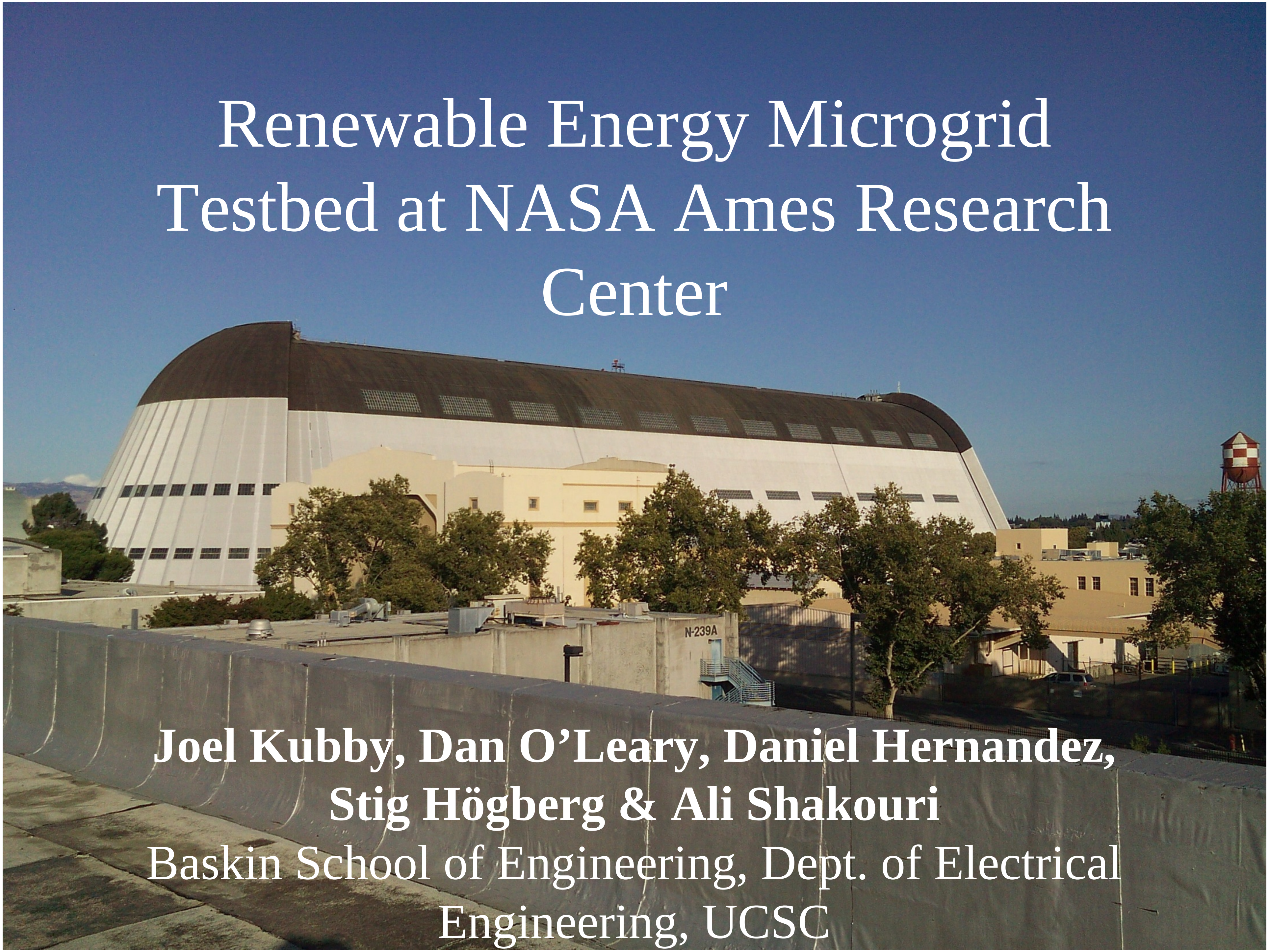


Renewable Energy Microgrid Testbed at NASA Ames Research Center

Joel Kubby, Dan O'Leary, Daniel Hernandez, Stig Högberg & Ali Shakouri

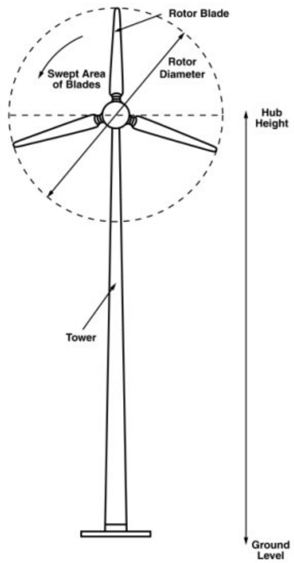
Baskin School of Engineering, Dept. of Electrical Engineering, UCSC

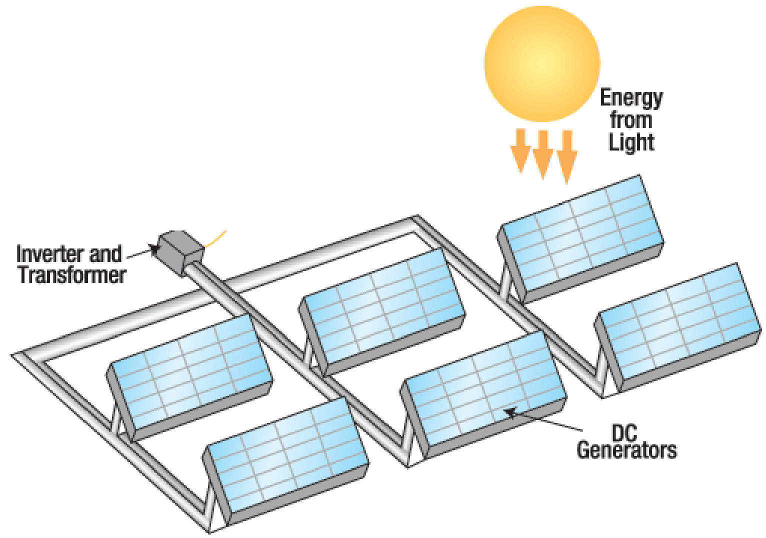
Goals

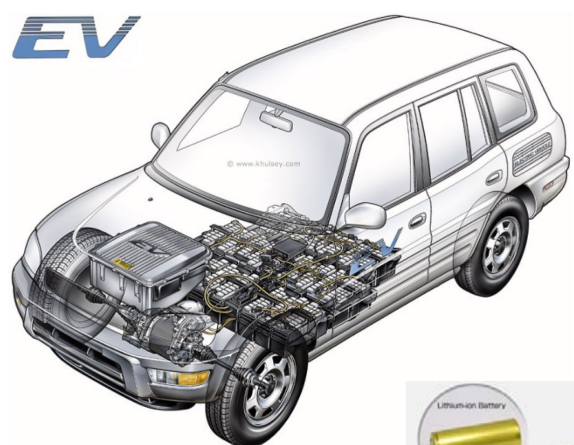
- Set-up a unique microgrid test-bed for renewable energy monitoring, generation and storage
- Use the facility for testing systems integration of new renewable energy components
- Enable web access to the test-bed for a remote access lab in renewable energy

Microgrid Components

- Energy Generation
  - Tracking photovoltaic array (six Sharp 180W PV panels, Wattsun AZ 225 tracker)
  - Wind turbine (Air X-12 400W)
- Energy Storage
  - Batteries
    - 400 Ah SLA
  - Electric Vehicle
- Energy Conversion
  - Xantrex inverter
- Monitoring
  - IV curve tracer (Daystar DS-100C)
  - Weather station (Cambell Instruments)
  - Wind anemometer
  - Solar radiometers
    - Normal incidence Pyroheliometer
    - Precision Spectral Pyranometer
  - Data logger


Rotor Blade
Swept Area of Blades
Rotor Diameter
Hub Height
Tower
Ground Level


Energy from Light
Inverter and Transformer
DC Generators


EV


Lithium-ion Battery
Li-ion Battery
Lithium Ion Battery Module

Background

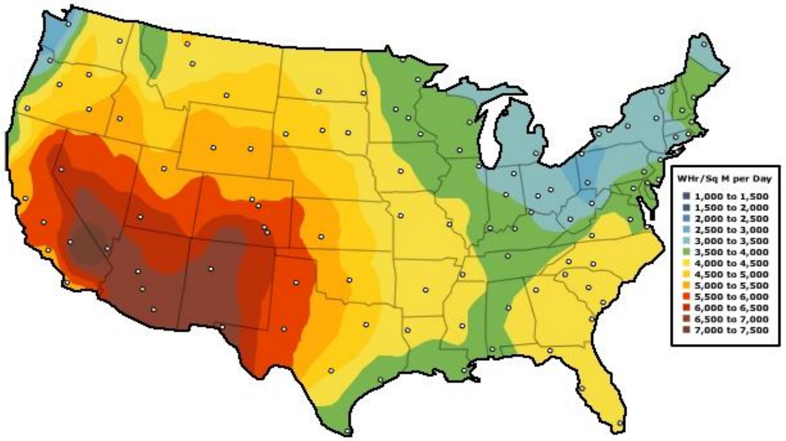
- Group project from LoCal RE 2008 Summer School on "*Electricity Grid using Localized Renewable Generation*"
- Intermittent wind and solar power generation at the household scale balanced using electric vehicles

Questions

- Is it possible to have a hybrid renewable energy system as a microgrid with an electric vehicle as battery storage?
- Could this type of microgrid system be price-competitive with typical grid-connected systems?
- How will this vary when applied to Denmark and the USA respectively?

California: Solar Resource

- Highest solar radiation in the southwest (7,000 to 7,500Whr/m^2/day, Yearly sum 2700kWh/m^2)
- Lowest solar radiation in northwest and northeast (2,500Whr/m^2/day)
- Abundant solar resource

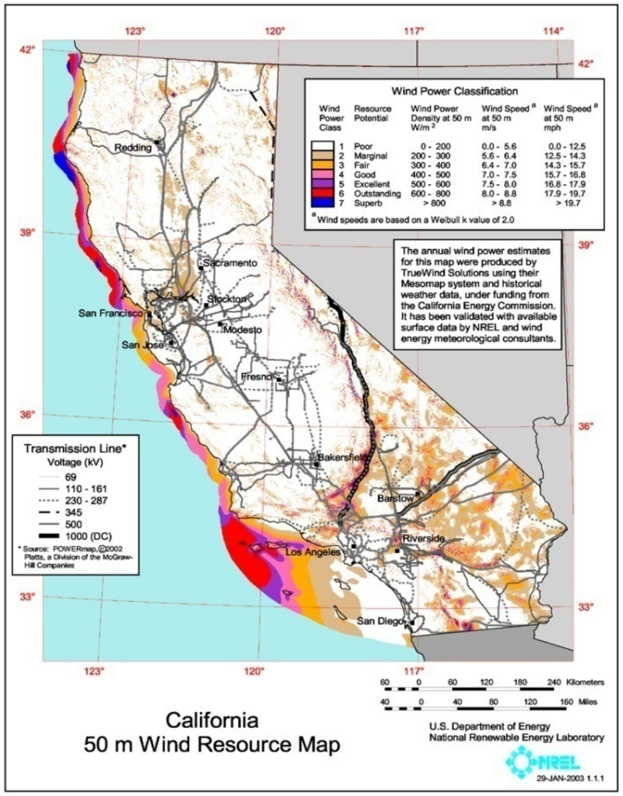


Annual Mean Global Solar Radiation

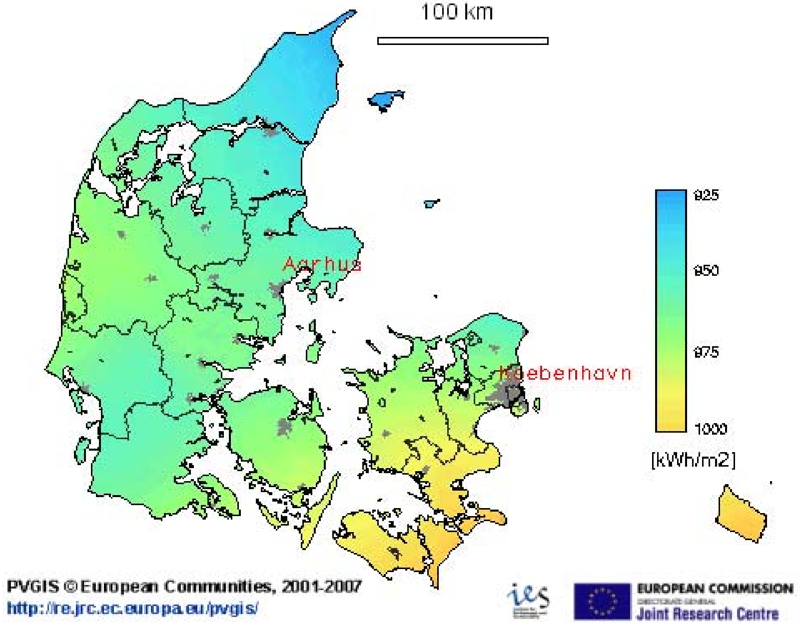
http://www.hi-valley.com/solar.htm

California: Wind Resource

- Wind resource in the coastline of California
- Highest wind power density of 500-800 W/m^2 and wind speed from 8.0 to 8.8 m/s.
- Wind resource varies greatly with locality

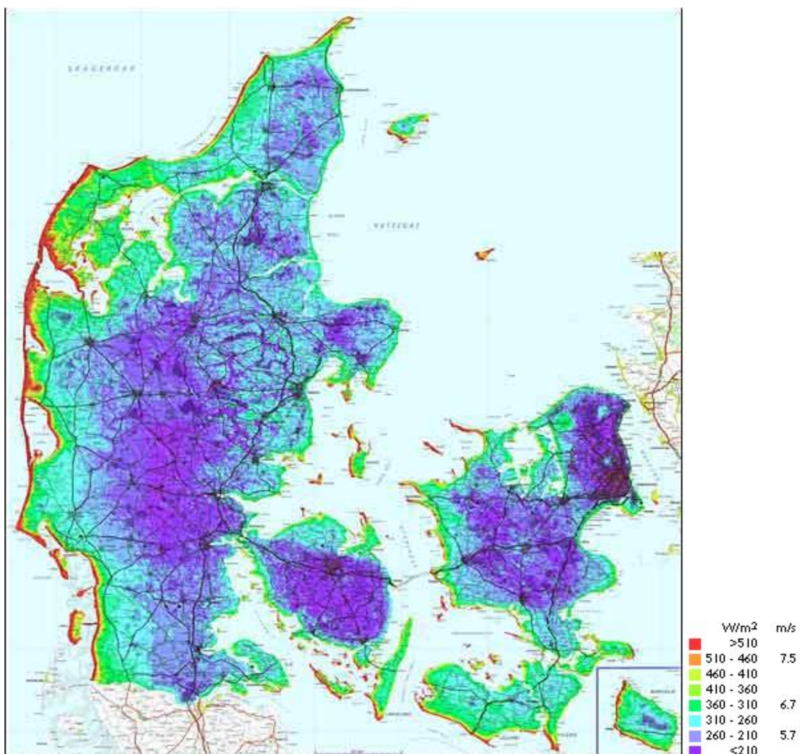


Denmark: Solar Resource



- Yearly sun in Jutland is between 925kWh/m^2 - 950kWh/m^2
- Lolland has the highest solar radiation with more than 1000kWh/m^2
- Less solar resource than California

Denmark: Wind Resource



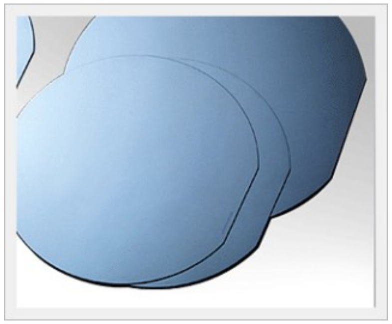
Wind Map of Denmark © 1999 Danish Energy Agency, Energy & Environmental Data, Risoe National Laboratory

- Abundant wind resource in the coastline.
  Speed > 10m/s, density > 510W/m^2

- Wind resources vary by location, but on average are high.

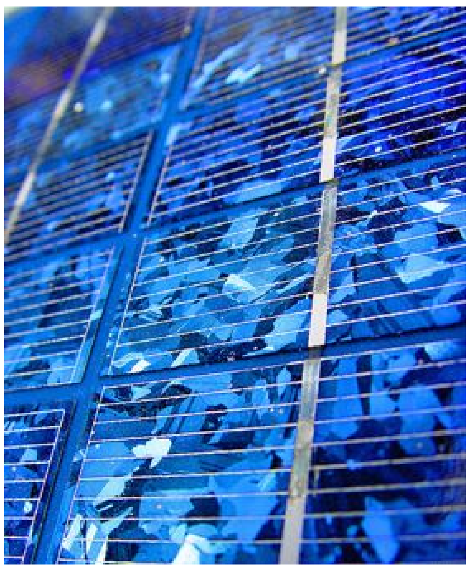
Batteries

	L16P	GMEV1	Prius NiMH	OEMTek	Tesla
Capacity (kWh)	2.16kWh	16.5 kWh	1.4kWh	9kWh	53kWh
Voltage	6V	312V	201V Bus	240V Bus	375V Bus
Manufacturer	Trojan	Delphi	Toyota	Valence Tech	Valence Tech
Mass	58kg	1175kg	39kg	95kg	450kg
Cost	$270		$3k	$12k	$40k

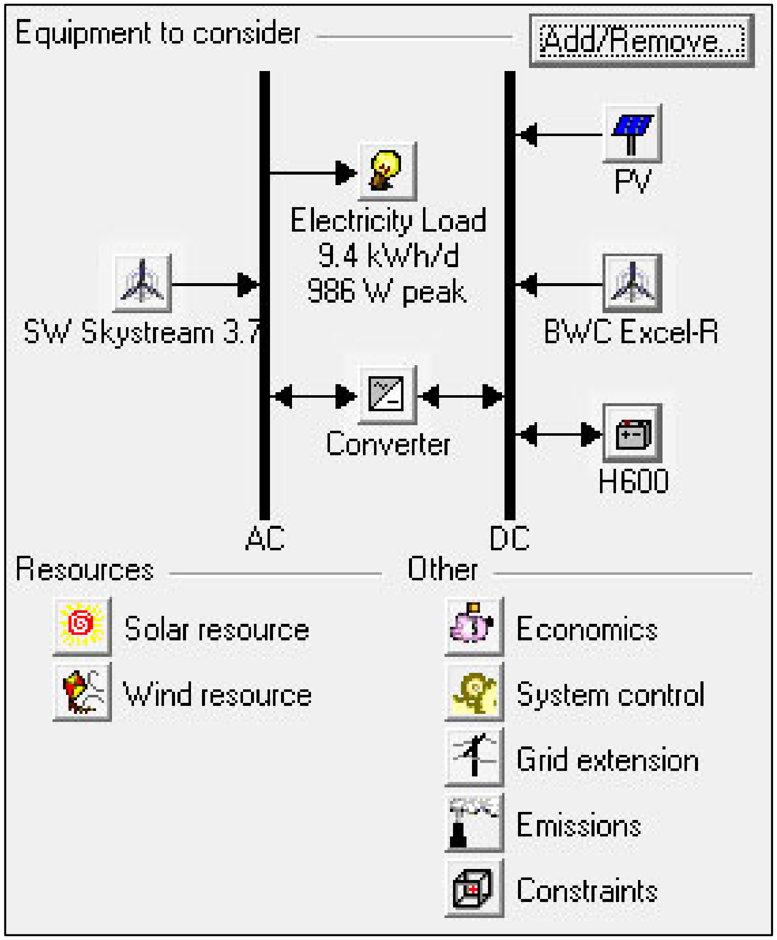


Solar Cells

	Mono	Poly	Amorphous	Multi	Thin Film
Efficiency	24%	18%	13%	40.7%	19.9%
W/Area 120W/m^2	Avg	Avg	Avg	Large	Small
Reliability	25yr	25yr	25yr	experimental	unreliable
Mass/W	Medium	Medium	Medium-Light	Lighter	Lightest
Cost	Moderate	Moderate	Cheaper	Very Expensive	Cheapest



System Modeling using HOMER



https://analysis.nrel.gov/homer/

Selected Components

- Bergey Excel-R (7.5 kW DC)
- Toyota Prius with OEMTek PHEV Kit (9 kWh)
- Photovoltaic (4 & 8 kW systems considered)
- Outback 3.6 kW inverter (stackable)

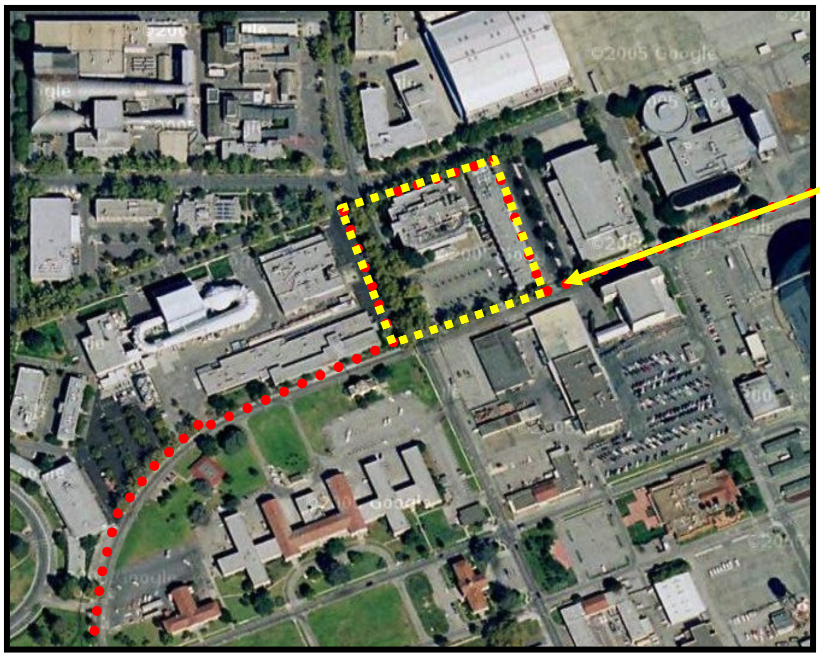
Initial Findings

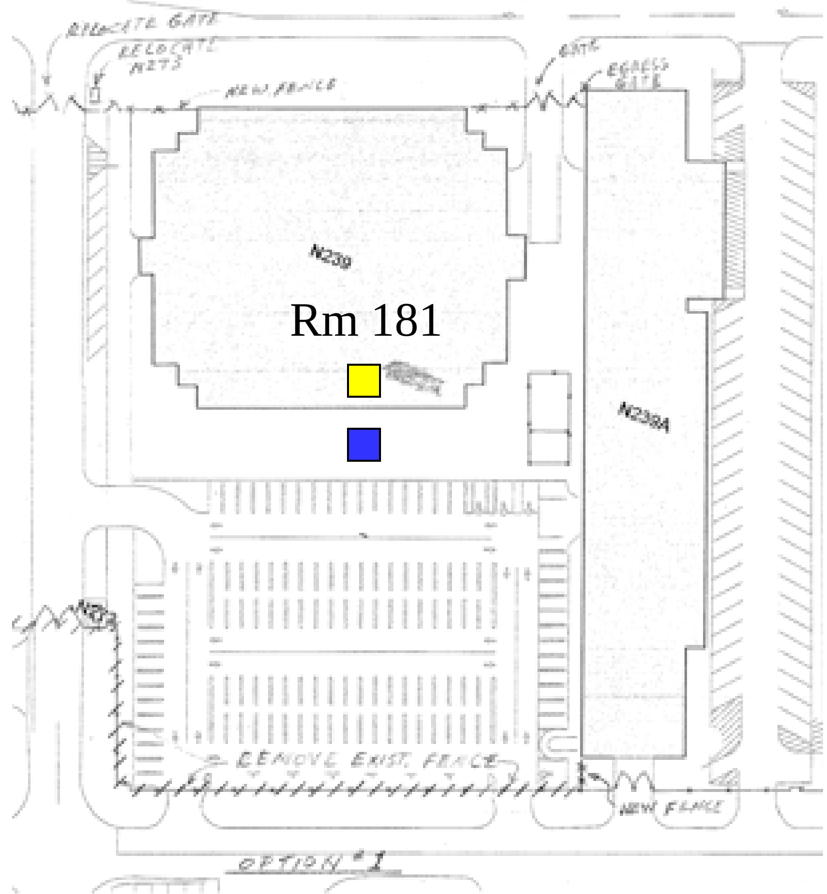
- The PHEV Prius Battery is too small to balance the system.
  - HOMER was unable to find a system utilizing only the Prius battery.
  - 9 kWh of storage is not enough to balance the system in California or Denmark
  - ~50 kWh battery capacity is needed to run the system (Tesla EV)

Implementation of a Renewable Energy Test-bed at NASA Ames

- Set up solar tracker, weather station, and complete test and measurement control room at NASA Ames
- Add in wind turbine, electric vehicle energy storage and recharging station
- CCLI proposal funded by NSF to put the facility on-line for a remotely accessible renewable energy laboratory
- Plan to use testbed to create links with renewable energy industrial partners

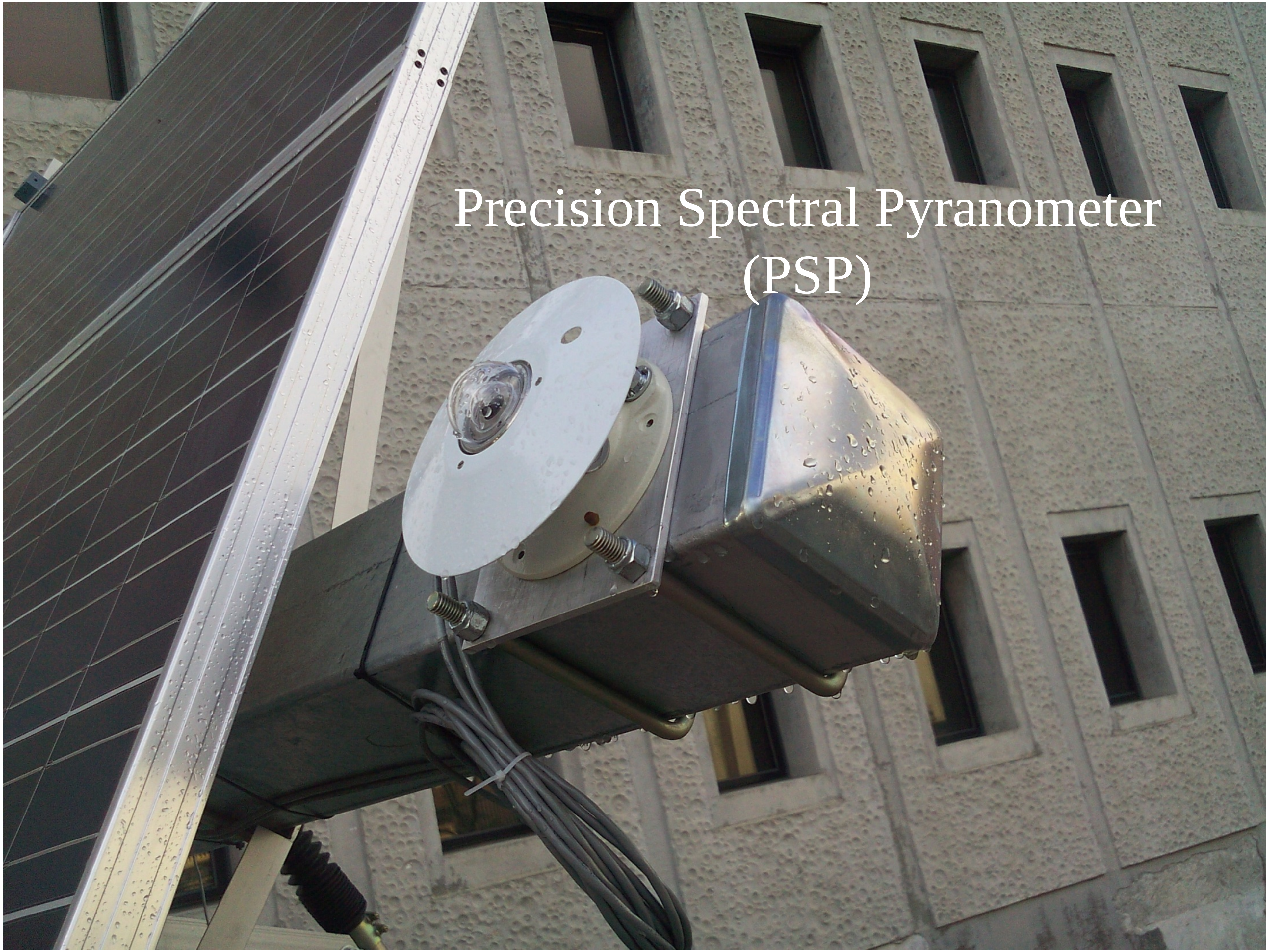
Implementation of Testbed at NASA Ames B239N



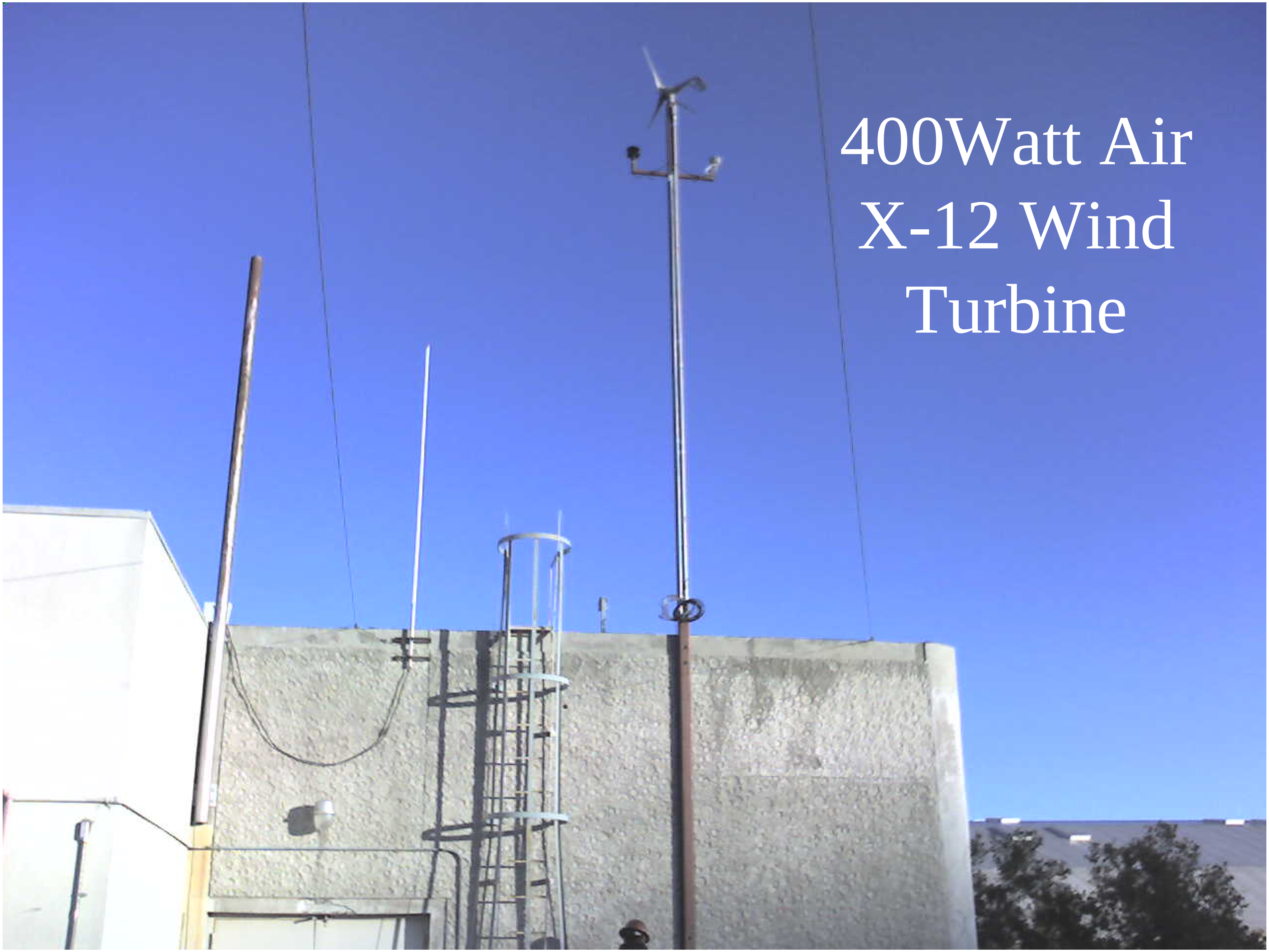


Normal
Incidence
Pyroheliometer
(NIP)

Precision
Spectral
Pyranometer
(PSP)


Precision Spectral Pyranometer
(PSP)


Normal Incidence
Pyroheliometer (NIP)


400Watt Air
X-12 Wind
Turbine

Predicted Energy Production

Predicted Monthly Energy Production

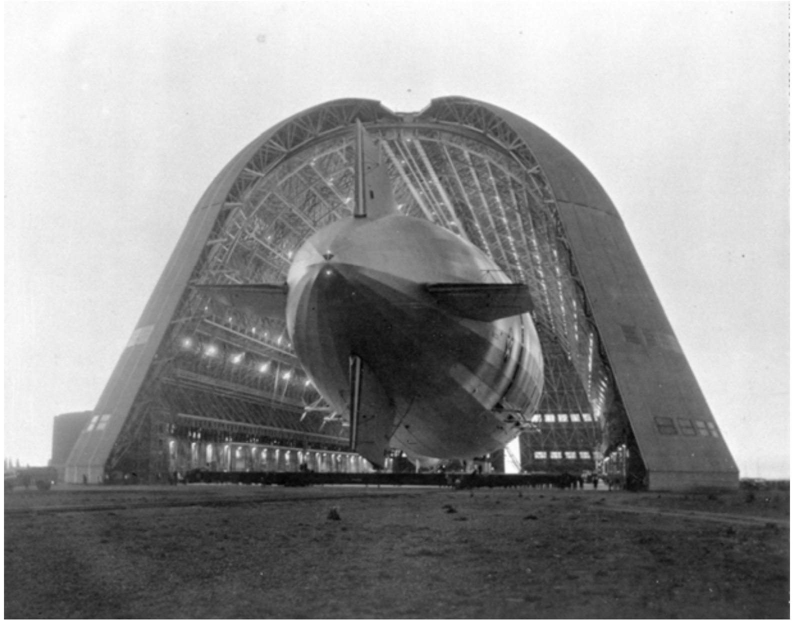
Wind Speeds Taken at Top of Tower

Average Wind Speed	8 mph	9 mph	10 mph	11 mph	12 mph	13 mph	14 mph
Excel–S (AC kWh)	240	370	520	700	900	1,130	1,370
Excel–R (DC kWh)	340	500	680	880	1,090	1,320	1,550

Wind Speeds Taken at 10 meters (per standard wind resource maps)

Average Wind Speed		8 mph	9 mph	10 mph	11 mph	12 mph	13 mph	14 mph
60 ft. Tower	Excel–S	330	480	670	870	1,110	1,350	1,610
	Excel–R	440	620	830	1,050	1,280	1,510	1,740
80 ft. Tower	Excel–S	430	620	840	1,100	1,370	1,670	1,960
	Excel–R	560	780	1,030	1,290	1,550	1,820	2,060
100 ft. Tower	Excel–S	490	700	950	1,220	1,510	1,820	2,130
	Excel–R	630	870	1,140	1,410	1,680	1,950	2,200
120 ft. Tower	Excel–S	550	780	1,050	1,340	1,650	1,970	2,280
	Excel–R	700	960	1,240	1,530	1,800	2,070	2,320

Assumptions: Inland Site, Rayliegh Distribution, Shear Exponent = 0.18, Altitude = 1,000 ft.
Note: Battery charge regulation (batteries full) will reduce actual Excel–R performance.
Your Performance May Vary.

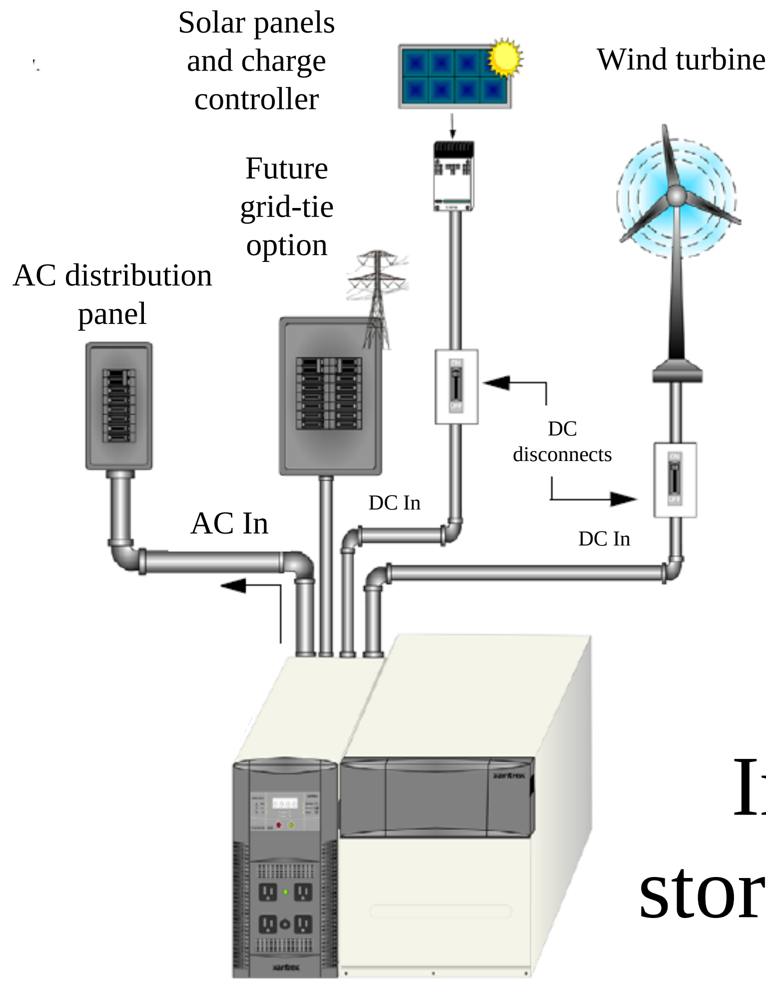


There isn't much wind in Mountain View!

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Mountain	DIR	N	N	NNW	NNW	NNW	NNW	NNW	NNW	NNW	NNW	NNW	NNW	NNW
View/	SPD	5	5	6	6	7	7	7	7	5	5	5	3	6
Moffett NAS	PGU	64	64	51	49	44	46	38	39	38	55	53	62	64

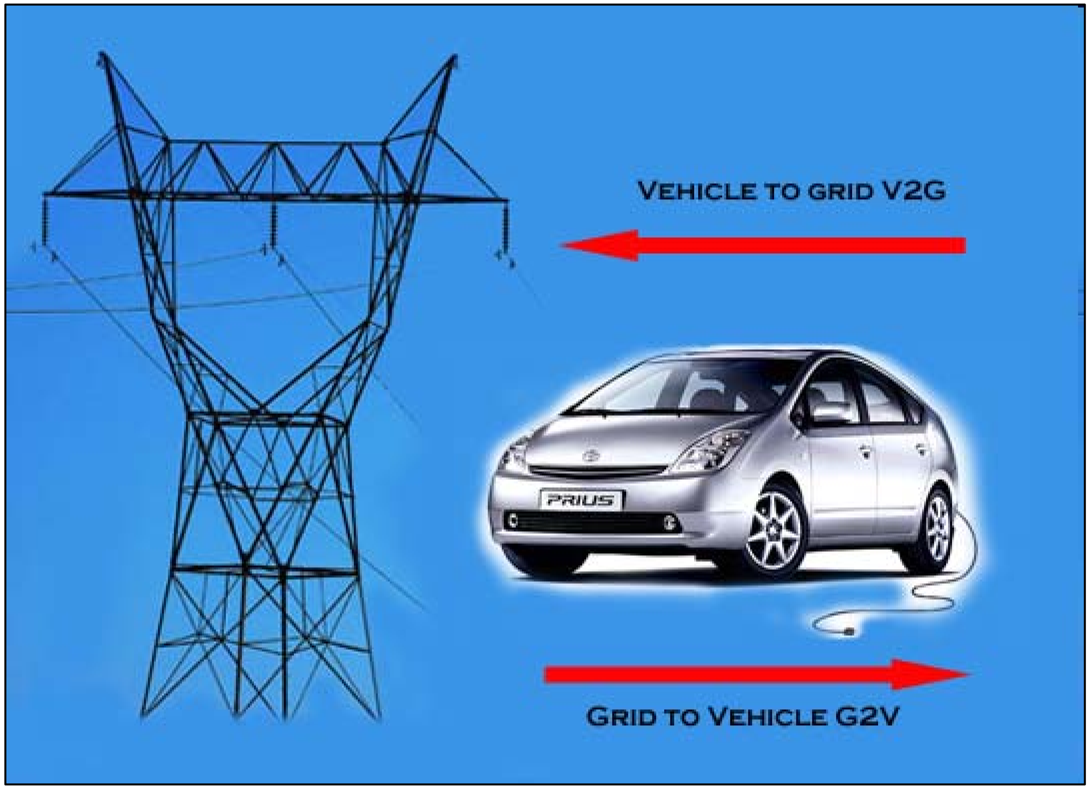
It's so calm you could probably land a blimp!

Initial System Configuration



Initial energy storage in batteries

Vehicle to Grid



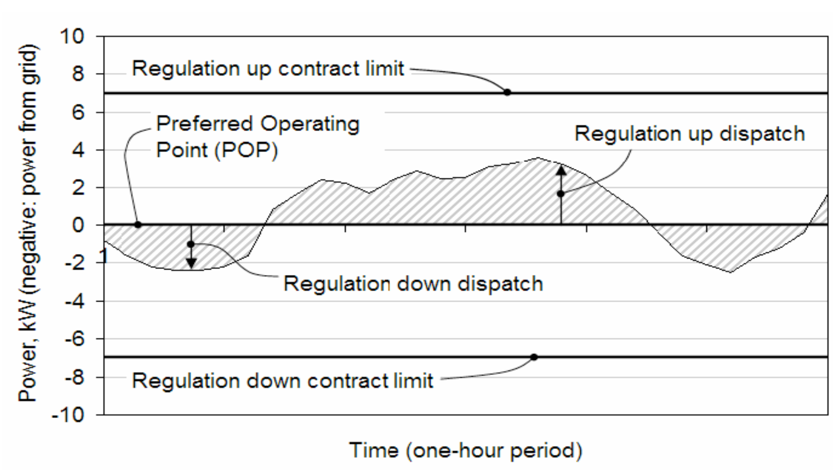
Vehicle to Grid

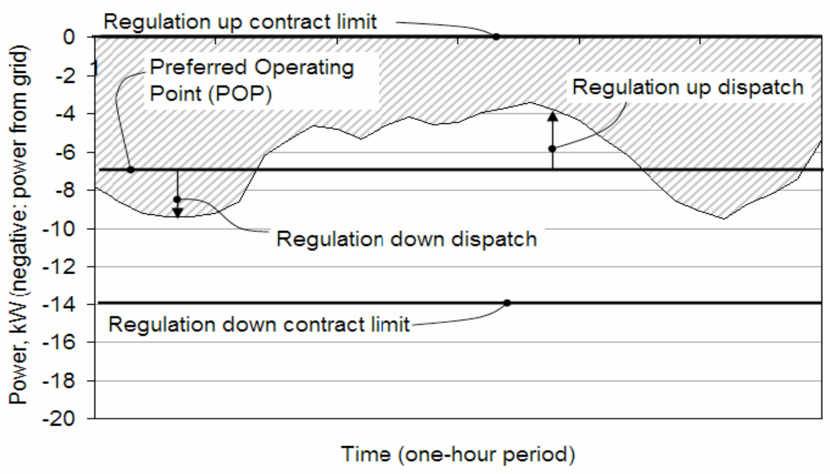
- Average US car: Driven 1 hour/day (2001)
- Serve as:
  - Regulating power (frequency)
    - Often automatic (governor)
  - Spinning reserve (outages)
    - Standby power plants (often running at 30-40% rated)
  - Back-up service (microgrid)

AC Propulsion

- T-Zero
  - Battery management
  - Bi-directional flow of electricity

Variable Load for Grid Stabilization





Two way power flow

One way power flow

Myers Motors - NMG

- 15 kWh Li-ion
- 80 mph
- 45 miles range
- 5 h full charging
- 1 person
- Regenerative Braking System

Green Vehicles - Triac

- 23 kWh Li-ion
- 80 mph
- 100 mile range
- 5 h full charging
- 2 persons
- Freeway driving
- Regenerative Braking System

Tesla Roadster

- 42, 65, 85 kWh Li-ion
- 125 mph
- 160, 230, 300 mile range
- 3.5 hours (240V, 70A)
- 2 persons
- 0-60 mph in 3.5 seconds

Recharge Station

Photo showing Electric Car at a Recharge Station from Better Place http://www.betterplace.com/

Acknowledgements

- LoCal RE 2008 study group
  - Electricity Grid using Localized Renewable Generation; Wind and Solar Power Balanced by Electric Vehicles
    - Phil Chiu (UC Davis)
    - Stig Hoegberg, Nan Qin and Jiang (DTU)
    - Jeremy Hieb (UCSC)
- Rose Grymes, Wenonah Vercoutere Lisa Witt, Steve Hinge, ASL
- Nima Mostafi, UC Santa Cruz
- Funding
  - UARC Aligned Research Program
  - BIN-RDI