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Energy+Environmental Economics

California Solar Initiative (CSI) Research, Development, Demonstration, and Deployment Program Grant # 2 Demonstration

Supported by the California Public Utilities Commission (CPUC), managed by Itron, Inc, and hosted at the University of California, San Diego Campus

February 16, 2012

Agenda

- Opening Remarks (ITRON)
- Grant Objectives (Nancy Miller)
- About Viridity, About E3(Rick Schaal, Eric Cutter)
- Introductions and Acknowledgments, Project Overview (Nancy Miller)
- Policy Context for Managing Distributed Energy Resources (Eric Cutter)
- UCSD Campus Resources Overview (Priya Sreedharan)
- UCSD Baseline and Historical Operations (Priya Sreedharan)
- Master Controller Overview (Chuck Richter)
- VPower Demonstration (Chuck Richter)
- UCSD Optimization Strategies (Chuck Richter)
- Project Discoveries (Nancy Miller)
- Next Steps
- Questions

CSI Grant Overview

Working with the California Independent System Operator (CAISO), San Diego Gas and Electric (SDG&E) and our host site, the University of California San Diego (UCSD), one of the most advanced microgrids in the state, Viridity Energy and Energy+Environmental Economics (E3), have merged their respective expertise to:

- Analyze and demonstrate how load can serve as a flexible resource to integrate high penetration solar

- Demonstrate that the barriers to deployment of solar resources can be overcome through providing appropriate incentives for real-time management and optimization of distributed energy resources.

- Provide economic, reliability and market price benefits to California ratepayers that accompany increased deployment of solar resources

Viridity Energy - Recognized Leader in Smart Grid Technology

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Key Company Facts

Founded in 2008 by **well known industry executives**

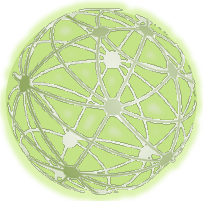
Experienced Team:

- Experienced utility and power market executives
- Technology innovators
- Regulatory policy and affairs experts

Recipient of multiple **industry awards and grants**

Unparalleled Solutions

Integrated energy management from Demand Response to Dynamic Load Management and Microgrids



Patent pending software platform
optimizes and integrates energy assets such as controllable loads, cogeneration, renewables, and energy storage systems

Network Operating Center
supports customer participation in wholesale power markets

Types of Clients

Industrial

Commercial

Institutional

Utilities

Data Centers

Military

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Intelligence Moving to The Edge of the Grid: Real-Time Generation + Dynamic load

Major Trend #1:

Global proliferation of distributed energy resources:

- Solar
- Electric vehicles
- Distributed generation
- Smart buildings

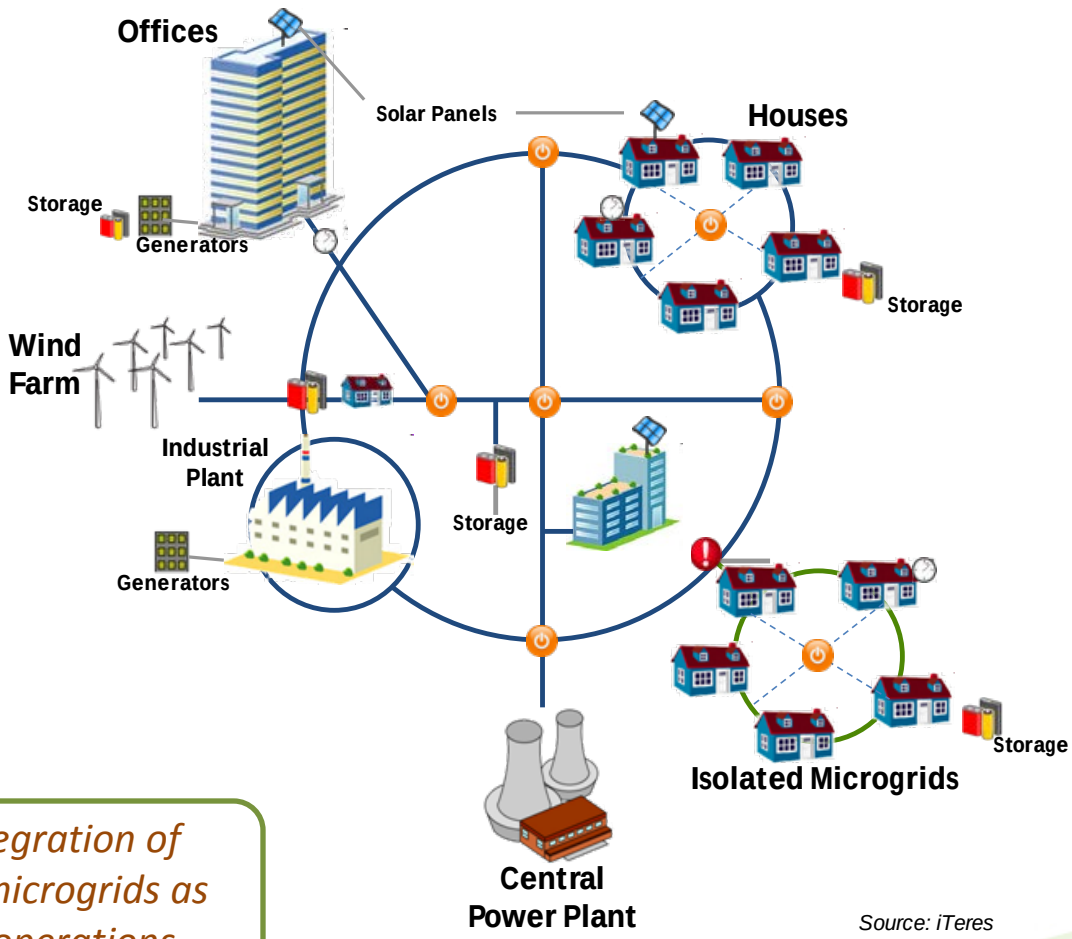
Major Trend #2:

Power Grid will evolve from centralized command and control to distributed interconnected systems that are:

- Inter-coordinated
- Self-scheduling
- Self-healing

Viridity Energy enables the seamless integration of distributed resources, smart loads and microgrids as Virtual Power into real time power grid operations

The Grid is a Single Machine



Source: iTeres

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About E3

E3's expertise in 8 key practice areas has placed us at the center of energy planning, policy and markets in California and the West.

- Emerging Technology Strategy
- Energy Markets and Financial Analysis
- Transmission Planning and Pricing
- Resource Planning and Procurement
- Energy and Climate Policy
- Energy Efficiency and Distributed Resources
- Cost of Service and Rate Design
- International Electricity Policy and Planning

Project Overview

- Expand the model of UCSD campus resources
- Propose strategies for the integration of high penetration PV solar systems
- Propose tariffs and incentives for Distributed Energy Resources (DER) technologies and Load Management Strategies
- Establish Baseline performance for UCSD DER operation under current rates and incentives
- Refine and test proposals with VPower™ in simulation and realtime mode
- Provide a robust cost-benefit analysis of the DER management strategies
- Provide an transparent analysis tool for public use as a part of the final report

Additional project information can be found at:
http://www.calsolarresearch.ca.gov/Funded-Projects/solicitation2-viridity.html

POLICY CONTEXT FOR MANAGEMENT OF DISTRIBUTED ENERGY RESOURCES

California's Renewable Energy Challenges

Managing RPS costs with "smart", cost-effective interconnection and management of distributed energy resources (DER)

1) Increase Interconnection Potential for Distributed PV

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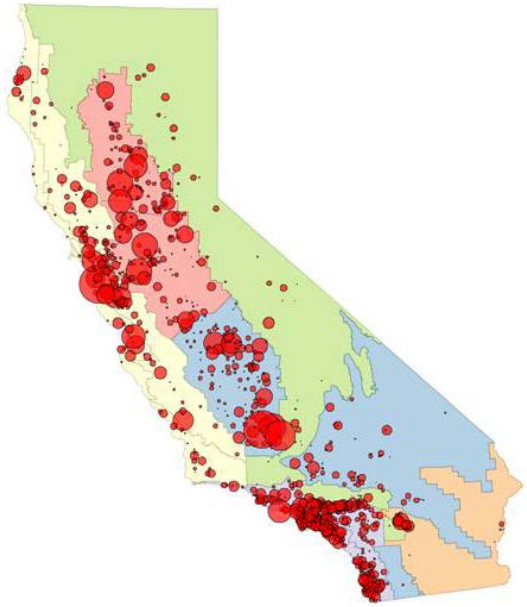
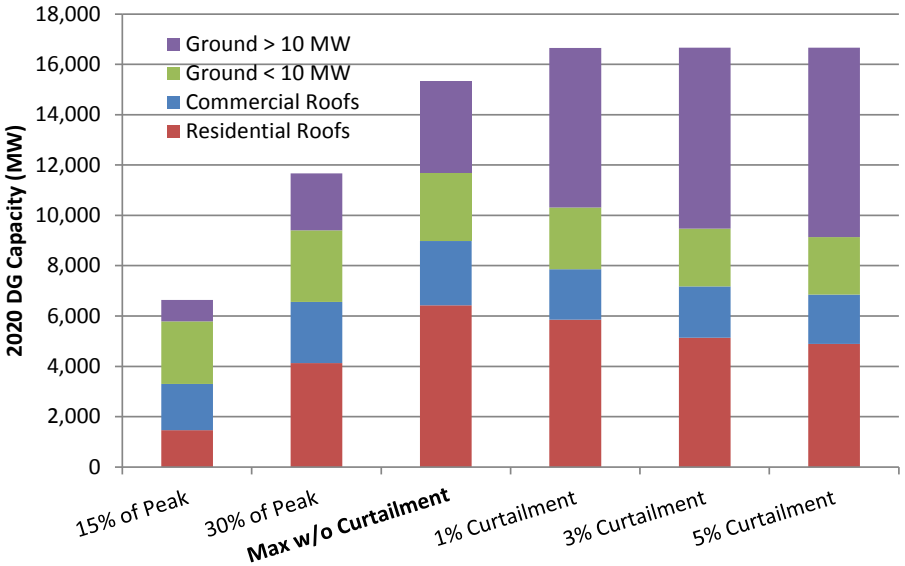
Relative substation interconnection potential



"Raw" PV potential based on substation loading

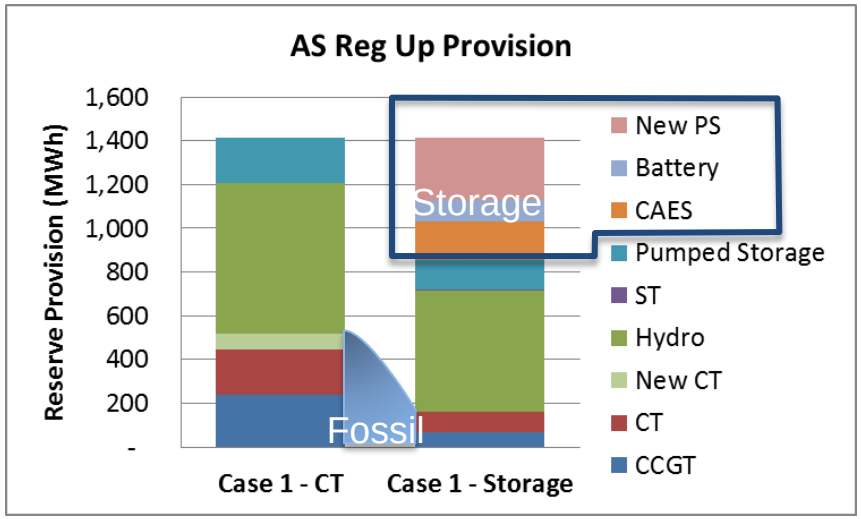


Management of distributed energy resources can potentially interconnect PV at 3 X today's levels

Graph shows "raw" PV solar potential based on minimum substation loading

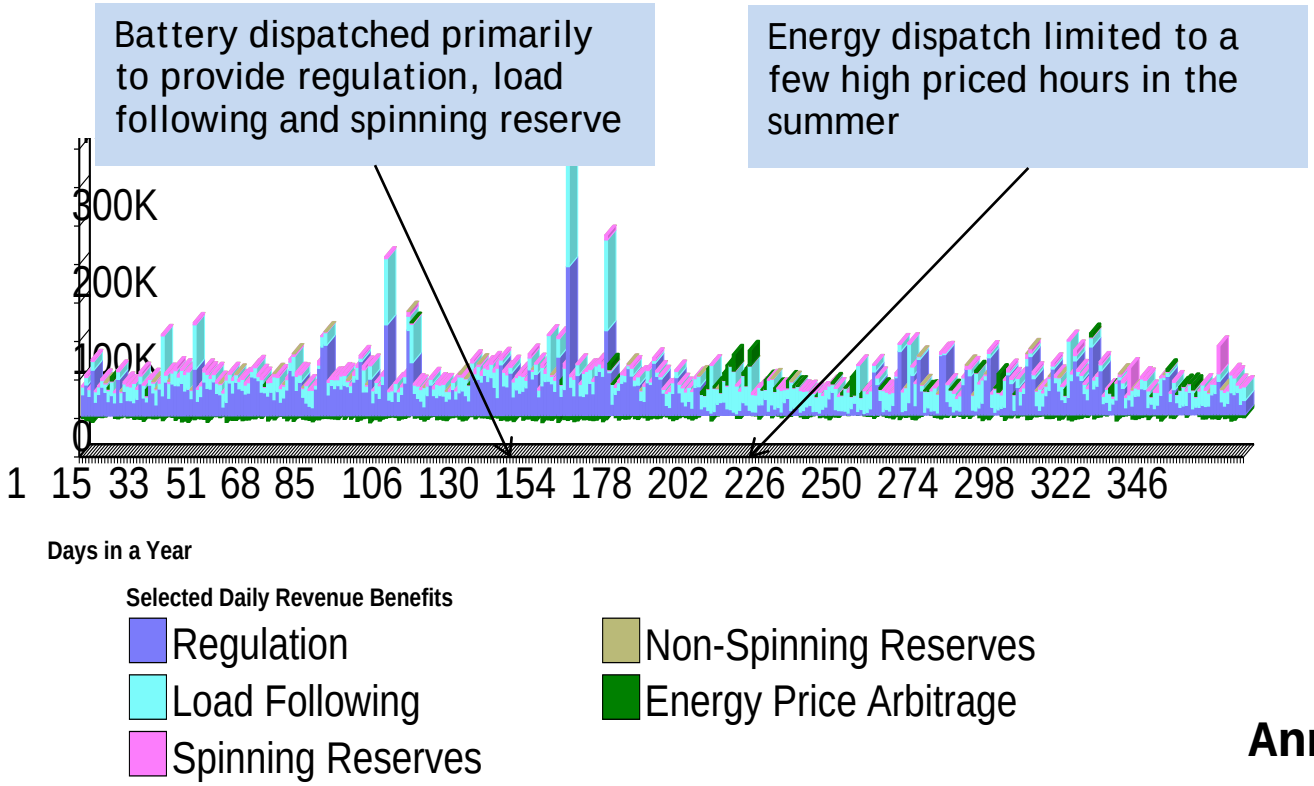
2) Provide Low/No Carbon Flexible Resource

- There is an identified need for flexible resources to integrate renewables.
- **BUT,** there is excess capacity based on planning reserve margin



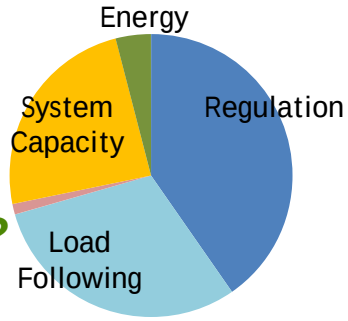
Can distributed energy resources displace fossil generation as an economic and flexible resource?

3) Meet System Need for Flexibility



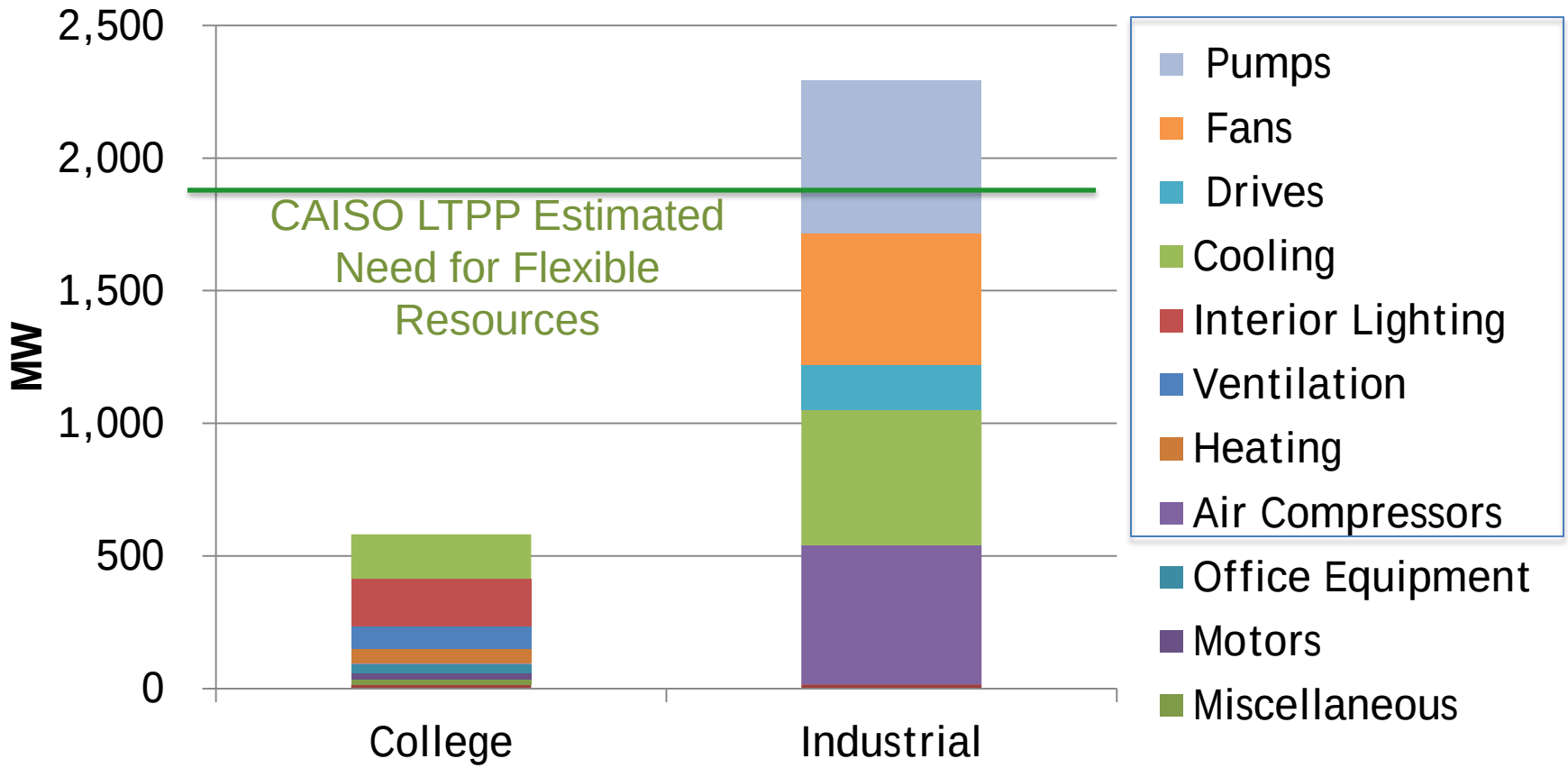
- 50 MW, 4 Hour Bulk Battery
- California 2020 RPS Compliant Scenario
- Modeled with PLEXOS and EPRI/E3 Energy Storage Valuation Tool

Annual Revenues



Energy storage is dispatched for flexibility… not energy. Shouldn't we harness the flexibility in distributed resources?

Illustrative Flexible Load Potential in California



Distributed, flexible resources and loads can provide a significant portion of our anticipated need for flexible capacity

LTPP: Long Term Procurement Planning

OVERVIEW OF UCSD RESOURCES

UCSD microgrid

UC San Diego operates a 42 MW microgrid

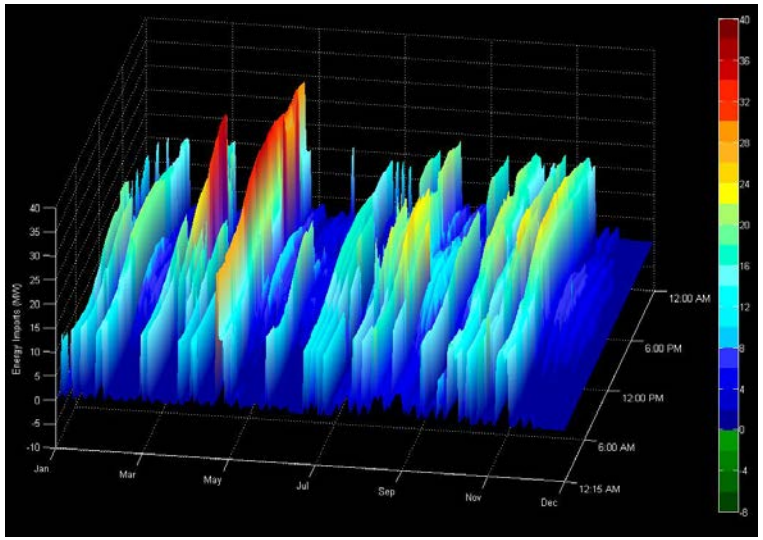
With a daily population of over 45,000, UC San Diego is the size and complexity of a small city.

11 million sq. ft. of buildings, $250M/yr of building growth

Self generate ~ 90% of annual demand

- 30 MW natural gas Cogen plant
- 2.8 MW of Fuel Cells in operation
- 1.2 MW of Solar PV installed, additional 2 MW planned
- Twice the energy density of commercial buildings

UC San Diego grid imports 2007



Central plant resources

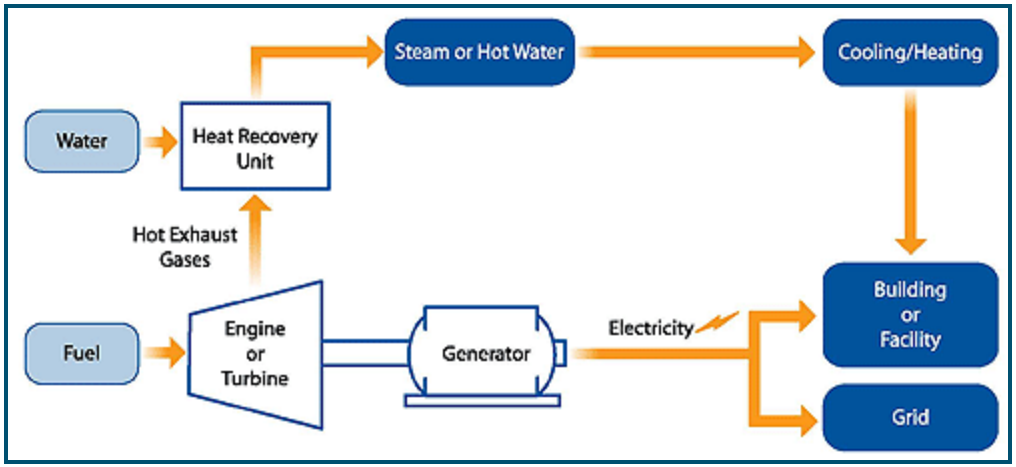
- The central plant is rich with dispatchable resources
  - Two 13 MW natural gas generators
  - One 3 MW steam generator
  - Three Steam driven chillers (~ 10,000 tons capacity)
  - Eight electric driven chillers (~ 7800 tons capacity)
  - 3.8 million gal thermal storage tank
  - Backup diesel generation
- >1 MW of solar PV
- ~ 1.4 MW of DR-ready reducible building load
- Visibility at the building level

Chilled water tank at UCSD campus

Simple illustration of cogeneration

- Let's review the concept of 'cogeneration' or 'combined heat and power' systems
- Electricity generated and can be used onsite and/or exported to the grid
- Heat is recovered used for various purposes

Gas turbine/engine with heat recovery



Source: EPA Combined Heat and Power Partnership website. http://www.epa.gov/chp/basic/index.html

UCSD's cogeneration system

Cogeneration is a core component of UCSD's microgrid

Steam chiller at UCSD campus

- The UCSD cogeneration system has the following
  - Natural gas turbine generates electricity for onsite use & steam
  - Steam is used to generate hot water, more electricity (steam turbine) and chilled water (steam-driven chillers)
  - Cogeneration offsets imported electricity, boiler fuel use for generating hot water & chilled water, and electricity consumption required to generate chilled water

Flexibility of the UCSD resources

- UCSD resources can shift load, reduce load and move load between gas and electricity fuels
  - Natural gas generators produce electricity and steam; once on, can go up/down ~ 6 MW
  - Tank can deliver significant portion of campus chilled water needs and can be variably charged/discharged
  - Steam from generators can be used to generate hot water, chilled water and additional electricity in varying amounts
  - Building load can be reduced ~ 1.4 MW for DR events

UCSD online energy dashboard

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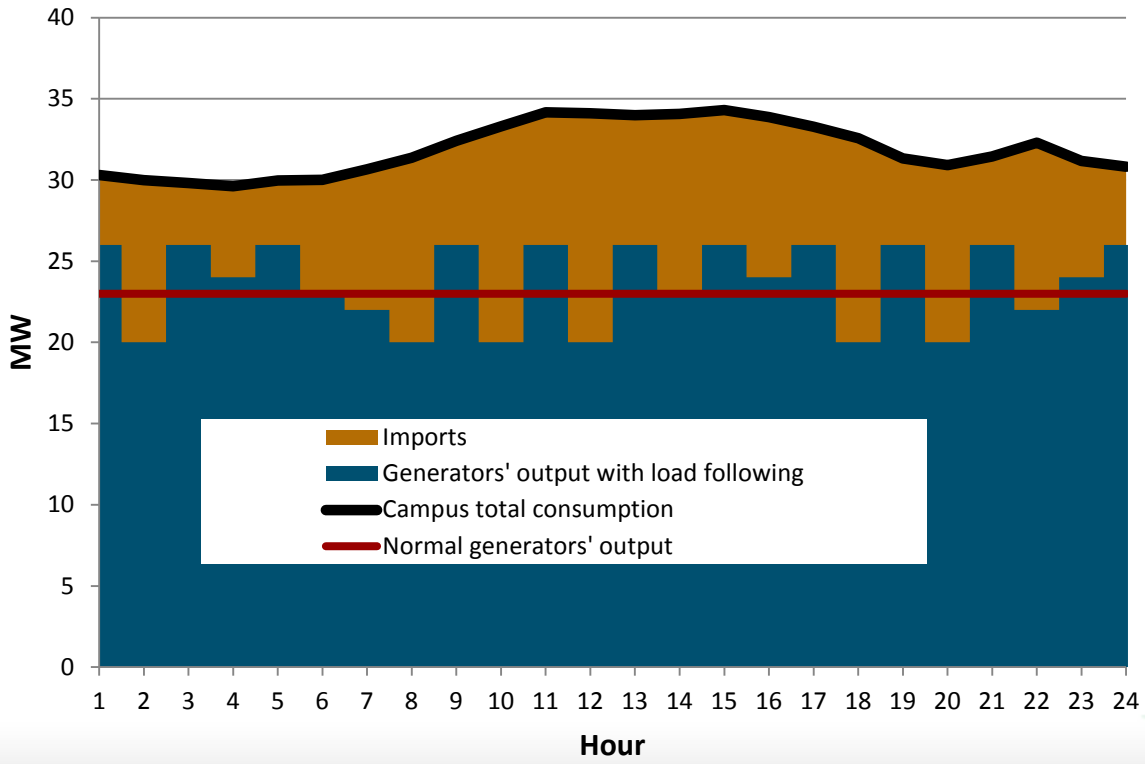
Source: http://energy.ucsd.edu/campus/campus.php

Renewables integration with VPower

- Hypothetical load following scenario using UCSD actual data for 6/7/2011
  - Generators are ramped up and down within their acceptable operating range throughout the day



BASELINING THE CAMPUS RESOURCES

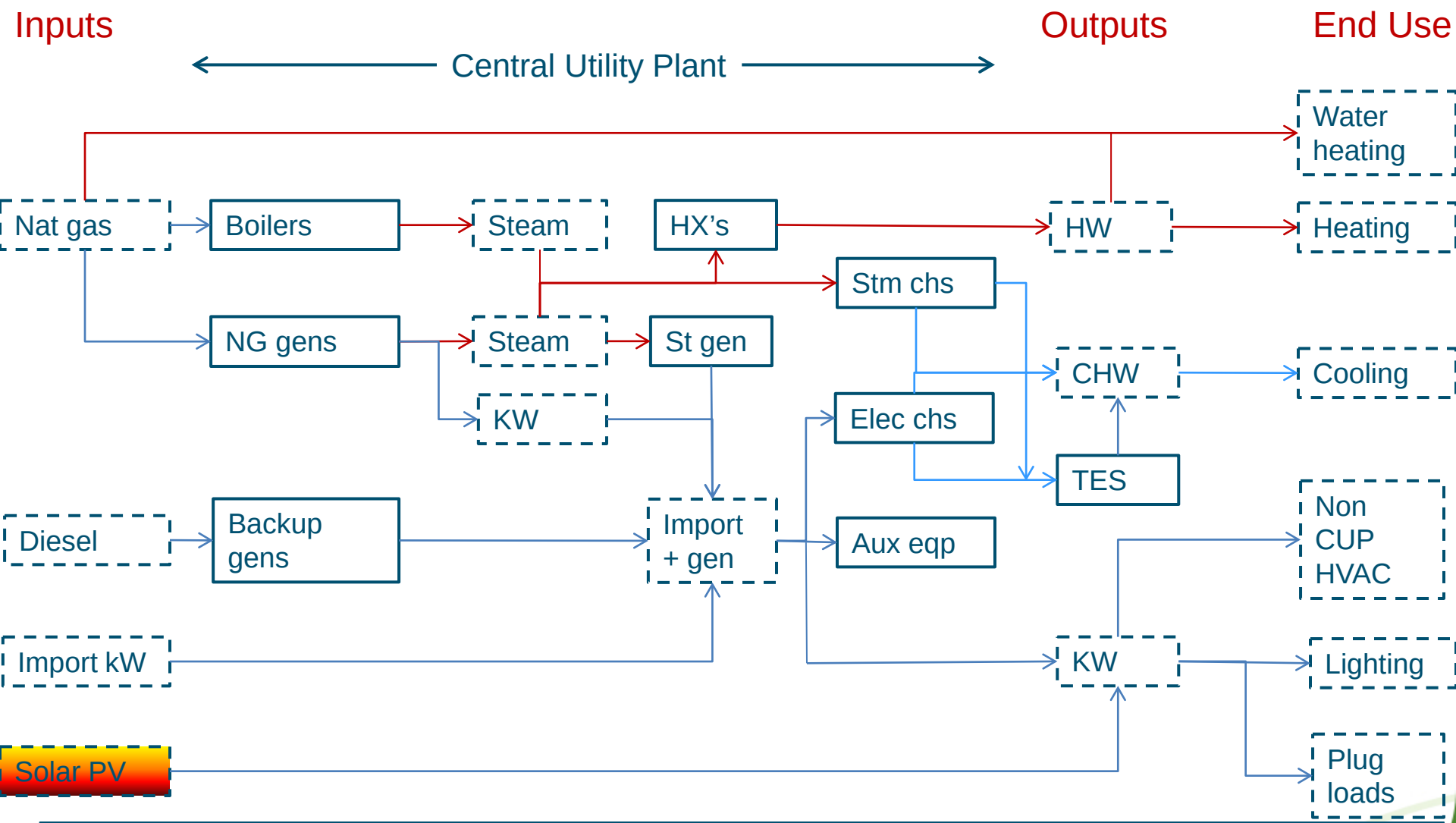
Review of baselining effort

- Overall goals for baselining
  - Understanding thermal & electrical campus needs
  - Quantify efficiencies & understand operating strategies
  - Identify opportunities for operational improvement
  - Validate / calibrate VPower to ensure tool generates plausible operational strategies
- Key questions
  - How do the campus needs vary by hour, season, month?
  - What are the overall system efficiencies (CHP, steam utilization) and equipment-level efficiencies (chillers, generators, etc.)?
  - What are the regular modes of operation of each system?
  - How much capacity is available for changing operations?

UCSD data resources

- Baselining data obtained from multiple sources:
  - MSCADA system: 15-minute power data
  - Johnson Control Metasys System: thermal storage tank data
  - 'BOP' System: steam data for boilers, generators
  - 'Efftrack' chiller diagnostic system: chiller data
  - Daily central plant logs: gas usage
  - UCSD expert knowledge (i.e., John Dilliott, Energy Manager)
  - Solar data from Prof. Jan Kleissl
- Future: disparate data sources will be integrated into a campus-wide data historian

Analytical framework



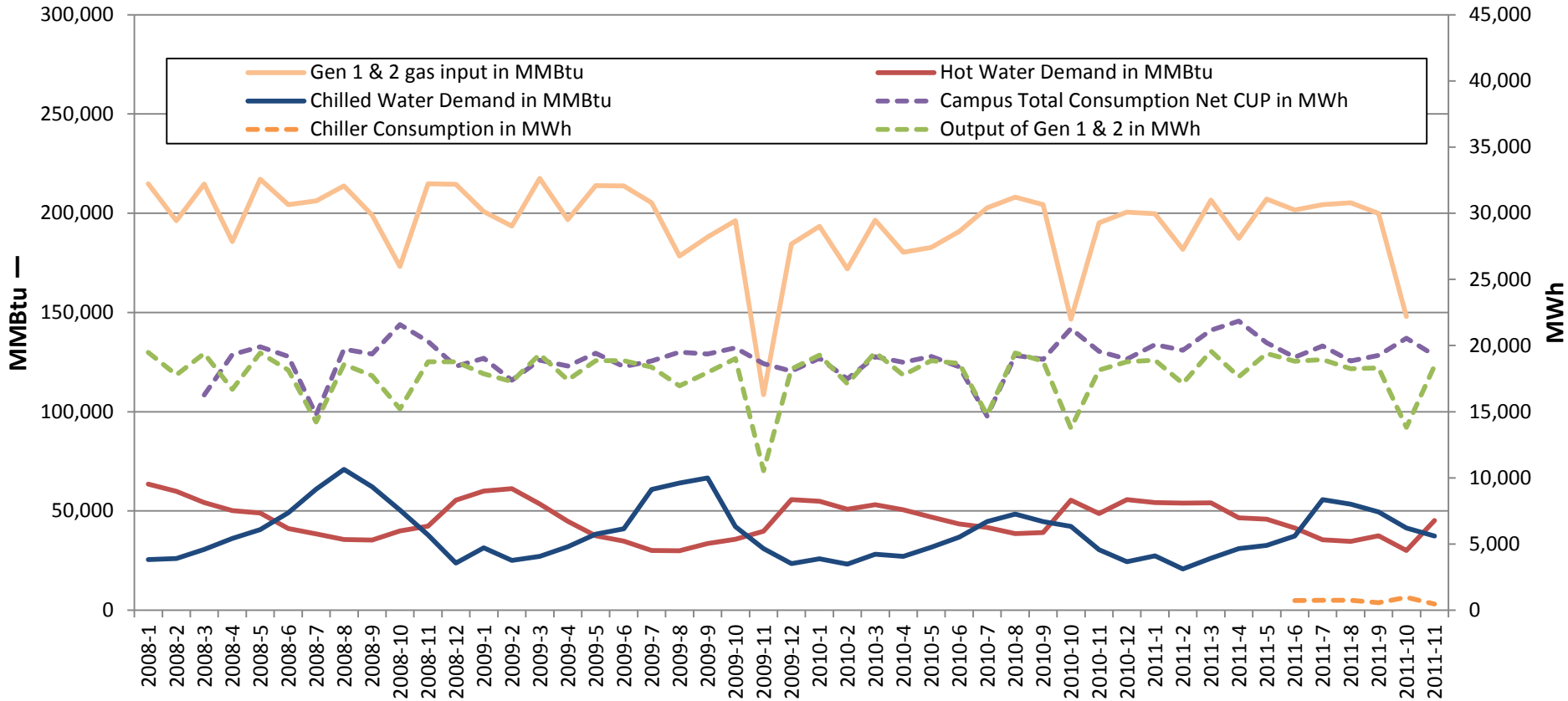
Baseline data gives input / output relationships, equipment efficiency, capacity factors, seasonal and diurnal patterns of usage, historical costs.

Methodology steps

- Collect data
  - **Electrical data:** Imports, central plant generators, chillers, auxiliary, solar
  - **Thermal data:** Chillers, boilers (partial), campus hot water & chilled water needs, thermal storage tank operation, generator fuel
  - Up to 3 years of data collected
- Assemble data
  - To understand system level operation: generate data sets with consistent time stamps to understand inputs/ outputs across the energy flow diagram
  - Quantifying individual operating efficiencies and capacities: all individual equipment data can be used
- Visualize and analyze data
  - Daily, monthly, yearly summaries of main loads
  - Calculate equipment level efficiencies
  - Calculate system level efficiency (overall inputs to outputs)
  - Forecast campus needs based on binning analysis

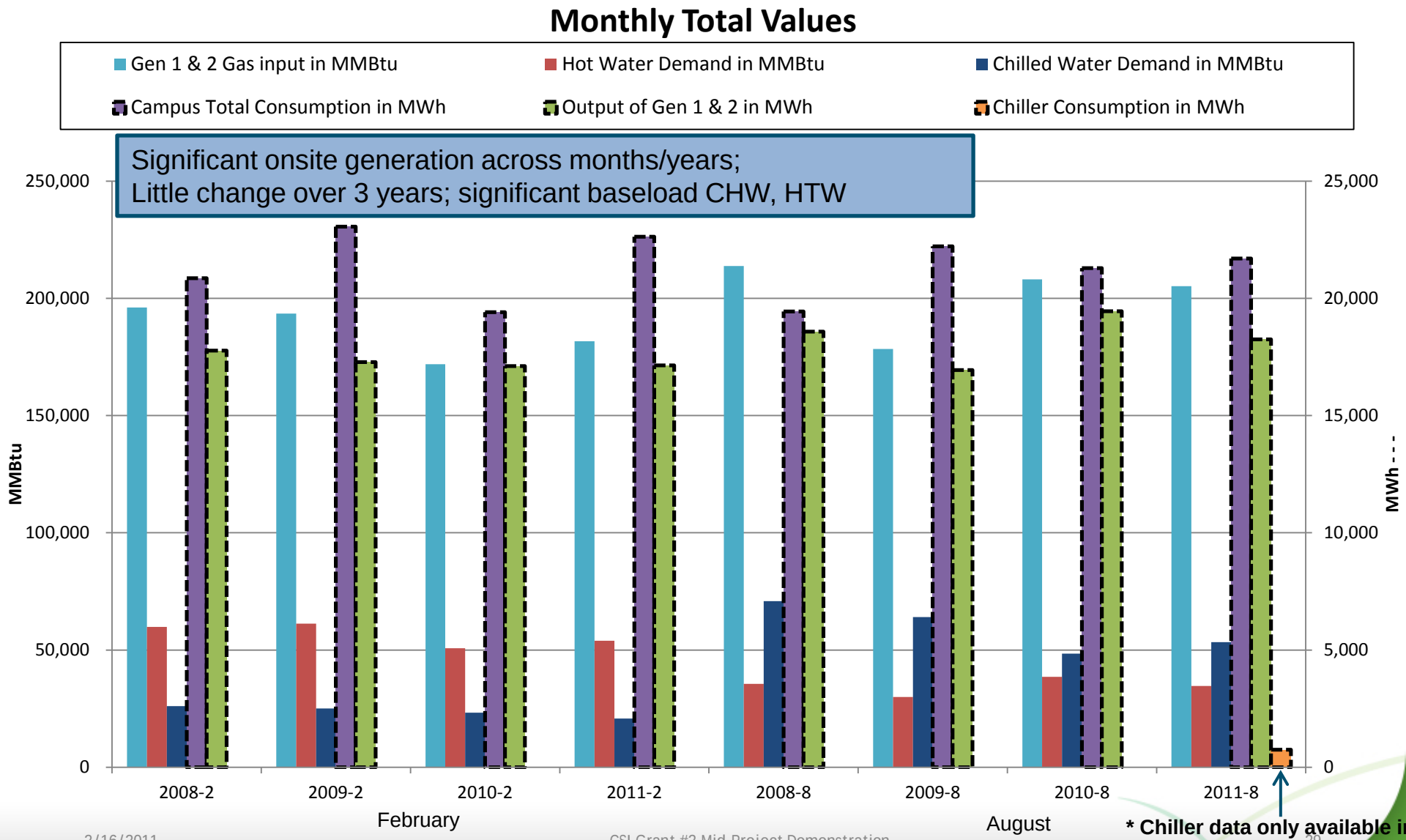
SNAPSHOTS FROM BASELINING EFFORT

Overview of campus needs: timeseries across entire data set



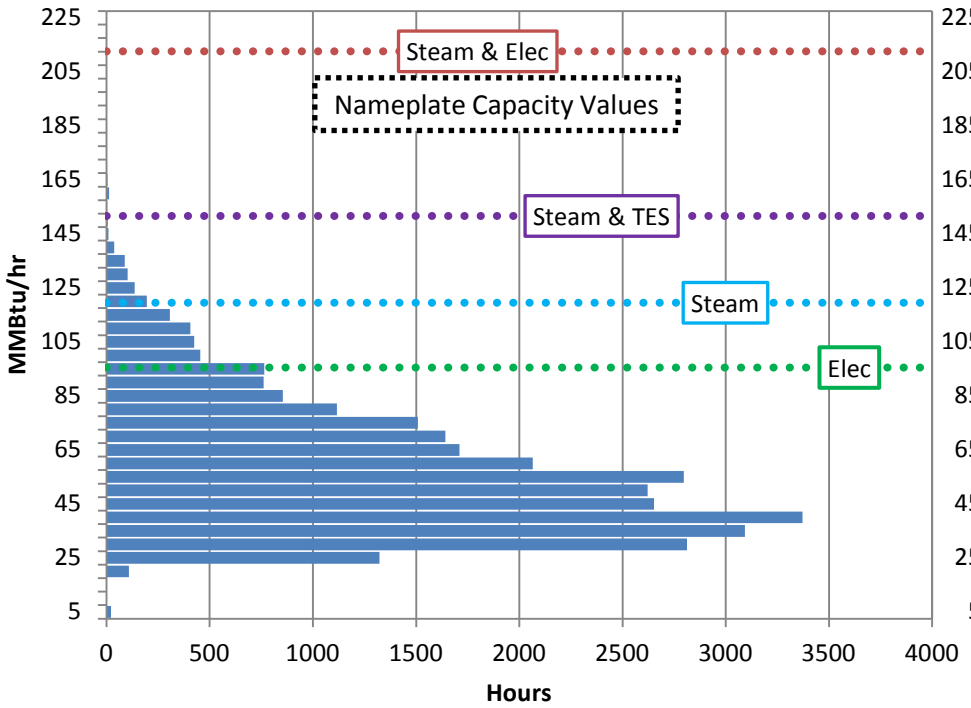
Seasonal dependence of CHW, HTW w/ base requirements; generation satisfies much of total campus needs

Overview of campus needs: comparison of monthly totals

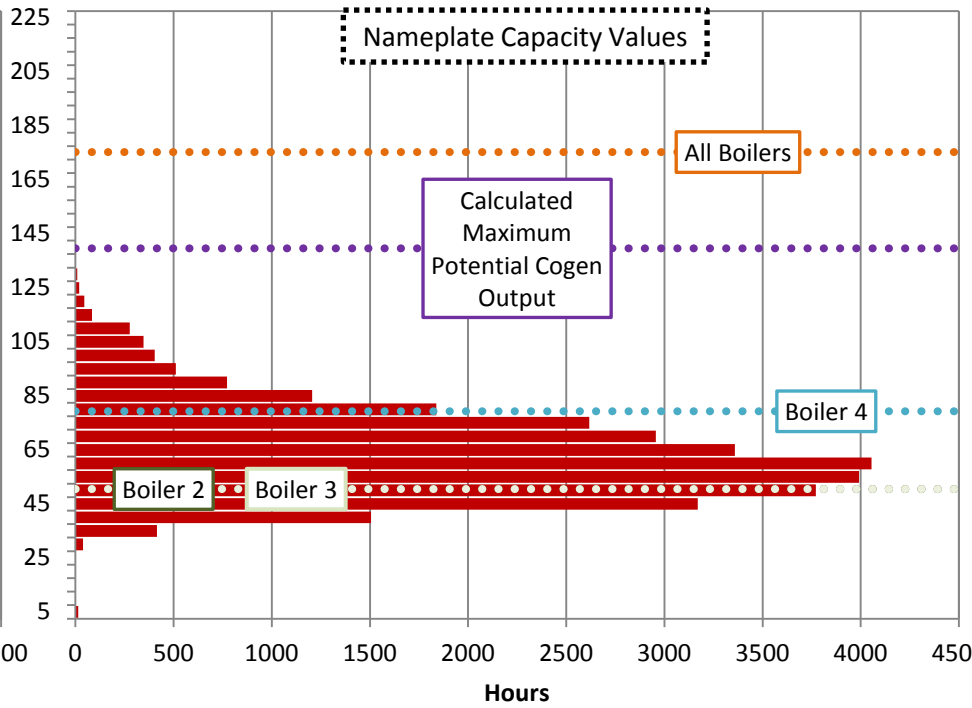


Flexibility in providing campus hot water and chilled water

Histogram of CHW Demand

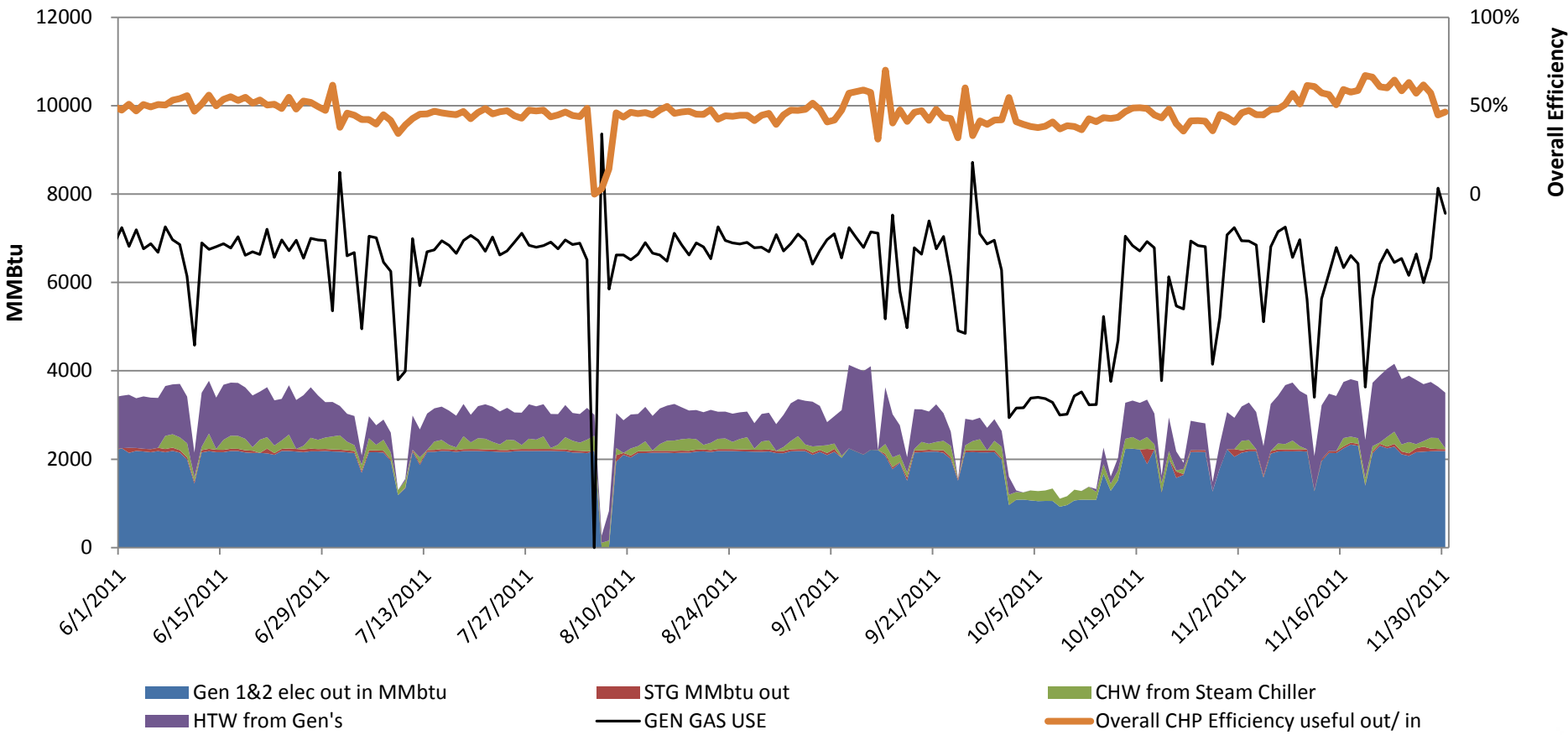


Histogram of HTW Demand



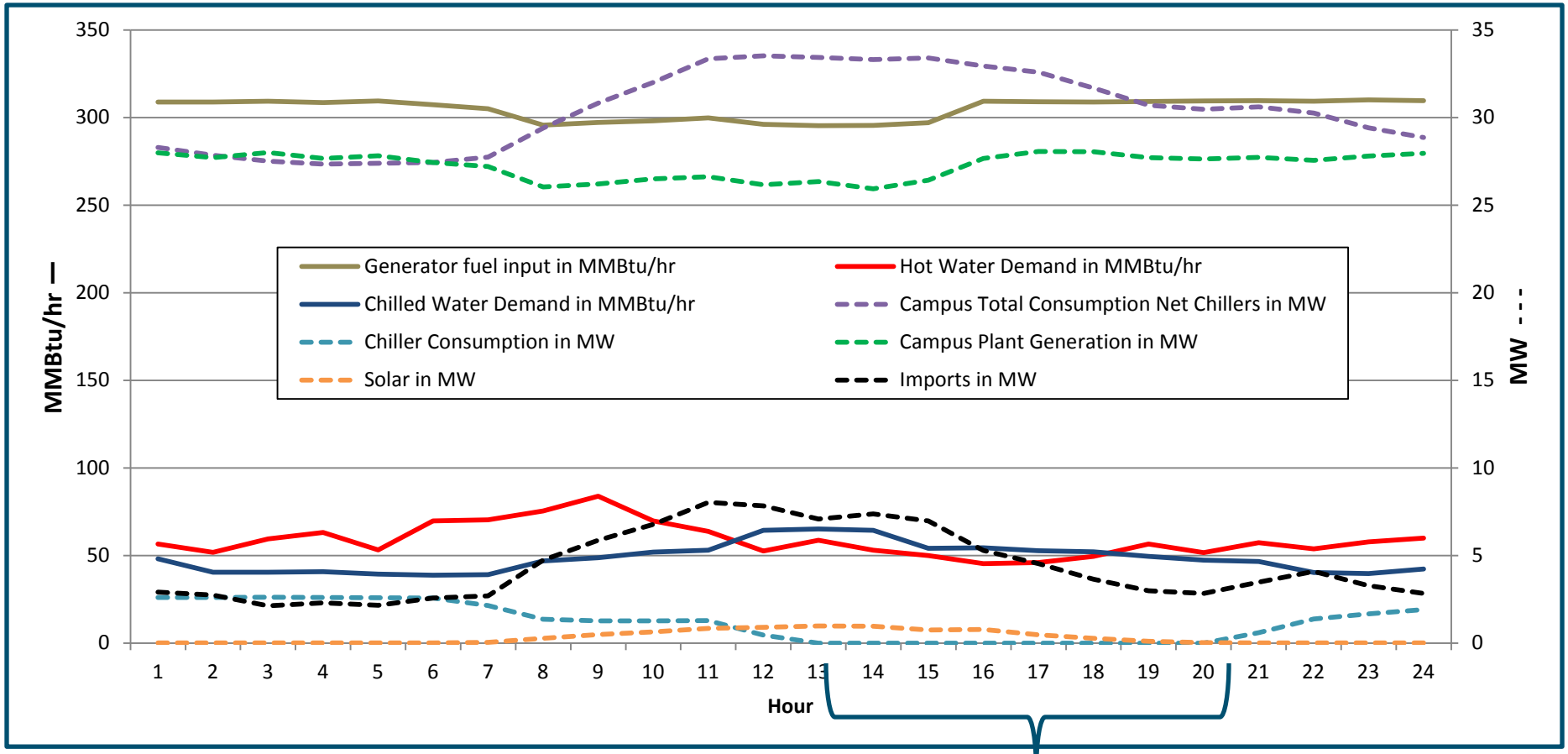
Campus needs can be met amply through existing resources and there is flexibility to meet the need through different combinations

Overall system efficiency



Actual operations: June 7, 2011

Thermal and electrical needs vary over the day but contain significant baseload components (high load factor).



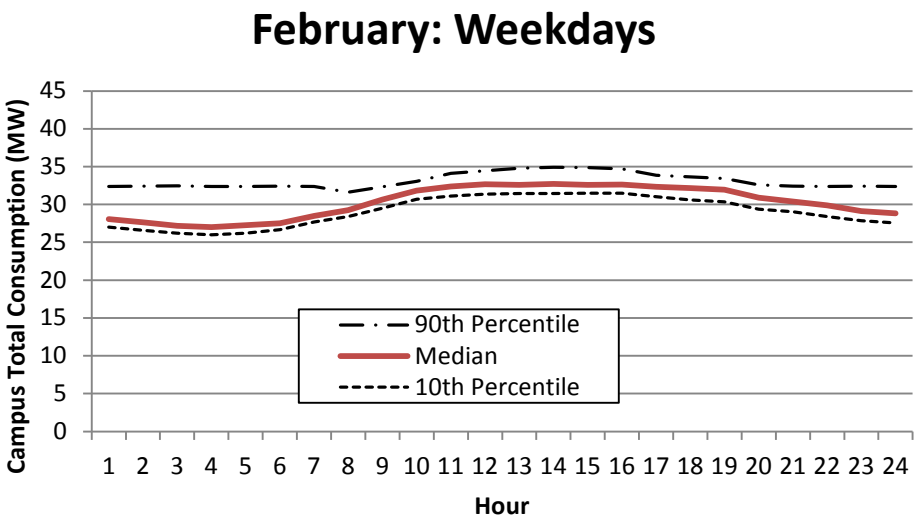
Solar PV output ~ 1 MW

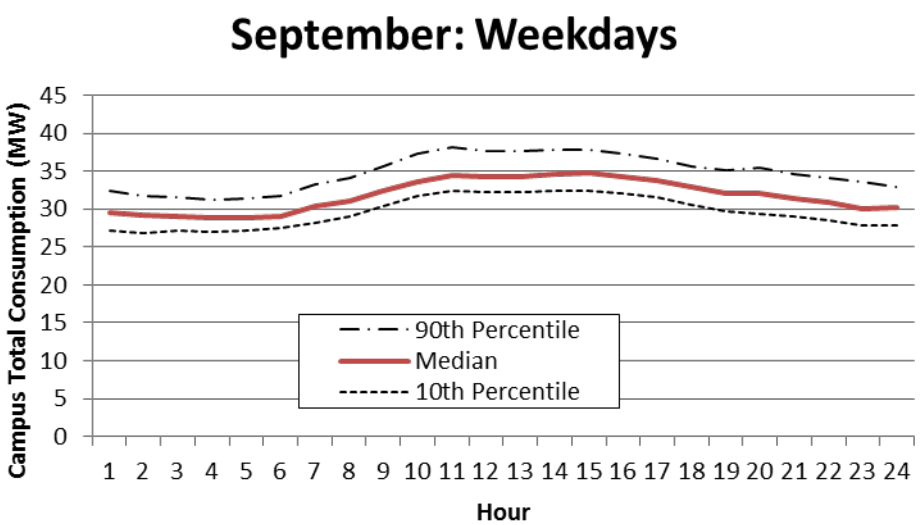
Load shifting from thermal storage lowers electrical chiller consumption

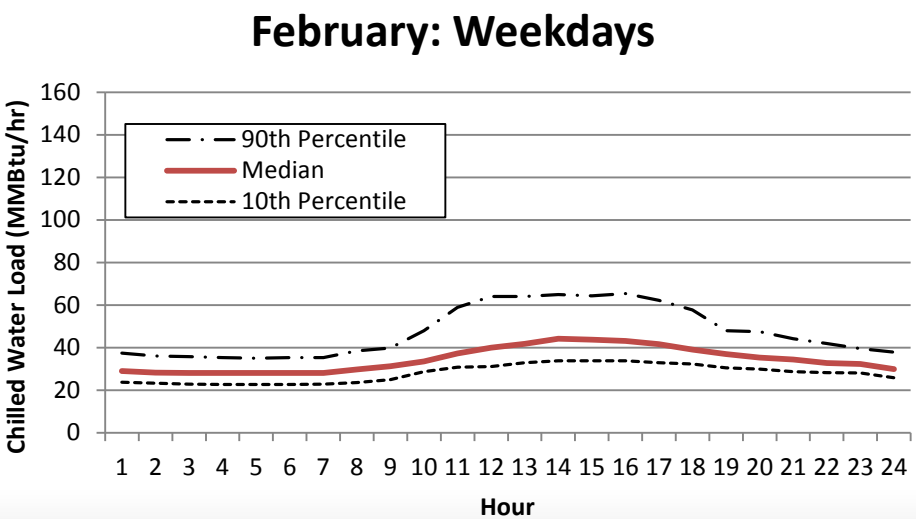
Binning analysis to forecast loads

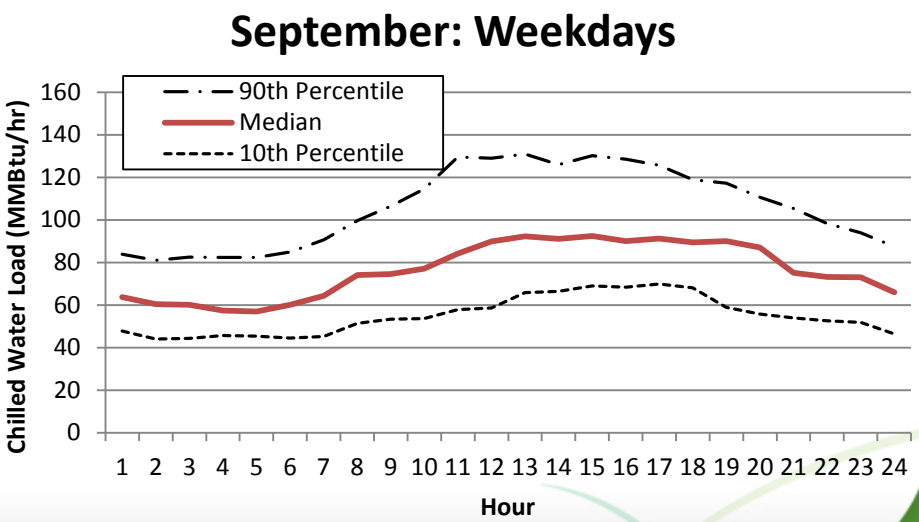
- Analyzed chilled water, hot water, campus power requirements over 3 years
- Preliminary insights:
  - Significant baseload across all hours
  - Seasonal dependence exists but relatively tempered
  - Weekday vs. weekend operation variability small
  - Variability across years exists but not growth related

Snapshot: variation across months









Overall observations

- Majority of operating rules and efficiencies have been validated
- Loads have significant baseload component; variability due to hour, season, year
- Flexibility in resources to meet loads confirmed

PRELIMINARY BUSINESS ANALYSIS

Preliminary business analysis

- How might a microgrid maximize its revenues and reduce costs?
  - Should it run cogen to maximum capacity?
  - How should storage be utilized?
  - How should resources be scheduled including loading order of heat recovery systems?

Scenarios analyzed

- What is the value of controllable UCSD assets in support of high penetration PV and lowering campus costs?
- Spreadsheet model developed to analyze the following scenarios using real UCSD load data
  - Scenario 1: full import
  - Scenario 2: full import + thermal storage tank
  - Scenario 3: cogen (natural gas generators, steam chillers, hot water heat exchanger, steam generator)
    - Conducted sensitivities on 1 vs. 2 generator, steam gen
  - Scenario 4: cogen + thermal storage tank
    - Conducted sensitivities on steam gen

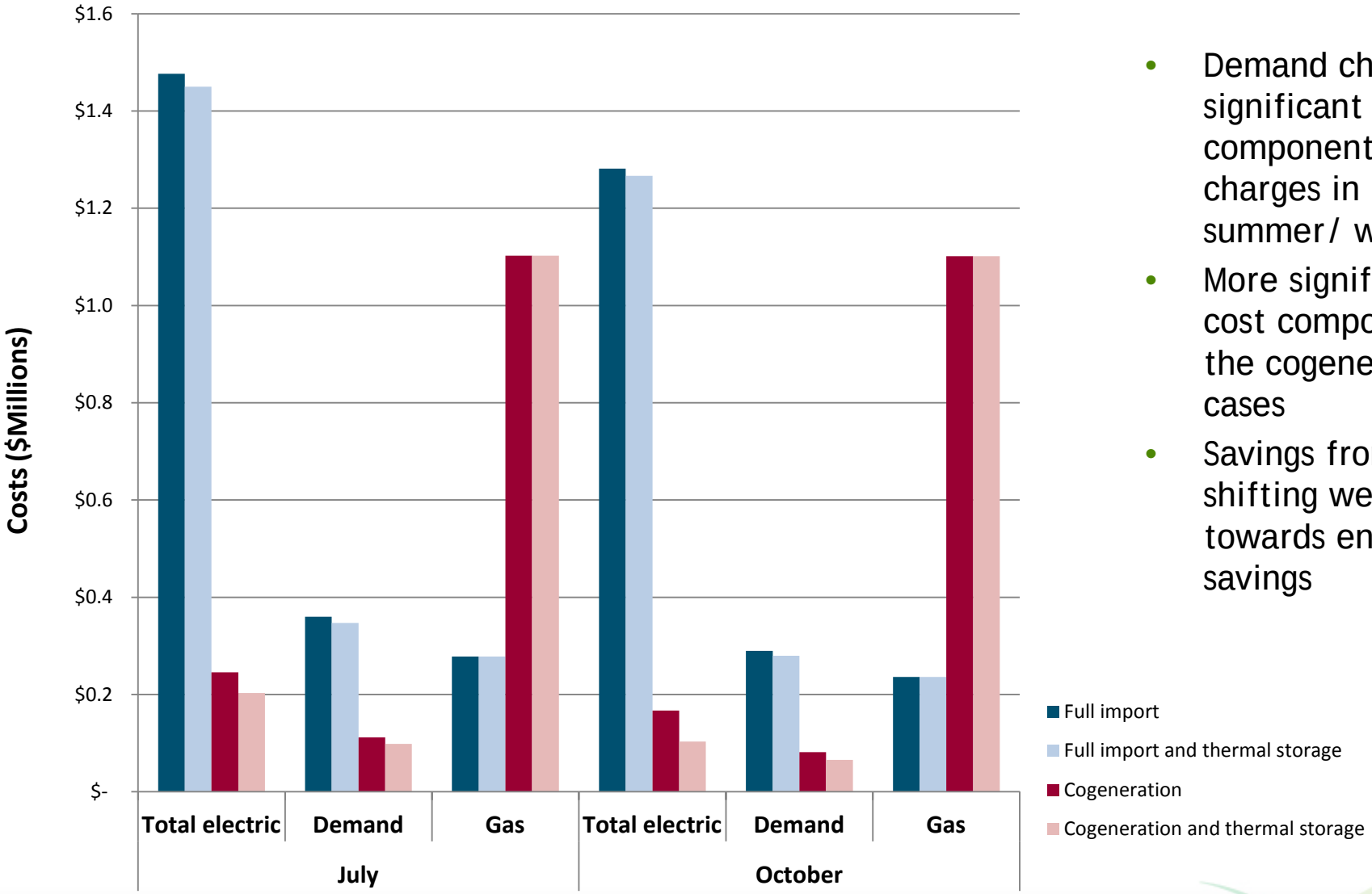
Methodology

- Spreadsheet model developed to analyze the cases using real UCSD load data from June-Oct 2011
  - Consistent with campus thermal and elec needs
  - Loading order consistent with UCSD operations
  - Efficiencies & capacities from baseline effort used

Results of preliminary business analysis:

Estimated energy costs between June 1 and October 31 2011 for the idealized scenarios								
$Millions		Electrical		Gas		Total		Savings
Full import	$	6.8	$	1.3	$	8.1		0%
Full import and thermal storage	$	6.7	$	1.3	$	8.0		1%
Cogeneration	$	1.0	$	5.3	$	6.3		22%
Cogeneration & thermal storage	$	0.8	$	5.3	$	6.1		25%

Breakdown by month and energy/demand charges



- Demand charges significant component of elec charges in both summer/ winter
- More significant cost component in the cogeneration cases
- Savings from load shifting weighted towards energy savings

Insights and opportunities for further optimization

- Preliminary scenario analysis suggests general operating strategy saves campus $
- Baseline and preliminary analysis suggest opportunities for enhancement
  - Tank operation, staging of equipment
- Limitations
  - Analysis performs limited number of sensitivities that assumes an operating scenario (rather than solving for it)
  - Assumes perfect foresight of campus needs
  - To manage the complexity of the problem space, a realtime optimization tool is beneficial --- > VPower

MASTER CONTROLLER

Microgrid controller

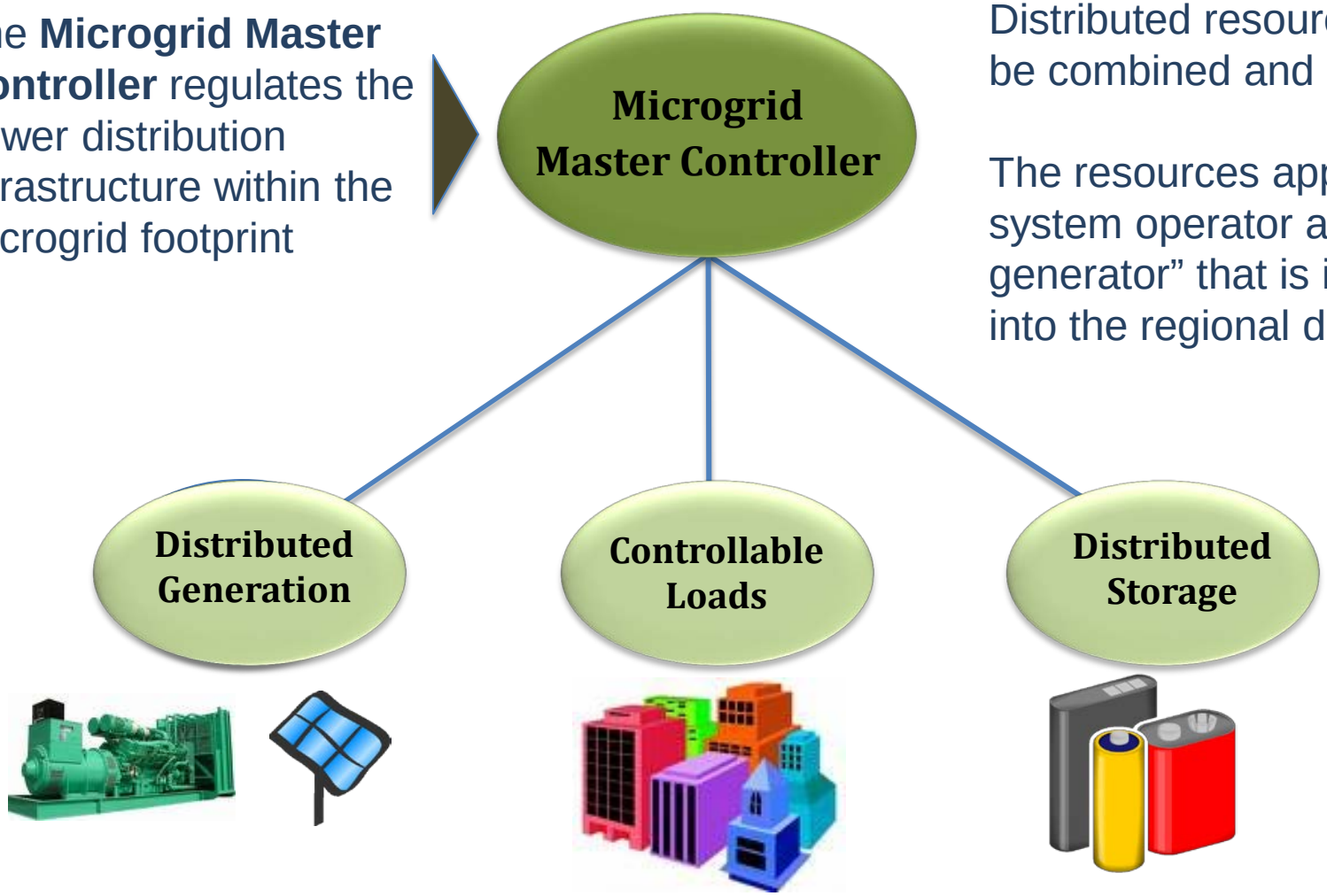
- Making load elastic/controllable/price-responsive is facilitated through decentralized 'microgrid' control.
- Improving microgrid control:
  - can help with transmission congestion constraints
  - can improve load participation in DR programs or energy markets (in some cases through load control which looks a virtual generator to the wholesale market)
  - can improve grid utilization through the integration of distributed energy generation, including intermittent renewables
- Typical microgrid control:
  - includes real-time monitoring and control of resources (SCADA)
  - advanced analytics to perform load flow analysis and optimization
  - interaction with the electric power markets

Microgrids include a "central nervous system" that directs the operations of distributed resources

The **Microgrid Master Controller** regulates the power distribution infrastructure within the microgrid footprint

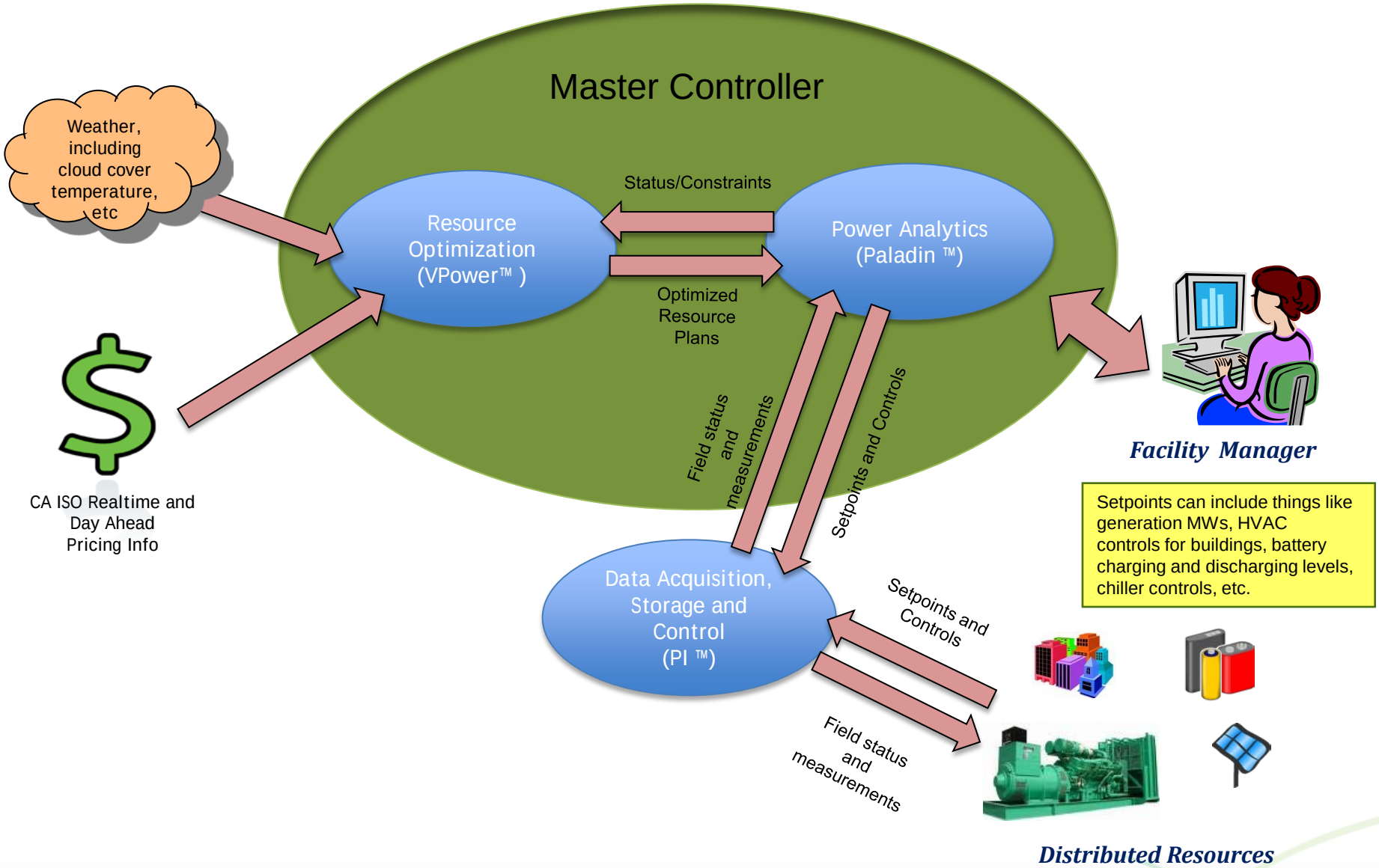
Distributed resources need to be combined and optimized

The resources appear to the system operator as a "virtual generator" that is integrated into the regional dispatch

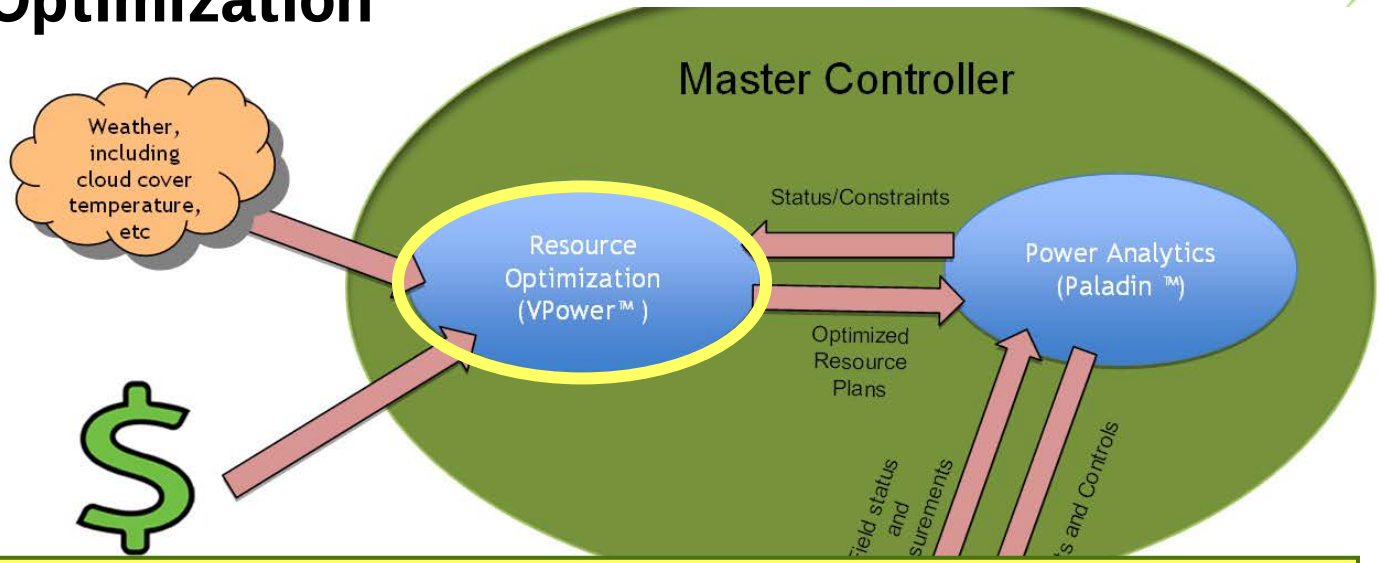


Distributed Resources

UCSD Master Controller

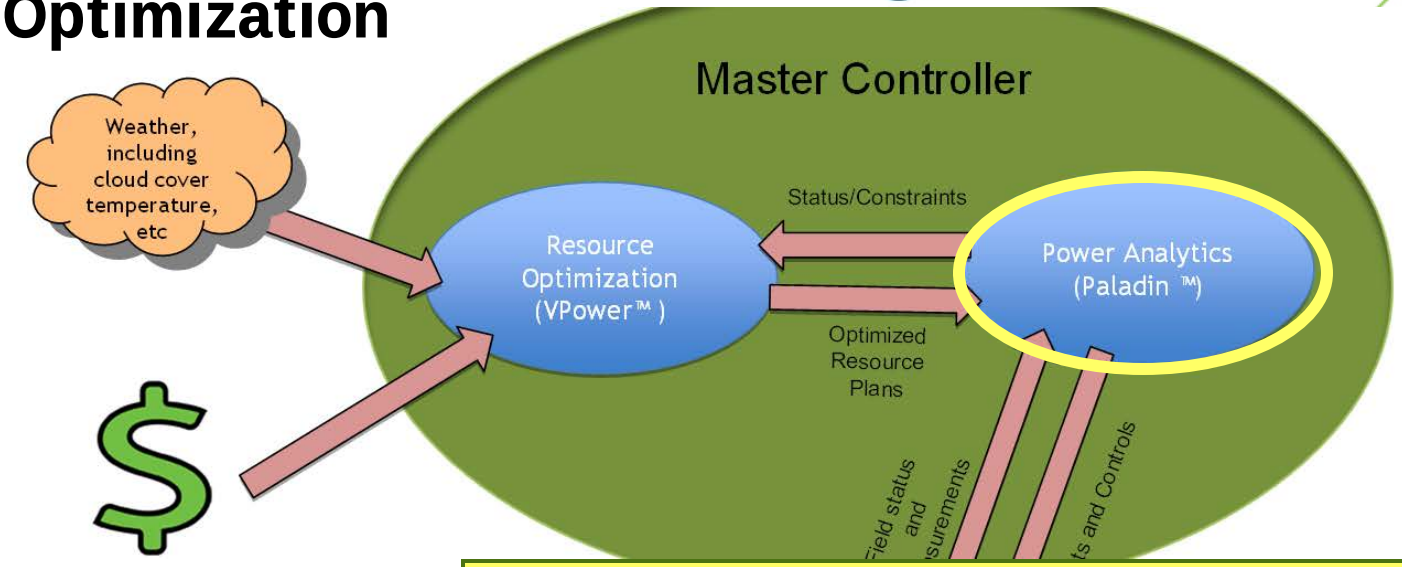


Master Controller: VPower Optimization



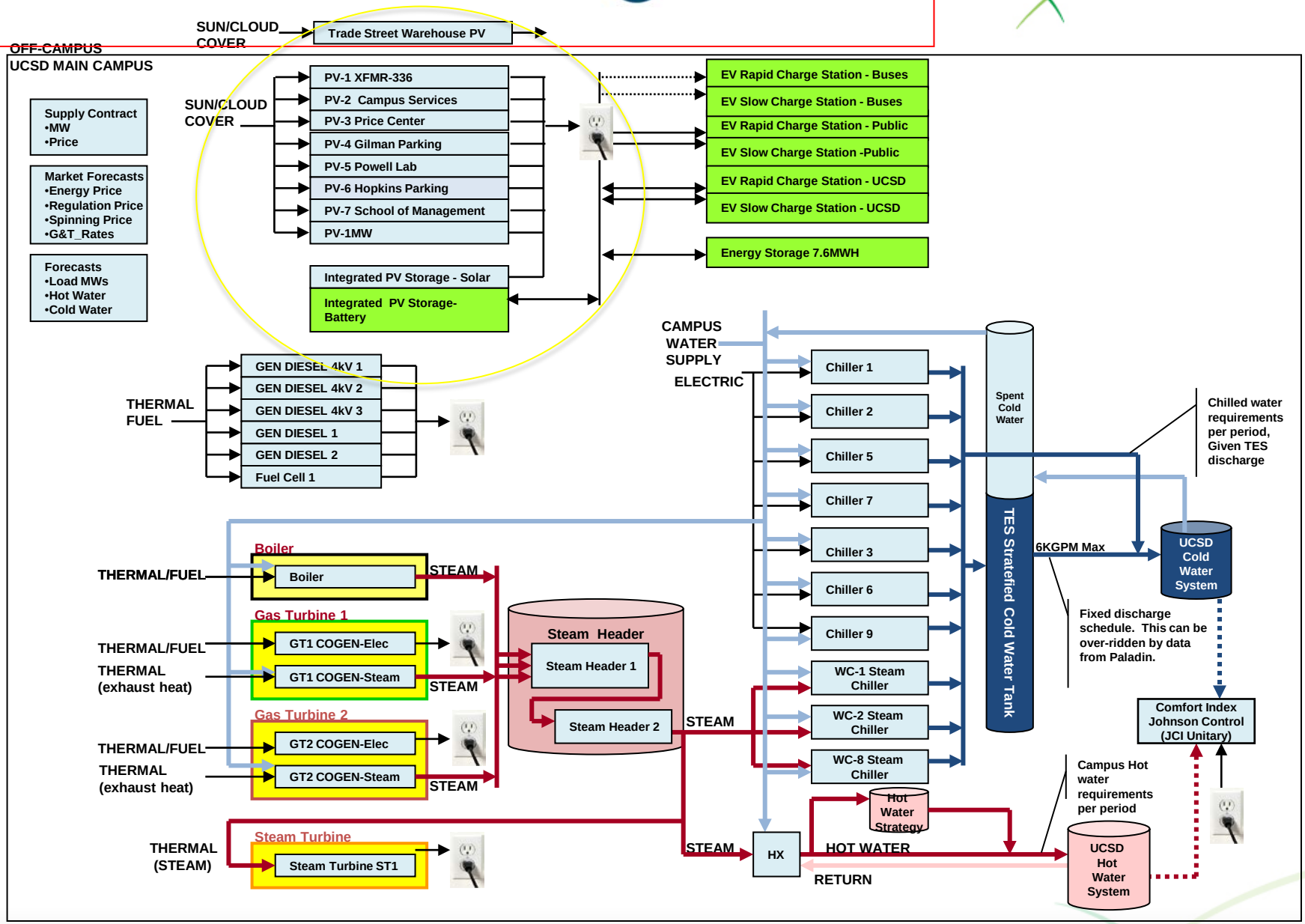
- VPower resource models include
  - Electric (including renewables like solar) and steam generators
  - Chillers and heat exchangers
  - Electric and thermal storage devices
  - Fixed and interruptible load
- VPower study cases are prepared with
  - Resource parameters and efficiency rates
  - Period-by-period operator-entered over-rides (if desired)
  - Electrical and thermal (hot/chilled water) requirements
  - RT or DA electric energy price data from CAISO
  - Weather forecasts
- Economically optimized cases schedule the resource output (MMBTU and MW) to minimize costs subject or maximize revenues while meeting thermal and energy requirements.
- Each day, multiple cases can be prepared to investigate the impact of various inputs, scenarios, etc.

Master Controller: VPower Optimization



- The Master Controller handles the data exchange between VPower and Paladin.
- It passes VPower's economically optimized schedules to Paladin where they are checked for reliability.
- Paladin models the electric network in detail, and determines if the feeder and equipment energy flows are within their appropriate ratings.
- Paladin notifies VPower if any schedule modifications are needed for microgrid reliability, including optimization constraints to be included.

VPower Model of UCSD Resources



Dispatchable Virtual Generation

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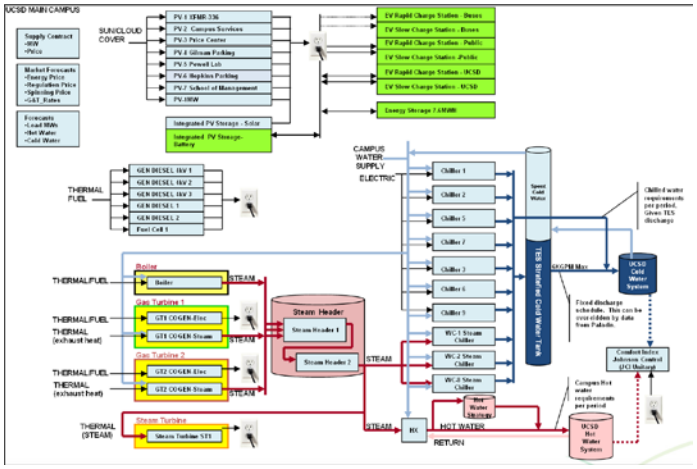
External perspective
(Energy market or utility)

~ Dispatchable virtual generator

High level microgrid model

Inelastic Consumption | Controllable Consumption | Generation resources

Detailed microgrid model



VPOWER DEMONSTRATION

VPower Live Demo

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admin Account Logout

Client: *University of California at San Diego* **Location:** *UCSD Main Campus* Change Location

RTO: *CAISO* **Weather Location:** *KSAN* **Price Location:** *UCSD_PRICE*

Operations Case Management Administration Resource Model

Resource Model - Generators

Fueled Generators | Fueled Generator Defaults | Renewable Generator | Renewable Generator Defaults

Create Fueled Generator

Show/Hide Columns

ID	Name	Emission Rate (lb/fuel)	Fuel Consumption Rate (fuel/MWh)	Incremental Cost ($/MWh)	Min Down time (hr)	Min
16	Fuel_Cell_1	0.00	45.00	25.00	0.0	
14	GEN-DIESEL-1	2.50	16.92	45.00	0.0	
15	GEN-DIESEL-2	2.50	16.92	45.00	0.0	
11	GEN-DIESEL4kV-1	2.50	25.38	45.00	0.0	
12	GEN-DIESEL4kV-2	2.50	25.38	45.00	0.0	
13	GEN-DIESEL4kV-3	2.50	25.38	45.00	0.0	
8	GT1_COGEN_El	2.50	11 000.00	190.00	6.0	
9	GT2_COGEN_El	2.50	11 000.00	190.00	6.0	
10	Steam_Turbine_	0.00	14.00	150.00	0.0	

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Client: *University of California at San Diego*

RTO: *CAISO* **Weather Location:** *KSAN*

Operations Case Management Administration Resource Model

Resource Model - Generators

Fueled Generators | Fueled Generator Defaults | Renewable Generator | Renewable Generator Defaults

Select Fueled Generator: GT1_COGEN_Elec

Save Cancel

Period Ending	Fixed Mode	Fixed Generation MW	Availability	Min Generation Capacity	Max Generation Capacity
01:00	0	0.000	1.00	0.000	13.500
02:00	0	0.000	1.00	0.000	13.500
03:00	0	0.000	1.00	0.000	13.500
04:00	0	0.000	1.00	0.000	13.500
05:00	0	0.000	1.00	0.000	13.500
06:00	0	0.000	1.00	0.000	13.500
07:00	0	0.000	1.00	0.000	13.500
08:00	0	0.000	1.00	0.000	13.500
09:00	0	0.000	1.00	0.000	13.500
10:00	0	0.000	1.00	0.000	13.500
11:00	0	0.000	1.00	0.000	13.500

UCSD OPTIMIZATION STRATEGIES

Optimization Strategies and Next Steps

- Short term: tuning VPower models
  - Detailed comparison between baseline data and VPower results
    - Cases: supply from grid; grid+elec from GTs; grid+GT including steam; add-in TES tank, etc. for peak days, typical days, etc.
- Mid term: When tuning is complete, use VPower to assess UCSD microgrid impact and opportunities
  - Post analysis of operations (what would have been the best schedule?)
  - Analyzing operational rules or control actions
    - Best periods for interrupting load?
    - Best time to charge thermal electrical storage tank
    - Suggested Electric Vehicle charging schedules
    - When to shift electric and thermal usage to reduce costs, or maximize revenues
  - Determination of the value of supply contracts
  - Analyzing tariff changes or potential DR agreements/programs
- Mid to Longer Term: Further involve UCSD operations staff using the Master Controller
  - Review predicted results with actual results
  - Monitor data collected in central repository and verify efficiencies
  - Support energy market opportunities and benefits

PROJECT DISCOVERIES

Project Discoveries

Data Gathering and Preparation Takes Time

Real-time Controls

Good working relationship with the end user is important

Demand Charges

Security – Physical and Cyber

Model Complexity

Interoperability between systems

NEXT STEPS

Distributed *Firm & Flexible* Resources

Energy+Environmental Economics

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Customer

- Improve power quality
- Reduce trips/faults
- Reduce frequency and duration of outages

Distribution

- Prevent Islanding
- Prevent reverse flow
- Reduce Volt/VAR fluctuation
- Manage uncertain interactions
- Decrease O&M

Smart Grid

System

- Provide frequency regulation

Flex

- Reduce load & generation forecast error
- Provide
  - Fast ramp (MW/min)
  - Load following
  - Load for overgeneration

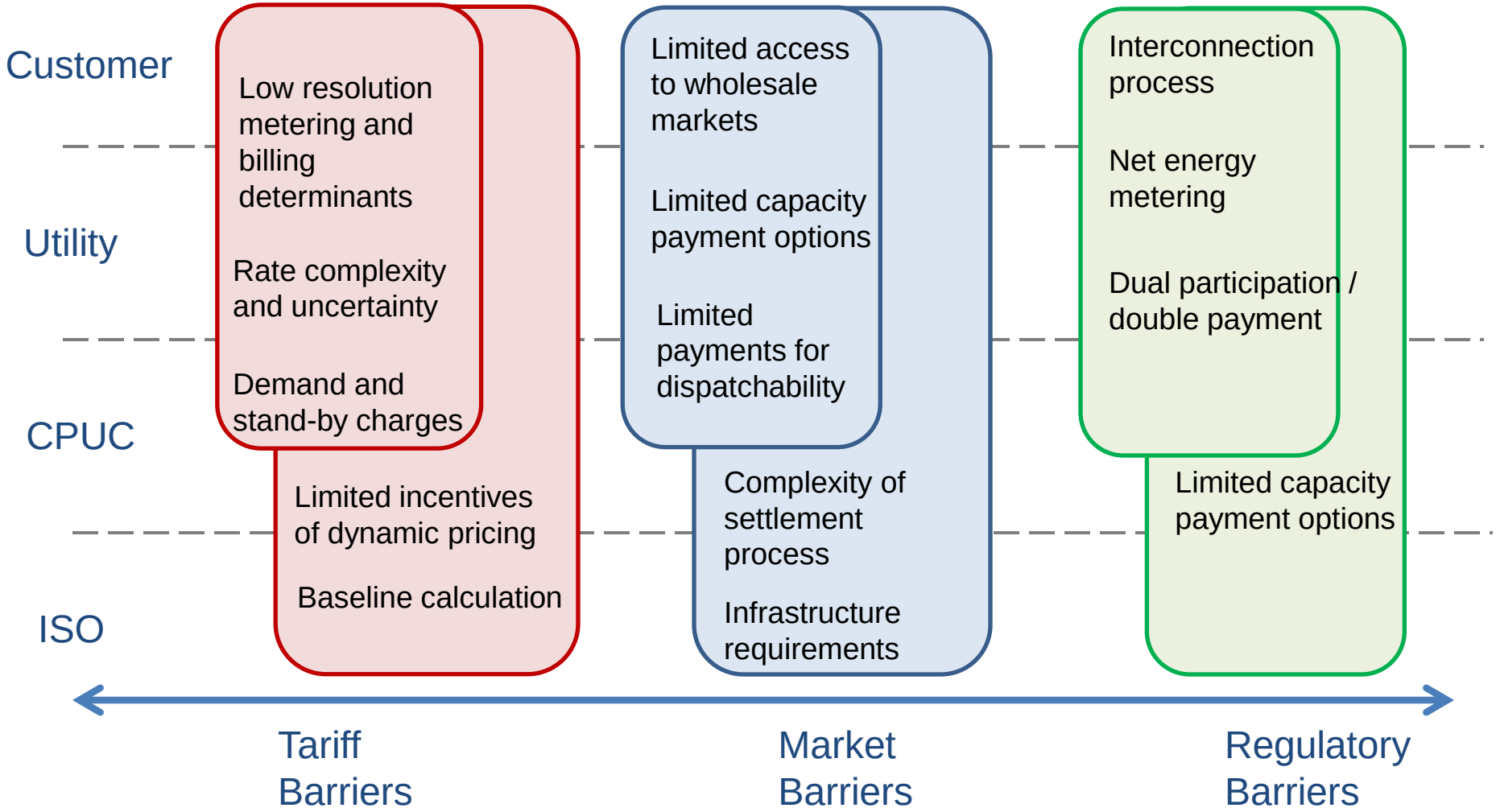
Firm

- Bill reduction
- Risk reduction (financial)
- Demonstrate physical assurance
- Reduce interconnection cost
- Provide firm/predictable resource
- Increased equipment life
- Provide firm/predictable resource for:
  - system peak load (RA/ NQC)
  - N-1 contingencies (NERC)

< 5 min | **20 min** | **1 hr** | **1 day** | **1 year**

Focus on flexibility and capacity value of distributed resources

Address Tariff, Market and Regulatory Barriers



Address some (but not all) barriers to interconnection of distributed resoruces

Innovative Business Models

Incentives	Reason

• Two-part rates
  • Demand Subscription
  • Firm Service Level
	• Allows greater flexibility in designing incentives and recovering fixed revenue requirement

• Scheduled Load
  • Provide load schedule
  • Allow re-schedule by utility/ISO
	• Provide generation/load balancing

• Incentives for flexibility/dispatchability • Load Participation	• Emphasis on high value benefits that are not currently captured.

Dynamic Pricing and Load Participation are not sufficient for renewable integration or grid support

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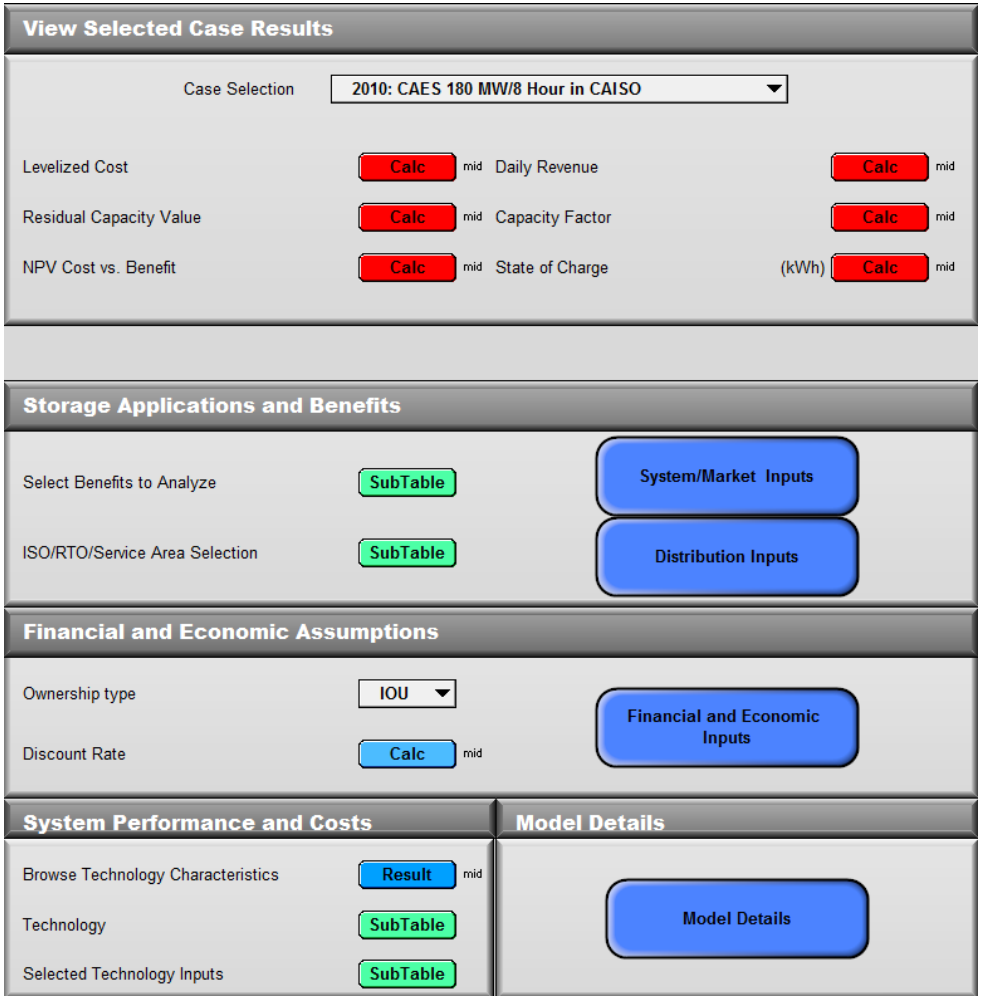
Cost-Benefit Analysis Tool



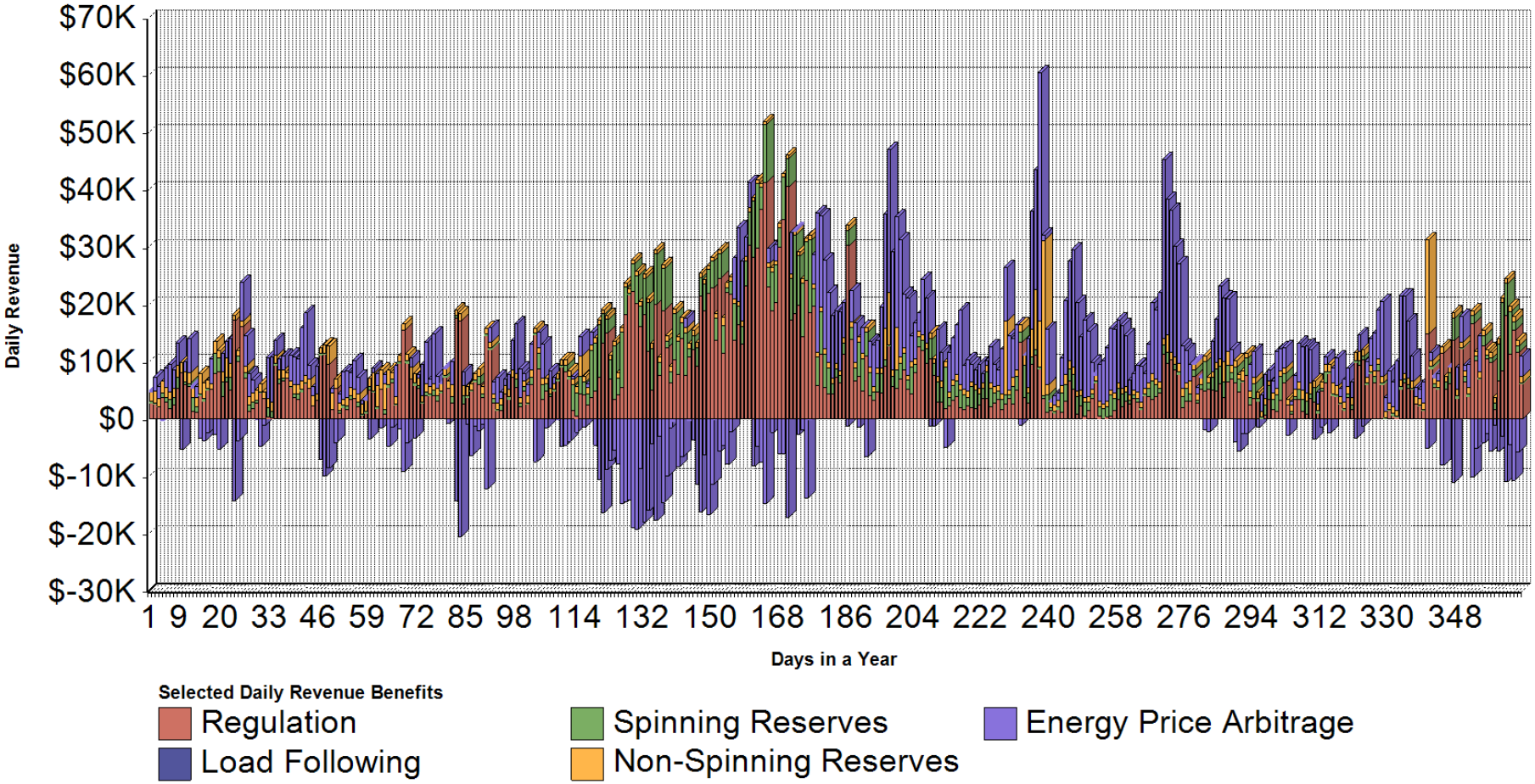
Web Based Demonstration Model

http://www.ethree.com/public_projects/energy_storage_cost_effectiveness_evaluation.php

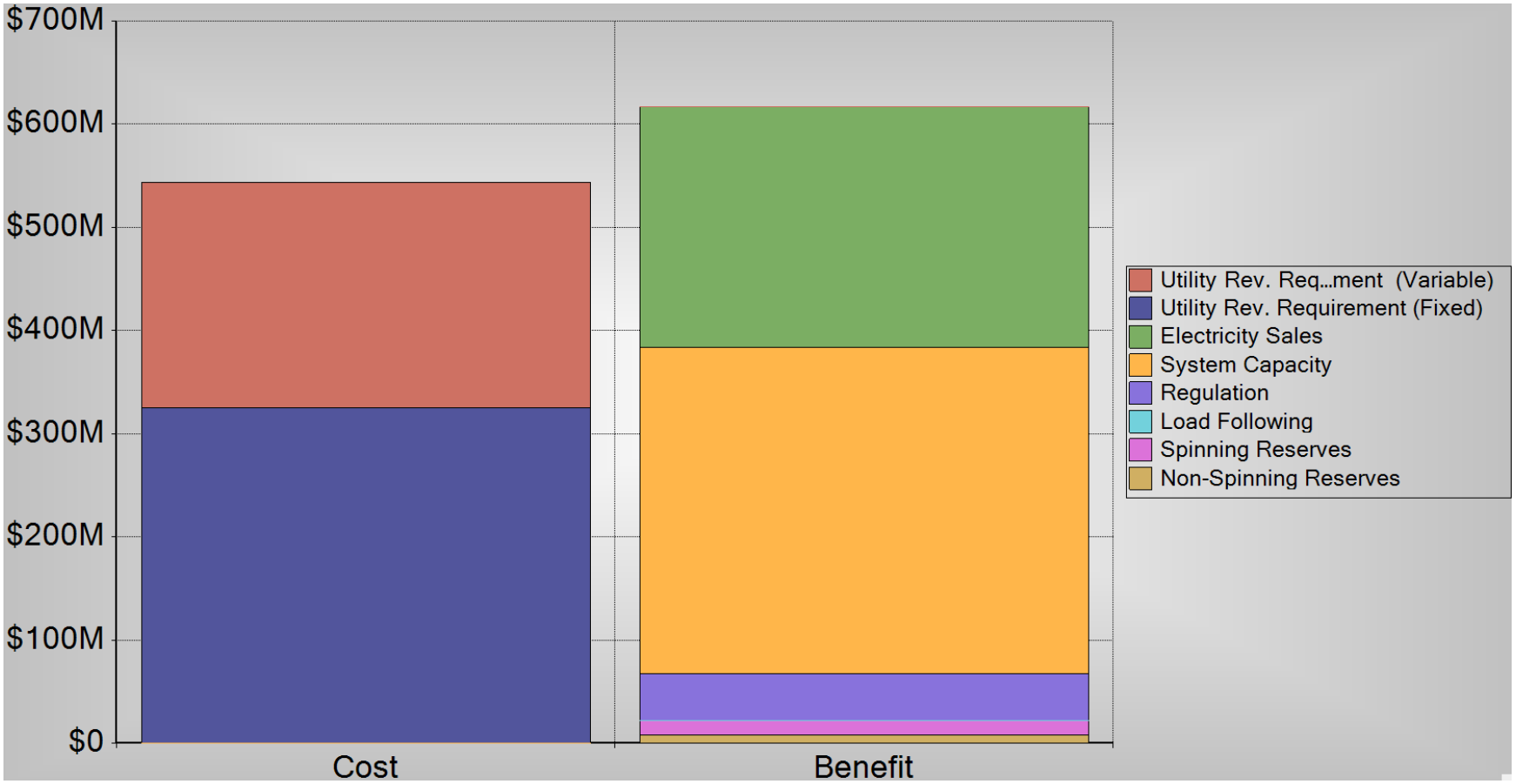
http://goo.gl/kYNpv

(Will be available February 17, 2012)

Daily Revenue by Benefit/Market



Present Value Cost/Benefit Comparision



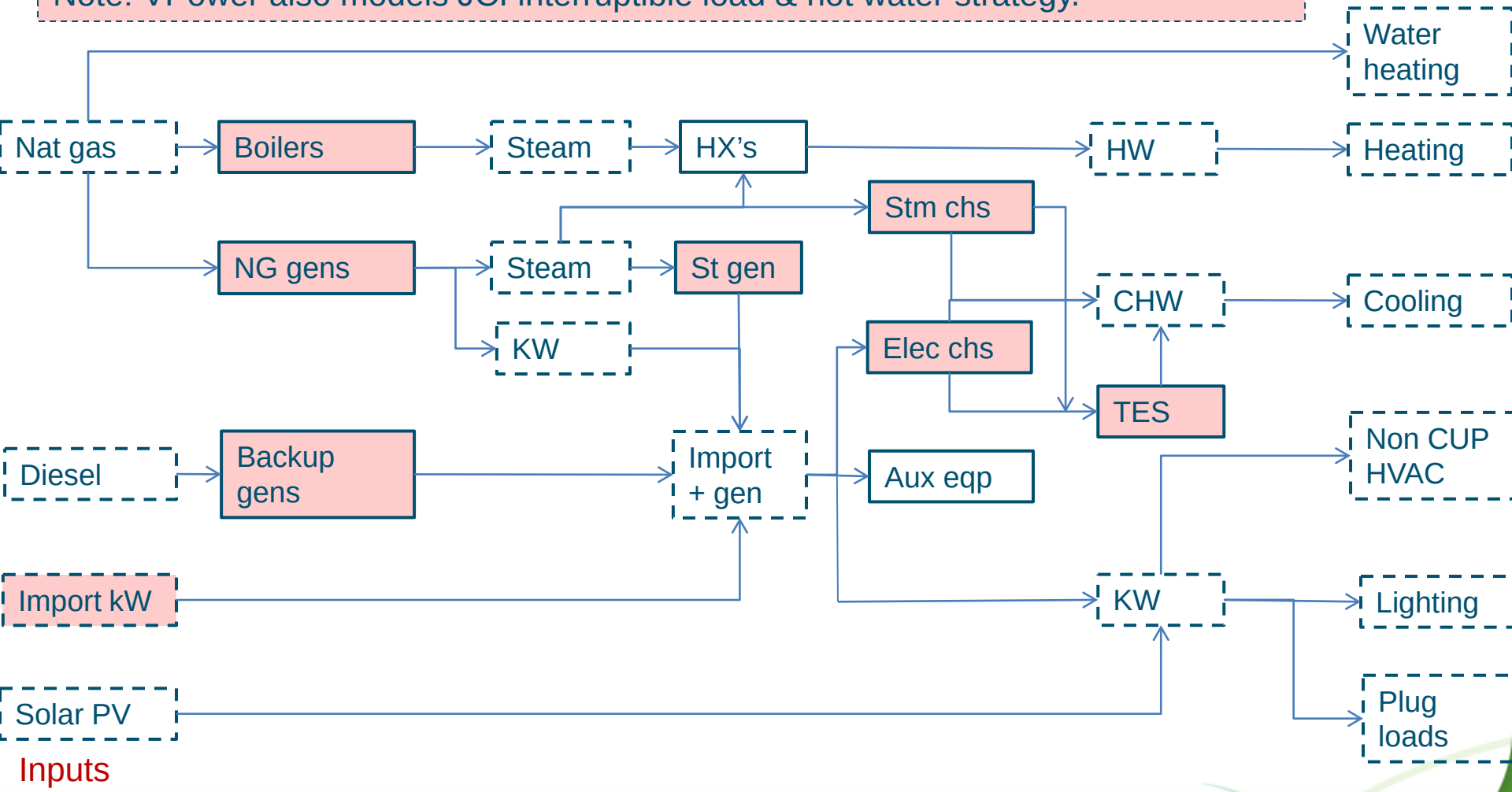
QUESTIONS

THANK YOU FOR PARTICIPATING

APPENDIX SLIDES: BASELINING AND PRELIMINARY ANALYSIS

Resources VPower will optimize

Denotes resources for which schedules will be optimized by VPower
Note: VPower also models JCI interruptible load & hot water strategy.

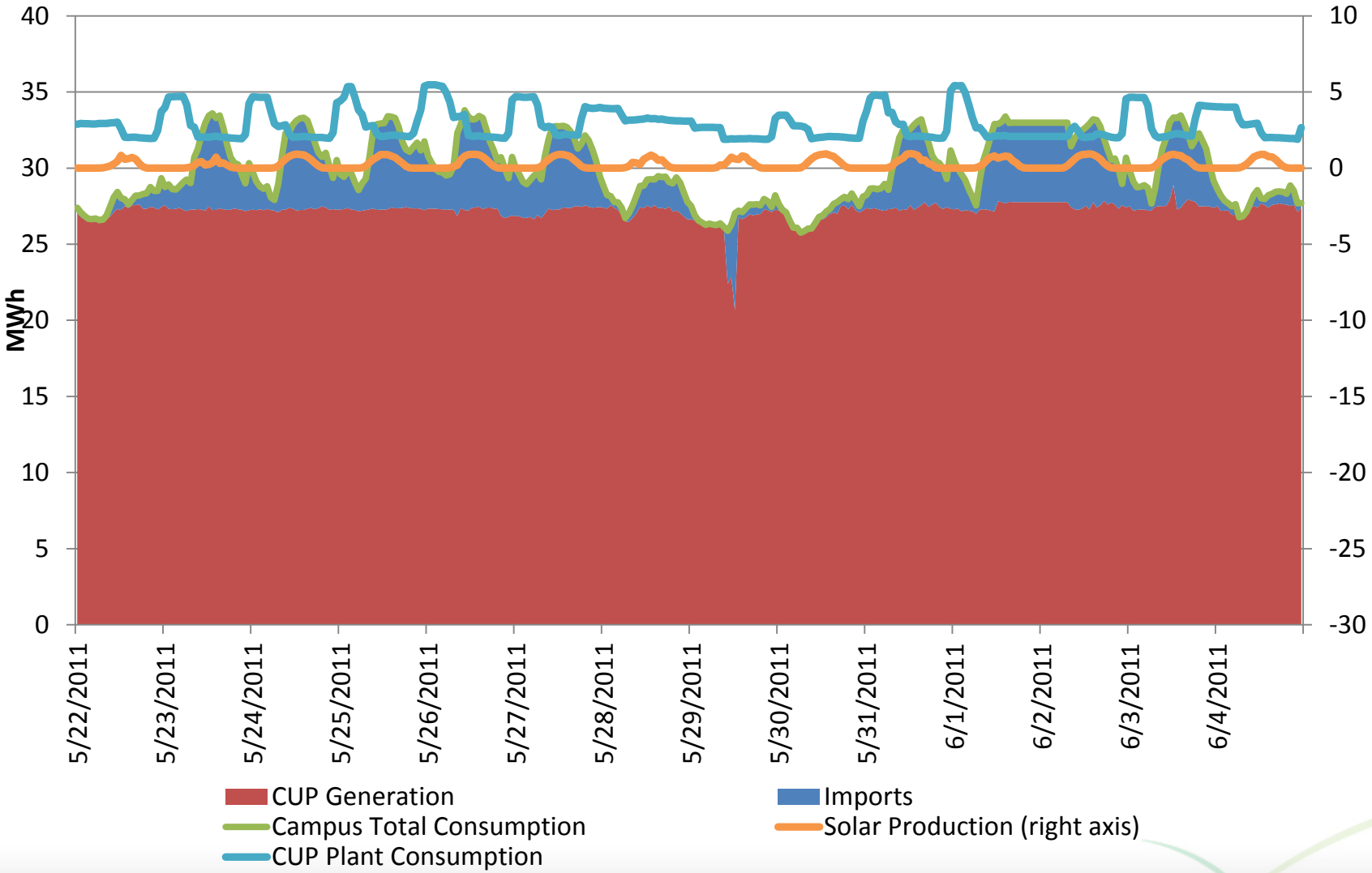


Services that VPower will treat as constant: CUP CHW, CUP HW, kW net CUP electric chillers

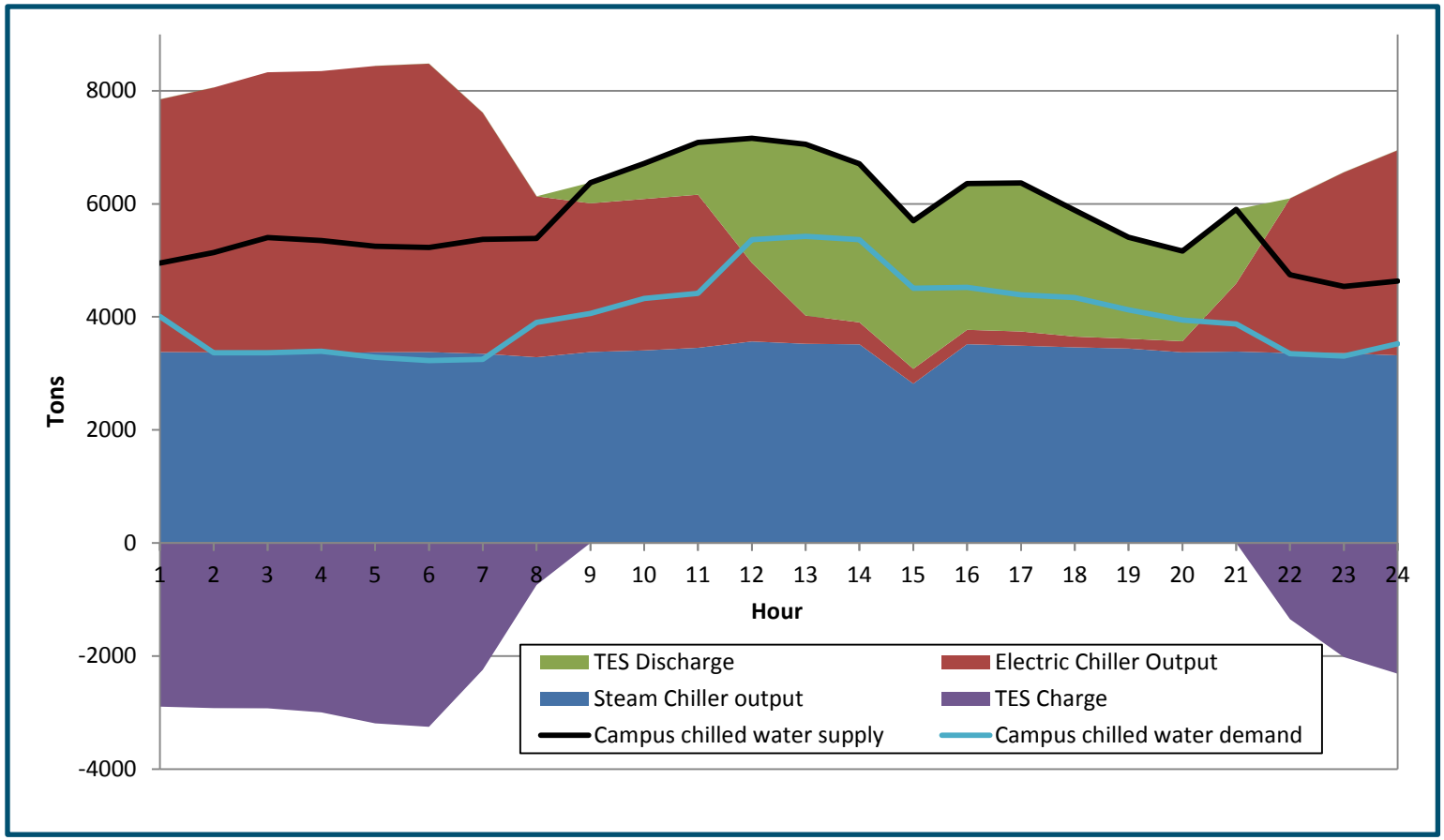
Data collected and analysis completed

- Daily data
  - Greensheet (dating back 2005)
  - Imports, hours of op, CUP gen, gen gas use, some chiller kW
- Hourly data
  - Chilled water & hot water to campus (dating back 2007)
- 15 minute interval data
  - MSCADA: Imports, CUP gen
  - JCI system: TES
  - BOP: steam data for boilers, generators
- Solar data
  - 15 minute inverter & meter data dating back 2009
- Historical price info
  - Gen & delivery prices dating back 2009 (CAISO day-ahead, NGI; ALTOU, EG and GTNC tariffs)
- Efftrack
  - Chiller data obtained
  - Nameplate capacity and efficiency info
  - Historical data dating back to June 2011

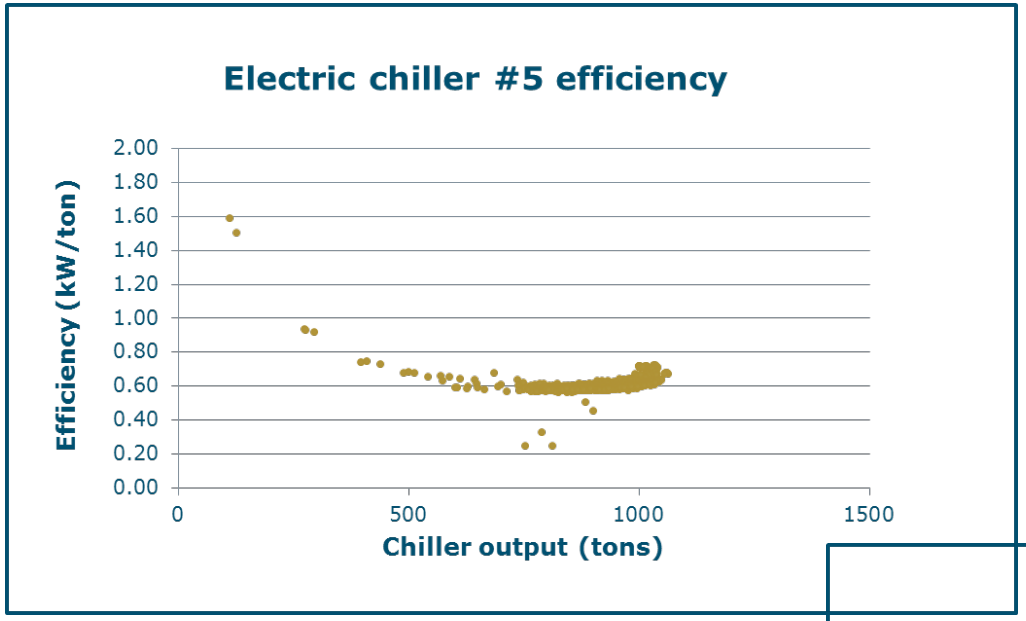
Snapshot: hourly/15 min analysis

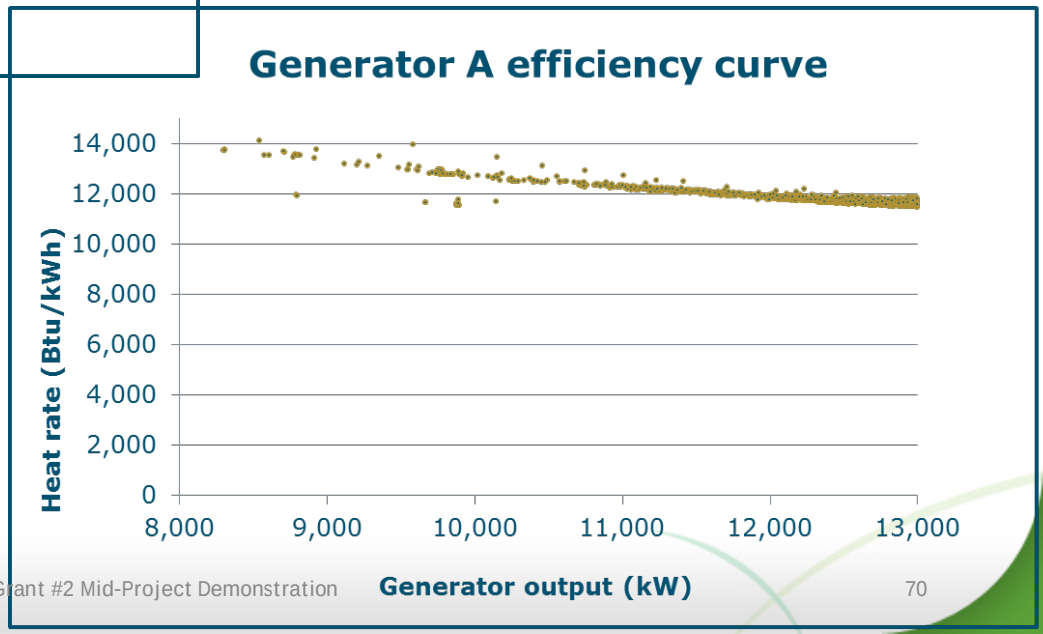


Actual operations chilled water system: June 7, 2011



Individual equipment efficiencies



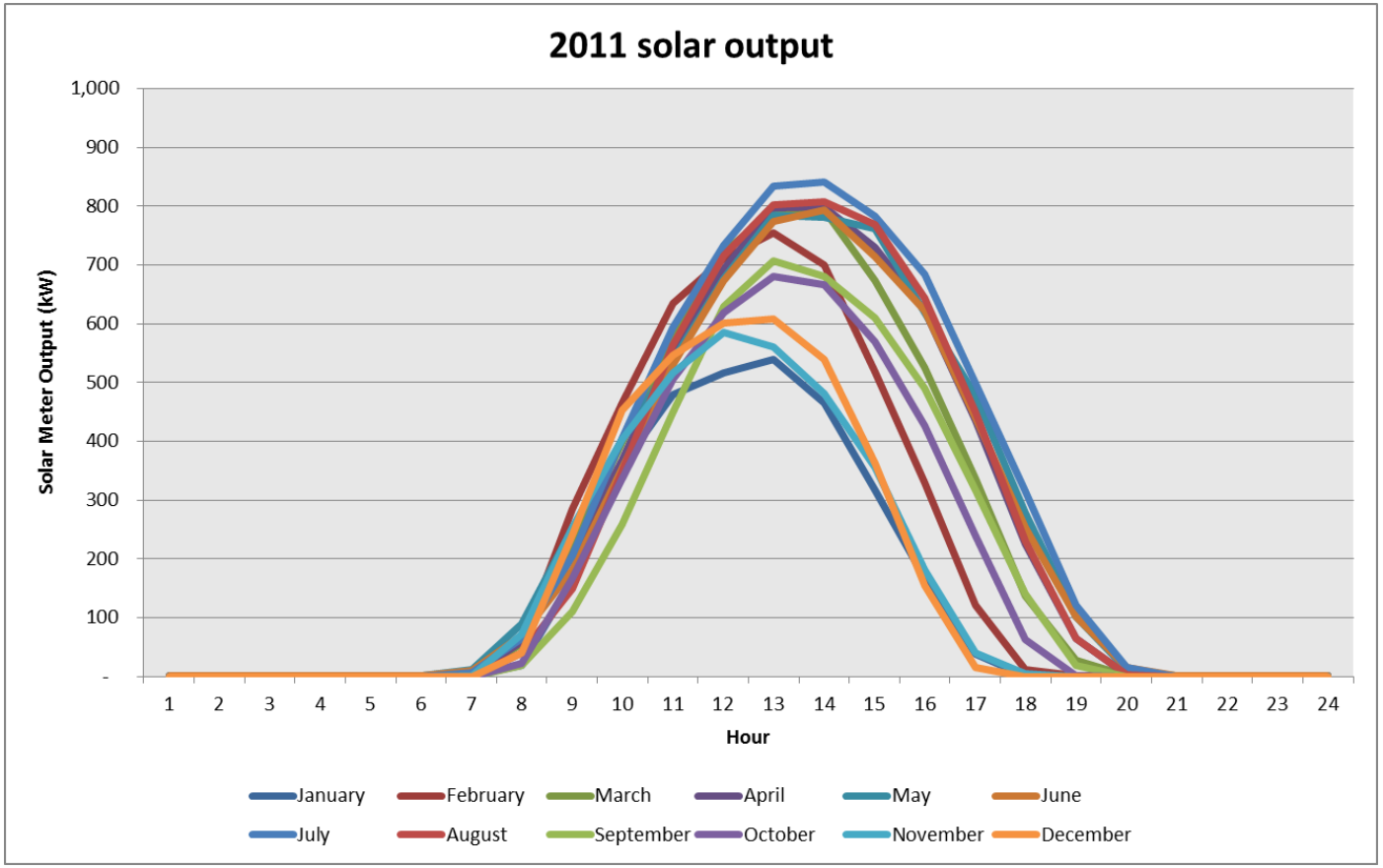


Equipment level metrics (3)

- Thermal storage tank was analyzed: charge, discharge times, rates, losses generated

Quantity	10th %	Median	90th %
Daily discharge - ton-hr	6,401	16,250	24,504
Charge start time (hr starting)	21	23	1
Charge duration (hr)	8	10	13
Discharge start time (hr starting)	8	9	12
Discharge duration (hr)	10	14	16
Flow rate (gpm)	663	2,491	4,958
Delta T (deg F)	11	13	14
Overall tank efficiency over measurement period			
Charge ton-hr	6,751,512		
Discharge ton-hr	6,454,207		
Losses	4.4%		

Snapshot: solar PV analysis



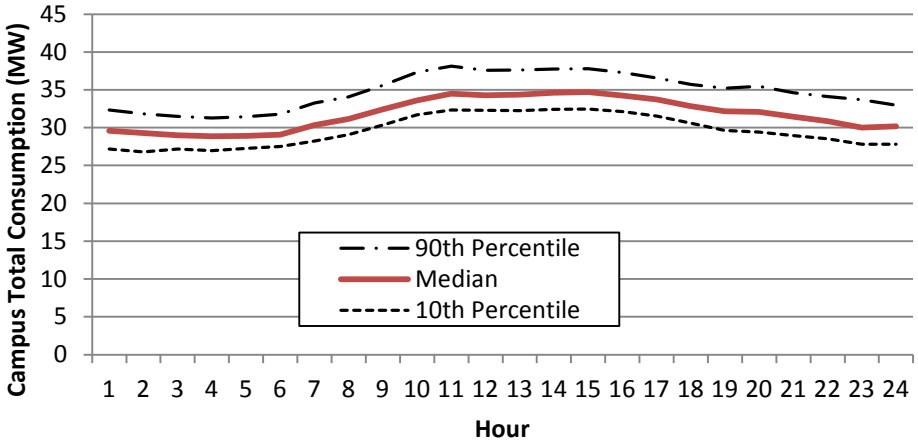
Summary of UCSD solar PV output

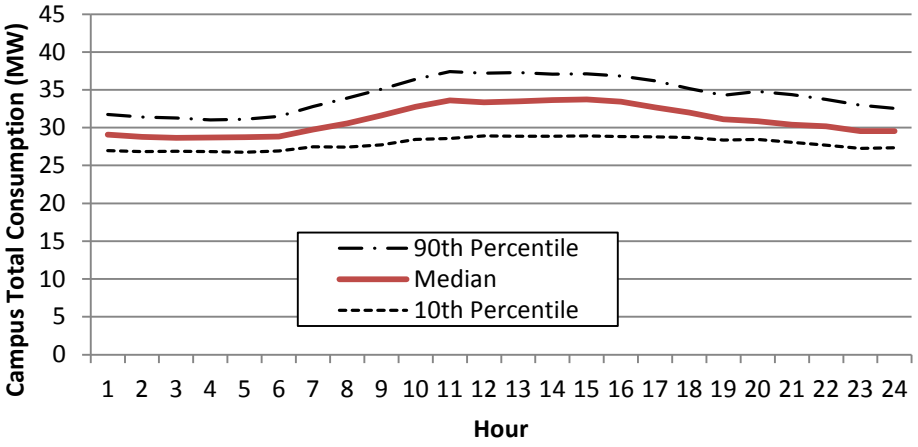
Solar Meter Location	ID	First Day of Output	Total Rated Power (kW DC)	Inverter Efficiency	Rated Power (kW AC)	Max. Solar Meter Output (kW)		
						2009	2010	2011
Birch Aquarium	BIRC_1608	**9/8/2009**	49.2	95%	46.7	44.6	47.0	45.1
Campus Services Complex - Buildings A to E & Trade Shops	CSC_1604	**9/17/2009**	258.4	97%	249.7	249.7	258.9	261.8
Campus Services Complex - Fleet Services Building	FLSV_1361	**Pre-2009**	28.7	96%	27.5	24.4	24.4	24.4
East Campus Central Utilities Plant	ECUP_1287	**Pre-2009**	28.7	96%	27.4	24.5	24.4	24.5
Engineering Building Unit 2	EBU_1362 and EBU_1363	**Pre-2009**	80.4	95%	76.5	66.6	66.6	66.5
Gilman Parking Structure	GILM_1364	**Pre-2009**	195.0	99%	192.9	138.1	137.8	135.3
Hopkins Parking Structure*	HOPK_1365	**Pre-2009**	338.0	99%	334.3	370.8	373.8	370.8
Price Centers, Buildings 1 to 4*	PRIC_1409	**Pre-2009**	206.6	96%	199.3	199.4	200.8	219.4
Total			1,185.0		1,154.3	855.6	1,075.6	1,071.9

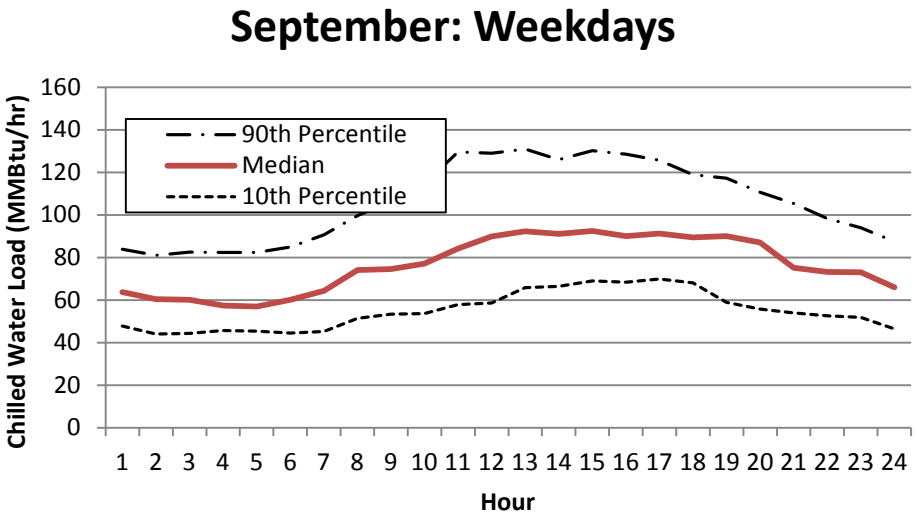
**Solar Meter Output from July 1, 2010 to June 30, 2011 was only provided as a daily average (kWh).*

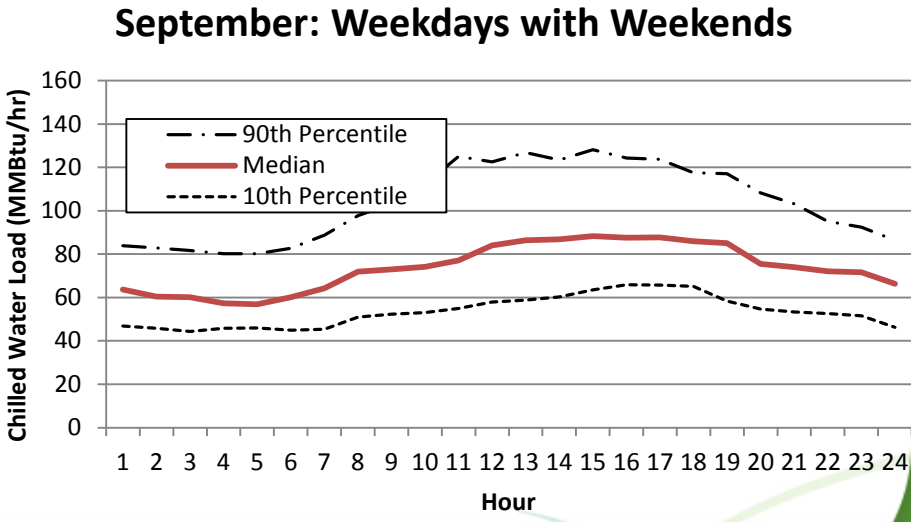
Solar Meter Location	Annual Energy (kWh)			Operating Hours			Capacity Factor (%)		
	2009	2010	2011	2009	2010	2011	2009	2010	2011
Birch Aquarium	16,471	68,389	65,890	2,751	8,756	8,754	12.8%	16.7%	16.1%
Campus Services Complex - Buildings A to E & Trade Shops	87,132	399,739	415,048	2,928	8,760	8,760	11.9%	18.3%	19.0%
Campus Services Complex - Fleet Services Building	50,805	47,928	45,293	8,759	8,759	8,008	21.1%	19.9%	20.6%
East Campus Central Utilities Plant	44,458	47,745	50,470	8,172	8,759	8,759	19.8%	19.9%	21.0%
Engineering Building Unit 2	127,833	122,500	116,428	8,760	8,760	8,760	19.1%	18.3%	17.4%
Gilman Parking Structure	220,738	206,717	202,387	8,759	8,510	7,854	13.1%	12.6%	13.4%
Hopkins Parking Structure*	536,719	504,082	524,575	8,759	8,759	8,753	18.3%	17.2%	17.9%
Price Centers, Buildings 1 to 4*	281,352	292,998	338,367	8,760	8,760	8,760	16.1%	16.8%	19.4%
Total	1,365,409	1,690,041	1,742,042	8,760	8,760	8,760	13.5%	16.7%	17.2%

Day type influence

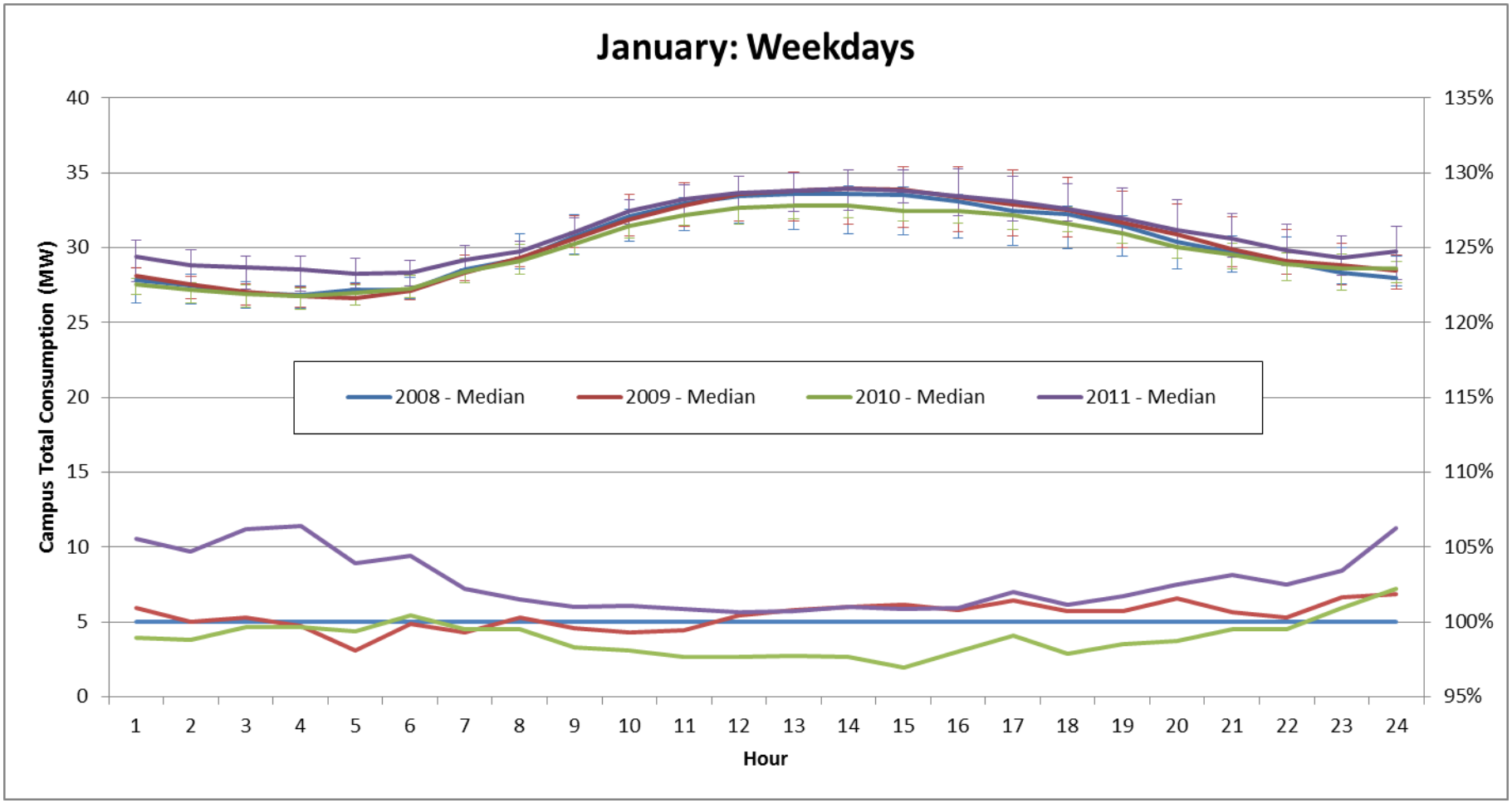




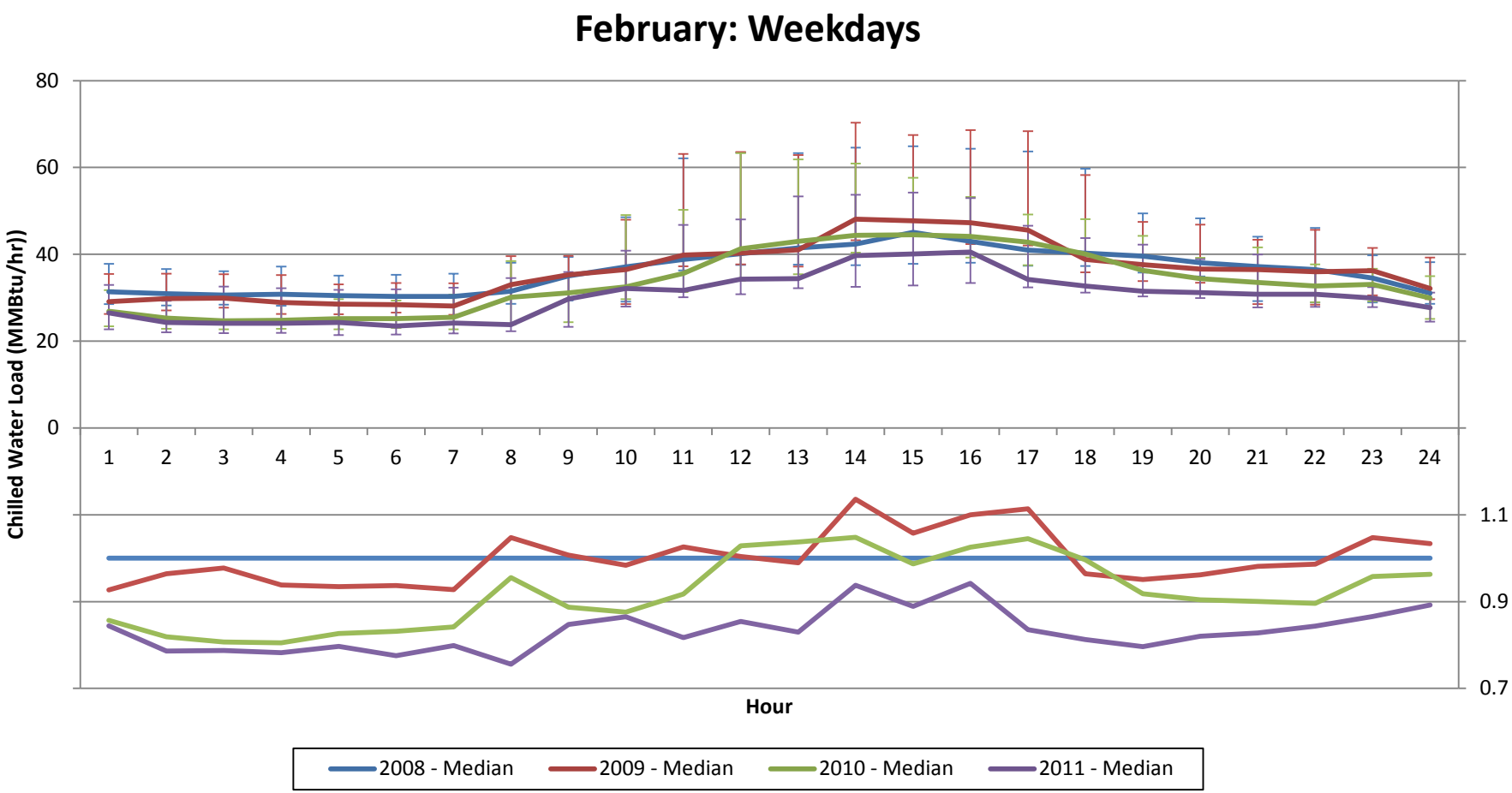




Year to year differences of campus power consumption: January look



Year to year differences of campus chilled water needs: February look



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