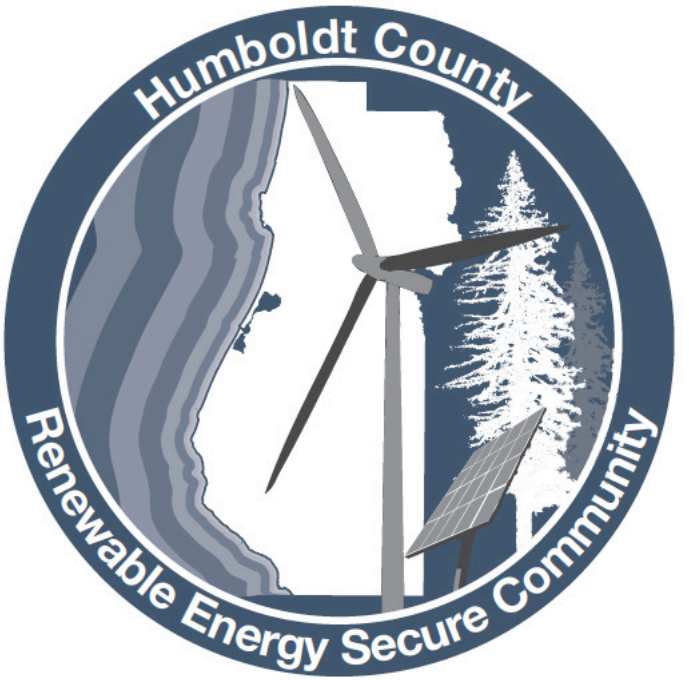
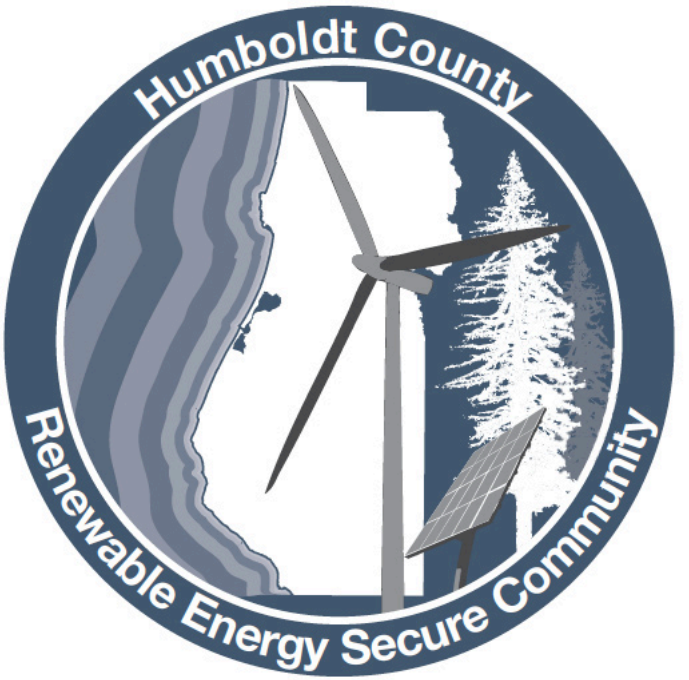

Humboldt County
Renewable Energy Secure Community

Humboldt County RESCO Project: Modeling Framework



Peter Alstone and Colin Sheppard

Schatz Energy Research Center

November 18, 2010

HSU Mathematics Colloquium

Copyright © Schatz Energy Research Center 2011

RESCO Goal

Develop a strategic plan for Humboldt County to develop its renewable energy resources to meet 75-100% of local electricity demand and a significant fraction of heating and transportation demand.

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

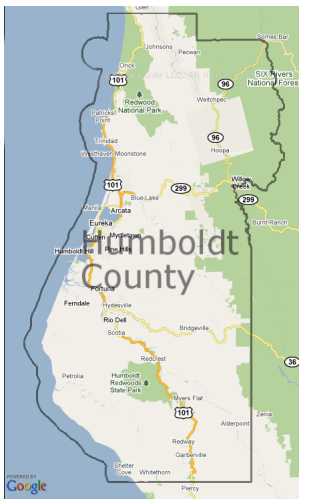
RESCO Participants

- **Redwood Coast Energy Authority** - Lead Agency
- **Schatz Energy Research Center** - Primary Research Team
- **Pacific Gas and Electric Company** - Integration Issues
- **Local Stakeholders** - Input on Strategic Plan

Redwood Coast Energy Authority

SCHATZ ENERGY RESEARCH CENTER

PG&E



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Today's Talk:

- Snapshot of Humboldt Co. energy sector and context
- Modeling Approach: a year-long hourly energy balance model
- Optimization of the model: Differential Evolution
- Preliminary results and next steps

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

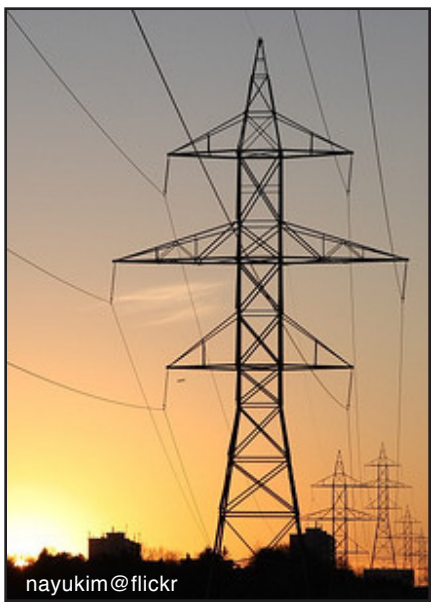
Humboldt's Energy Resources:

Conventional Energy

- **Natural Gas**: pipeline connection with limited production in Eel River Valley; used for electricity, heating, and process needs.

- **Conventional Electricity**: Local Natural Gas powered generation and imported from Western US Grid via interconnection lines.

- **Transportation Fuels:** Gasoline and Diesel barged into the county.



SCHATZ ENERGY RESEARCH CENTER

Humboldt County
Renewable Energy Secure Community

Humboldt's Energy Resources:

Biomass as a key resource in the past and future

ASSOCIATED PRESS / BEN MARGOT

Humboldt's Energy Resources:

Intermittent Renewable: Wind, Wave, Hydro, and Solar

Humboldt's Energy Demands:

Declining traditional industry, growth in others

Humboldt's Energy Sector:

State, national, & global political context

California on the move:

AB 32 upheld in recent election – Greenhouse gas (GHG) reductions goal of 1990 levels by 2020.

Title 24 building code ensures efficient new construction.

National political action on GHG stalled:

Continuing progress in spite of policy deadlock, untapped potential waiting for stability.

International trends towards clean energy:

International support for renewables continues.

Price of conventional resources climbing as renewable technology develops and costs fall.

Our modeling challenge:

Create a tool that integrates Humboldt County's energy supply and demand.

Make it detailed and well documented enough to be useful for helping to make decisions about policy and investments to achieve RESCO goals.

Do it using a fixed project budget.

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Framework: Guiding Principles

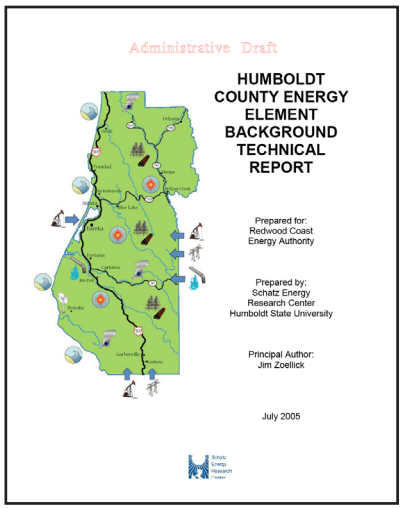
- **Be data driven** – rely on real world data when it is available. Modeled (synthetic) data is second best.
- **Be results driven** – prioritize effort on elements that are likely to impact the results. Don't sweat the small things.
- **Modular Structure** – for easier development
- **Use open source software** (we used R) – facilitate migration of the tool to other locations.

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Framework: Previous Works

- **Humboldt County Energy Element** - SERC
- **Integrating Humboldt County Energy Systems** (EnergyPLAN software implementation) - Michael Winkler
- **Distributed Renewable Energy…in Humboldt** (HSU Thesis) - Darrell Ross


Administrative Draft

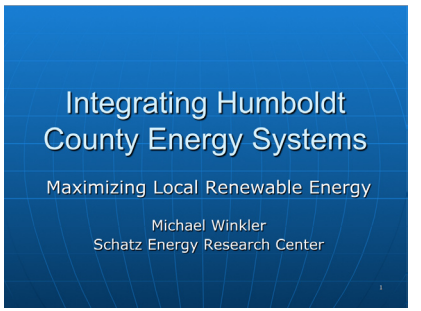
HUMBOLDT COUNTY ENERGY ELEMENT BACKGROUND TECHNICAL REPORT

Prepared for:
Redwood Coast Energy Authority

Prepared by:
Schatz Energy Research Center
Humboldt State University

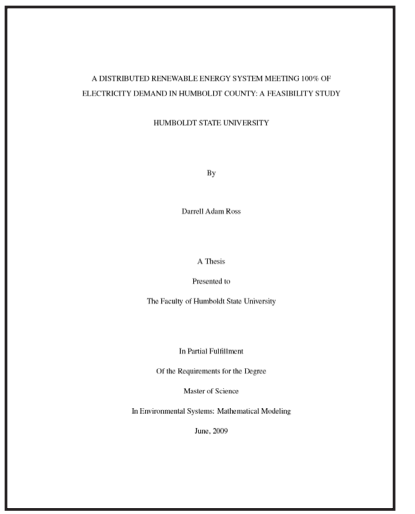
Principal Author:
Jim Zoellick

July 2005


Integrating Humboldt County Energy Systems

Maximizing Local Renewable Energy

Michael Winkler
Schatz Energy Research Center


A DISTRIBUTED RENEWABLE ENERGY SYSTEM MEETING 100% OF ELECTRICITY DEMAND IN HUMBOLDT COUNTY: A FEASIBILITY STUDY

HUMBOLDT STATE UNIVERSITY

By

Darrell Adam Ross

A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

In Environmental Systems: Mathematical Modeling

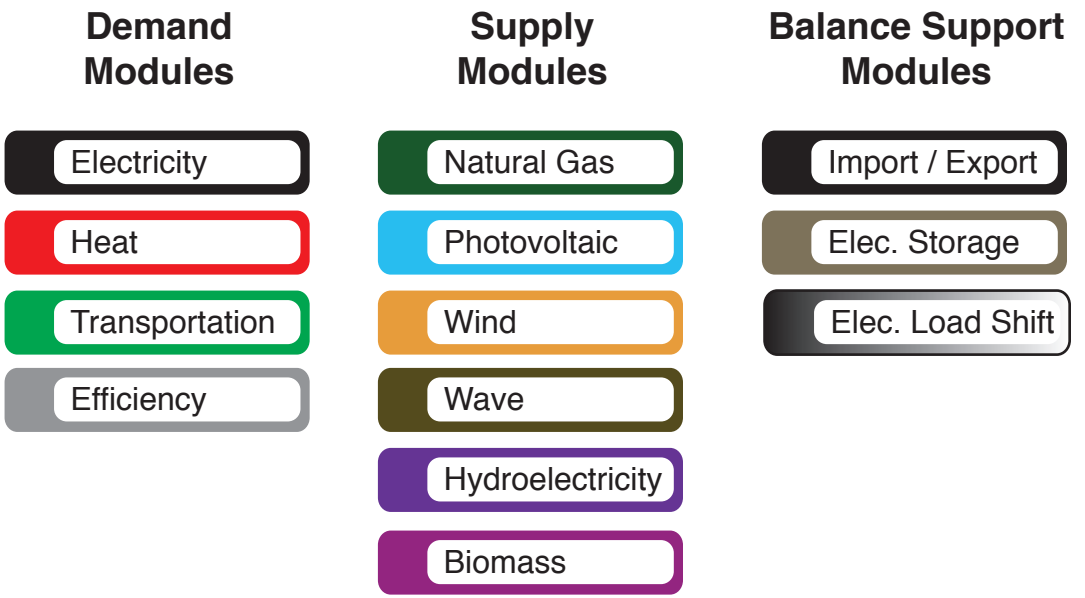
June, 2009

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Framework: Tech. & Resource Modules

Establish demand and supply availability based on demographics, resources, and installed technology.



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Framework: Energy Balance Algorithm

Meet demands by dispatching Supply and Balance Support technologies according to their availability.

Demand Modules

- Electricity
- Heat
- Transportation
- Efficiency

Supply Modules

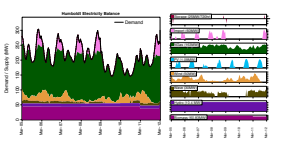
- Natural Gas
- Photovoltaic
- Wind
- Wave
- Hydroelectricity
- Biomass

Balance Support Modules

- Import / Export
- Elec. Storage
- Elec. Load Shift

Energy Balance Algorithm

- Supply Dispatch
- Grid Stability
- Power Reliability

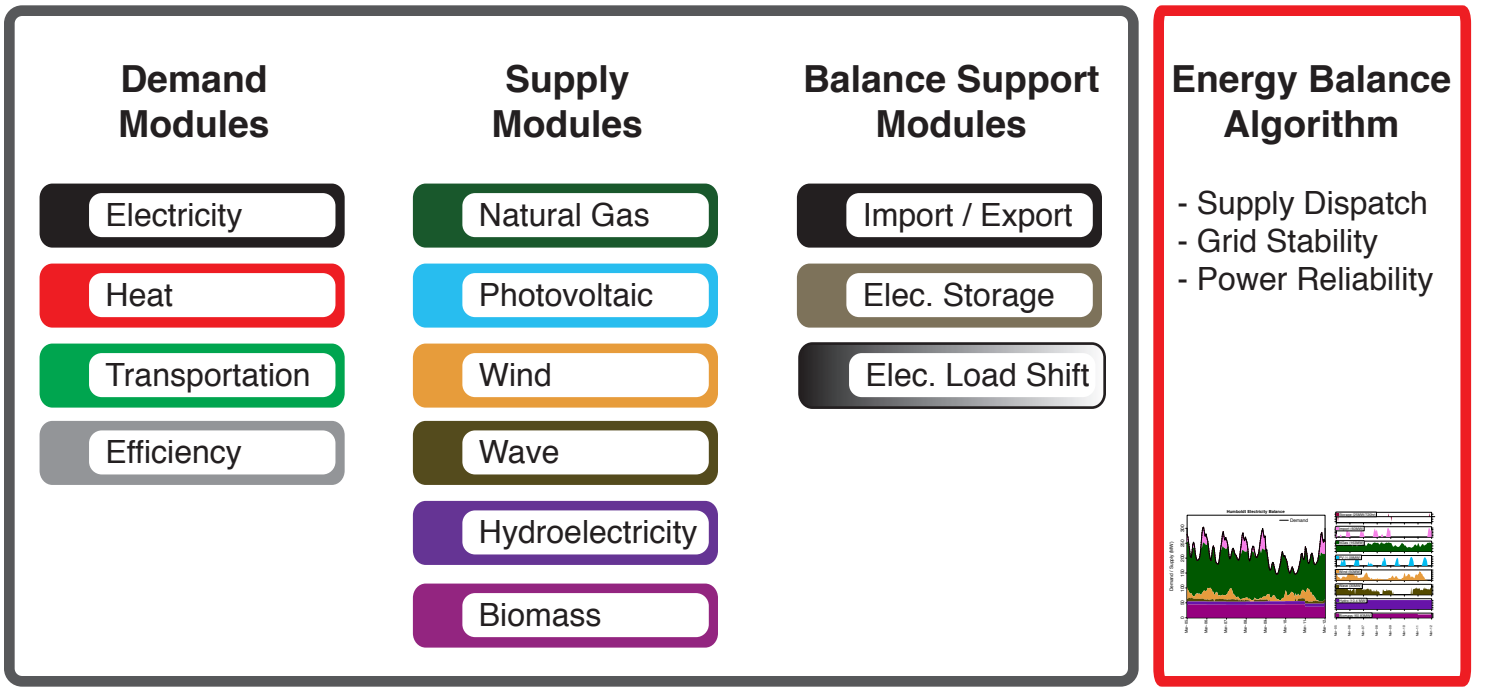


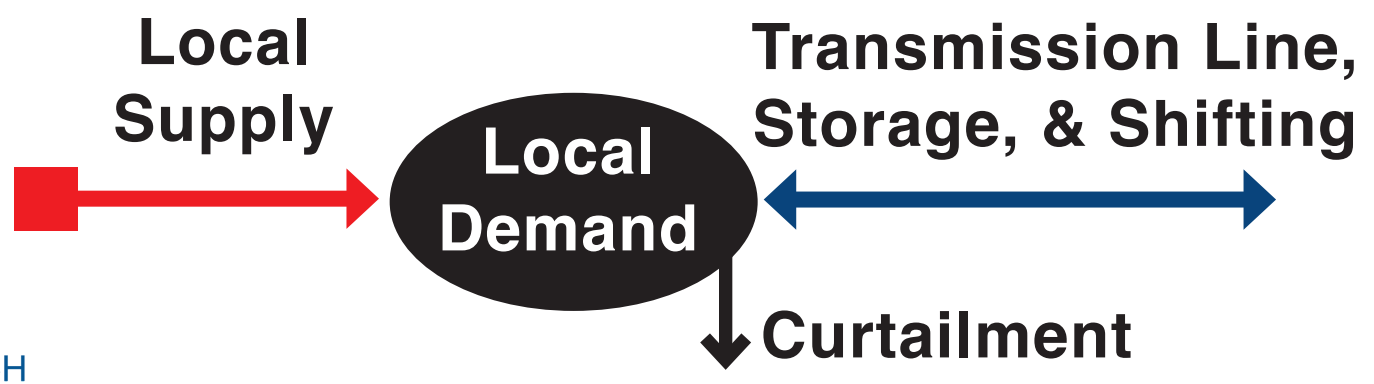
SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Framework: Energy Balance Algorithm

Single node model focused on temporal matching on an hourly basis through a one-year period based on a given scenario.





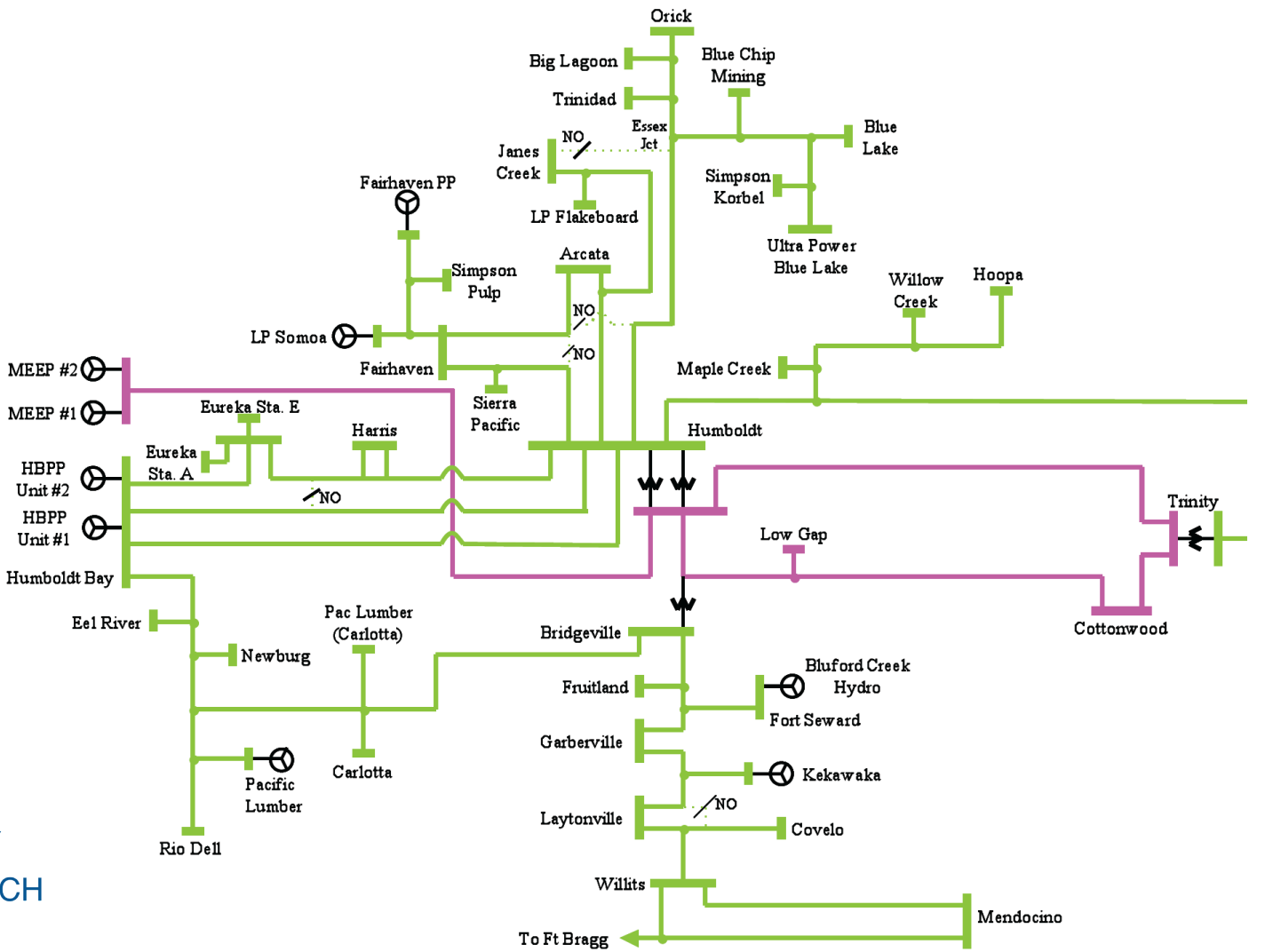
SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Key Assumption: Single Node Approximation

PG&E's role:

Power Flow & Transient Stability Analysis of Infrastructure



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Framework: Post Processing

Calculate key metrics that describe the performance of the scenario.

Demand Modules

- Electricity
- Heat
- Transportation
- Efficiency

Supply Modules

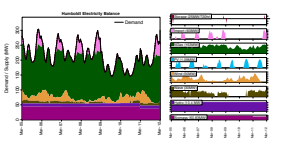
- Natural Gas
- Photovoltaic
- Wind
- Wave
- Hydroelectricity
- Biomass

Balance Support Modules

- Import / Export
- Elec. Storage
- Elec. Load Shift

Energy Balance Algorithm

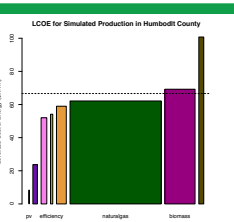
- Supply Dispatch
- Grid Stability
- Power Reliability



Post Processing

Economics:
- Cost of Energy
- Job Creation
- Local Economy

RESCO Goals:
- GHG Emissions
- Fraction Renewables



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Framework: Optimization I/O

Key Inputs: Demand levels, installed capacities

Demand Modules

- Electricity
- Heat
- Transportation
- Efficiency

Supply Modules

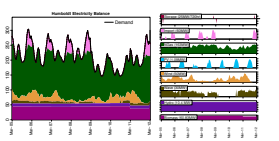
- Natural Gas
- Photovoltaic
- Wind
- Wave
- Hydroelectricity
- Biomass

Balance Support Modules

- Import / Export
- Elec. Storage
- Elec. Load Shift

Energy Balance Algorithm

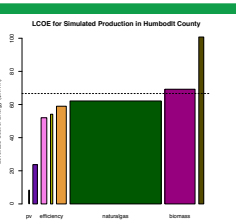
- Supply Dispatch
- Grid Stability
- Power Reliability



Post Processing

Economics:
- Cost of Energy
- Job Creation
- Local Economy

RESCO Goals:
- GHG Emissions
- Fraction Renewables



Key Outputs: Cost of Energy, GHG Emissions, Service Quality

Model Details: Demand Modules

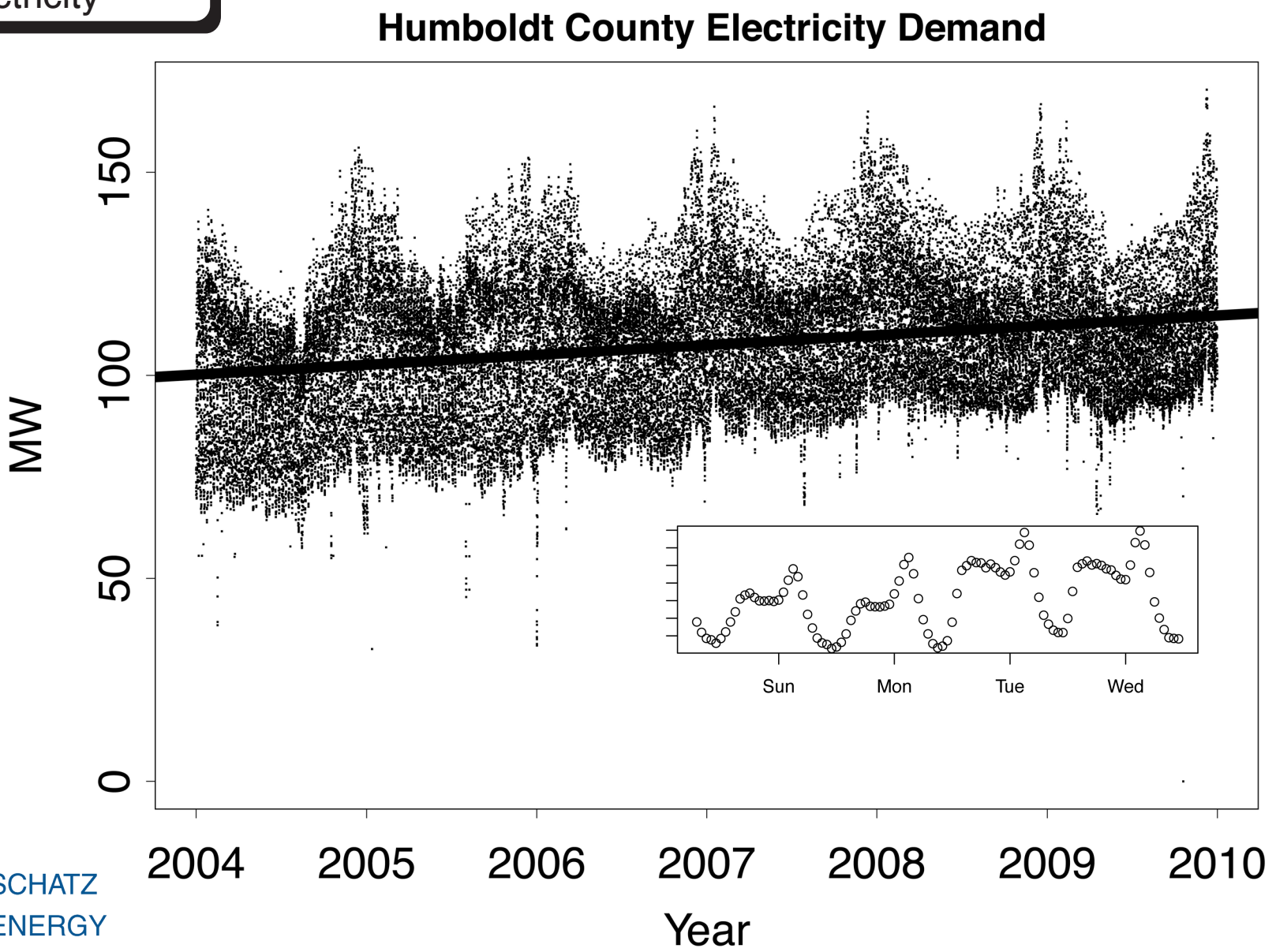
Sector	2008 Scale (PJ)	Other Units	Notes
Electricity	3.4	1 TWh	5 years of 15 minute interval data
Heat	5.7	54e6 therms	Building Model + Monthly NG data
Transportation	8.0	66e6 gal. gas	EPRI technology model
Efficiency	~0.007	2 GWh	Utility Program Scoping Study

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Module Highlight: Electricity Demand

Electricity



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Module Highlight: Load Building

Heat

Transportation

Heat pumps and electrified transportation can **build electricity demand** for local renewable generation and replace conventional fuels.

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Details: Supply Modules

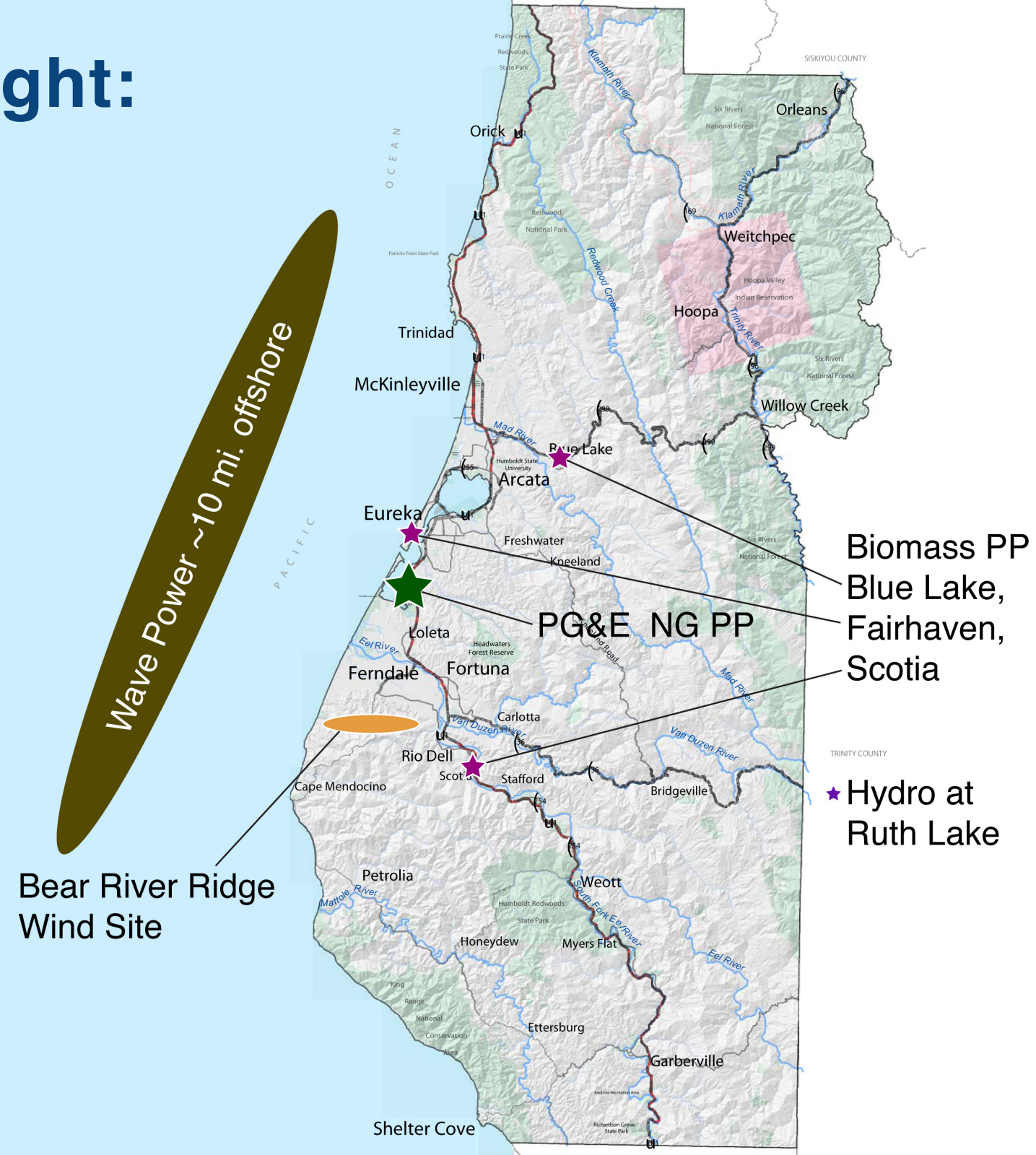
Technology	Capacity (MW) Baseline	Outlook	Notes
Natural Gas	163	163	PG&E King Salmon Plant
Photovoltaic	~ 1	1-15	Based on NSRDB Data
Wind	~ 0	0-250	NREL model for Bear River Ridge
Wave	0	0-100	NOAA Buoy + Wave Machine Matrix
Hydroelectricity	10.5	10.5-35	Hydrological + Energy Model
Biomass	61	61-250	Scotia, Fairhaven, Blue Lake Plants

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Module Highlight:

Supply Locations

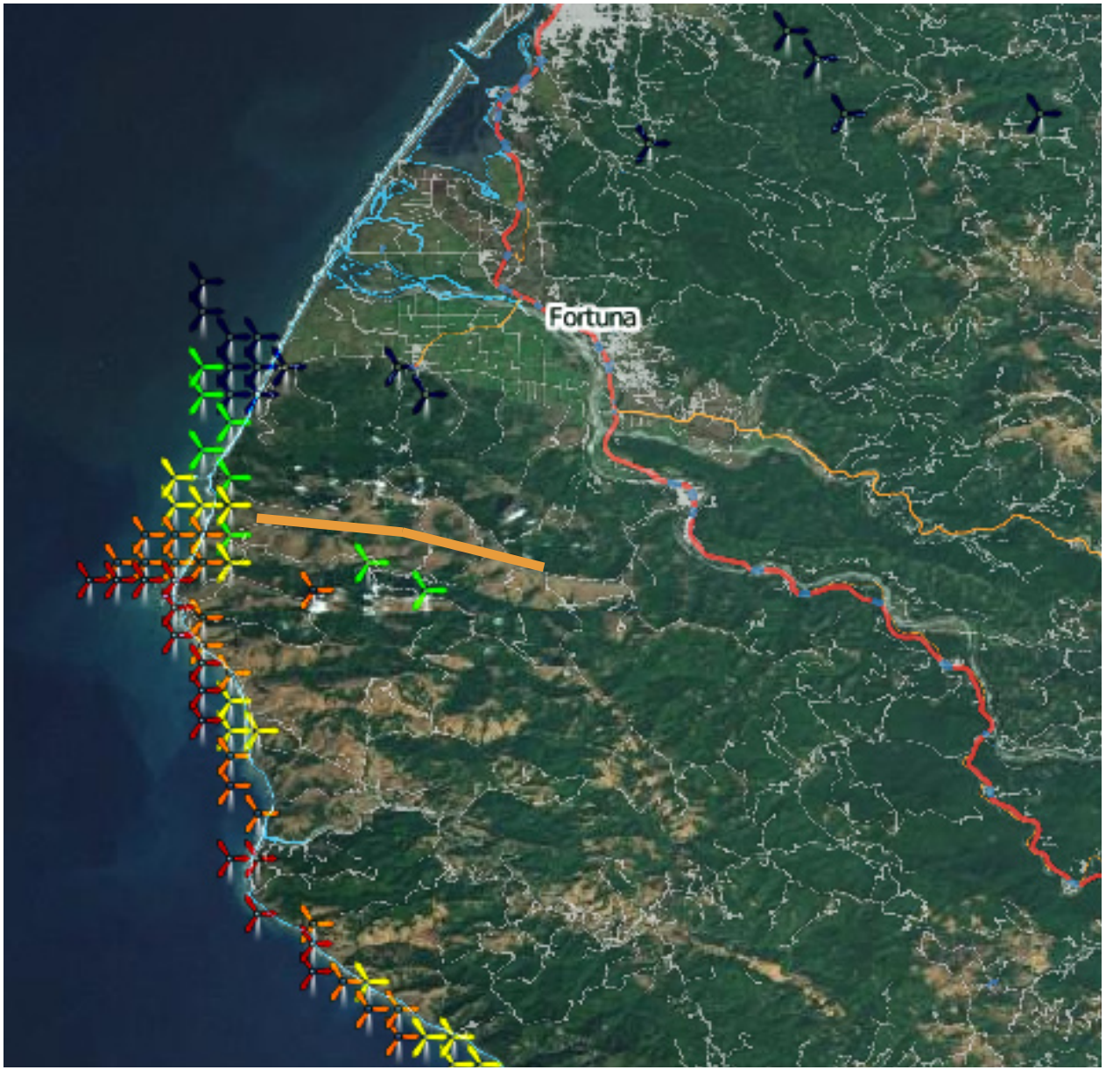


Module Highlight: Bear River Ridge Wind

Wind

Data Source:

Icons show sites with three years of modeled wind farm output from NREL's Western Wind Dataset; it was produced by 3Tier.



Bear River Ridge

Orange line shows potential Shell Wind installation

Model Details: Balance Support Modules

Sector	Capacity (MW) Baseline	Outlook	Notes
Import / Export	60	60-200	Main Lines: 2x 115 kV to Redding
Elec. Storage	0	0-100	Batteries, Pumped Hydro, CAES
Elec. Load Shift	~0	0-24	Demand Response across sectors

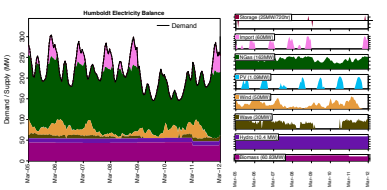
SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Details: Energy Balance Algorithm

- Meet demand
- Use renewables first
- Don’t export power from fossil fuels
- Meet reserve requirements
- Meet stability constraints

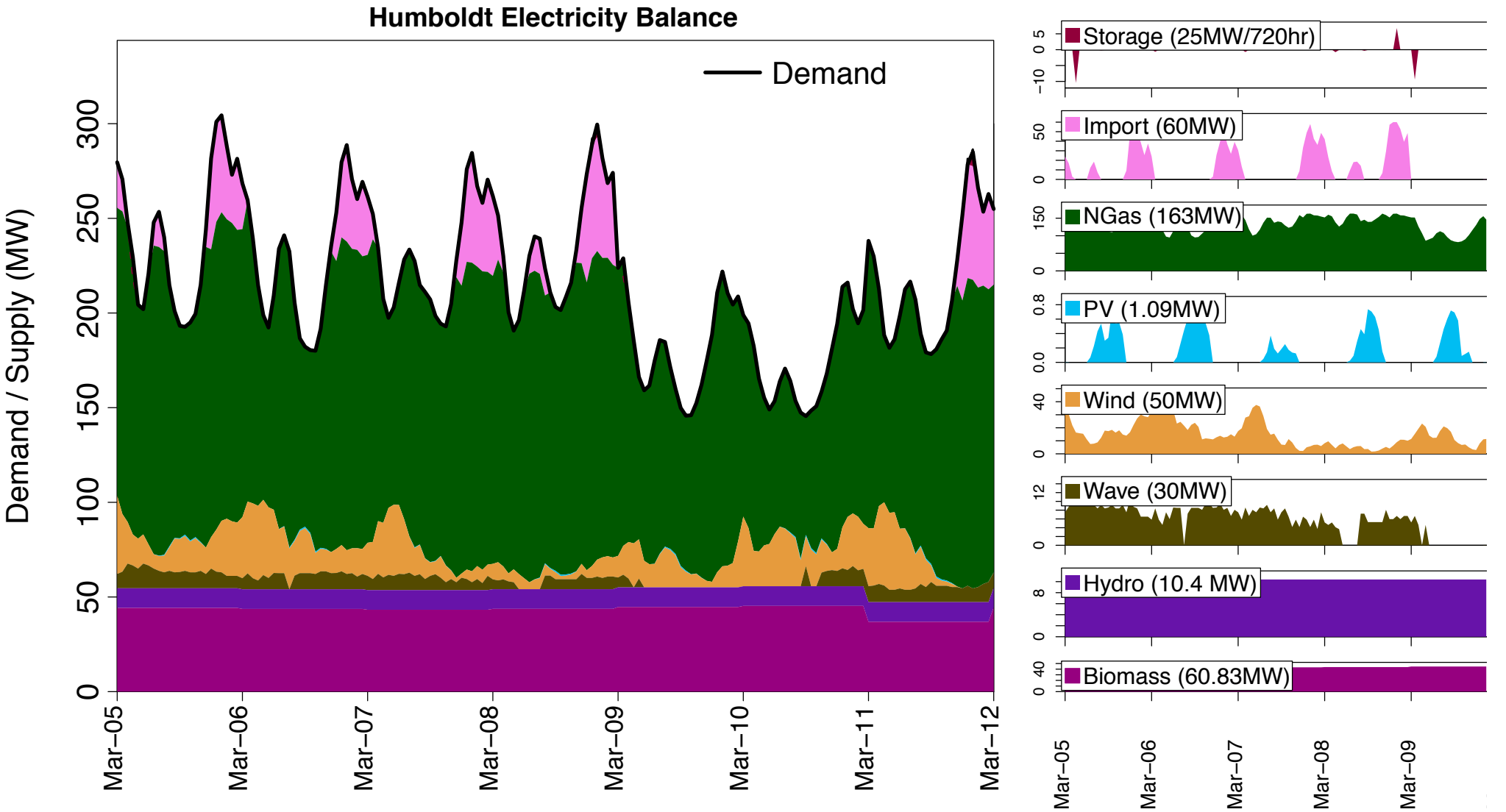
Energy Balance Algorithm



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

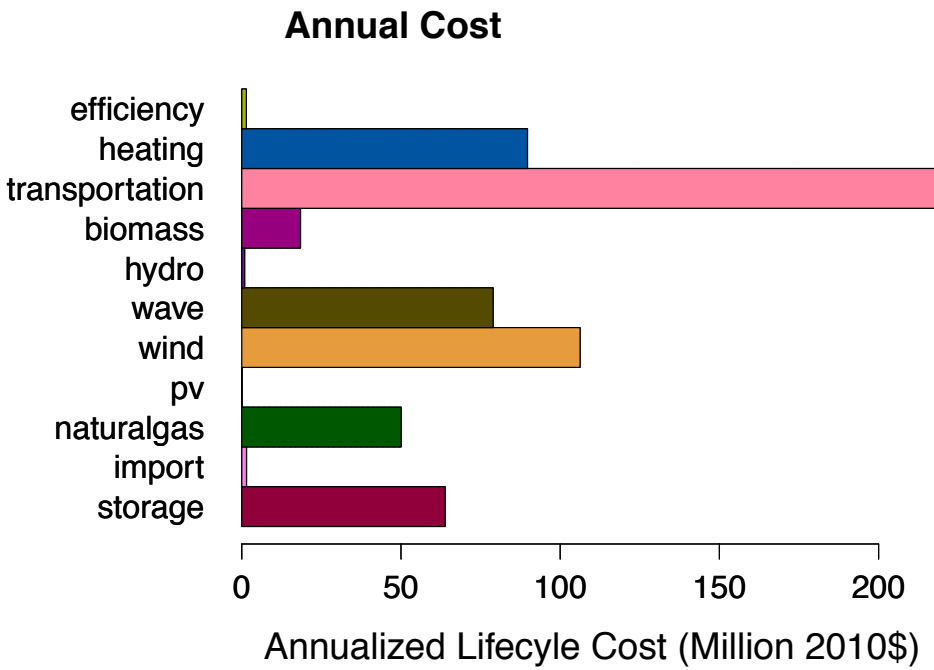
Model Details: Energy Balance Dashboard

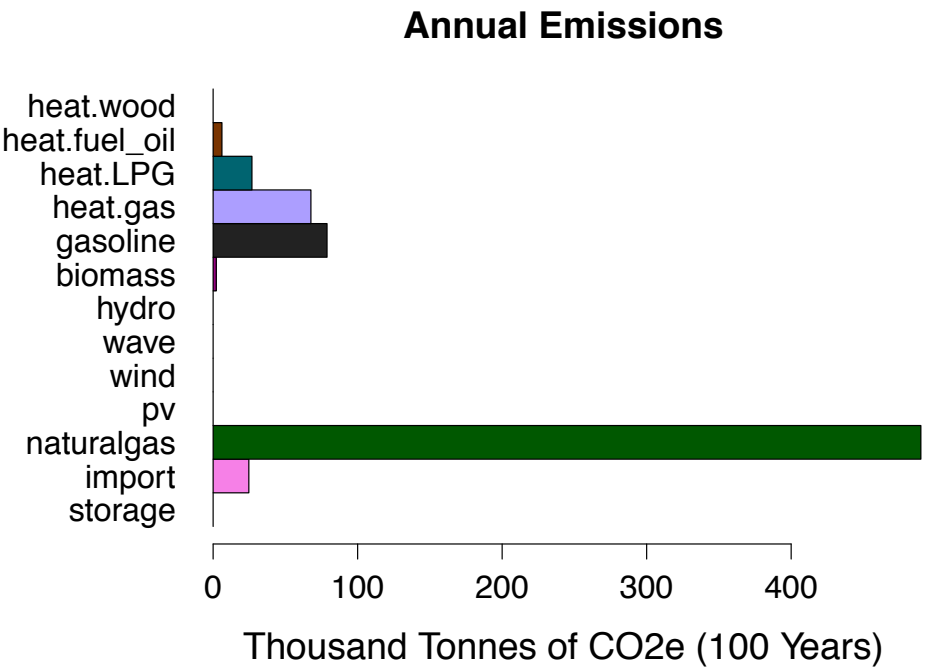


SCHATZ ENERGY RESEARCH CENTER

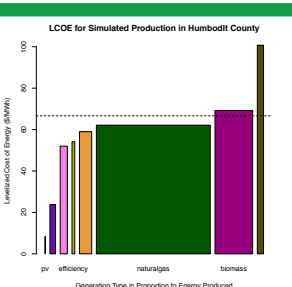
Humboldt County Renewable Energy Secure Community

Post processing: Scenario Summary





Post Processing



-

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Model Application:
What is our model capable of?

For any portfolio of supply and demand options:

- Is demand met / grid stable?
- Life cycle cost
- Carbon emissions
- Fraction of renewables

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Objectives / Constraints

Objectives

- Maximize the fraction of renewables
- Minimize carbon emissions
- Minimize the annual cost

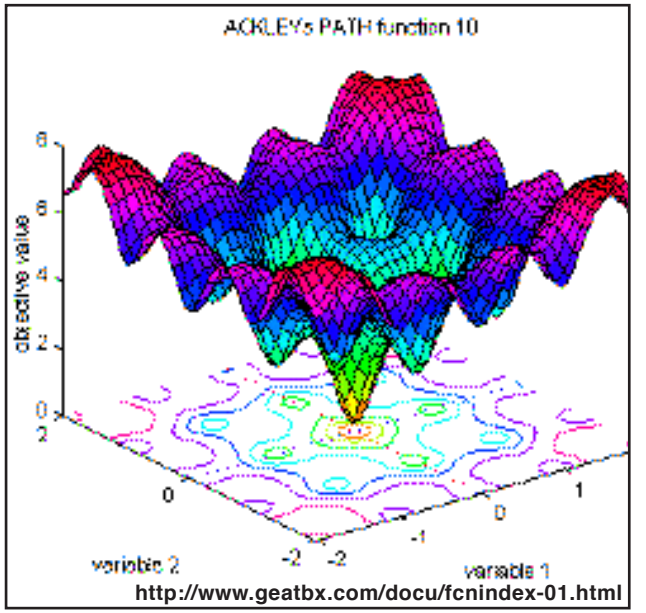
Constraints

- Meet demand 99.9% of the time
- Maximum annual cost
- Maximum carbon level
- Minimum fraction of renewables

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Differential Evolution



DE is a variant on genetic algorithms

- Global optimization: robust when function has local minima or correlated independent variables
- For sufficiently complicated objectives, much more efficient than particle swarm or conventional G.A.

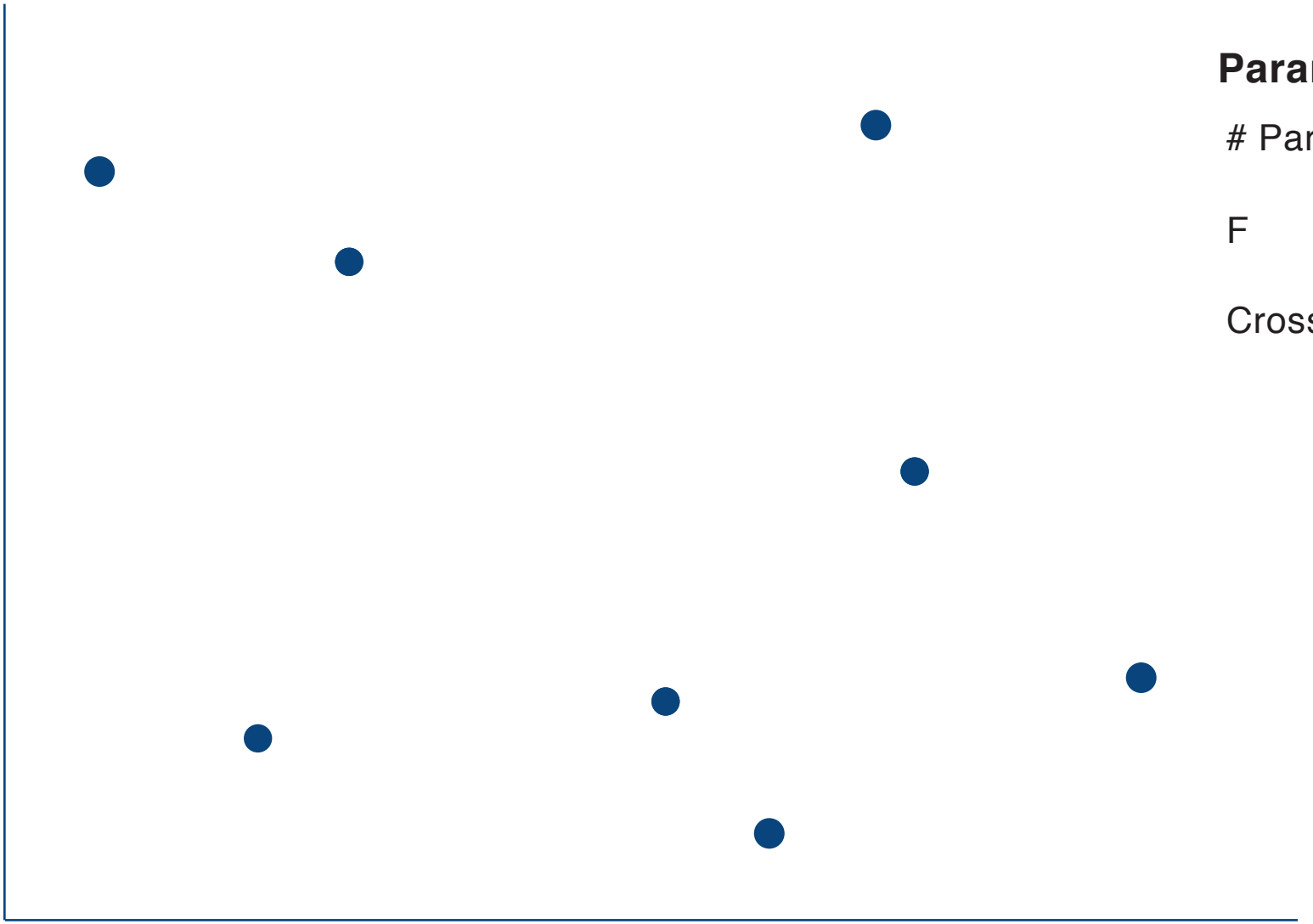
Key Inputs:

- Objective function (in form of minimization)
- Constraints (implemented as infinite penalty on the objective)
- Decision variables

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Differential Evolution



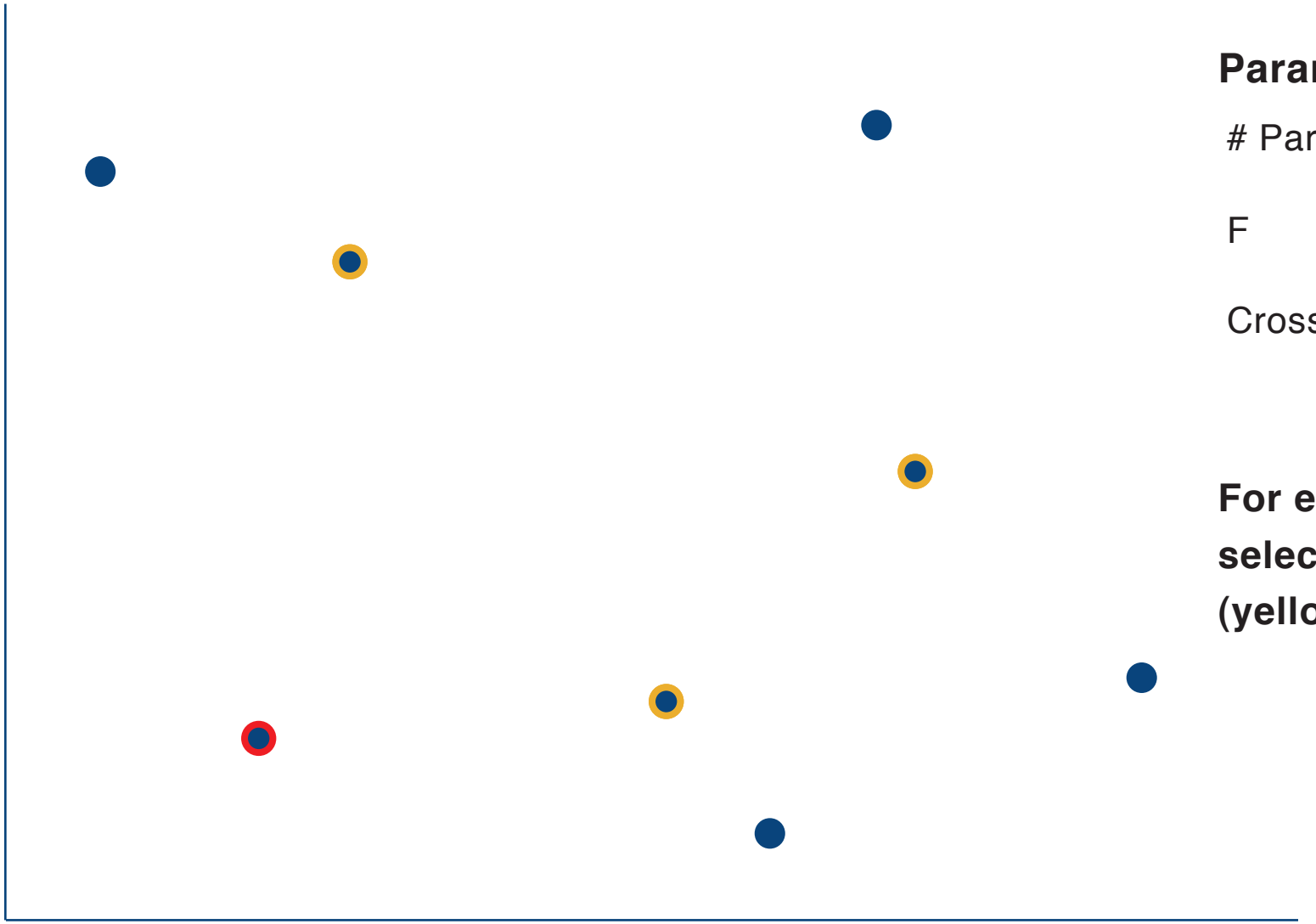
Parameters:

# Particles	45
F	0.65
Cross-over	0.71

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Differential Evolution



Parameters:

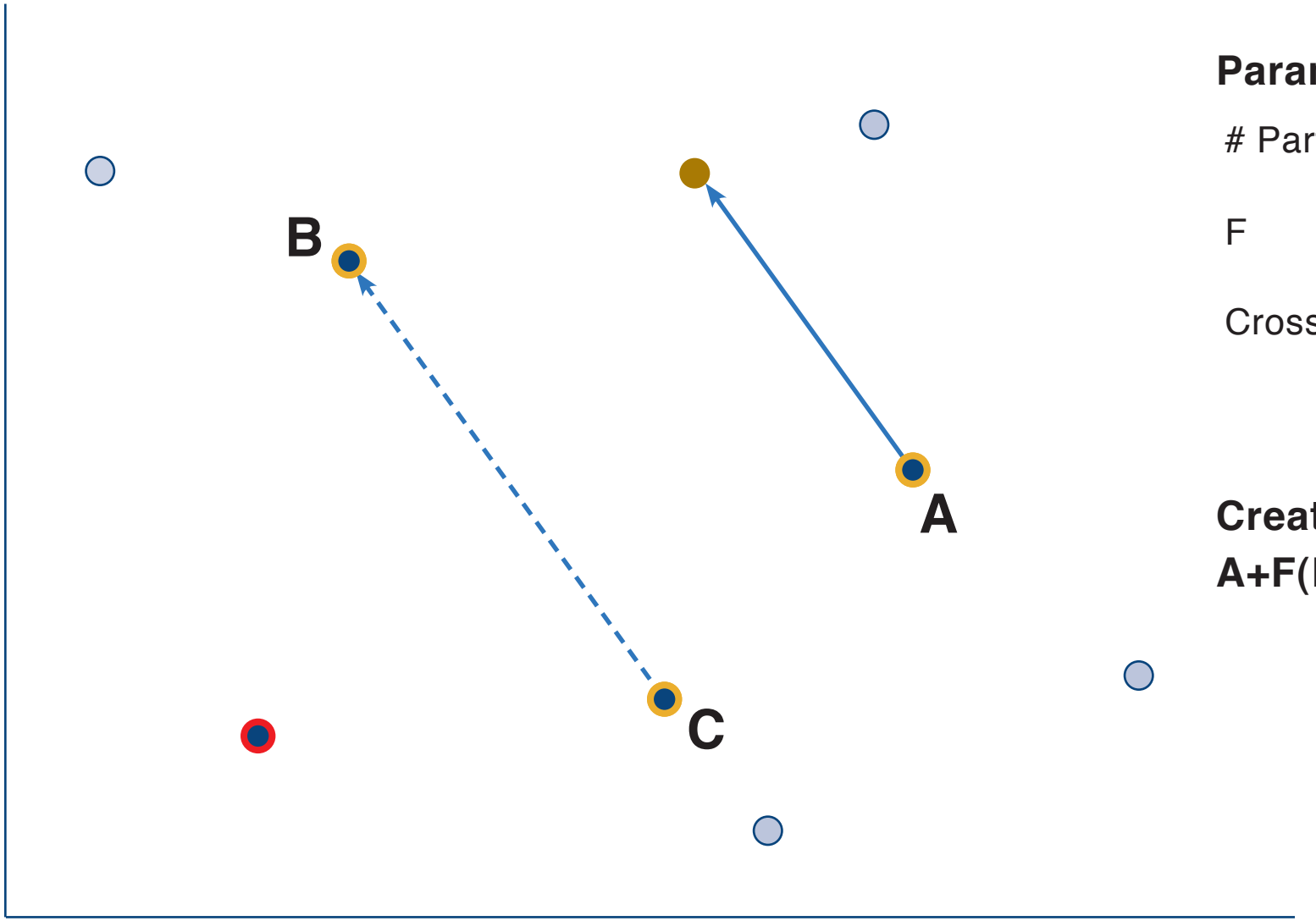
# Particles	45
F	0.65
Cross-over	0.71

For each particle (red), select 3 other particles (yellow).

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Differential Evolution



Parameters:

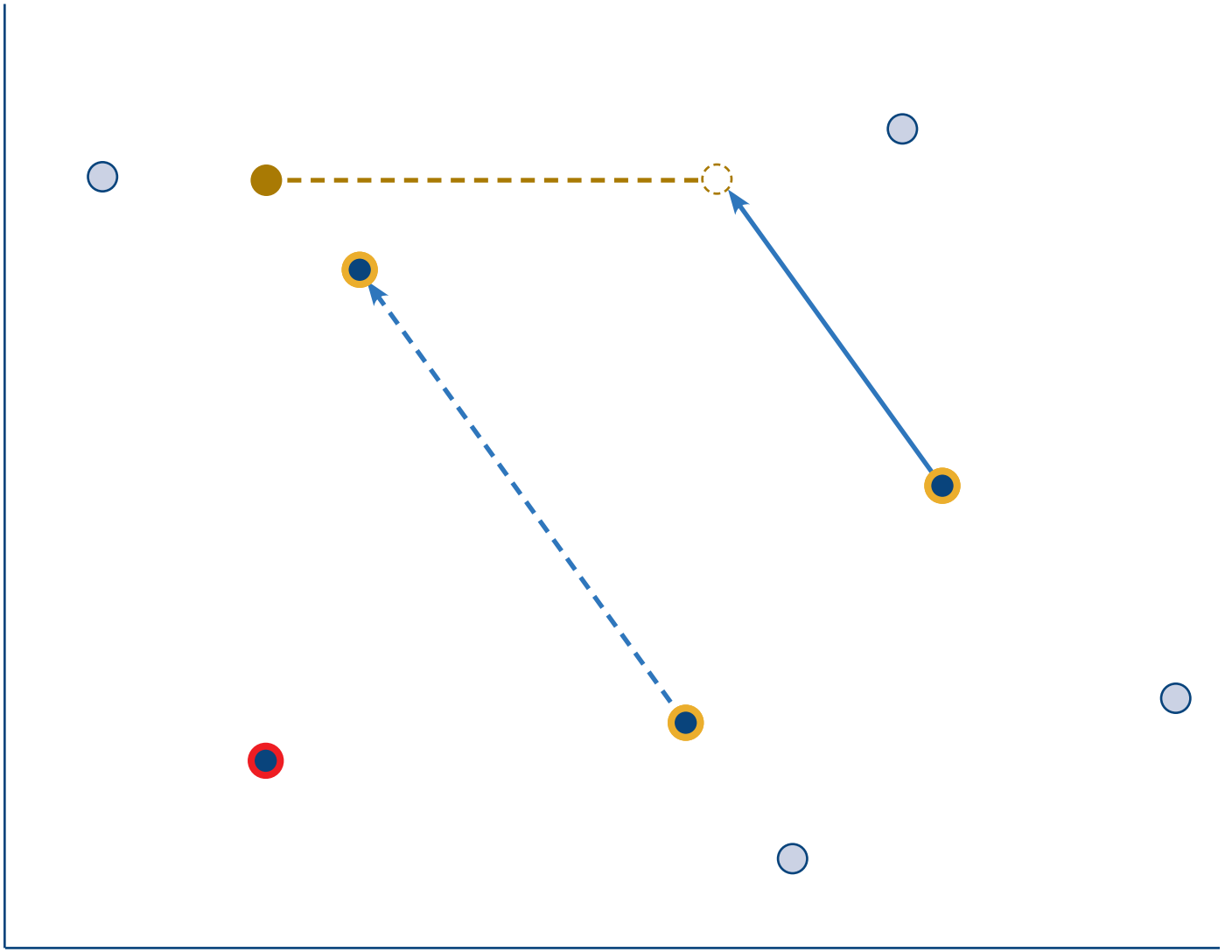
# Particles	45
F	0.65
Cross-over	0.71

Create candidate ptx
A+F(B-C)

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Differential Evolution



Parameters:

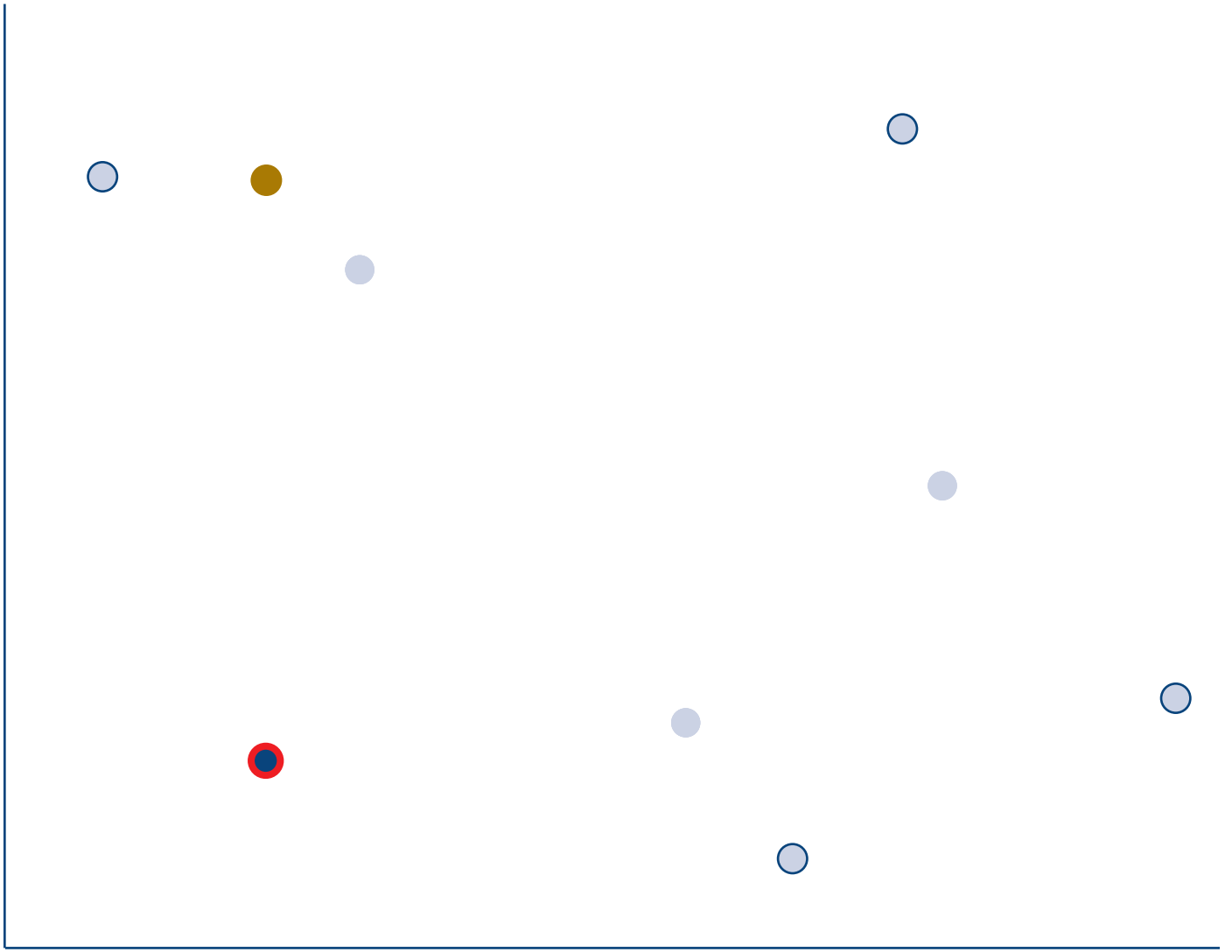
# Particles	45
F	0.65
Cross-over	0.71

For n-1 dimensions of candidate ptx, if random draw > cross-over rate, reset dimension of candidate to original ptx.

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Differential Evolution



Parameters:

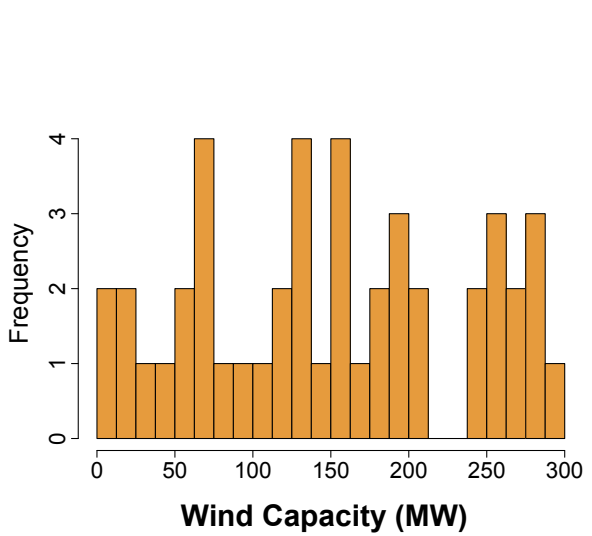
# Particles	45
F	0.65
Cross-over	0.71

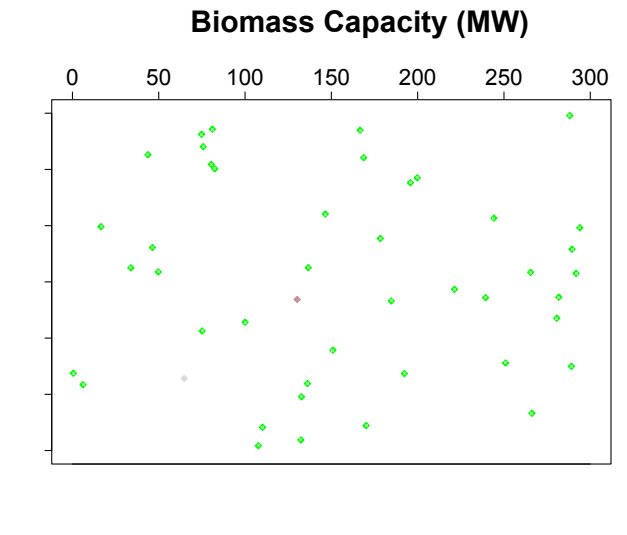
Evaluate fitness of candidate particle, if it's less than the original, replace original with candidate.

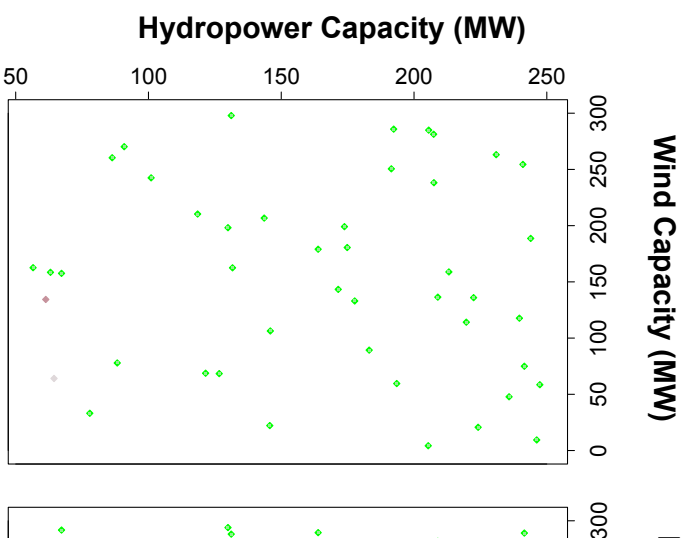
SCHATZ ENERGY RESEARCH CENTER

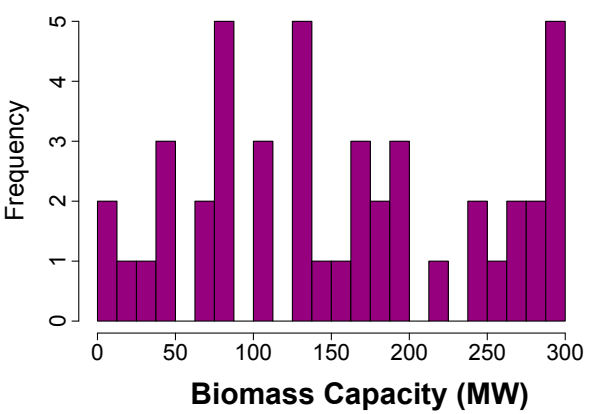
Humboldt County Renewable Energy Secure Community

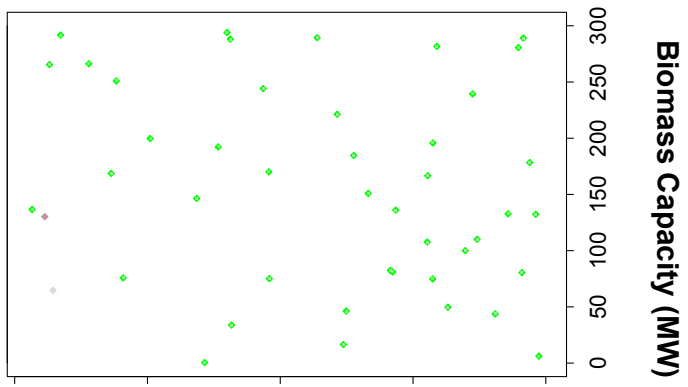
Optimization: Demonstration

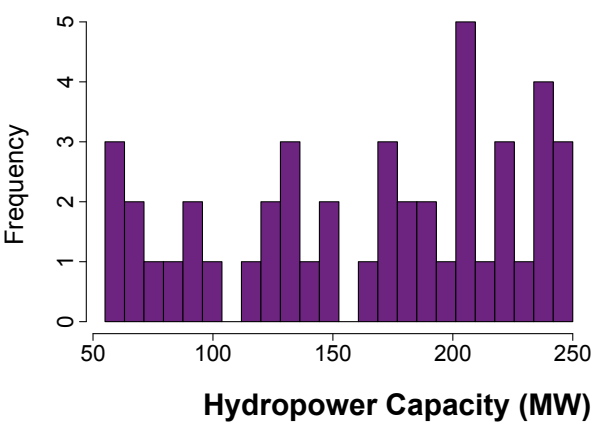




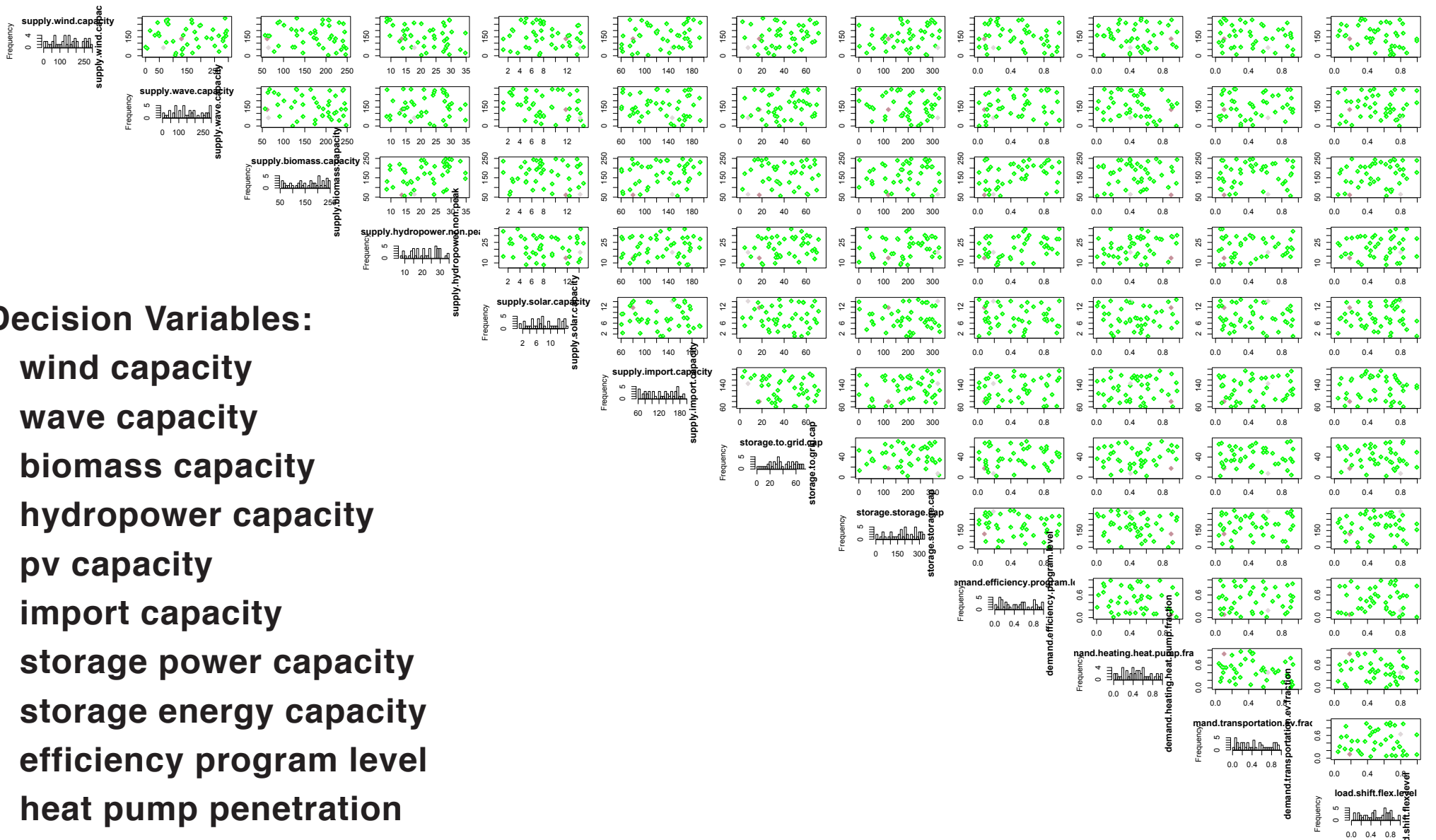








Optimization: Demonstration



Decision Variables:

- wind capacity
- wave capacity
- biomass capacity
- hydropower capacity
- pv capacity
- import capacity
- storage power capacity
- storage energy capacity
- efficiency program level
- heat pump penetration
- ev/phev penetration
- demand response level

Optimization: Preliminary Results

1478 kilotonnes (100% BAU)

$357 million (13% Max Cost)

$2,550/cap

2030 Business as Usual (reference scenario)

Renewables

Wind 0 / Wave 0 / Hydro 10.5 / Biomass 61 / PV 1

Other Supply

Import 60 / Storage 0,0

Demand options

Heat pumps 0% / EV 0% / Efficiency 0% / Demand response 0%

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Preliminary Results

165 kilotonnes (11% BAU)

$2730 million (100% Max Cost)

$19,500/cap

Objective:

- Minimize carbon emissions

Constraints:

- Meet demand

Renewables

Wind 300 / Wave 300 / Hydro 35 / Biomass 250 / PV 8

Other Supply

Import 60 / Storage 55,127

Demand options

Heat pumps 100% / EV 100% / Efficiency 100% / Demand response 0%

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Preliminary Results

191 kilotonnes (13% BAU)

$1781 million (65% Max Cost)

$12,700/cap

Objective:

- Minimize carbon emissions

Constraints:

- Meet demand
- Cost <= $1939 million

Renewables

Wind 72 / Wave 284 / Hydro 35 / Biomass 174 / PV 4

Other Supply

Import 61 / Storage 66,320

Demand options

Heat pumps 100% / EV 100% / Efficiency 100% / Demand response 83%

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Preliminary Results

201 kilotonnes (14% BAU)

$1155 million (42% Max Cost)

$8,270/cap

Objective:

- Minimize carbon emissions

Constraints:

- Meet demand
- Cost <= $1158 million

Renewables

Wind 0 / Wave 1 / Hydro 35 / Biomass 250 / PV 1.4

Other Supply

Import 60 / Storage 5,173

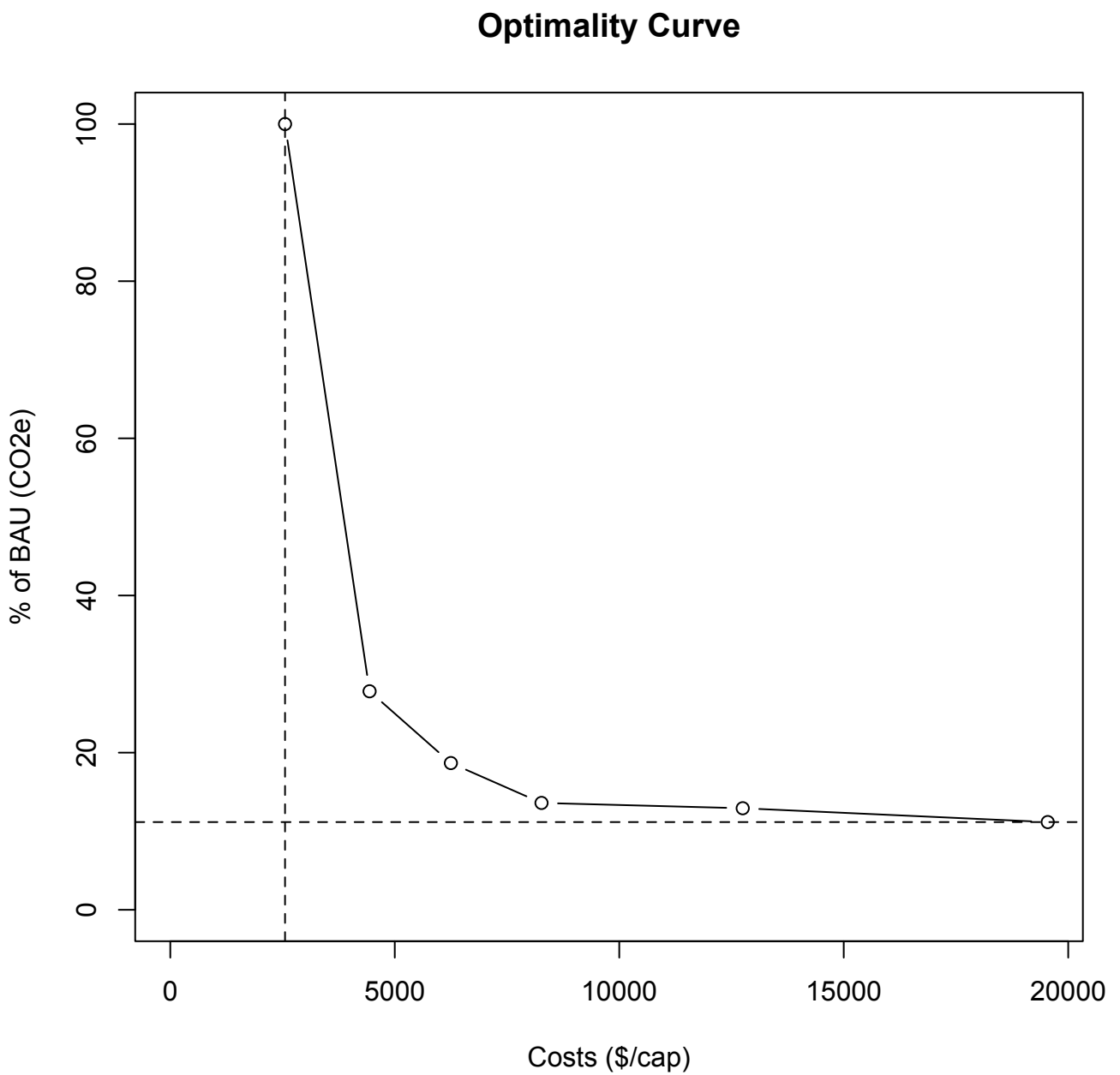
Demand options

Heat pumps 100% / EV 100% / Efficiency 76% / Demand response 58%

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Optimization: Preliminary Results



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Next Steps

- Develop/explore new objective functions based on community priorities
- Continued model development and validation
- Use model to work toward strategic plan of acheiving project goals in Humboldt County

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Project Participants: Invaluable Contributors

Redwood Coast Energy Authority

- David Boyd, Dana Boudreau, the Board

Schatz Energy Research Center

- Jim Zoellick (project manager), Charles Chamberlin, Steven Hackett, Peter Lehman, Luke Scheidler, Ruben Garcia, Adam Schumaker, Andrea Alstone, Thomas Quetchenbach

PG&E

- David Rubin, Alison Talbott, Ian Caliendo

Others

- Bob Marino (Fairhaven power plant), California Energy Commission (RESCO program), Headwaters Fund

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Thanks!

Demand: Electricity

photo: http://www.innsnorthamerica.com/

Includes demands from non-heating electric end-uses in the Residential, Commercial, Industrial Sectors

Key Inputs:

- 15-minute interval data from PG&E for County-wide demand
- Expected growth in population and electric intensity

Current Peak:
170 MW

Current Total:
1 TWh

2030 Peak:
180-300 MW

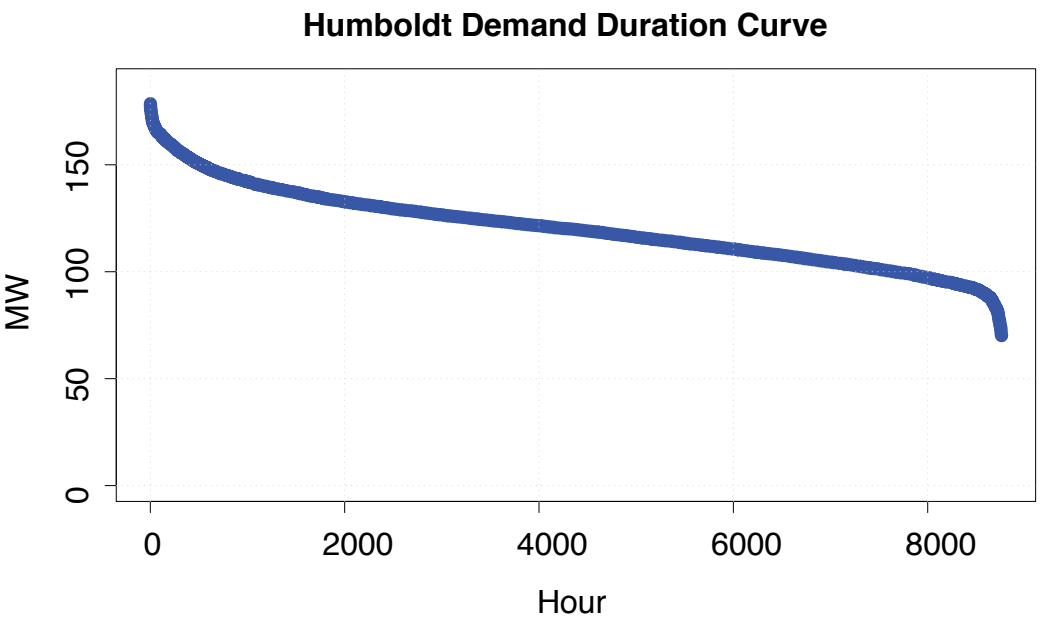
2030 Total:
1-2 TWh

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Demand: Electricity

Raw data is de-trended; weeks are chosen randomly from available years to create a full year of demand.



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Demand: Heat

Includes demands from heat end-uses in the Residential, Commercial, Industrial Sectors for space heating and water heating.

Key Inputs:

- Mix of heating technology and market shares (efficiency and fuel type) by building sector.
- Heating service demand curve from DOE2 building energy model, census data, etc.
- Key inputs from Census, RECS, CBECS

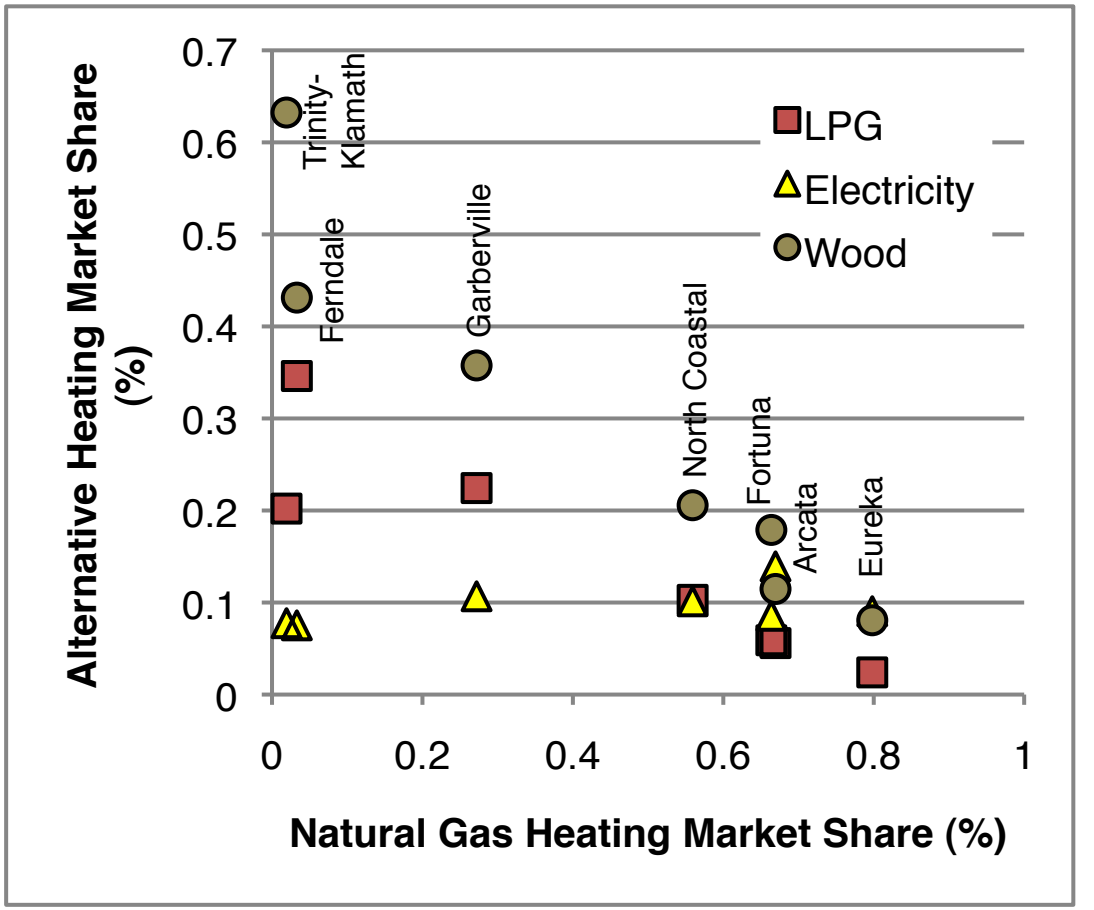
Current Use:

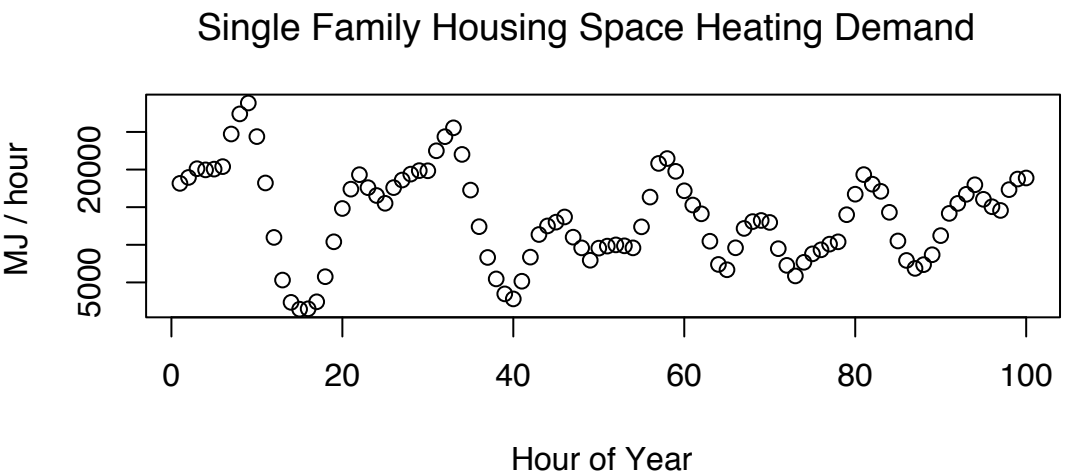
5.3 PJ of fuel
~0.4 PJ electricity

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Demand: Heat





SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Demand: Transportation

Based on estimates of technology learning curves from EPRI and NREL charging model.

Key Inputs:

- Fraction of fleet conversion from conventional to EV
- Charging strategies (determines distribution of electricity demand)

Current Use:

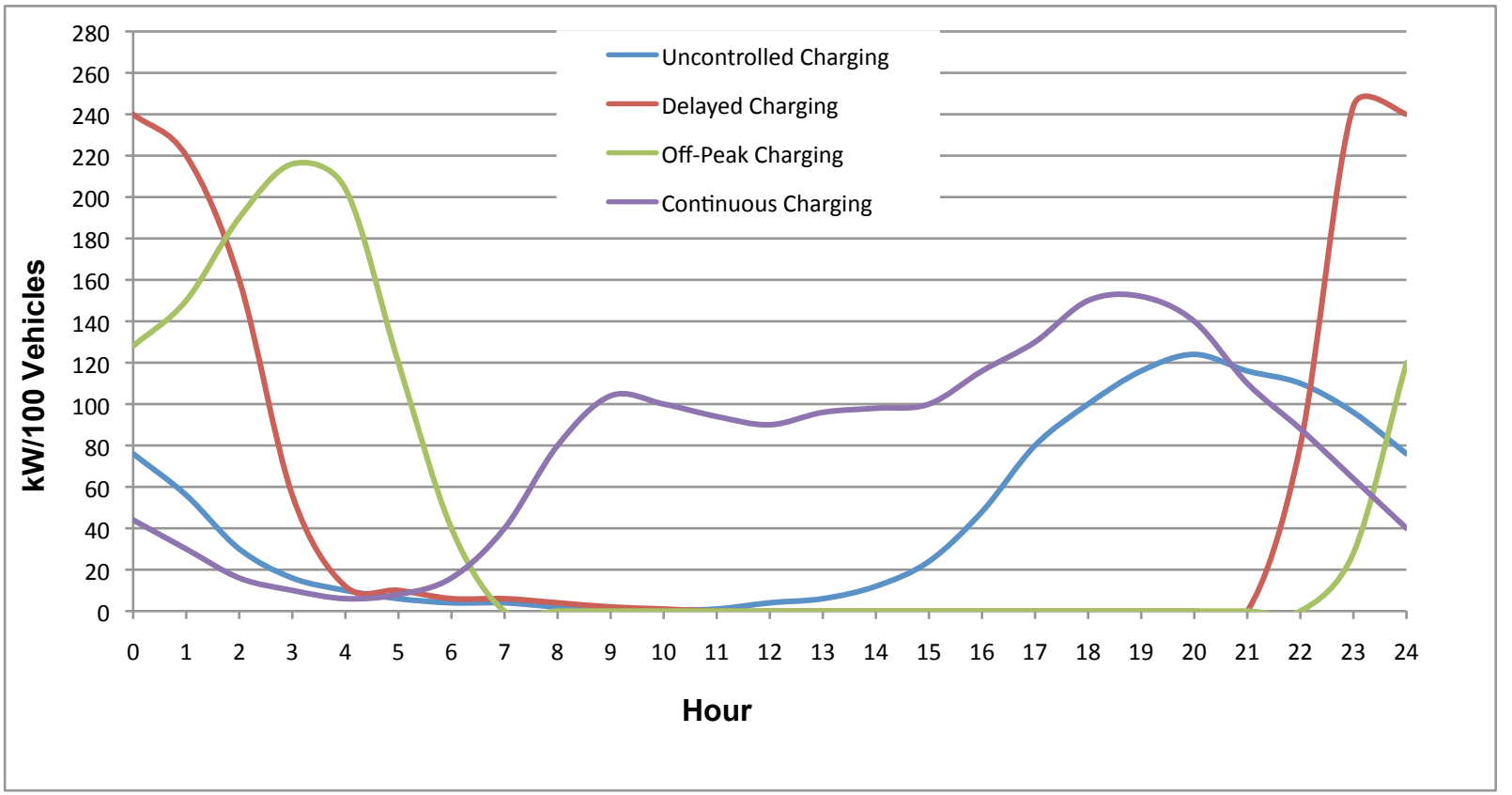
66 million gallons of gasoline / year

2030 potential:

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

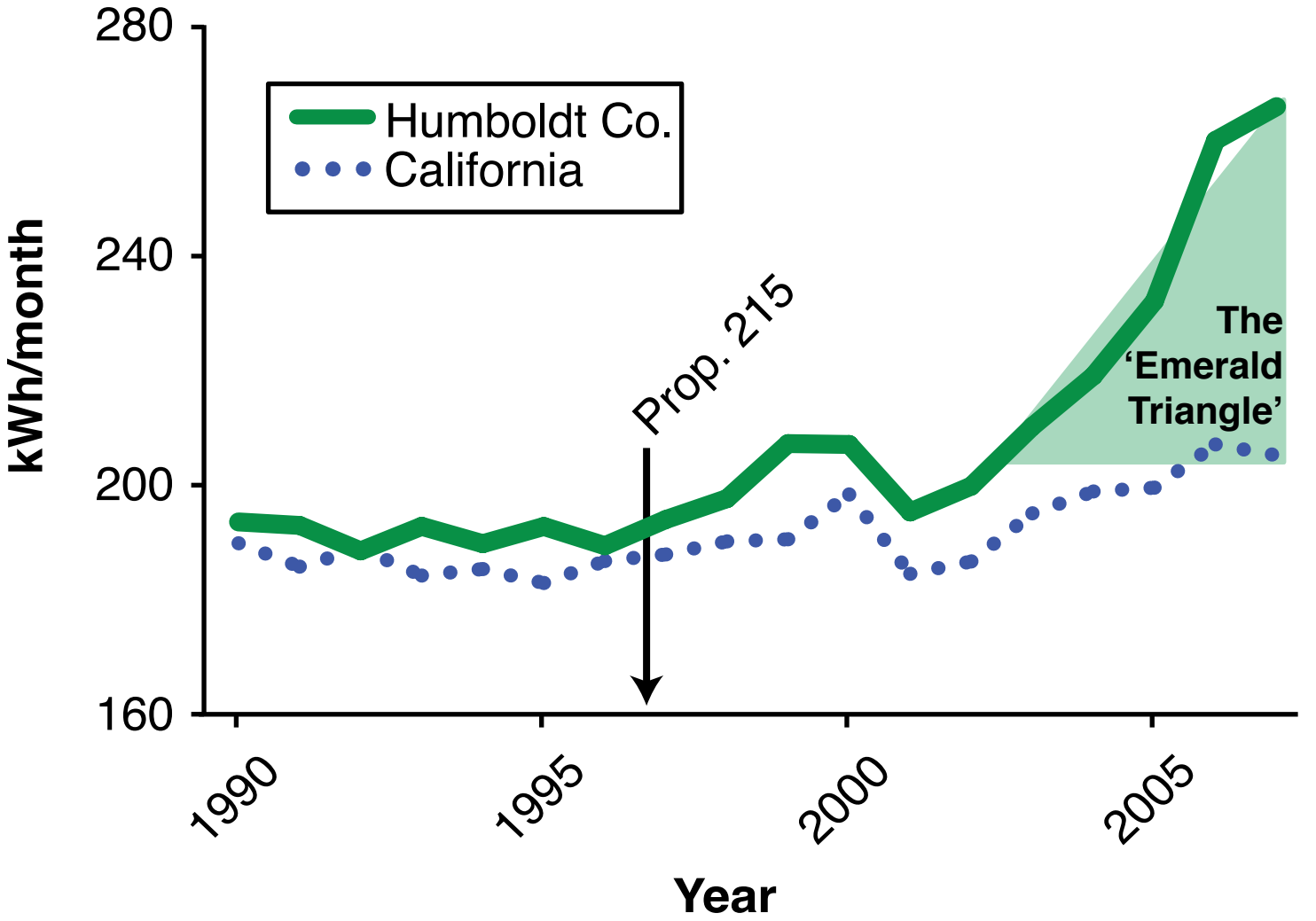
Demand: Transportation



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Residential Electricity Consumption per Capita

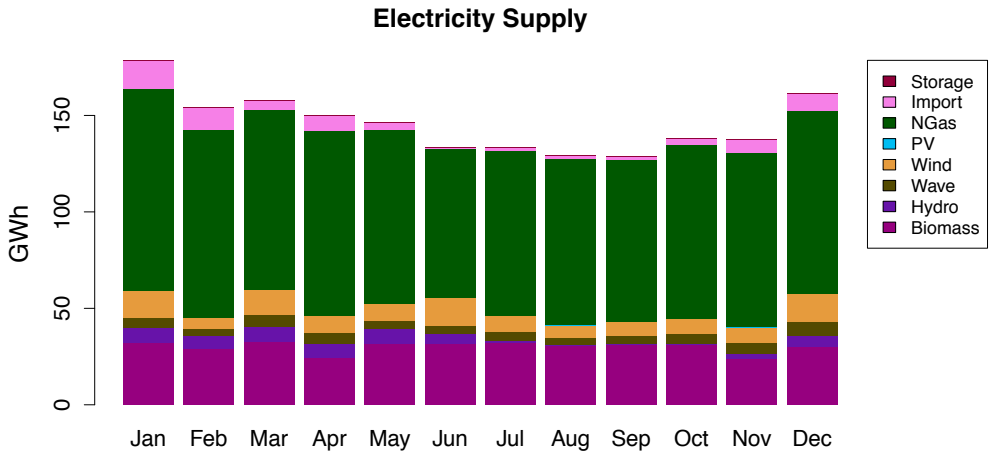


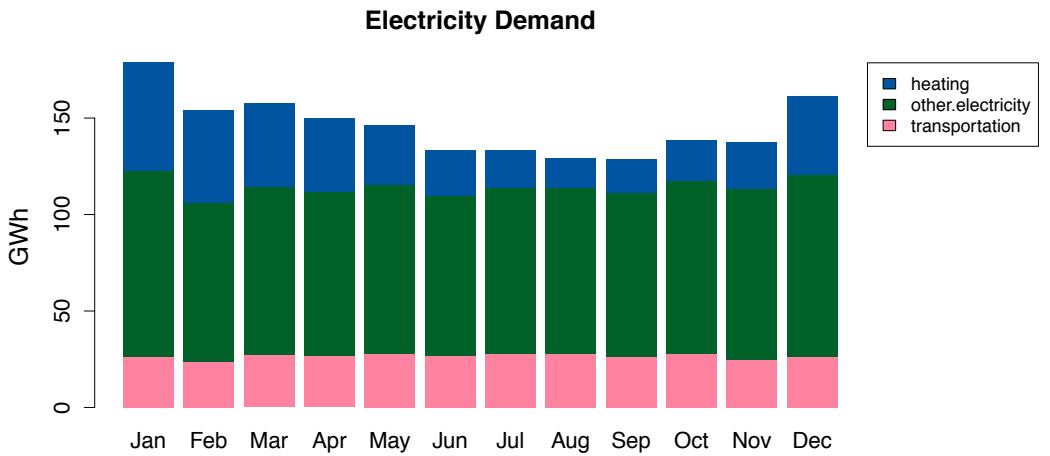
Data Sources: California Energy Commission, U.S. Census

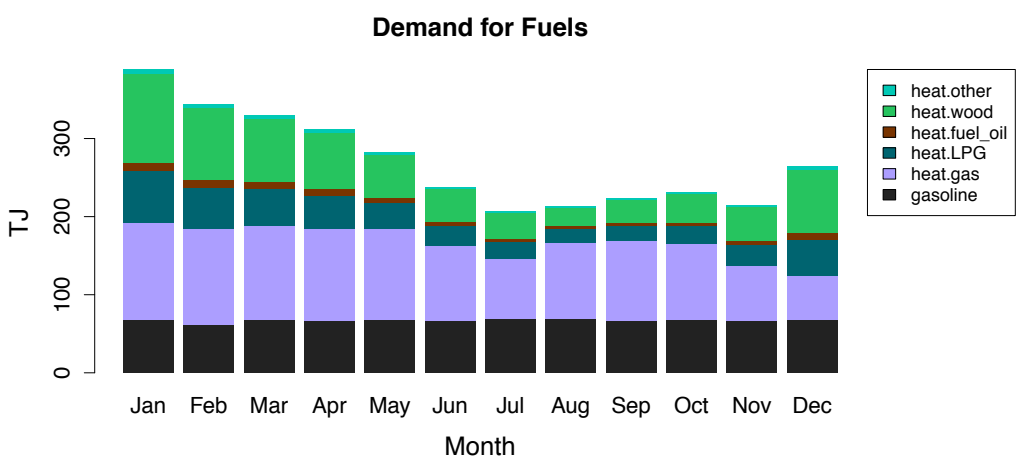
SCHATZ ENERGY RESEARCH CENTER

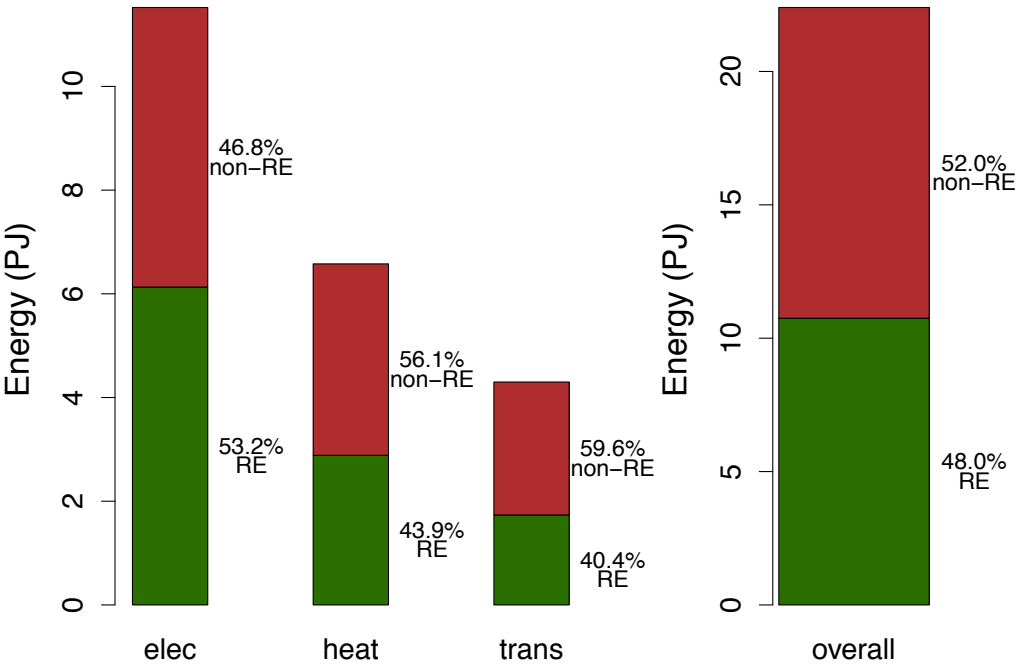
Humboldt County Renewable Energy Secure Community

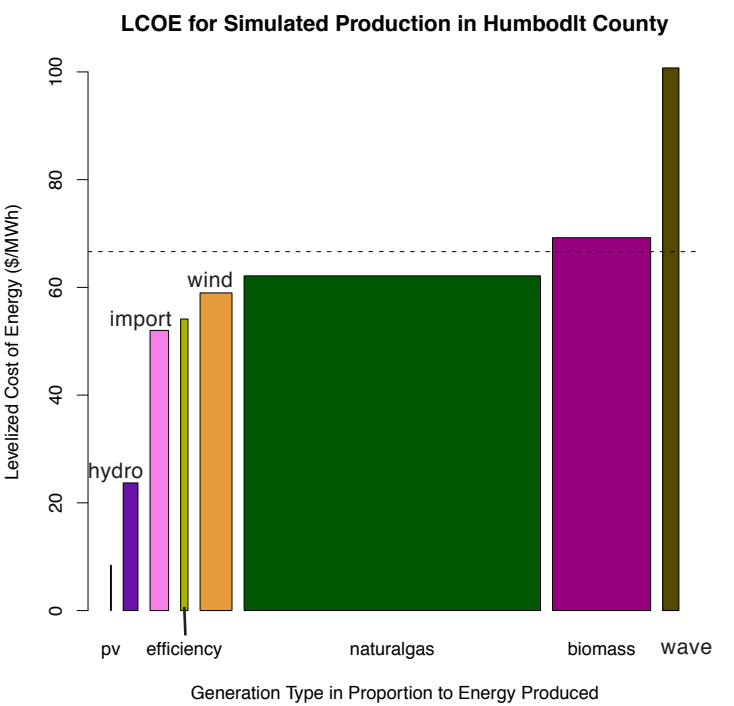
Post processing: Scenario Summary











Supply: Natural Gas

Model based on new Humboldt Bay Repower, 10 x 16MW Internal Combustion Engines. Assumed to always be available and have load following capability.

Current Capacity:
163 MW

2030 Potential:
163 MW

Key Inputs:

- Priority
- Minimum turn down factor
- Stability share
- Reserve capability
- Heat rate

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply: Biomass

Existing Plants in Scotia, Fairhaven, Blue Lake. Stochastic time series model which accounts for un/scheduled maintenance and observed fluctuations in daily output.

Key Inputs:

- Capacity
- Capacity factors

Current Capacity:
61 MW

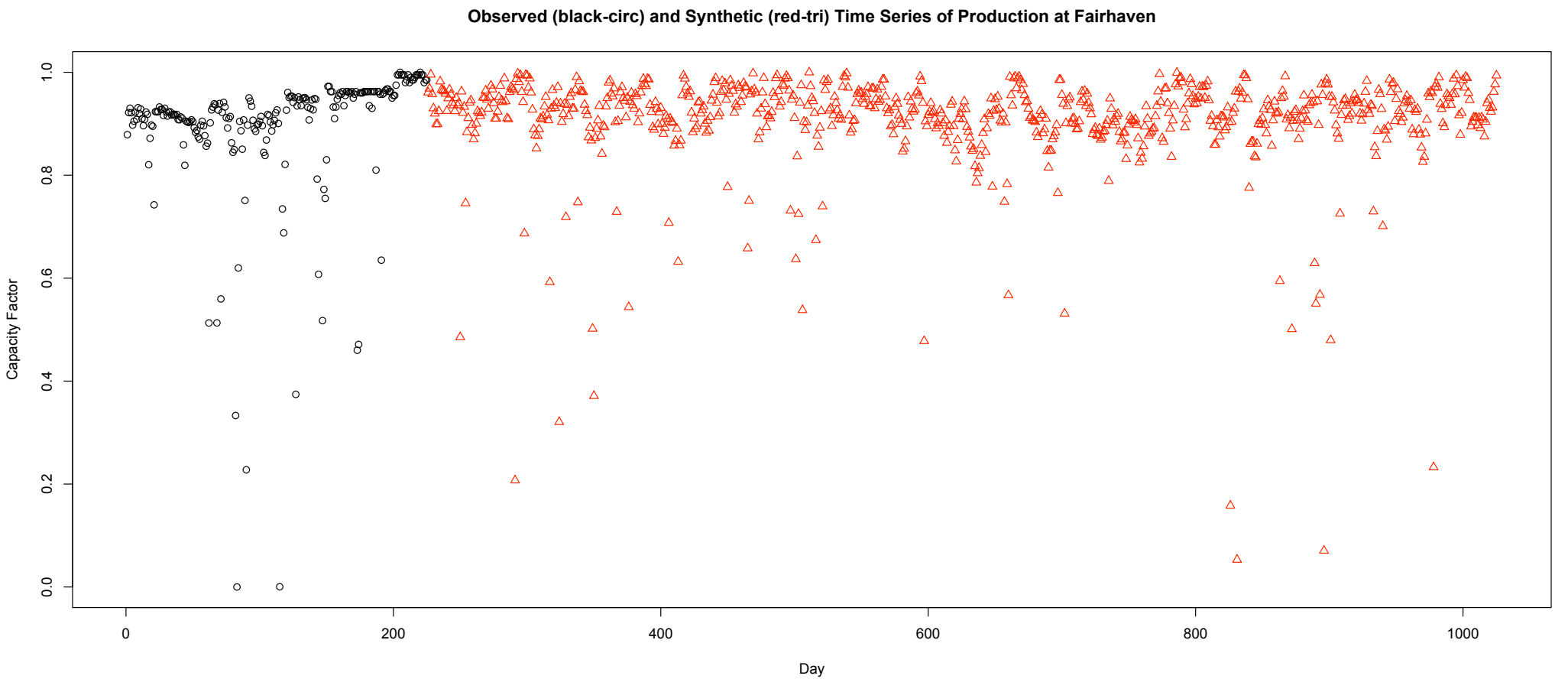
2030 Potential:
61-250 MW

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply: Biomass

Time series model - Separated Normal Operation (CF ≥ 80%) from Unscheduled outages (CF < 80%) and from Scheduled outages

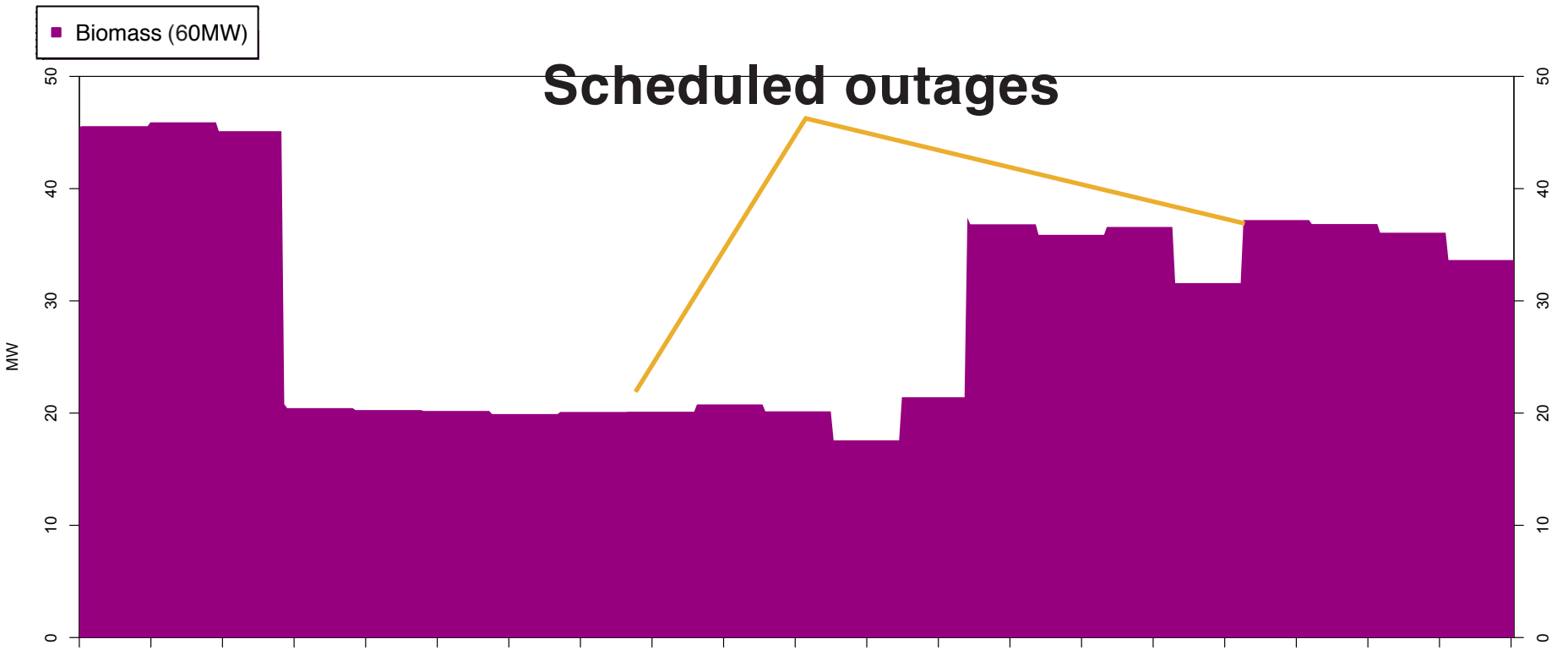


SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply: Biomass

Scheduled outages occur at Fairhaven for ~1 week just before and just after the summer season when prices increase.



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply: Hydropower

Sum of three time series models:

- Matthews Dam ~1.3MW
- Run of the river installations ~7.5MW
- Run of the river with peaking ~ 1.7MW

Key Inputs:

- Capacity
- Precipitation year

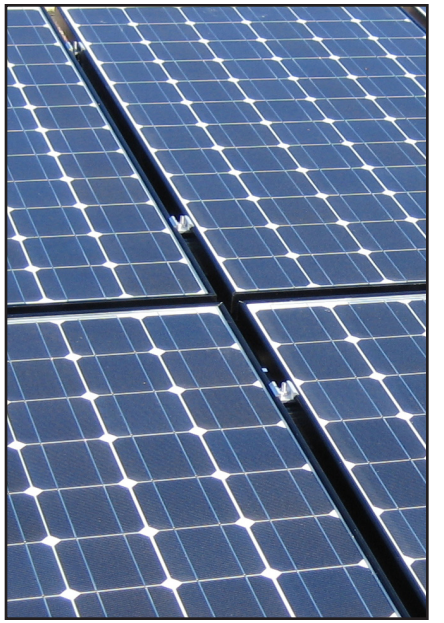
Current Capacity:
10.5 MW

2030 Potential:
10.5-35 MW

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply: Photovoltaic



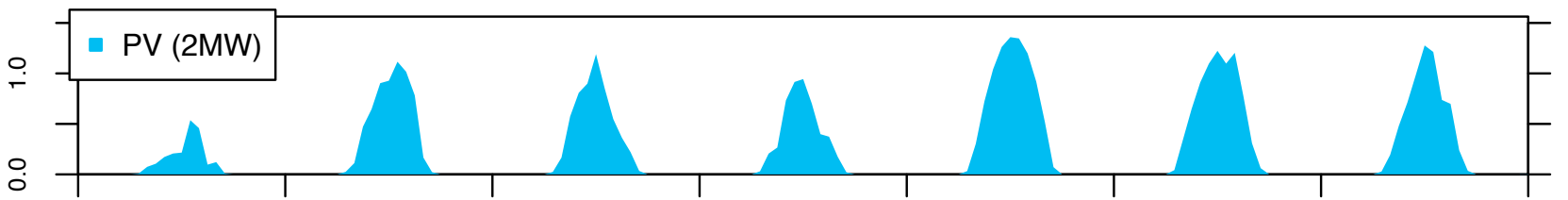
Model based on data from National Solar Radiation Database.

Key Inputs:

- Capacity
- Solar year
- Derate factor

Current Capacity:
1 MW

2030 Potential:
1-15 MW



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply: Wind

Based on modeled data from 3Tier by way of NREL.

Key Inputs:

- Hourly wind farm production estimates from NREL Western Wind Data Set.
- Source year (2005-2007), source location (Bear River Ridge, Offshore, etc.)

Current Capacity:
0 MW

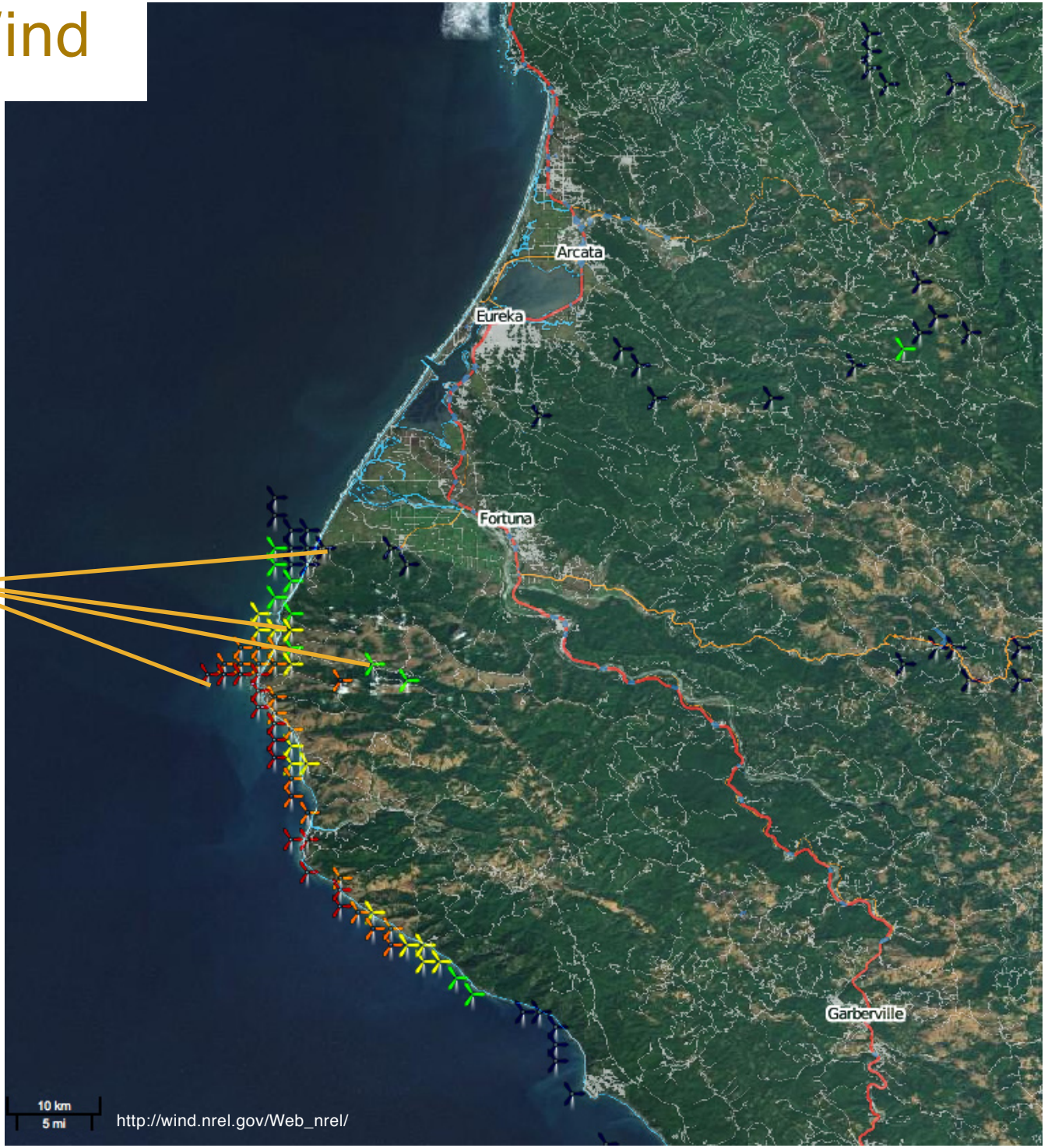
2030 Potential:
0-300 MW

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply: Wind

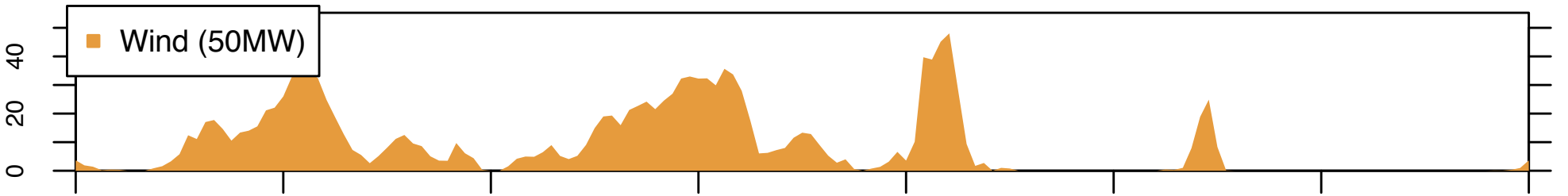
Selected Locations

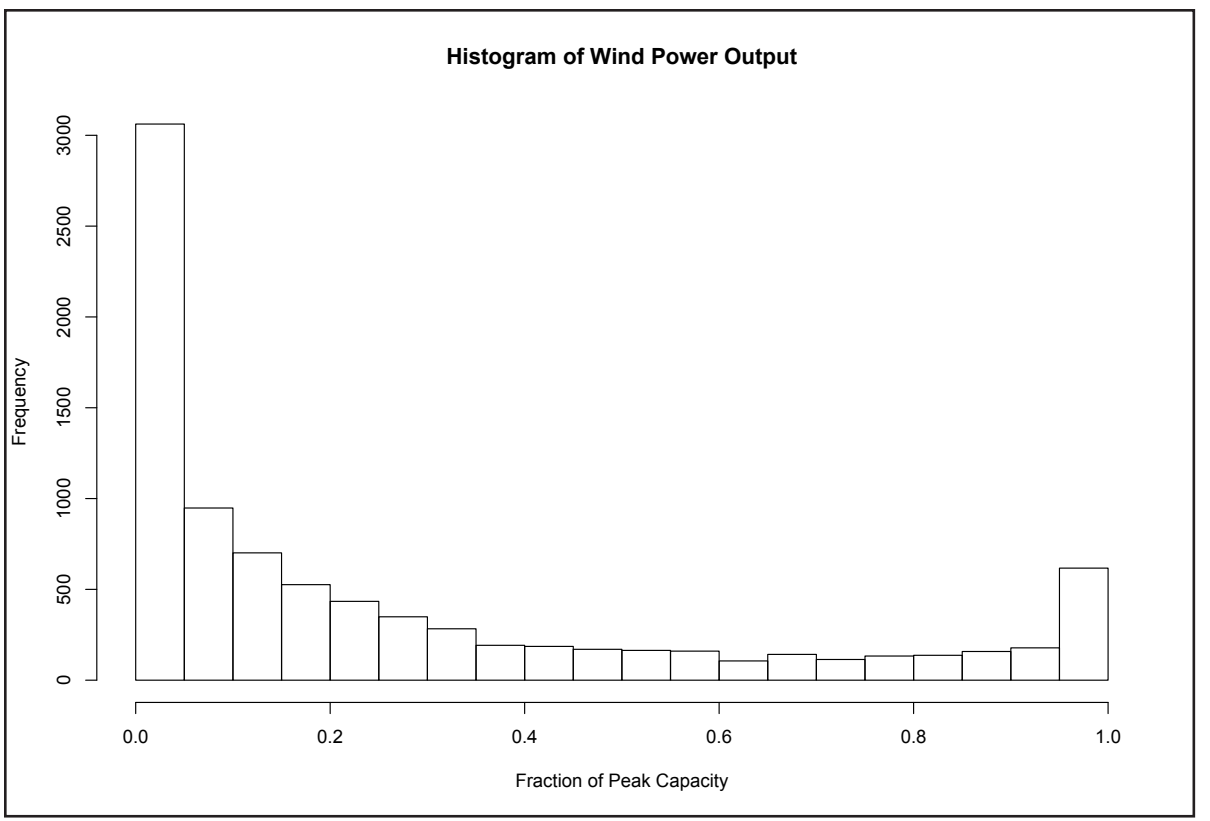


SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply: Wind





SCHATZ ENERGY RESEARCH CENTER

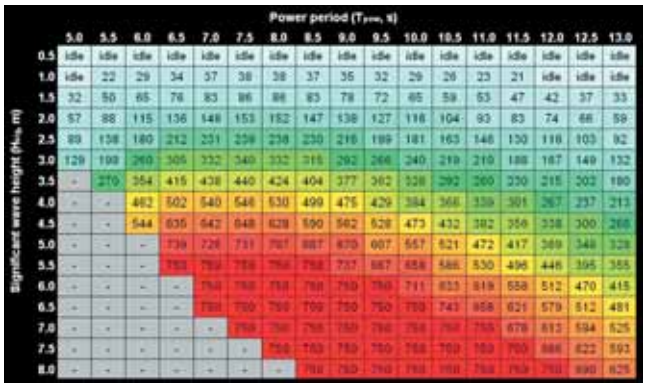
Humboldt County Renewable Energy Secure Community

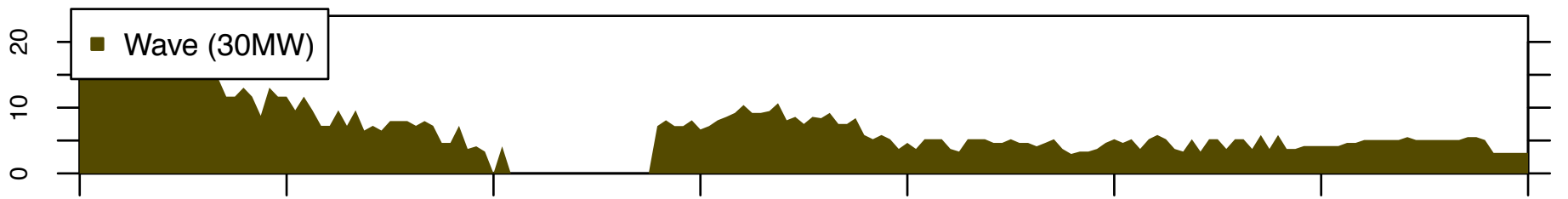
Supply: Wave

Data from NOAA Buoy 46022, power estimates based on Pelamis power matrix.

Key Inputs:

- Capacity
- Wave year





Current Capacity:
0 MW

2030 Potential:
0-100 MW

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

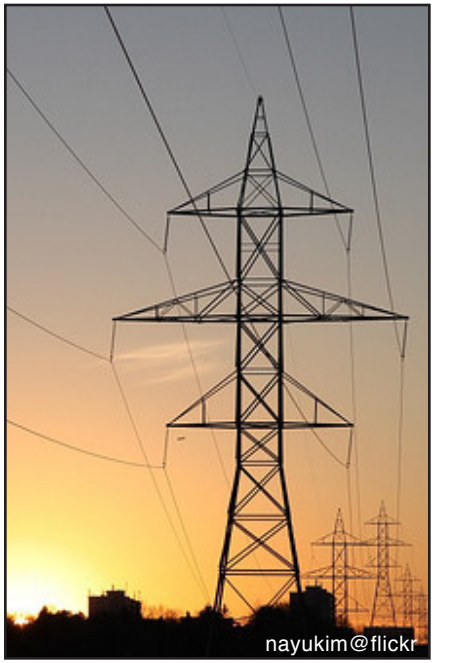
Supply/Demand: Import/Export

There are four circuits connecting Humboldt to rest of California: 2 x 115kV and 2 x 65kV lines

We assume that we can fully utilize transmission in either direction at any time.

Key Inputs:

- Capacity



Current Capacity:
60 MW

2030 Potential:
60-200 MW

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply/Demand: Storage

Considered three technologies:

- **NaS Battery**
- **Pumped Hydro (PH)**
- **Compressed Air Energy Storage (CAES)**

Key Inputs:

- Power capacity / Storage capacity
- Efficiency / Stored energy decay rate
- Operational strategy

Current Capacity:
0 MW

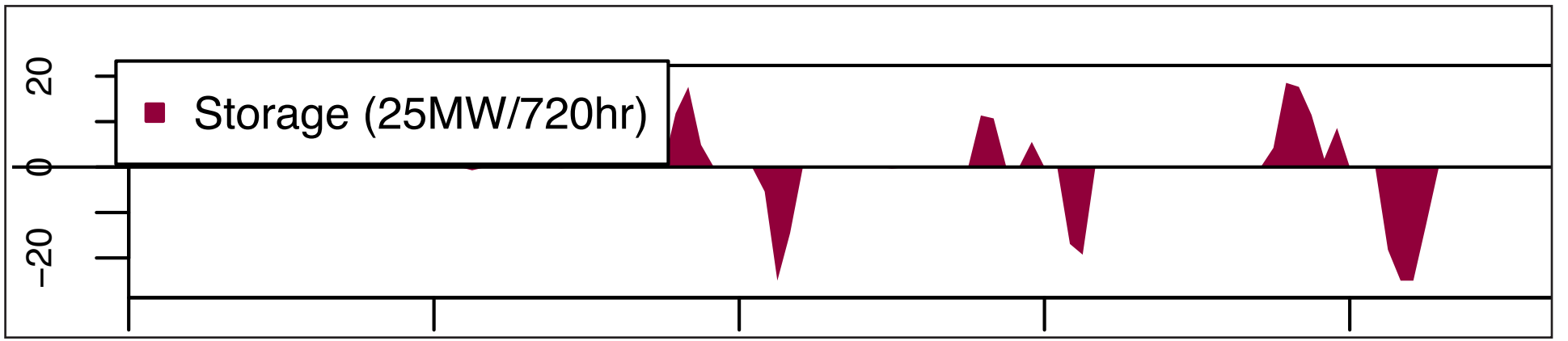
2030 Potential:
0-100 MW

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Supply/Demand: Storage

Strategy is to prevent “spillage” and blackouts.



SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community

Dispatch: Reserve

- In any hour, a certain amount of generation capacity must be held in reserve to accommodate unexpected deviations in supply or demand.
- We used the “three sigma” rule on a persistence forecast as our estimate of the requirement.
- Mean requirement in 2030 with no wind/wave: 6.8%
- Mean requirement in 2030 with wind/wave: 19.0%

Key Inputs:

- Demand distribution
- Wind/Wave distributions

SCHATZ ENERGY RESEARCH CENTER

Humboldt County Renewable Energy Secure Community