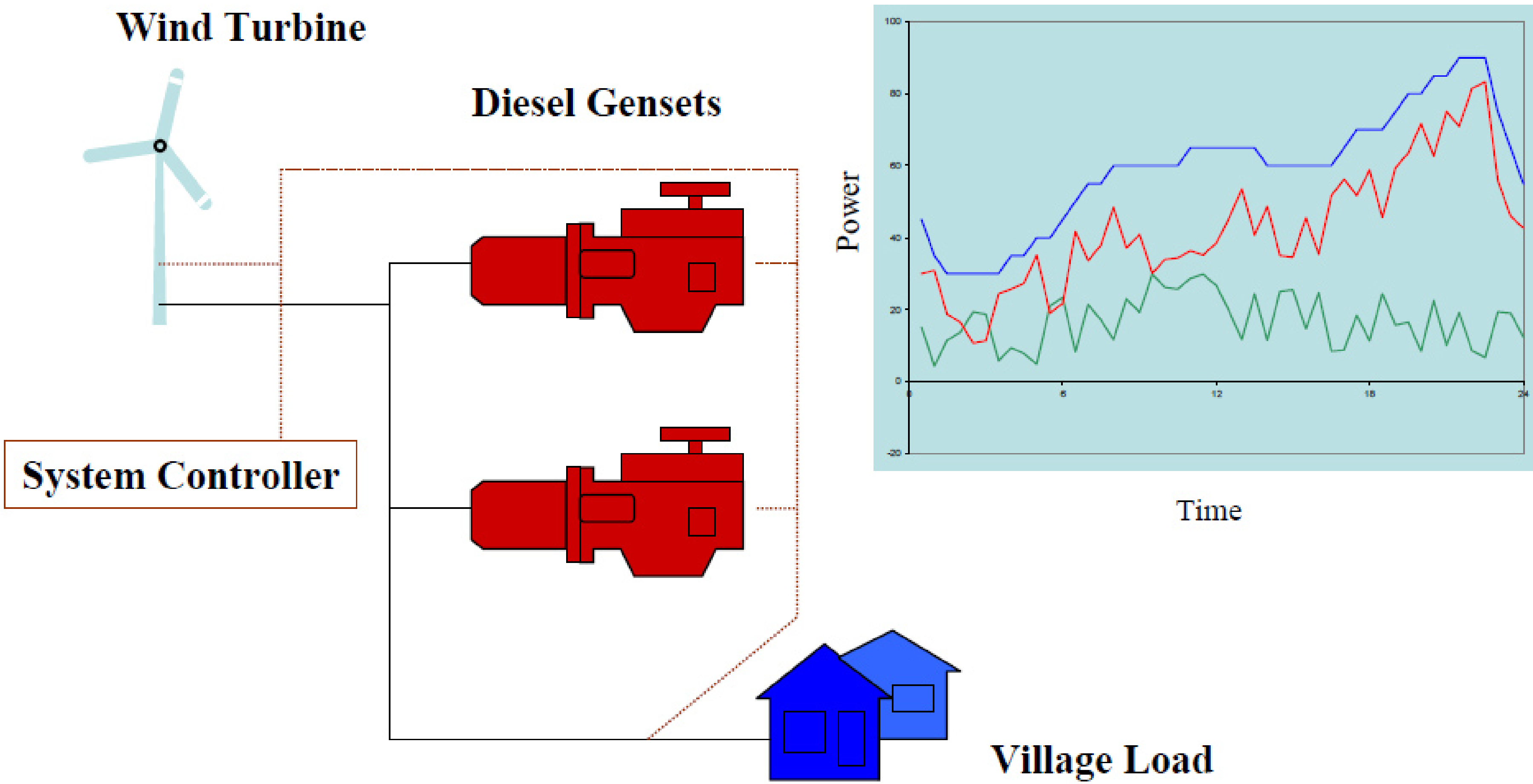
Low Penetration W/D Specifications

- Equipment
  - Wind turbine or series of turbines
  - Dump load to smooth out power fluctuations
  - Capacitor bank used correct power factor if needed
- Control
  - Wind turbine monitoring
  - Power control of wind turbines possible but not required
  - Minor controls to allow remote turbine shut down in extreme cases

Low Penetration W/D Schematic



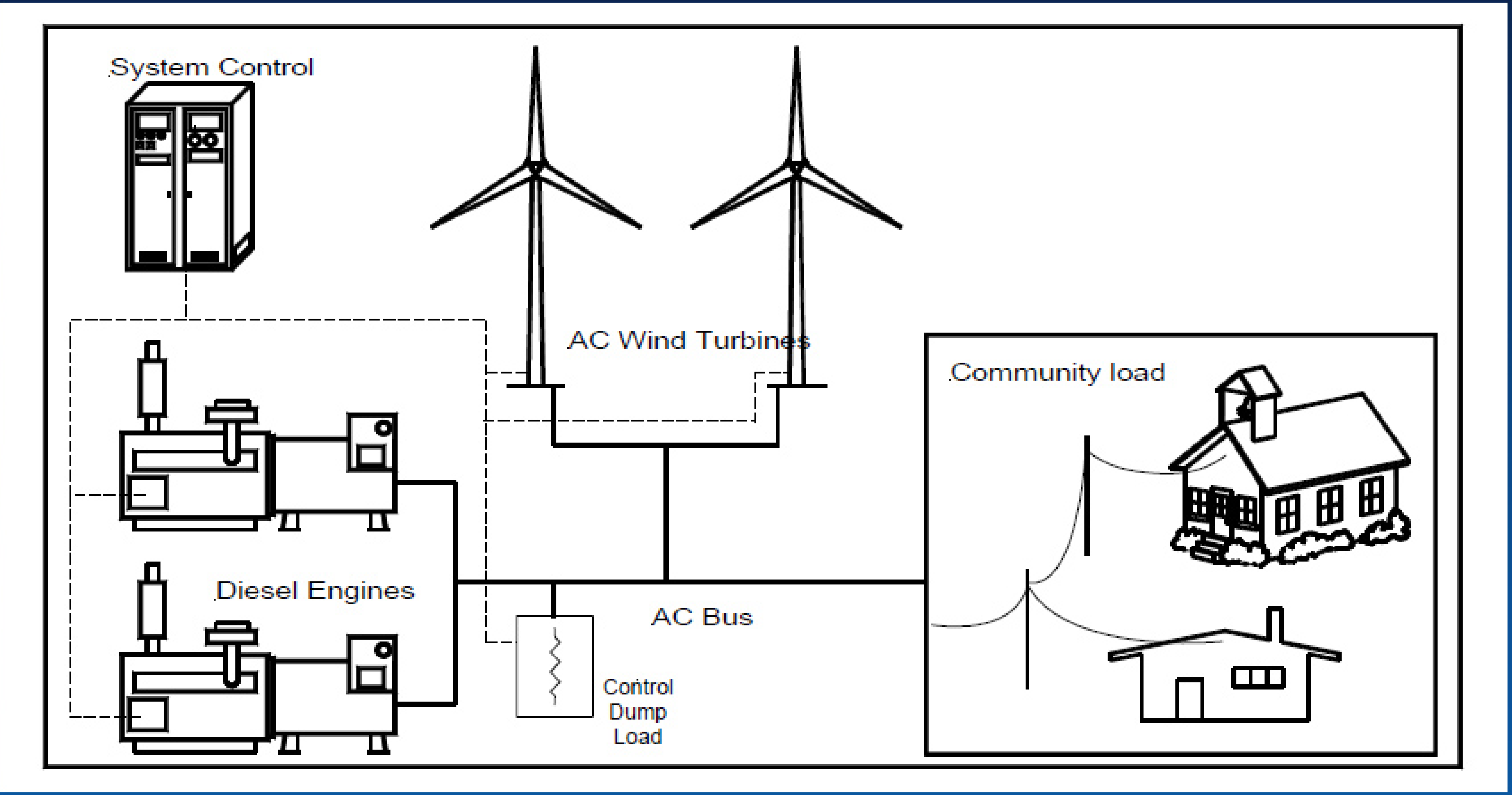
Low Penetration wind/diesel system



Medium Pen W/D Specifications

- Equipment
  - – Wind turbine or series of turbines
  - – Dump load to smooth out power fluctuations
  - – Dispatchable loads to reduce loading on diesels and help control system frequency - May have capacitor bank
- Control
  - – Wind turbine controls
  - – Power control of wind turbines possible but not required
  - – Diesel control
  - – System controller to maintain system stability and dispatch primary diesels and wind turbines as needed
  - – Some power forecasting may be implemented

Medium Penetration W/D Schematic



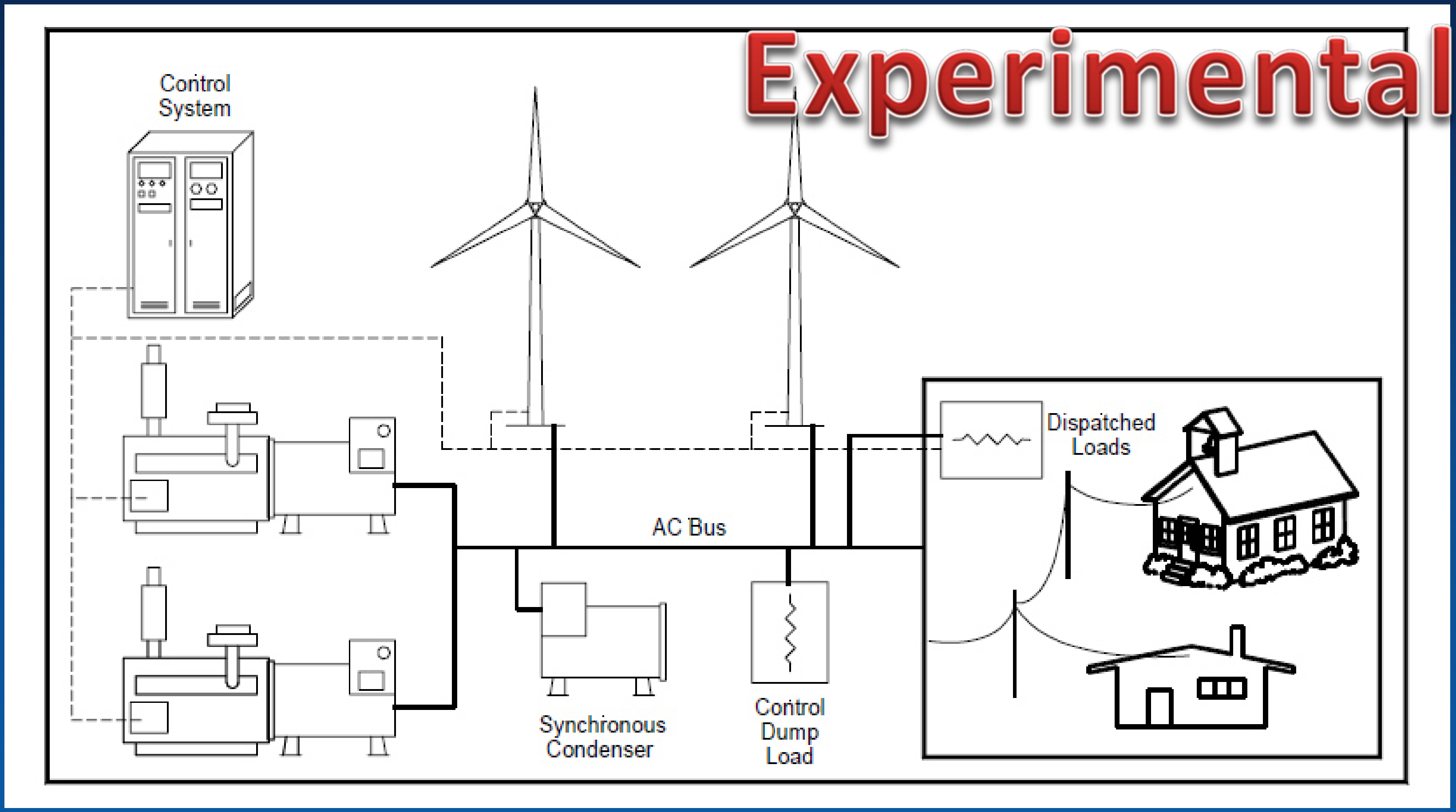
Batteries in Medium Penetration W/D Systems

- Batteries can play a role in medium penetration systems
- Used for short periods of load/supply time shifting
- Not intended for diesel-off operation
- An option to be weighed against/with more secondary loads, synchronous condensers

Batteries in Medium Penetration W/D Systems

- Many types
  - Lead Acid (deep cycle and shallow cycle)
- – NiCad
- Two uses/sizing:
- – Store energy to cover long periods (residential)
- – Store power to cover short periods (community wind-diesel)
- Requires periodic replacement
- Sensitive to environment
- Life dependent on use and the environment

High Penetration W/D Schematic

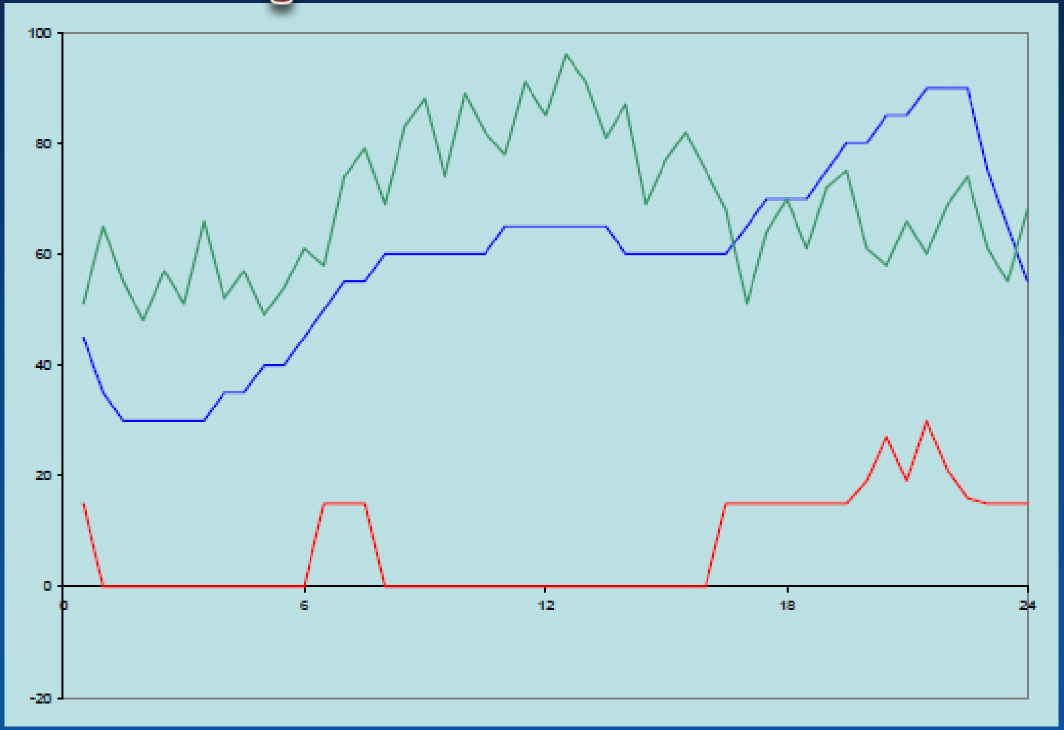


Wind Diesel without Storage

Experimental

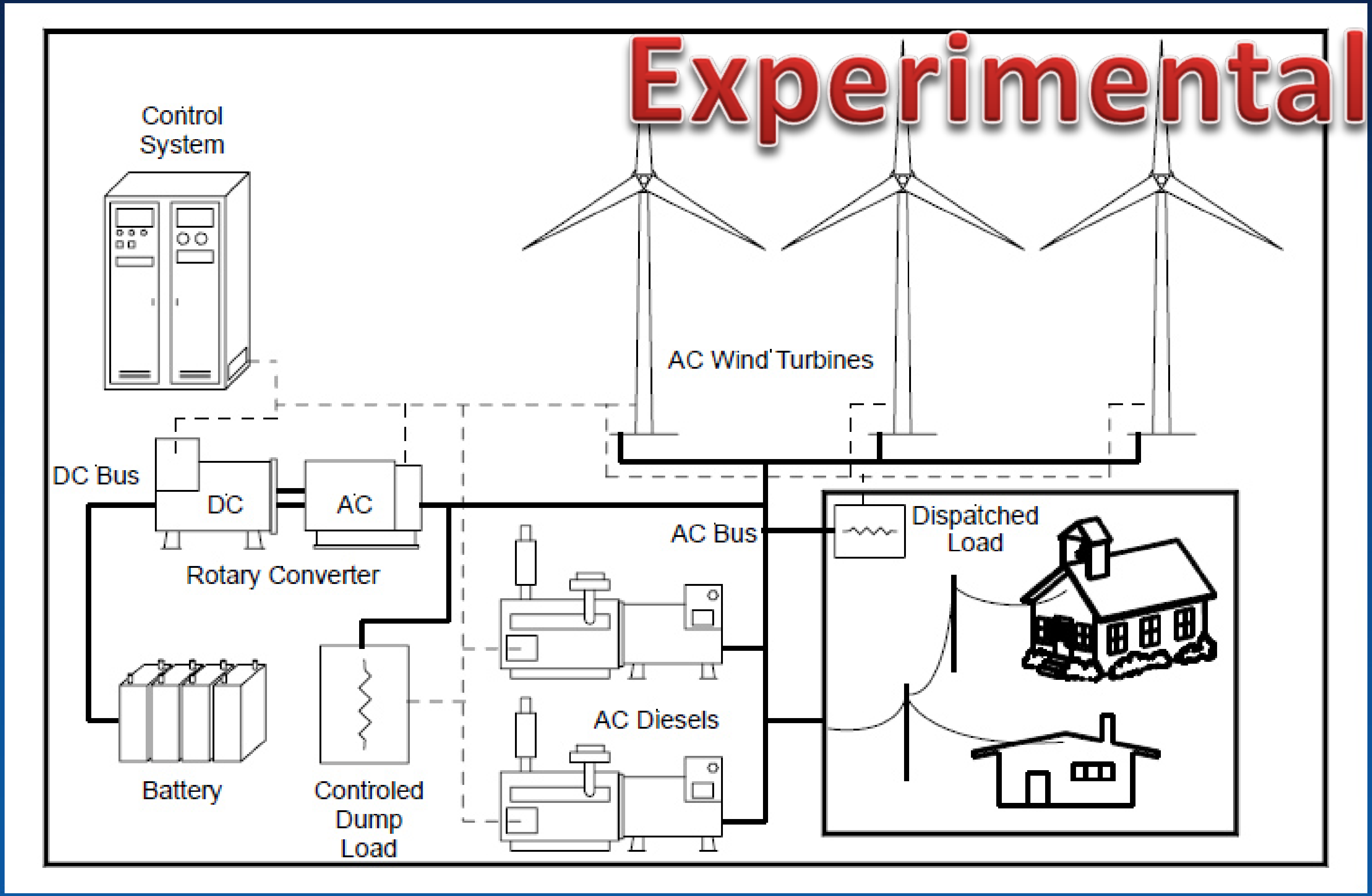
When the wind power is larger than the load by some margin - Diesel is shut off.

- Frequency controlled by dump load
- Voltage controlled by condenser

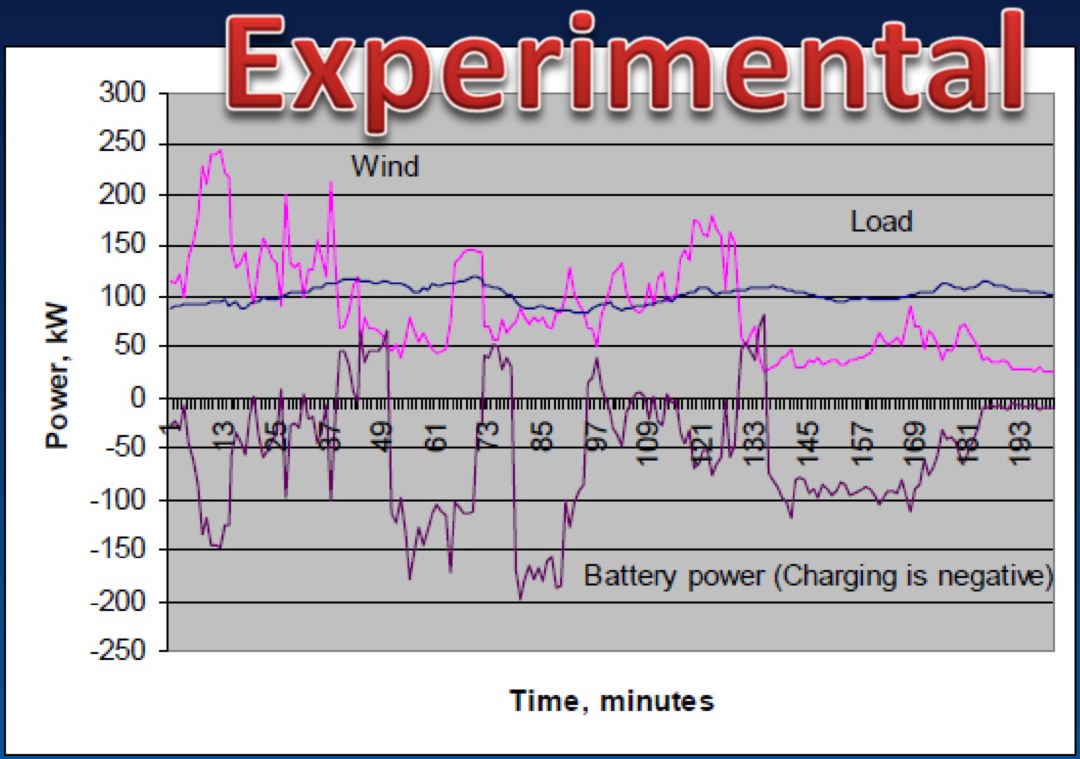


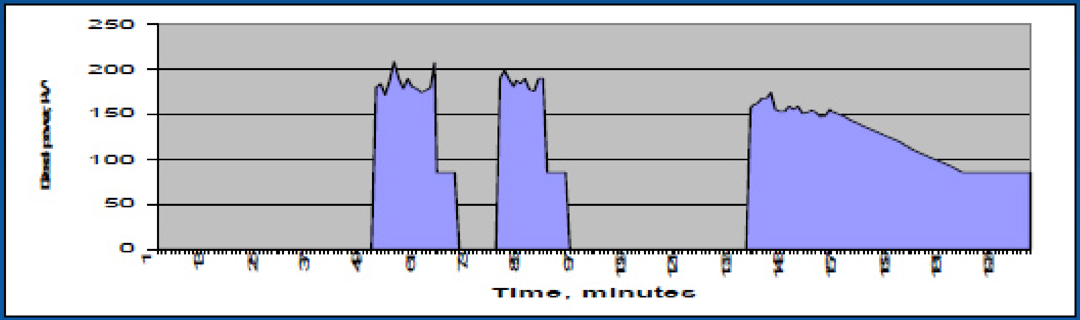
Red = Diesel
Blue = Load
Green = Windpower

High Penetration W/D Schematic



Wind/Diesel with Short Term Storage





- Diesel used to provide power to system when the wind can not cover load.
- Battery used to fill short gaps in or to start diesel

Systems and Components

- Hybrid power systems are made up of separate pieces of equipment that are brought together to form a cohesive power system
- Configuration and component size depend on the load and resource available at site
- Controlling the power systems is a complicated question, both logically and technically.
- Must understand the components

Dispatchable Generators

- Generators that can be turned on with short notice.
  - Diesel, Gas, Natural Gas, Bio-gas
- Usually require a lot of maintenance
- Role depends on system design.
- Wide range of old and new technology
- Wide range of control

40 kW Diesel Generator

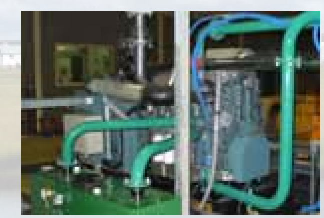
Other Active Power Control

- Allows active control of grid stability
- Allows access to small amounts of instantaneous power
- Generally modular
- Spinning losses
- Long research history, very short operational experience

Flywheel

Experimental

Low Load Diesel



Power Smoothing and Conditioning

- Help to control voltage and balance active and reactive power needs on the grid
- Primarily used when all diesel engines have been shut off
- Might provide limited "storage"
- Has a standing loss

75 kW Synchronous Condenser

Grid Conditioner

Secondary Loads and Community Heating

- Remove excess energy from the grid
- Help to control frequency
- Made of resistive heating elements and some control
- Two uses
  - Dispatched to provide heating (value added)
  - Fast-reacting heating elements exhausting to the open air. (dump load)

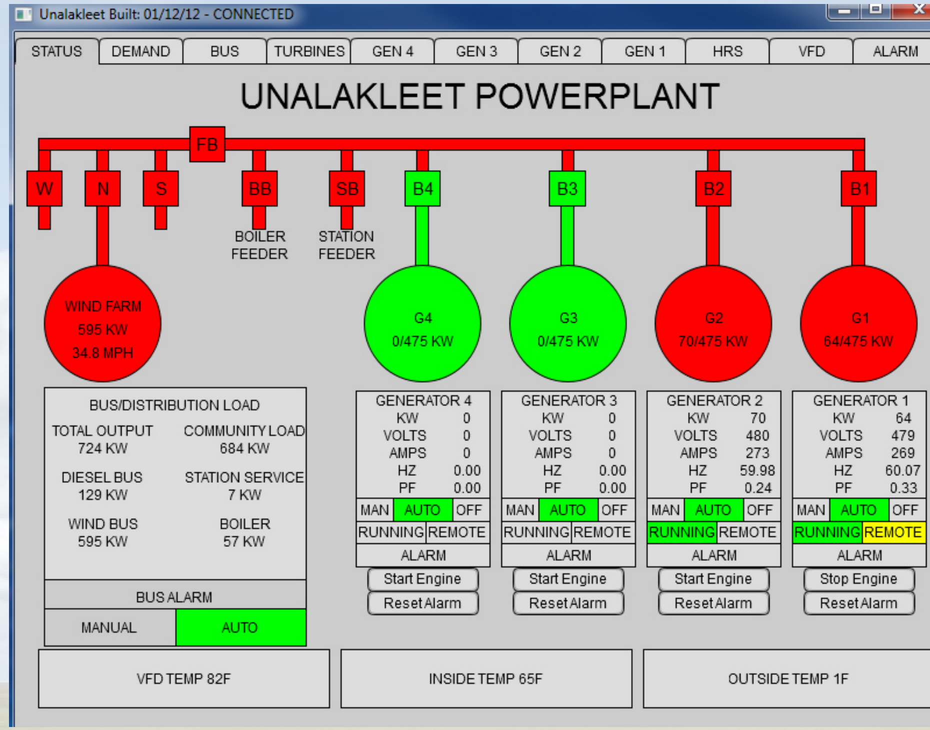
100 kW dump load

System Controls

- The things that make everything work together.
- Individual components and central control
- High speed (behind the scene) and general control
- Can Reduce staffing costs and increase service

Monitoring and Remote Access

- Remote access allows oversight of system performance
- Enables real time system interrogation and troubleshooting even when off site
- With expert analysis system reduces maintenance and down time
- Small incremental cost



Has become a required component of any remote power system

Financial Impacts of PCE on W-D

Village name:	Anuqamute	
Total kWh produced:	3,202,657	
kWh sold:	3,065,046	
Station service:	137,611	4.49%
PCE eligible residential kWh:	747,592	24.39%
PCE eligible community facilities kWh:	514,346	16.78%
Non PCE and commercial kWh:	1,803,108	58.83%
Diesel kWh:	2,202,657	68.78%
Wind kWh:	1,000,000	31.22%
Non fuel expenses:	$777,960	
Fuel expenses	$622,165	
Calculated res/comm rate - before PCE	$0.4568	Without wind energy
Calculated PCE reduction	$0.2973	Without wind energy
Calculated residential rate after PCE	$0.1595	Without wind energy
Fuel expense with wind energy	$436,460	
Drop in fuel cost per kWh with wind	$0.0606	
Calculated res/comm rate with wind	$0.3962	With wind energy
Drop in Calculated residential rate	$0.0606	
Calculated PCE reduction with wind	$0.2397	With wind energy
Drop in PCE discount with wind	$0.0576	
Calculated residential post PCE rate	$0.1565	With wind energy
Actual change to residential rate after PCE----->	**$0.0030**	
Actual change to commercial rate with wind energy	**$0.0606**	
* Actual rates will be higher when residential customers exceed the 500kWh per month PCE limit.		

Conclusions

- Many design options for hybrid systems
  - Very low penetration - relatively easy but minimal fuel savings
  - Low penetration - generally easy and simple
  - Medium penetration - more complex, challenging to find value-add secondary loads
  - High penetration - very complex, expensive and leading-edge
- There is a lot of off the shelf technology that can be used to implement these systems but some level of skill is required to make them work
- Power quality is a key issue, but not an insurmountable problem at any penetration
- Approach is the same as building a power station, just different technology being implemented
- Many organizations that would be willing to assist in any project development activity