University of California Riverside
Testing Facilities for Sustainable Technologies
UC Riverside’s Bourns College of Engineering-Center for Environmental Research and Technology (CE-CERT) has unique capabilities to test a variety of electric drive vehicles, including pure battery electric, fuel-cell, hybrid electric, and plug-in hybrid electric vehicles. With two state-of-the art chassis dynamometers, both light-duty and heavy-duty EVs can be tested. CE-CERT has developed a wide range of electric drive testing protocols, providing research results to industry, government agencies, and academia.
CE-CERT’s dynamometers have been designed to handle a range of vehicles and vehicle loads at on-road driving conditions. The Heavy-Duty 48” Electric AC Chassis Dynamometer has dual, direct connected, 300 horsepower motors attached to each roll set with a base inertia of 45,000 lbs. with the addition of a large flywheel. The dynamometer applies appropriate loads to a vehicle to simulate factors such as the friction of the roadway and wind resistance that it would experience under typical driving. A driver accelerates and decelerates following a driving trace while the vehicle is driven in place.

In addition to standard vehicle performance measurements of velocity and acceleration, CE-CERT is able to measure battery SOC, system voltage and current, energy efficiency per mile (kWh/mile) and gradeability.

Through extensive vehicle activity studies, CE-CERT has developed a number of “drive cycles” specific for electric vehicles and trucks. These drive cycles, in addition to certification drive cycles, can be tested repeatedly in a controlled environment.
## Electric Drive Vehicle Testing Laboratories

**UC Riverside**

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<thead>
<tr>
<th>Technology Type</th>
<th>Testing Capabilities</th>
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<tbody>
<tr>
<td><strong>Heavy Duty Chassis Dynamometer</strong></td>
<td>Capable of testing any electric truck in a wide range of configurations</td>
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<tr>
<td><strong>Light Duty Chassis Dynamometer</strong></td>
<td>Capable of testing any light-duty electric vehicle in a wide range of configurations</td>
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<tr>
<td><strong>EV Data Acquisition System:</strong></td>
<td>Capable of measuring dynamometer physical loads, battery SOC, vehicle voltage, current, energy efficiency</td>
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<tr>
<td><strong>Real-Time Monitoring System Software and Sensors</strong></td>
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UCR has well established microgrid testbeds and laboratories for pre-commercial testing of new technologies in a “living lab” environment. Over the last seven years, UCR researchers have designed and implemented numerous microgrid systems including 2.2 MWh of battery energy storage, over 11 MW solar PV, 8 MW of Thermal Energy Storage (TES) for chiller operations, and multiple electric vehicle chargers including supervisory control and data acquisition systems.

These unique microgrid/smartgrid testbeds with plug and play capabilities possess the ability to validate various Hardware in Loop (HiL) scenarios. In addition to energy system modeling, UCR can utilize its microgrid testbed for evaluating specific microgrid designs that will be placed elsewhere.
Battery Storage

- 2 MWh integrated battery energy storage
- Stationary and mobile battery platforms
- 10 MW of controllable loads
- Load shifting and peak shaving algorithm optimization
- Demand response

Renewable Energy Generation

- 8 MW of PV solar capacity islanding operation and control
- Curtailment optimization & Soiling evaluation
- Fixed vs. tracking characterization
- Zero net energy microgrid demonstration with storage and load control integration

System Integration

- SCADA microgrid controller development
- Power quality monitoring and analysis with load monitoring and control
- Microgrid optimization
- EV charging with microgrid integration
- Anomaly detection and response
**Off-Grid Solar Energy Systems**

- Stand-alone (off-grid) system deployment, demonstration, and measurements
- Testing of control algorithms for managing self consumption, loads, and energy storage
- Greenhouse energy management systems (load controller, charge controller, microcontrollers, and battery management systems)

**Mobile Renewable Energy Power Systems**

- Modular and deployable solar-plus-battery system demonstration and testing
- Portable battery performance cycling and testing
- Solar energy generation, inverter, and load data monitoring, reporting, and analysis
- Versatile and adaptable testbed system

**Soiling Testing Stations**

- Testbed for testing different module types, coatings, designs, and cleaning cycles
- Soiling, light induce degradation (LID) studies, and potential induced degradation (PID)
- Performance metrology and environmental equipment
- Data collection and analysis methodologies
Sustainable Integrated Grid Initiative (SIGI) Testbed
UC Riverside

Batteries to Prevent Minimum Import Violation
- Large scale integration of ZnBr flow batteries
- Real time load forecast and dynamic control
- Energy management system and control algorithm development
- Benefit-to-cost analysis
- Minimum import interconnection agreement

Flow Batteries Integration
- Rule 21 and NFPA compliance
- Demonstration of peak shaving, load shifting, demand response, and emergency back-up power
- Energy, economic, and emissions savings analysis
- System optimization based on operational constraints and requirements

Microgrids
- Islanding studies and demonstration Increased grid stability, robustness, and reliability
- Advanced data and energy management systems
- Optimized utilization of solar energy and stored energy
- Implementation of use cases and scenarios
- Measurement and verification (M&V) analysis
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<tr>
<td>Solar Panels</td>
<td>Soiling, efficiency, curtailment, performance, microgrid integration, islanding</td>
</tr>
<tr>
<td>Inverters</td>
<td>Efficiency testing (5kW to MW+), curtailment, islanding, voltage support, reactive power control, grid ancillary services</td>
</tr>
<tr>
<td>Battery Energy Storage</td>
<td>Microgrid integration, control optimization, Battery Management System (BMS), performance, islanding</td>
</tr>
<tr>
<td>Microgrid Control and Integration</td>
<td>System architecture, net zero configuration, controls, distributed generation, load management</td>
</tr>
<tr>
<td>Load Management</td>
<td>SCADA, islanding, microgrid integration, control optimization, energy profiling</td>
</tr>
<tr>
<td>Supervisory Control and Data Acquisition (SCADA)</td>
<td>System optimization, system configuration, energy measurement, load management, performance monitoring</td>
</tr>
<tr>
<td>Vehicle to Grid</td>
<td>As of 2019, SIGI now offers testing of vehicle-to-grid algorithms using the latest V2G inverter systems.</td>
</tr>
</tbody>
</table>
UC Riverside’s Department of Electrical and Computer Engineering, in collaboration with Winston Chung Global Energy Center (WCGEC) and the Bourns College of Engineering-Center for Environmental Research and Technology (CE-CERT) has the unique capabilities to test various smart grid sensor technologies (e.g., synchrophasors, synchowaveforms, grid asset sensors, line sensors, substation SCADA systems, behind-the-meter sensors, building sensors, fault location, isolation, and service restoration (FLISR), etc.); as well as various smart grid control technologies (e.g., Volt-VAR control and Volt-Watt control based on inverter-based distributed energy resources (DERs), voltage and frequency ride-through control, DERMS, Advanced Distribution Management Systems (ADMS), distribution-level Flexible Alternating Current Transmission System (FACTS), building energy management, frequency regulation, demand response, etc.). The available field test capability is at medium voltage and low voltage three-phase systems; including a collection of multiple 12 kV power distribution feeders; with various types of loads and DERs.

In addition to true-scale field testing capabilities, UC Riverside also has the capabilities to conduct lab-scale (i.e., pre-field-test) assessment of smart grid monitoring and control technologies by using its state-of-the-art hardware-in-the-loop (HIL) testing facility; including both performance and cyber-security assessment.
Field Testing and HiL Testing of Smart Grid Monitoring and Control Technologies
UC Riverside

GPS-time-synchronized High-resolution Phasor Measurements (PSL Micro-PMUs)

Non-contact Line-Mounted Current Sensors and Fault Indicators (Sentient Line Current Sensors)

Big-data Analytics

Power quality and waveform sensors (PMI PQ Sensor - Revolution)
Field Testing and HiL Testing of Smart Grid Monitoring and Control Technologies
UC Riverside

DERMS: DER Management System (SGS DER Controller); supporting inverter-based Volt-VAR and Volt-Watt control

Lab-scale Hardware-in-the-Loop (HIL) testbed with a Real-Time Digital Simulator (RTDS) for Power Grid Simulation.
Vehicle to Grid (V2G) Testing
UC Riverside

Diesel to Electric Conversions
• Equipped for bi-directional energy transfer
• Light duty and transit vehicle platforms
• 100 kW V2G capability
• Load shifting and peak shaving algorithm optimization
• Demand response

Battery Energy Storage with V2G Integration
• Load management utilizing V2G algorithms
• Smart charging based on distributed generation
• Aggregation algorithm development
• Vehicle activity monitoring
• Carbon based pricing for EV charging

EV charging Monitoring and Control
• Peak shaving and shifting
• Energy cost optimization
• Zero net energy algorithm development
• Utility integrated demand response
Vehicle to Grid (V2G) testing

Vehicle to Grid (V2G) architectures allow grid connected vehicles to transfer power from the vehicle back to the electric supply infrastructure. The optimization of V2G requires properly configured vehicles and electric vehicle supply equipment (EVSE).

UC Riverside has created a microgrid testbed with integrated V2G capabilities. The system utilizes both light duty passenger EVs and larger transit vehicles.

Research is focused on system architectures, controls, optimization, energy management, and communications.

Shown in Picture: Electric Vehicle supplying power to the storage bank (inside trailer) which is connected to the building microgrid
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<tr>
<td>Electric Vehicle Supply Equipment (EVSE)</td>
<td>V2G capability, performance, measurement, access control, billing, communications</td>
</tr>
<tr>
<td>V2G capabilities</td>
<td>Energy measurement, capacity, vehicle connectivity, protocols</td>
</tr>
<tr>
<td>Microgrid Control and Integration</td>
<td>System architecture, net zero configuration, controls, load management</td>
</tr>
<tr>
<td>Load Management</td>
<td>SCADA, islanding, microgrid integration, control optimization, energy profiling</td>
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<tr>
<td>Vehicle Activity</td>
<td>Energy profiles, trip activity, charging activity, GIS based analysis, vehicle energy monitoring</td>
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The Advanced Materials and Energy Devices Laboratory (AMEDL) specializes in renewable energy generation and energy storage. The AMEDL group has expertise in the extensive testing of materials and devices for photovoltaic, photoelectrochemical, piezoelectric, delivery platforms, and battery applications. AMEDL’s research is focused on experimental work including high quality synthesis of materials, characterization, device fabrication, measurement and testing. Testing includes electrochemical measurements photoresponsive measurement under diverse light sources including a solar simulator and UV lamps.
Materials Synthesis, Device Fabrication and Testing

UC Riverside

Battery Fabrication and Testing
- Electrochemical depositions and measurements
- Potentiostatic/Galvanostatic and programmed cyclic techniques
- Voltammetry and Electrochemical Impedance Spectroscopy (EIS)
- Current sensitive sensing, corrosion and inhibitors studies, combined with frequency response analyzer (FRA), coating technologies

Solar Cell Fabrication and Testing
- 450 W Xe Class AAA solar simulator
- 0.1 to 1 Sun irradiation power adjustment
- Horizontal and vertical beam path
- UV and visible light filters

Material Synthesis and Characterizations
- Diverse material synthesis and nano-engineering system
- Extensive materials characterization equipment and tools
- Large selection of deposition and etching systems including e-beam physical vapor deposition (EBPVD), sputter, atomic layer deposition (ALD), focused ion beam (FIB) milling and photolithography
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<tr>
<td>Renewable Generation</td>
<td>Solar Cells - Efficiency, stability, testing under artificial environment, and testing of next-generation solar cells</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>Batteries - Charging/discharging, cyclic performance, long-term stability, and rate performance</td>
</tr>
<tr>
<td>Material-Based</td>
<td>Electrochemical Cells - Cyclic/linear/chrono voltammetry, coulometry and potentiometry, and electrochemical impedance spectroscopy</td>
</tr>
<tr>
<td>Material-Based</td>
<td>Materials Characterization - Electron microscopy, optical spectroscopy, crystallographic analysis, elemental analysis, and surface topography</td>
</tr>
<tr>
<td>Material-Based</td>
<td>Materials Synthesis - Chemical vapor deposition (CVD), hydrothermal and solvothermal synthesis, and electrodeposition</td>
</tr>
<tr>
<td>Material-Based</td>
<td>Device Fabrication - Thin-film devices, solar cells, photoelectrochemical cells, electrochemical cells, and coin-cell batteries</td>
</tr>
</tbody>
</table>
When considering how to get to zero-carbon mobility, there are generally four strategies to consider: 1) build more efficient vehicles that emit less carbon (e.g., HEVs, BEVs, and fuel-cell EVs); 2) utilize low- or zero-carbon fuel such as electricity or hydrogen; 3) implement programs that reduce overall VMT; and 4) employ ITS and automation technology to improve transportation system efficiency. UC Riverside has set up testbeds to evaluate Shared Mobility (addressing strategy 3), Transportation Electrification (addressing strategies 1 & 2), and Connected and Automated Vehicles (addressing strategy 4).
Shared, Electric, Connected, and Automated Vehicle Testing
UC Riverside

A key vehicle testbed, the Innovation Corridor, located in Riverside, California, consists of a six-mile section of University Avenue between the main UCR campus and downtown Riverside. This arterial corridor has been outfitted with traffic signal controllers that broadcast signal phase and timing, employ video analytics, and is used for experimentation with shared, electric, connected and automated vehicle (e.g., cars, buses, and trucks).

https://www.cert.ucr.edu/transportation-systems-vehicle-infrastructure-interaction/city-riverside-innovation-corridor
Shared, Electric, Connected, and Automated Vehicle Testing

Innovation Corridor

Consists of 10 instrumented intersections along a 4-lane urban arterial. Intersections utilize modern traffic signal controllers that broadcast signal phase and timing and employ video analytics; Corridor also has multiple air quality monitors.

Example connected vehicle application

The corridor is used to conduct Eco-approach and departure studies at signalized intersections. Vehicles can “listen” to an upcoming signal’s phase and timing and adjust their speed to reduce energy consumption and improve throughput.

Demo at: https://youtu.be/j9Tg2g9YTjc

Simulation and testing platforms

Complementing real world testing, modeling enables the projection of mobility and environmental benefits from the wide-scale adoption of shared, electric, connected and automated vehicle technologies.
Los Angeles Testbed

UCR has set up three arterial corridors with 15 connected traffic signals nearby the port of Los Angeles to support a variety of connected truck applications such as Eco-Approach and Departure, freight signal priority.

See demo at: https://youtu.be/1CR4vMh8ufE

Traffic Signal Information System (TSIS)

The connectivity of these connected traffic signals is enabled by 4G/LTE cellular communication where real-time signal phase and timing (SPaT) information is sent to the Traffic Signal Information System (TSIS) server at UCR. Vehicles traveling on the testbed can request and receive the SPaT information from the TSIS server through the same cellular communication. Currently, the testbed is being used to test and evaluate an EAD application for heavy-duty trucks, developed by UCR.
## Shared, Electric, Connected, and Automated Vehicle Testing

**UC Riverside**

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<tr>
<td>Shared Mobility Evaluation</td>
<td>Using LBNL’s BEAM model, travel demand activity can be evaluated for a number of shared mobility scenarios, measuring a variety of performance metrics</td>
</tr>
<tr>
<td>Evaluating Connected and Automated Vehicles (CAVs) in Simulation</td>
<td>Using a wide range of simulation tools (e.g., VISSIM, PARAMICS, SUMO) and specific APIs, a wide range of CAV scenarios can be tested</td>
</tr>
<tr>
<td>Evaluating Connected and Automated Vehicles (CAVs) using Hardware in the Loop testing</td>
<td>A unique hardware-in-the-loop testing system for CAVs has been developed, combining traffic simulation and a real-world vehicle on a dynamometer</td>
</tr>
<tr>
<td>Evaluating Connected and Automated Vehicles (CAVs) on the road</td>
<td>UCR has developed several CAV testbed sites in Riverside California, and Carson California, installing communication infrastructure on the road</td>
</tr>
</tbody>
</table>
This testing facility, developed with California Energy Commission (CEC) funding, is capable of efficiency and load testing of electric motors and Adjustable Speed Drive (ASD) up to 100hp. The facility can also measure electric system harmonics.

This is the first independent electric motor testing center in the state of California capable of providing unbiased evaluation of motor efficiency at various operating conditions. This facility is available for the use by the industry professionals, academics, and other stakeholders.
Motor Efficiency Measurement & Verification

Output power is monitored and measured using the torque transducer, which separates the load from the motor to isolate output measurement at the shaft of the motor.

External portable Fluke Power Analyzers enable the accurate measurement of both input and output power necessary to find operational efficiency of a motor. This used to verify efficiency of an electric motor.

Improving Software for Efficient Motor Selection

- Many commercial and in-house software used by architectural and engineering firms design HVAC systems with inflated safety factors used in calculating three-phase motor sizes for buildings.
- UCR quantifies energy waste due to the: (i) use of lower efficiency motors, (ii) use of oversized motors in existing buildings, and (iii) selection of oversized motors in the architectural and engineering design stage of new buildings.
<table>
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<td>Industrial Electric Motors</td>
<td>Zero to Rated Torque, Efficiency at Various Loading Condition, Quantification of Voltage and Current Harmonics, Range 0-100hp</td>
</tr>
<tr>
<td>Variable Frequency Drives</td>
<td>Efficiency at Various Loading Condition, Quantification of Voltage and Current Harmonics, Range 0-100hp</td>
</tr>
<tr>
<td>Wind Generators</td>
<td>Zero to Rated Torque, Efficiency at Various Loading Condition, Quantification of Voltage and Current Harmonics, Range 0-100hp</td>
</tr>
<tr>
<td>Custom Designed Special Purpose Motors</td>
<td>Zero to Rated Torque, Efficiency at Various Loading Condition, Quantification of Voltage and Current Harmonics, Range 0-100hp</td>
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</table>
About 20% of electricity use in California is treating, pumping, and distribution of water. With funding from California Energy Commission (CEC), College of Engineering – Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside (UCR) has demonstrated and deployed an energy management and data acquisition and supervisory control strategies that reduce peak loads and electricity costs in the delivery and treatment of water at each of the three water district locations. The three deployments utilize existing on-site SCADA architecture and implement the Energy Management System (EMS) within the existing architecture.

This demonstration project highlights a pathway for water agencies in California to reduce their peak energy consumption substantially with no decrement in service or reliability. The project also identifies “real world” implementation issues that have not emerged in previous proof-of-concept research.
Water Delivery Optimization

Integration of software and hardware at water delivery pumping, storage, or treatment facilities that enable the integration and transmission of data from energy meters directly or indirectly into Supervisory Control and Data Acquisition (SCADA).

Reducing Peak Energy Consumption

This demonstration project highlights a pathway for water agencies in California to reduce their peak energy consumption substantially with no decrement in service or reliability.

The project also identifies “real world” implementation issues that have not emerged in previous proof-of-concept research.

Individual SCADA System Integration

Combined with historical energy use integrated with real time SCADA control displays, operators can manage systems in real time to monitor and control peak demand.

Real time energy usage monitoring provides both instantaneous and 15min average relative to Time of Use (TOU) rate schedules, and alarm notifications optimized to provide operators with real time energy demand and the current existing peak load that has been recorded to date.
<table>
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<tbody>
<tr>
<td>Energy Management System (EMS)</td>
<td>Customized Development and Validation</td>
</tr>
<tr>
<td>Supervisory Control and Data Acquisition (SCADA)</td>
<td>Customized Development and Validation</td>
</tr>
<tr>
<td>Real-Time Monitoring System Software and Sensors</td>
<td>Development, Testing, and Validation</td>
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</table>
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https://oasis.ucr.edu