NREL
NATIONAL RENEWABLE ENERGY LABORATORY

ENERGY SYSTEMS INTEGRATION FACILITY

U.S. DEPARTMENT OF ENERGY

ESIF

ENERGY SYSTEMS INTEGRATION FACILITY

A megawatt-scale systems integration R&D facility.

Unique Capabilites

Hardware-in-the-Loop at Megawatt-scale Power

Megawatt-scale power-in-the-loop allows researchers and manufacturers to conduct integration tests at full power and actual load levels in real-time simulation and evaluate component and system performance before going to market.

High Performance Computing Data Center (HPCDC)

Petascale computing at the HPCDC enables unprecedented large-scale modeling and simulation of material properties, processes, and fully integrated systems that would otherwise be too expensive, too dangerous, or even impossible to study by direct experimentation.

Research Electrical Distribution Bus (REDB)

The ultimate power integration circuit, made up of two AC and two DC ring buses, connects multiple sources of energy and interconnects “plug-and-play” testing components in all the labs.

Supervisory Control and Data Acquisition (SCADA) Systems

The SCADA system monitors and controls REDB operations and safety and gathers real-time, high-resolution data for collaboration and visualization.

Data Analysis and Visualization

Analysis and visualization capabilities at the ESIF go beyond what is found in a typical utility operations center. Fully integrated with hardware-in-the-loop at power capabilities, an electrical distribution bus, a SCADA system, and petascale computing, the ESIF allows researchers and NREL partners to visualize complex systems simulations and operations in a completely virtual environment.

Smart Power, Smart People

Partnerships are Key

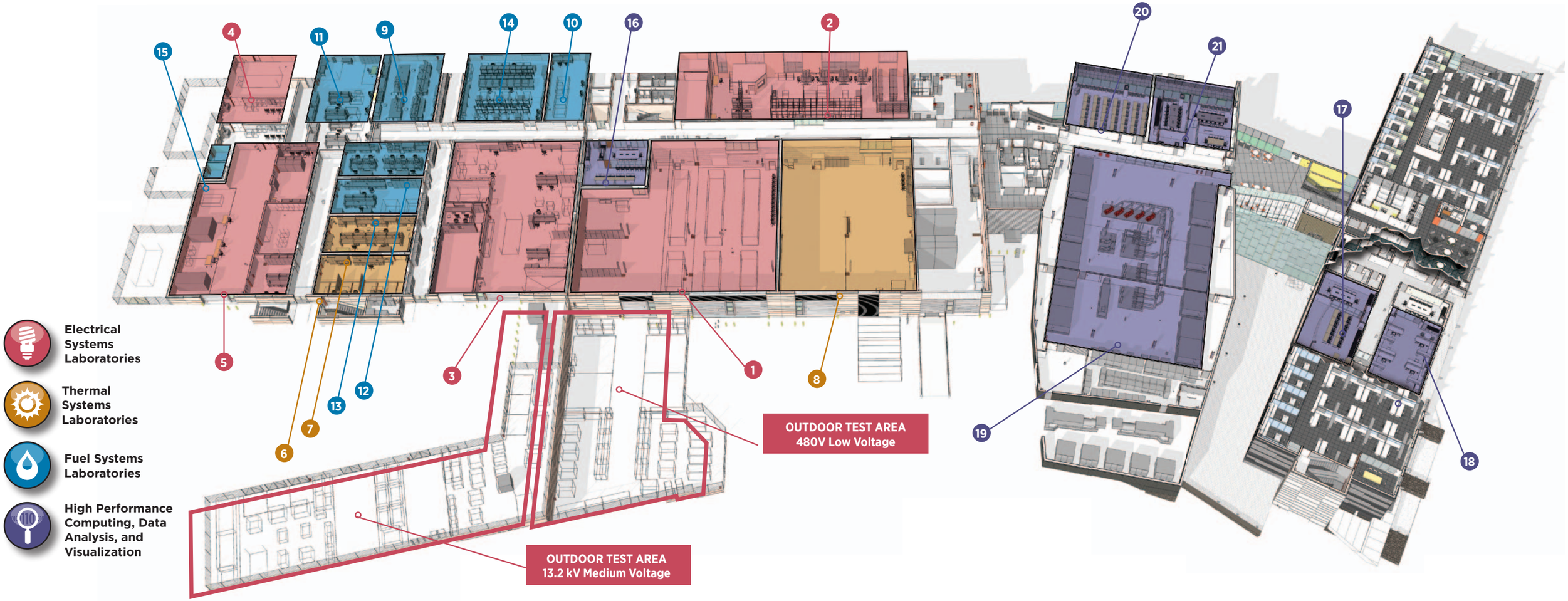
The Energy Systems Integration Facility provides NREL with the transformative capabilities needed to advance the nation's energy system into a cleaner, more intelligent infrastructure. But we can't do it alone.

The state-of-the-art facility, with its unprecedented integrated megawatt-scale testing and real-time simulation capabilities, is designed to allow NREL's world-renowned integration experts to work with a wide range of energy stakeholders to help develop, evaluate, and test their individual technologies before going to market greatly reducing the risks associated with early market penetration.

Participation from utilities, equipment manufacturers, renewable systems integrators, universities, and other national labs and related industries in fully utilizing ESIF's capabilities will dramatically accelerate the research required to transform the energy system to one that is cleaner, more secure, and more reliable.

Several options exist for partners interested in partnering with NREL on utility-scale projects focused on solving today's issues related to grid integration of renewable energy and other efficiency technologies.

Please contact us to explore these collaborative opportunities.



- Electrical Systems Laboratories
- Thermal Systems Laboratories
- Fuel Systems Laboratories
- High Performance Computing, Data Analysis, and Visualization

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The Energy Systems Integration Facility (ESIF) is a unique new national asset for energy systems integration research, development, testing, and analysis. Located on the U.S. Department of Energy's National Renewable Energy Laboratory campus in Golden, Colorado, the 182,500 sq. ft. facility contains approximately 200 office and collaboration spaces, 15 state-of-the-art laboratories, and several outdoor test areas.

Uniquely equipped with megawatt-scale test capabilities; integrated electrical, thermal and fuel infrastructures; advanced data analysis and visualization capabilities; hardware-in-the-loop simulation; and a high performance computing data center, the ESIF stands in a class of its own.

1. Power Systems Integration
2. Smart Power
3. Energy Storage
4. Electrical Characterization
5. Energy Systems Integration
6. Thermal Storage Process and Components
7. Thermal Storage Materials
8. Optical Characterization
9. Energy Systems Fabrication
10. Manufacturing
11. Materials Characterization
12. Electrochemical Characterization
13. Energy Systems Sensor
14. Fuel Cell Development and Test
15. Energy Systems High Pressure Test
16. ESIF Control Room
17. Energy Integration Visualization Room
18. Secure Data Center
19. High Performance Computing Data Center
20. Insight Center Visualization Room
21. Insight Center Collaboration Room

A Smart, Energy-Efficient Facility

NREL and its industry partners will work together to overcome the challenges of integrating renewable energy into the electrical grid in a facility that is safe, efficient, and respectful to its surrounding environment. The ultra-efficient ESIF building design includes many energy conservation strategies:

- Reuse of data center and laboratory waste energy
- Electrical energy transfer between laboratories
- Underfloor air distribution
- Active radiant beams
- Evaporative-based central cooling
- Natural ventilation through operable windows
- Daylighting

The ESIF is designed in accordance with the U.S. Green Buildings Council's standards and is expected, at a minimum, to achieve LEED Gold certification.

More information about the ESIF can be found on NREL's website: **www.nrel.gov/eis/facilities_esif.html.**

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ESIF

The ESIF is expected to be the nation's only megawatt-scale research and development facility.

ESIF Snapshot

- Cost: $135M
- Square feet: 182,500
- Occupants: ~200
- High performance computer: one-half petaflop scale; planned to be expanded to petaflop
- State-of-the-art electric systems simulation and visualization
- Component and systems testing at MW-scale power
- Integration of functioning systems with utility system simulations for real-time, real-power evaluation of high penetration scenarios
- Construction complete: fall 2012

Illustrations courtesy of SmithGroup

Transforming our Nation's Energy System

With all the benefits associated with renewable energy, why hasn't the grid already been modernized to accommodate these clean sources of energy? The short answer is: Megawatt-scale integration is hard to find.

Our nation's existing power grid is crucial to our way of life and cannot be shut down, overhauled, and started back up again. Yet, critical to moving clean energy technologies onto the electrical grid is the ability to carry out research, development, and megawatt-scale testing of the complex integrated systems, devices, and concepts of future electric supply and demand systems.

The Energy Systems Integration Facility (ESIF) on the campus of the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) in Golden, Colorado, will soon be the nation's first facility that can conduct integrated megawatt-scale research and development of the components and strategies needed in order to safely move clean energy technologies onto the electrical grid "in-flight" at the speed and scale required to meet national goals.

A Unique Partnering Facility

This state-of-the-art facility will enable NREL and industry to work together to develop and evaluate their individual technologies on a controlled integrated energy system platform. Testing and optimization at megawatt scale will help reduce risks associated with early market penetration. Participation from utilities, equipment manufacturers, renewable systems integrators, universities, and other national labs and related industries that fully utilize ESIF's capabilities will dramatically accelerate the research required to transform the energy system to one that is cleaner, more secure, and more reliable. Major electric system manufacturers and companies have already demonstrated interest in conducting their own research and development at the ESIF, once the facility is completed.

Energy Integration Research Focus

Research and development conducted in the ESIF will aim to overcome the challenges of integrating renewable energy into the electrical grid. These application and technology challenges span the entire electric power system — from generation to transmission, to distribution, and to end-use applications. Of particular focus are electric systems, buildings and facility systems, community power generation and microgrids, utility generation, thermal and hydrogen systems, energy efficient and advanced grid technologies, electricity system architectures, interoperability, and utility generation and grids that incorporate renewable energy (solar, wind, hydrogen, and advanced vehicles).

Labs and Equipment

To support these areas of research, the 182,500-sq. ft. ESIF will house approximately 200 scientists and engineers and a wide range of fully equipped, state-of-the-art laboratories and outdoor test areas, including:

Laboratories

- Power Systems Integration
- Smart Power
- Energy Storage
- Electrical Characterization
- Energy Systems Integration
- Thermal Storage Process & Components
- Thermal Storage Materials
- Optical Characterization Lab
- Energy Systems Fabrication
- Manufacturing
- Materials Characterization
- Electrochemical Characterization
- Energy Systems Sensor
- Fuel Cell Development and Test
- Energy Systems High Pressure Test

Outdoor test areas

- 13.2 kV - medium voltage
- 480 V - low voltage
- Rooftop test area
- Energy Storage

In addition, the ESIF will include other key service and support features, such as:

- Research Electrical Distribution Bus (REDB)
- High Performance Computing Data Center (HPCDC)
- Hardware-in-the-Loop Prototyping at Megawatt-scale Power
- Collaboration and Visualization Rooms
- High Bay Control Room

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Uniquely Tied Together

Integrated throughout the ESIF, the Research Electrical Distribution Bus (REDB) will function as the ultimate power integration "circuit" capable of utilizing multiple AC and DC buses that connect multiple sources of energy and interconnecting laboratories and experiments to test and simulate equipment. Running parallel with the REDB is a Supervisory Control and Data Acquisition (SCADA) system that monitors and controls facility-based processes and gathers and disseminates real time data for collaboration and visualization.

Parallel with the REDB are the thermal and fuel infrastructures built into the ESIF that all together provide a variety of electricity, thermal power, and fuel type connections.

Hardware-in-the-Loop at Power

Hardware-in-the-loop simulation is not a new concept, but adding megawatt-scale power takes research to another level. Equipped with hardware-in-the loop simulators, the ESIF's Smart Power Lab is the test lab for research and development of the power electronics components, circuits, and controls used in clean and sustainable energy integration. It will allow researchers and manufacturers to conduct integration tests at full power and actual load levels in real-time simulation, and evaluate component and system performance before going to market.

High Performance Computing Capabilities

In addition to high-tech collaboration and visualization rooms, the ESIF will include a high-performance computing data center (HPCDC) that will serve the breadth of NREL, expanding the laboratory's capabilities in modeling and simulation of renewable energy technologies and their integration into the existing energy infrastructure. The one-half petaflop scale (planned to be expanded to petaflop scale) will enable large-scale modeling and simulation of material properties, processes and fully integrated systems that would be too expensive, or even impossible, to study by direct experimentation.

Not only will the HPCDC house the fastest computing system dedicated to energy efficiency and renewable energy technologies in the world, it will also be one of the most energy efficient data centers in the world, operating at a power usage effectiveness (PUE) rating of 1.06 or better.

Office of the Future

The ESIF will demonstrate NREL's commitment to a sustainable energy future with its energy-saving workplace environment and will include energy efficient features such as natural ventilation through operable windows, daylighting, open air cubicles, and 'chilled beam' technology, to name a few.

Illustrations courtesy of SmithGroup

Walking the Talk

The Energy Systems Integration Facility will not only meet the nation's crucial research objectives for integrating clean and sustainable energy technologies into the grid, but will do it in a way that is safe, efficient, and respectful to its surrounding environment. The ESIF will be built in accordance with the U.S. Green Buildings Council's standards and is expected, at minimum, to achieve LEED Gold Certification.

Energy Conservation Strategies

- Reuse of data center and High Bay laboratory waste energy to maximize building/campus heating
- Transfer of electrical energy (via REDB) from experiments between laboratories for simultaneous use/reuse
- Underfloor air distribution for interior cooling and ventilation; outside air economizer
- Active radiant beams provide for perimeter cooling and heating
- Evaporative-based central cooling meets ASHRAE 55 thermal comfort range
- Natural ventilation mode with operable windows and ventilation shafts
- Daylighting with high efficiency lighting (lights off 10 AM to 2 PM)
- Energy Star rated equipment

For More Information

More information about the ESIF can be found on NREL's Web site: *http://www.nrel.gov/eis/facilities_esif.html* or by calling NREL's Public Affairs Office at (303) 275-4084.

Illustrations courtesy of SmithGroup

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Power Systems Integration Laboratory

At NREL's Power Systems Integration Laboratory in the Energy Systems Integration Facility (ESIF), research focuses on developing and testing large-scale distributed energy systems for grid-connected, stand-alone, and microgrid applications. The laboratory can accommodate large power system components such as inverters for photovoltaic (PV) and wind systems, diesel and natural gas generators, battery packs, microgrid interconnection switchgear, and vehicles. Closely coupled with the research electrical distribution bus at the ESIF, the Power Systems Integration Laboratory will offer power testing capability of megawatt-scale DC and AC power systems, as well as advanced hardware-in-the-loop and model-in-the-loop simulation capabilities. Thermal heating and cooling loops and fuel also allow testing of combined heating/cooling and power systems (CHP).

Laboratory Specifications

- 8,600 sq. ft. - space enough for three 40 ft. and three 20 ft. ISO containers
- 30 ft. high ceilings
- 30 ft. high overhead roll-up doors
- In floor carbon monoxide exhaust systems
- Diesel storage tank
- AC and DC power source
- Service connections include:
  - *Process cooling water*
  - *Process heating water*
  - *Research cooling water (chilled water)*
  - *Natural gas*
  - *Compressed Air*
  - *480 / 277 Vac*
  - *208 / 120 Vac*
  - *240 Split-phase Vac*

Application Scenarios

Hardware-in-the-loop experiments:

- Development of control algorithms for power electronics
- Simulation of grid conditions for development and evaluation of power system components and systems

Power system integration:

- Development and evaluation of optimal dispatch algorithms
- Development and evaluation of communication interfaces

Prototype testing:

- Electrical interconnection testing (i.e., IEEE 1547, UL 1741 type of tests)
- Advanced functionality testing (i.e., IEEE 1547.8, IEEE 2030 capability tests)
- Electrical performance testing (efficiency, maximum power)
- Safety testing
- Model validation testing
- Long duration reliability testing

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Power Systems Integration Laboratory may include:

- Manufacturers of distributed generation and microgrid system components (e.g., PV inverters, microgrid switches, batteries, generators)
- Utilities
- Microgrid and stand-alone power system integrators
- Certification laboratories
- Government agencies
- Universities
- Other National laboratories

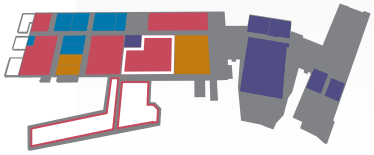
Contact Us

If you are interested in working with NREL's Power Systems Integration Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- Hardware-in-the-Loop Simulator
- Grid simulator
- AC load banks
- Bidirectional DC supplies
- Research Chiller
- Research Boiler
- SCADA Data Collection and Control System
- PV Simulator



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Smart Power Laboratory

Research at NREL's Smart Power Laboratory in the Energy Systems Integration Facility (ESIF) focuses on the development and integration of smart technologies including the integration of distributed and renewable energy resources through power electronics and smart energy management for building applications. The 5,300 sq. ft. laboratory is designed to be highly flexible and configurable, essential for a large variety of smart power applications that range from developing advanced inverters and power converters to testing residential and commercial scale meters and control technologies.

Laboratory Specifications

- Hardware-in-the-loop.
- Research Electrical Distribution Bus (REDB) connections to various AC equipments such as grid simulators, load banks, wind turbine simulators and DC equipments, such as DC supply, PV panels, batteries, and DC loads through AC and DC REDB.
- Multiple three-phase AC REDB (250A, 1600A) and DC REDB (250A, 1600A) for running multiple experiments in parallel.
- Three separate and enclosed power electronics test bays with sound-abatement walls for long duration testing of power converters.
- A 96 sq. ft. walk-in fume hood in one of the power electronics test bay to test early prototype systems that have greater risks of failure.
- Instrument and equipment development area for building prototype converters and monitoring equipments.
- Four test bays capable of supporting a variety of household appliances. Each bay represents the load of a house and has connections for 120/240 Volt electric service, water, and natural gas.

Application Scenarios

- Development of power converters for integration of distributed and renewable energy resources
- Development of advanced controls for smart power electronics
- Testing prototype and commercially available power converters for electrical interconnection and performance, advanced functionality, long duration reliability and safety
- Hardware-in-loop development and testing of power electronics systems in smart distribution grid models
- Testing of advanced appliances, home automation, HVAC, and energy management systems
- Research on various new distribution scenarios such as household DC systems, Residential scale generation and storage integrated with the home energy managements systems
- Electric vehicle integration
- Hardware-in-the-loop modeling for the characterization of household loads and generation
- Advanced metering technology, including utility grade smart meters and energy metering

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at NREL's Energy Systems Integration Facility to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Smart Power Laboratory may include:

- Smart appliance, home automation, and energy management system manufacturers
- Home automation and energy management system manufacturers
- Power electronics device vendors
- Utilities
- State energy commissions
- Certification laboratories
- Universities
- Other National laboratories

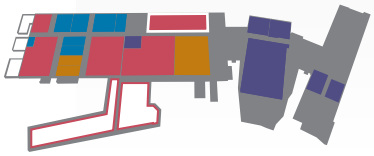
Contact Us

If you are interested in working with NREL's Smart Power Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- Various mechanical utilities in each test areas such as process cooling water, process heating water, research cooling water (chilled water), dedicated exhaust.
- Various facility power outlets in each test area such as three-phase 480/277 Vac, 208 / 120 Vac, 240 split-phase Vac and 120V single-phase Vac.
- Inverter HIL
- Grid simulator
- AC load banks
- Bidirectional DC supplies
- ELGAR Grid Simulator
- Electronic Load banks.
- Research Chiller
- Research Boiler
- SCADA Data Collection and Control System
- PV Simulator



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Energy Storage Laboratory

At NREL's Energy Storage Laboratory in the Energy Systems Integration Facility (ESIF), research focuses on the integration of energy storage systems (both stationary and vehicle-mounted) and interconnection with the utility grid. Focusing on battery technologies, but also hosting ultra-capacitors and other electrical energy storage technologies, the laboratory will provide all resources necessary to develop, test, and prove energy storage system performance and compatibility with distributed energy systems. The laboratory will also provide robust vehicle testing capability, including a drive-in environmental chamber, which can accommodate commercial-sized hybrid, electric, biodiesel, ethanol, compressed natural gas, and hydrogen fueled vehicles. The Energy Storage Laboratory is designed to ensure personnel and equipment safety when testing hazardous battery systems or other energy storage technologies. Closely coupled with the research electrical distribution bus at ESIF, the Energy Storage Laboratory will offer megawatt-scale power testing capability as well as advanced hardware-in-the-loop and model-in-the-loop simulation capabilities.

Laboratory Specifications

- This laboratory provides 9,600 sq. ft. of space
- Environmental chambers, both medium sized for battery pack, capacitor, and electronics testing, and a very large drive-in environmental chamber
- Wind turbine simulator
- Robust safety design to handle any kind of battery or energy storage system
- REDB plug-in bus connections for easy connection to any ESIF laboratory or resource
- Can accommodate:
  - *Floor space equivalent to up to two 20 ft. ISO containers*
  - *Large commercial vehicles up to city-bus size*
  - *Large battery systems, power electronics packages, and integrated system tests*
- Power conversion equipment for energy storage
- Ultra- and super-capacitor systems
- DC systems, such as commercial microgrids

Application Scenarios

The following types of tests:

- Performance
- Efficiency
- Safety
- Model validation
- Long duration reliability

Performed on the following equipment types:

- Vehicle batteries (both charging and discharging V2G)
- Stationary batteries

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Energy Storage Laboratory may include:

- Battery manufacturers
- Energy storage system integrators and installers
- Vehicle charging station integrators, vehicle manufacturers
- Utilities
- Certification laboratories
- Government agencies
- Universities
- Other National laboratories

Contact Us

If you are interested in working with NREL's Energy Storage Laboratory, please contact:

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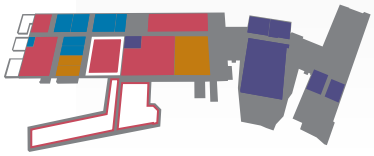
303-275-3036

Major Laboratory Equipment

- DC Power Testing Station 250 kW, up to 900 Vdc
- Environmental chamber large enough to drive vehicles into
- Electrical research bus connections
- PV simulator power supply
- Process liquids and gases (natural gas, biodiesel, cooling water, heating water, compressed air)
- Advanced data acquisition and monitoring equipment
- Typical Microgrid system components
- Grid simulator
- AC load banks
- Bidirectional DC supplies
- Research Chiller
- Research Boiler
- SCADA Data Collection and Control System
- PV Simulator



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Electrical Characterization Laboratory

Electrical Characterization Laboratory at NREL's Energy Systems Integration Facility (ESIF) focuses on the detailed electrical characterization of components and systems. This laboratory allows researchers to test the ability of equipment to withstand high voltage surges and high current faults, including equipment using standard and advanced fuels such as hydrogen.

Laboratory Specifications

The Electrical Characterization Laboratory is 1,500 sq. ft. with a separate control room and exterior entrance to the building. It is designed as a safe and secure environment that can survive destructive testing of equipment. The separate control room provides a safe location for researchers with video links into the main test area. This room also has a separate ventilation system. The electrical service and testing area is designed to be Class 1, approved. The laboratory is outfitted with natural gas, hydrogen gas, nitrogen, and compressed air service. Facility liquid cooling and liquid heating loops are provided for connection to equipment. An integrated safety PLC (programmable logic controller) and SCADA (supervisory controls and data acquisition) systems with high-speed data acquisition and secure data storage are present.

Application Scenarios

Equipment that interconnected to the electric power grid is required to meet specific surge withstand capabilities. This type of application tests the ability of electrical equipment to survive a lightning strike on the main grid. These are often specified in IEEE standards such as IEEE Std. 1547. In addition, this lab provides a space for testing new, unproven, or potentially hazardous equipment for robust safety assessment prior to use in other labs at ESIF. The Electric Characterization Laboratory is in a location where new, possibly sensitive or secret equipment can be evaluated behind closed doors.

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Electrical Characterization Laboratory may include:

- Equipment manufacturers
- Universities
- Other National laboratories

Contact Us

If you are interested in working with NREL's Energy Systems Integration Laboratory, please contact:

ESIF Manager
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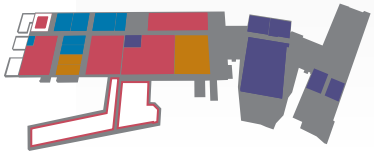
303-275-3036

Major Laboratory Equipment

- High Current Surge Tester
- High Voltage Surge Tester



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Energy Systems Integration Laboratory

The Energy Systems Integration Laboratory at NREL's Energy Systems Integration Facility (ESIF) provides a flexible, renewable-ready platform for research, development, and testing of state-of-the-art hydrogen-based and other energy storage systems. The main focus of the laboratory is assessment of the technical readiness, performance characterization, and research to help industry move these systems towards optimal renewable-based production and efficient utilization of hydrogen. Research conducted in the Energy Systems Integration Laboratory will advance engineering knowledge and market deployment of hydrogen technologies to support a growing need for versatile distributed electricity generation, applications in microgrids, energy storage for renewables integration, and home and station-based hydrogen vehicle fueling.

Laboratory Specifications

This laboratory provides over 3,000 sq. ft. of monitored Class I, Division 2 approved test space, a 600 sq. ft. control room, an electrical room, and a separate gas analysis area. Features of the laboratory include:

- Large test bays to accommodate various sized electrolyzers, fuel cells and related systems
- Combustible gas monitoring
- Automated monitoring and control systems
- Liquid and air cooling, nitrogen, natural gas, and electrical power supply options
- Two high pressure testing bays fully rated for testing systems to 15,000 psig
- A large adjacent outdoor testing area for hydrogen storage, compression, or other large equipment

Application Scenarios

Research activities are targeted to improve the technical readiness of the following:

- Low and high temperature electrolyzers, reformers and fuel cells
- Mechanical and electrochemical compression systems
- Hydrogen storage
- Hydrogen vehicle refueling
- Internal combustion or turbine technology for electricity production.

Examples of experiments include:

- Close- and direct-coupling of renewable energy sources (PV and wind) to electrolyzers
- Performance and efficiency validation of electrolyzers, fuel cells, and compressors
- Reliability and durability tracking and prediction
- Equipment modeling and validation testing
- Internal combustion or turbine technology for electricity production
- Safety and code compliance

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Energy Systems Integration Laboratory may include:

- Hydrogen equipment manufacturers
- Automobile OEM's
- System developers, integrators, and installers
- Vehicle refueling equipment manufacturers
- High-pressure hydrogen component manufacturers
- Certification laboratories
- Government agencies
- Universities
- Other National laboratories

Contact Us

If you are interested in working with NREL's Energy Systems Integration Laboratory, please contact:

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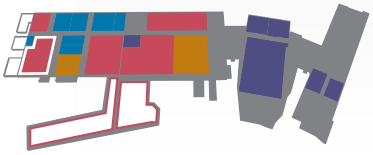
303-275-3036

Major Laboratory Equipment

- High accuracy hydrogen mass flow systems for improved efficiency monitoring
- PEM electrolyzer
- Alkaline electrolyzer
- Fuel cell
- H2 high pressure compressor
- AC and DC electrical research buss connections
- Advanced data acquisition and monitoring equipment
- Gas Chromatograph
- Ion Chromatograph



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Thermal Systems Process and Components Laboratory

The focus of the Thermal Systems Process and Components Laboratory at NREL's Energy Systems Integration Facility (ESIF) is to research, develop, test, and evaluate new techniques for thermal energy storage systems that are relevant to utility-scale concentrating solar power plants. The laboratory holds test systems that can provide heat transfer fluids for the evaluation of heat exchangers and thermal energy storage devices. The existing system provides molten salt at temperatures up to 800°C. This unit is charged with nitrate salt rated to 600°C, but is capable of handling other heat transfer fluid compositions. Three additional test bays are available for future deployment of alternative heat transfer fluids such as hot air, carbon dioxide, or steam systems.

Laboratory Specifications

The 950 sq. ft. laboratory features four test bays, each capable of supporting a 30kW test system. One bay resides inside in a HEPA-rated enclosure so articles containing nanofluids can be tested. Outside cooling air is available from a roof-mounted blower and hot air can be exhausted through the ceiling.

The laboratory contains 30kW test systems designed to provide hot heat transfer fluid to pilot-scale thermal energy storage systems. Storage systems can be cycled through multiple charge and discharge cycles to evaluate performance and storage efficiency.

Application Scenarios

The Thermal Systems Process and Components Laboratory performs pilot-scale thermal energy storage system testing through multiple charge and discharge cycles to evaluate heat exchanger performance and storage efficiency. The laboratory equipment can also be utilized to test instrument and sensor compatibility with hot heat transfer fluids.

Future applications in the laboratory may include the evaluation of thermal energy storage systems designed to operate with supercritical heat transfer fluids such as steam or carbon dioxide. These tests will require the installation of test systems capable of providing supercritical fluids at temperatures up to 700°C.

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Thermal Systems Process and Components Laboratory may include:

- CSP technology developers
- Utilities
- Certification laboratories
- Government agencies
- Universities
- Other National laboratories

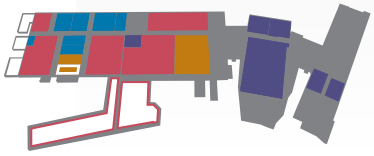
Contact Us

If you are interested in working with NREL's Thermal Systems Process and Components Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- Four 10 ft. X 10 ft. test bays for evaluation of 30kW thermal systems
- Custom test system to provide hot salt or molten metal heat transfer fluid to the test device
- LabView computer interface for unit control and data acquisition
- Thermal energy storage process test loops
- Outdoor air feed and exhaust for system cooling
- HEPA-rated enclosure for testing systems containing nanomaterials



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Thermal Storage Materials Laboratory

The Thermal Storage Materials Laboratory at NREL's Energy Systems Integration Facility (ESIF) investigates materials that can be used as high-temperature heat transfer fluids or thermal energy storage media in concentrating solar power (CSP) plants. Research objectives include the discovery and evaluation of candidate fluids and phase-change materials (PCM) to serve as thermal energy storage media in the temperature range of 300°C to 800°C. Knowledge of thermophysical properties such as melting point, heat of fusion, density, viscosity, thermal stability are essential for understanding how candidate materials could be deployed in CSP plants.

Laboratory Specifications

Within the 950 sq. ft. laboratory samples can be evaluated for melting point, heat capacity, heat of fusion, viscosity, density, thermal stability, and other physical properties using state-of-the-art analytical equipment. The laboratory contains a controlled-environment glovebox for preparation of materials that are sensitive to moisture, oxygen, or trace gases such as carbon dioxide. The lab glovebox and fumehood have HEPA filtration to allow testing of nanofluids and nanomaterial containing samples.

Instrumentation in the laboratory can determine the thermophysical properties of materials at temperatures up to 1,200°C.

Application Scenarios

The laboratory runs high-temperature instruments for the analysis of thermophysical properties. Small samples of candidate materials are prepared and characterized using differential scanning calorimetry, thermogravimetric analysis, and other specialized analytical methods.

Instrumentation capabilities are being expanded to allow for analysis of samples up to 1,200°C. Higher temperature operation is one method to increase the efficiency and lower the cost of CSP systems.

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Thermal Storage Materials Laboratory may include:

- CSP technology developers
- Utilities
- Certification laboratories
- Government agencies
- Universities
- Other National laboratories

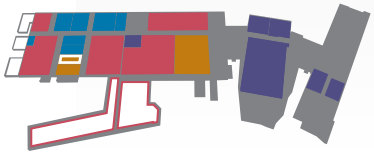
Contact Us

If you are interested in working with NREL's Thermal Storage Materials Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- Differential scanning calorimeter (to 1,200°C)
- Thermal gravimetric analyzer (to 1,100°C)
- High-temperature rheometer (to 1,100°C)
- Densitometer
- Glovebox with HEPA filtration
- Analytical balances and general chemistry supplies
- Controlled atmosphere furnace (to 1,100°C)



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Optical Characterization Laboratory

The Optical Characterization Laboratory at NREL's Energy Systems Integration Facility (ESIF) conducts optical characterization of large solar concentration devices. Concentration solar power (CSP) mirror panels and concentrating solar systems are tested with an emphasis is on measurement of parabolic trough mirror panels.

Laboratory Specifications

The Optical Characterization Laboratory provides state-of-the-art characterization and testing capabilities for assessing the optical surface quality and optical performance for various CSP technologies including parabolic troughs, linear Fresnel, dishes, and heliostats.

Application Scenarios

- Optical testing of panels and systems
- Weathering of panels

In the near-future, capabilities beyond troughs will be implemented and will address linear Fresnel, dish, and heliostat options. In addition, structural analysis and testing will be added to support detailed design of CSP concentrator systems.

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Optical Characterization Laboratory may include:

- CSP manufacturers
- Utilities
- Certification laboratories
- Government agencies
- Universities
- Other National laboratories

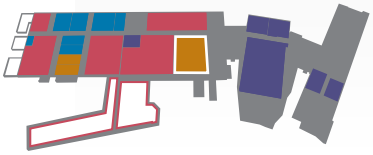
Contact Us

If you are interested in working with NREL's Optical Characterization Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- VSHOT (Video Scanning Hartman Optical Tester)
- SOFAST (Sandia Optical Fringe Analysis Slope Tool)
- Weather Chamber
- Large Thermal Cycling Chamber (future)



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Energy Systems Fabrication Laboratory

The Energy Systems Fabrication Laboratory at NREL's Energy Systems Integration Facility (ESIF) manufactures components for fuel cells and electrochemical cells using a variety of manufacturing techniques. Fabricated components include catalysts, thin-film and gas diffusion electrodes, and membrane electrode assemblies (MEAs). The laboratory supports NREL's fuel cell and electrochemical cell related research.

Laboratory Specifications

- Current fabrication of MEAs up to 50cm^2 electrode area
- Planned fabrication of MEAs up to 400cm^2 electrode area
- Availability of various coating techniques such as handpainting, knife spreading, and spray coating for catalyst coated membranes (CCM) and gas diffusion electrode (GDE) fabrication
- Individually adjusted ink formulation for each fabrication method and application
- Protocols for reproducible manufacturing and material preparation
- Wet chemical synthesis and fabrication of materials and device components

Application Scenarios

The main focus of the laboratory is to provide support for fuel cell research that is performed in adjacent laboratories. The laboratory enables NREL to manufacture fuel cells in-house using, for example, experimental catalyst developed at NREL. It further enables the creation of MEAs containing artificial defects required for the systematic study of performance and lifetime effects and the evaluation of in-house and externally developed quality control diagnostics for high volume production of fuel cell. Experiments performed in the laboratory focus mainly on the development of alternative fuel cell manufacturing methods.

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Energy Systems Fabrication Laboratory may include:

- MEA manufacturers
- Fuel cells and electrochemical cells manufacturers
- Certification laboratories
- Universities
- Other National laboratories

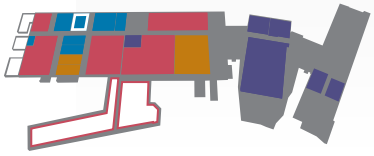
Contact Us

If you are interested in working with NREL's Energy Systems Fabrication Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- Ultrasonic and air brush spray systems
- 12 ton hot press; future planned 50 ton hot press
- High precision balances
- Ball mill
- Vacuum hot plates and gel dryer
- Hot plates
- Ultrasonicator
- Ultrasonic bath
- Stir plates
- Convection oven
- Fume hood



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Manufacturing Laboratory

The Manufacturing Laboratory at NREL's Energy Systems Integration Facility (ESIF) focuses on developing methods and technologies that will assist manufacturers of hydrogen and fuel cell technologies, as well as other renewable energy technologies, to scale up their manufacturing capabilities to volumes that meet DOE and industry targets. Specifically, the manufacturing activity is currently focused on developing and validating quality control techniques to assist manufacturers of low temperature and high temperature fuel cells in the transition from low to high volume production methods for cells and stacks. Capabilities include initial proof-of-concept studies through prototype system development and in-line validation. Existing diagnostic capabilities address a wide range of materials, including polymer films, carbon and catalyst coatings, carbon fiber papers and wovens, and multi-layer assemblies of these materials, as well as ceramic-based materials in pre- or post-fired forms.

Laboratory Specifications

This laboratory includes continuous web processing (roll-to-roll) equipment and various diagnostic measurement platforms. The lab will be used for internal development, evaluation of commercial diagnostics, and as a flexible development platform (user facility) for industry partner R&D.

Application Scenarios

Work leading to the development of non-contact, non-destructive techniques to measure critical dimensional and functional properties of fuel cell and other materials, and validation of those techniques on the continuous processing line. This work will be supported by materials provided by our partners.

Looking forward, the equipment in the laboratory is set up to be modified and extended to provide processing capabilities such as coating, casting, and deposition of functional layers, as well as associated processes such as drying or curing. In addition, continuous processes are used for components of organic and thin film photovoltaics (PV) as well as battery technologies, so synergies with these important areas will be explored.

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Manufacturing Laboratory may include:

- Manufacturers of cells and cell components for low and high temperature fuel cells
- Manufacturers of other renewable energy technologies using and/or exploring roll-to-roll processing
- Manufacturers or developers of quality control devices
- Manufacturers of continuous processing equipment
- Certification laboratories
- Universities
- Other National laboratories

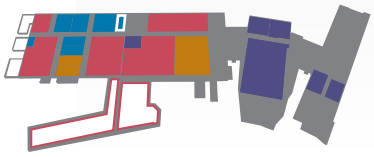
Contact Us

If you are interested in working with NREL's Manufacturing Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- Continuous processing line
  - Suitable for 6" - 18" wide webs
  - One to 100 foot per minute line speed
  - 0.5 – 5.0 pounds per lineal inch tension range
- Infrared diagnostic platform:
  - IR camera detector with various optics
  - Various excitation strategies
  - Sample hardware for various static measurements
  - Benchtop roller prototype
  - Commercial data acquisition and processing software
- Optical diagnostic platform:
  - Various detectors, sources, and lenses
  - In-house developed data acquisition and processing software
  - Motion stage
- Thickness measurement:
  - Dual laser thickness instrument
  - Ultra-low force pneumatic caliper



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Materials Characterization Laboratory

The Materials Characterization Laboratory at NREL's Energy Systems Integration Facility (ESIF) research focus is the physical and photoelectrochemical characterization of novel materials. In this laboratory unknown samples are characterized by identifying and quantifying molecular species present through the implementation of a suite of analytical instrumentation and techniques. This leads to the ability to deconvolute decomposition routes and elucidate reaction mechanisms of materials through thermal and evolved gas analysis. This aids in the synthesis of next generation materials that are tailored to optimize stability and performance.

These techniques and next generation materials will have many applications. One particular focus is the stable and conductive tetherable cations for use as membrane materials in anion exchange membrane fuel cells. Another is to understand the leachant contaminants derived from balance of plant materials used in proton exchange membrane fuel cell vehicles. Once identified and quantified, these organic and ionic species are dosed as contaminants into ex/in-situ fuel cell tests, to determine the effect on durability and performance.

This laboratory also acts in support of fuel cell catalysis, manufacturing, and other related projects.

Laboratory Specifications

- Integration of an array of analytical instrumentation to perform novel evolved gas analysis experimentation.
- A wide range of analytes can be safely tested and evolved with the expert operators and ventilated instrument enclosures.

Application Scenarios

The Materials Characterization Laboratory will cover multiple analytical operations, with the overall goal of troubleshooting synthetic materials or process streams to improve performance. Having novel evolved gas analysis and other analytical capabilities; this laboratory provides a viable location to analyze small batch samples, whereas setting up these types of capabilities and expertise would be cost and time prohibitive for most institutions.

Experiments that can be performed include:

- Evolved gas analysis
- Heterogeneous catalysis
- Trace level contaminants analysis
- Catalyst characterization
- Kinetics and stability
- Hyphenated techniques
- Isotopic analysis for elucidating reaction mechanisms and decoupling chemical reactions

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Materials Characterization Laboratory may include:

- PEMFC industry
- Certification laboratories
- Universities
- Other National laboratories

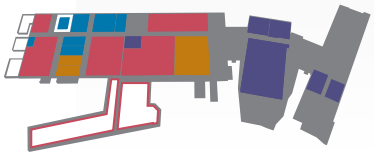
Contact Us

If you are interested in working with NREL's Materials Characterization Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- Gas chromatography mass spectrometer with liquids, headspace, and SPME autosampler and direct insertion probe
- Thermogravimetric analyzer
- Thermal desorber to perform TG-GCMS type experiments
- Fourier transform infrared spectrometer with ATR, DRIFTS, and gas cell accessories to sample liquids, powders, solids, and gases
- Total organic content analyzers with autosamplers (5% and <50ppm sensitivities)
- Evolved gas analysis software and accessories to properly employ EGA techniques
- Mobile MS and GC residual gas analyzer



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Electrochemical Characterization Laboratory

The research focus at the Electrochemical Characterization Laboratory at NREL's Energy Systems Integration Facility (ESIF) is evaluating the electrochemical properties of novel materials synthesized by various techniques and understanding and delineating the reaction mechanisms to provide practical solutions to PEMFCs commercialization issues of cost, performance and durability. It is also involved in the development of new tools and techniques for electrochemical characterization.

Laboratory Specifications

The laboratory is equipped with state-of-the-art instrumentation that permits the synthesis, electrode preparation and comprehensive electrochemical characterization of novel electrocatalysts and supports for PEMFCs. Gas manifolding to specific workstations allows different reactions to be probed.

The laboratory is also equipped with potentiostats, electrochemical half-cells, wet-chemical synthesis set-ups and electrode preparation capabilities that provides a comprehensive characterization of materials and interfaces especially those related to fuel cell technology.

Chemical hoods and HEPA filters are present in the lab to allow work with nanoparticles.

Application Scenarios

The laboratory concentrates on the development and characterization of new materials for PEMFCs such as electrocatalysts, catalyst supports in terms of electrochemical activity, electrochemical surface area and corrosion/durability. The impact of impurities and/or contaminants on the catalyst activity is also under study.

Experiments that can be performed include:

- Determination and benchmarking of novel electrocatalyst activity
- Determination of electrochemical surface area
- Determination of electrocatalyst and support corrosion resistance and durability
- Synthesis and characterization of novel electrocatalyst
- Determination of fundamental electrochemical parameters
- Estimation of electrocatalyst utilization

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Electrochemical Characterization Laboratory may include:

- PEMFC industry
- Certification laboratories
- Automotive fuel cell industry
- Fuel cell component suppliers
- U.S. and foreign Universities
- Other National laboratories

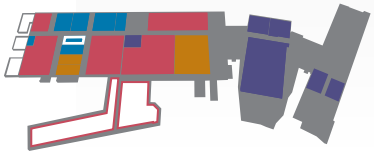
Contact Us

If you are interested in working with NREL's Electrochemical Characterization Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- Conductivity measurement station
- Ovens
- Explosion proof refrigerators



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Energy Systems Sensor Laboratory

The mission of the Energy Systems Sensor Laboratory at NREL's Energy Systems Integration Facility (ESIF) is to research, develop, test, and evaluate the performance of commercial and developing hydrogen sensor technologies to support the needs of the emerging hydrogen infrastructure. Sensor performance metrics analogous to national and international standards are quantified. Information gained from the sensor testing is provided to the sensor manufacturers to aid in sensor development, to end users to guide sensor selection and deployment, and to committees to support the development of codes and standards. The laboratory also provides support to end-users, including assessment of technologies for applications, information on deployment.

Laboratory Specifications

The laboratory consists of a sophisticated sensor testing apparatus developed at NREL. The system is fully automated for around-the-clock operation with remote control and monitoring capabilities via the internet. Standard testing protocols have been developed, but can be adjusted based upon individual needs.

Advanced capabilities of the Energy Systems Sensor Laboratory include:

- Parallel testing of multiple sensors
- Sub-ambient to elevated temperature extremes (ca. -40° C to +80° C; an expanded higher range is possible)
- Sub-ambient to elevated pressure (0.6 to 1.2 Bar, but an expanded range is possible)
- Active humidity control
- Accurate control of gas parameters with six precision digital mass flow meters operating in parallel
- Test conditions (T, P, RH and flow) monitored with traceable probes
- Gas composition continuously verified by mass spectrometric analysis to provide near real-time analysis of the test gas
- Evaluations carried out in the sensor chamber, which isolates the test sensor from the external environment
- LabVIEW based DAQ system for sensor data logging and system control
- Response time apparatus developed to determine sensor response and recovery time upon exposure to unsafe conditions.

Application Scenarios

- Testing and analyzing sensors are over a range of controlled and monitored environmental conditions.
- Testing the impact of interferants and poisons.
- Evaluating the life span of sensors with separate dedicated life test fixtures.
- Testing of hydrogen sensors for process applications, including responses under high hydrogen concentrations.

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Energy Systems Sensor Laboratory may include:

- Hydrogen sensor manufacturers
- Codes and standards development organizations
- Certification laboratories
- Government agencies
- Universities
- Other National laboratories

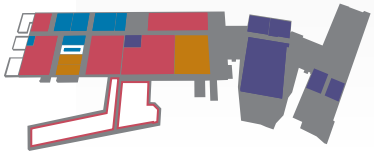
Contact Us

If you are interested in working with NREL's Energy Systems Sensor Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- SSTL sensor test apparatus (designed and built by NREL)
- National Instruments Data Acquisition System
- LabVIEW 2011
- Gas parameters controlled by precision digital mass flow controllers
- Pressure controlled by a precision digital pressure controller
- Relative Humidity controlled by HPLC pump interfaced to a custom built vaporizer
- Temperature controlled via a circulating cooler
- Gas flow monitored by a certified precision digital mass flow meter
- Pressure monitored by a certified digital pressure transducer
- Relative humidity and temperature monitored by a certified transmitter
- Quadrupole Mass Spectrometer



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Fuel Cell Development and Test Laboratory

NREL's state-of-the-art Fuel Cell Development and Test Laboratory in the Energy Systems Integration Facility (ESIF) supports NREL's fuel cell research and development projects through in-situ fuel cell testing. Current projects include various catalyst development projects, a system contaminant project, and the manufacturing project. Testing capabilities include but are not limited to single cell fuel cells and fuel cell stacks.

Laboratory Specifications

- ≥ 10 test stands offering 25 - 250 A range
- Comprehensive host of state-of-the-art fuel cell diagnostics
- Testing capabilities for PEMFC, DMFC, PAFC (PBI), AEMFC, and SOFC
- Spatial testing capabilities using 121-channel 50cm^2 segmented cell system or multi-channel potentiostat
- Host of calibration equipment
- Calibration standards in accordance with or exceeding USFCC standards

Application Scenarios

Diagnostics will include, but are not limited to:

- VI performance evaluation
- Linear sweep voltammetry for
  - H2- and MeOH-crossover limiting current determination,
  - Anode polarization, and
  - H2-pump experiments
- Cyclic voltammetry for electrochemically active Pt surface area determination
- AC impedance spectroscopy
- High frequency resistance determination
- Over-potential separation
- Start/stop
- Contaminant effects
- Defect effects
- Load, RH, or temperature cycling
- Durability
- Accelerated stress tests

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Fuel Cell Development and Test Laboratory may include:

- Fuel cell and fuel cell component manufacturers
- Certification laboratories
- Government agencies
- Universities
- Other National laboratories

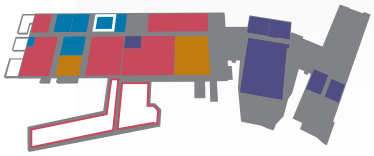
Contact Us

If you are interested in working with NREL's Fuel Cell Development and Test Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- Single cell fuel cell test stations
  - For PEMFCs sized 5 – 100 cm^2
  - Automated backpressure control
  - Various flow configurations
  - Fully calibrated
  - Script execution
  - Remote access
- Segmented cell fuel cell test station
  - 50cm^2
  - 121 segments, 0.41 cm^2 each
  - 121-channel load unit
  - Script execution
- Autolab potentiostat/ galvanostat
- Solartron multi-channel potentiostat/galvanostat
- Calibration Equipment
  - Bios Met Lab ML-800 Flowmeter
  - Vaisala & Viaspace Humidity Sensors
  - Traceable Temperature Sensors and Pressure Gauges
- *Planned:*
  - Mass spectroscopy/Gas chromatography
  - Full size fuel cell stack test station
  - Additional single cell fuel cell test stations



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NREL NATIONAL RENEWABLE ENERGY LABORATORY | ENERGY SYSTEMS INTEGRATION FACILITY

U.S. DEPARTMENT OF ENERGY

Photo from iStock/03364509. Illustration courtesy of SmithGroup.

Energy Systems High Pressure Test Laboratory

The purpose of the Energy Systems High Pressure Test Laboratory at NREL's Energy Systems Integration Facility (ESIF) is to provide space where high pressure hydrogen components can be safely tested. High pressure hydrogen storage is an integral part of energy storage technology for use in fuel cell and in other distributed energy scenarios designed to effectively utilize the variability inherent with renewable energy sources. The high pressure storage laboratory is co-located with energy storage activities such as ultra-capacitors, super conducting magnetic flywheel and mechanical energy storage systems laboratories for an integrated approach to system development and demonstration.

Hazards associated with hydrogen storage at pressures up to 10,000 psi include oxygen displacement, combustion, explosion, and pressurization of room air due to fast release and physical hazards associated with burst failure modes. A critical understanding of component failure modes is essential in developing reliable, robust designs that will minimize failure risk beyond the end of service life. Development of test protocol for accelerated life testing to accurately scale to real world operating conditions is essential for developing regulations, codes and standards required for safe operation.

NREL works closely with industry partners in providing support of advanced hydrogen technologies. Innovative approaches to product design will accelerate commercialization into new markets. NREL works with all phases of the product design life cycle from early prototype development to final certification testing.

Laboratory Specifications

The walls of the Energy Systems High Pressure Test Laboratory are built from concrete, capable of sustaining an overpressure condition or in the case of a component failure during test, and can act as secondary containment. Remote data and remote cameras are used for test observation, providing the added safety mechanisms needed to safely perform high pressurized tests.

Application Scenarios

High pressure tests are performed on hydrogen components, primarily for the validation of developing new codes and standards for high pressure hydrogen applications. The following types of tests can be performed:

- Performance
- Component and system level efficiency
- Strength of materials and hydrogen compatibility
- Safety demonstration
- Model validation
- Life cycle reliability

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Energy Systems High Pressure Test Laboratory may include:

- High pressure testing component manufacturers
- Codes and standards development organizations
- Certification laboratories
- Government agencies
- Universities
- Other National laboratories

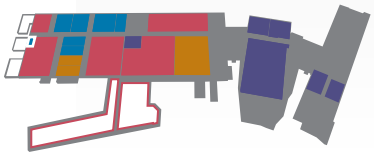
Contact Us

If you are interested in working with NREL's Energy Systems High Pressure Test Laboratory, please contact:

ESIF Manager
Carolyn Elam
Carolyn.Elam@nrel.gov
303-275-3036

Major Laboratory Equipment

- High pressure systems capable of cyclic loading and fast fill
- Hydrogen storage and recovery capability for extended life testing
- Automated operating systems with safety interlocks
- Pressure rated pumps, compressors and control system components
- Secondary containment vessels for end of life testing
- Hydraulic pressurization capability for proof testing
- Advanced data acquisition and monitoring equipment



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High Performance Computing Data Center

The new high performance computing (HPC) data center in NREL's Energy Systems Integration Facility (ESIF) is designed to be one of the most energy efficient data centers in the world, featuring warm water liquid cooling and waste heat capture and re-use. It's HPC capabilities will support the breadth of research at NREL, leading to increased efficiency and lower costs for important technologies including solar photovoltaics, wind energy, energy storage, electric vehicles, and the large-scale integration of renewables with the Smart Grid.

With state-of-the-art computational modeling and predictive simulation capabilities, the HPC data center will reduce the risks and uncertainty that are often barriers to industry adopting new and innovative technologies, thereby accelerating the transformation or our nation's energy system.

Energy Efficient Supercomputing

Initially, the HPC data center will house a petascale computing capability (one million billion calculations per second) and provide room for future systems that enable large-scale modeling and simulation of novel materials, biological and chemical processes, and fully integrated systems that would be too expensive, or even impossible, to study by direct experimentation. Not only will NREL's data center house the fastest HPC system in the world dedicated to advancing energy efficiency and renewable energy technologies, it will also be one of the most energy efficient data centers in the world, operating at a power usage effectiveness (PUE) rating of 1.06 or better.

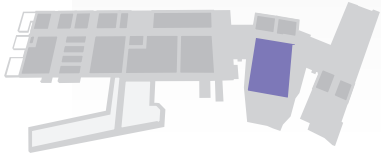
A 2006 study conducted by the U.S. Environmental Protection Agency estimated that data centers account for about 2% of all electricity consumed in the U.S. alone—roughly equivalent to the energy used by the entire airline industry. What's more, the industry is in the midst of the biggest build-out of new data center capacity in its history, therefore, improving energy efficiency in data center designs is critically important. NREL's HPC data center in the ESIF will be a showcase data center facility demonstrating best-in-class technologies for a holistic, integrated approach to energy efficient high performance computing.

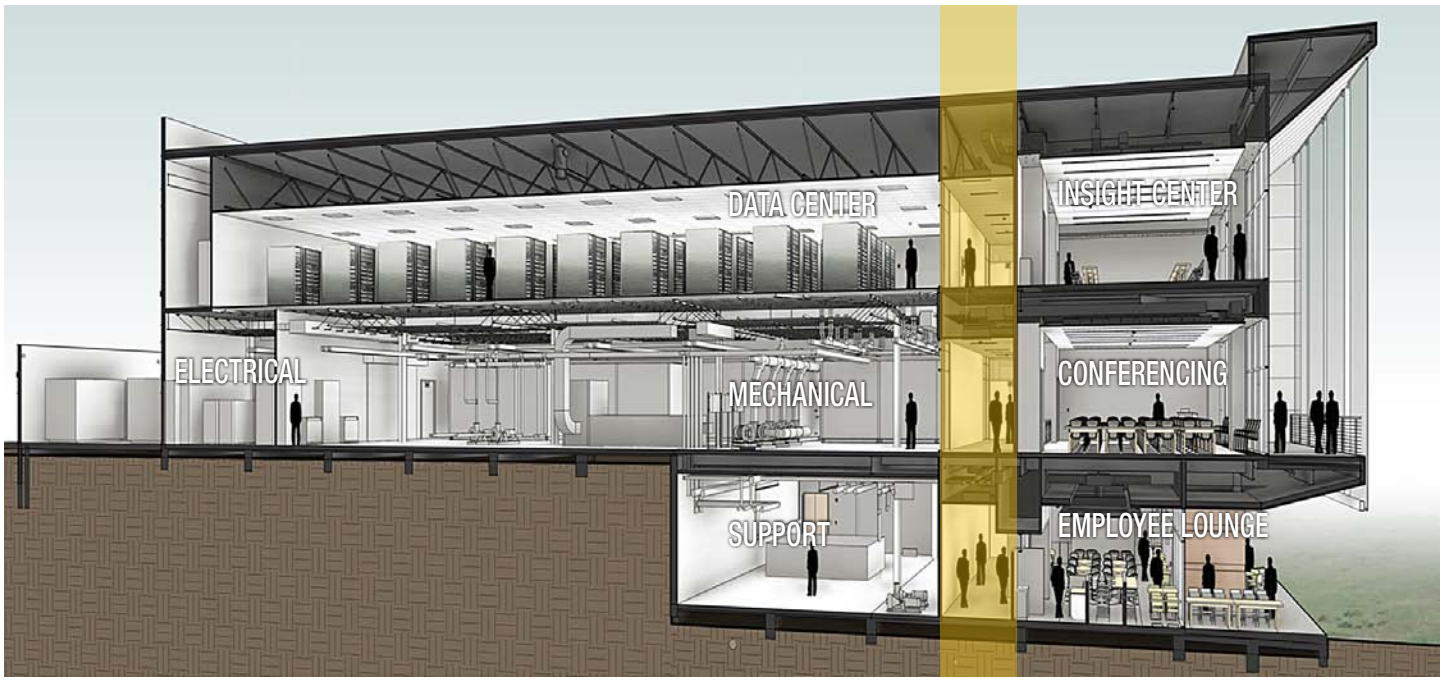
Innovative Cooling Design

Traditional data centers circulate mechanically cooled air (typically 50°F) under pressurized raised floors up through grated floor tiles in front of the compute racks in an attempt to keep vital computer chips from going above 150°F. The new ESIF data center will take advantage of the fact that liquid has approximately 1000 times the cooling capacity of air and pumps circulating liquid cooling are much more efficient than fans circulating air. The primary means for keeping the HPC systems in the data center from overheating is a liquid-cooled approach—*warm* liquid, that is.

The working fluid will start at approximately 75°F. It will circulate through heat exchangers in the HPC system to efficiently capture waste heat from the HPC system. The liquid will be heated to 95°F or warmer by the HPC system and be utilized as the primary source of heating for laboratory and office spaces in the ESIF. Provisions have been made to export heat beyond the ESIF to the rest of the campus. Data center waste heat will even be circulated through piping under walkways to keep pedestrian areas free of dangerous ice and snow in cold months. Reuse of the data center waste heat also saves water cooling tower water. Data center waste heat not needed by the building can be rejected via efficient evaporative cooling towers serving the HPC data center.

The ESIF HPC data center is approximately 10,000 sf^2 of uninterrupted, usable machine room space and is designed to be ultra energy efficient, capturing both the critical bytes of information for scientific research as well as the heat generated by powering multi-megawatts of HPC equipment, then used to heat office and laboratory space in the new facility.





Cross section view into the ESIF HPC data center. *Illustration from SmithGroupJJR*

Innovative Building Design

The top floor has approximately 10,000 sf^2 of uninterrupted, usable machine room space to house HPC and related equipment. The data center ceiling height is 11 feet, with return openings as required for any residual data center heat not captured to the hydronic cooling system. Return air chases on the north and south direct warm air from the ceiling plenum above down to the main fan wall air-handling units below. The middle floor is the mechanical space for pumps and power distribution. The lowest level is a pump room that allows the ESIF to connect to central heating and cooling services as needed for backup or to supply heat to other parts of the NREL campus.

Tour corridors with large viewing window areas are on all three floors. All major components of the mechanical and electrical system will be color coded to identify the role they play in this energy efficient infrastructure and will be viewable from the tour routes. The stacked nature of the data center provides for a very compact design resulting in short run lengths for both electrical and plumbing components. Data center efficiency will be highlighted with LED monitors at the viewing windows reporting instantaneous, season, and cumulative values for PUE and energy re-use.

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your innovative research in computational science, mathematics, and scientific computing.

Partners at the ESIF's High Performance Computing Data Center may include:

- Researchers and scientists
- Visualization software developers
- Energy manufacturers and investors
- Utilities
- Government agencies
- Universities
- Other National laboratories

Contact Us

If you are interested in working with NREL's High Performance Data Computing Center, please contact:

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Computational Science Center
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303-275-4121

Top front page photo from iStock/03364509.
Illustration from SmithGroupJJR

The Energy Systems Integration Facility (ESIF) will be one of the only megawatt-scale test facilities in the United States that integrates electricity, thermal, and fuel systems with high performance modeling and simulation capabilities.

NREL scientists and engineers at the ESIF will research and test integrated energy systems, devices, and concepts for electric supply and demand systems.

For more information on the ESIF and to take an online tour of the laboratories of the ESIF, visit www.nrel.gov/esi/esif.html.

Illustration from SmithGroupJJR

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Secure Data Center

The Secure Data Center (SDC) at NREL's Energy Systems Integration Facility (ESIF) plays a crucial role in NREL's independent, third-party analysis and validation of proprietary technologies in real-world operation. The SDC is designed for secure management, storage, and processing of proprietary data from industry. Access to the off-network SDC is limited to NREL's Technology Validation Team, which analyzes detailed data and reports on technology status, progress, and technical challenges.

Laboratory Specifications

NREL partners submit operational, maintenance, safety, and cost data to the SDC on a regular basis, typically every three months. NREL's Technology Validation Team uses an internal network of servers, storage, computers, backup systems, and software to efficiently process raw data, complete quarterly analysis, and digest large amounts of time series data for visualization.

Application Scenarios

SDC analysts currently generate results for durability, reliability, maintenance, costs, operation, utilization, range, efficiency, safety, and end user trends using the NREL Fleet Analysis Toolkit (NRELFAT). NRELFAT has processing and analysis capabilities for a variety of applications, including:

- Fuel cell, hybrid, and plug-in electric vehicles
- Fuel cell buses
- Material handling equipment (forklifts)
- Laboratory data
- Backup power
- Stationary power
- Fueling infrastructure

While the raw data are secured by NREL to protect commercially sensitive and proprietary information, individualized data analysis results are provided as detailed data products (DDPs) to the partners who supplied the data.

Individual system, fleet, and site analysis results are aggregated into public results called composite data products (CDPs) that show the status and progress of the technology without identifying individual companies or revealing proprietary information.

Since 2004 NREL has produced around 200 CDPs for these hydrogen and fuel cell technology validation projects:

- Hydrogen Fuel Cell Vehicle and Infrastructure Learning Demonstration
- Early Fuel Cell Market Demonstrations
- Fuel Cell Technology Status

View published CDPs online at *www.nrel.gov/hydrogen/proj_tech_validation.html*.

Partner with Us

Work with NREL experts and take advantage of the state-of-the-art capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering. Partners at the ESIF's Secure Data Center include:

- Government agencies
- Vehicle manufacturers
- Transit agencies
- Hydrogen suppliers
- Fuel cell developers
- Hydrogen and fuel cell organizations

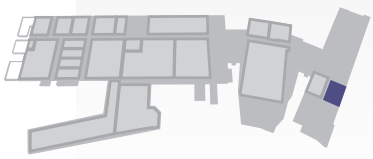
Contact Us

If you are interested in working with NREL's Secure Data Center, please contact:

NREL's Technology Validation Team
techval@nrel.gov

Major Laboratory Equipment

- Secure lab space with 24/7 controlled badge access
- Internal server network for storing and processing data
- Secure conference room for collaboration
- Dedicated computer processing
- Data backup system
- MATLAB



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Energy Integration Visualization Room

In the Energy Integration Visualization Room at NREL's Energy System Integration Facility (ESIF), researchers and partners can visualize experiments being performed in the electricity, thermal, and fuel labs as well as display information from external demonstration sites and large-scale simulation runs. With its large size and exceptional quality, the Energy Integration Visualization Room provides a high-resolution experience that allows researchers from all disciplines of science and engineering to visualize highly complex, large-scale systems and operations in a completely virtual environment.

Fully integrated throughout the ESIF are an electrical distribution bus and a monitoring and control system. The monitoring and control system transfers information from experiments being performed in the ESIF labs to a central computer, and researchers and NREL partners can view this data in real time.

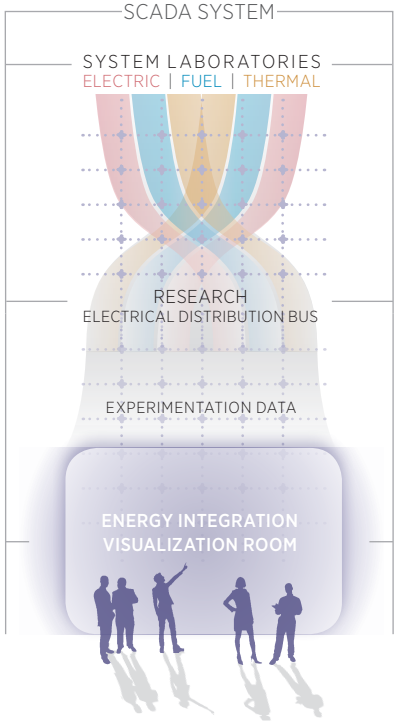
Uniquely Connected

The Research Electrical Distribution Bus (REDB) functions as the ultimate power integration "circuit", and is capable of utilizing multiple AC and DC buses to connect multiple sources of energy. Integrated throughout the ESIF, the REDB interconnects laboratories and experiments to allow testing and simulation of equipment and technologies that span the entire electric power system from generation to transmission, distribution, and end-use applications.

Parallel with the REDB are flexible thermal and fuel infrastructure built into the ESIF that, when combined with the REDB, provide a variety of electricity, thermal power, and fuel type connections.

Viewable Testing

The Supervisory Control and Data Acquisition (SCADA) system at the ESIF monitors and controls research facility-based processes, and gathers and disseminates real-time data. In addition to serving as the computer control system for the REDB, the SCADA also provides high-resolution data output from experiments in the ESIF for collaboration and visualization in the Energy Integration Visualization Room. The data from the experiment is streamed to secure servers, so if a utility is working with the lab that information can remain with the researcher and their partner. It's easily compartmentalized so that an experiment has its own power system and data..



The SCADA system provides high-resolution data output from experiments in the ESIF for collaboration and visualization in the Energy Integration Visualization Room. *Illustration by Christina Chase/NREL*

The Display Wall

The display wall in the Energy Integration Visualization Room is made up of 10 projectors, each with 1080p resolution, blended together to form one large high-resolution display. The display is powered by a high-performance workstation, video wall processor, and a projector image blending system. The result is a 6 ft. x 23 ft. optical glass visualization screen with a combined

Major Laboratory Equipment

- 6 ft. x 23 ft. visualization screen with 3D-capable projection system, 10x1080p resolution, and optical glass
- Connection to SCADA system
- Secure connections to partner networks
- High-performance researcher workstation
- Standalone computer connections

resolution of 9600p x 2160p. The size and resolution of the display allows for crisp, clear viewing—even when zooming in on small details.

The room is also equipped with a permanent, high-performance researcher workstation plus connections for additional computers for testing experimental software programs.

Training Environment

The Energy Integration Visualization Center, with its high-performance workstation and display wall, serves as an ideal software testing environment. Software developers can test their visualization software to develop new electrical data applications that enable a more intelligent electric grid, and utility providers can use the room to simulate a transmission and distribution control center for training purposes.

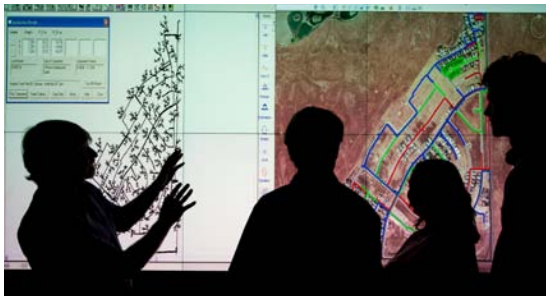
Virtual Connections

NREL is also working to make virtual connections between the ESIF and other laboratories across the country in an effort to share expertise. For example, partners can connect to the ESIF from a remote laboratory and take advantage of the building's equipment and testing capabilities. The room also accommodates video conferences and remote viewing of experimental data and video feeds. These capabilities will not only help remote developers complete development in a considerably shorter time frame, but by sharing knowledge and expertise across the nation, it will help to identify optional utility solutions—with greater certainty and confidence—before major capital investments are made.

Application Scenarios

Imagine using a visualization room where:

- A utility can see the impact of its integrated solar energy systems in a nearby town using NREL's data visualization software layered with live energy usage data.
- Innovators and researchers can collaborate on the effectiveness of a grid-connected energy storage device by watching live streaming data and video feeds from an experiment being conducted in one of the ESIF laboratories.
- NREL and a remote partner laboratory can conduct a live joint experiment where one portion, such as a simulated electrical distribution system connected to a power electronic converter, is located at ESIF and the other portion, such as a home with smart appliances and a residential energy storage device, is located at the partner laboratory.



Researchers examine the impacts of high penetration PV on distribution circuits. *Photo by Dennis Schroeder, NREL/PIX 19335*

With its real time data stream, state-of-the-art technology, large size, and exceptional resolution, the Energy Integration Visualization Room at the ESIF provides a high-resolution experience that is unequaled in similar laboratories.

Partner with Us

Work with NREL experts and take advantage of the capabilities at the ESIF to make progress on your projects, which may range from fundamental research to applications engineering.

Partners at the ESIF's Energy Integration Visualization Room may include:

- Researchers and scientists
- Visualization software developers
- Energy manufacturers and investors
- Utilities
- Universities
- Other national laboratories

Contact Us

If you are interested in working with NREL's Energy Integration Visualization Room, please contact:

Carolyn Elam, ESIF Manager
Carolyn.Elam@nrel.gov
303-275-3036

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Cover illustration courtesy of SmithGroupJJR

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