Kilowatt-Range Turbine Implementation at the South Pole

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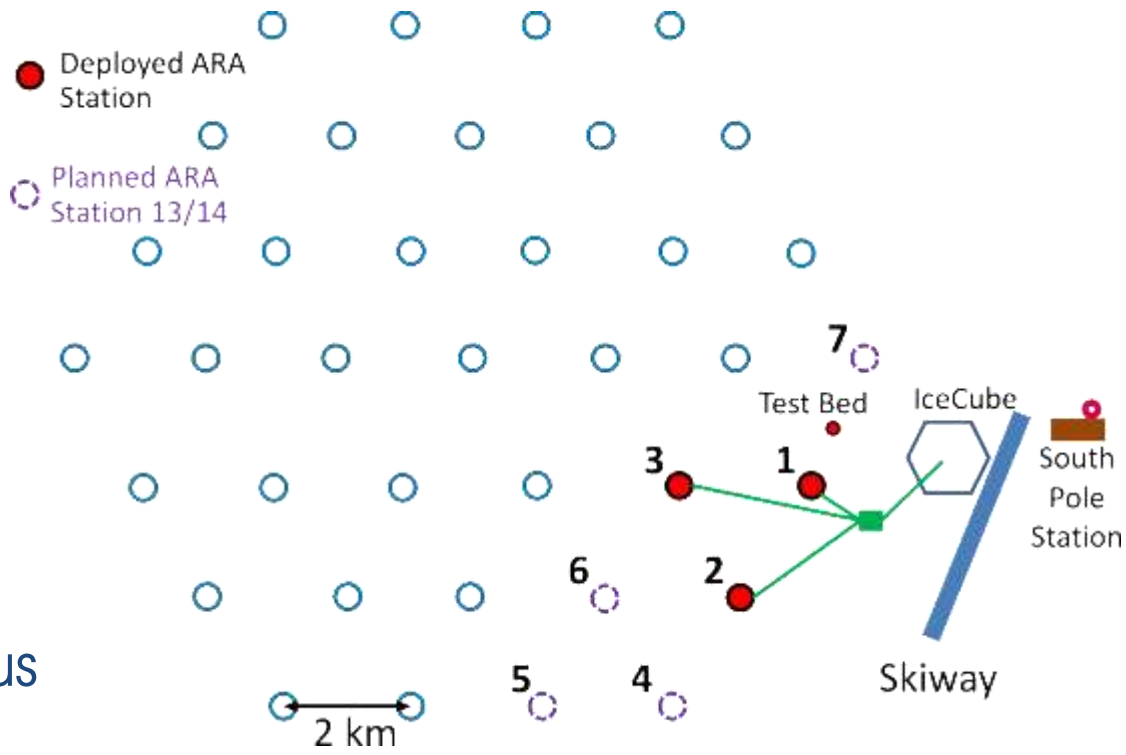
ARA Design Specifications

- ARA: Askaryan Radio Array – neutrino observatory with radio detection
- Current phase: 37 stations spread over 100 km^2.
- Power requirements: about 120W continuous per station.
- Contain the noise!
- Usual requests: low maintenance, 100% uptime, easily installed & maintained, low cost, etc.



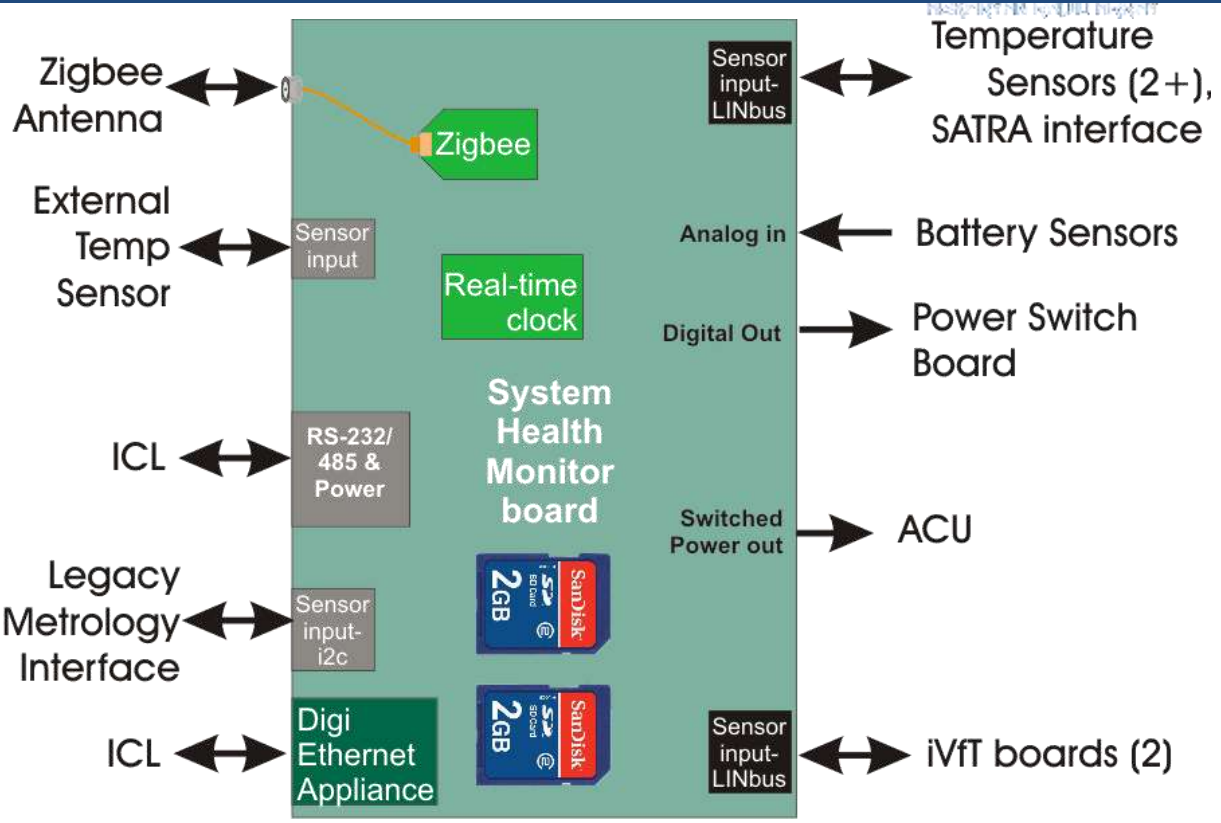
Design factors for Turbine/PV station

- Turbine selection
- Grease
- PV selection
- Battery selection
- Instrument Box Design
- Tower Design
- Charge controller

- Values for components
  - Number of turbines per station
  - Number of PV panels
  - Number of batteries
  - Tower height
  - Box temperature
  - Controller parameters

Need Data! System Health Monitor

- Multiple sensor inputs:
  - i2c
  - LINbus,
  - digital I/O,
  - Analog.
- Multiple Comms:
  - RS232/RS485
  - Ethernet,
  - Zigbee.
- Dual SD card
  - (2GB each)



- LINbus implemented to enable full-duplex multi-component comms with power over a single pair. The LINbus is a master-slave network used in automotive networks

Other electronics notes

- SHM handles 3 metrology units (T, wind speed, direction)
- Incoming Voltage & current (use Hall effect with temperature correction)
- Power cables have PV-connectors
- 8-12 awg cables (PE or "seoprene" insulation) crimped with power crimper.
- Lots of ferrites
- Power-switching with Solid State Relays
- Component failures
  - RTC "loses its mind" for days and then recovers
- Monitoring failures: fiber into which we connected failed 2 years in a row.

Turbines

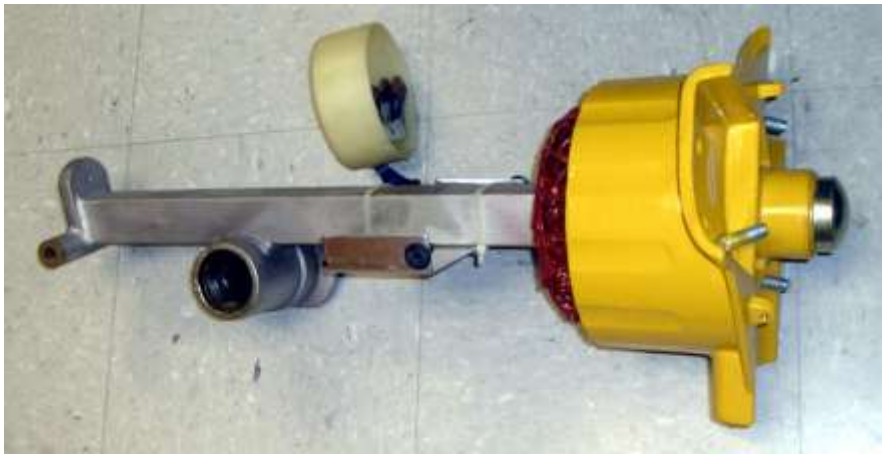
- Raum (Sask, CA)
  - Very robust construction
  - 3-phase
  - Good power production at high winds
  - Very high "start-up" speed. (Being retro'd; hope to diagnose.)
  - Multiple installations in northern Saskatchewan.
  - Apparently out of business.
- Hummer (China)
  - Good power producer
  - Failed mechanically
  - Too heavy
  - Very difficult to maintain
  - Only 2-phase
  - No longer in business

Smaller Turbines

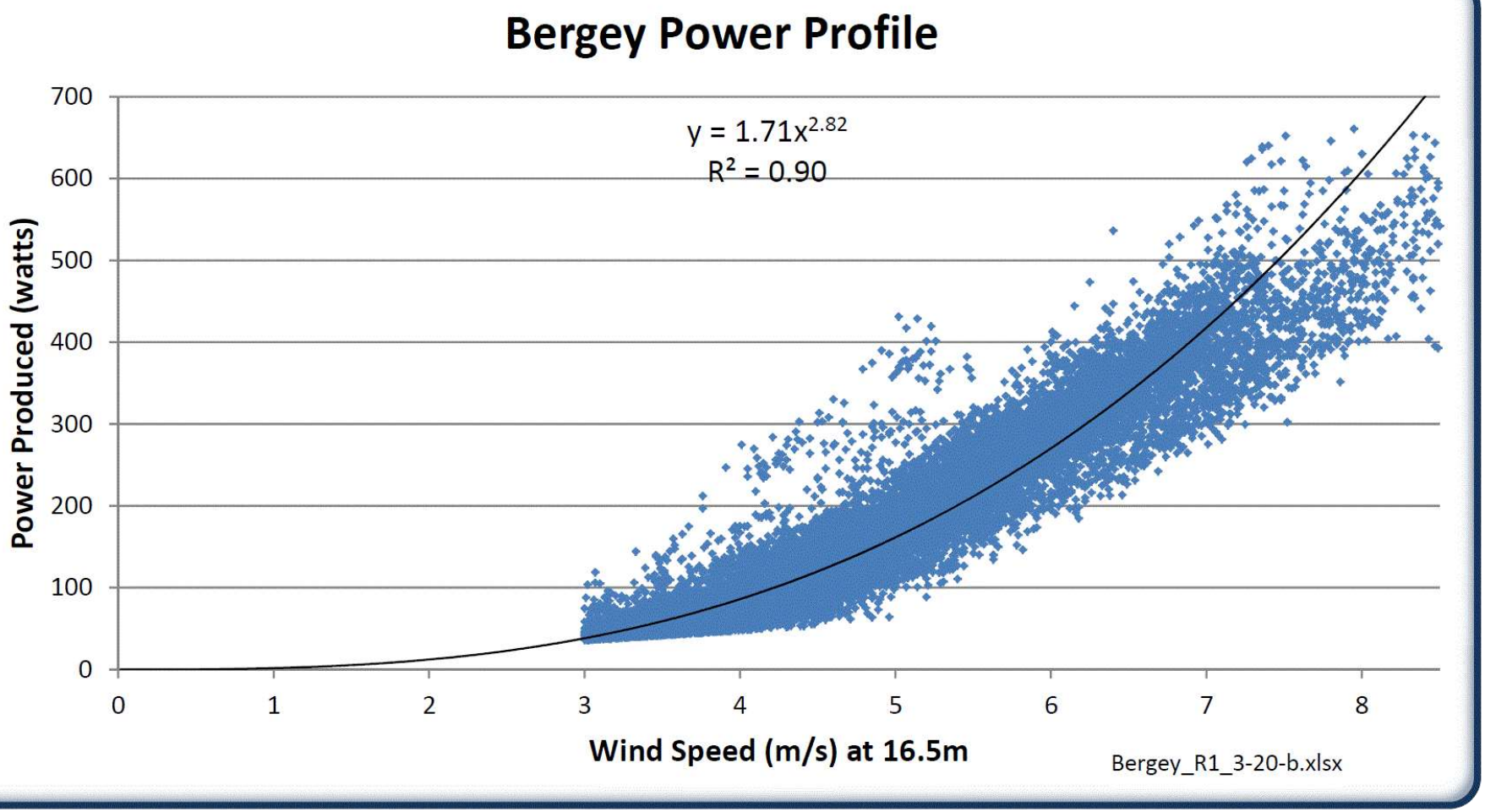
- Southwest Whisper (New Mexico)
  - Moderate productivity
  - Two failure modes in 2012:
    - the yaw mechanism packed with ice & stuck.
    - slip rings failed.
  - No longer in production.
- Aero6gen – sub-kilowatt
  - Well-known, robust, but too small
- Air40 (Primus Windpower) – sub-kilowatt
  - Installed this season at Mina Bluff (ARIANNA)
  - Internal controller could be discarded
  - Too small for ARA-37

Bergey XL1: (Norman, OK)

- Simple design
- Robust (no problems in 2+ seasons)
- Roller bearings easy to maintain.
- 3-phase
- Good power production
- Minor failure in the slip rings at cold.



Bergey Response Curve



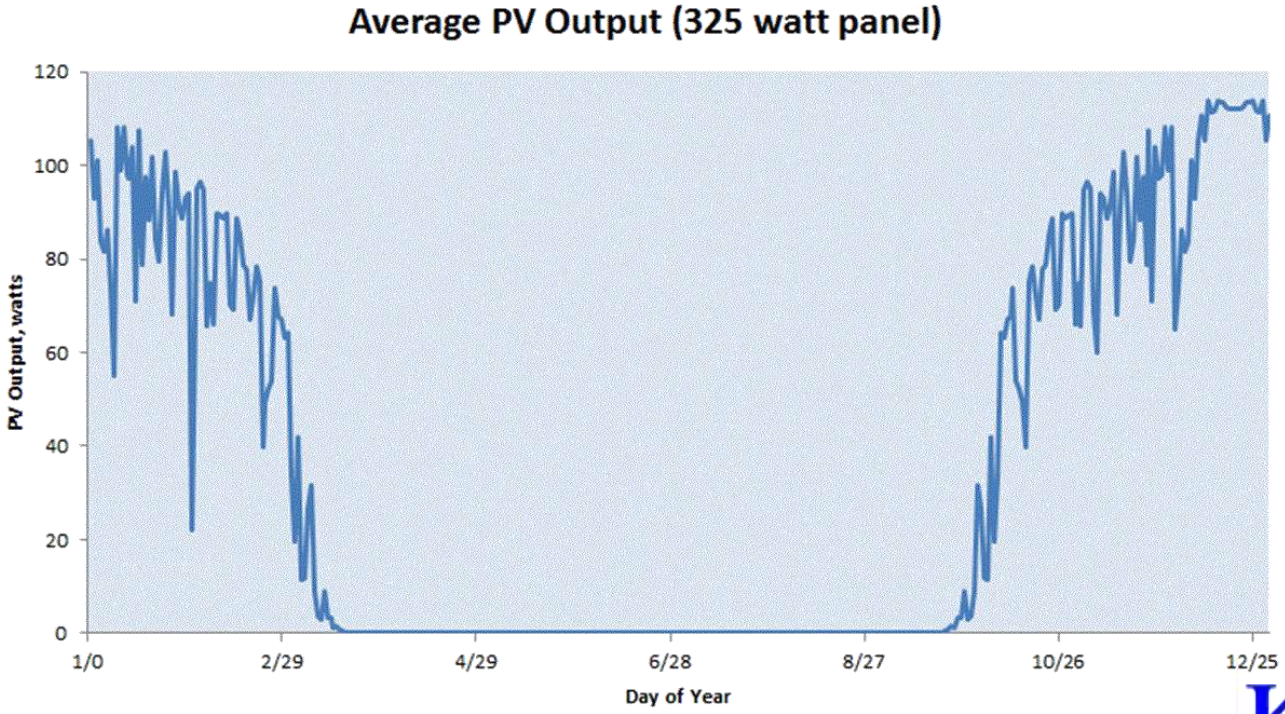
Grease

- Types in use:
  - Royco 27
  - Molykote 33 medium
  - Mobil 33

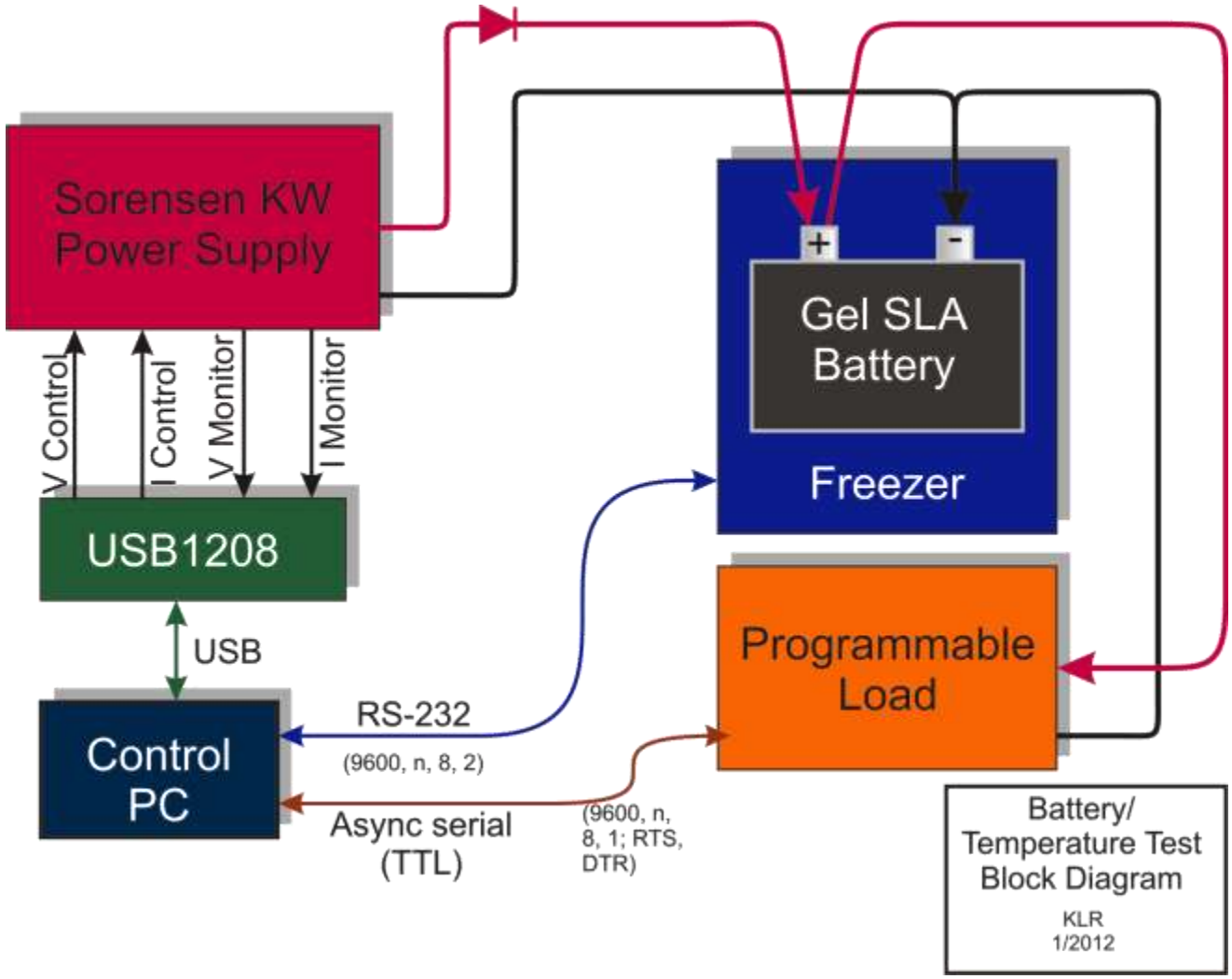
- No basis for choosing yet; all seem OK now.
- 5 Air40s deployed in December use the 3 greases

PV panels and Batteries

- ARA deployed 325W Sharp panels.
  Same family as other workers.
- Mounted at 90° per accepted standard.
- Profile taken from ARA and USAP panels.



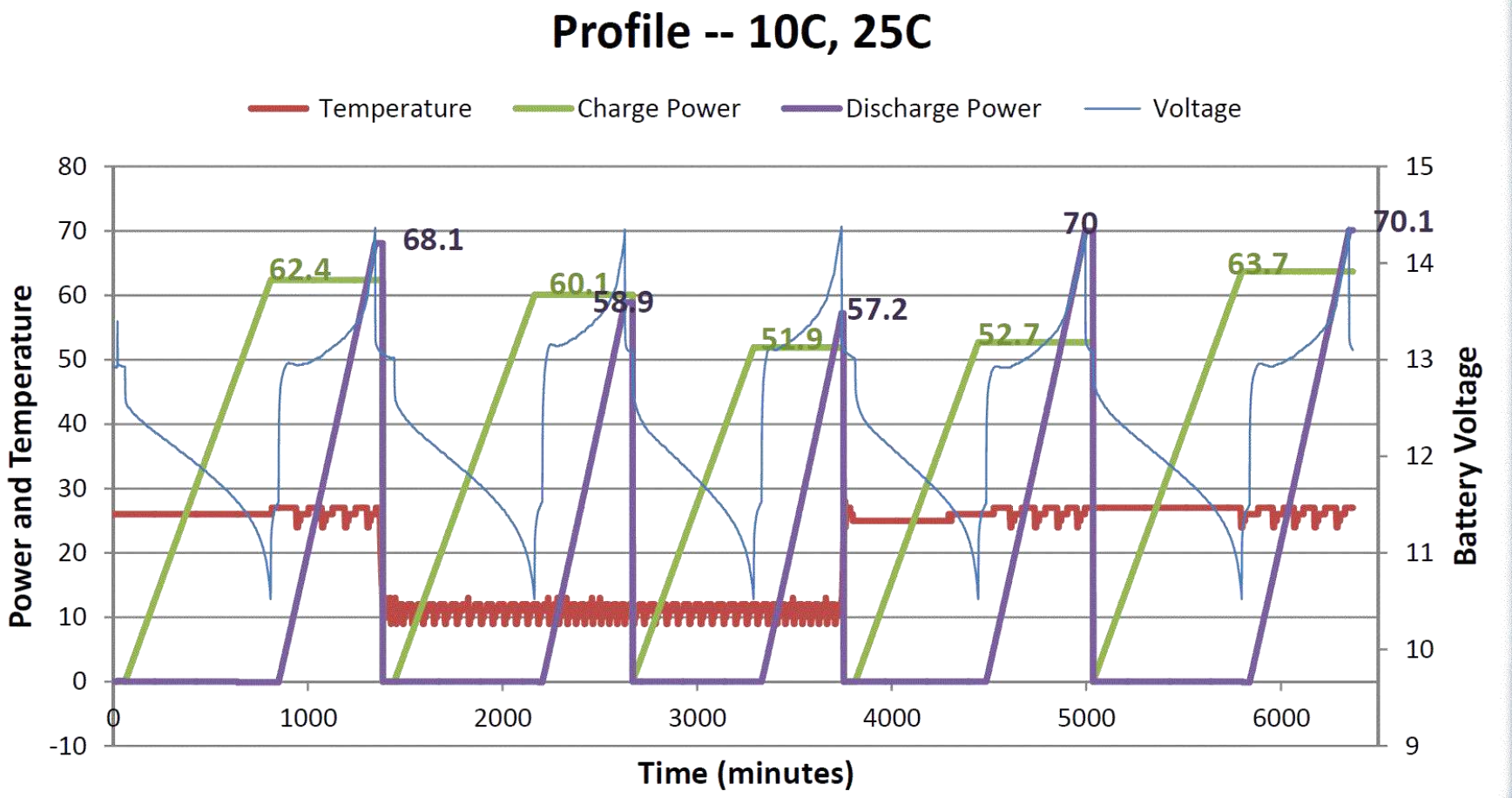
Battery Performance Study



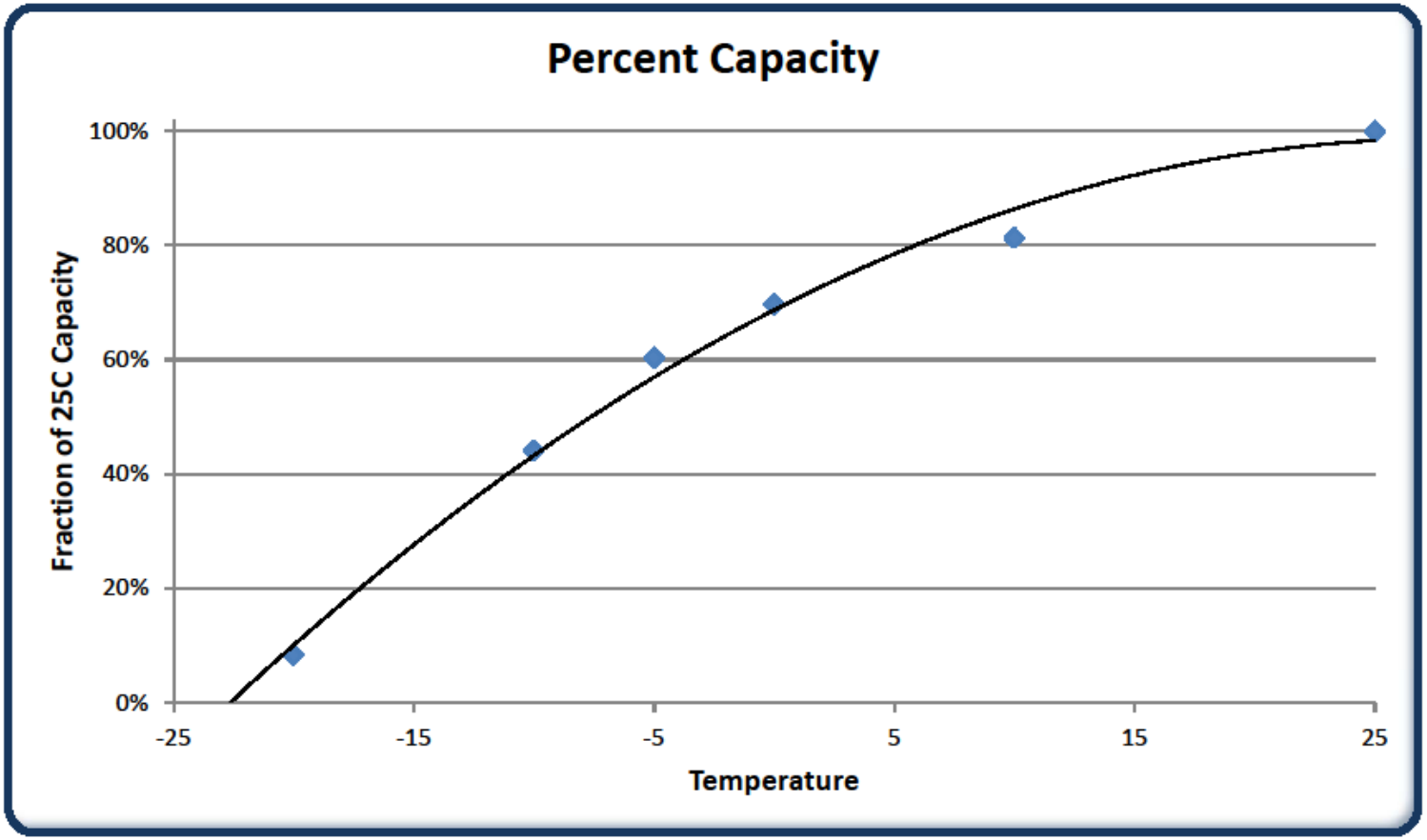
Deka 8G31DT

Charge / Discharge at multiple temperatures

Typical Battery Run

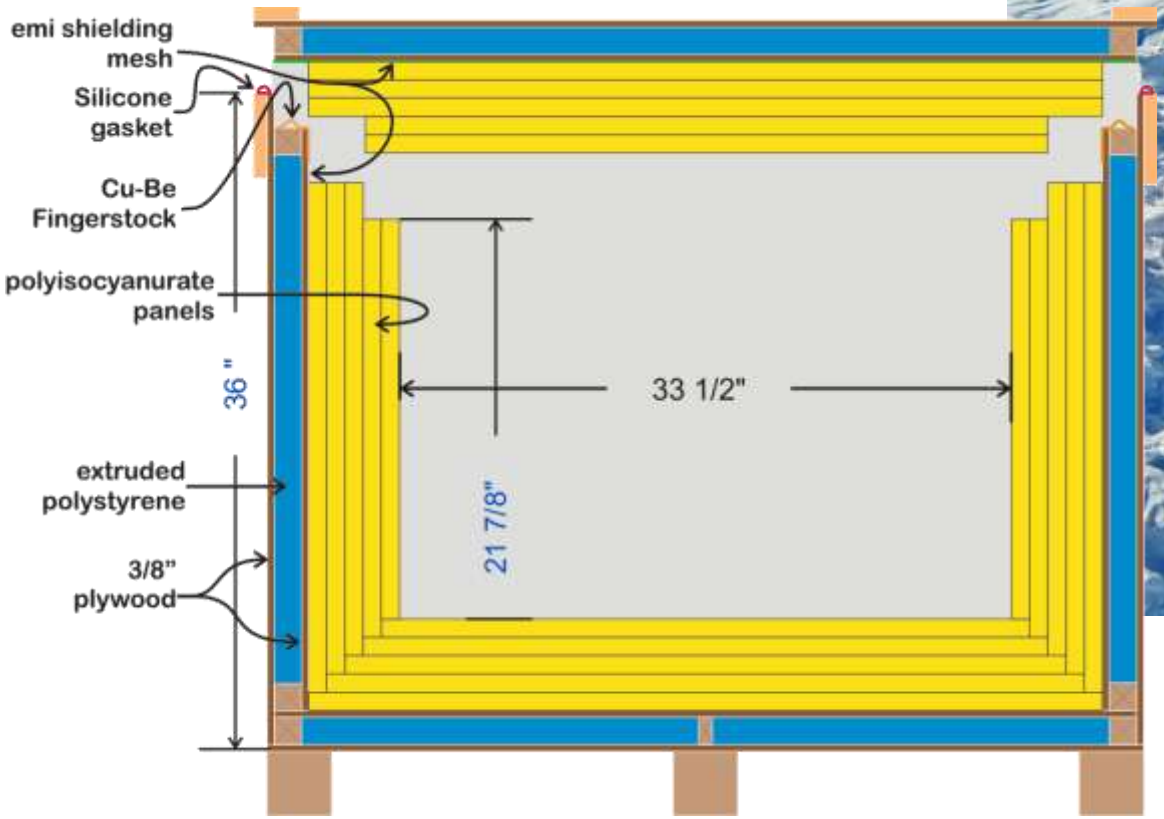


Battery Capacity / Temperature



Instrument Box

- Need both thermal and rf isolation.



Iridited Al connector panel

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Tower Design Summary

- 3 towers installed.
  - 60’ Monopole with single set of steel guys: too unstable; reduced to 50’.
  - 50’ tapered lattice tower. Single set of guys. Good tilt-up. “Overkill;” shipping inconvenient.
  - 60’ monopole; 3 sets of guys (used Kevlar).

Tower Design Summary – Tapered Lattice

- 50’ tapered lattice tower. Single set of guys.
- Good tilt-up.
- “Overkill;” shipping inconvenient.

Tower Design Summary: Simple Monopole

- Monopole with 3 sets of guys.
- Fixed gin pole does not allow adequate support: reduced from 60’ to 50’.

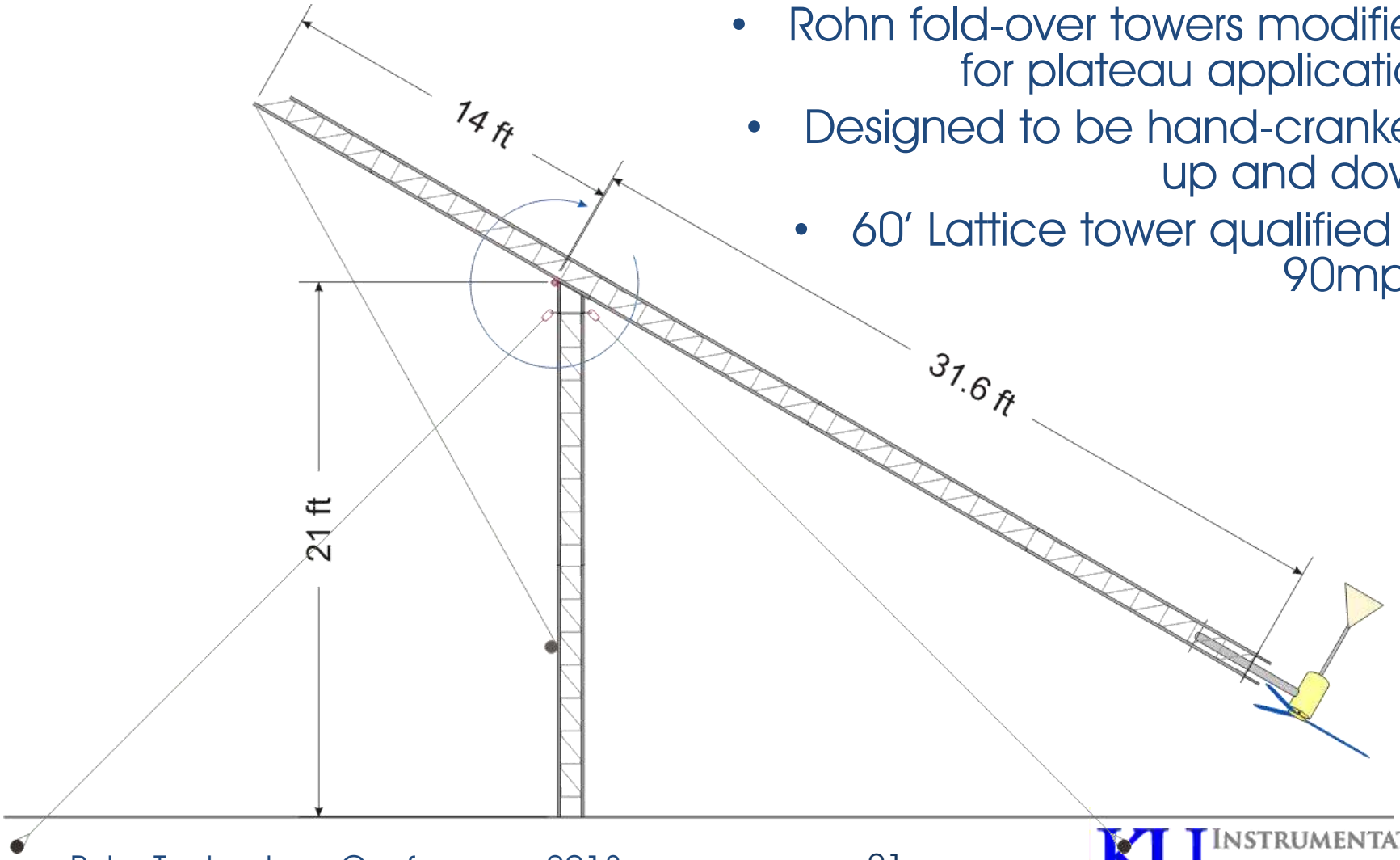
Tower Design Summary: Moving gin pole

- 60’ monopole; 3 sets of guys (Kevlar).
- Setup and adjustment very tedious.
- Once adjusted, tilts up and down easily.

Tower Design Future

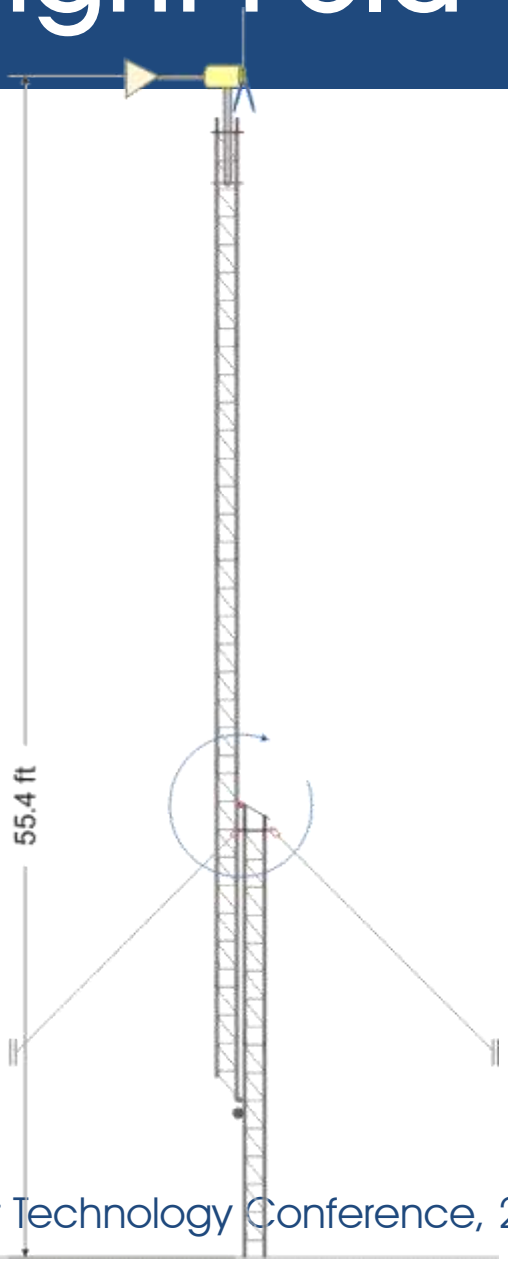
- 50'-60' compromise height (discuss later).
- Light-weight materials with single set of guys. (Winds on plateau are low; don't need to over-engineer.)
- Standard tilt-up requires too much digging in later years.
- If we had deployed last season, it would have been a Rohn lattice tower.
- If we were to deploy next season, it would be a modified **fold-over tower.**

Fold-over tower



- Rohn fold-over towers modified for plateau application
- Designed to be hand-cranked up and down
- 60’ Lattice tower qualified to 90mph.

Upright Fold-over Tower



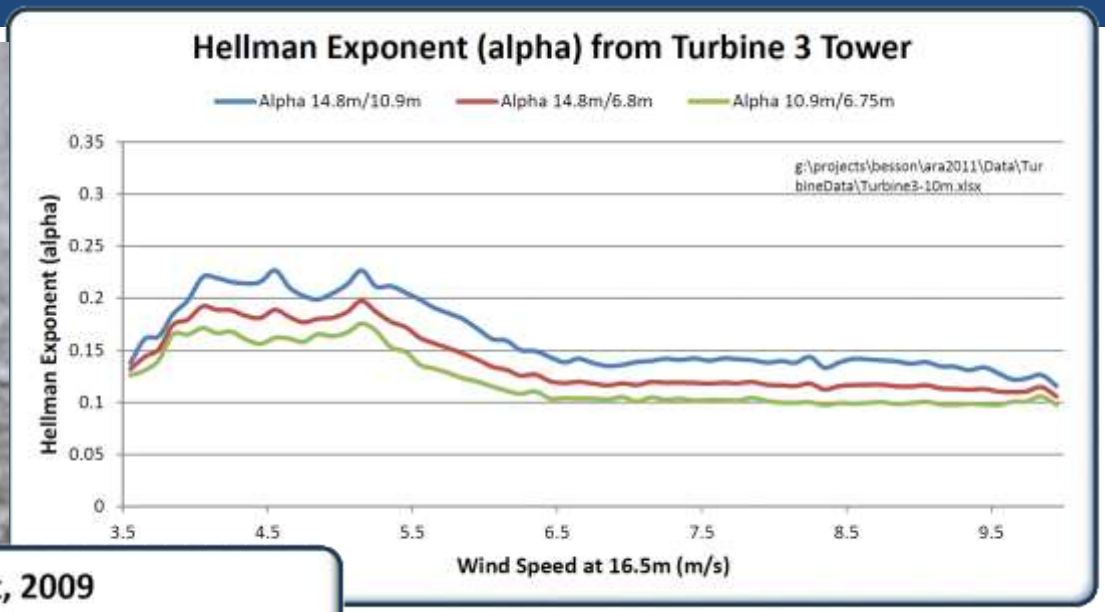
- Lower segment slightly longer than standard to handle accumulating snow.
- 3 or 4 guys at a single level.
- Readily testable in KS

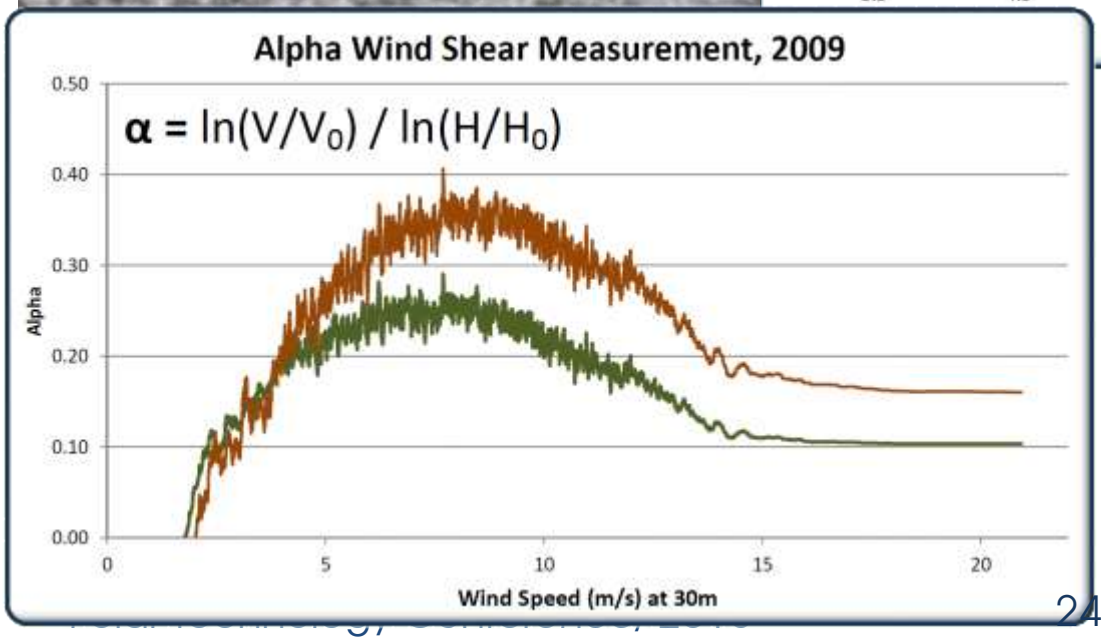
Tower Height

Velocity (V)-dependence on height (H) determined by surface roughness: measured with the alpha coefficient

- $V = (H/H_0)^{\alpha} V_0$ (Not a derived equation)
- Typical α values
  - 0.07 Ice
  - 0.09 Calm sea
  - 0.16 Short grass prairie
  - 0.24 Scattered trees
  - 0.43 Woodlands

Some α measurements





- Sastrugi present significant surface roughness.
- At low wind, turbulence significantly reduces power .

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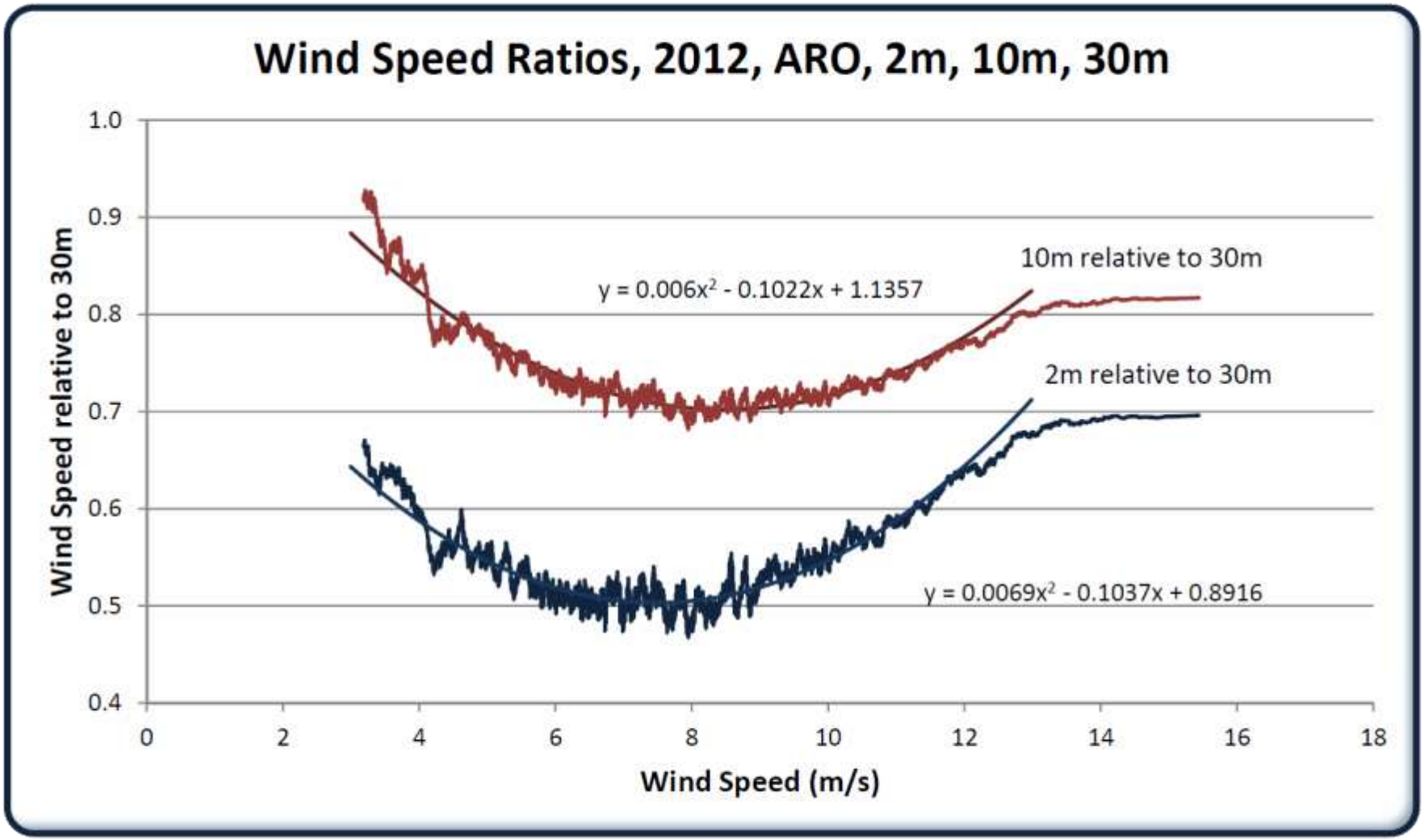
Wind Speed Ratios as f(tower ht.)

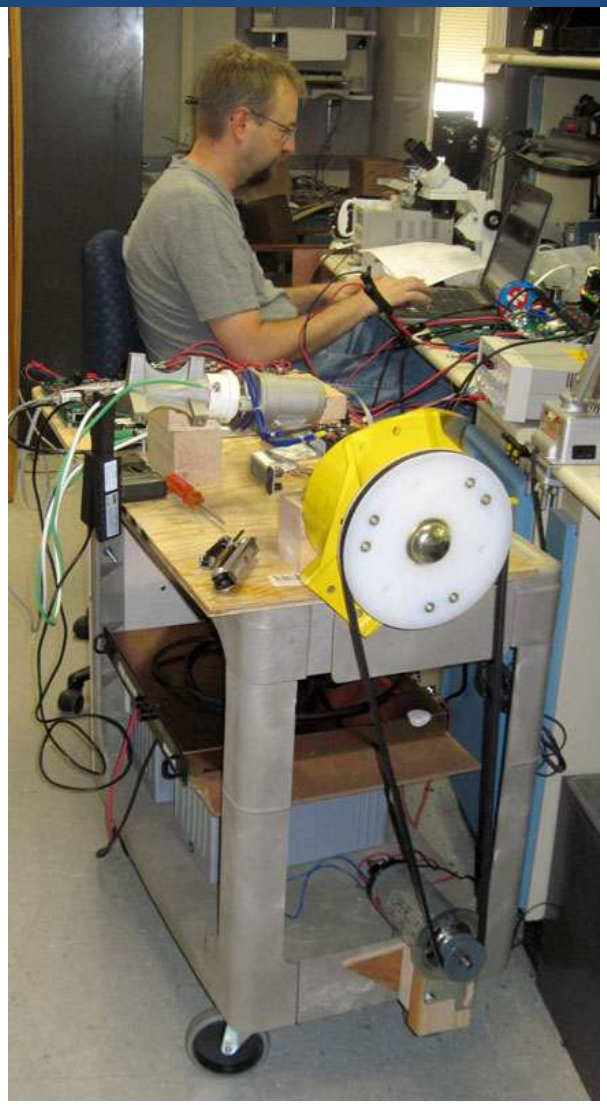


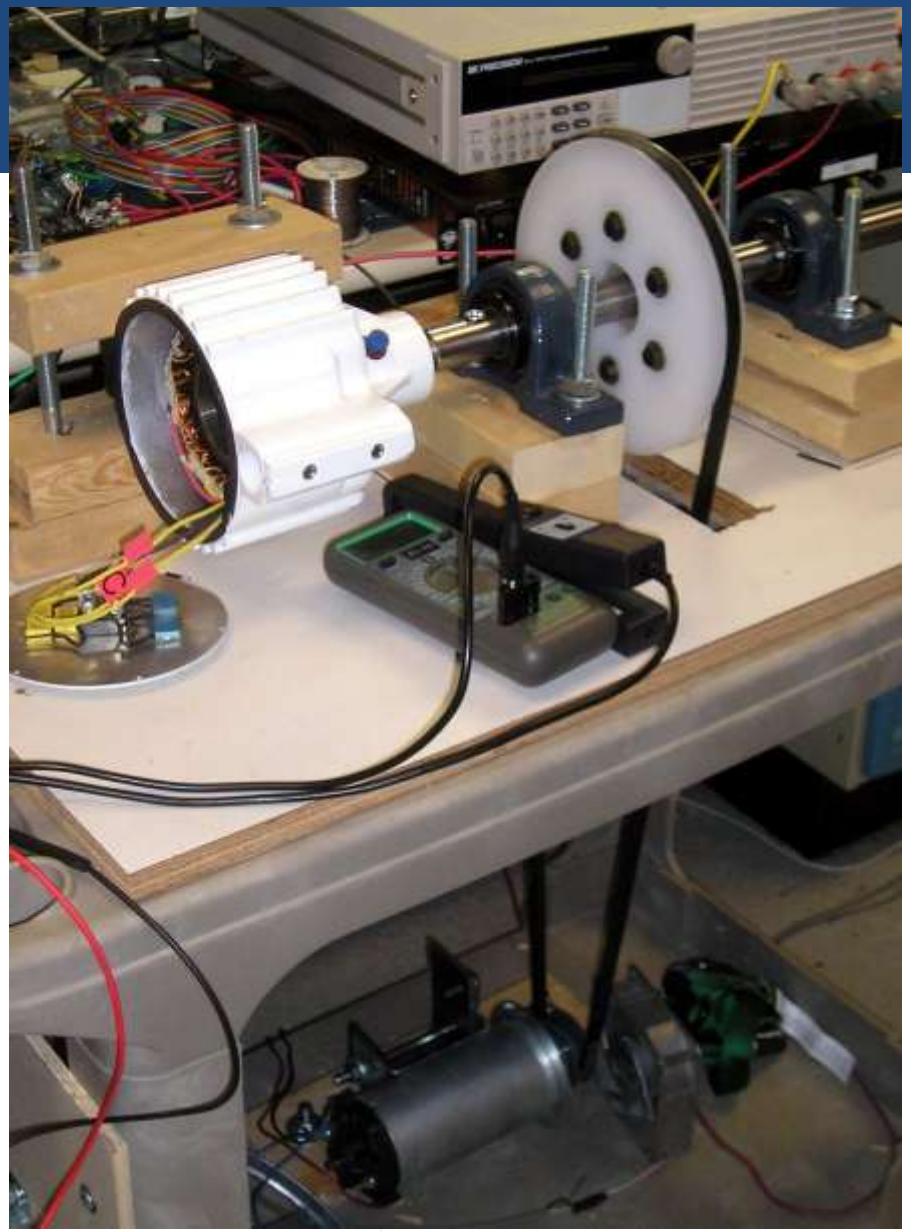
Charge Controller Requirements

- Very Low Noise
- Hi efficiency
- Programmability

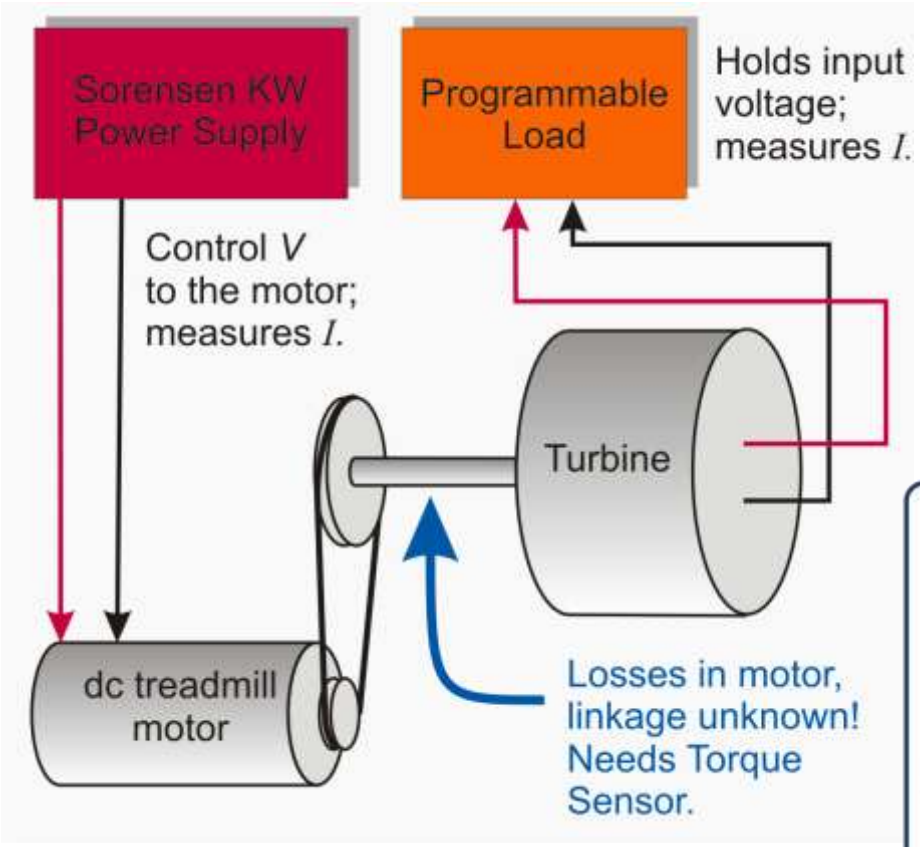
- Set up experiment to examine efficiency w.r.t. Load Voltage.
  - Currently does not account for varying motor efficiencies

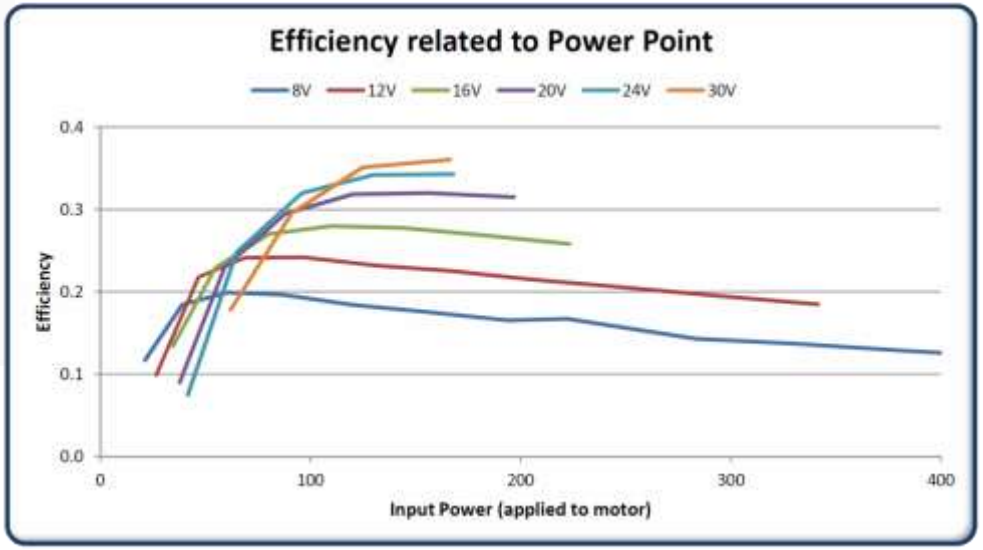
Turbine Efficiency





Power Points for Aero6gen, 12V

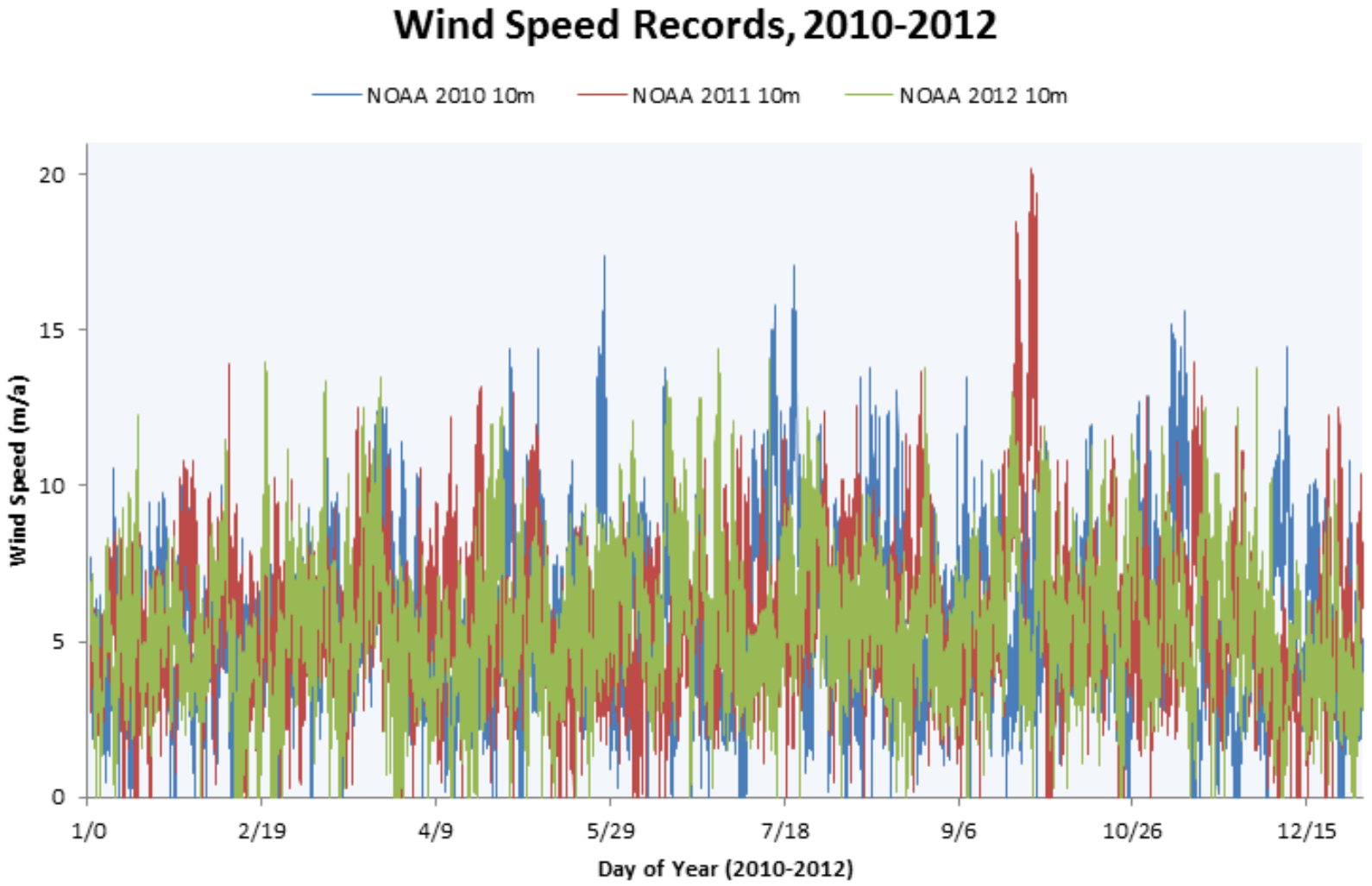




Modeling Live Time: Inputs

- 30m wind data from ARO for one year.
- Model of wind speed ratios for various heights.
- Observed PV output, adjusted for the annual profile.
- Battery capacity adjusted for selected temperature.
- Subtract:
  - Experiment requirements.
  - Box Heating requirements adjusted for selected temperature.
  - (Failed to account for energy when battery is charged that could be used to heat the box.)
- Assume experiment is live if battery voltage is above the lower threshold.

3-yr Wind Speed Data



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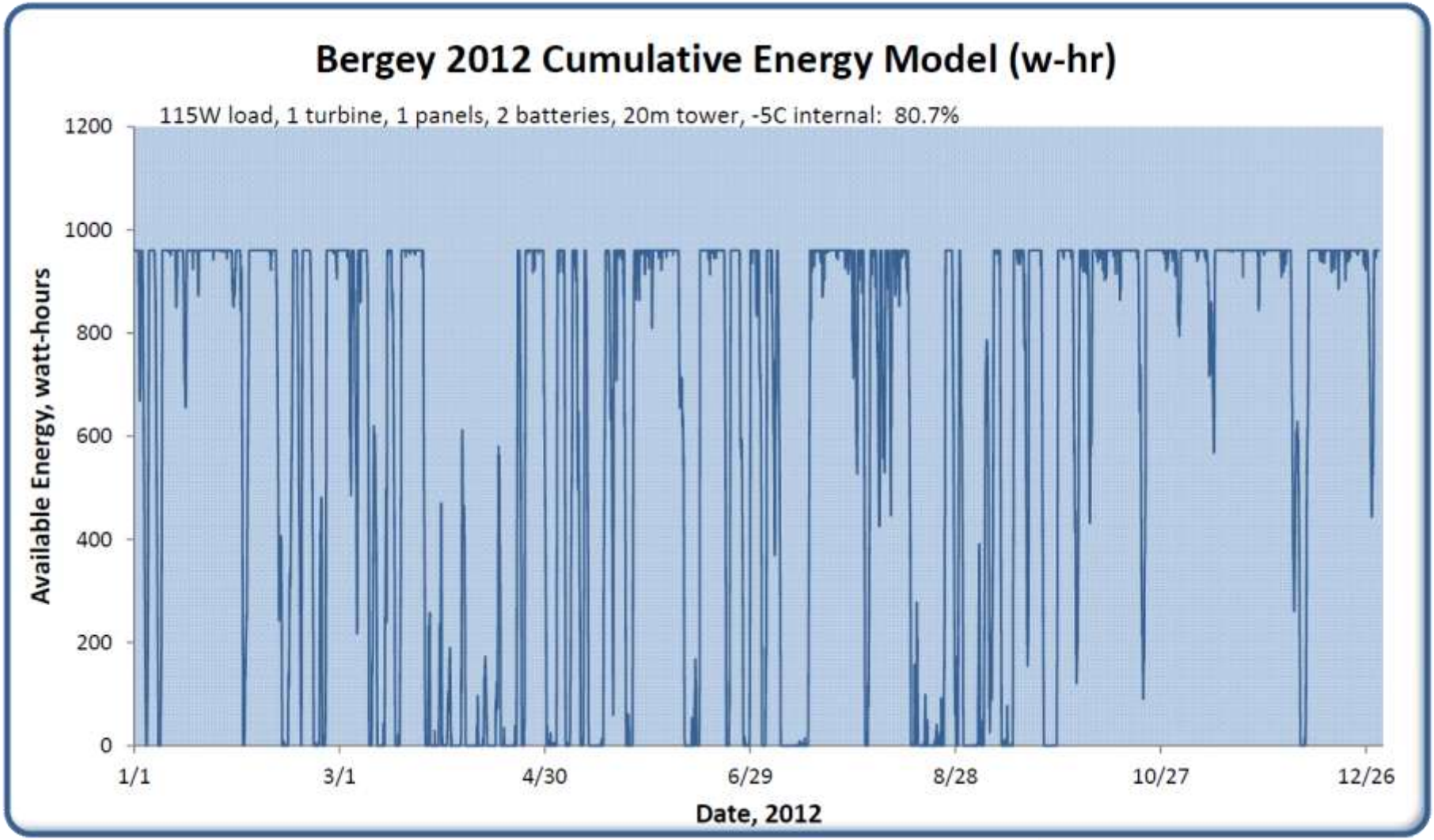
Example Live-Time



Model Results:

Change	# of Turbines	# of panels	Expt Load	# of batteries	Height of tower	Temp-erature	Live Time
(Reference)	1	1	115	2	20 m	-5C	80.7%
Turbines	2	1	115	2	20 m	-5C	97.2%
Panels	1	2	115	2	20 m	-5C	82.3%
Panels	1	0	115	2	20 m	-5C	64.3%
Temperature	1	1	115	2	20 m	-10	80.6%
Temperature	1	1	115	2	20m	+5	80.5%
Tower	1	1	115	2	15m	-5C	73.1%
Tower	1	1	115	2	10 m	-5C	64.8%
Battery	1	1	115	4	20 m	-5C	84.5%
Load	1	1	115	2	20 m	-5C	85.7%