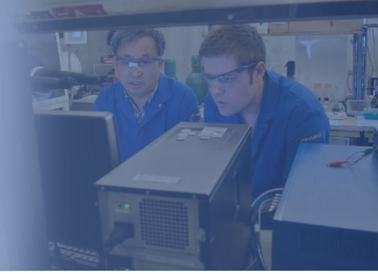
Winston Chung Global Energy Center

STATUS REPORT

JUNE 2016

UCR | Bourns College of Engineering

From the Director



For the past few decades especially, global energy demand has increased significantly. While technological advancements have improved use of natural resources, we have only scratched the surface of possibilities that can lead to a more sustainable energy future.

At the forefront of our groundbreaking energy research is the Winston Chung Global Energy Center (WCGEC), which focuses on developing emerging energy solutions related to storage, generation and distribution to advance the science and applications of energy technology.

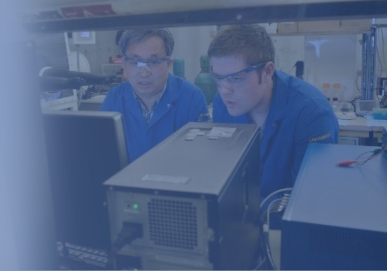
WCGEC is a leading renewable energy center and is unique in its approach that collaborators focus on real-world outcomes, combining research and education to develop practical energy applications. Its interdisciplinary platform brings together highly qualified faculty and researchers who approach energy exploration with short- and long-term benefits to maximize the return of efforts.

As a result of support from energy leaders including Chinese businessman and inventor Winston Chung, government agencies like the South Coast Air Quality Management District, and the Riverside Public Utilities, the WCGEC has continued to make successful advancements in several areas. Among the center's many significant projects is the launch of the Sustainable Integrated Grid Initiative (SIGI), a first-of-its-kind renewable energy project that manages solar power too use during peak usage hours, providing new energy management strategies impacting the city's power grid operation.

The WCGEC will continue to serve a pivotal role as changes in the way we store, generate and distribute energy shapes the way we go about our daily lives. The next major energy invention is right around the corner, and it's happening here at the WCGEC.

Reza Abbaschian, Director
Winston Chung Global Energy Center

Dual Approach to Research



Nosang Myung
WCGEC Co-Director

Renewable energy sources including wind and solar have vast potential to reduce dependence on fossil fuels and greenhouse gas emissions. Unfortunately, solar and wind energy have variable and uncertain which may lead to concerns regarding the reliability of an electric grid. Because the wind doesn't always blow and the sun doesn't always shine at any given location, there has been an increased call for the deployment of energy storage as an essential component of future energy systems that use large amounts of variable renewable resources. In addition to renewable energy storage sector, there is a great need to develop electric energy storage system to realize the next generation electric vehicles with great mileage and low cost. One of main research focus in WCGEC to development next generation high performance energy storage devices including Li-ion, Li-Air and Li-S batteries with high energy density and power density. Various nanoengineered materials with tailor-made properties are systematically synthesized and characterized to achieve our goal.

Sadrul Ula
WCGEC Co-Director

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WCGEC MISSION, VISION & GOALS

Mission

To advance solutions for today's energy demands, while developing advanced energy storage, generation and distribution research and energy-use strategies for tomorrow's applications.

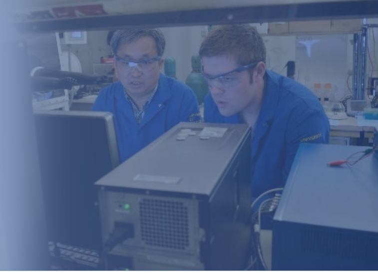
Vision

To bridge the gap between industry and academia to address energy generation, storage and distribution needs and issues.

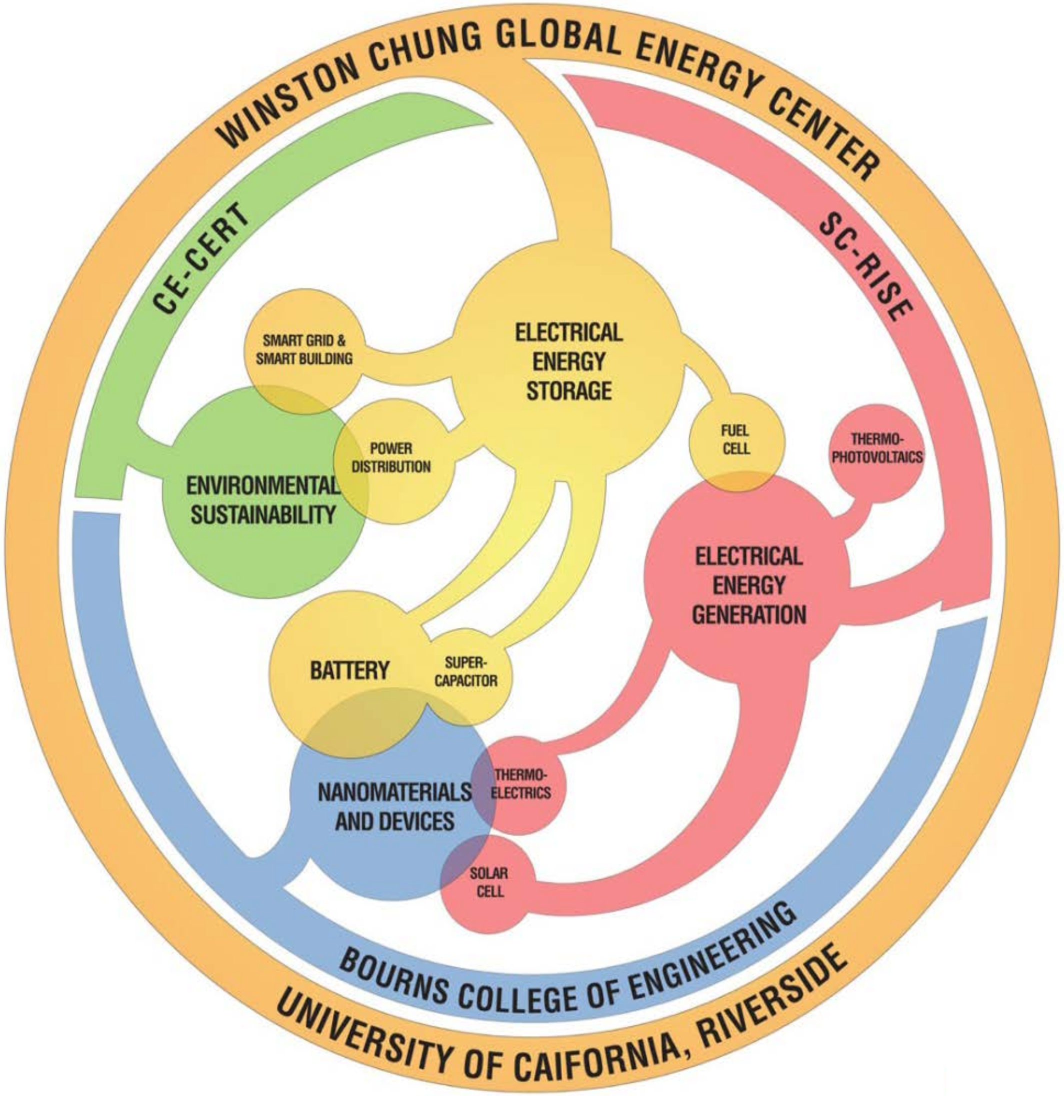
Goals

- Foster a premier academic environment of research and discovery in sustainable energy, with an initial focus on storage and distribution issues
- Educate a diverse and distinguished engineering workforce that is dedicated to addressing global energy needs
- Offer tools and training to increase the capacity of public and private planners, architects, engineers, utilities and developers to design and build energy-efficient community projects
- Build partnerships with global organizations and businesses to foster clean energy solutions
- Inspire leadership and community to take action to address energy issues in California and the world

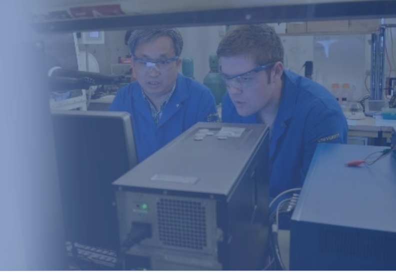
Integrated Research



The WCGEC is unique in that its findings and applications are valuable to a variety of other college research centers. The center's focus on electrical energy storage assists CE-CERT in identifying new environmental sustainability options, SC-RISE capitalizes on electrical energy generation through its innovative research and development, and the overall campus efforts focused on nanomaterials and devices.



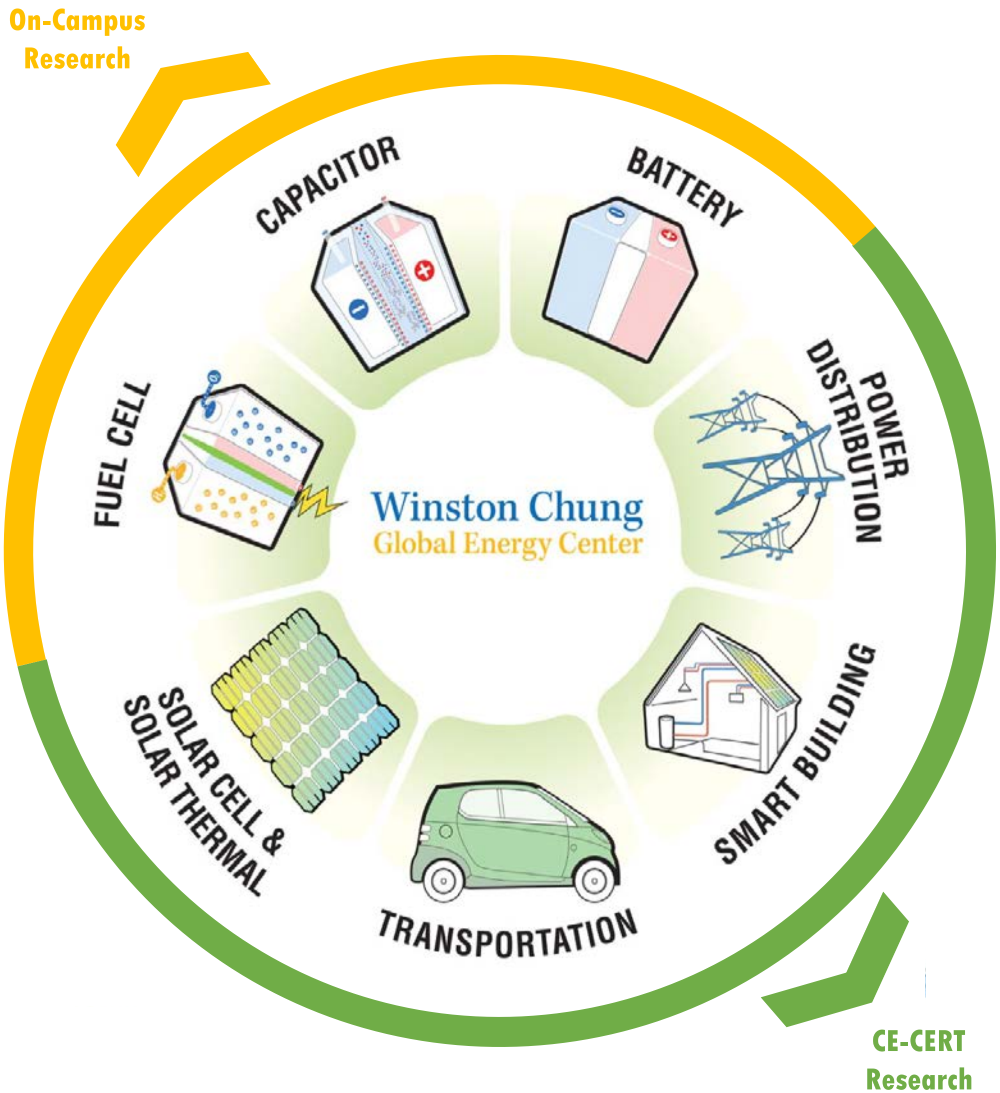
Integrated Research



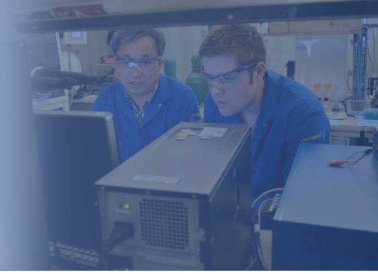
Research at the WCGEC focuses on seven major areas. Those areas focusing primarily on energy storage and generation, such as fuel cell, super capacitor and battery research, are housed mostly at the Bourns College of Engineering campus location.

Meanwhile, the implementation of these technologies, such as solar cell and solar thermal, transportation, smart building and power distribution, is researched at CE-CERT, which is located at our research center off campus at the Bourns, Inc. headquarters site.

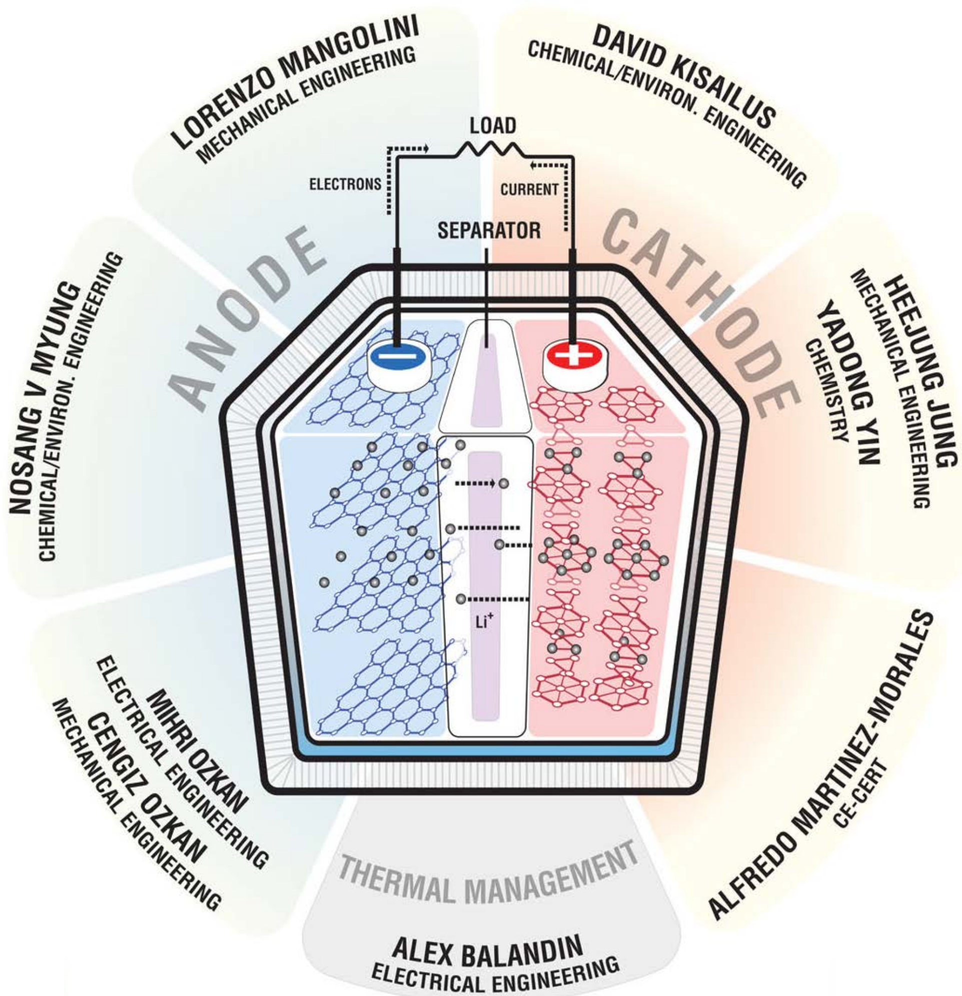
Having research occur at two locations assists in having the space available to both work in labs and test on-site.



Battery Research



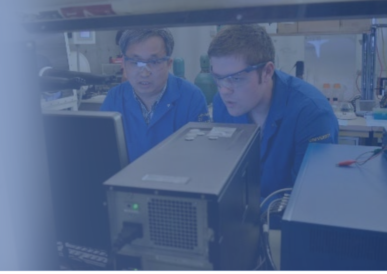
Battery advancements are a critical component to research at the WCGEC. A dedicated team of nine interdisciplinary researchers explore battery technologies to identify new ways that can further improve upon current technologies.



CENTER ADVANCEMENTS

2011-Present

Center Establishment



With successful research efforts in areas including nanomaterials and devices, electrical energy, and environmental sustainability, the College created a collaborative center that advances emerging energy technologies. The WCGEC was established as part of a $10 million gift given to the College by Chinese businessman and inventor Winston Chung. Initial offerings and goals included:

Center Offerings

- Integrated Smart Grid system (Sustainable Integrated Grid Initiatives)
  - Battery Energy Storage System (BESS)
    - Two 1.1 megawatt-hour battery storage
  - Photovoltaics
  - Electric vehicles including bus
  - EV chargers
- Shared state-of-the-art research facilities
  - Battery and other energy storage and generation system
  - Nanomaterials synthesis and characterization facilities
  - Large scale energy storage/distribution facility

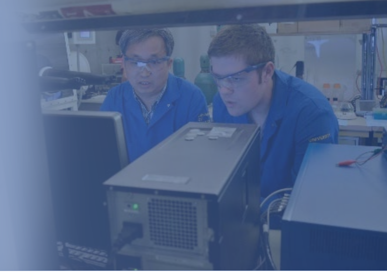
Research

- Developing an energy system by integrating power generation and storage
- Applying a center grant to various federal and local agencies
- Continue funding seed grants of innovative ideas

Facilities

- State-of-the-art materials characterization facility
- Battery prototyping & assembly facility (coin-cell level) in main campus
- Large scale energy storage/distribution facility

About Winston Chung



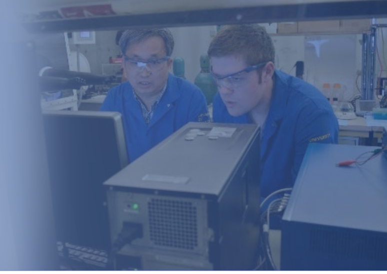
Dean Reza Abbaschian (L) with Winston Chung

Winston Chung is the founder, Chairman and Chief Executive Officer of Winston Global Energy Co., Ltd., a company engaged in the manufacturing and sales of energy storage solutions and lithium batteries. He also serves as the People's Republic of China National 863 Lithium Battery Research and Development Center Director and Chief Scientist, and invented the world's first plastic lithium ion rechargeable battery among other superior innovations that have changed the industry.

In 2011, Mr. Chung donated $10 million to the Bourns College of Engineering. This gift, along with subsequent donations, led to the college's newest building to be named Winston Chung Hall and the establishment of the Winston Chung Global Energy Center among other recognitions.

His philanthropic contributions, coupled with his clean energy inventions, result in generations of students and faculty researchers sharing their knowledge with global communities and lead to the development of new materials and energy sources.

Looking Ahead: Facility Renovations

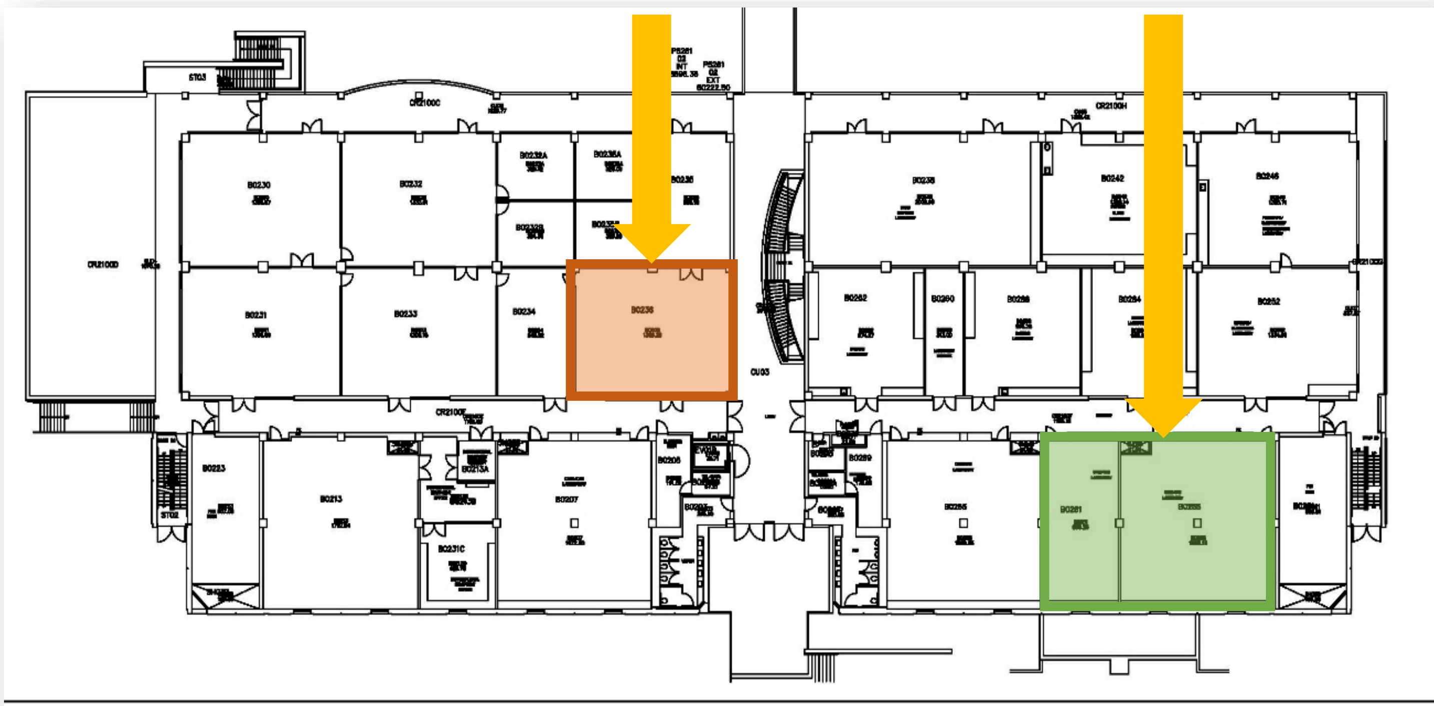


Starting in the summer of 2016, BCOE will begin work on a $10 million renovation of Bourns Hall B Second Floor to improve building systems and increase wet laboratory capacity. In addition to creating or enhancing more than 23,000 square feet of wet-lab space, the renovation will result in a new space and significant upgrade to the current WCGEC facilities on campus.

Bourns Hall B Second Floor

Current Lab Space

Proposed Lab Space



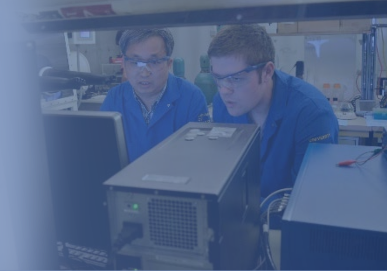
New Lab Features

More than **double** the area of work space

Upgraded research facilities including new exhaust fans, air handlers, duct work, fume hoods, lab utility piping and connections and laboratory airflow controls

SIGNIFICANT RESEARCH PROJECTS & FINDINGS

Research Projects



Large Scale Power Generator/Storage/Distribution Projects

Sustainable Integrated Grid Initiative (SIGI)

- Research facilities
- EV Chargers
- Solar PV System
- Battery Energy Storage System (BESS)
- Building Monitoring and Control
- Trolley Bus Electric Conversion and Integration
- Operational Results
- Battery Optimization – Summer
- Battery Optimization – Winter
- Demand Reduction – Riverside Public Utilities

Rancho Cucamonga Microgrid System

Chemehuevi Indian Tribe Microgrid System

UCR-LANL Energy Storage Research Institute

Economic Progress through Sustainability

Next Generation Energy Generation and Storage Projects

Silicon Quantum Dot: Graphene Composite as Anode for Li+ Batteries

Nano-Micro Hierarchically Structured Porous Metal Oxide Electrodes

Electrospun Metal Oxide Nanofiber Mats

Carbon Coated – LiFePO4 Nanowires Cathode

Biologically Inspired Synthesis & Application of Nano Structured Materials for Energy Storage

Scalable 3D Carbon Nanotube-Graphene Nano-Architectures for Supercapacitors and Batteries

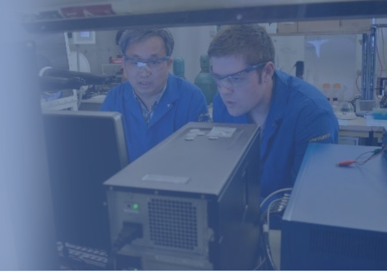
Lithium Sulfide – Polyacrylonitrile Derived Cathode Composites for Li-Sulfur Batteries

Efficient Thermal Management of High-Power Batteries and Battery Packs with Graphene-Based Materials

Solar Driven CO2 Conversion to Fuels

Nanostructured Pathway Biocatalysts for Enzymatic Fuel Cells

SIGI



About

SIGI was established as part of the WCGEC, is located at BCOE's Center for Environmental Research and Technology (CE-CERT) and is one of the largest integrated renewable energy projects of its kind in the state. A key component of the project is to demonstrate that electric vehicles can be seamlessly introduced into the existing grid system through "smart integration" of renewable energy, storage and advanced dispatch controls.

Key Project Features

Load Management

- Reduces risk of grid failure/blackout (due to decreased peaks)
- Increased predictability of demand (flattens peak demand)

Outage Prevention

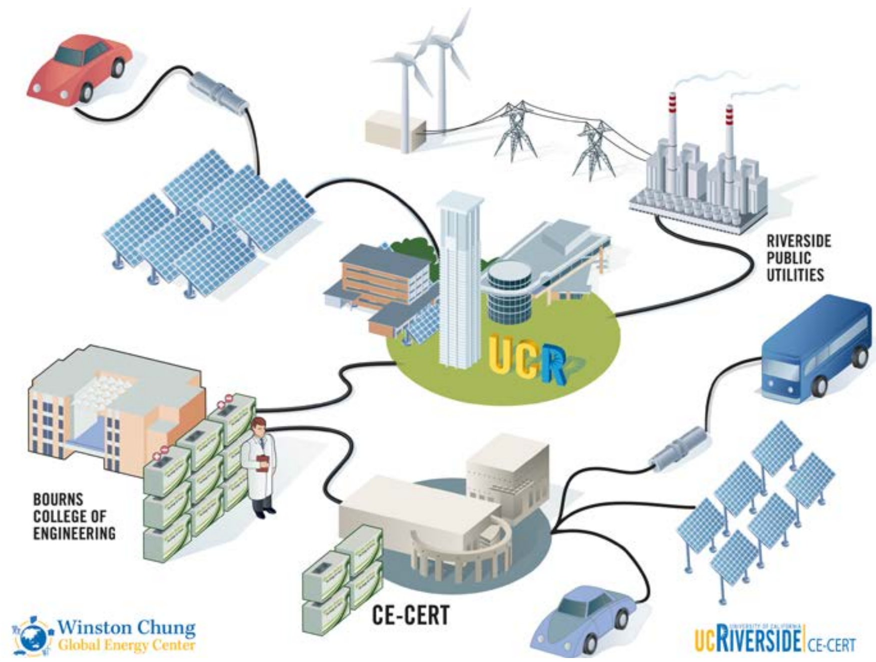
- Relieves stress on grid

Outage Support

- Battery dedicated to critical loads

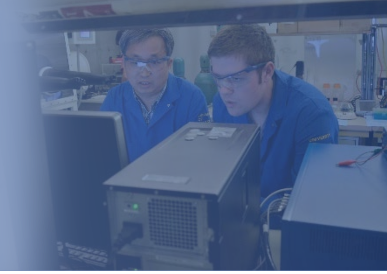
Distributed Energy Resource Support

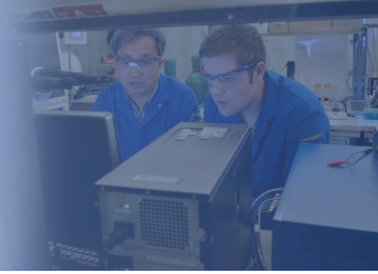
- Microgrids support distributed solar systems



Project Partners

SIGI: Research Facilities





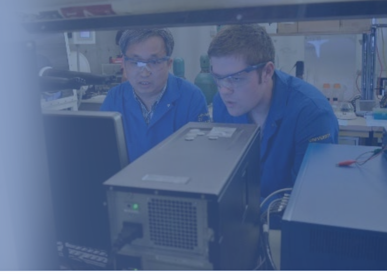
SIGI: EV Charger

About

- EV charging is monitored and managed
- Battery Energy Storage utilized to offset energy demand from EV charging
- Renewable PV energy is integrated with EV charging needs
- Optimized algorithms utilizing EV, Building, Solar, and Battery Energy storage profiles
- Vehicle to Grid energy management strategies are being incorporated
- Peak energy loads are reduced in spite of higher energy demand from EV charging

CE-CERT's Administration Building Level II Chargers

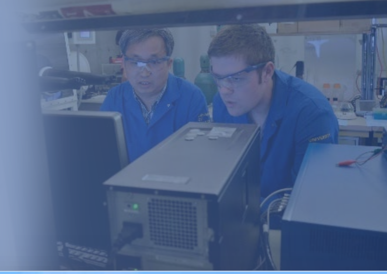
SIGI: EV Charger

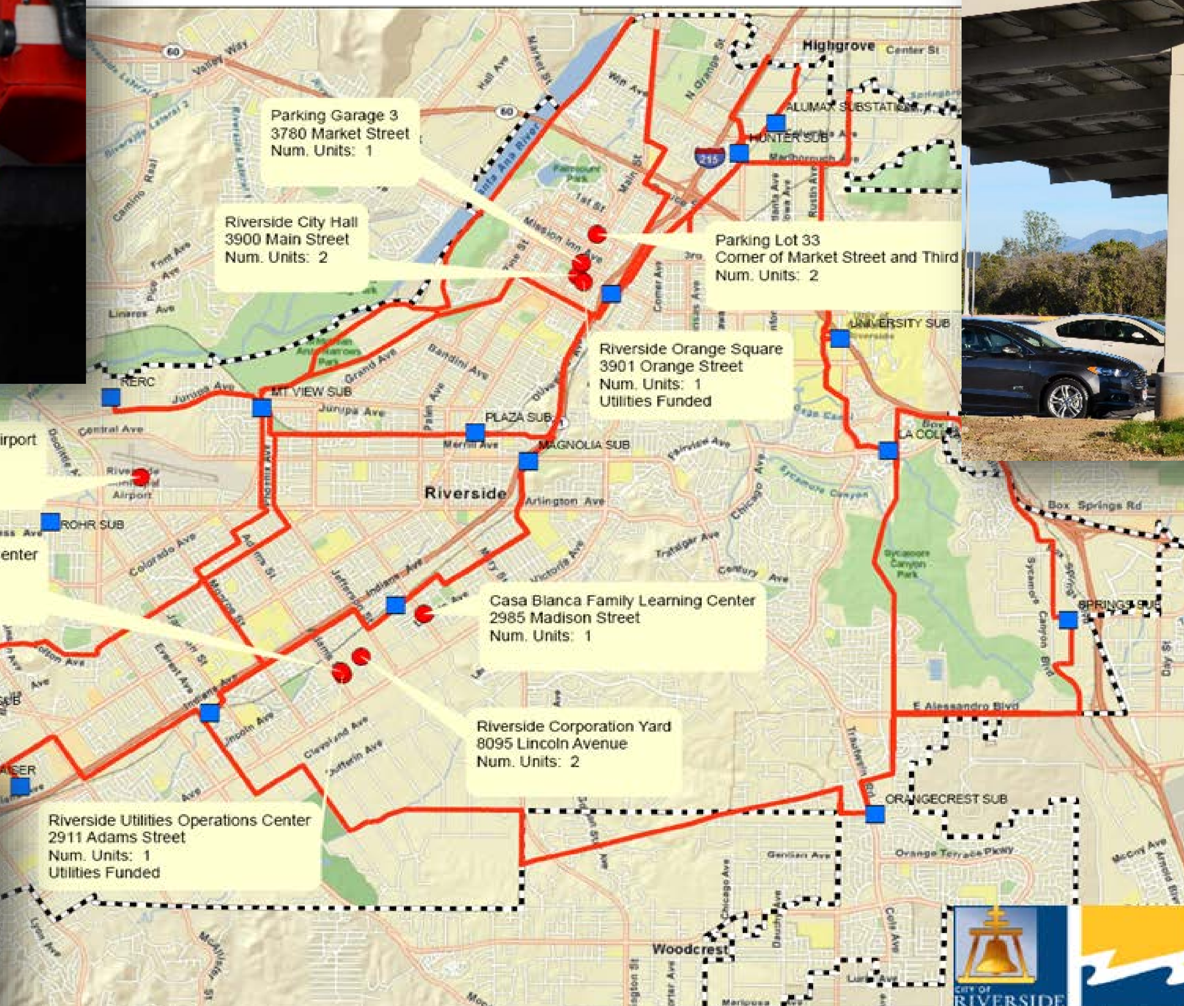


26 Level-2 chargers placed throughout the City of Riverside, the chargers service fleet and private vehicles

Level-3 chargers installed in the Fall of 2015 and service the electric trolley and other fast charging vehicles

SIGI: Citywide EV Chargers





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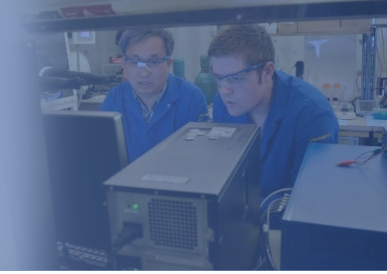
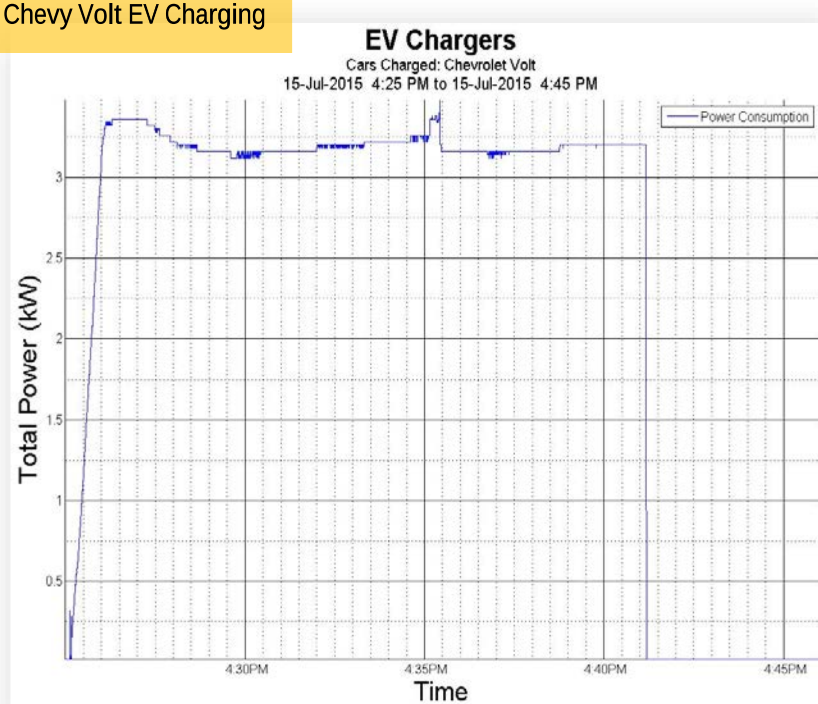


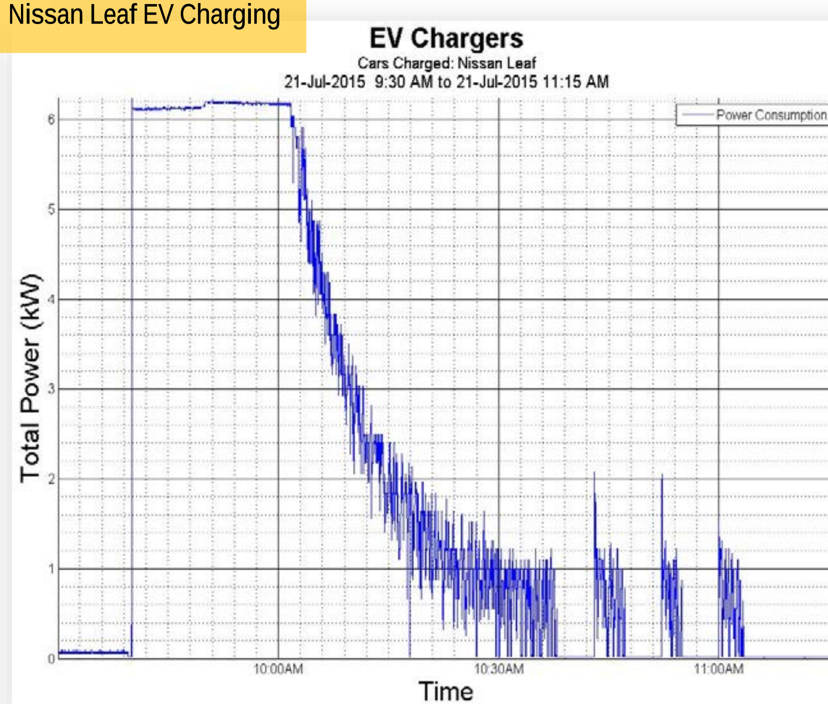
Results

- EV charging characteristics are monitored to determine frequency, duration, profiles, and energy impacts
- EV profiles evaluated include the Chevy Volt, Nissan Leaf, Ford Fusion and Mitsubishi Miev
- Energy profiles are dependent upon length of charging event, vehicle type, and battery State of Charge
- EV charging profiles require complex algorithms to manage integrated energy strategies within a microgrid

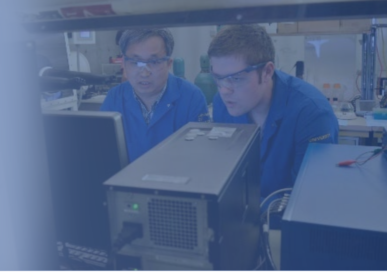
Chevy Volt EV Charging



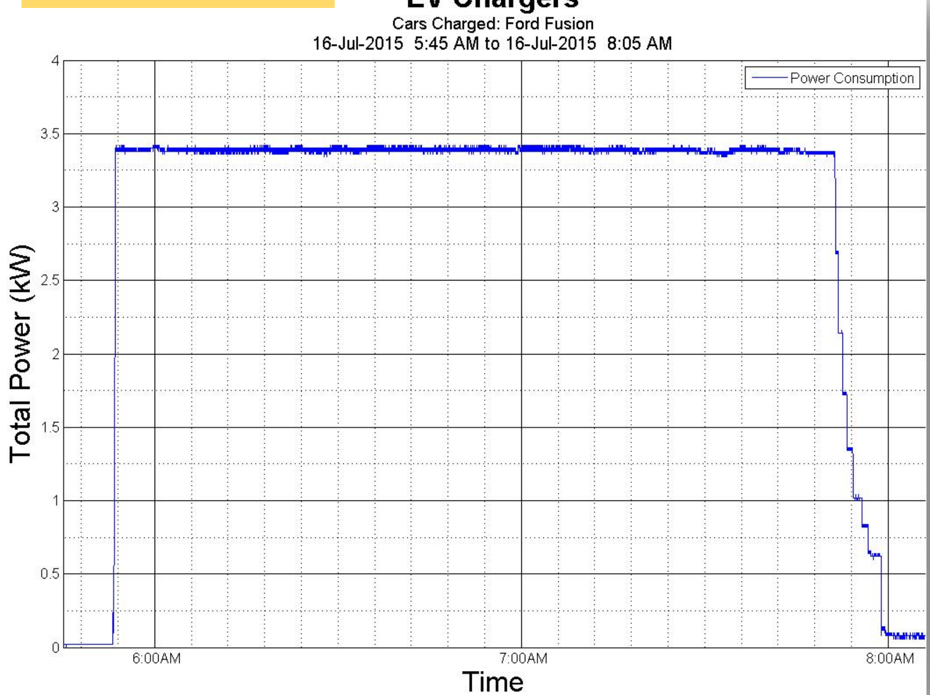
Nissan Leaf EV Charging



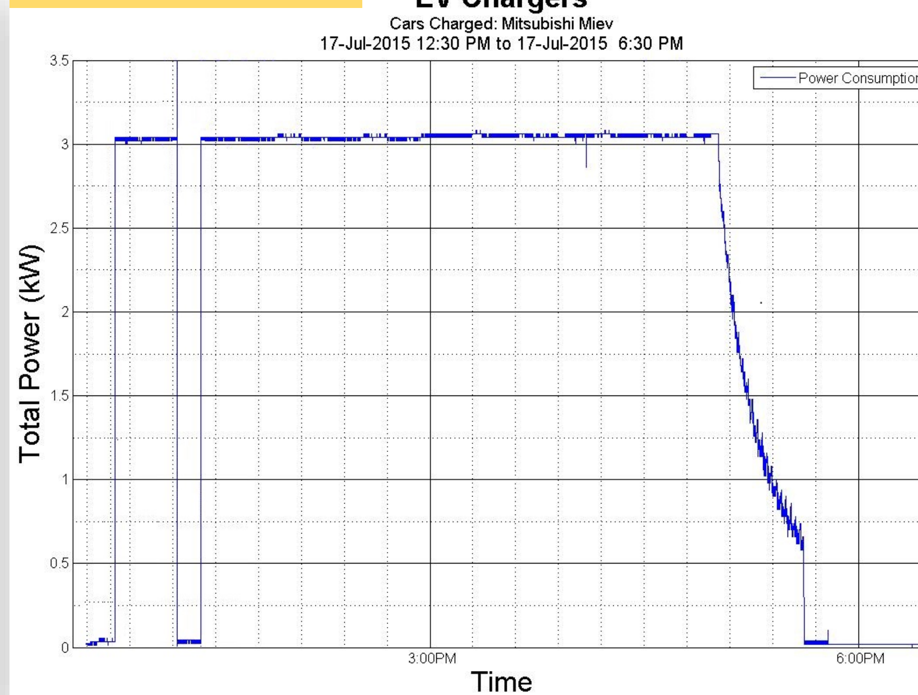
SIGI: EV Charger



Ford Fusion EV Charging



Mitsubishi Miev EV Charging



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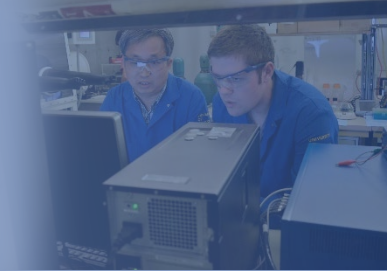
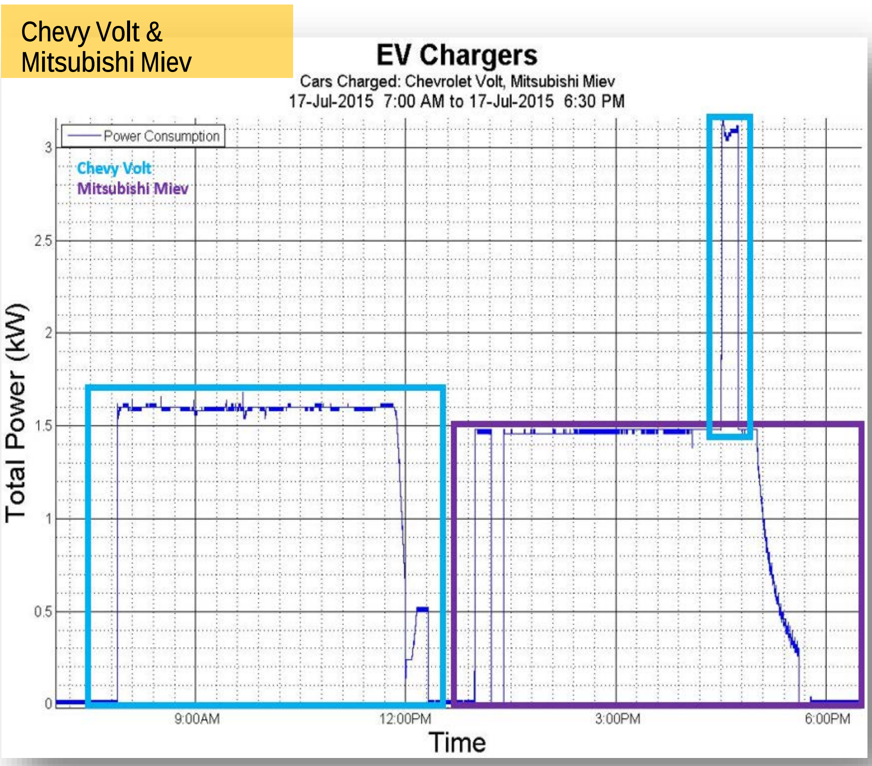
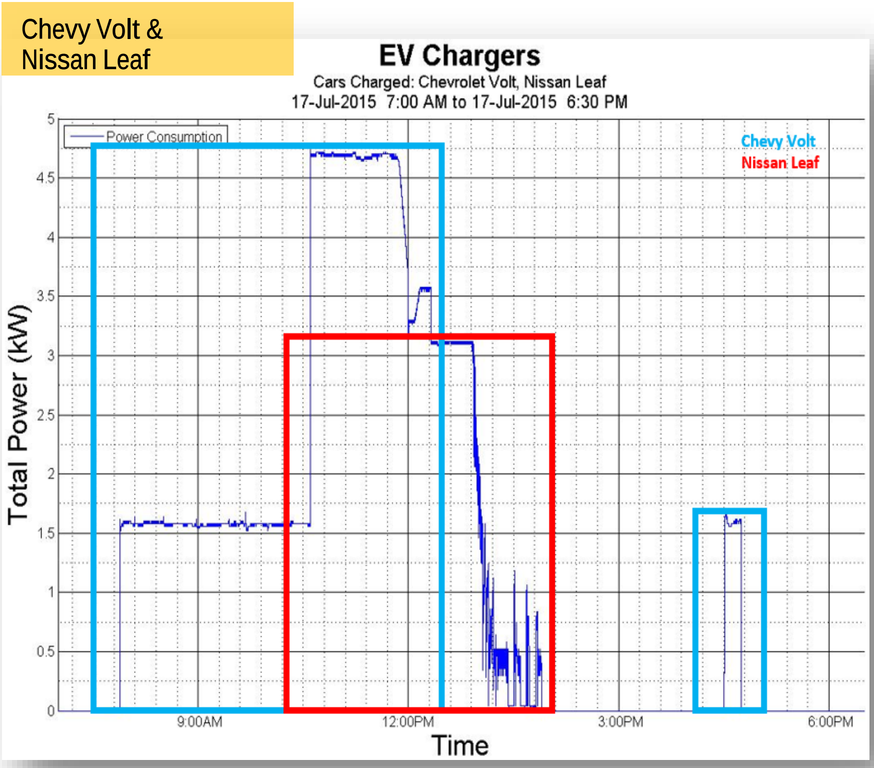


- Simultaneous EV charging events increases the complexity of microgrid energy management strategies
- Combined EV charging increases the potential for high energy demand events when improperly managed
- Energy profile complexity is dependent upon quantity of vehicles charging, length of charge, and vehicle characteristics
- Combined battery energy storage coupled with advanced energy management can offset EV charging needs





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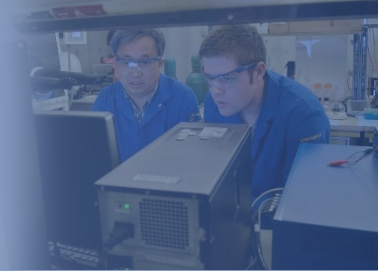

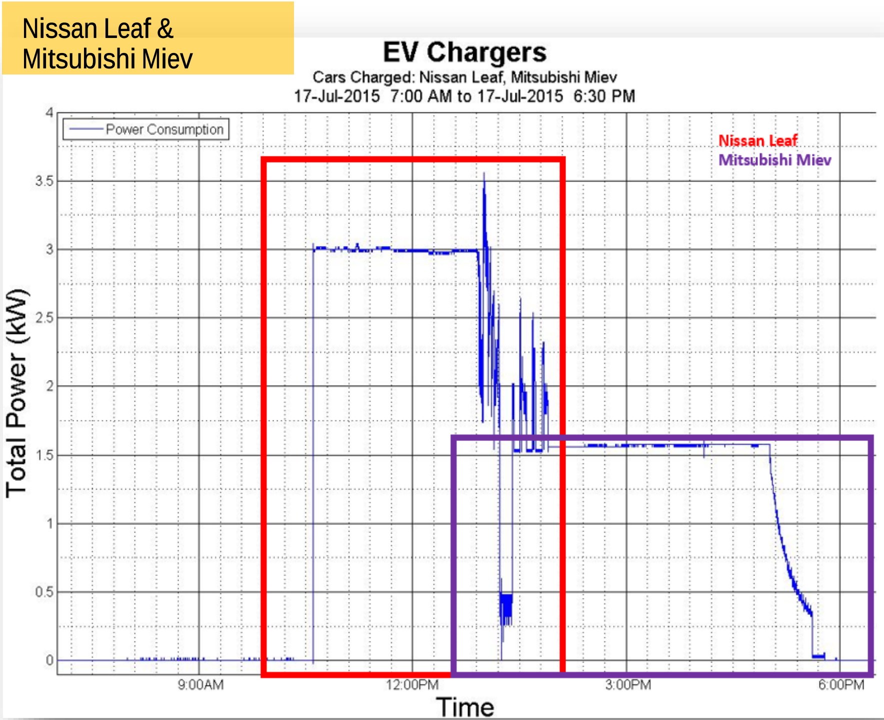

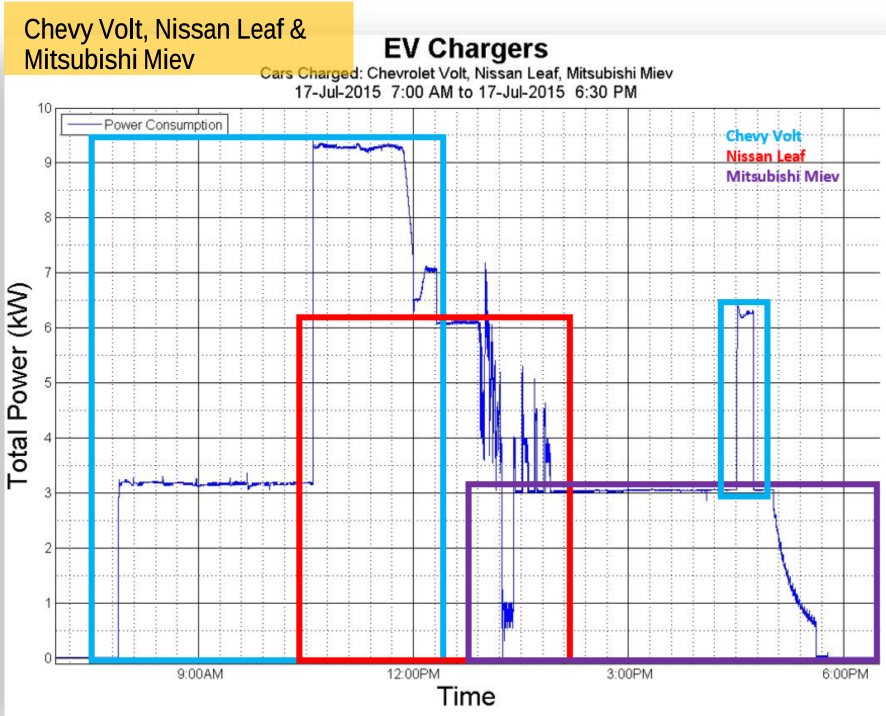

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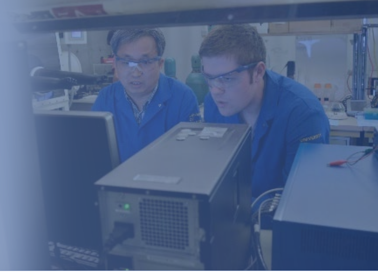
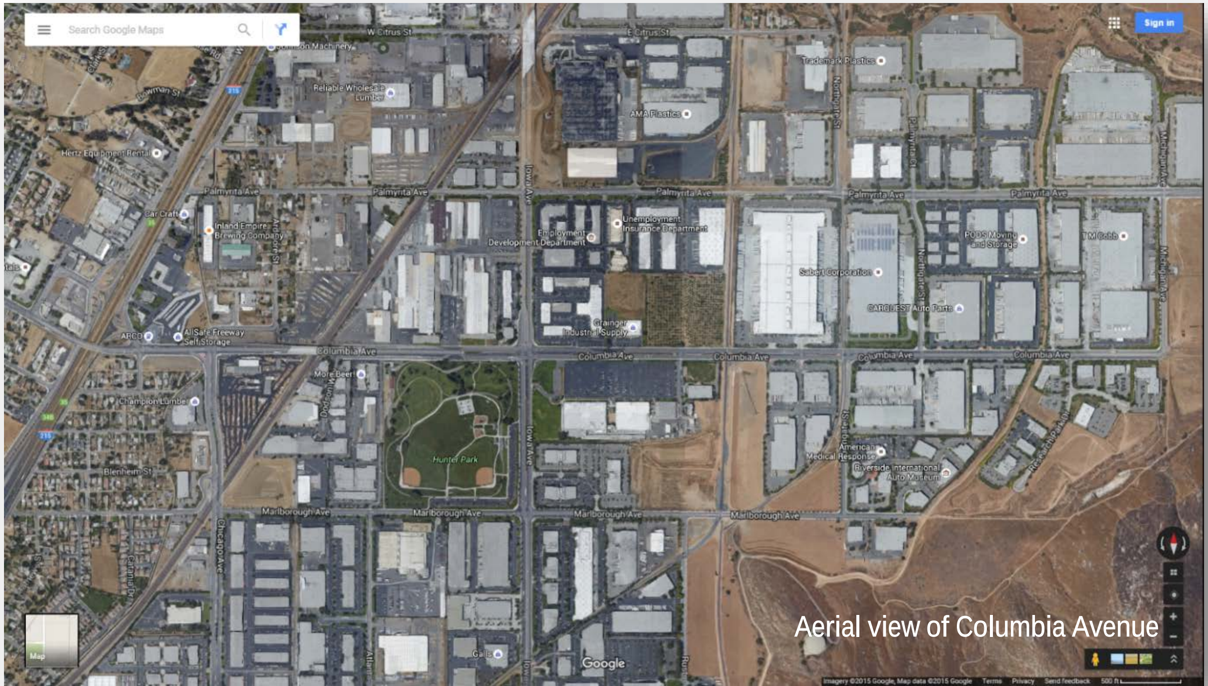


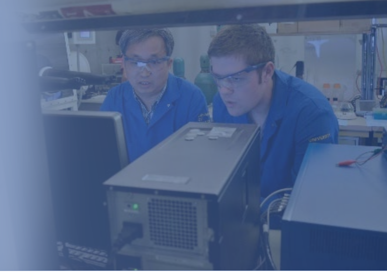
Projected Impact of High EV Charger Penetration in a Distribution Feeder Supplying a Typical Commercial/Industrial Area

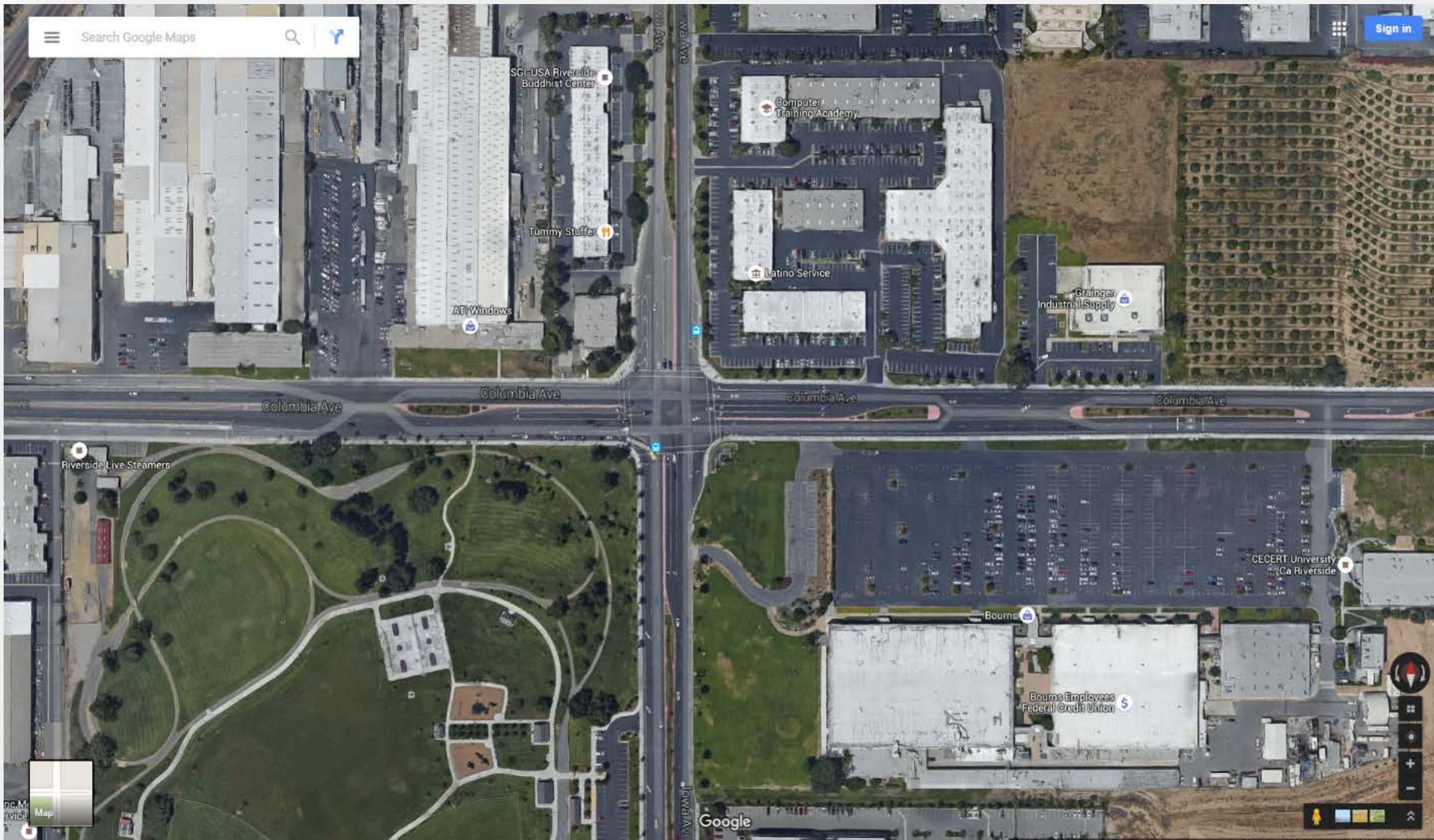
- The number of parking spaces required vary depending on the type of manufacturing, commercial, or industrial use
- U.S. Parking Industry generates more than $25-30 billion in gross parking revenue
- According to the U.S. Census Bureau, it is estimated there are more than 105 million commercial parking spaces in this country
- Projected EV penetrations within commercial parking creates significant energy demands and opportunities for energy management strategies



Aerial view of Columbia Avenue

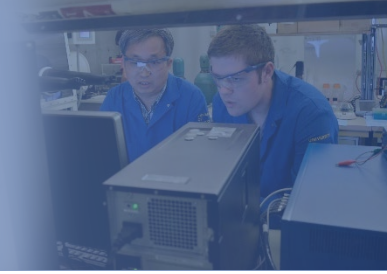
SIGI: EV Charger





Zoomed in aerial view of Columbia Avenue including CE-CERT facilities

SIGI: EV Charger



Potential Impact of High EV Penetration in a Distribution Feeder

A case study analysis along Colombia Avenue from the I-215 Freeway to Michigan Avenue, approximately 1.7-mile long industrial/commercial sector of Riverside, there is a total of 2,288 parking spaces. If 10 percent of these parking spaces are turned into EV charging spaces, roughly will be 230 EV charging stations. The measurement results presented shows an average kilowatt usage per car to be approximately 3.875 kW. The additional maximum demand created on the distribution feeder is evaluated.

Scenario 1

The additional maximum demand created by the charging stations will be approximately 890 kW. 12.47 kV feeder may have a 4MW capacity, so only 10% EV penetration adds an additional 22% to the peak capacity.

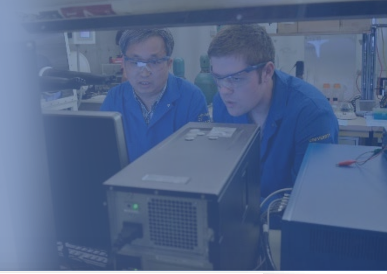
Scenario 2

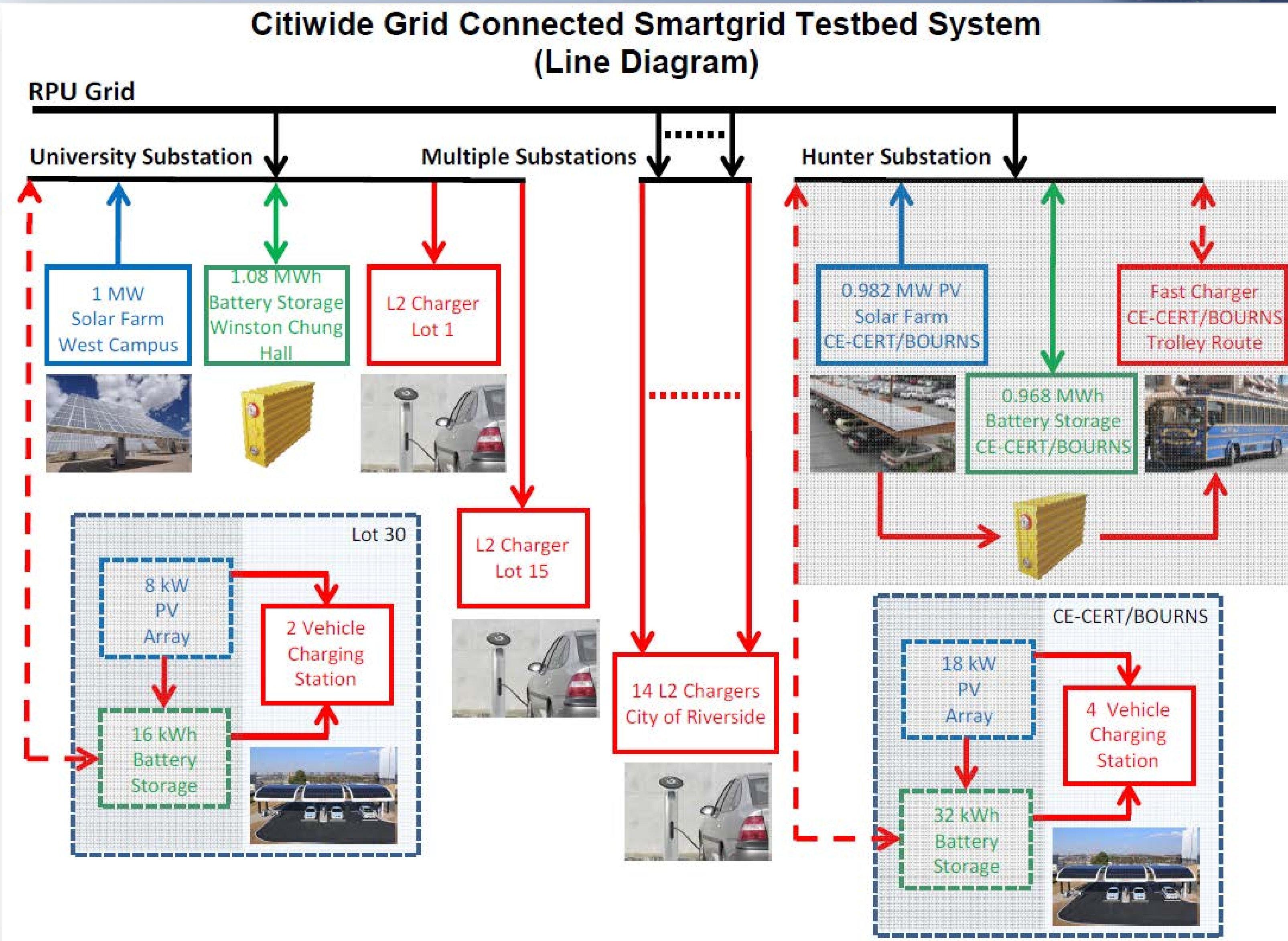
If 20% of the available parking spaces are converted into EV charging stations, then the additional maximum demand created by the charging stations will approximately be 1.8MW. A 20% EV penetration will add an additional 45% to the peak demand for that feeder.

Scenario 3

If 50 percent of the available parking spaces are converted into EV charging stations, then the additional maximum demand created by the charging stations will approximately be 4.45MW resulting in an additional 111 percent to the peak demand.

SIGI: EV Charger





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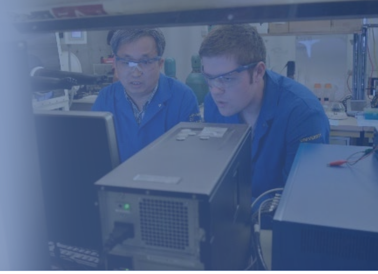
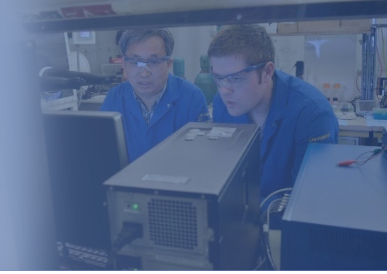


Conclusion

- EV charging should be monitored and managed to minimize energy demand impacts
- Battery Energy Storage should be integrated to offset high energy peaks due to EV charging
- Renewable PV coupled with Battery Energy Storage can minimize grid impacts of EVs
- Optimized algorithms are required to manage the energy needs associated with high penetrations of EV chargers
- Vehicle to Grid energy management strategies can provide additional energy solutions



SIGI: Solar PV System

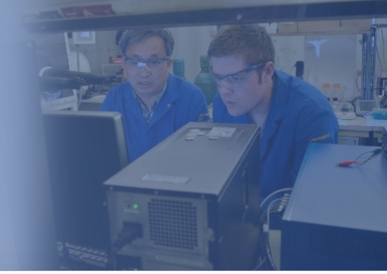
About

The CE-CERT research campus is serving as home to the newly implemented 500 kW of photovoltaic power generation and has been integrated with energy storage and smart grid monitoring and control. Solar generation is being optimized to reduce peak demand on the local distribution feeder. Facility power usage, monitoring, and control are being implemented for energy optimization strategies for daily power demand.

Locations of CE-CERT's SIGI System Components

Inverters Supplying Energy to Three Research Building

SIGI: Battery Energy Storage System (BESS)



Winston Chung Hall

One megawatt-hour of battery energy storage was installed at UC Riverside's Winston Chung Hall. The system is physically comprised of two 500 kilowatt-hour systems; each with its own inverter, battery management system (BMS), and control hardware. The Princeton Power Systems bi-directional inverters are capable of charging the batteries at a rate of up to 95kW/h, and discharging at up to 100kW/h. The Battery Energy Systems BMS provides real-time data of the system, including pack state-of-charge, pack voltage, and pack current. The control hardware provides a gateway to inverter control, inverter data, and BMS data, and allows implementation of different control algorithms such as peak-shaving, and demand-response.

Winston Chung Hall: 1 MWh Lithium Iron Phosphate Battery at BCOE


CE-CERT's 500 kWh Stationary Battery System

CE-CERT 1200

500 kilowatt-hours of battery energy storage were installed in CE-CERT's 1200 building. This system has a similar design to the systems in Winston Chung Hall and uses the same components as well.

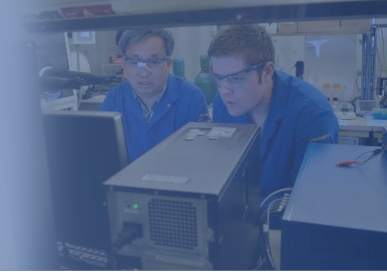
SIGI: BESS CE-CERT Mobile Battery System

About

A 500 kilowatt-hour battery system was implemented in an enclosed box trailer. This system also shares the same design as the 1200 building and Winston Chung Hall systems. The mobile nature of this system allows for connecting to the different CE-CERT buildings, and implementing different strategies. The trailer is also available for demonstration and field implementation at suitable electric utility feeder locations for congestion reduction.

500kWh Mobile Battery System showing the trailer connected to CE-CERT's admin building

SIGI: Building Monitoring & Control



About

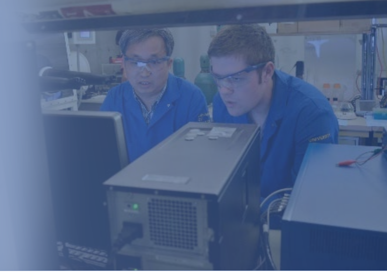
The Administration Building of UC Riverside’s CE-CERT is a 6,500 square feet office building that has typical electrical load consisting of air conditioners, office equipment, lighting, refrigerators, computers, and other plug loads. However, the main power usage is from 16 roof-mounted Heating Ventilating and Air Conditioning (HVAC) units. As these units turn on and off as needed, during certain periods of the month, all 16 units come on at the same time creating a large peak demand. Electric utilities bill the user a peak demand charge based on a 15 minutes rolling average. There is a significant potential for electrical saving when a user can manage to reduce this monthly peak.

In this project, a sensing and control system was designed and implemented for peak reduction in this building. Commercially available hardware and software where adapted to control run times of these 16 HVAC units.

There are 16 HVAC units of different sizes mounted on the roof of the administration building. Sensors are placed at each of the HVACs thermostat circuit for control purposes.

Image: Roof view of HVAC locations at the Administrative Building

SIGI: Building Monitoring & Control



Individual HVAC Demand at Admin Building

This figure shows the total power demand of the individual HVACs coming on and off on a hot summer afternoon. The power increase due to an individual HVAC turning on is shown in blue, while the power reduction is shown in red when an individual HVAC is turned off. At 12:45 p.m., all 16 HVACs turned on resulting in a cumulative peak of about 65 kW. However, within five minutes the peak was below 50 kW continuing to go down. A smart controller was designed and implemented to utilize the fact that coincidental peak usually do not last that long and may occur only a few times a day.

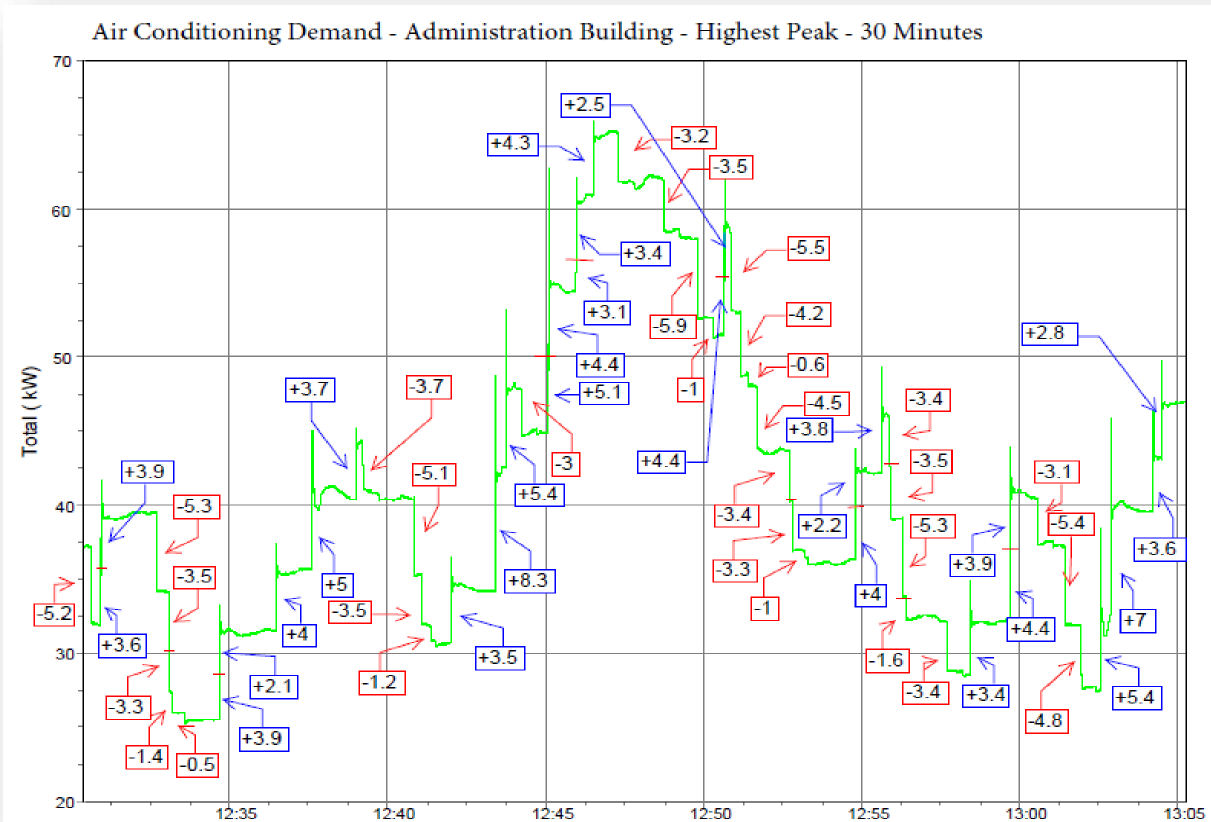
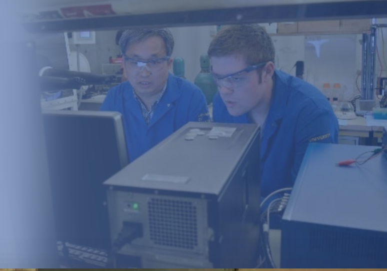


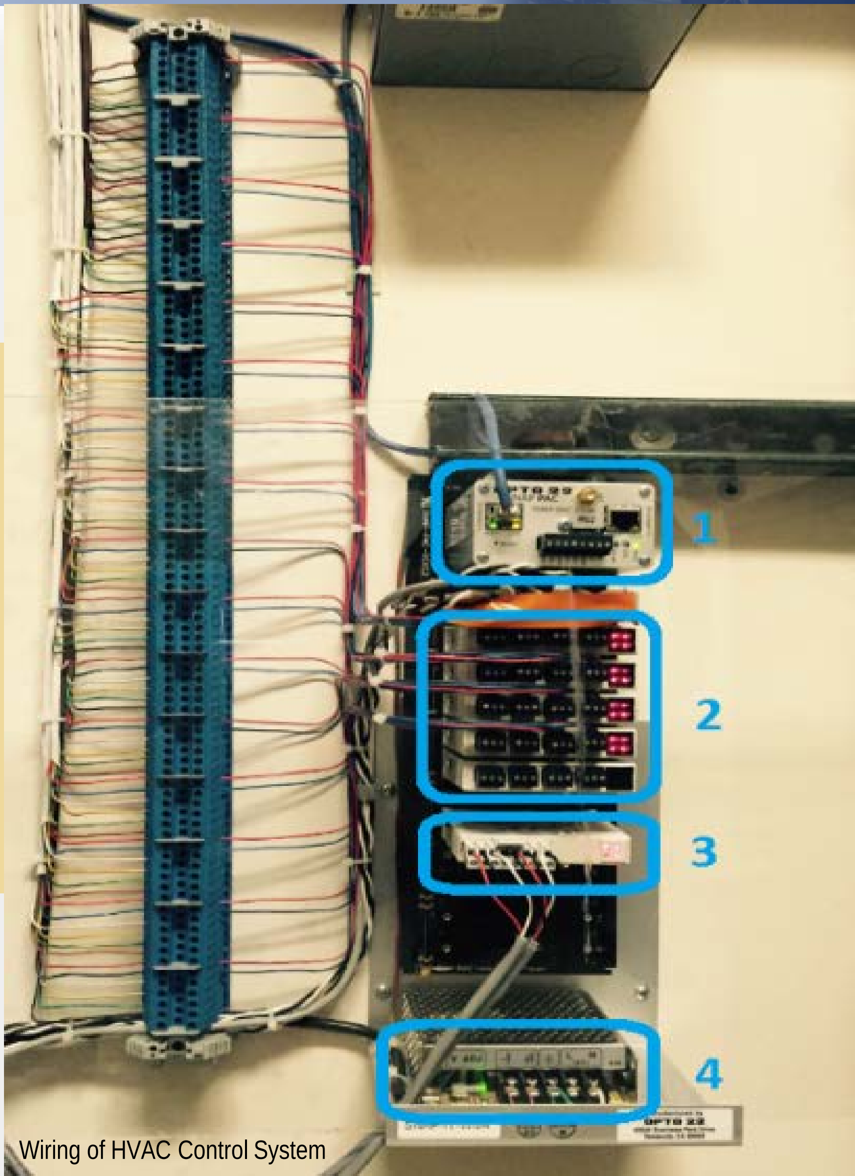
Figure 4.2 Individual HVAC Demands

SIGI: Building Monitoring & Control



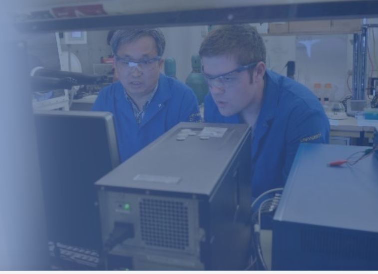
This figure shows the HVAC Controller installed in the electrical room of the Administration Building. The 16 pairs of wires shown on the left part of the figure control the thermostat signals. The hardware part of the control system contains four components:

1. The brain of the control system that is responsible for transmitting data and automatically making control decisions
2. The cluster of smart relays that turn on and off the HVAC thermostats
3. The power monitor that measures real time power usage information
4. The power supply for controller component



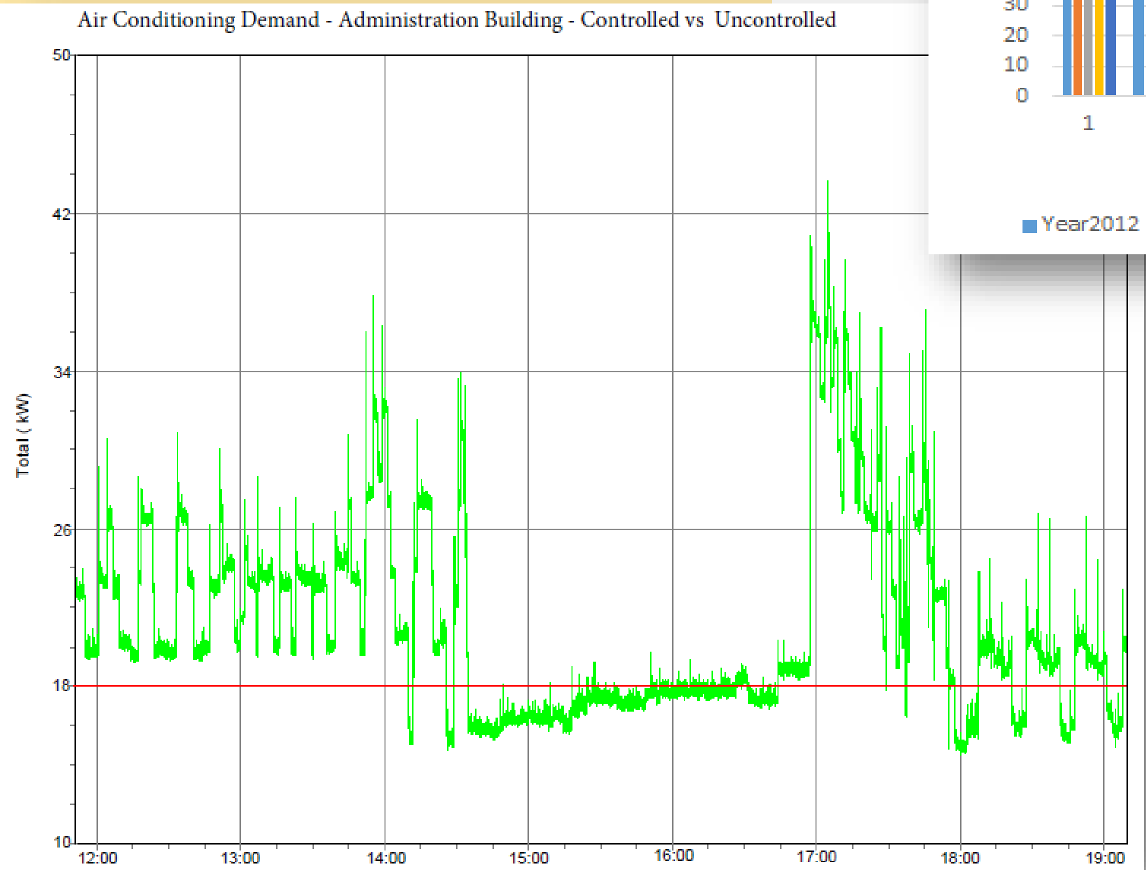
Wiring of HVAC Control System

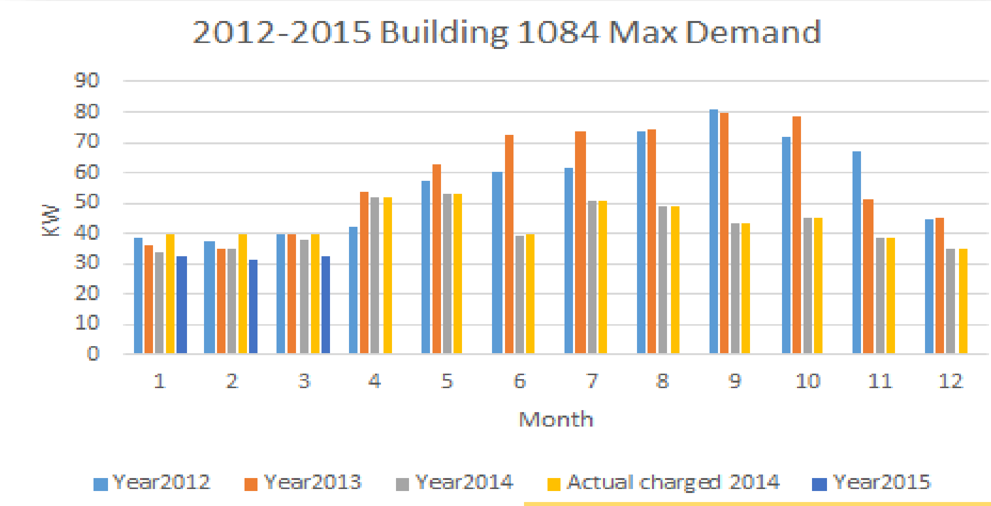
SIGI: Building Monitoring & Control



Reduction in Demand

(below) BCOE student designed controller in action capping building maximum demand at 18 kW for a duration of 2.5 hours.

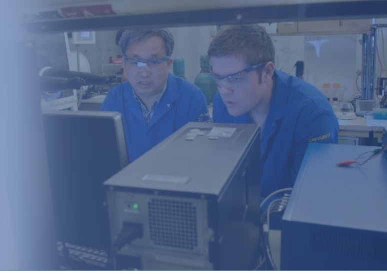




Peak Demand Reduction

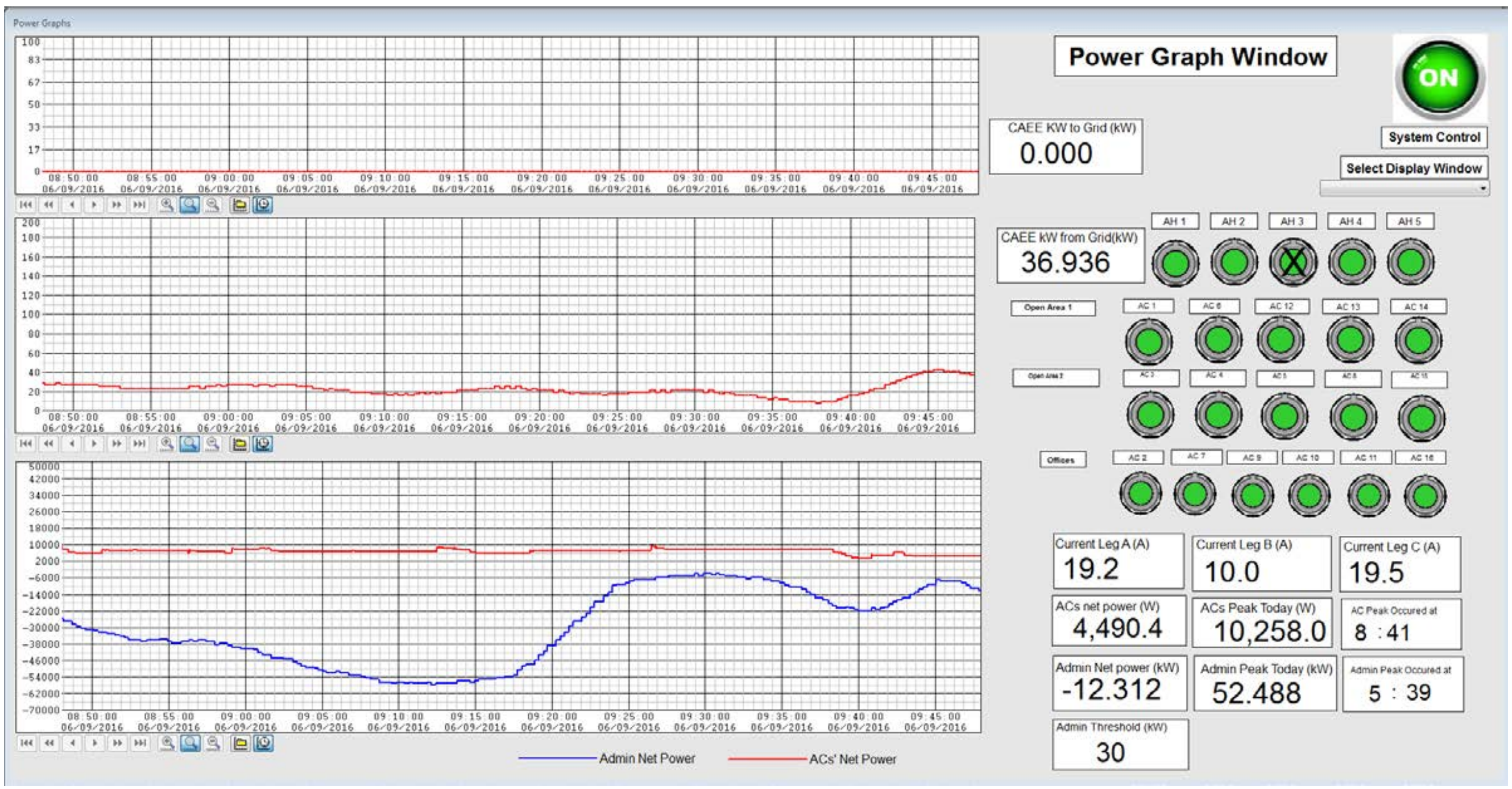
(above) Compared to years 2012 and 2013, for every month of the year, peak demand is lower in 2014 and 2015 due to the controller actions. For the month of January through March 2014, the reduction was so steep that the utility company had to charge a higher minimum demand charge (shown in yellow) which was higher than the actual peak demand.

SIGI: Building Monitoring & Control

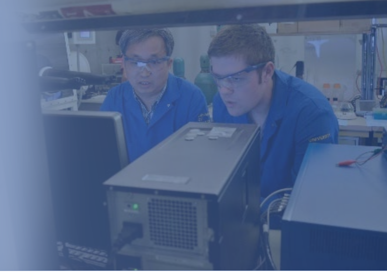


Conclusion

In this project, WCGEC students designed and implemented a controller for peak electrical demand reduction for a research/industrial building. Commercially available hardware and software were used to control 16 roof mounted HVAC system. The peak demand reduction was documented and reflected in the local utility's monthly bills. The technology developed and demonstrated here is also applicable in larger electrical energy using systems like large industrial facilities, water districts, oil fields, pipelines, etc. This can potentially have a significant impact on electrical efficiency improvement throughout the state of California and beyond.

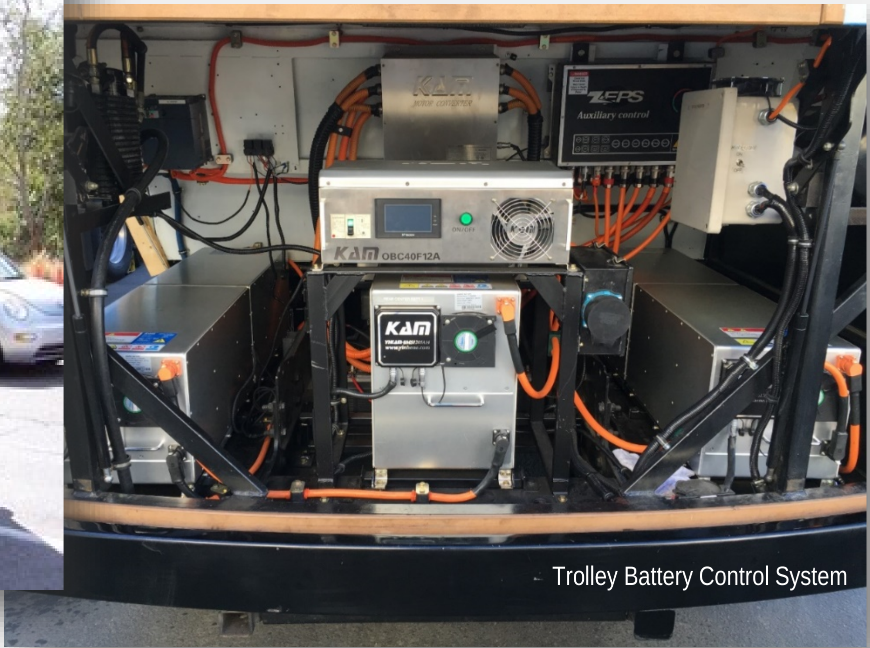


SIGI: Trolley Bus Electric Conversion and Integration



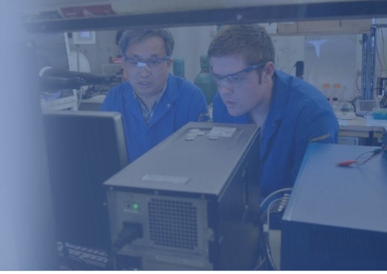
About

SIGI's 32-passenger trolley is powered by a 155kWh battery pack, powering a 350V motor with a max output of 90 kW. This diesel trolley from UCR's Transportation and Parking Services department was converted to a fully electric drivetrain.



Trolley Battery Control System

SIGI: Operational Results



About Zero Net Energy (ZNE)

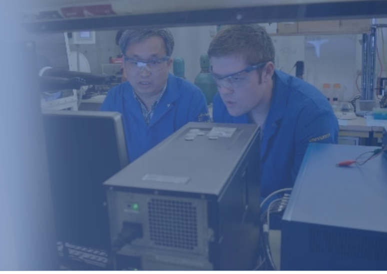
The State of California is mandating future residential and commercial buildings to be Zero Net Energy (ZNE) starting from 2020 and 2030. The Sustainable Integrated Grid Initiative (SIGI) testbed is capable of demonstrating ZNE scenario and UC Riverside CE-CERT Administration Building is chosen for this implementation. As part of SIGI project, solar PV production started in May 2014. Initially 100kW of PV was connected to this building which provided between 45 to 90 percent of this building's electrical energy needs on a monthly basis.

Design of ZNE with Additional Solar

- Total power production for a two day period for CE-CERT's Administration Building with original 100 kW solar PV configuration, shown in lower blue arch
- 90 kW of additional solar panels were transferred to achieve ZNE, potential maximum production shown in green
- A potential of 190 kW inverter would have allowed solar energy production, as shown in green
- The original 100 kW inverter cuts-off PV production at 100 kW, as shown in black
- With this new configuration, CE-CERT's administration building has a 67 percent increase in PV energy production, as highlighted in orange

Inverter Configuration Results

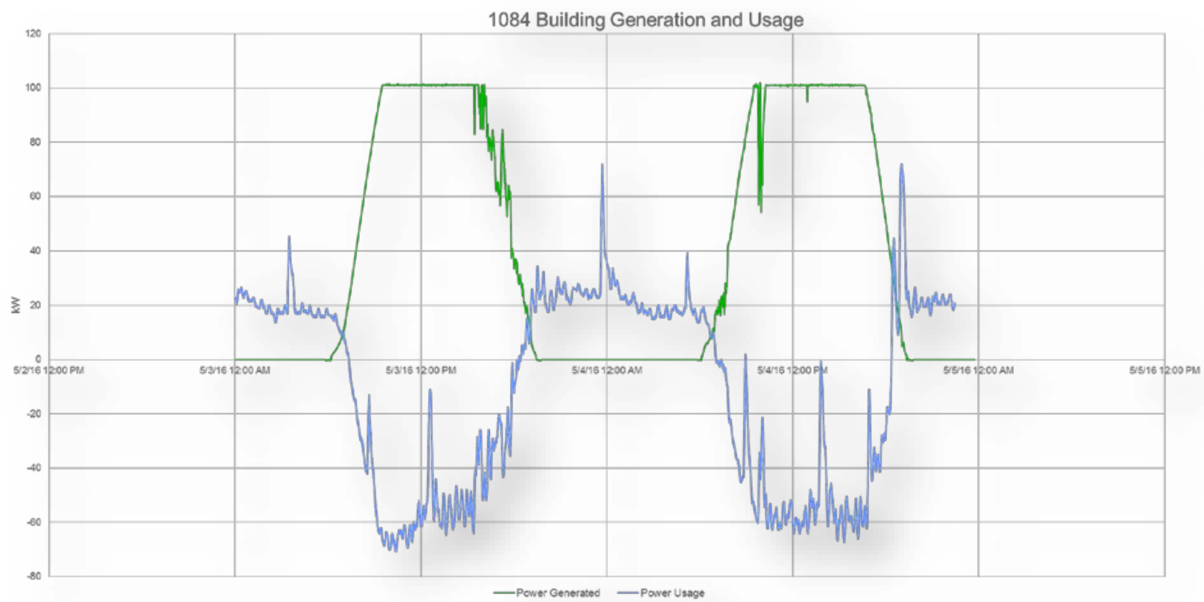
SIGI: Operational Results



New Configuration Results

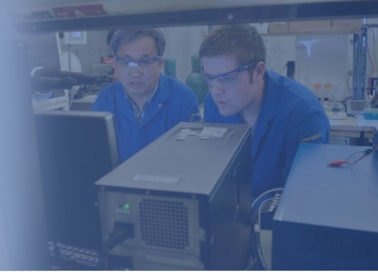
Results of the Administration Building's new configuration with PV production, shown in green with 100 kW inverter limiting solar production during mid-day hours. The figure shows actual data for May 3rd and May 4th 2016. The net electricity usage of the building, as seen by the power company meter, is shown in blue.

The blue values above horizontal zero axis are energy being imported from the grid at night while, the blue values under zero axis are energy being exported to the grid during the day due to surplus solar production. This building is net zero because the exported energy is larger than the imported energy usage.



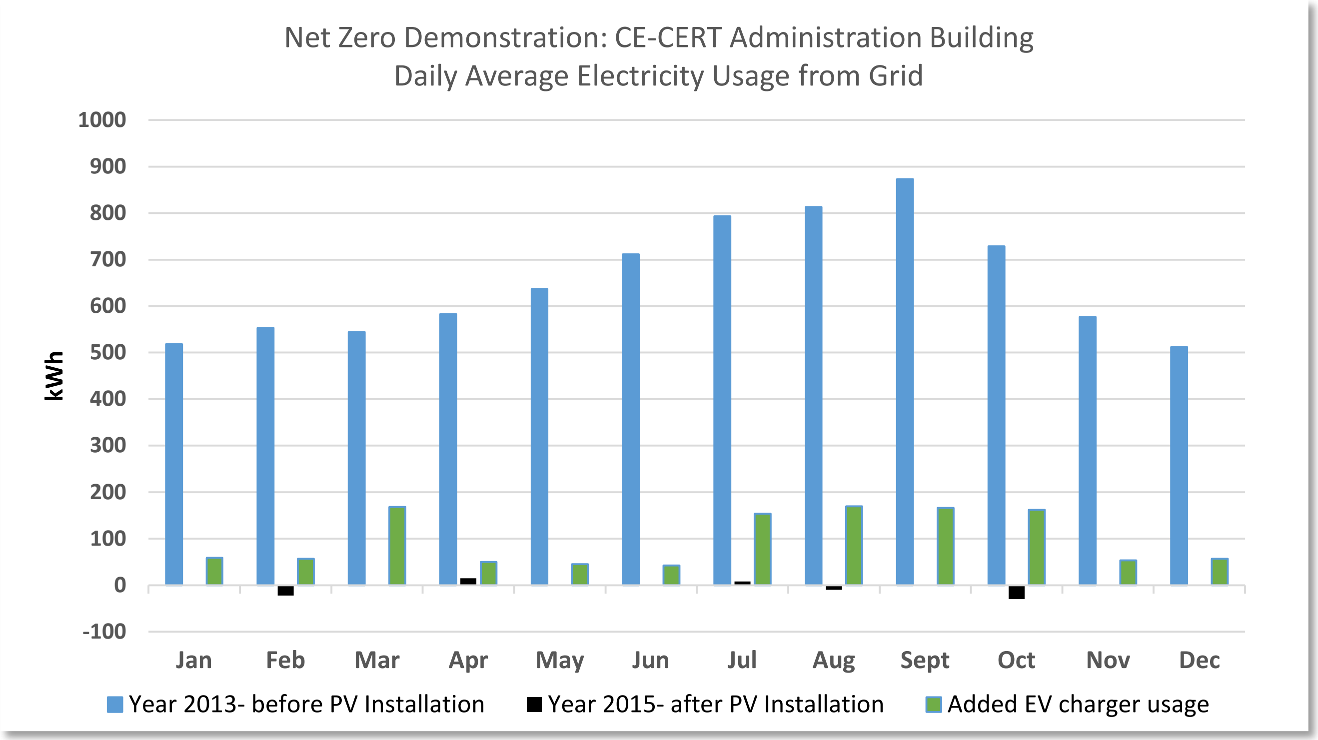
1084's Building Generation and Usage

SIGI: Operational Results

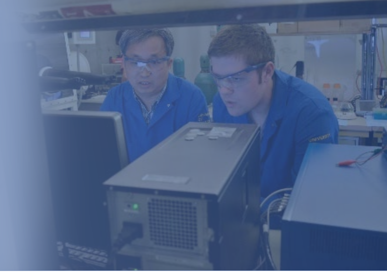


Net Zero Results

Within the figure, the blue bar represents Administration Building usage without solar during 2013. After solar PV was installed on-site, the black bar is a representation of the building's net usage from the grid. Black bars which are very small in some months are not clearly visible in the plot. The green bars represent additional pass-through energy for four Level II and one Level III EV chargers connected to the building.



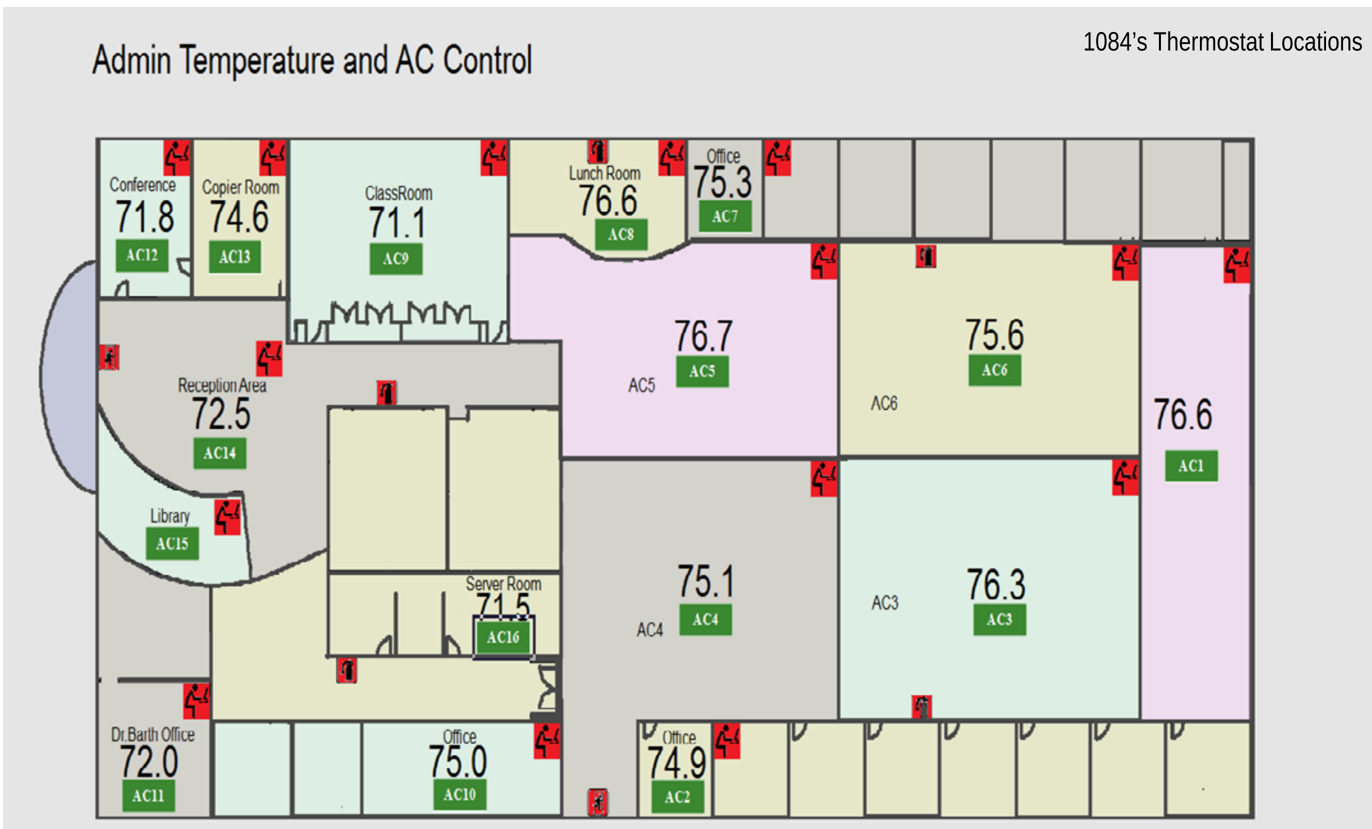
1084's Daily Electricity Usage



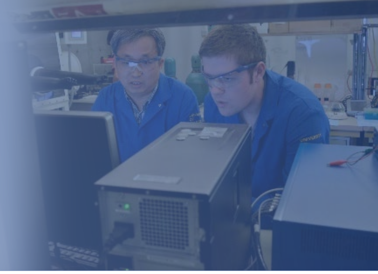
SIGI: Operational Results

Managing Peak Demands with the Help of HVACs

Proper energy management of a ZNE building requires reducing the peak demands to match available on-site renewable energy with the energy available from the utility grid. CE-CERT's Administration Building has 16 rooftop Heating Ventilating Air Conditioning units (HVAC) as shown as green in the figure. A WCGEC student designed controller monitors the building peak demand and cycles the HVACs in a way to limit the peak usage below a set value.

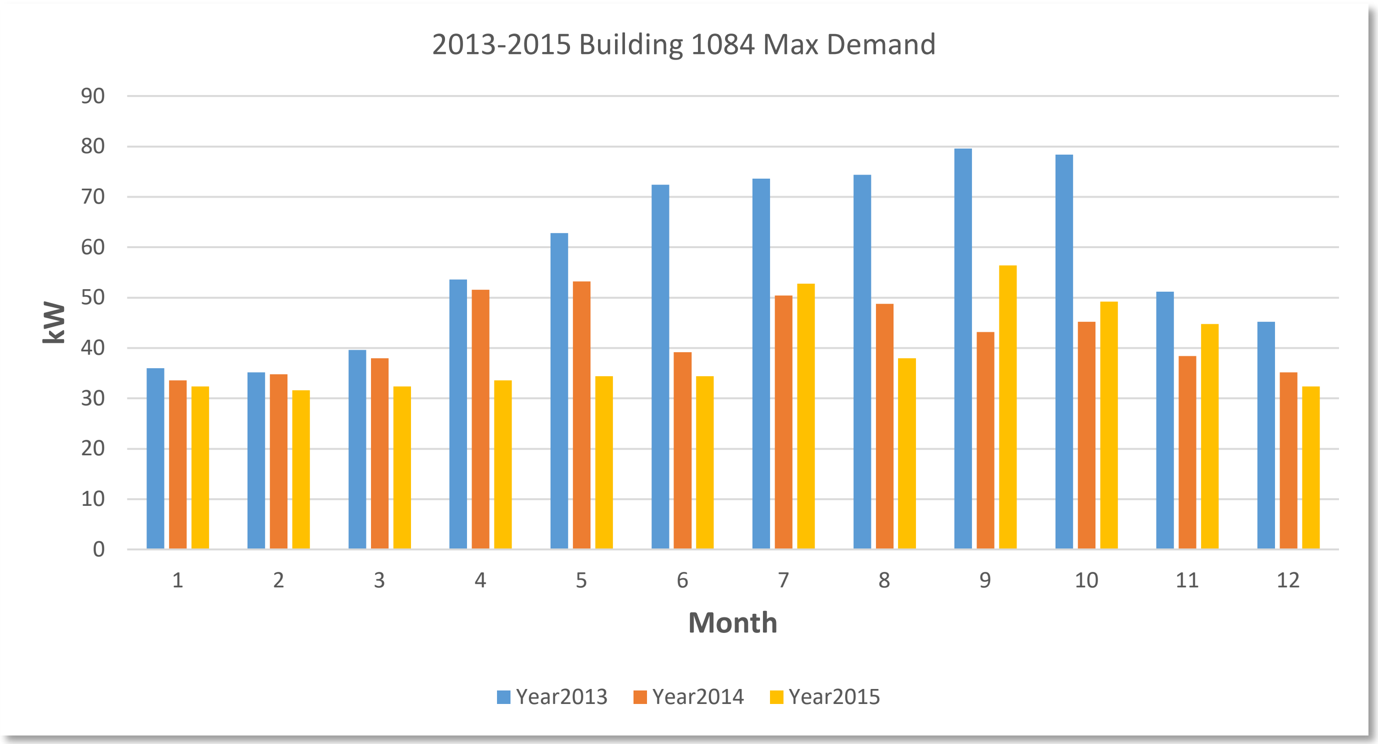


SIGI: Operational Results



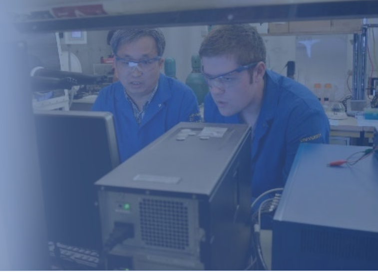
Peak Demand Reduction

For commercial and industrial customers, electric utilities charge for maximum demand in any 15-minute period over a month. The maximum demand reduction achieved with WCGEC's controller is shown in the figure below. This figure shows the peak reduction over the years from 2013 to 2015. The average building demand has been reduced by 30 percent throughout 2-year period.



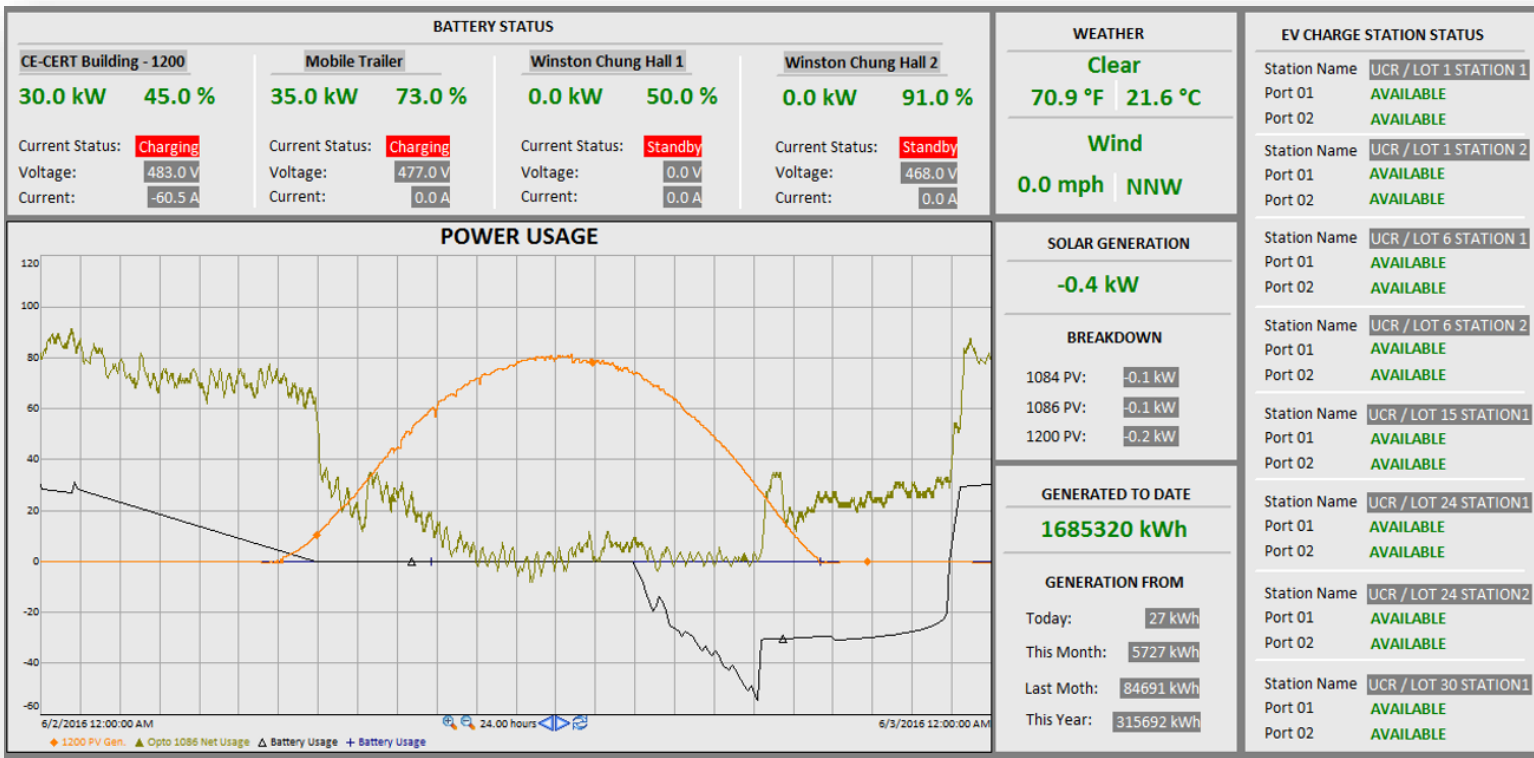
1084's Max Demand Reduction

SIGI: Operational Results

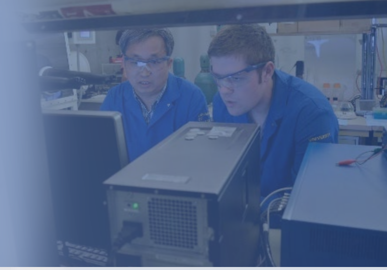


Conclusion

CE-CERT's Administration Building used to be supplied by a 100 kW solar PV system providing about 75 percent of its kWh needs on an annual basis. To make this building Zero Net Energy, additional solar PV were added to the 100 kW inverter. To avoid costly new 190 kW inverter and wiring upgrades, it was decided to utilize the existing inverter. Even though the 100 kW inverter limited production during summer mid-day hours, the increased solar production during other hours was enough to achieve ZNE for this building. To help reduce the peak demands for this ZNE building, a student designed controller managed HVAC on and off cycles. Both the ZNE and peak demand reductions were validated by monthly utility bills.



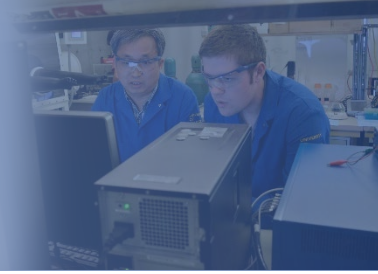
SIGI: Battery Optimization



About

Due to the intermittent nature of renewable energy sources, battery energy storage systems (BESS) have been integrated into the architecture of microgrid systems to make them more efficient and robust. Within a microgrid system, the BESS can be used to reduce the electricity cost by delivering energy during the On-Peak rate period and storing energy (i.e. charging) during the Off-Peak rate period. SIGI's real-time battery control methods collect the real-time data from the system and determines the proper value for the BESS to operate during the entire day. The control methods include algorithms and control strategies for Off-Peak, Mid-Peak and On-Peak rate periods.

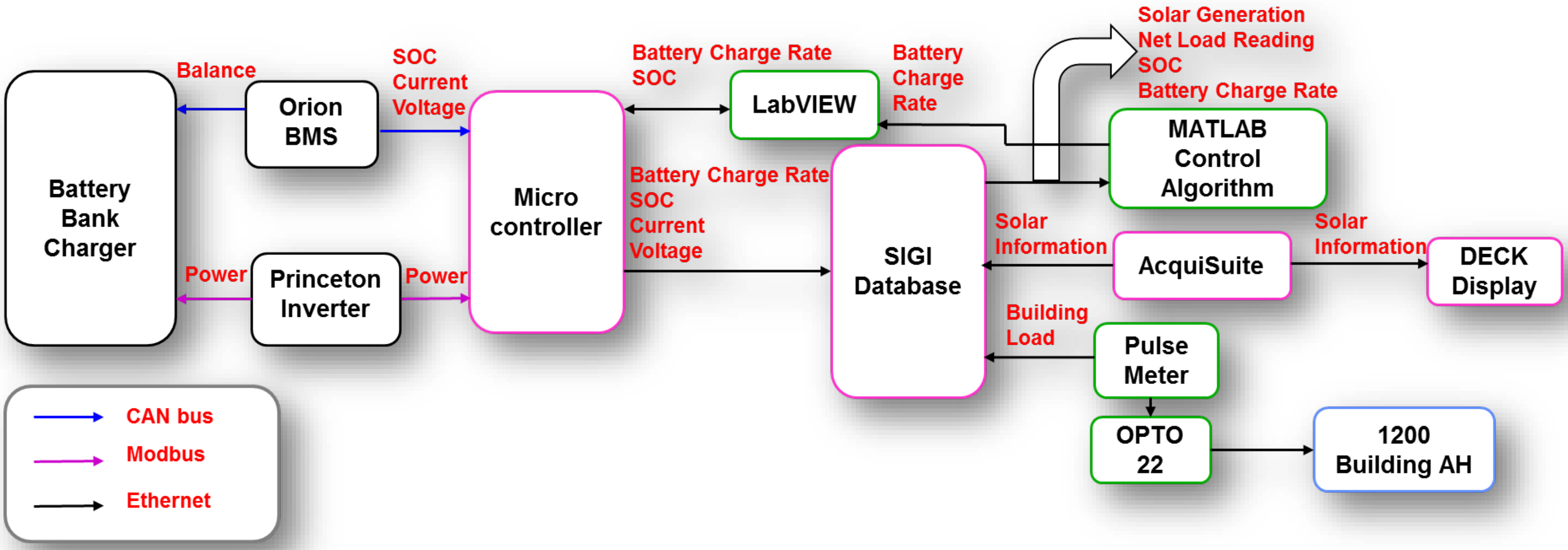
SIGI: Battery Optimization



BESS Control System (Communication and Data Flow)

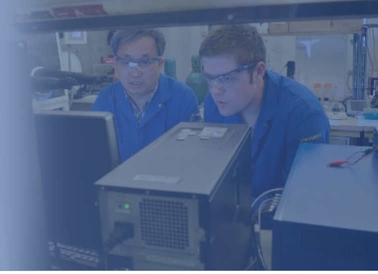
With the optimized integration of communication and control devices, the BESS can be optimized to charge or discharge at a certain kW rate to achieve optimal electricity usage and peak shaving (i.e. demand reduction).

The communication and data flow diagram shows that the controller calculates the charging/discharging rate by optimizing the electricity cost function using real-time solar generation, building usage and the battery state of charge (SOC).



Communication and Data Flow Diagram of the BESS Control System

SIGI: Battery Optimization



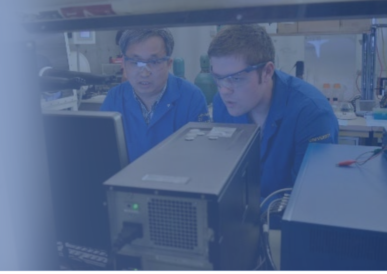
SUMMER

About

The adjusting demand threshold model predictive control (ADT-MPC) algorithm is used for the summer On-Peak rate period. ADT-MPC can better deal with unpredictable solar generation and/or changing building loads. The On-Peak threshold under this algorithm is adjusted to the optimal value during the On-Peak rate period. The ADT-MPC algorithm excels when forecasting is more unpredictable.

The control algorithm for Off-Peak rate period is set to charge the battery to 90 percent state of charge (SOC) and maintain a relatively low Off-Peak demand value. The control strategies for Mid-Peak rate period is developed to avoid high mid-peak and use up the remaining battery capacity left from the On-Peak rate period. With the real-time battery control method, the BESS continuously maintains the lowest demand and optimizes energy consumption throughout the entire day.

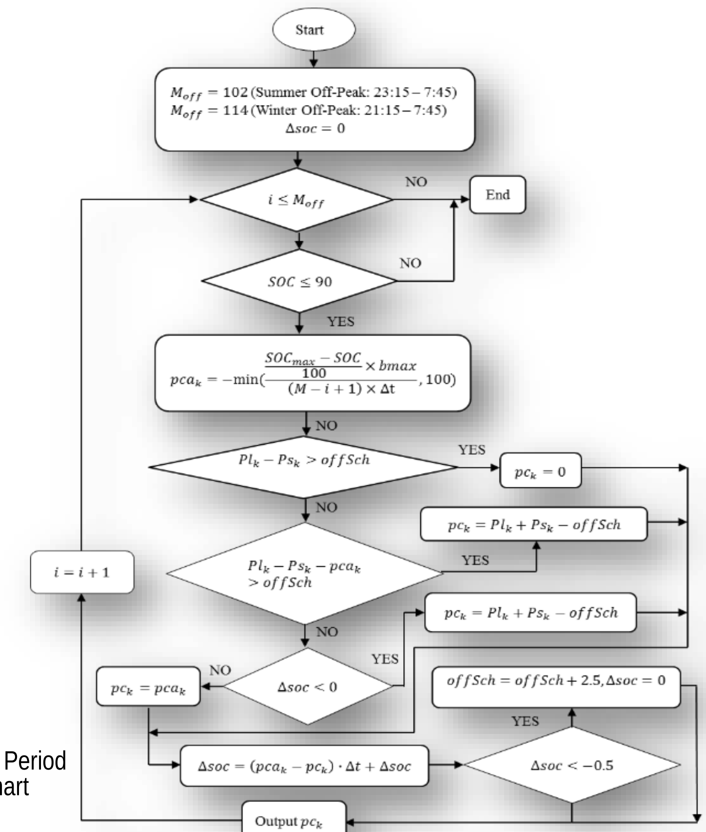
SIGI: Battery Optimization



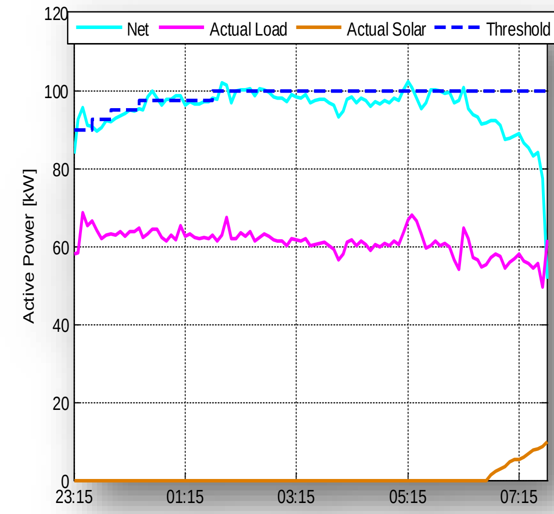
SUMMER

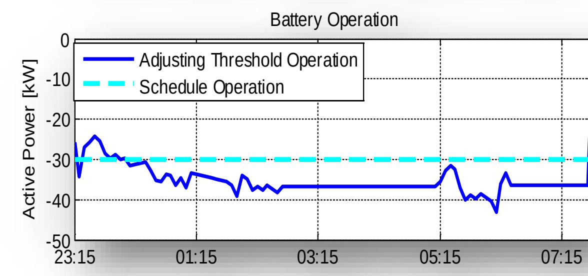
Off-Peak Control Strategy (ADT-MPC Algorithm) and Simulation Results

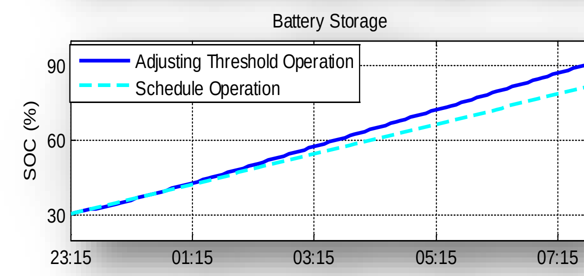
During working days, the Off-Peak rate period is from 23:00 to 08:00. Weekends and holidays are in the Off-Peak rate period. During the Off-Peak rate period, the electricity rate is the lowest and electricity consumption in the building is also the lowest and relatively stable.



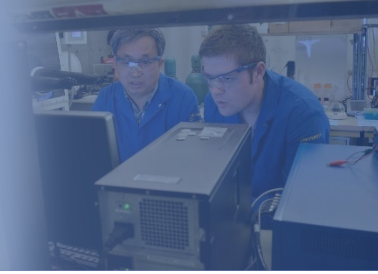
Summer Off-Peak Rate Period Control Strategy Flowchart





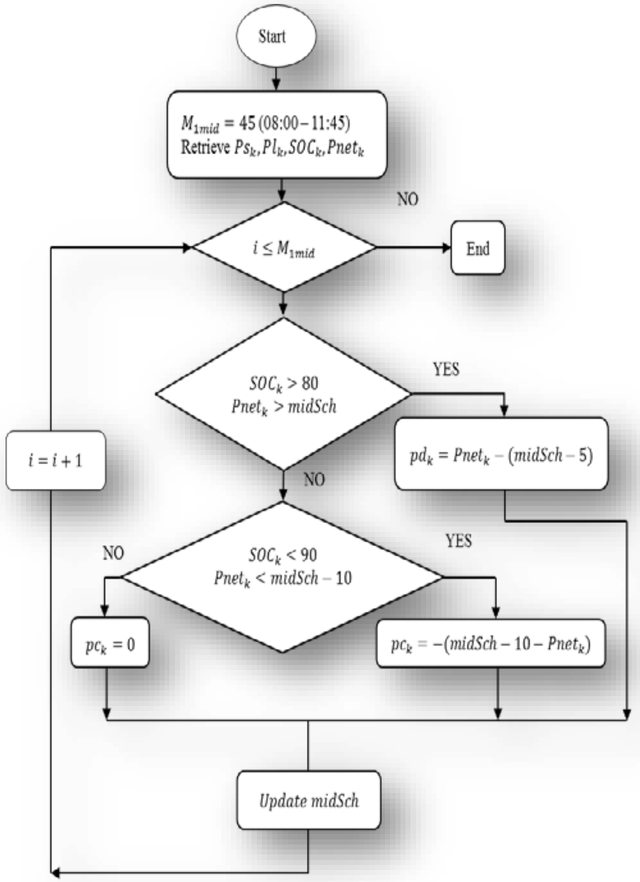


SIGI: Battery Optimization

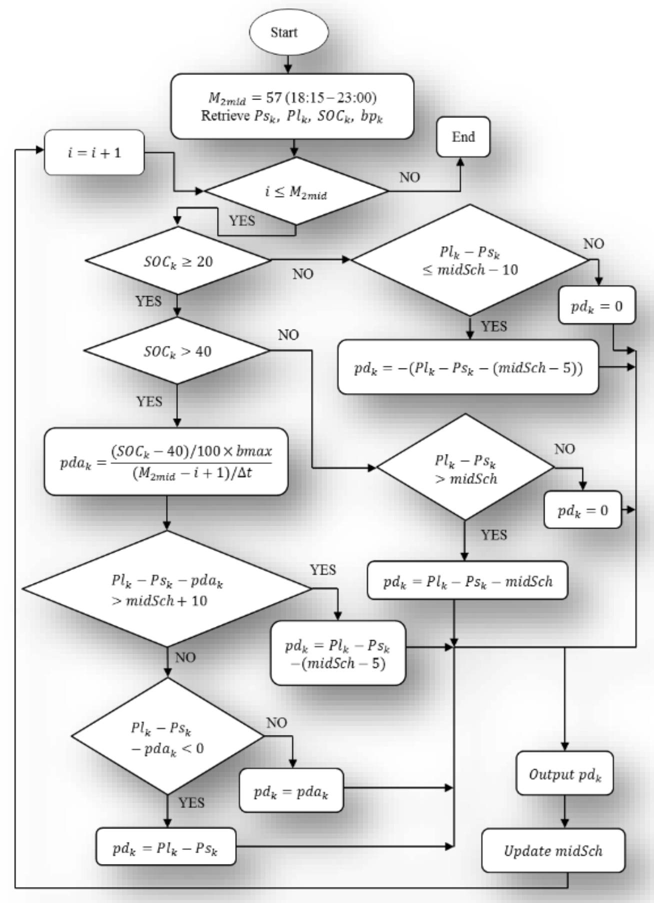


SUMMER

Summer Mid-Peak Control Strategy

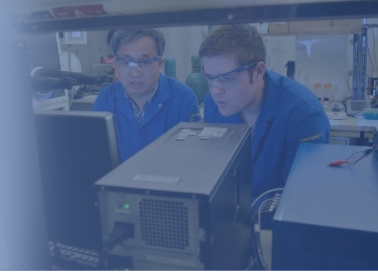


Summer First Mid-Peak Rate Period Control Strategy Flowchart



Summer Second Mid-Peak Rate Period Control Strategy Flowchart

SIGI: Battery Optimization



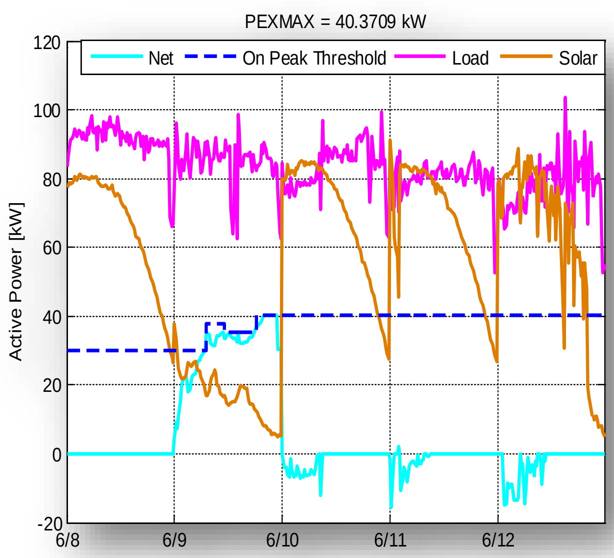
SUMMER

Off-Peak Control Strategy (ADT-MPC Algorithm) and Simulations Results

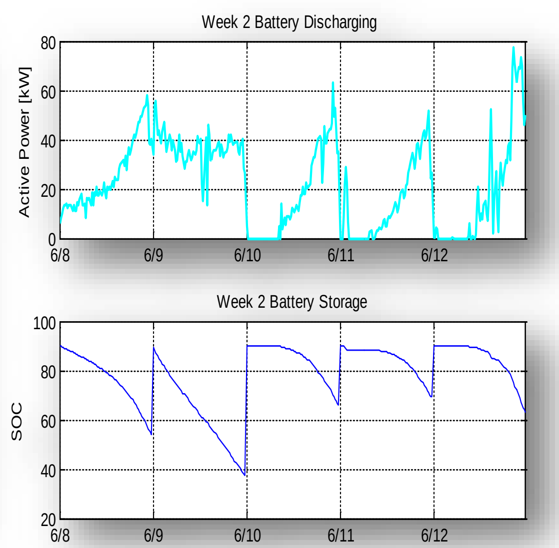
Principles

- Use the first step of MPC optimization as the current control operation
- Use the second step of MPC optimization as the tracking parameter: tracking the SOC deviation (ΔSOC) between the actual change and the predicted change
- Change the on-peak threshold $onSch$ when $\Delta SOC \leq \varepsilon$

$$onSch_k = \max(\max(previous\ net\ load), onSch_{k-1}) - \frac{\Delta SOC \cdot batteryCapacity}{last\ onSch\ changed\ point}$$



Net Load and Threshold Adjustment Under ADT-MPC Algorithm

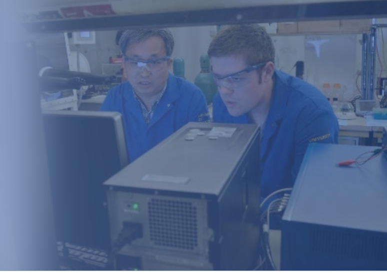


Battery Operation and Storage Under ADT - MPC Algorithm

Results

The simulations use data from June 2015. The solar generation in most days is large enough so that at the end of on-peak rate period, the remaining SOC is larger than 40 percent and can be used during the mid-peak control algorithm. The initial threshold kW is large enough for most of the days, and the net load can be maintained near 0 kW. The adjustment happens on 6/9 and the peak demand for this day is 40.37 kW. The occurrence of one high peak early in the week results in the on-peak threshold staying at 40.37 kW.

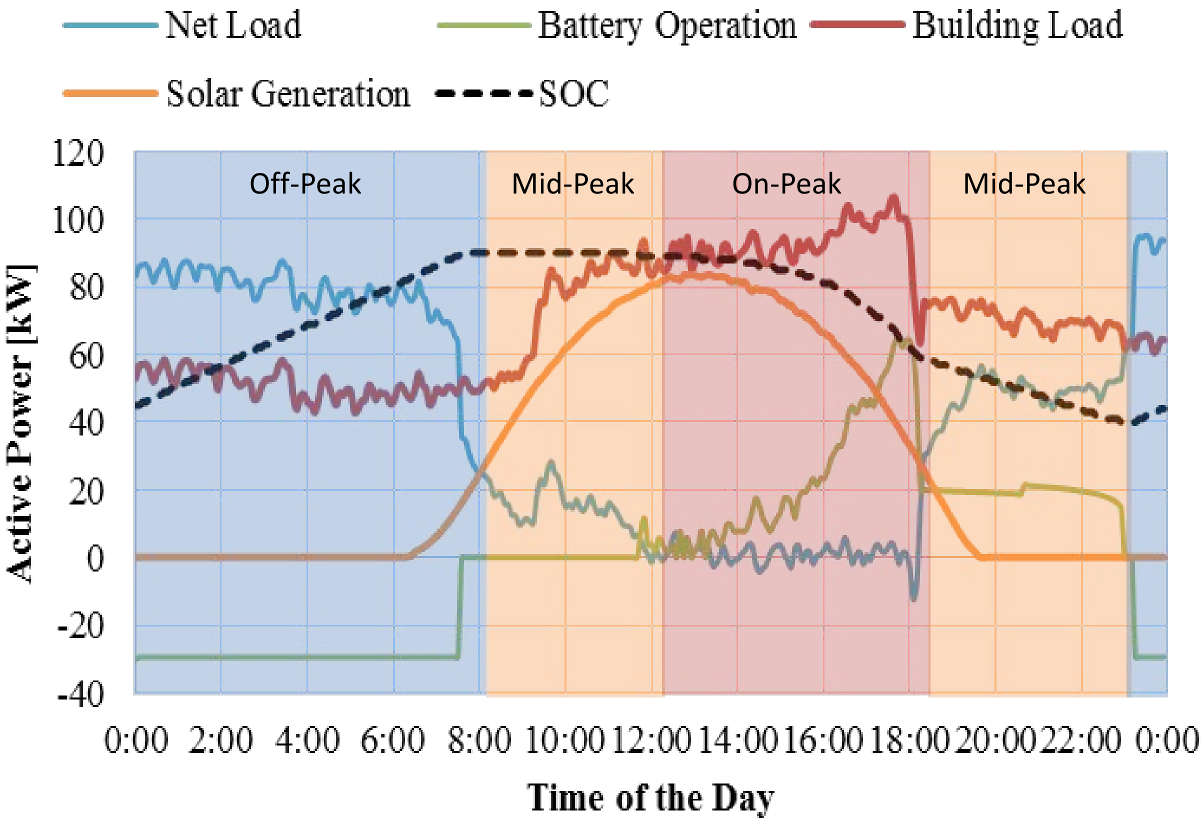
SIGI: Battery Optimization



SUMMER

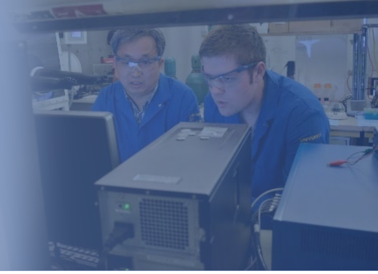
Real-Time Battery Control Method Experiment

The results of a full-day experiment conducted on July 28, 2015 are shown in the figure below. The three different shaded areas show the three different rate periods within a 24-hour period. The battery is charged during the Off-Peak rate period and then discharged during the On-Peak, and the second Mid-Peak rate periods. Due to high solar generation during the day the SOC was around 60% by the end of On-Peak rate period, and the net load during the entire On-Peak rate period is maintained near 0 kW.



One-day experiment with three different rate periods control algorithms

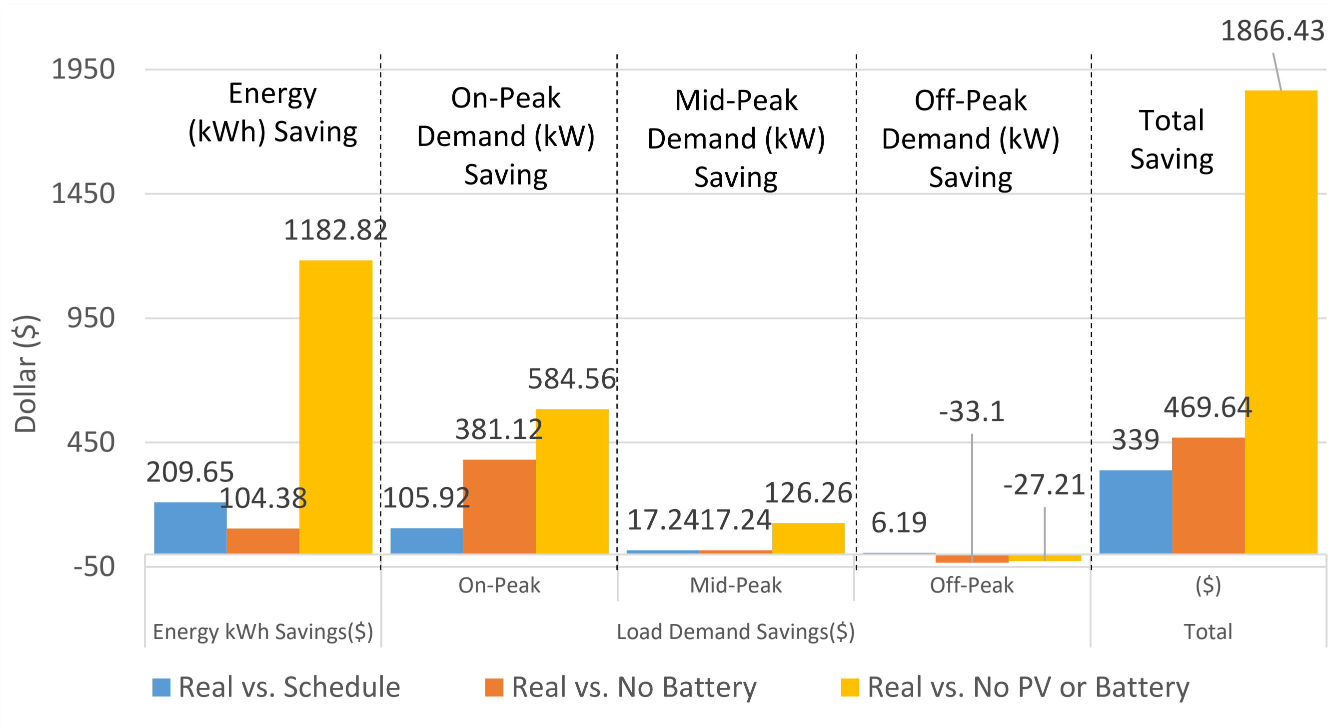
SIGI: Battery Optimization



SUMMER

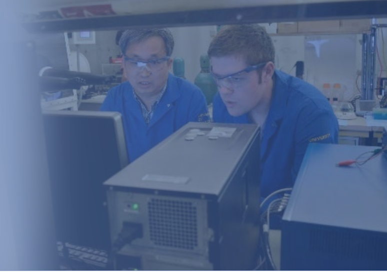
Dollar Savings

The electricity cost comparison is based on the actual data for workdays in June (summer season). The electricity cost is calculated for different systems arrangements: B1200 with solar generation and a BESS using the real-time battery control method(shown as ‘Real’), B1200 with solar generation and a BESS using a schedule controller system (shown as ‘Schedule’), B1200 with only solar PV generation (shown as ‘No battery’), and B1200 without solar PV generation or BESS (shown as ‘No PV or Battery).



June 2015 electricity cost comparison for different system architectures

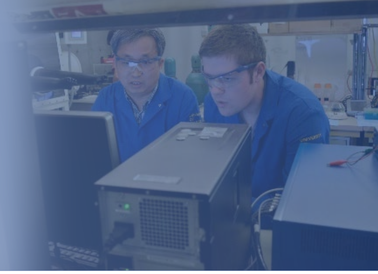
SIGI: Battery Optimization



WINTER

About

In the Winter season, a constant threshold MPC (CT-MPC) is employed. The CT-MPC works well on a system with relatively stable solar generation and a well-known building load profile. CT-MPC can maintain the on-peak demand under a certain value during the entire on-peak rate period.

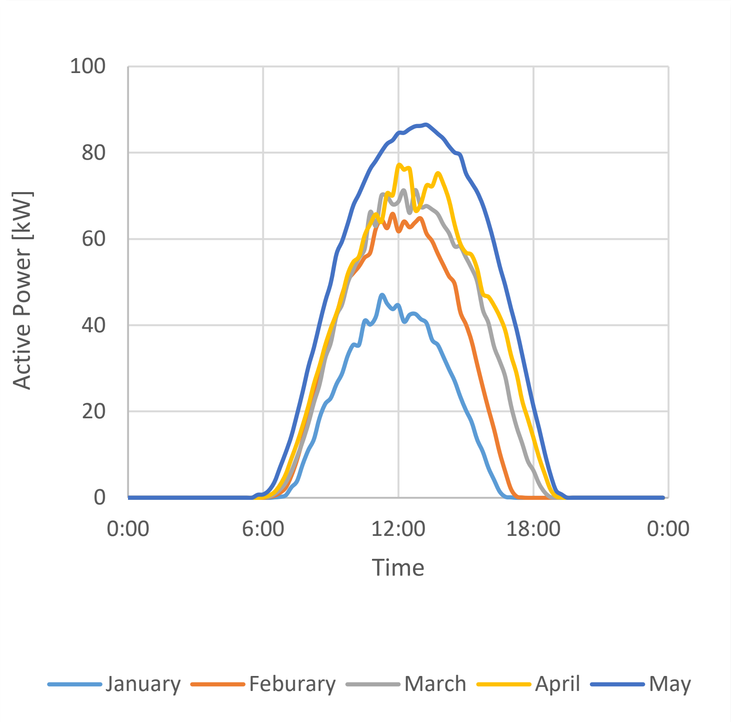


SIGI: Battery Optimization

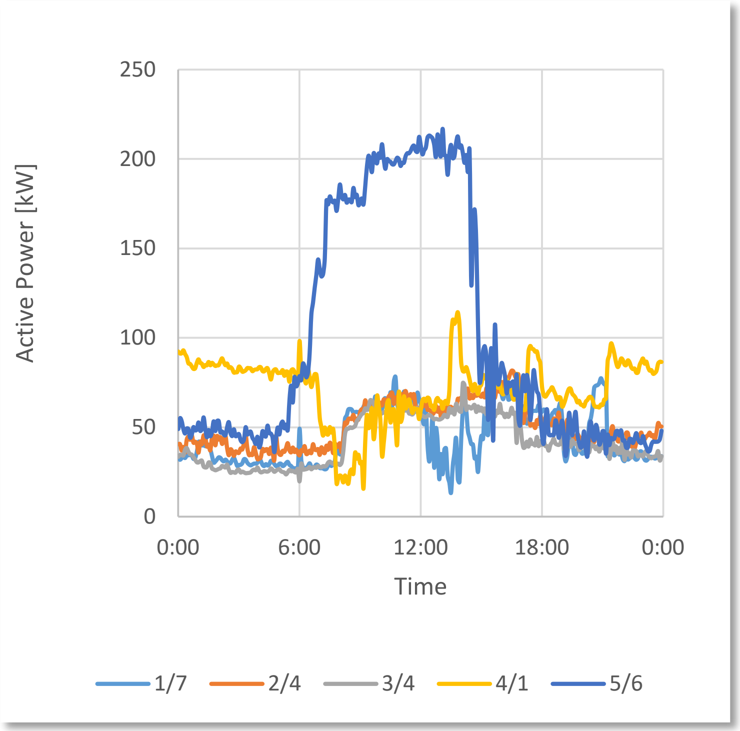
WINTER

Solar Power Generation and Building Usage Profile for CE-CERT Admin Building

The solar and building load profile for the1200 building are from January to Early May of 2016. The solar generation curves are shifted by day time savings on March 13rd and solar motion. The load profiles are based on the first Wednesday of each month. Due to the nature of the building (i.e. research facility and laboratories), the building load varies greatly each day.

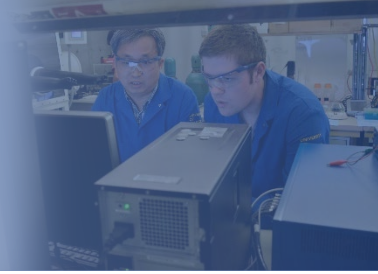


Average solar generation in the Winter



1200 building load profile in the Winter

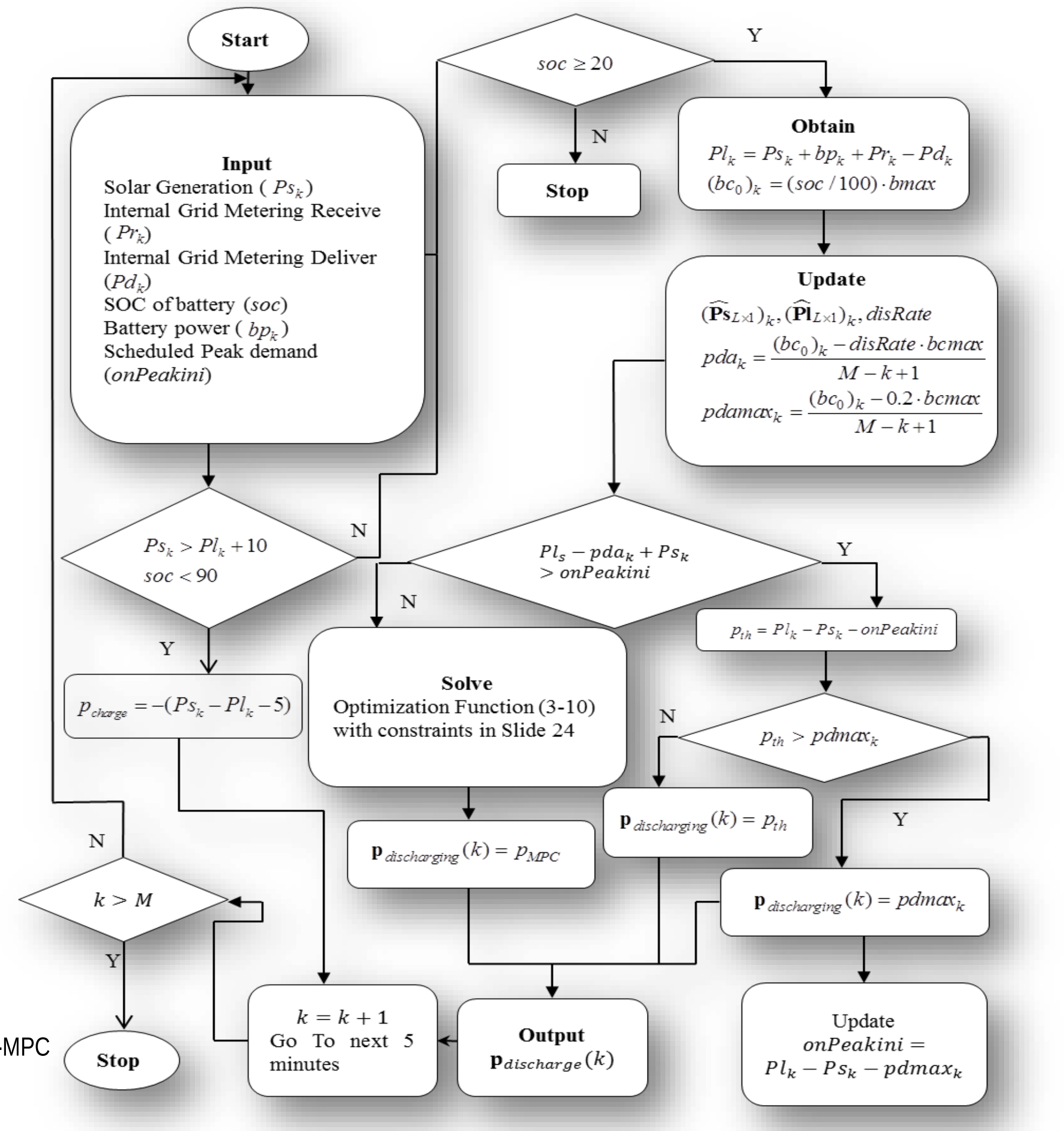
SIGI: Battery Optimization



WINTER

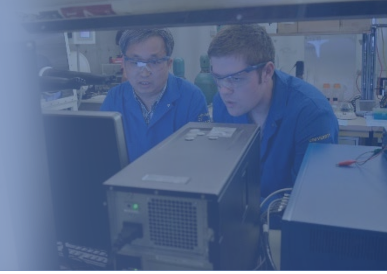
On-Peak Control Strategy (CT-MPC Algorithm)

The CT-MPC control algorithm is executed based on the BESS SOC. One important constraint for the optimization problem is determining the maximum discharging power that will allow for maximizing demand reduction, while retaining enough battery capacity for the entire on-peak period.



Winter On-Peak Rate Period CT-MPC Control Strategy Flowchart

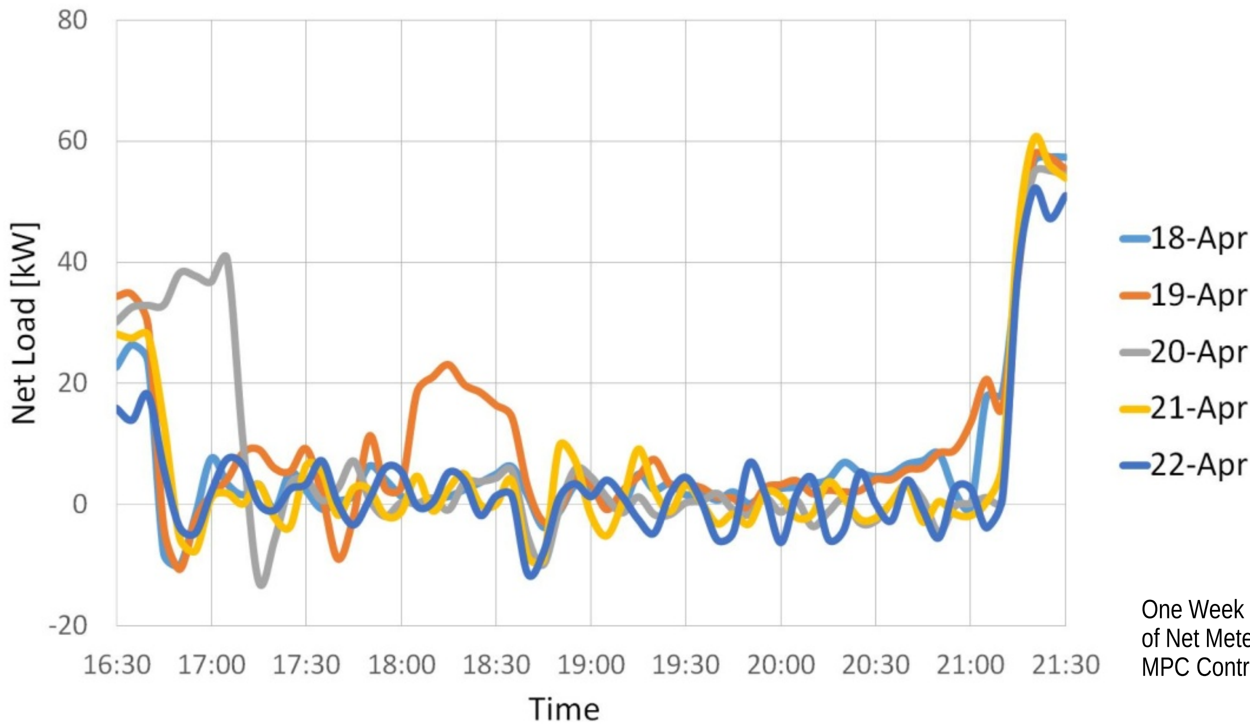
SIGI: Battery Optimization



WINTER

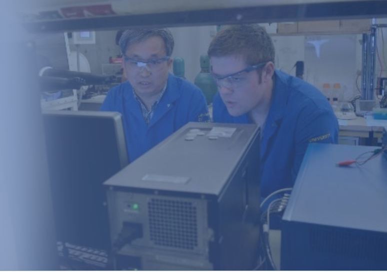
CT-MPC Control Experiments

As the on-peak demand is billed by Riverside Public Utilities on a 15-minute average basis, the control operation is started/ended 15 minutes before/after the on-peak rate period begins/ends every day. The control algorithm maintains the maximum building load below a certain value (30 kW). In the figure below, most of the time, the net load is maintained below 10 kW due to the sufficiently large battery capacity of the BESS (500 kWh)



One Week Demonstration of Net Meter Reading Under MPC Control

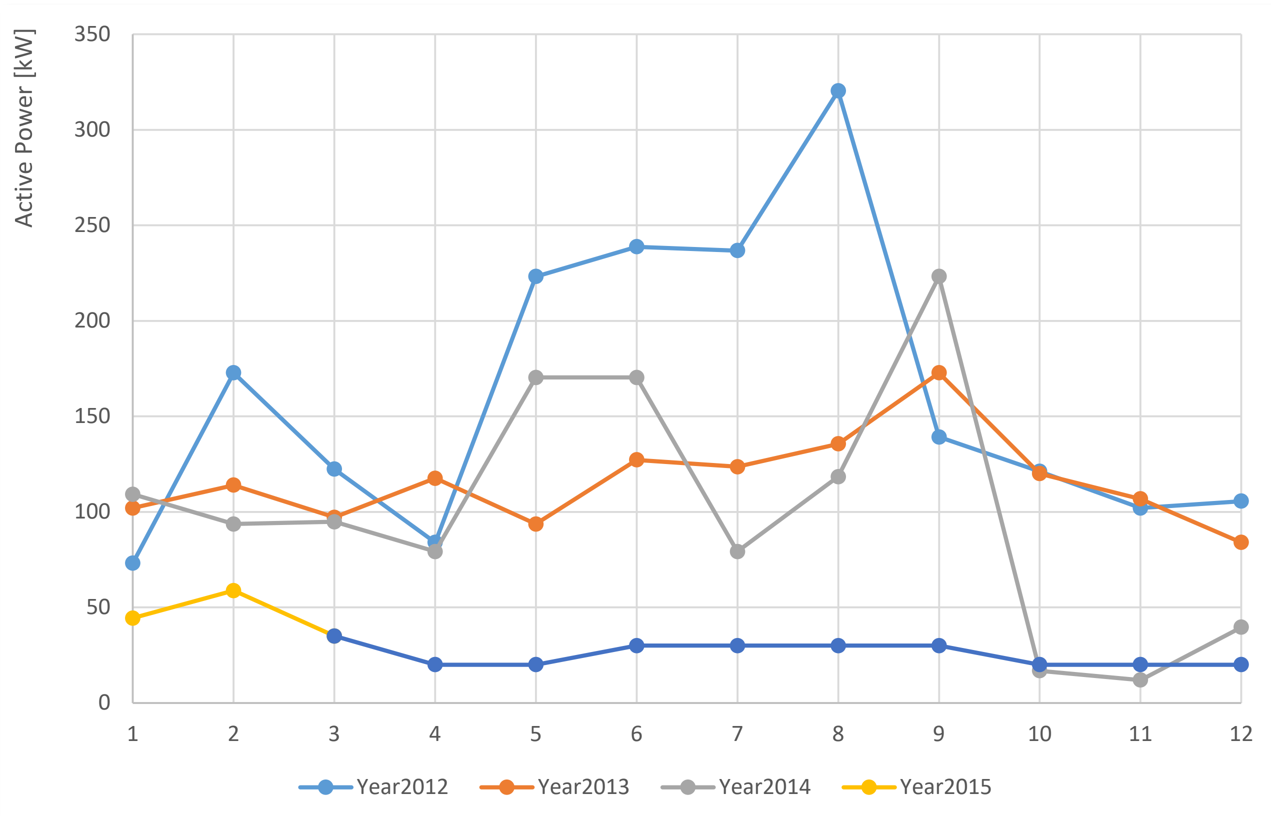
SIGI: Battery Optimization



WINTER

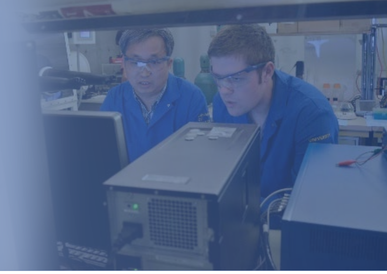
On-Peak Demand Shaving

The PV solar system was installed in May 2014 and battery storage system was implemented in October 2014. In late April 2015, MPC control was implemented. With MPC, on-peak demand can be controlled below a designated threshold.



On-peak maximum demand for four years

SIGI: Demand Reduction – Riverside Public Utilities' Voluntary Load-Shedding Request



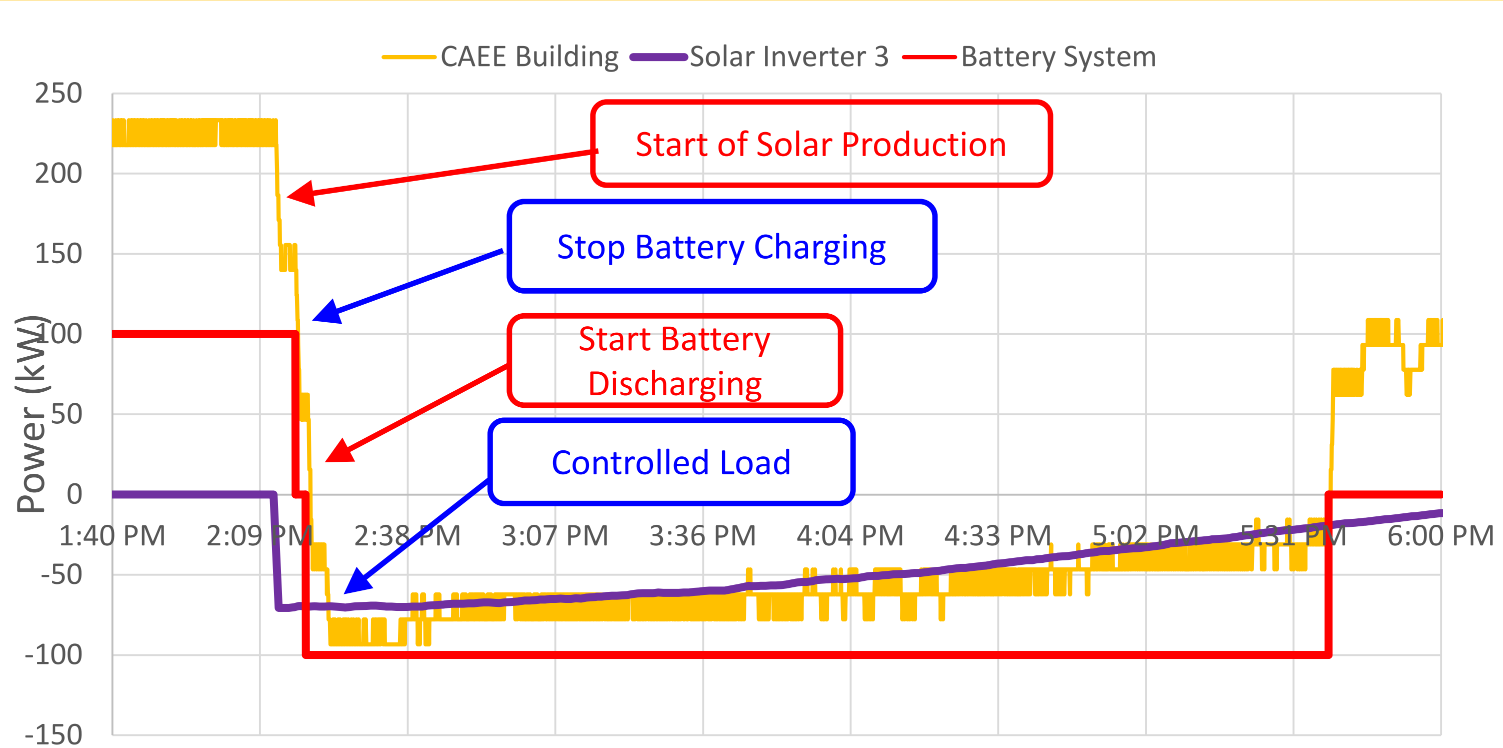
CE-CERT Net Demand Reduction

In September 14, 2014, triple digit temperatures led to RPU reaching a new all-time high electricity demand of 610 megawatts (MW). In the days to follow RPU send out an appeal to larger customers to conserve electrical energy, specifically between 2 pm to 5 pm. In response, CE-CERT's SIGI Testbed provided the flexibility to not only curtail the nominal power consumption of 365 kW from the three CE-CERT buildings, but also provided 225 kW back to the grid, resulting in a 590kW swing for three hours, as shown below.

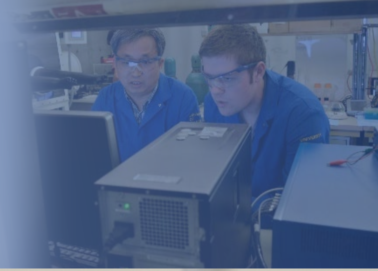
Admin Building: 95 kW

APL Building: 180 kW

CAEE Building: 315 kW



SIGI: Demand Reduction – Riverside Public Utilities' Voluntary Load-Shedding Request

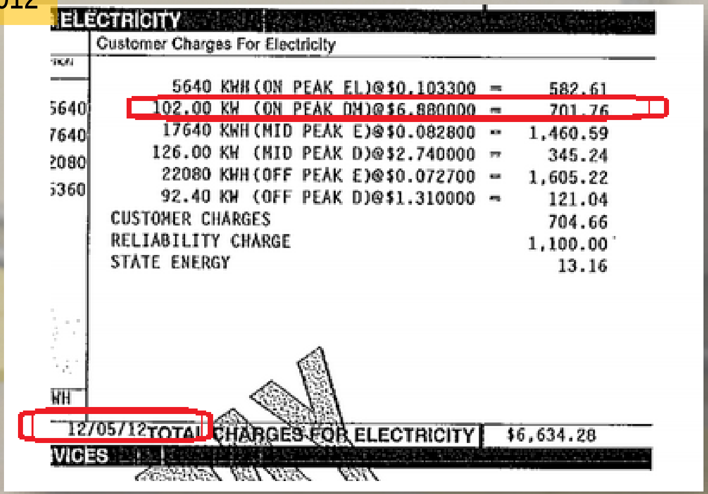


Application of Battery Energy Storage for Demand Reduction

Actual monthly utility bills showing 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 ~$1000)

2012

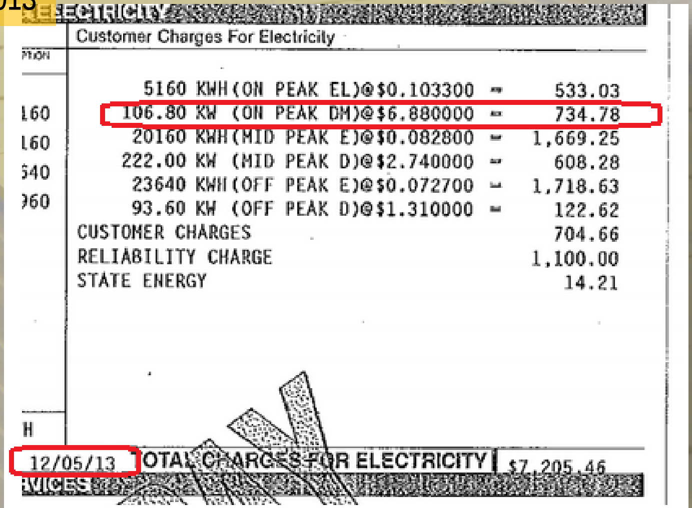


ELECTRICITY

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

2013

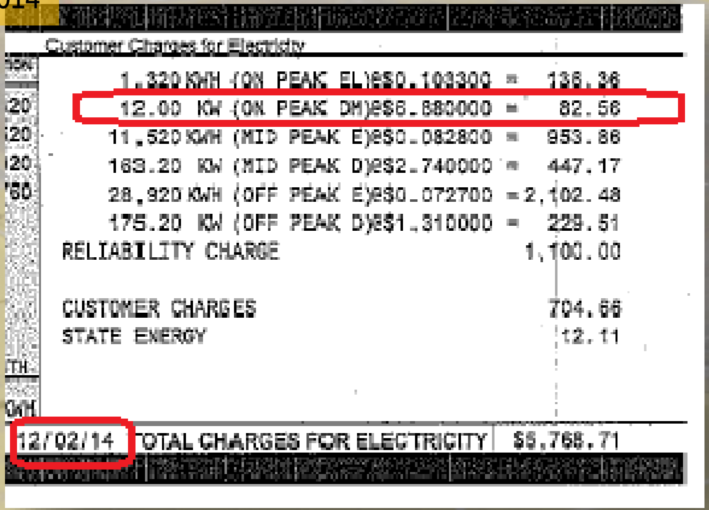


ELECTRICITY

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

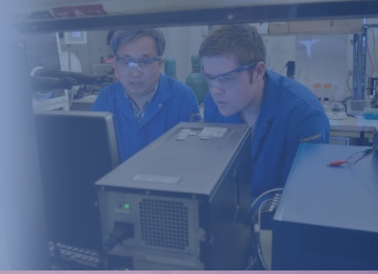
2014



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

Rancho Cucamonga Microgrid System



About

- Deployment and demonstration of a microgrid system at City Hall in Rancho Cucamonga, CA.
- Microgrid system composed of 100 kW solar carport PV system, 100 kW/87 kWh Li-ion battery energy storage system (BESS), data server and control system.
- Objective is to demonstrate the potential for minimizing the costs associated with demand charges by optimizing the utilization of microgrid resources (solar PV and battery).
- Microgrid optimization is achieved by a predictive control framework.

Project Partners

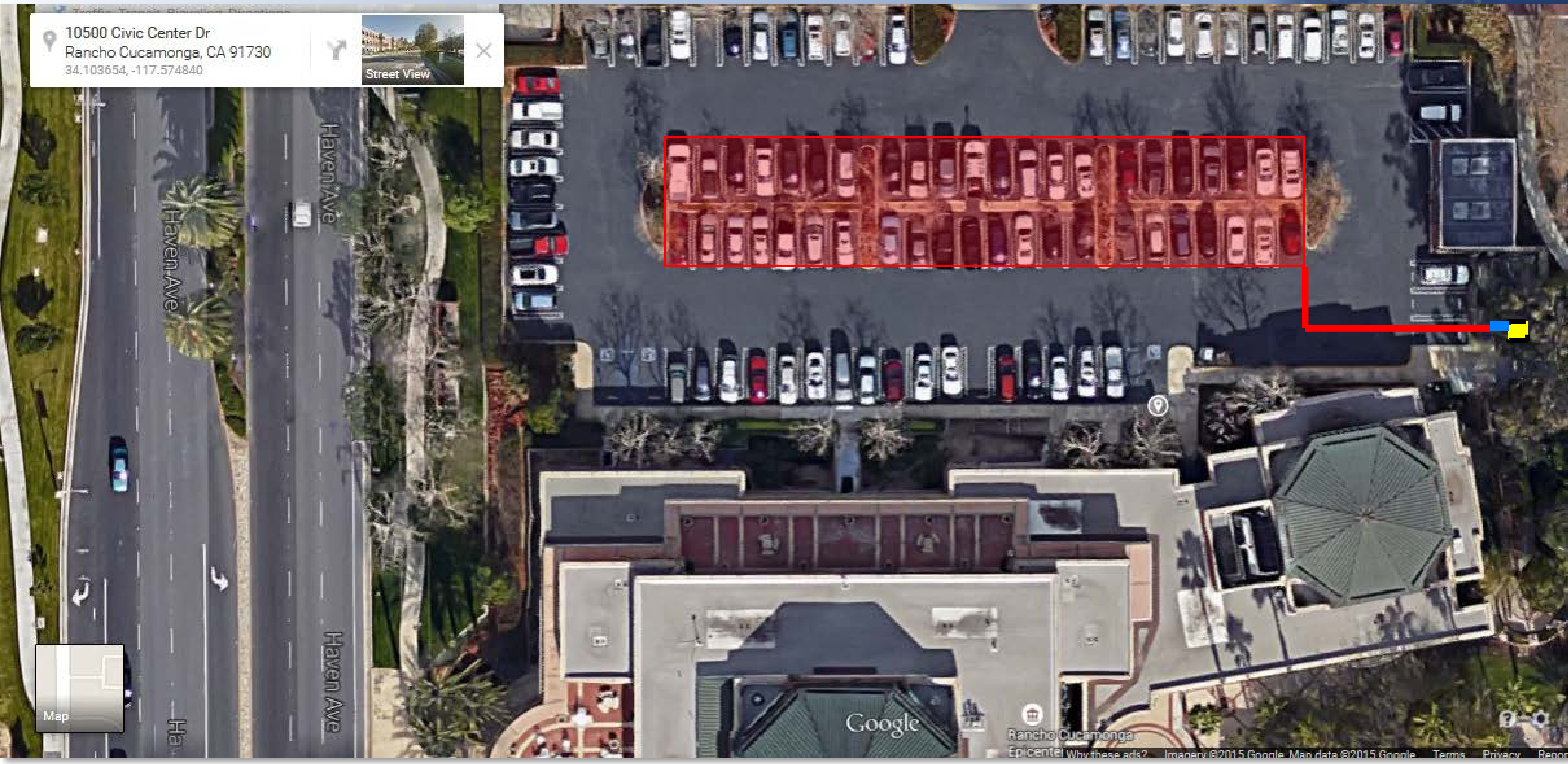
APPA American Public Power Association SEVENTY-FIVE YEARS

Rancho Cucamonga Municipal Utility

PACIFIC ENERGY

DESIGN AND BUILD ENERGY CONTRACTORS MD Energy, Inc. THE PATH TO A BRIGHTER FUTURE

Rancho Cucamonga Microgrid System



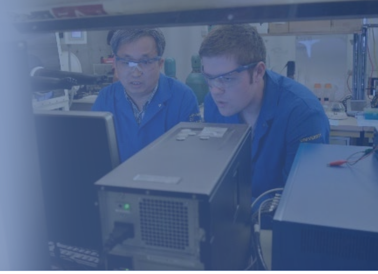
PV System

Inverter

Battery Energy Storage System/Charger-Inverter

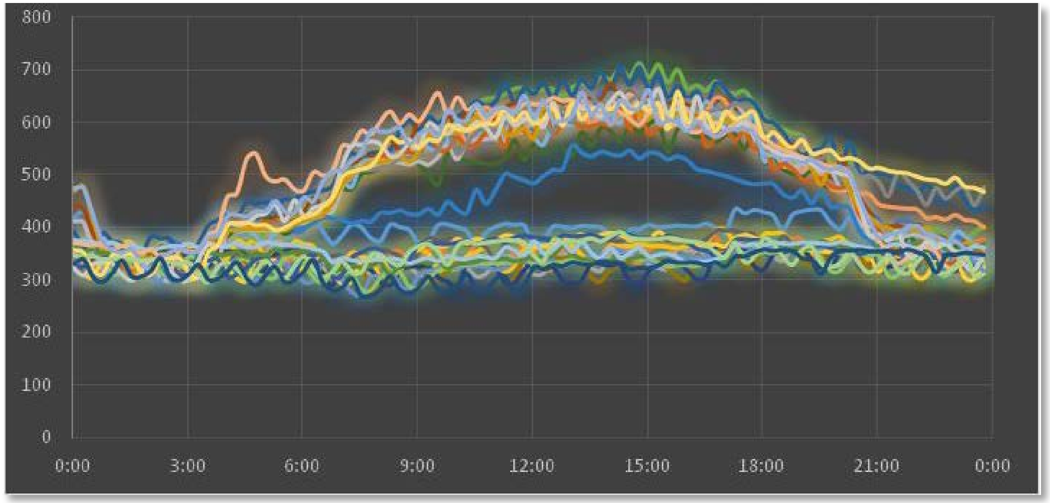
Conduit

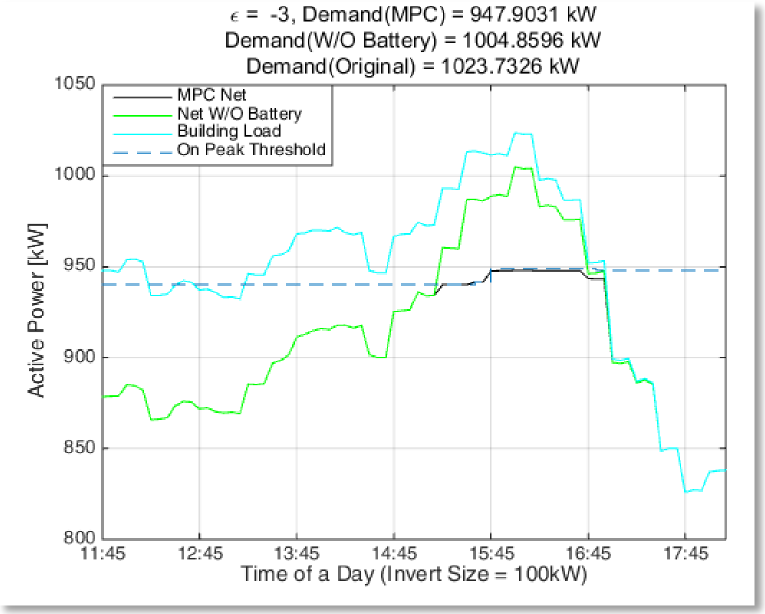
Rancho Cucamonga Microgrid System

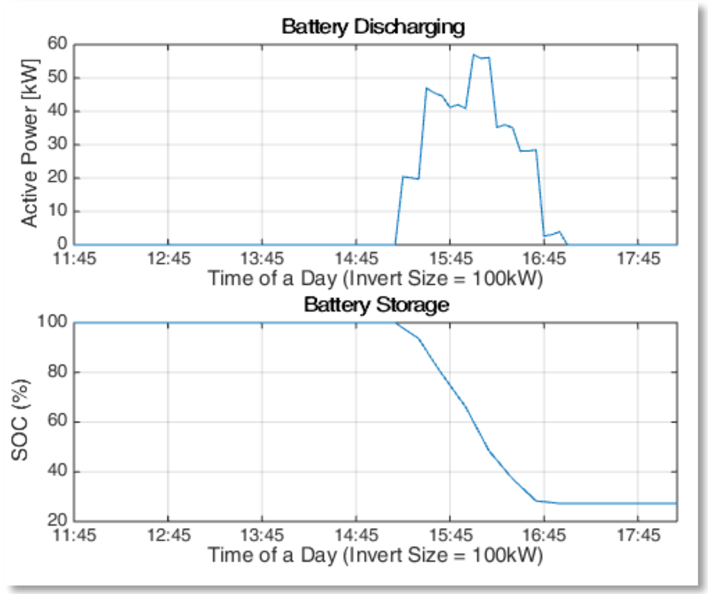


Simulation Results

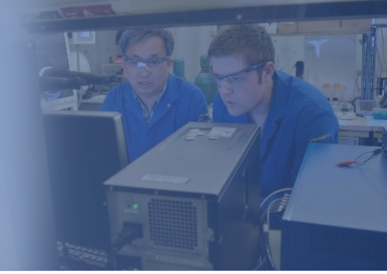
Battery Capacity = 87 kWh By allowing using 80 percent of the battery capacity, the demand load decreases by 78.83 kW (including PV); 56.96 kW is reduced by battery.







Chemehuevi Microgrid



About

The project objective is to manage energy use profiles and provide uninterruptable power at the Chemehuevi Indian Tribe's Chemehuevi Community Center (emergency response center for the community) located in Havasu Lake, CA. The Microgrid system is composed of 90 kW solar PV system, 30 kW/60 kWh flow battery energy storage system, data historian, advanced control system, and energy management strategies. Energy management strategies include: 1) Peak Reduction, 2) Load Shifting, 3) Demand Response, and 4) Storage to Grid activities.

Background

- Remote communities with a single transmission line connection to the grid are extremely vulnerable to power outages and downtime maintenance.
- Microgrids are ideal for providing resiliency to critical facilities within remote communities.
- There is need for the successful demonstrations and pilot projects that demonstrate and document energy, economic and societal benefits of community-based microgrids.
- To achieve greater grid resiliency new solutions and technologies will be required for microgrids to provide reliable and cost-effective electricity.

Benefits

- Projected benefits to the CCC (over 20 years)
- Lower energy costs (i.e. demand charge reduction)
- Improved data and energy management
- Increased grid stability, robustness, and reliability
- Support increased renewables and market-ready technologies
- Decreased GHGs emissions
- Workforce development & best practices

Project Partners

SUNPOWER® SOLAIRE® by SUNPOWER®

SMA SOLAR TECHNOLOGY

PRIMUS POWER

OSIsoft.

PACIFIC ENERGY

GRID ALTERNATIVES

Chemehuevi Microgrid

Project Site

50 kW SunPower Carport PV System (P17-340W)

40 kW SunPower Carport PV System (Bifacial)

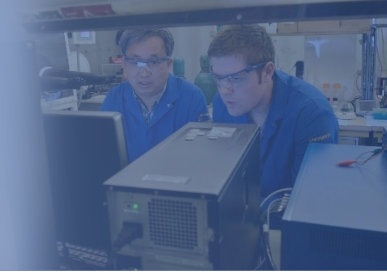
30 kW/60 kWh Primus Power Flow Battery

50 kW Inverter

40 kW Inverter

Conduit

UCR-LANL Energy Storage Research Initiative



About

The project's objective is to provide a path forward in developing high temperature thermal storage materials using an unusual class of metallic alloys known as binary Zintl intermetallics. *The most important characteristic of Zintl phases in application to high temperature thermal storage is that the materials are extremely robust and have very large volumetric enthalpies of fusion, ranging between 800 and 1800 J/cm3. The project will leverage the unique properties of Zintl intermetallics to develop next generation phase change materials (PCMs) for thermal energy storage.*

Energy Relevance

Electrical load leveling is a critical technical gap for the sustainability of our nation's electrical grid. Load leveling directly impacts effective utilization of power produced during off-peak hours and defines a viable path for integrating less predictable renewable power sources into the electrical infrastructure. Zintl intermetallics have the potential to be the next generation thermal energy storage materials.

Participants

PI: Prof. Javier E. Garay (UCR, MSE & ME)
Co-PI: Dr. Stephen Obey, LANL

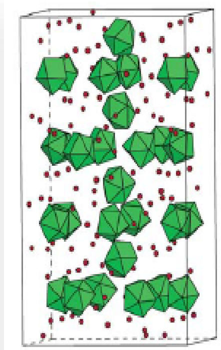


Figure 1. Crystal structure of the Zintl phase Cs_4Ge_9 containing deltahedral Ge_9^{-4} clusters (green polyhedra) and cesium counterions (red balls).

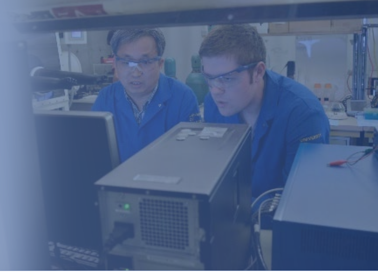
Milestones

Year 1: Design and Synthesis of Zintl phase material

Year 2: Assess thermodymanic characteristics and phase change kinetics

Year 3: Demonstrate the viability of UCR –LANL designed Zintl phases for TES

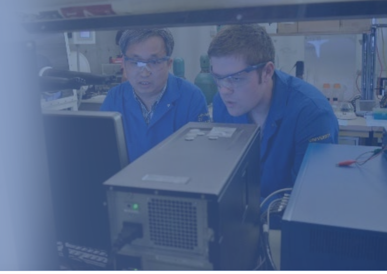
Economic Progress through Sustainability



About

- Partnership with the Department of Commerce
- Establishing a resource center at UCR BCOE
- Support the training of workers in renewable energy industry
- Guide entrepreneurs with new energy ideas in the development of their own ideas toward commercialization
- Develop and implement a network of sustainability companies, agencies and resources

Silicon Quantum Dot: Graphene Composite as Anode for Li+ Batteries

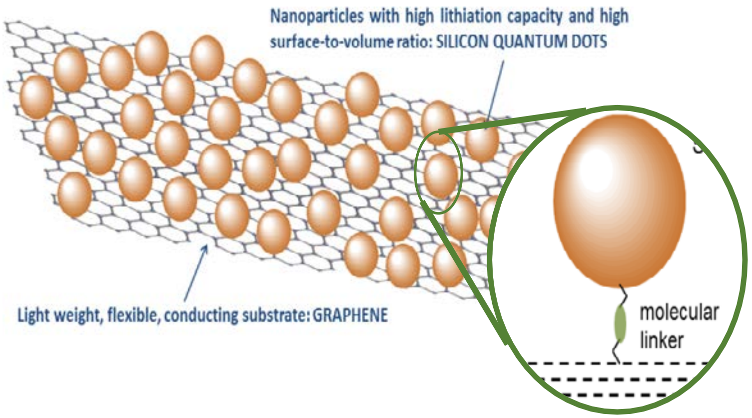


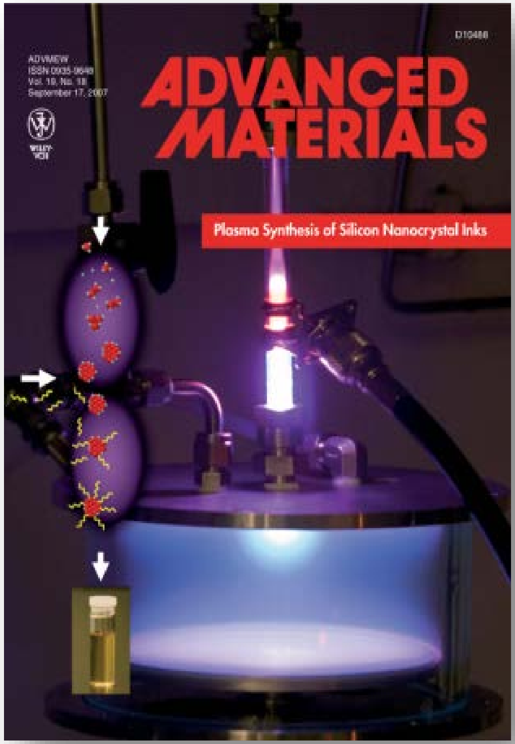
About

We will realize an anode architecture composed of silicon quantum dots anchored onto a conductive layer composed of graphene sheets. This architecture will enable high charging capacity (4212 mAh/g), high charge and discharge rate due to the small particle size, high reliability due to the stability of graphene, and a lightweight, flexible design. Applications for this technology include automotive, flexible electronics and wearable, light weight batteries.

Properties

1. High energy density
2. High power density
3. Composed of earth-abundant materials (C and Si)
4. Produced using a non-thermal plasma process – low cost and easily scalable





Principal Investigator

Dr. Lorenzo Mangolini
Assistant Professor,
Mechanical Engineering & Materials Science and Engineering

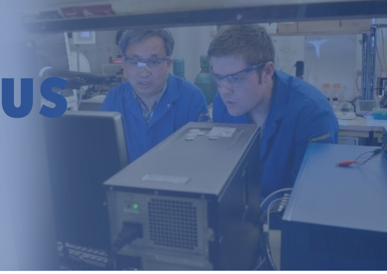
Milestones

Year 1: Synthesis of silicon quantum dots, graphene and other carbon nanostructures, linkage formation

Year 2: Testing of battery prototypes

Year 3: Optimize materials properties for maximize capacity and cyclability

Nano/Micro Hierarchically Structured Porous Metal Oxide Electrodes



About

This project pursues a new method for designing electrode materials with nano/micro hierarchically structured porous structures for lithium-ion batteries. We will combine solution phase pyrolysis, gas phase spray pyrolysis, flame synthesis, and self-assembly process to produce metal oxide materials containing porosity at different length scales (nano/micro).

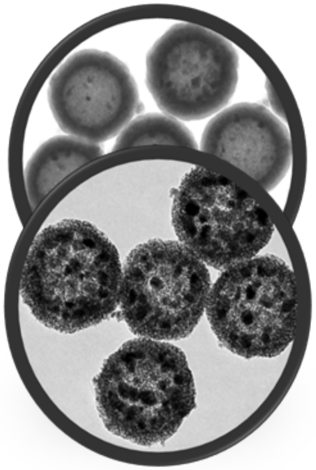
Participants

Heejung Jung
Professor,
Mechanical
Engineering

Yadong Yin
Professor
Chemistry

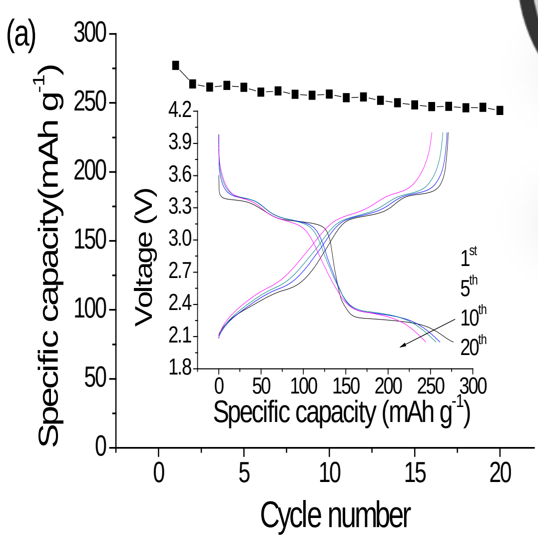
Products

- Nano/Micro hierarchically porous electrode materials include $LiFePO_4$, $LiCoO_2$, $LiMn_2O_4$, $Li_3V_2(PO_4)_3$ etc.
- Nanostructured carbon materials can be incorporated to enhance electric conductivity of electrodes



Energy Relevance

- Advanced electrode materials for energy with significantly enhanced performance of lithium ion batteries.
- Education and industrial collaboration. This project will train students and foster collaborations with academic organizations, national laboratories, and local and national industries.



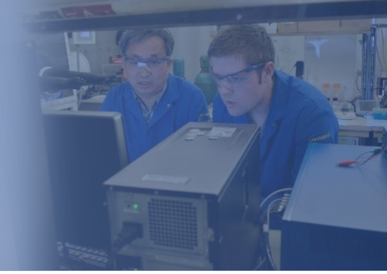
Milestones

Year 1: Synthesis of nanoparticles for electrode materials

Year 2: Self-assembly of nanoparticles of electrode materials; Surface cleaning of the porous materials through calcination

Year 3: Characterization and optimization of the nanostructured porous materials for LIB

Electrospun Metal Oxide Nanofiber Mats



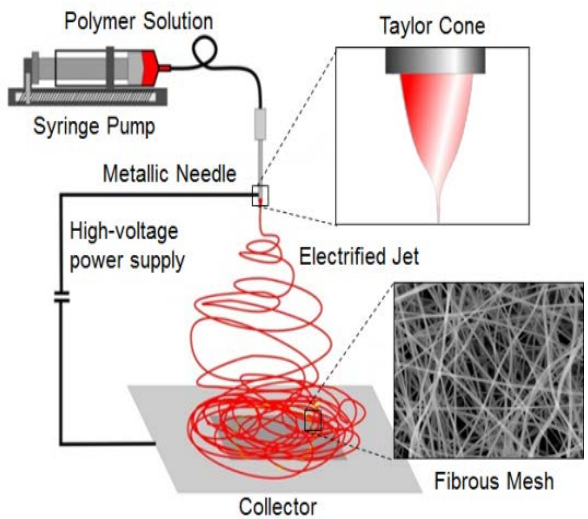
About

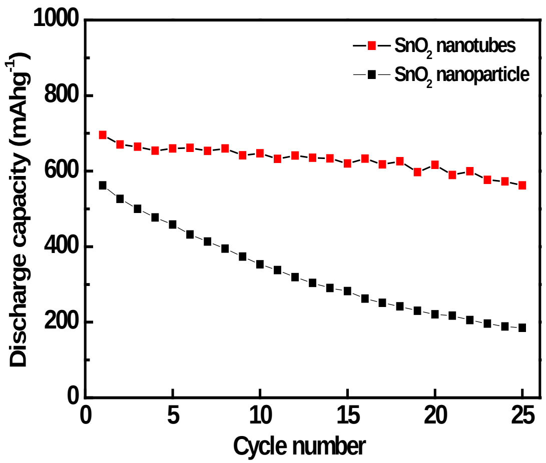
The overall objective of the proposed work to develop a low-cost and high yield electrospining method to massively produce high performance lithium ion battery. By controlling dimensions, composition, morphology, and crystallinity, we will optimize the battery performance.

Energy Relevance

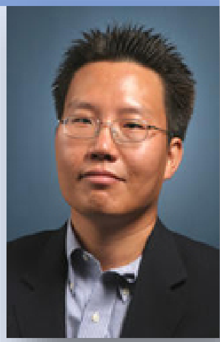
This project will address the following areas:

- Cost-effectiveness synthesis of various metal oxide nanofiber mats for energy applications
- Development of new materials with optimize electrical and electrochemical properties for lithium ion and lithium sulfur battery
- Education of graduate students with expertise in materials and energy storage





Participant



Nosang V. Myung
Professor, Chemical and Environmental Engineering

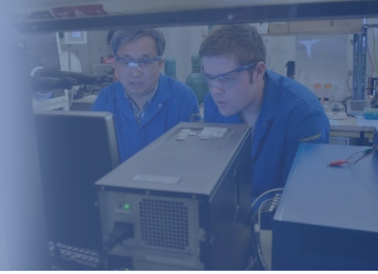
Milestones

Year 1: Synthesis of tin oxide, nickel oxide, cobalt oxide nanofibers with controlled dimensions and morphology

Year 2: Demonstrate the ability to massively fabricate the optimized nanofibers

Year 3: Demonstrate enhance lithium ion battery performance

Carbon Coated-LiFePO4 Nanowires Cathode



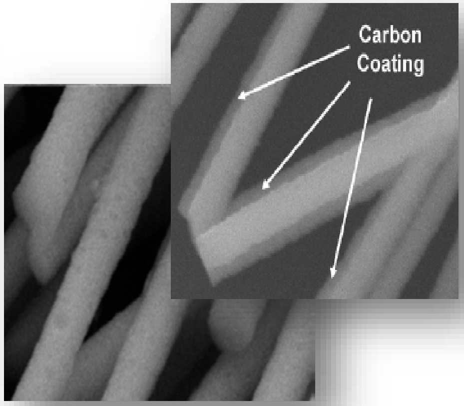
About

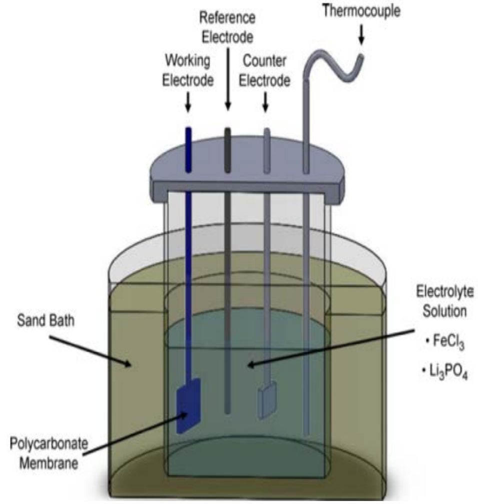
The objective of this project is to explore and demonstrate carbon coated electrochemically synthesized lithium iron phosphate nanowires ($LiFePO_4$ NWs) as an effective cathode electrode material for improving battery energy and power density for Li-ion battery technology. $LiFePO_4$ NWs will be extensively studied to demonstrate a charge storage capacity greater that existing bulk and thin-film $LiFePO_4$ cathodes.

Energy Relevance

This project will address the following areas:

- Achieve lower synthesis cost
- Address safety issues of Li-ion battery technology
- Use environmental friendlier materials
- Improve electrochemical behaviors (i.e. cyclability and rate capacity)
- Maintain initial capacity and high volumetric energy density





Participant

Alfredo A. Martinez-Morales
Professor, Electrical and Computer Engineering

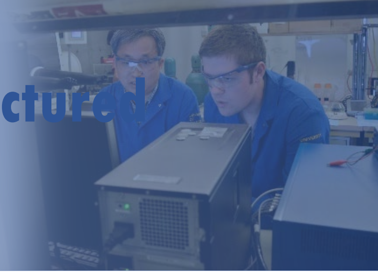
Milestones

Year 1: Optimization of synthesis parameters to achieve high performance of carbon coated LiFePO4 NWs as a cathode material.

Year 2: Design, integration and device fabrication of carbon coated $LiFePO_4$ NWs cathode onto a battery system

Year 3: Demonstrate enhanced performance of Li-ion battery technology based on carbon coated $LiFePO_4$ NWs as a cathode material.

Biologically Inspired Synthesis & Application of Nanostructured Materials for Energy Storage



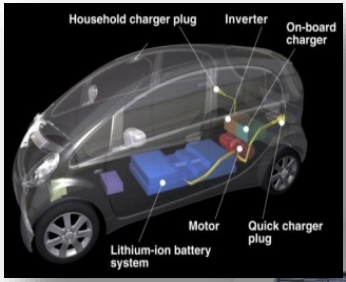
About

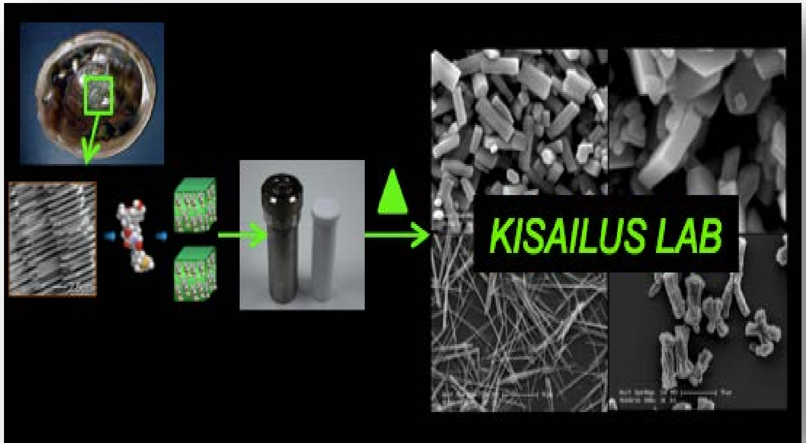
The overall objective of the proposed work to develop a low-cost, environmentally friendly method to produce nanostructured $LiFePO_4$ for high performance lithium ion batteries. Using inspiration from biological systems, that utilize precise control of solution conditions in an environmentally friendly manner, we will guide the formation of cathode materials with controlled size, shape, and composition, which will be used to enhance and optimize battery performance.

Energy Relevance

This project will focus on:

- Low-cost synthesis of lithium ion cathodes for energy storage.
- Producing nanomaterials with carefully controlled material features for optimized electrochemical performance in lithium ion batteries.
- Design of mechanically robust structural batteries
- Provide the workforce with well-trained, diverse scientists and engineers in materials and energy storage.





Participant

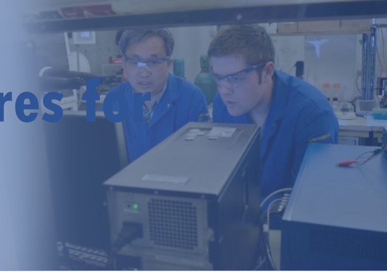
David Kisailus
Professor, Chemical and Environmental Engineering

Milestones

Year 1: Synthesize $LiFePO_4$ with controlled size, shape and composition

Year 2: Demonstrate performance improvement and initiate scale-up of process

Year 3: Optimization of performance; Incorporate into vehicle platform testing; Initiate structural battery



Scalable 3D Carbon Nanotube-Graphene Nano-Architectures for Supercapacitors and Batteries

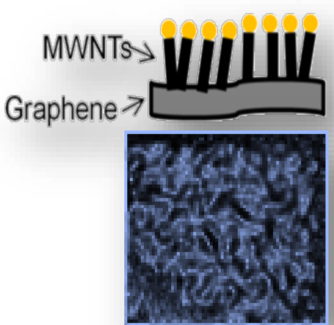
About

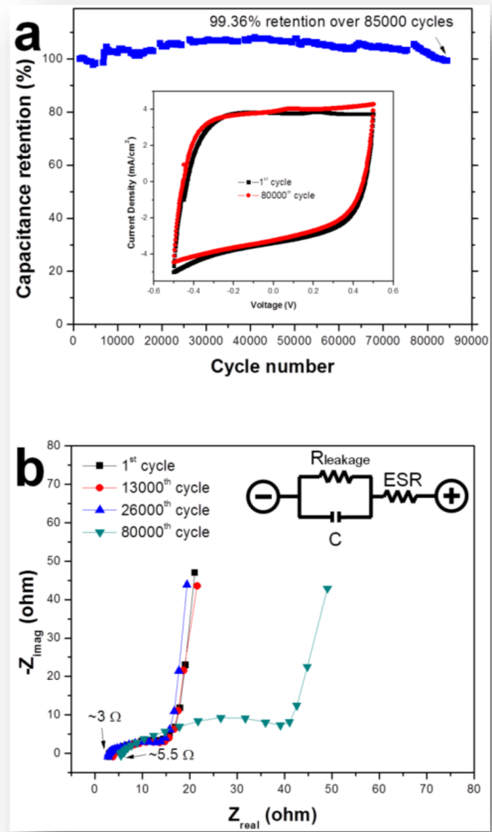
3D multiwall carbon nanotube-graphene nano-architectures as novel electrodes for high performance supercapacitors and batteries. Seamless connection between multiwalled carbon nanotubes to graphene will be achieved using patented growth technology developed by Ozkans' laboratory.

Energy Relevance

This project will provide:

- Batteries with low internal serial resistance, high power density, high energy density, longer cycle life
- Thermally and chemically more stable electrodes
- Scalable technology using standard thin-film based processing technology





Participants

Cengiz Ozkan
Professor, Mechanical Engineering

Mihri Ozkan
Professor, Electrical and Computer Engineering

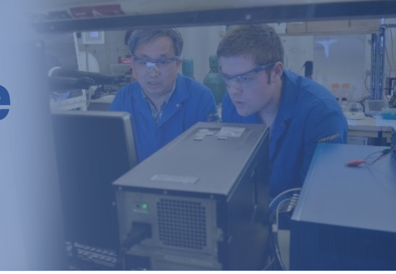
Milestones

Year 1: 3D carbon electrode with large surface area > 1000 m^2g^{-1} with low impediance

Year 2: >98% capacitance retention >5000 cycles

Year 3: Power density > 300 $kWkg^{-1}$ and internal series resistance < 5 Ohms

Lithium Sulfide-Polyacrylonitrile Derived Cathode Composites for Li-Sulfur Batteries

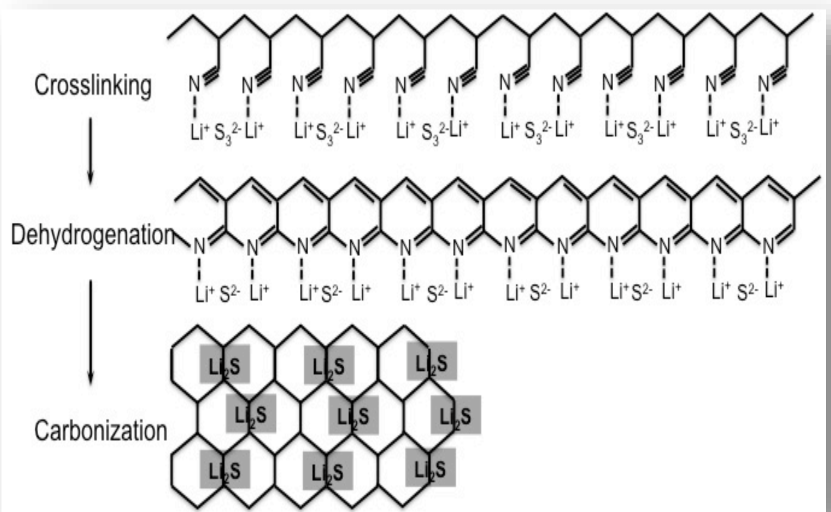


About

This project focuses on developing a novel cathode material for Li-S batteries with lithium sulfide (Li_2S) as active material. Utilizing the interaction between Li-ion and nitrile group, Li_2S can be uniformly encapsulated into a carbon matrix framework using polyacrylonitrile as carbon precursor through crosslinking reaction. Fundamental properties of the Li_2S-polyacrylonitrile system including Li-nitrile interaction and sulfur-carbon affinity will be carried out towards a successful cathode material for Li-S batteries. Tin and silicon will be tested as potential anode materials in full batteries.

Energy Relevance

- Fundamental understanding of the interactions between sulfur active materials and carbon host materials
- Development of high energy-density and high power-density lithium-sulfur batteries
- Education of undergraduate and graduate students with expertise in energy storage technologies



Participant

Juchen Guo
Assistant Professor,
Chemical and
Environmental Engineering

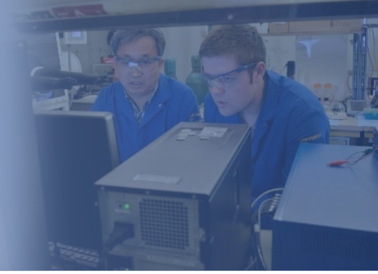
Milestones

Year 1: Synthesis of Li_2S-carbon composites derived from lithium sulfide-polyacrylonitrile system

Year 2: Optimization of the Li_2S-carbon composite guided by electrochemical studies

Year 3: Demonstration of full battery performance with tin or silicon anode and Li_2S-carbon cathode

Efficient Thermal Management of High-Power Batteries and Battery Packs with Graphene-Based Materials



About

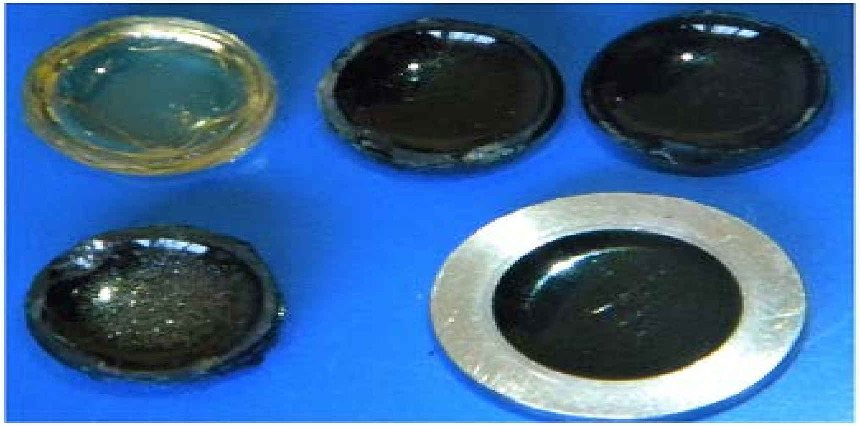
The objective of this project is to develop graphene-based thermal interface materials (TIMs) for the battery packs and the few-layer-graphene Li-ion battery electrode materials for the efficient heat removal during battery charging and for improved thermal management of high-capacity batteries.

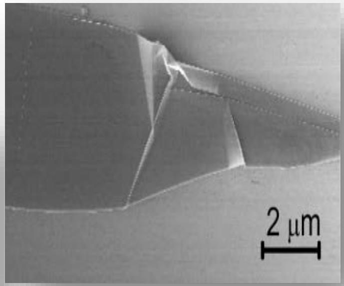
Energy Relevance

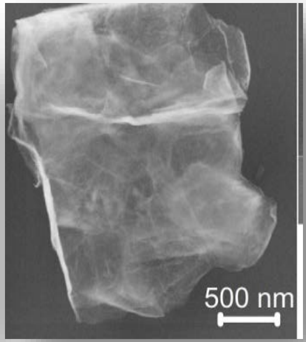
The project will lead to development of high-capacity Li-ion batteries and battery packs with improved thermal management leading to faster charging times and major energy saving.

Participant

Alexander Balandin
Professor, Electrical and Computer Engineering







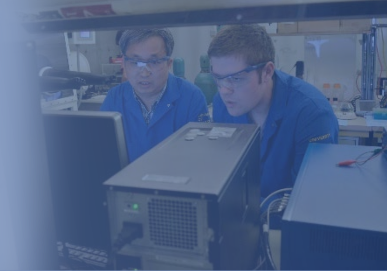
Milestones

Year 1: Demonstration of graphene-based TIMs for batteries with strongly enhanced thermal conductivity (~20 W/mK) allowing for more efficient heat removal

Year 2: Demonstration of few-layer graphene electrodes for Li-ion batteries with improved performance

Year 3: Testing of the high-capacity Li-ion batteries with FLG electrodes and TIMs

Solar Driven CO2 Conversion to Fuels



About

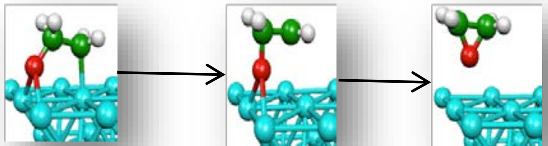
Develop efficient photo-catalysts and photo-catalytic processes for conversion of CO_2 to sustainable fuels. Our approach is to leverage knowledge of reactions that can be driven by photons, and reactions that can be driven by heat to develop hybrid catalytic systems that efficiently convert CO_2 to fuels, such as CH_4. To accomplish this, we will combine experimental and theoretical approaches to analyze the individual elementary steps that control the overall process. Once the critical elementary steps are identified we will design targeted photo-catalytic materials and reactors to optimize performance.

Energy Relevance

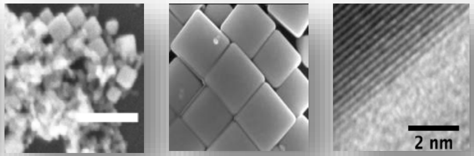
This project will address the following areas:

- The scientific and engineering feasibility of driving CO_2 conversion by combining solar and thermal energy inputs
- The ability to enhance the rate of this process and control the selectivity of the process by manipulating catalyst characteristics
- Education of graduate students with expertise in materials and catalytic conversion of CO_2

Developing mechanistic insights



Synthesis of hybrid nano-catalysts



Novel reactor design

Participant

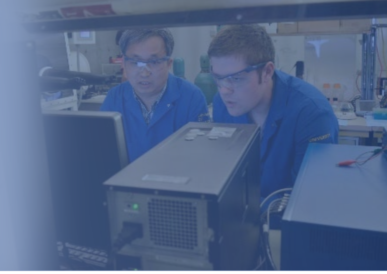
Phillip Christopher
Assistant Professor,
Chemical and
Environmental Engineering

Milestones

Year 1: Synthesis and mechanistic analysis (experiments + theory) of Pt, Cu and Co deposited on TiO_2 in a model reactor that allows manipulation of temperature, light intensity and pressure

Year 2: Synthesis, testing and reaction engineering of optimized bi-metallic photo-catalysts in model reactor

Year 3: Construction of novel reactor system that uses only solar input and demonstration of technology in real world system for producing sustainable fuels from CO_2



Nanostructured Pathway Biocatalysts for Enzymatic Fuel Cells

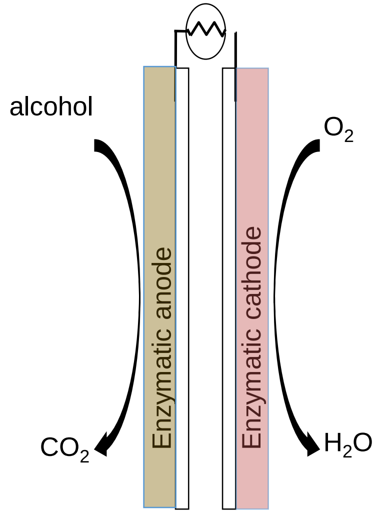
About

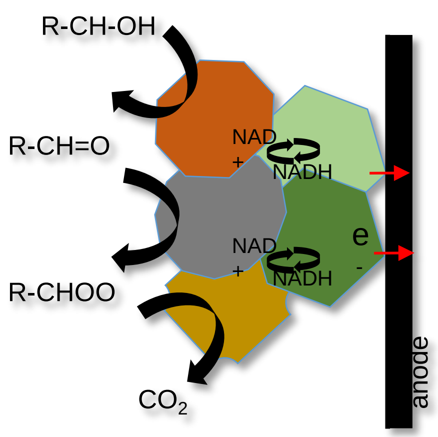
The overall objective of the proposed work is to develop multi-enzyme bioelectrocatalysts for the oxidation of alcohols to CO_2. The stepwise reaction will produce electrons at each oxidation, thus increasing maximum power densities in enzymatic fuel cells. By controlling the nanoscale spatial organization of enzymes in a multi-enzyme complex we will optimize overall reaction yield, electron transfer from enzyme reaction centers to electrode, and power density.

Energy Relevance

This project will address the following areas:

- Development of high power density fuel cells for microscale applications.
- Development of new bioelectrocatalysts with optimized nanoscale spatial organization for achieving high reaction pathway yields.
- Education of graduate students with expertise in micro-power generation and bioelectrocatalysis.





Participant

Ian Wheeldon
Assistant Professor,
Chemical and
Environmental Engineering

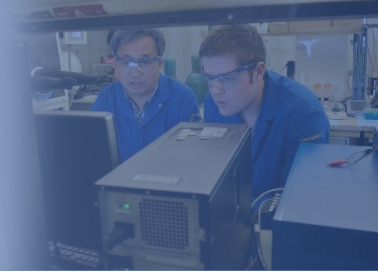
Milestones

Year 1: Synthesize multi-enzyme/DNA nanostructures with controlled inter-enzyme distance, shape, and enzyme stoichiometry

Year 2: Demonstrate the ability to completely oxidize alcohols to CO_2 by direct electron transfer from nanostructured bioelectrocatalyts to fuel cell anode

Year 3: Demonstrate high power density enzymatic fuel cells through complete oxidation of simple alcohols

Contracts and Grants



Following is a partial listing of active contracts and grants for the 2015-16 academic year:

- Alfredo Martinez-Morales. Demonstration of community scale low cost highly efficient PV and energy management system at the Chemehuevi Community Center
- Alfredo Martinez-Morales. Demand Reduction, Economic Benefits Analysis, and Micro-Grid Demonstration of an Optimization-Based Control Strategy, at City Hall in Rancho Cucamonga
- Alfredo Martinez-Morales. University of California Advanced Solar Technologies Institute (UC Solar)
- Sadrul Ula. Bringing Energy Efficiency Solutions to California's Water Sector with the Use of Customized Energy Management System (EMS) and Supervisory Control and Data Acquisition System (SCADA)
- Sadrul Ula. Analysis of Advanced PEV V2G Charging Strategies Coupled with PEV Vehicle Activity Analysis
- Hamed Mohsenian-Rad, Sadrul Ula. Monitoring and Control of PVs, Battery Storage Systems, and EV Chargers at a 12 kV Industrial Feeder and Substation Level
- Hamed Mohsenian-Rad, Sadrul Ula. Exploiting μPMU Data at RPU's 12 kV Industrial Feeder: Innovative Data Analytics and Optimal Energy Resource Operation