UCR | College of Engineering- Center for Environmental Research & Technology

Sustainable Integrated Grid Initiative (SIGI):

Technical and Economic Challenges of Integrating Renewable Energy, Electric Vehicle Charging and Battery Energy Storage in a Modern Grid

The International Cost Estimating and Analysis Association (ICEAA)
Southern California Chapter
September 9, 2015

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College of Engineering-
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October 16, 2014

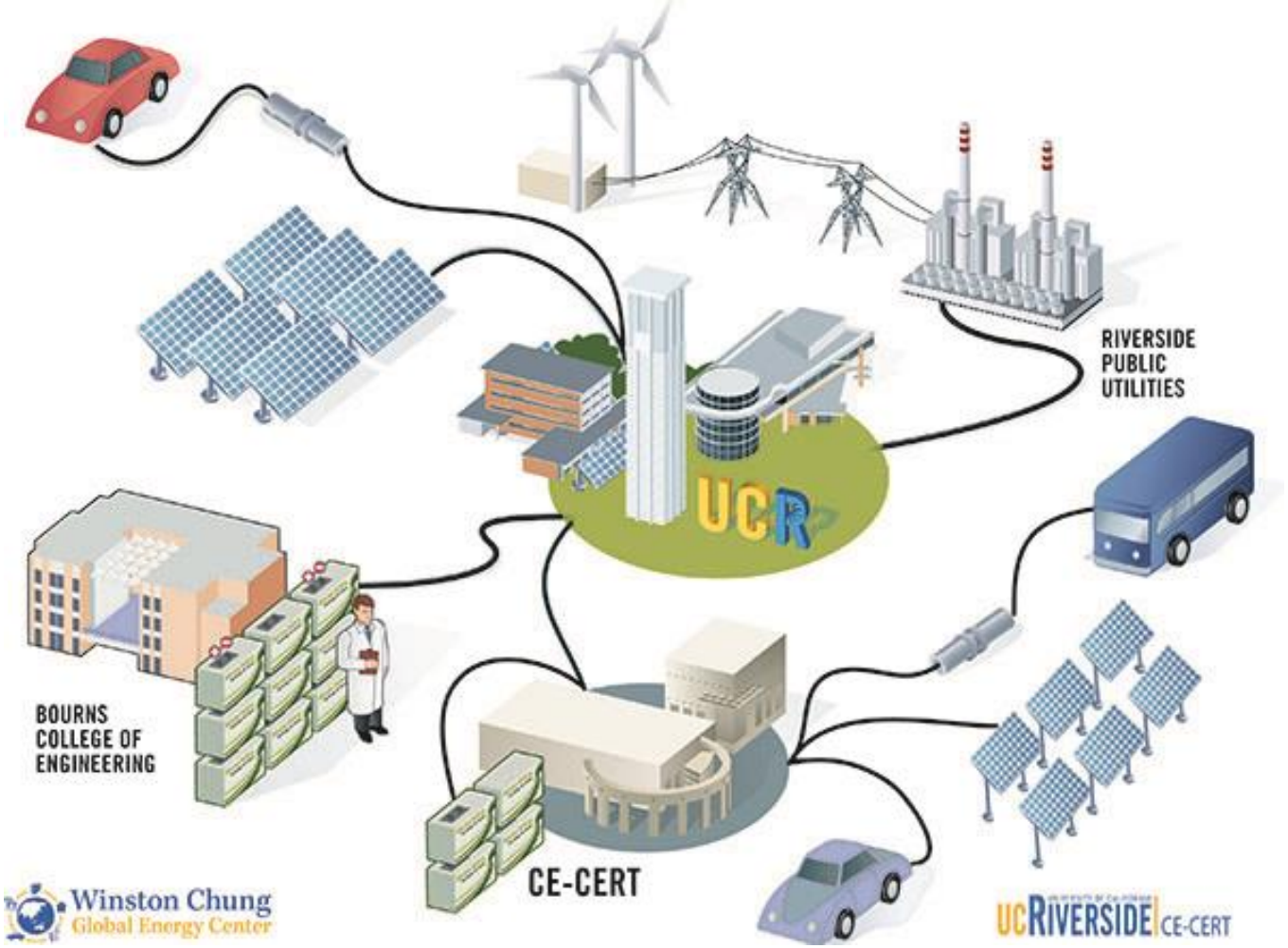
Research Motivation

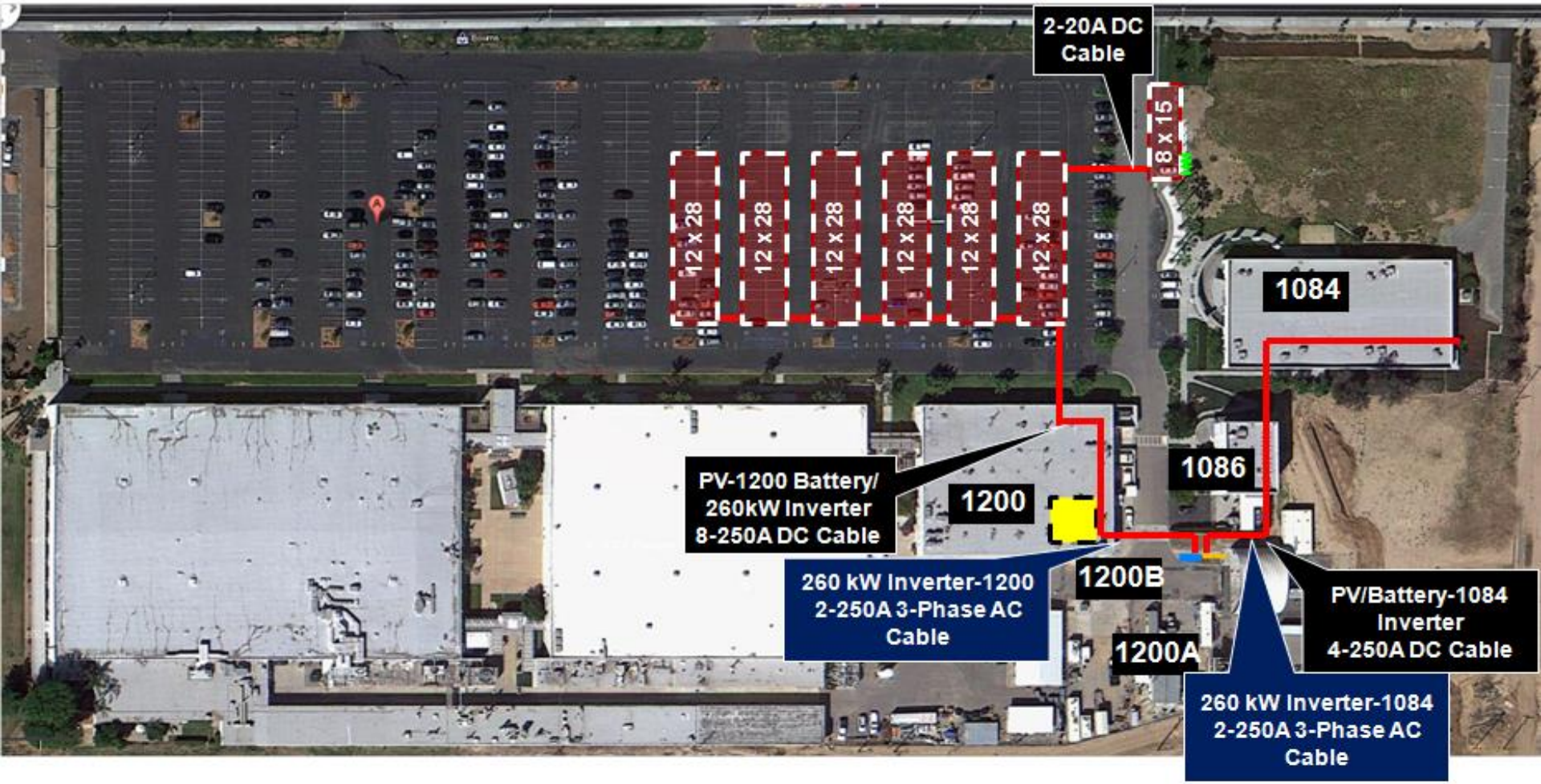
- Solar PV and wind energy are intermittent
- More value if dispatchable when needed
- Electrical energy storage challenge with old battery technologies – slow charging & no deep cycling
- New rare earth Lithium-ion battery can handle very quick charging and many cycles
- Electric vehicles creating new demands on the grid
- Need smart grid technologies to overcome distribution disturbances, additional harmonics
- Need a test bed to further study

College of Engineering- Center for Environmental Research & Technology

Sustainable Integrated Grid Initiative (SIGI):

Integrating Photovoltaics, Energy Storage, and a Local Utility for Electric Transportation





New Grid PV System

New Grid Conduit

Battery/Inverter Energy System

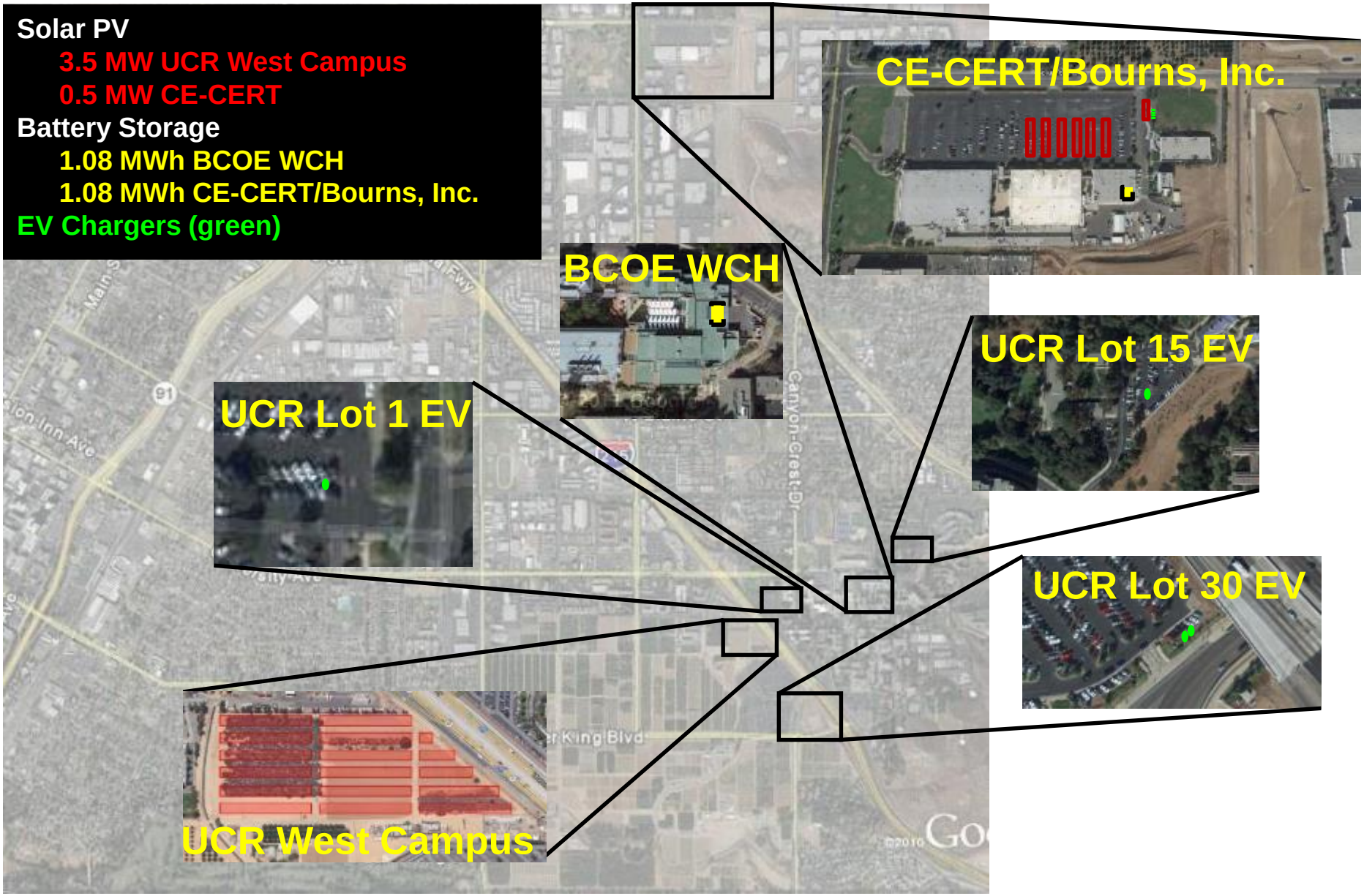
1 – 260 kW Inverter (AE 260TX)

2 – 100 kW Inverters (AE 100TX)

L2 – EV Charger

1 ft = .008"

UC Riverside Solar, Battery Energy Storage and EV Charging System



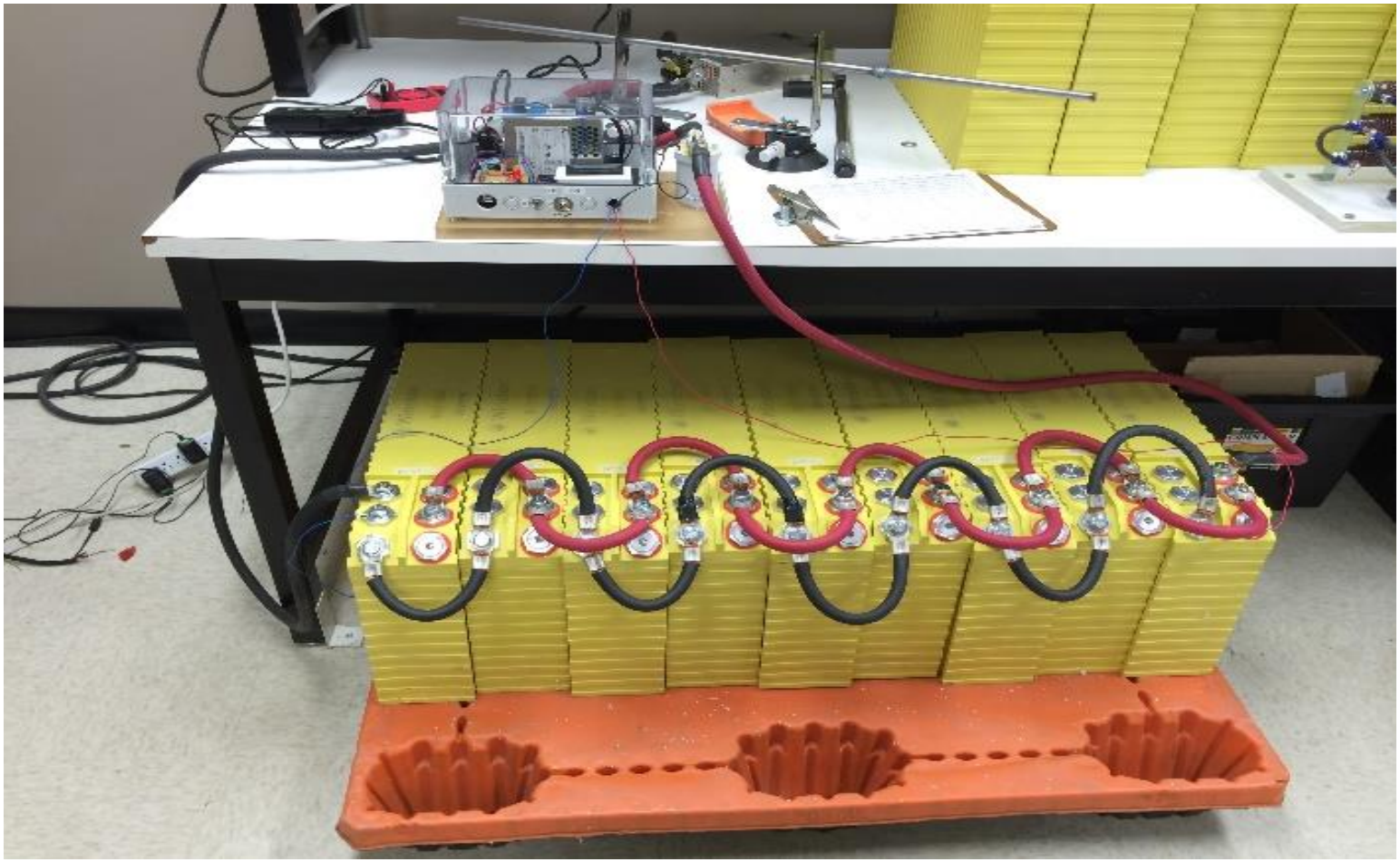
1.1 MWh Lithium-ion battery at UCR

Stationary Battery System 500kWh

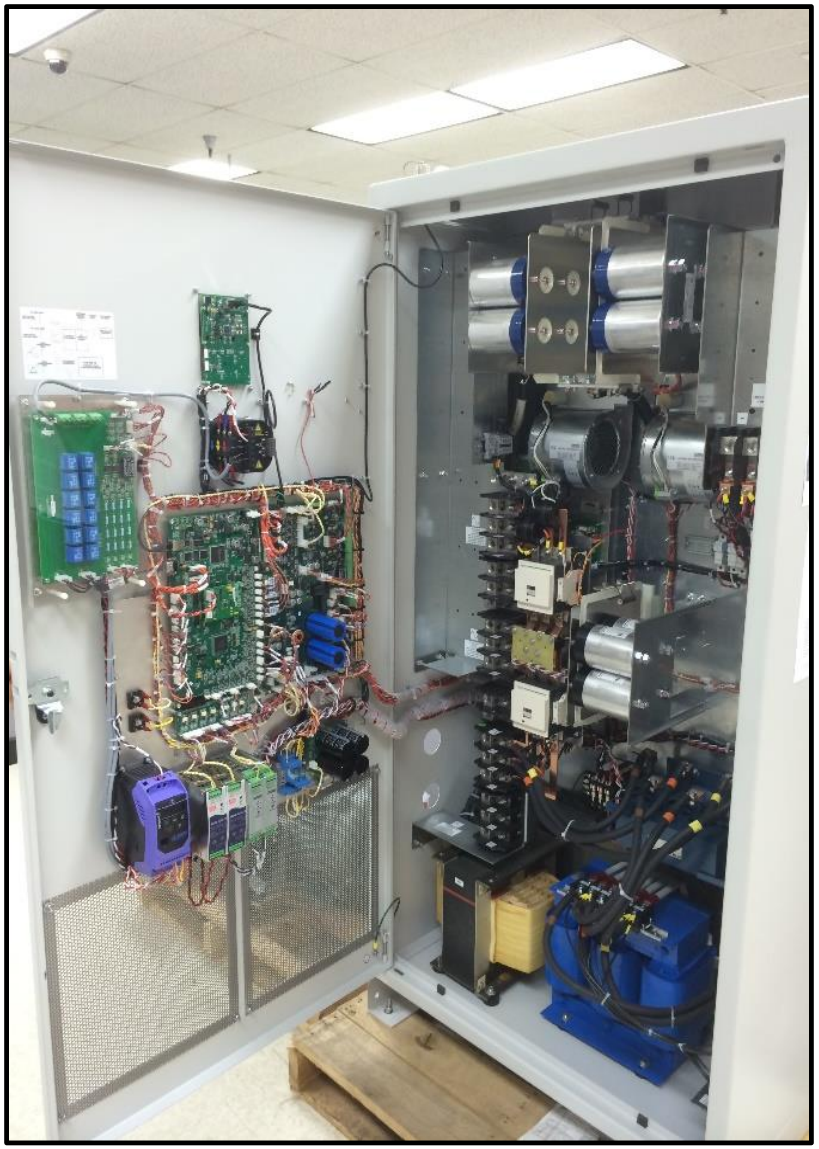
SIGI Mobile Battery Energy Storage Trailer

- 500 kWh storage
- 100 kW on board inverter/charger
- 480 V 3-phase plug in for charging and delivery
- 144 Lithium batteries each weighing 77 lbs
- 8’x24’ triple axle trailer

UCR Battery Testbed

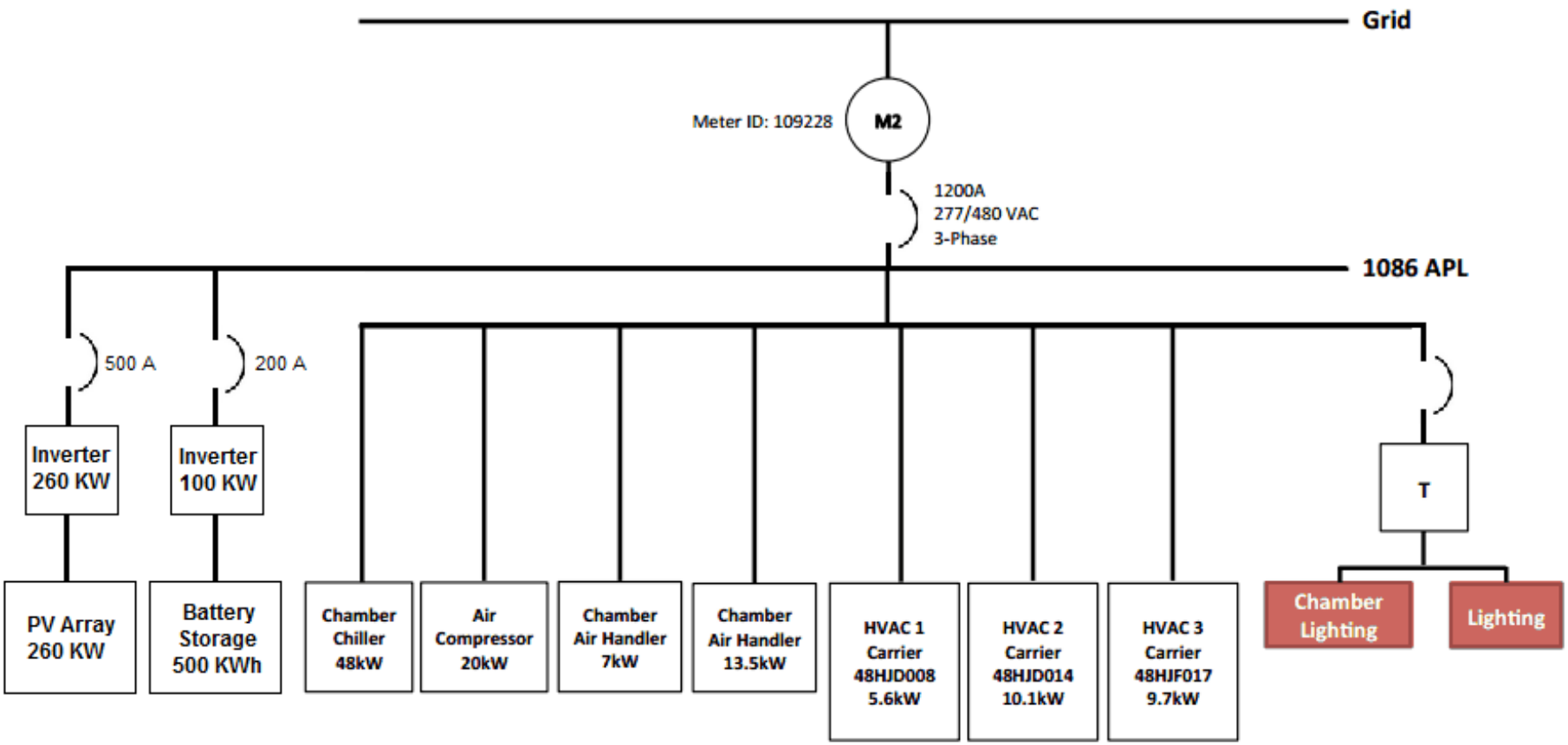


Grid-tied Battery Inverter: 100kW

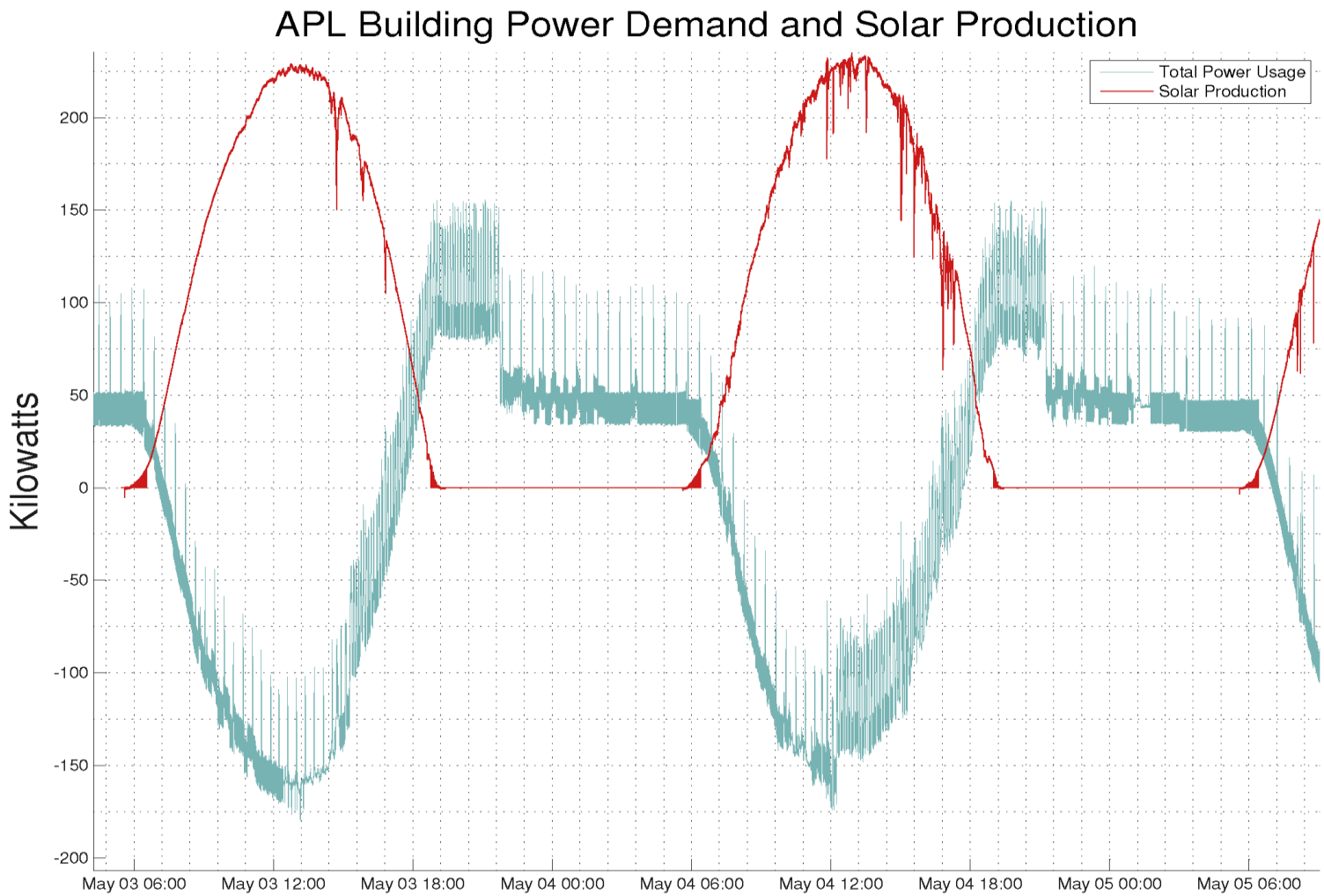


CE-CERT APL Building Electrical Layout 1086 Columbia

Figure 2: CE-CERT APL Building Electrical Layout (1086 Columbia Ave.)



Solar PV Inverters: 2x100kW & 260kW

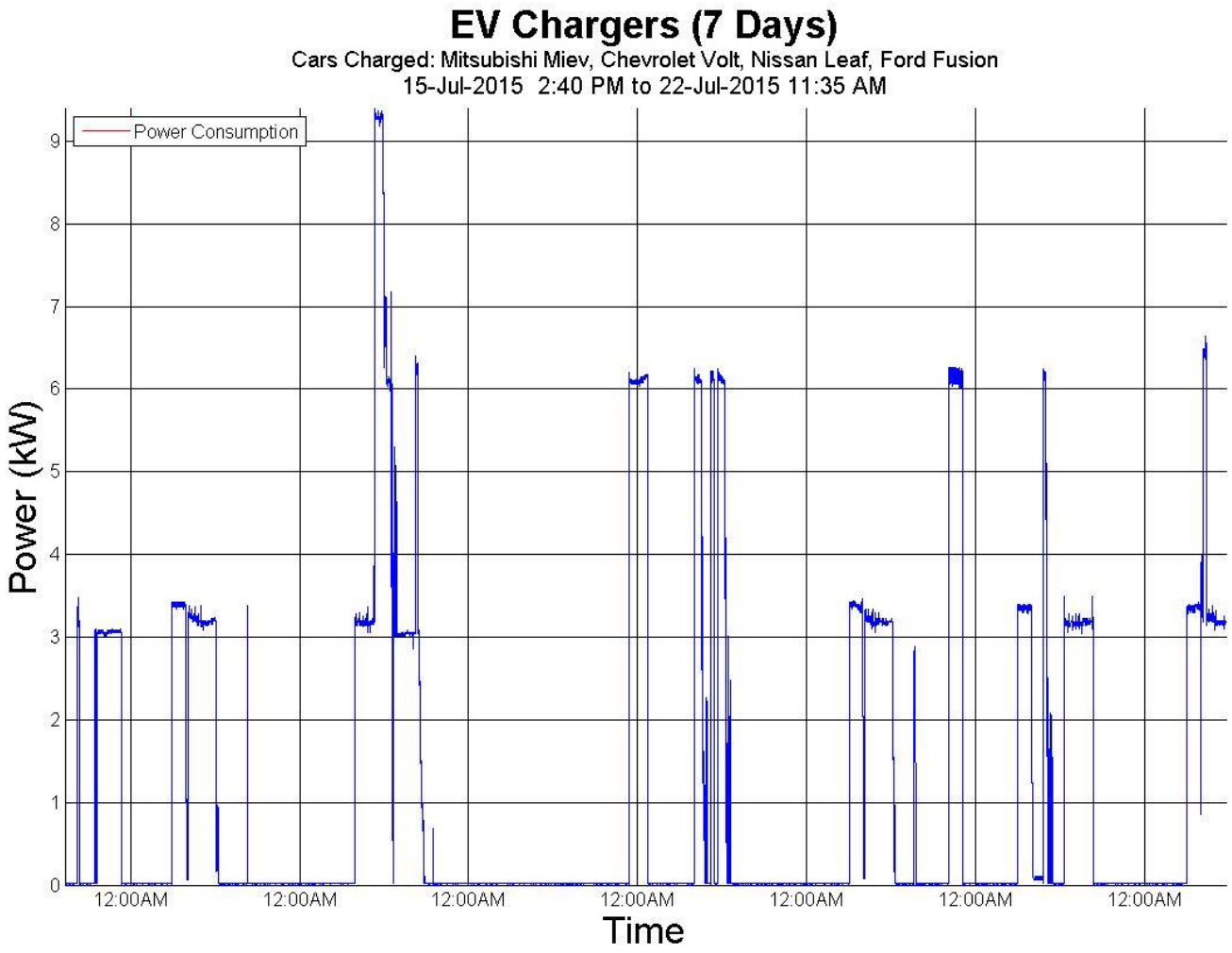

APL Building Power Demand and Solar Production
Total Power Usage
Solar Production
Kilowatts
200
150
100
50
0
-50
-100
-150
-200
May 03 06:00
May 03 12:00
May 03 18:00
May 04 00:00
May 04 06:00
May 04 12:00
May 04 18:00
May 05 00:00
May 05 06:00

California's Duck Curve

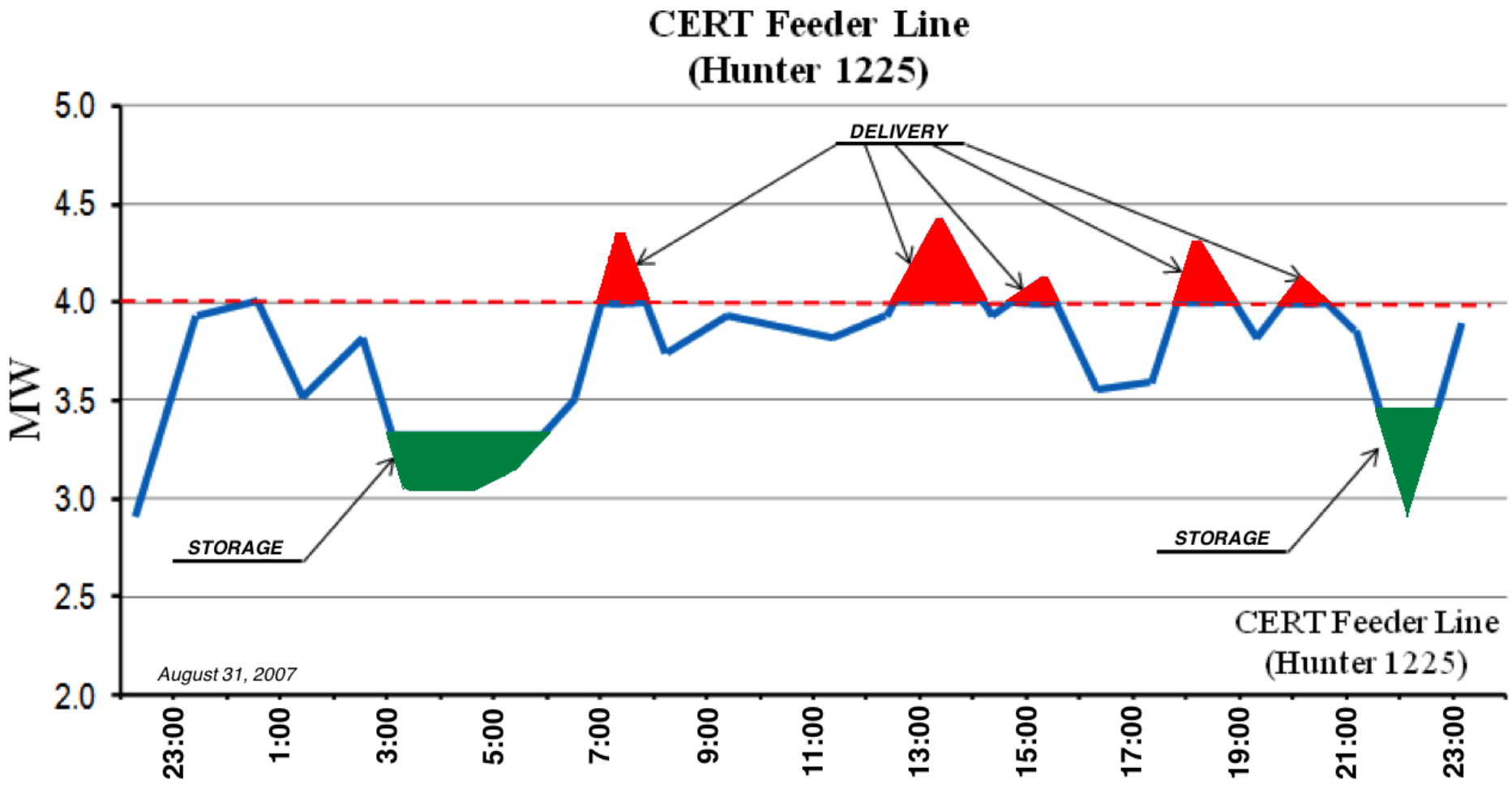
EV Chargers

26 Level-2 chargers placed all throughout the city of Riverside, the chargers will service fleet and private vehicles

Level-3 chargers will be installed in the Fall of 2014 and service the electric trolley and other fast charging vehicles


EV Chargers (7 Days)
Cars Charged: Mitsubishi Miev, Chevrolet Volt, Nissan Leaf, Ford Fusion
15-Jul-2015 2:40 PM to 22-Jul-2015 11:35 AM
Power Consumption
Power (kW)
0
1
2
3
4
5
6
7
8
9
12:00AM
12:00AM
12:00AM
12:00AM
12:00AM
12:00AM
12:00AM
Time

EV Demand / Building Peak Supplied by Battery Energy Storage



Public Utilities

RIVERSIDE PUBLIC UTILITIES PROVIDES RECORD ENERGY DEMANDS DURING CONTINUED TRIPLE DIGIT HEAT WAVE

9/15/2014

Riverside, Calif. – As triple digit temperatures continued to heat up Southern California to start the work week, Riverside Public Utilities (RPU) reached a new all-time high of energy provided to its customers surpassing 610 megawatts (MW).

Monday's peak surpasses the utility's previous one day all-time total for energy used which occurred on August 30, 2007 when RPU provided more than 609 MW (one megawatt is enough energy for about 650 homes).

"Our energy delivery and generation crews recognized that more energy would be needed as this week began," said RPU Assistant General Manager of Energy Delivery Pat Hohl. "Crews were at the ready, and we were able to start up our generation plants within the city to ensure there was enough power to meet the needs of our customer-owners."

Over the past decade, RPU has worked to build and acquire power plants that are located within the city of Riverside that can provide up to 192 MW of power to meet peak energy demands.

For additional information about Riverside Public Utilities, follow us on Facebook or Twitter

[Faculty] [On behalf of VC Coley] Voluntary Electricity Curtailment Notice - Internet Explorer

https://exchange.engr.ucr.edu/owa/#viewmodel=ReadMessageItem&ItemID=AAMkAGUwOGYwNjdmLWE4OWEtN(Certificate error

[Faculty] [On behalf of VC Coley] Voluntary Electricity Curtailment Notice

DELETE REPLY REPLY ALL FORWARD ...

mark as unread

faculty-bounces@scotmail.ucr.edu on behalf of Karen A Springer <karen.springe

Thu 9/18/2014 8:37 AM

To: faculty@scotmail.ucr.edu; msoadm@scotmail.ucr.edu; staff@scotmail.ucr.edu; students@scotmail.ucr.edu;

- This message was sent with High importance.
- You forwarded this message on 10/15/2014 7:42 PM.

1 attachment

ATT00001.txt

Faculty, Staff, and Students,

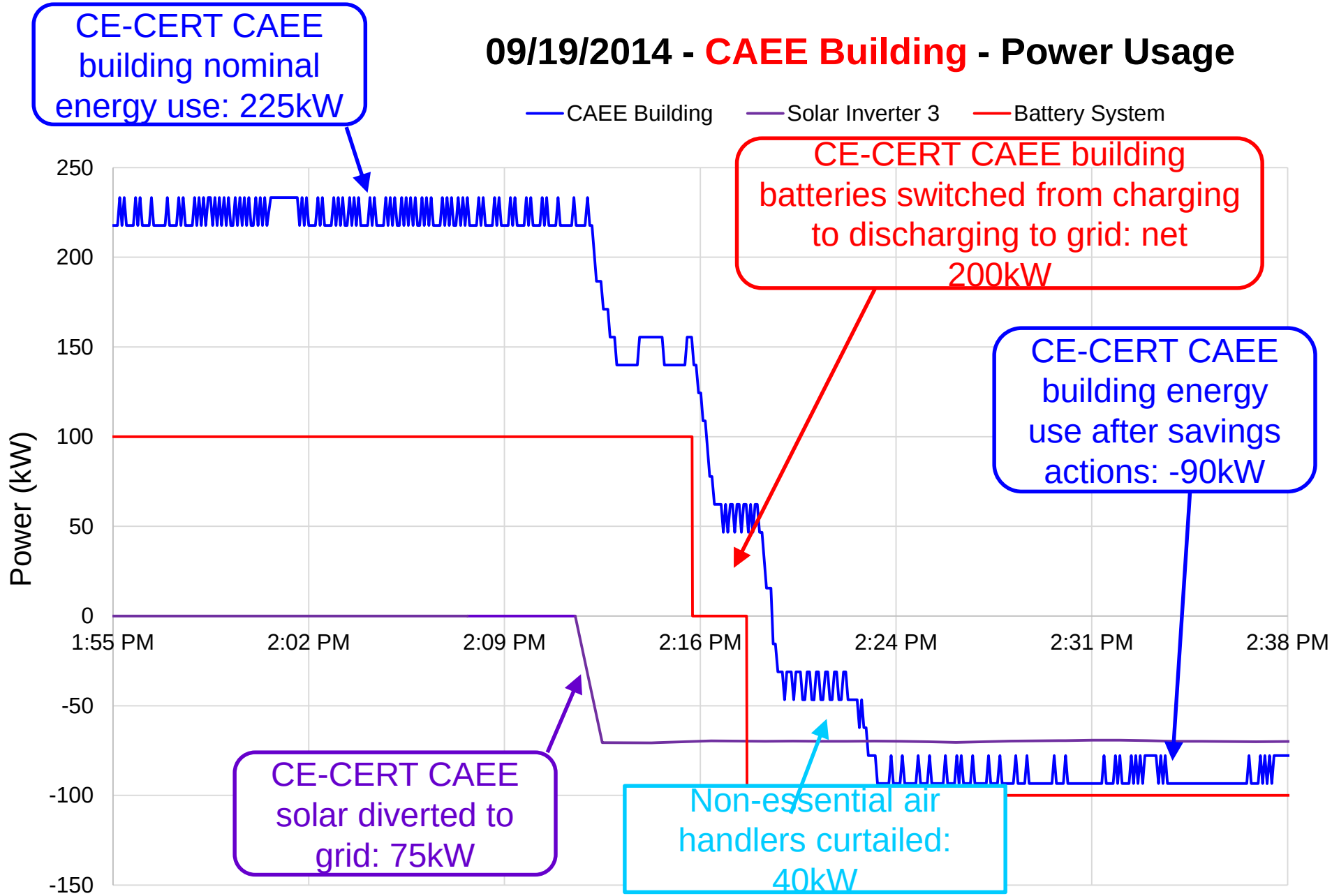
You may be aware that California hit an all-time record in electrical consumption yesterday. As a result our electrical provider, Riverside Public Utility, has asked us to voluntarily curtail any non-essential electrical use between the hours of 2:00 p.m. and 5:00 p.m. In order to protect our electrical grid and be proactive in the prevention of mandatory curtailment and/or brown outs, we are asking that every member of our UCR community do their part by turning off any non-essential appliances and lights. This curtailment request will be valid throughout this current heatwave.

Thank you in advance for your understanding and participation.

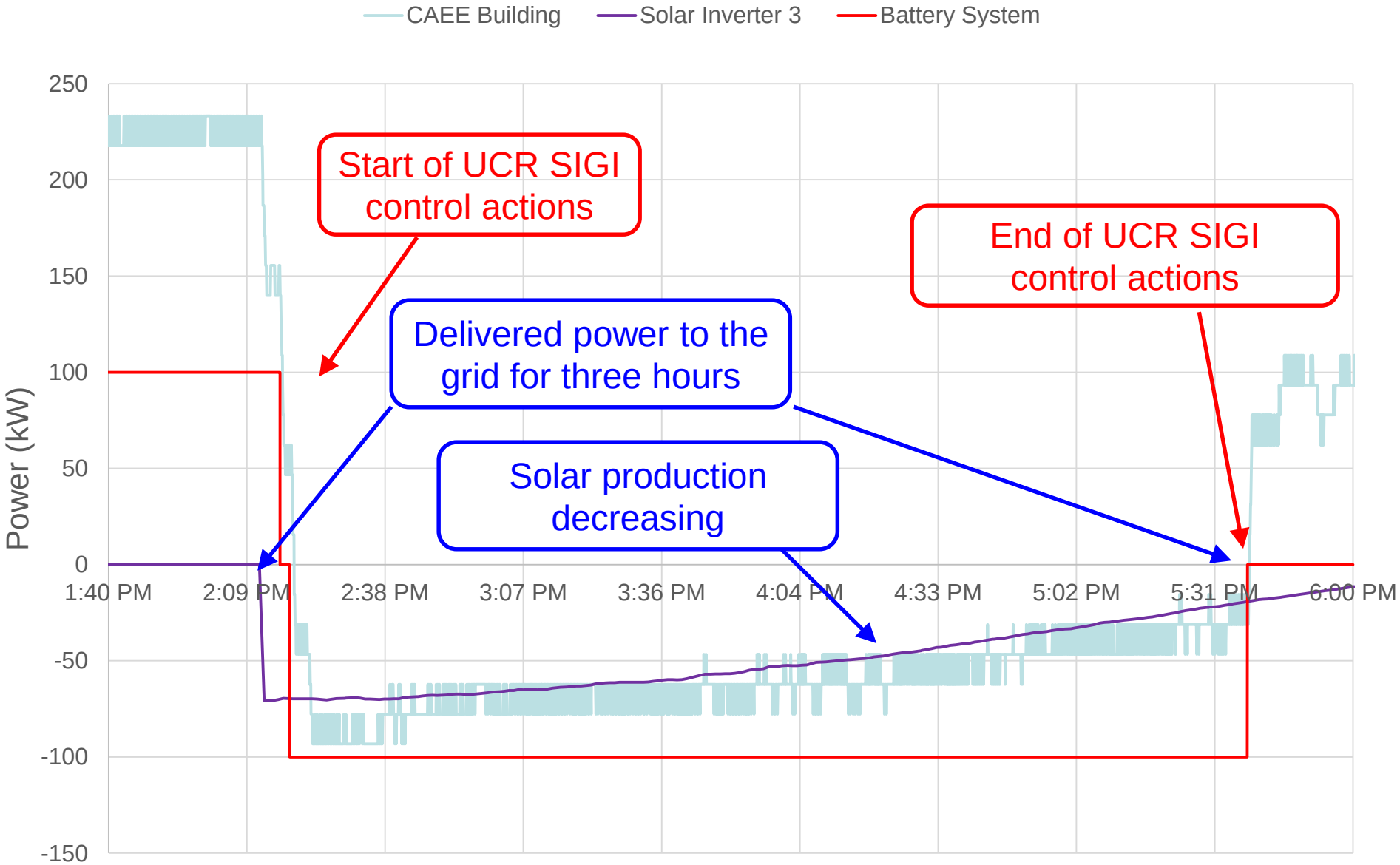
Ron T. Coley
Vice Chancellor
Business and Administrative Services
3125 Hinderaker Hall
(951) 827-3268

SIGI helps RPU ride through peak historic demand

- As triple digit temperatures continued to heat up Southern California to start the work week, Riverside Public Utilities (RPU) reached a new all-time high of electrical energy provided to its customers surpassing 610 megawatts (MW).
- Monday September 15, 2014's peak surpasses the utility's previous one day all-time total for energy used which occurred on August 30, 2007 when RPU provided more than 609 MW (one megawatt is enough energy for about 650 homes).
- In response to an appeal by RPU to conserve electrical energy, UCR officials requested faculty, staff and students to take actions to help reduce electricity use, specially between 2 pm to 5 pm.


09/19/2014 - CAEE Building - Power Usage
CAEE Building
Solar Inverter 3
Battery System
Power (kW)
250
200
150
100
50
0
-50
-100
-150
1:55 PM
2:02 PM
2:09 PM
2:16 PM
2:24 PM
2:31 PM
2:38 PM
CE-CERT CAEE building nominal energy use: 225kW
CE-CERT CAEE building batteries switched from charging to discharging to grid: net 200kW
CE-CERT CAEE building energy use after savings actions: -90kW
CE-CERT CAEE solar diverted to grid: 75kW
Non-essential air handlers curtailed: 40kW

09/19/2014 - **CAEE Buildings** - Power Usage



SIGI helps RPU during peak historic demand

September 19, 2014:

- **Triple digit temperatures lead to Riverside Public Utilities (RPU) reaching a new all-time high electricity demand of 610 megawatts (MW).**
- **RPU send out an appeal to larger customers to conserve electrical energy, specifically between 2 pm to 5 pm.**
- **CE-CERT's Sustainable Integrated Grid Initiative (SIGI) Testbed provided the flexibility to not only curtail nominal power consumption of 365kW, but provide 225kW back to the grid, resulting in a 590kW swing for three hours**
- **CE-CERT CAEE building net energy savings: 315kW**
- **CE-CERT admin building net energy savings: 95kW**
- **CE-CERT APL building net energy savings: 180kW**

Application of Battery Energy Storage for Demand Reduction

ELECTRICITY

Customer Charges For Electricity

5640 KWH (ON PEAK EL)@$0.103300 =	582.61
102.00 KW (ON PEAK DM)@$6.880000 =	701.76
17640 KWH (MID PEAK E)@$0.082800 =	1,460.59
126.00 KW (MID PEAK D)@$2.740000 =	345.24
22080 KWH (OFF PEAK E)@$0.072700 =	1,605.22
92.40 KW (OFF PEAK D)@$1.310000 =	121.04
CUSTOMER CHARGES	704.66
RELIABILITY CHARGE	1,100.00
STATE ENERGY	13.16
12/05/12 TOTAL CHARGES FOR ELECTRICITY	$6,634.28

ELECTRICITY

Customer Charges For Electricity

5160 KWH (ON PEAK EL)@$0.103300 =	533.03
106.80 KW (ON PEAK DM)@$6.880000 =	734.78
20160 KWH (MID PEAK E)@$0.082800 =	1,669.25
222.00 KW (MID PEAK D)@$2.740000 =	608.28
23640 KWH (OFF PEAK E)@$0.072700 =	1,718.63
93.60 KW (OFF PEAK D)@$1.310000 =	122.62
CUSTOMER CHARGES	704.66
RELIABILITY CHARGE	1,100.00
STATE ENERGY	14.21
12/05/13 TOTAL CHARGES FOR ELECTRICITY	$7,205.46

Customer Charges for Electricity

1,320 KWH (ON PEAK EL)@$0.103300 =	136.36
12.00 KW (ON PEAK DM)@$6.880000 =	82.56
11,520 KWH (MID PEAK E)@$0.082800 =	953.86
163.20 KW (MID PEAK D)@$2.740000 =	447.17
28,920 KWH (OFF PEAK E)@$0.072700 =	2,102.48
175.20 KW (OFF PEAK D)@$1.310000 =	229.51
RELIABILITY CHARGE	1,100.00
CUSTOMER CHARGES	704.66
STATE ENERGY	12.11
12/02/14 TOTAL CHARGES FOR ELECTRICITY	$5,768.71

Results from a 500 kWh, 100 kW lithium-ion Winston Battery System

Peak Demand

2012= 102 kW

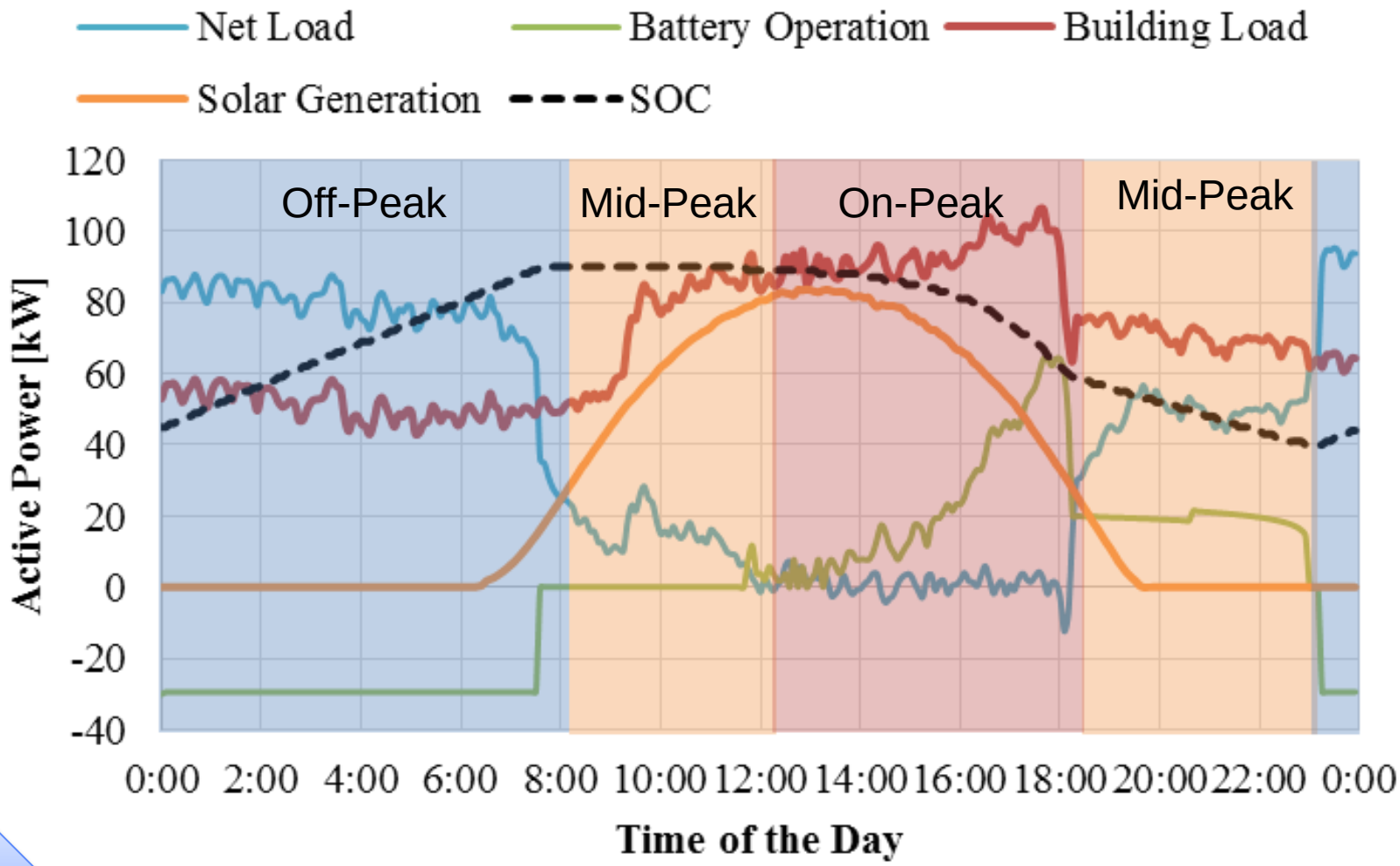
2013= 106 kW

SIGI Installed

2014 = 12 kW

(Monthly Cost Savings ~$1,000 In RPU Territory; ~$2,500 in SCE)

One-Day Experiment with Three Different Time Periods Control Algorithms



Outline

Cost Analysis

Comparisons Between Different System Architectures

System Comparison	Energy kWh Savings($)	Load Demand Savings($)			Total ($)
		On-Peak	Mid-Peak	Off-Peak	
Real vs. Schedule	209.65	105.92	17.24	6.19	339.00
Real vs. No Battery	104.38	381.12	17.24	-33.10	469.64
Real vs. No PV or Battery	1182.82	584.56	126.26	-27.21	1866.43

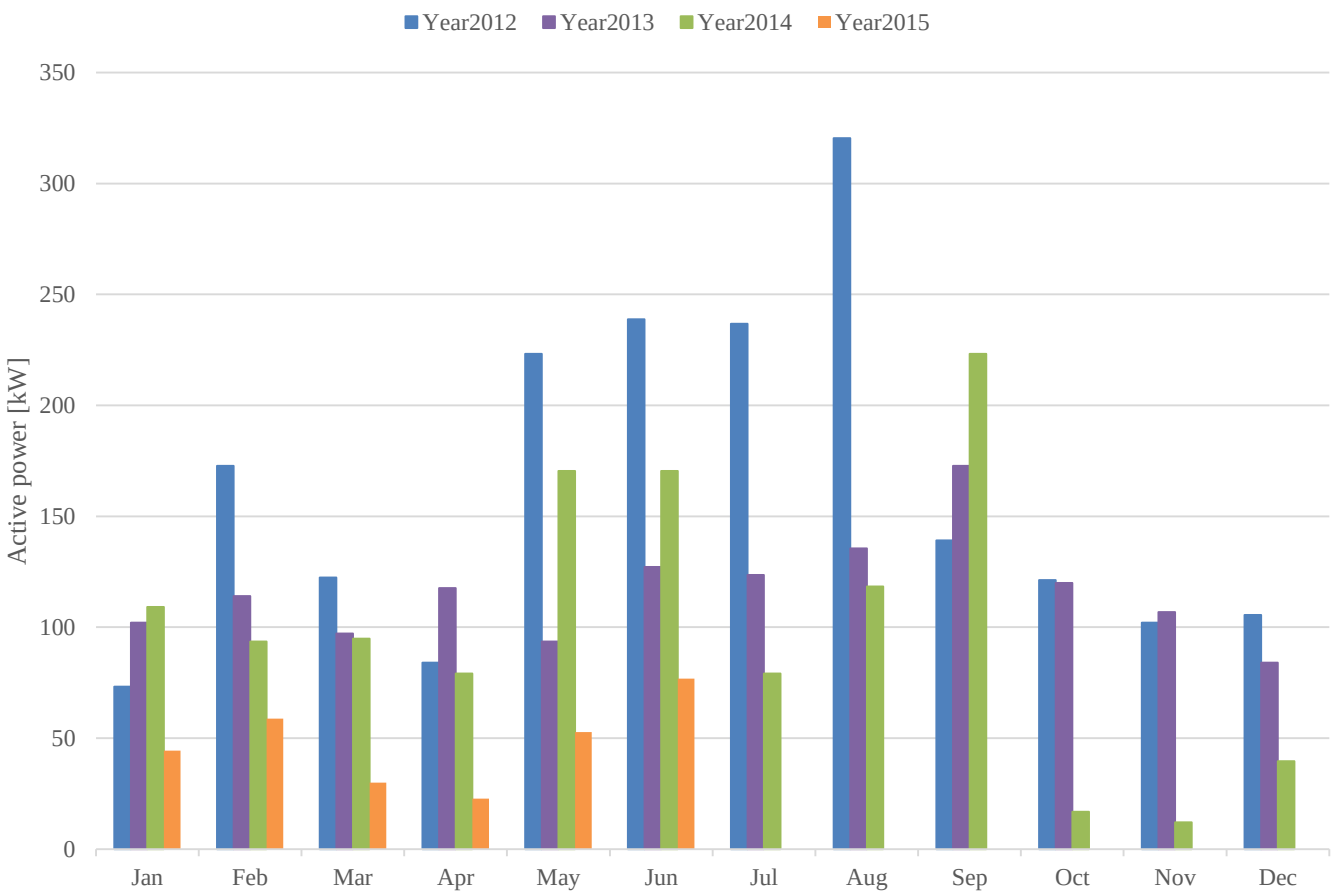
June 2015 Electricity Cost Comparison for Different System Architectures

Different Situation	Energy kWh Savings($)	Load Demand Savings($)			Total ($)
		On-Peak	Mid-Peak	Off-Peak	
Real vs. Schedule	84.26	59.5	0	14.6	158.36
Real vs. No Battery	97.44	472.3	24.84	-24.7	594.58
Real vs. No PV or Battery	953.7	585.65	115.44	-24.7	1630.09

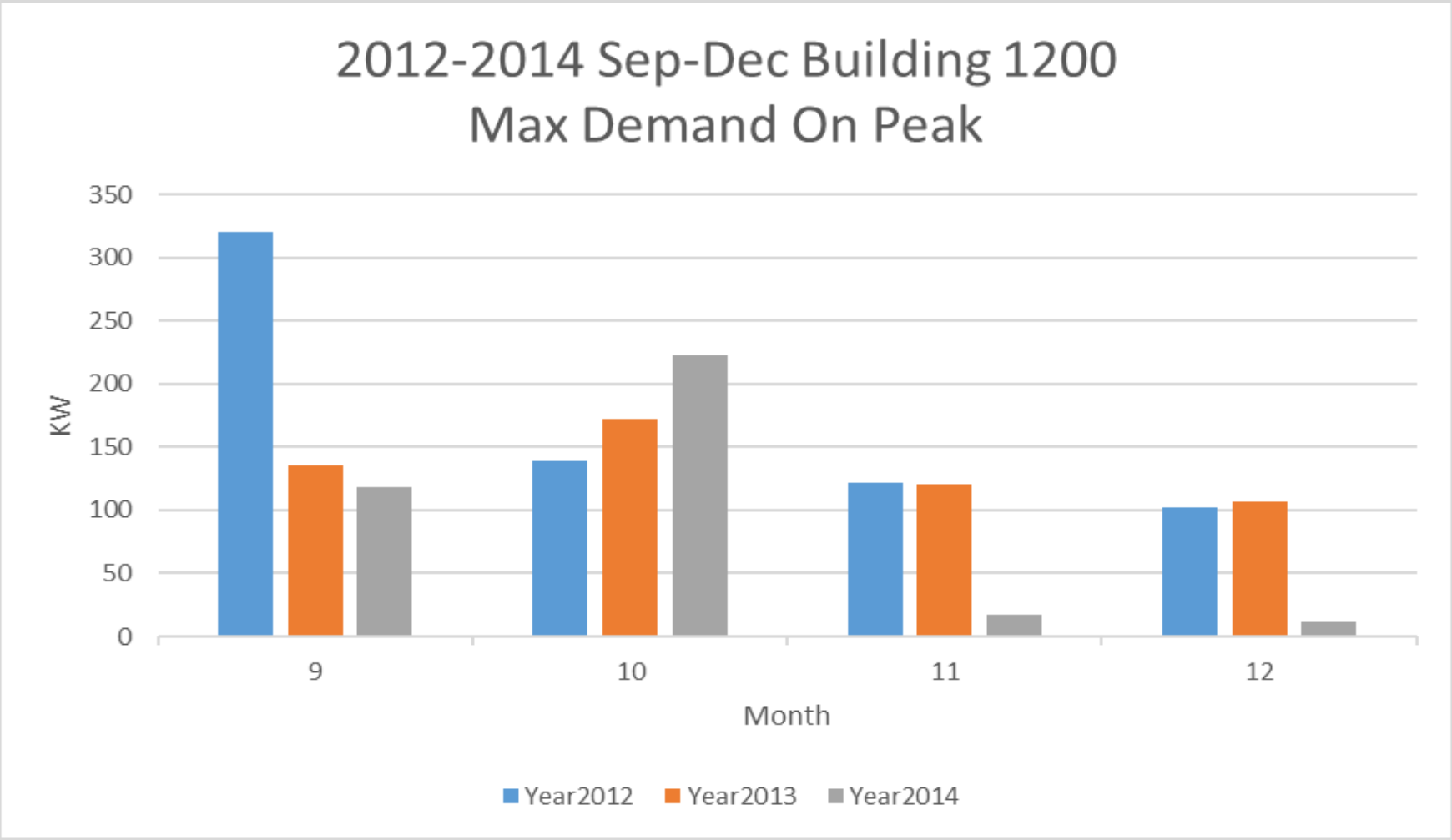
May 2015 Electricity Cost Comparison for Different System Architectures

Real refers to real-time control algorithm

Demand Comparisons



B1200 On-Peak Demand in Electricity Bill


2012-2014 Sep-Dec Building 1200
Max Demand On Peak
350
300
250
200
150
100
50
0
KW
9
10
11
12
Month
Year2012
Year2013
Year2014

Do We Understand Our Electric Bills?

.....

Which Unit is Time Dependent: kilo-Watt (kW) or kilo-Watt hour (kWh)?

Do We Understand Our Electric Bills?

1 in 10 of us?

.....

Which Unit is Time Dependent: kilo-Watt (kW) or kilo-Watt hour (kWh)?

Watt = Joules/second: kW is time dependent

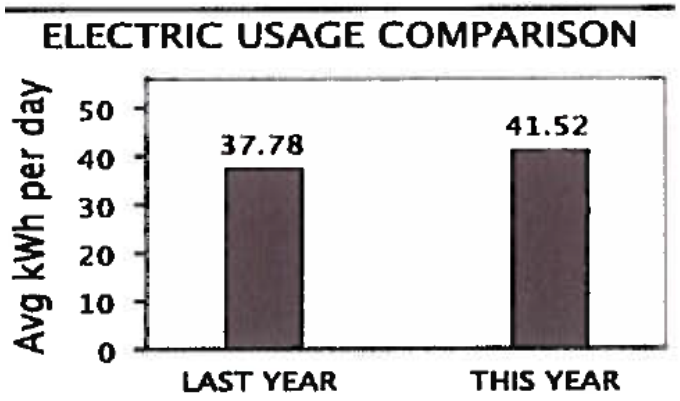
Anaheim Public Utilities Rate Schedule

Lifeline Usage	Per Meter, Per Month
Customer Charge	$3.37
Energy Charge (to be added to Customer Charge):	
First 270 kWh, Basic Lifeline per kWh	10.88¢
Plus 125 kWh for Electric Water Heating, per kWh	10.88¢
Plus 275 kWh for Electric Space Heating, for November 1 through April 30, per kWh	10.88¢
Plus all kWh for Life Support Allowance, per kWh	10.88¢
Non-Lifeline Usage:	
All kWh in excess of the above, per kWh	16.11¢
Minimum Charge:	
The minimum charge shall be the monthly Customer Charge.	

Anaheim Public Utilities Details of Electric Charges

6/22/15 – 8/19/15

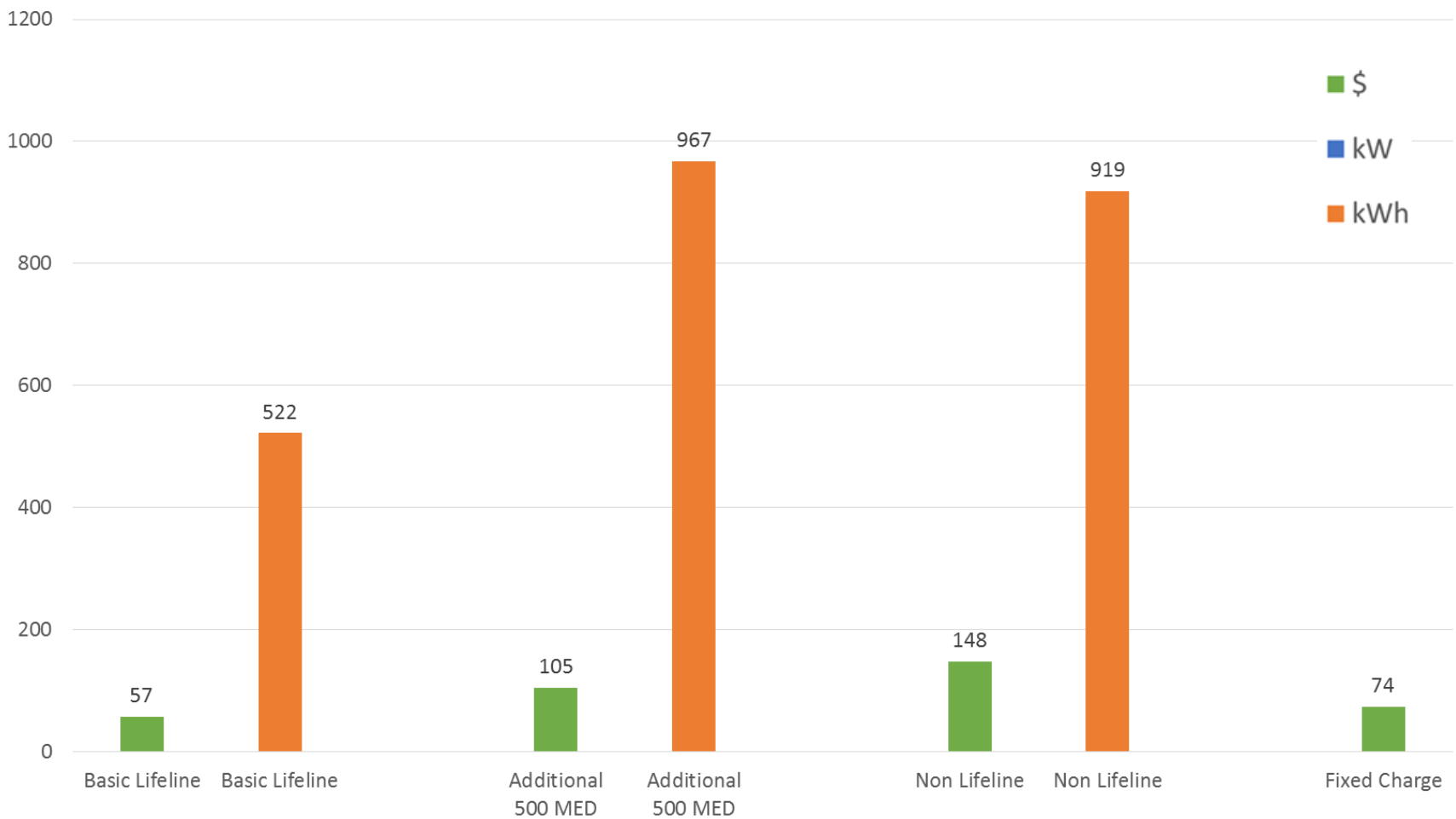
ELECTRIC CHARGES	CONSUMPTION	
CUSTOMER CHARGE		$6.52
BASIC LIFELINE	522 KWH	$56.79
ADDITIONAL 500 MED	967 KWH	$105.21
NON LIFELINE	919 KWH	$148.05
UNDERGROUND SURCHARGE		$12.66
RATE STABILIZATION		$54.50
	Total Electric Charges	**$383.73**



Electricity Charge for Anaheim Public Utilities Customers

$384 Present Use

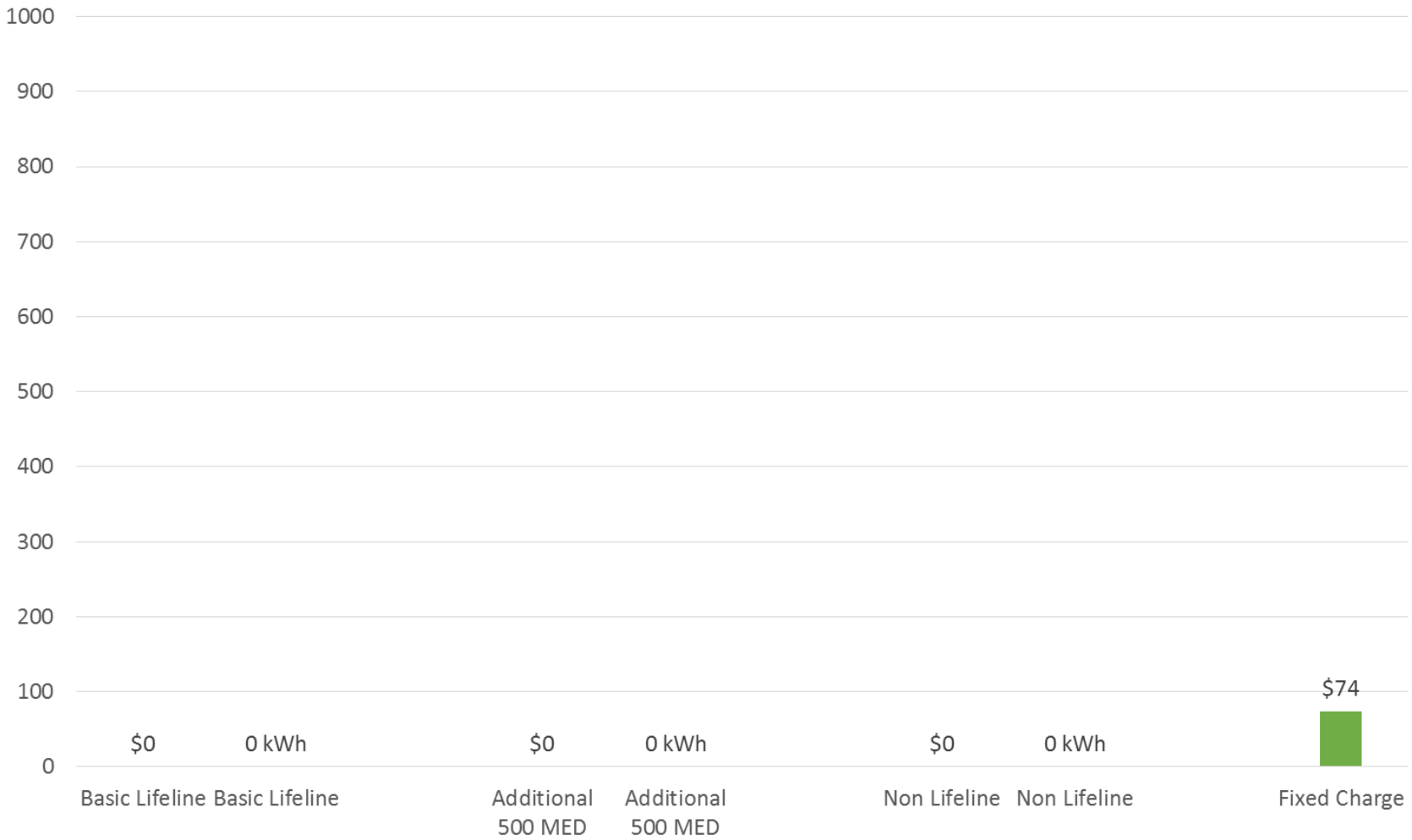
6/22/2015 – 8/19/2015



Electricity Charge for Anaheim Public Utilities Customers

$74 With 100% Energy Coming From Solar

6/22/2015 – 8/19/2015



ENERGY STATEMENT

PG&E

www.pge.com/MyEnergy

RECEIVED JUN 26 2015

Account No: [redacted]
Statement Date: 06/19/2015
Due Date: 07/06/2015

10128

2824061915

Service For:

[redacted]

Questions about your bill?

24 hours, 7 days/wk 1-800-468-4743
Business Specialist available:
Mon-Sat: 7am to 9pm
www.pge.com/MyEnergy

Local Office Address

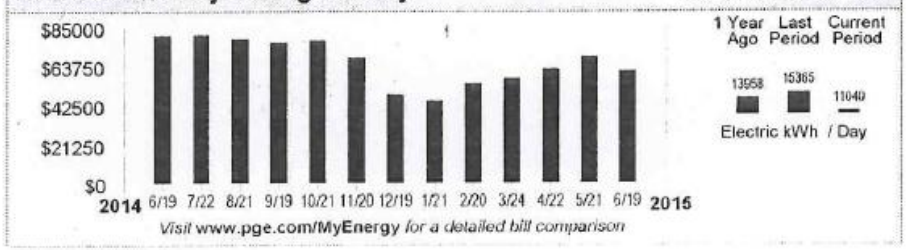
705 P ST
FRESNO, CA 93721

Your Account Summary

Amount Due on Previous Statement	$68,742.82
Payment(s) Received Since Last Statement	-68,742.82
Previous Unpaid Balance	$0.00
Current Electric Charges	$60,630.80
Total Amount Due by 07/06/2015	**$60,630.80**

ENT'D JUN 29 2015

Electric Monthly Billing History



05/21/2015 – 06/19/2015

Customer Charge	30	days	@ $32.85421	$985.63
Demand Charge				
Max Peak	760.000000	kW	@ $18.53000	14,082.80
Max Part Peak	704.000000	kW	@ $4.03000	2,837.12
Max Demand	760.000000	kW	@ $14.71000	11,179.60
Energy Charges				
Peak	67,200.000000	kWh	@ $0.14772	9,926.78
Part Peak	74,400.000000	kWh	@ $0.10275	7,644.60
Off Peak	189,600.000000	kWh	@ $0.07311	13,861.66
Power Factor Adjustment (@ 84.00% Power Factor)				16.56
Energy Commission Tax				96.05
Total Electric Charges				**$60,630.80**

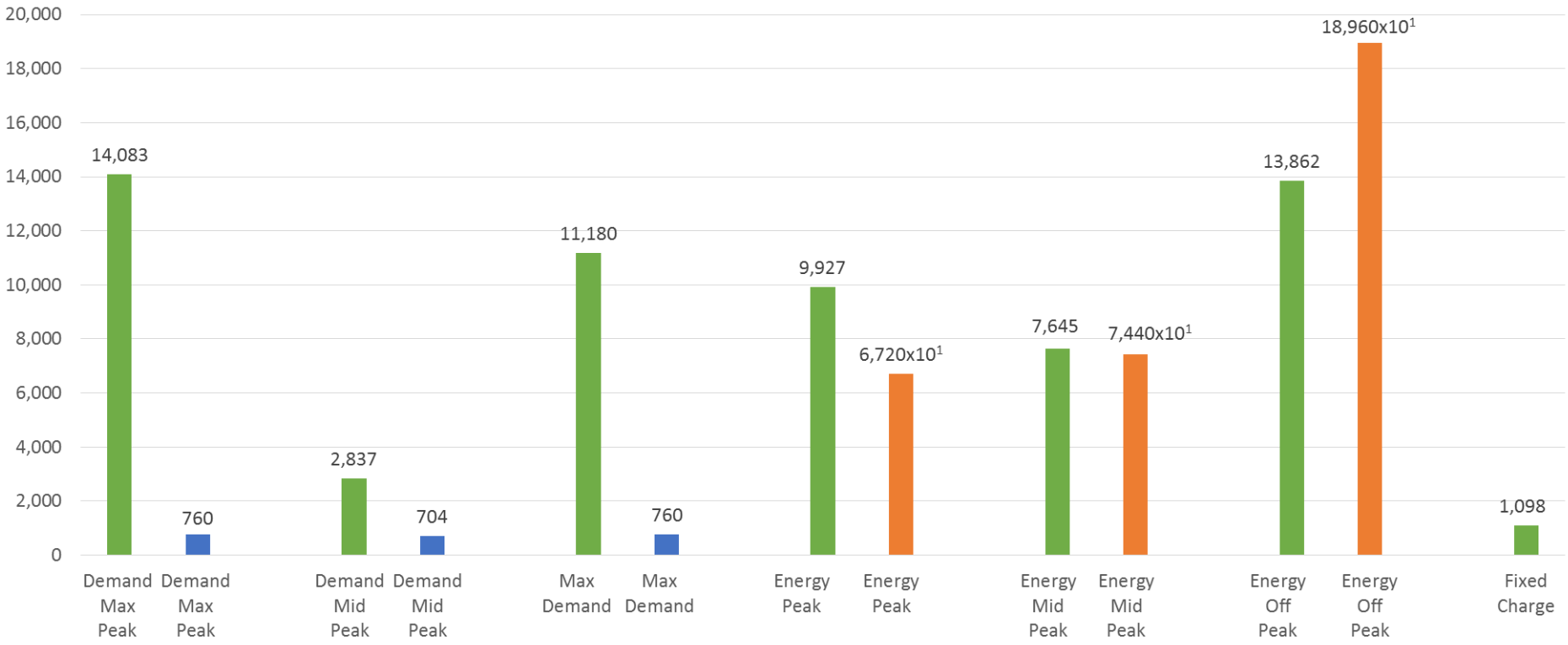
Rate Schedule for Customers with Max Demand of over 1000 kW

	Secondary Voltage	
Total Customer/Meter Charge Rates		
Customer Charge Mandatory E-20 ($ per meter per day)	$32.85421	
Optional Meter Data Access Charge ($ per meter per day)	$0.98563	
Total Demand Rates ($ per kW)		
Maximum Peak Demand Summer	$18.53	(I)
Maximum Part-Peak Demand Summer	$4.03	
Maximum Demand Summer	$14.71	(I)
Maximum Part-Peak Demand Winter	$0.27	
Maximum Demand Winter	$14.71	(I)
Total Energy Rates ($ per kWh)		
Peak Summer	$0.14772	(R)
Part-Peak Summer	$0.10275	(R)
Off-Peak Summer	$0.07311	(R)
Part-Peak Winter	$0.09636	(R)
Off-Peak Winter	$0.07431	(R)

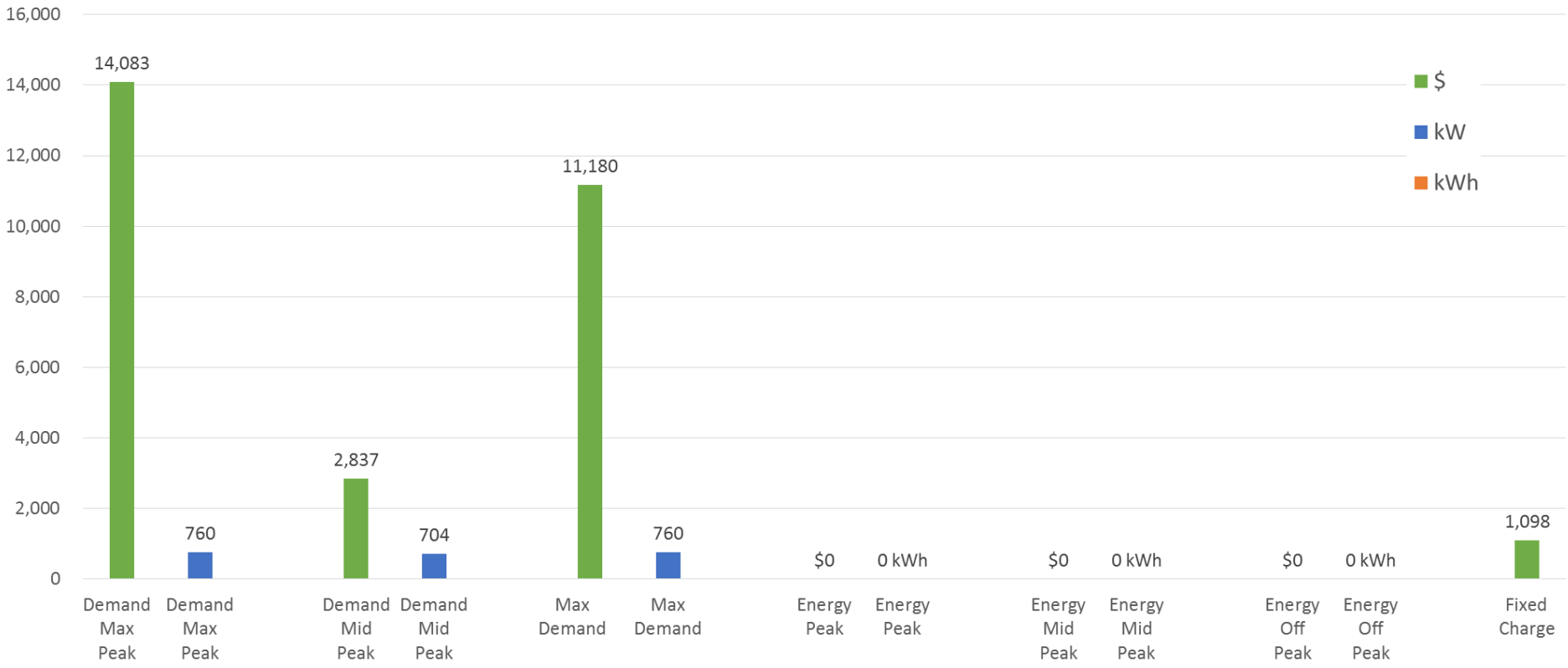
Definition of Time Periods for PG&E

SUMMER	Period A (Service from May 1 through October 31):	
Peak:	12:00 noon to 6:00 p.m.	Monday through Friday (except holidays)
Partial-peak:	8:30 a.m. to 12:00 noon AND 6:00 p.m. to 9:30 p.m.	Monday through Friday (except holidays)
Off-peak:	9:30 p.m. to 8:30 a.m. All day	Monday through Friday Saturday, Sunday, and holidays
WINTER	Period B (service from November 1 through April 30):	
Partial-Peak:	8:30 a.m. to 9:30 p.m.	Monday through Friday (except holidays)
Off-Peak:	9:30 p.m. to 8:30 a.m. All day	Monday through Friday (except holidays) Saturday, Sunday, and holidays

Electricity Charge for a PG&E Industrial Customer
$60,632 Present Use
5/21/2015 – 6/19/2015



Electricity Charge for a PG&E Industrial Customer
$29,198 With 100% Energy Coming From Solar
5/21/2015 – 6/19/2015



Conclusions

- Solar and wind energy are intermittent
- Dispatch-able electricity require storage
- New Lithium batteries offer opportunities
- EV charging strains power distribution system
- UCR's Sustainable Integrated Grid Initiative (SIGI) test-bed offer plug and play capabilities
- Testing and validation results give confidence to electric utilities for rapid adoption
- UCR's researchers and students offer electrical efficiency studies, analysis and help with new technology adoption to industries

Thank you

Questions?