NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Energy Systems Integration Facility

Supporting Clean Energy Research and Development

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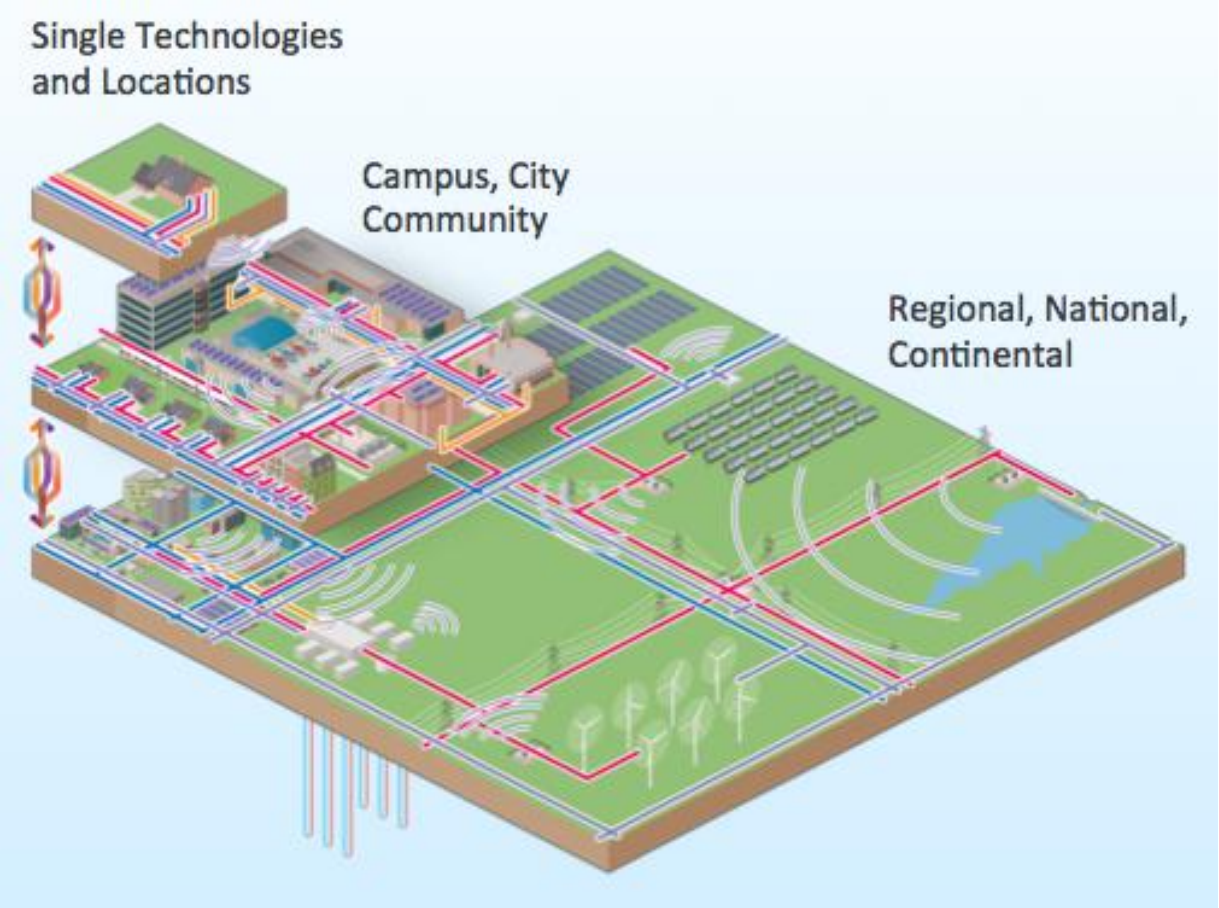
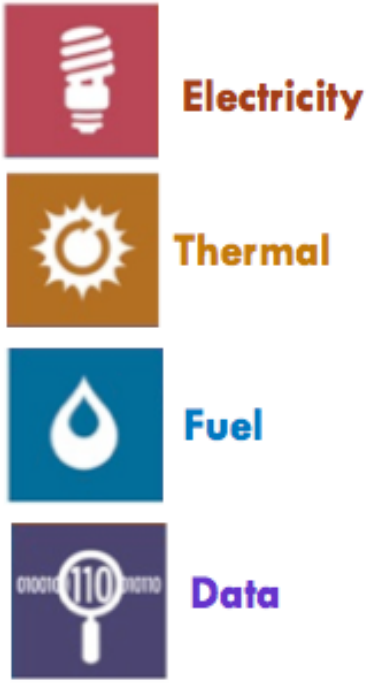
National Renewable Energy Laboratory

Energy Systems Integration – The Concept

ESI Vision: Highly integrated, flexible, and efficient systems that enable utilization of clean energy sources while maintaining reliability at an affordable cost





Energy Systems Integration – The Facility

Addressing the challenges of large-scale integration of clean energy technologies into the energy systems infrastructure

http://www.nrel.gov/eis/facilities_esif.html

"This new facility will allow for an even stronger partnership with manufacturers, utilities and researchers to help integrate more clean, renewable energy into a smarter, more reliable and more resilient power grid." *- Energy Secretary Ernest Moniz*

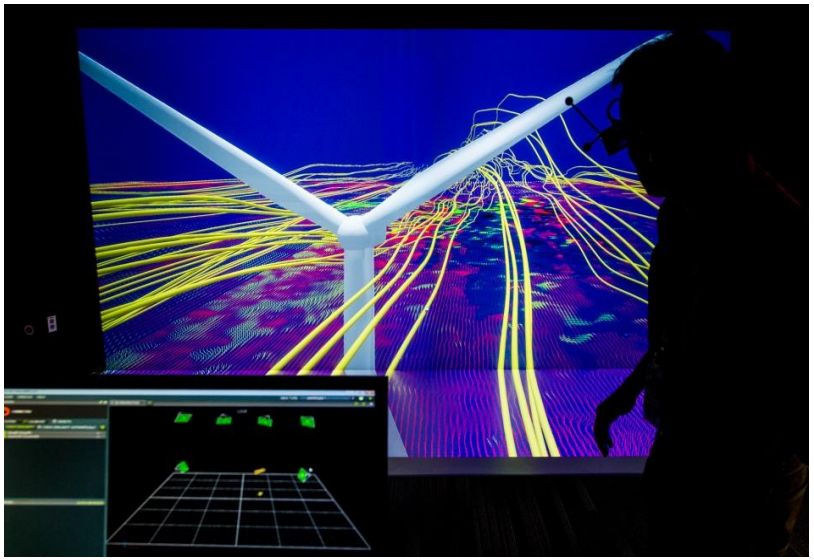
NREL NATIONAL RENEWABLE ENERGY LABORATORY | ENERGY SYSTEMS INTEGRATION FACILITY

U.S. DEPARTMENT OF ENERGY

- NREL's largest R&D facility (182,500 ft^2/20,000 m^2)
- Space for ~200 NREL staff and research partners
- Petascale HPC and Data Center supports all research at NREL
- Labs focus on R&D of integrated energy systems
  - Electricity
  - Fuels
  - Transportation
  - Buildings & Campus
- Integrated electrical, thermal, fuel, and data infrastructure

ESIF's Unique Advanced Capabilities

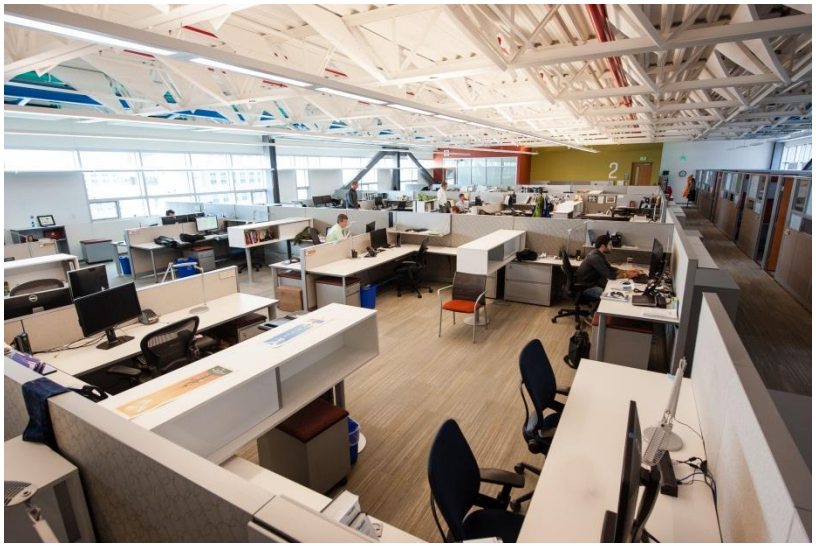
- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation
- Flexible interconnection points for electricity, thermal, and fuels
- Medium voltage (15kV) microgrid test bed
- Virtual utility operations center and visualization rooms
- Smart grid testing lab for advanced communications and control
- Interconnectivity to external field sites for data feeds and model validation
- Petascale HPC and data mgmt system in showcase energy efficient data center
- "Hardware-in-the-loop" simulation capability to test grid scenarios with high penetration of renewables

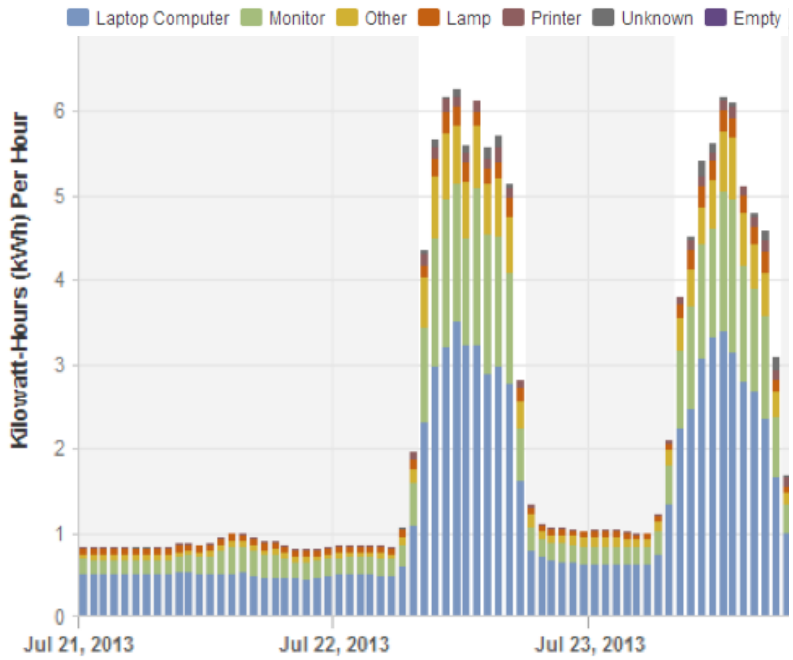


ESIF Office Area

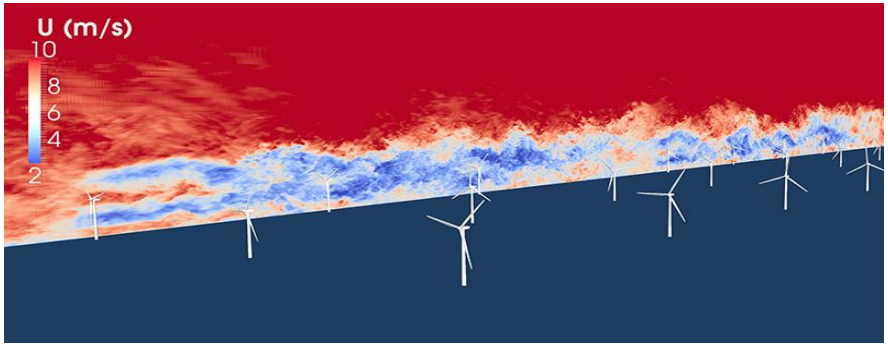
- Integrated Energy Efficiency into Design and Operations
- High use of daylight
- Natural use of ventilation through operable windows
- Uses about 25% national average for energy in office space
- Installed Enmetric plug load control system
- Collecting circuit level load information in office area

Enmetric Plug Load Controller





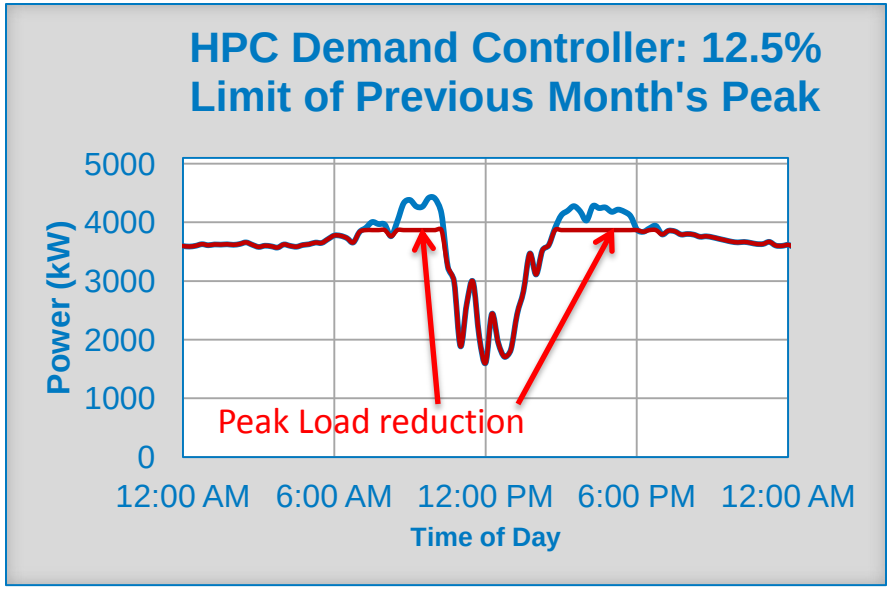
ESIF - High Performance Computing



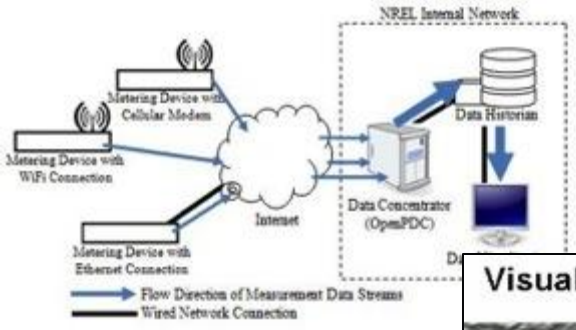
This computer-generated simulation shows the turbulent nature of wind turbine wakes. The simulation helped uncover potential differences in output between downstream 'waked' turbines and upstream turbines.

3D Simulation model of Polymeric organic nitroxide radical (PTMA) film for battery applications

- High performance computing provides a multi-faceted basis for simulating future integrated energy innovations that would otherwise be too expensive, too lengthy, too dangerous, or otherwise impossible to study by direct experimentation.
- HPC also has integrated energy control and waste heat capture



Energy System Visualization



NREL is working with SMUD on visualizing impact of DG deployments

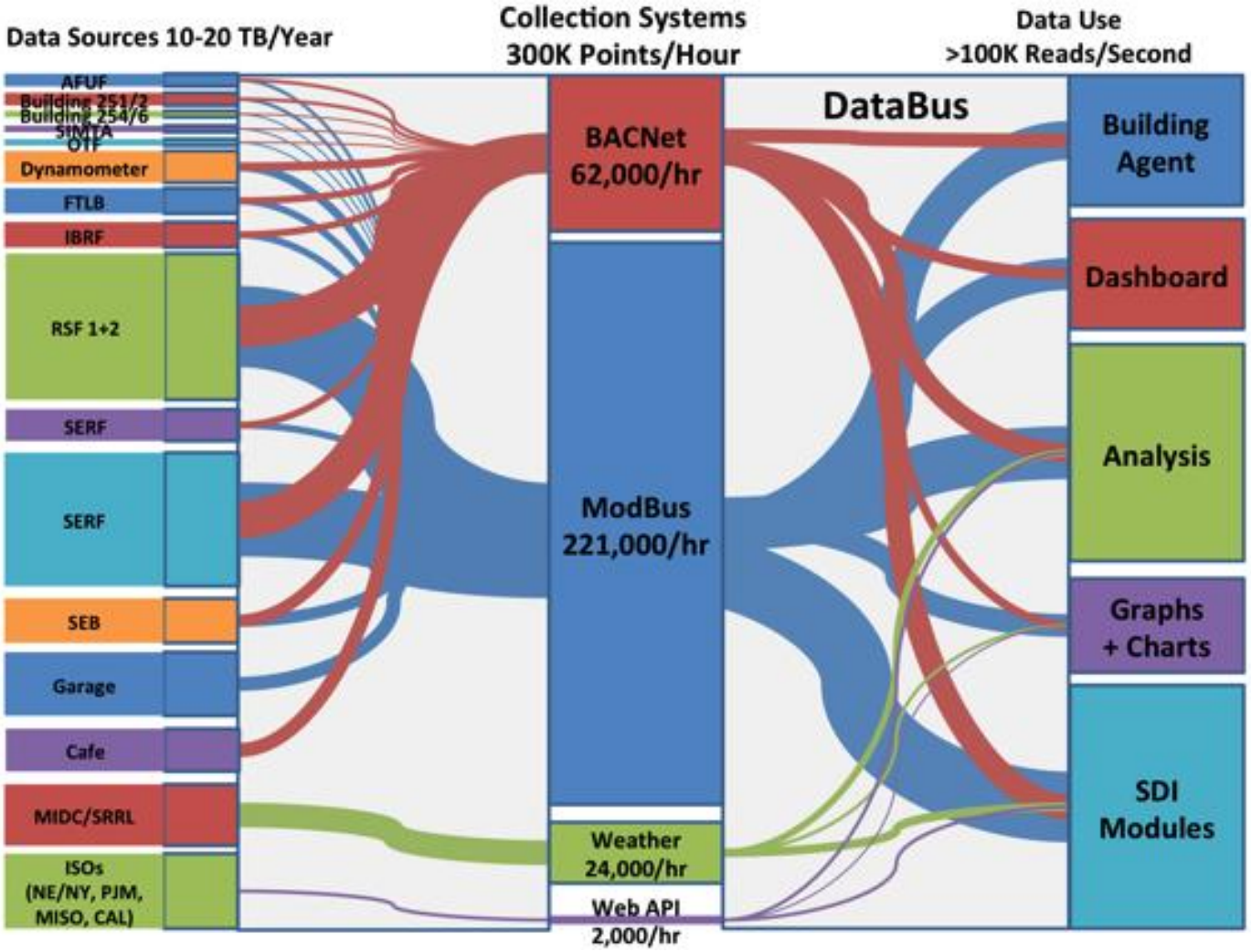
NREL Campus - Energy DataBUS

Energy DataBus http://www.nrel.gov/analysis/databus/

Open Source solution to collect, store, clean, aggregate data from energy systems

Connect to meter drivers (BACnet, Modbus, etc)

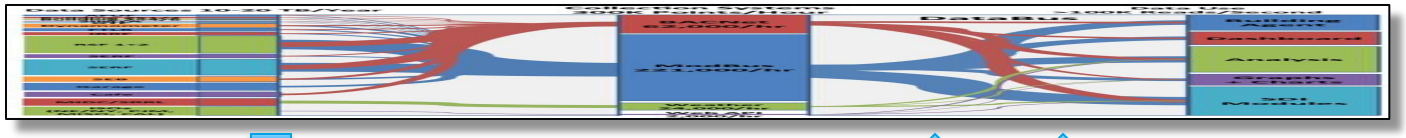
Push and pull into to app layer



Become a Databus partner: http://en.openei.org/wiki/NREL_Energy_DataBus/Partners

NREL Campus Energy - Apps

Energy DataBUS – Data Collection and Analytics



Campus Energy Dashboard

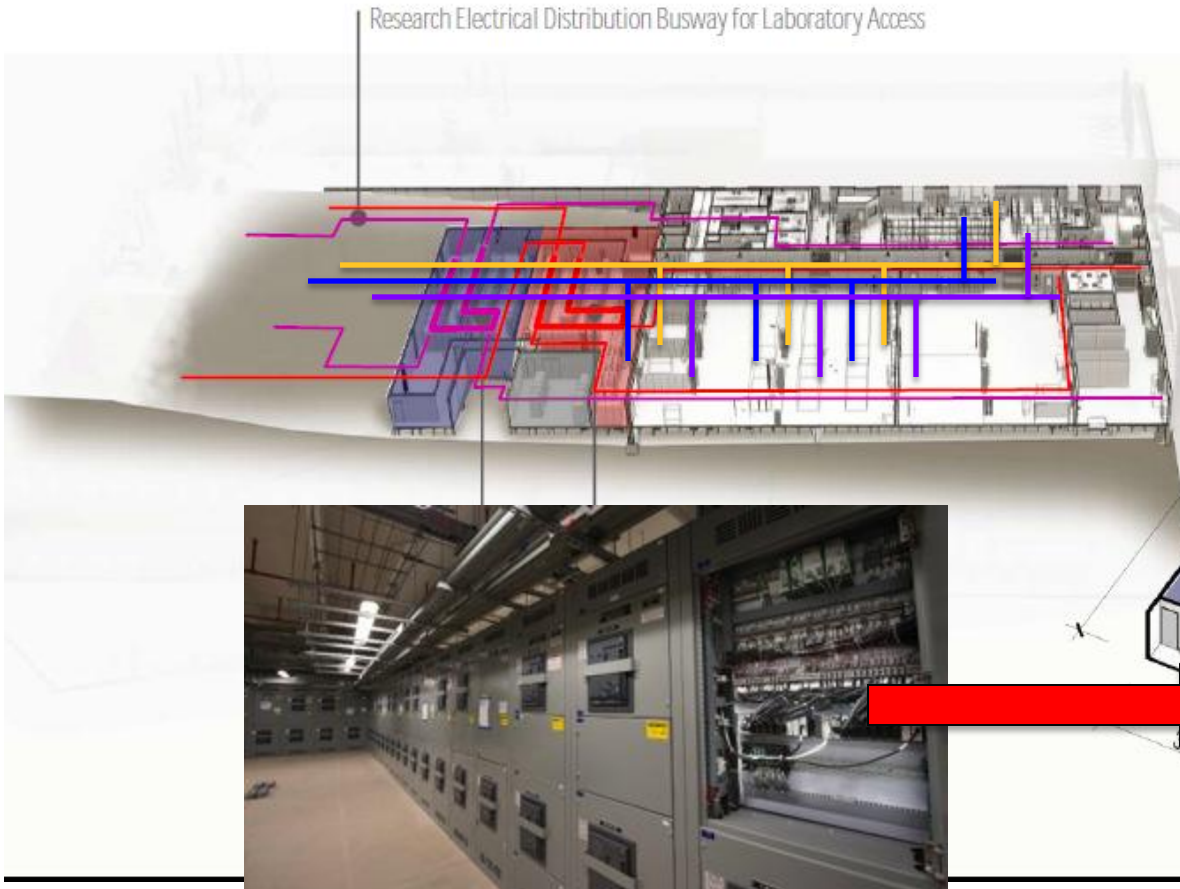
Engaging Occupants with Building Agent

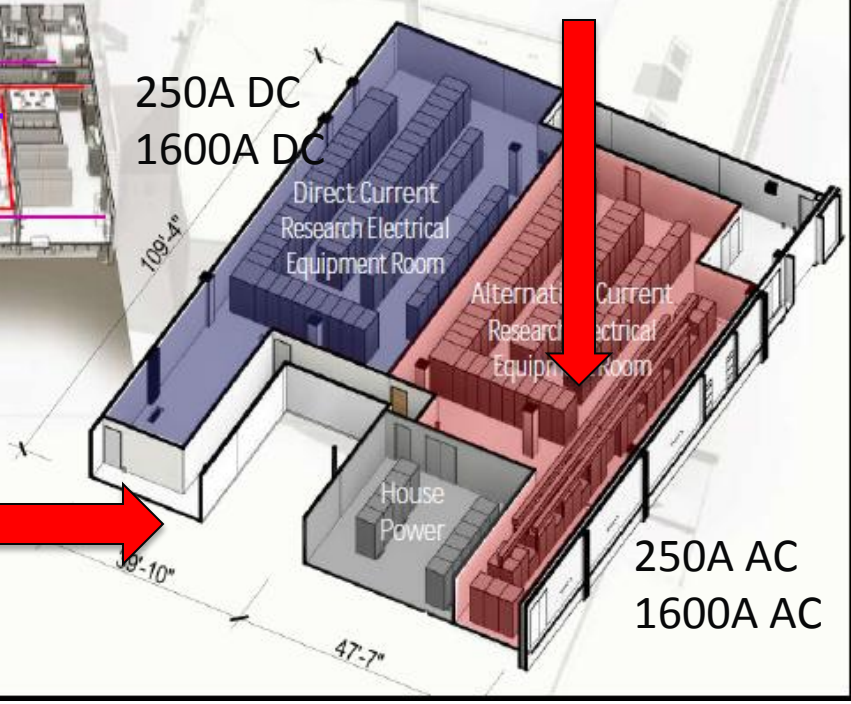
Campus Energy Control and Optimization

ESIF Research Infrastructure

- Research Electrical Distribution Bus – REDB (AC 3ph, 600V, 1200A and DC +/-500V, 1200A)
- Thermal Distribution Bus
- Fuel Distribution Bus
- Supervisory Control and Data Acquisition (SCADA)

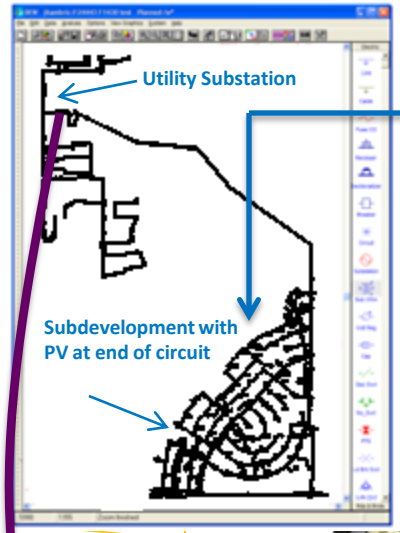
1MW Grid Simulator





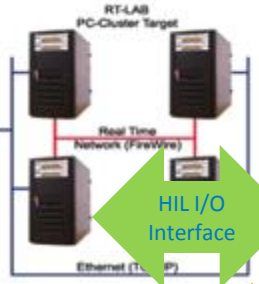
Hardware-in-the-Loop: Connecting Experiments to Simulations

Simulation validated with real field data



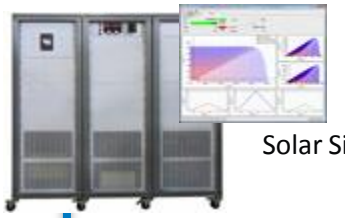
Simulation and Visualization at ESIF

Visualization Interface



HIL I/O Interface

Actual hardware at ESIF



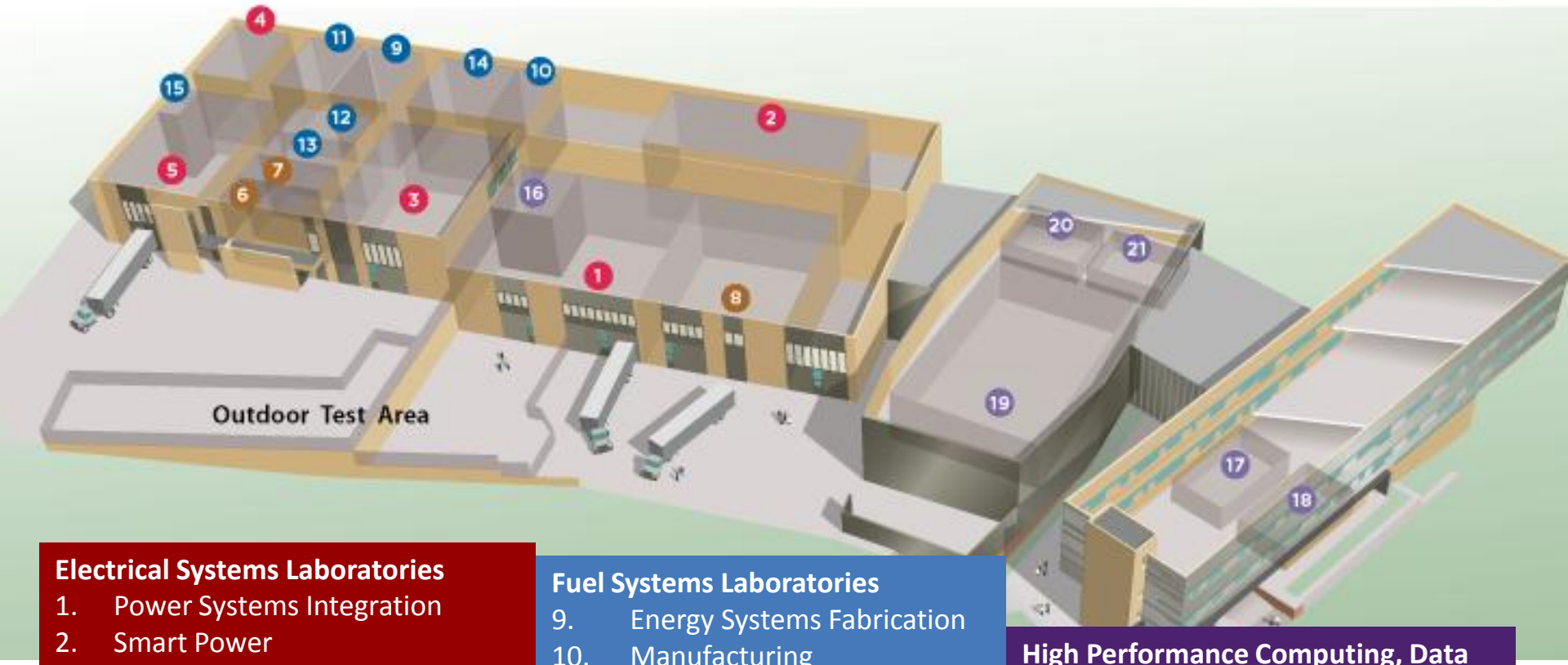
Solar Simulator

Device Under Test
(e.g. inverter, energy storage, EV, load, etc.)

Replicated into Larger Simulation

Simulation loop closed with actual hardware

ESIF Laboratories



Electrical Systems Laboratories
1. Power Systems Integration
2. Smart Power
3. Energy Storage
4. Electrical Characterization
5. Energy Systems Integration

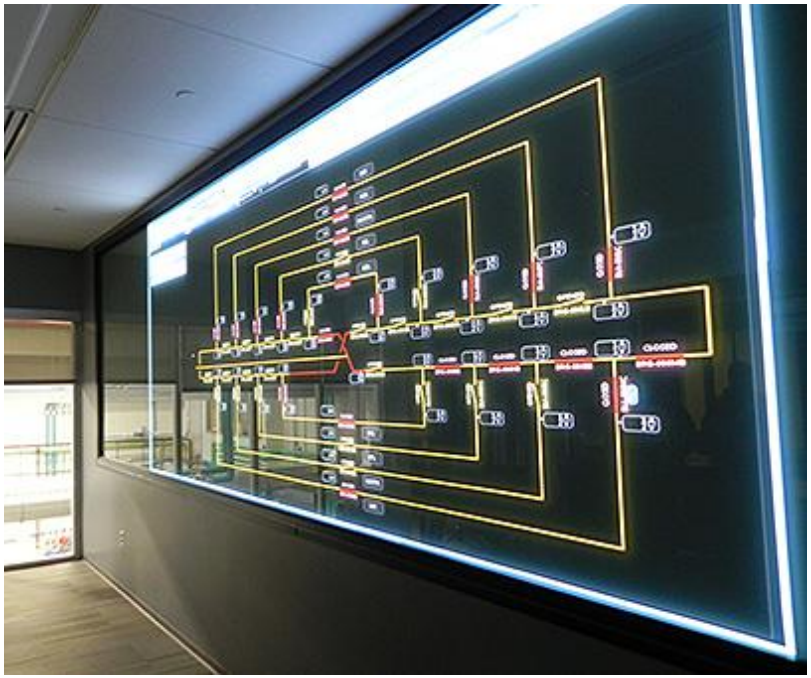
Thermal Systems Laboratories
6. Thermal Storage Process and Components
7. Thermal Storage Materials
8. Optical Characterization

Fuel Systems Laboratories
9. Energy Systems Fabrication
10. Manufacturing
11. Materials Characterization
12. Electrochemical Characterization
13. Energy Systems Sensor
14. Fuel Cell Development & Test
15. Energy Systems High Pressure Test

High Performance Computing, Data Analysis, and Visualization
16. ESIF Control Room
17. Energy Integration Visualization
18. Secure Data Center
19. High Performance Computing Data Center
20. Insight Center Visualization
21. Insight Center Collaboration

ESIF – Control Room

In the ESIF Control Room, researchers can see the electrical bus, close switches, and checkout grid simulators. The Supervisory Control and Data Acquisition (SCADA) system in the ESIF monitors and controls research facility-based processes and gathers and disseminates real-time data for collaboration and visualization.



Lab Functions

- The data from experiments throughout the facility is streamed to secure servers in the control room
- The SCADA supports a large visualization screen in the ESIF control room allowing researchers and partners to watch the experiment in real-time

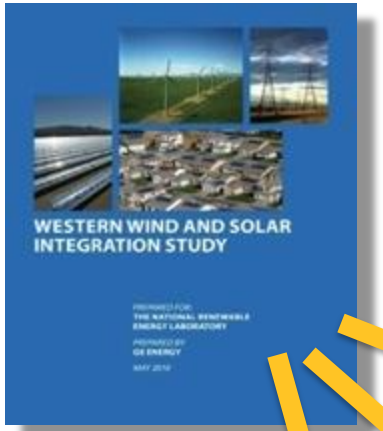
Major Lab Equipment

- SCADA
- State-of-the-Art Visualization Screen

ESIF - Energy System Simulated Operations

A Flight Simulator for Energy System Operators

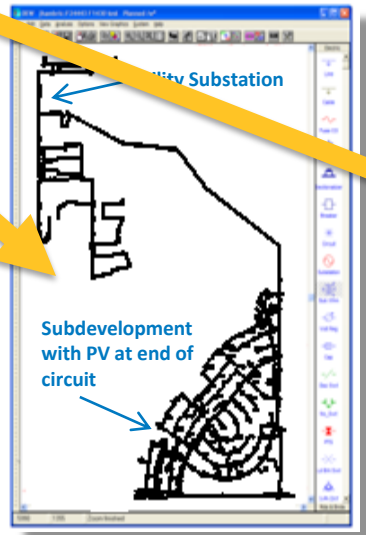
"connecting integration studies to operations"



Operations techniques development for:

- High renewables and energy efficiency penetrations
- New systems configurations and contingency response
- High storage / DR penetrations
- Resource forecast integration

Transmission



Distribution

Campus Energy Dashboard

ESIF – Power Systems Integration Lab

Research in the Power Systems Integration Laboratory focuses on the development and testing of large-scale distributed energy systems for grid-connected, standalone, and microgrid applications. The laboratory can accommodate large power system components, such as inverters for PV and wind systems, diesel and natural gas generators, battery packs, microgrid interconnection switchgear, and vehicles.

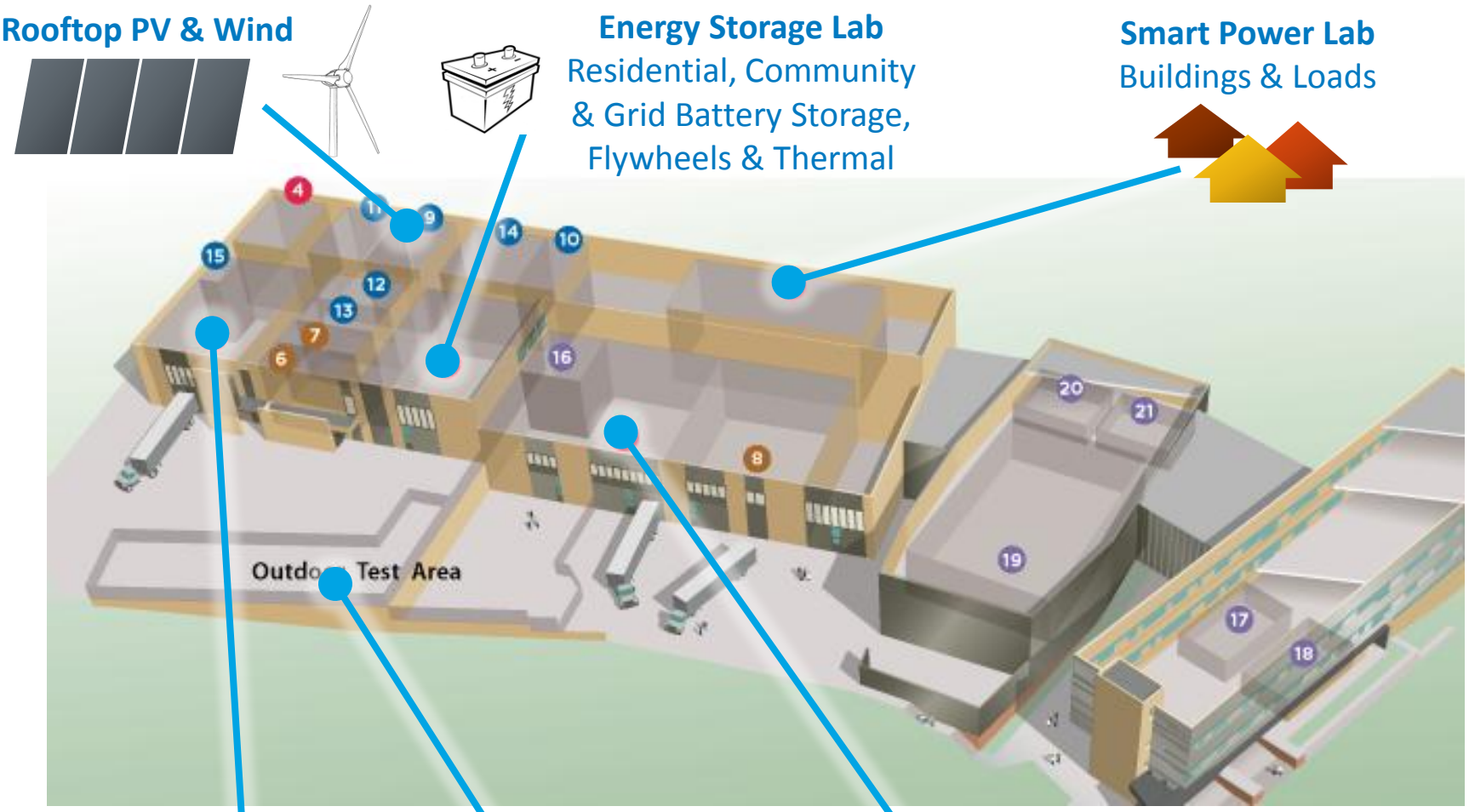
Lab Functions

- Main test lab for conducting electrical system integration activities.
- Research explores a variety of operating configurations including: grid connected stand-alone, microgrids, and hybrid power systems.
- House infrastructure for DG research (AC and DC power supplies for REDB, chiller and boiler)

Major Lab Equipment

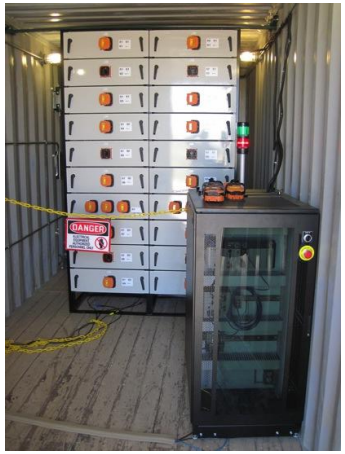
- 1 MW grid simulator
- Several 250kW DC power supplies
- 100 ton research chiller
- 750MBH research boiler
- Connections to REDB

Replication at Scale: Microgrid & Area



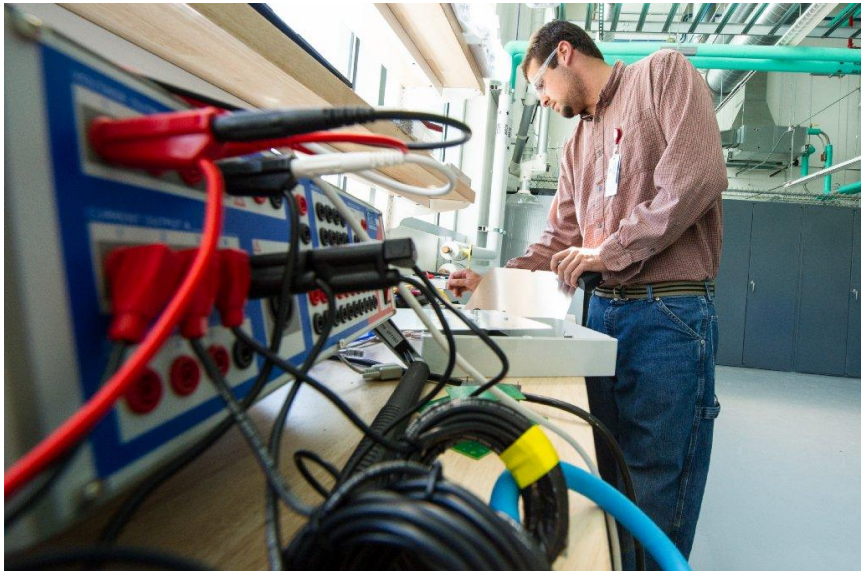
Microgrid Projects

- Development of IEEE 1547.4 – Microgrid Standard
- Portland General Electric (PGE)
- Sacramento Municipal Utility District (SMUD)
- Santa Rita Jail Microgrid
- SPIDERS – DoD high reliability microgrids
- Other US DoD Bases – microgrids for high reliability



ESIF – Smart Power Lab

Research in the Smart Power Laboratory focuses on the development and integration of smart technologies, including distributed and renewable energy resources and smart energy management. The 5,300-ft^2 laboratory is designed to be highly flexible and configurable to enable a range of smart power activities—from developing advanced inverters and power converters to testing residential- and commercial-scale meters and control technologies.



Lab Functions

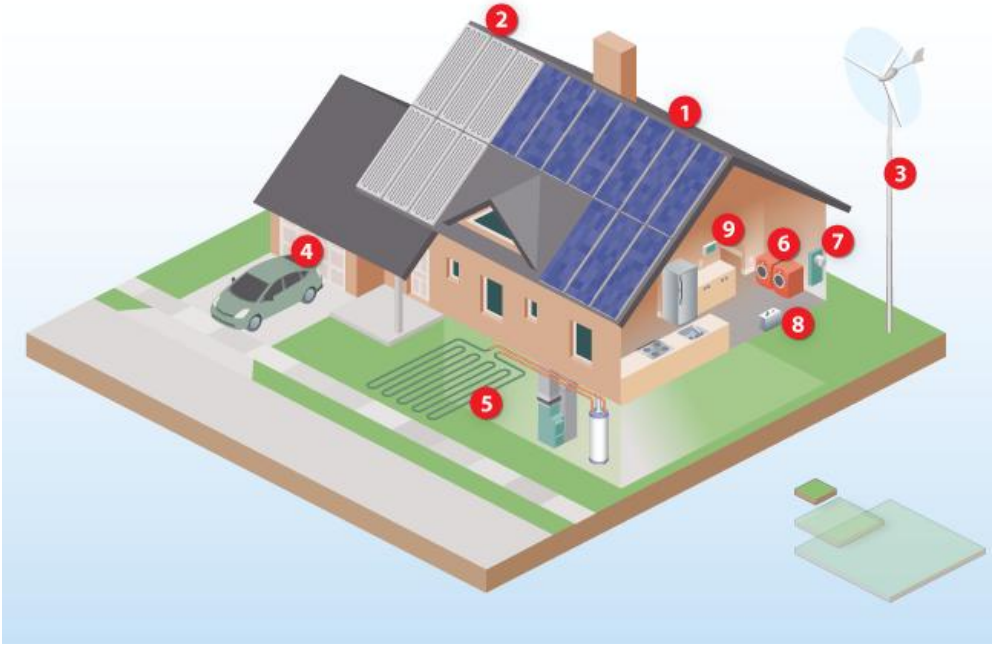
- Test lab for development and testing of the power electronics components and circuits used in renewable energy integration
- Instrument development area for basic electronics work

Major Lab Equipment

- AC power supplies
- Small grid simulators
- Opal RT and RTDS Hardware-in-the-Loop Systems
- Connections to REDB

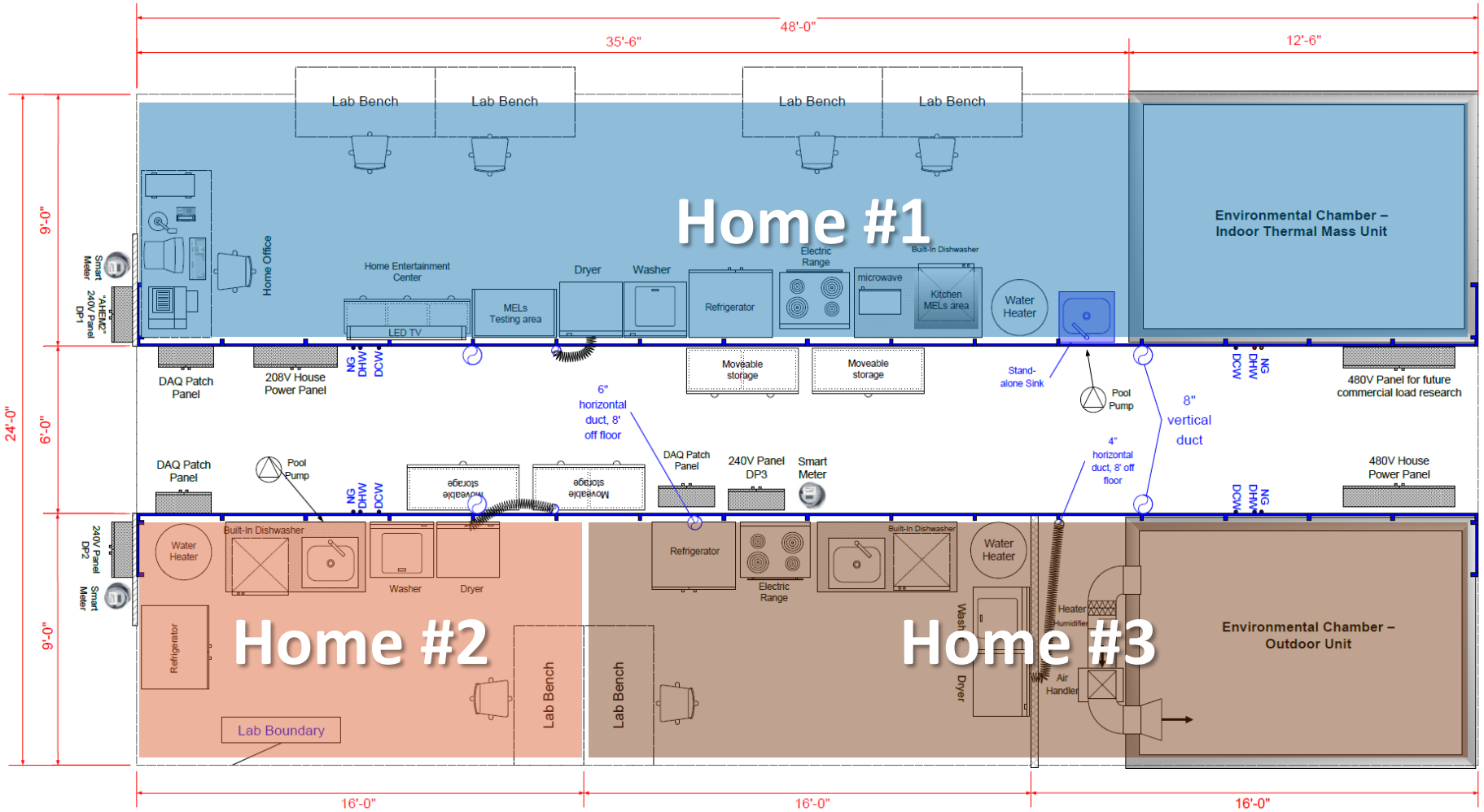
Residential and Commercial Scale

- **Demonstrate "end-to-end" microgrid capability**
  - Smart power optimization with responsive loads
  - Onsite small wind, PV
  - Electrical and thermal storage
  - EV charging
  - H_2 production
  - Visualization & analytics
  - Demonstrate interoperability and energy reliability



- **Multiple lines allow users to "plug and play"**

Smart Grid Simulation at Scale

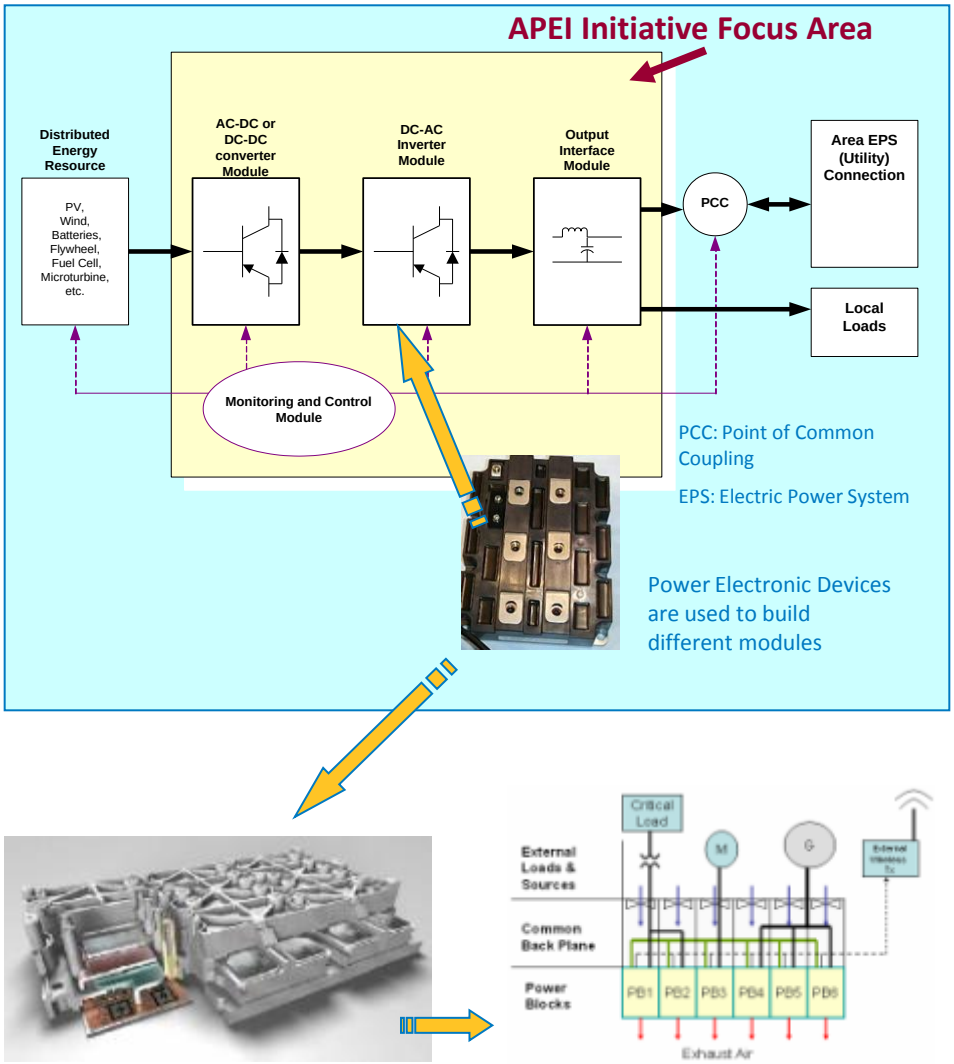


- Interaction between homes
- Different appliances, technologies, communications
- Impacts on distribution transformer
- Community-scale DR transients

Smart Distributed Energy Interfaces

Advanced Power Electronics Interfaces

- NREL is working with the California Energy Commission and several industry partners to develop a standardized, highly integrated, **modularized power electronic interconnection technologies** that will come as close as possible to "plug-and-play" for distributed energy resource (DER) platforms.
- The goal is to develop power electronics technology that improves and accelerates the use of DER systems.
- Reduce costs for DER and interconnections by developing standardized, high production volume, power electronic modules.



ESIF – Energy Storage Lab

At the Energy Storage Laboratory, research focuses on the integration of energy storage systems (stationary and vehicle-mounted) and their interconnection with the utility grid. Includes batteries, ultra-capacitors, flywheels, compressed air, etc.

Lab Functions

- Testing energy storage components when integrated with renewable energy electrical systems:
  - Performance
  - Efficiency
  - Safety
  - Model validation
  - Long duration reliably

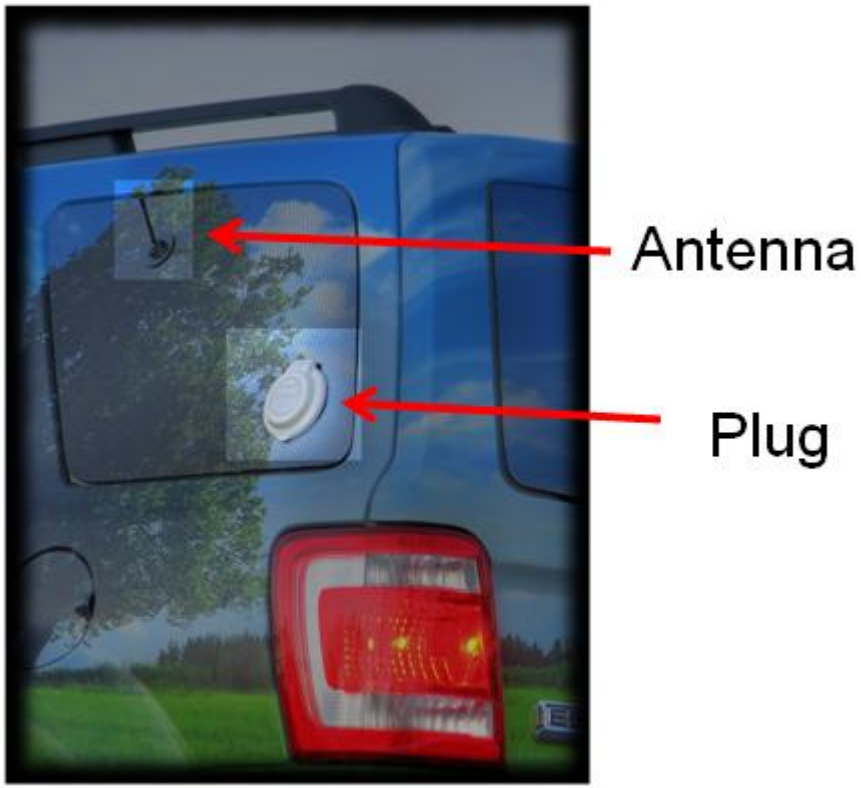
Major Lab Equipment

- DC Power Testing station 250 kW, up to 900 Vdc
- Grid Simulator
- REDB Connections
- Research Chiller & Boiler
- PV Simulator

V2G Testing and Applications

NREL conducts testing EV and PHEVs for Vehicle-to-Grid (V2G) application

Developing Standard test protocol for V2G



ESIF – Energy Systems Integration Lab

The Energy Systems Integration Laboratory provides a flexible, renewable-ready platform for research, development, and testing of state-of-the-art hydrogen based and other energy storage systems.

Lab Functions

- 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
- Testing of electrolyzers, fuel cells, compression equipment, delivery systems

Major Lab Equipment

- Gas Chromatograph
- Ion Chromatograph
- PEM electrolyzer
- Alkaline electrolyzer
- Fuel cell
- H2 high pressure compressor
- Two high pressure testing bays fully rated for testing systems to 15,000 psig

ESIF – Electrical Characterization Lab

The Electrical Characterization Laboratory supports 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.

Lab Function

- Provides a safe environment for conducting high voltage surge testing and high current short circuit tests on equipment

Major Lab Equipment

- Surge generator system for simulating lightning strikes and other high voltage, high current events
- Separate ventilation system
- Video links to main test area
- Class 1; Division 2 approved

ESIF – Optical Characterization Lab

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.

Lab Functions

- Optical testing of panels and systems
- Weathering of panels
- Structural analysis of CSP concentrator systems

Major Lab Equipment

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

ESIF – Thermal Storage Materials Lab

In the Thermal Storage Materials lab, fluids and other materials are characterized and properties are measured—including their capacity to hold heat, resist corrosion, or operate within a required temperature range.

Lab functions

- 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.

Major Lab Equipment

- Scanning Calorimeter
- Thermal Gravimetric Analyzer
- Vulcon Furnace

ESIF – Thermal Storage Process & Components

The Thermal Storage Process and Components lab focuses on environmental performance—in a process environment—of fluids and materials for heat transfer and storage.

Lab Functions

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

Major Lab 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
- Thermal energy storage process test loops
- Outdoor air feed and exhaust for system cooling
- HEPA-rated enclosure for testing systems containing nanomaterials

ESIF – Energy Systems Fabrication Lab

The Energy Systems Fabrication Laboratory supports NREL's fuel cell and electrochemical cell research. The lab is used for the manufacture of components for fuel cells and electrochemical cells using a variety of techniques. Fabricated components include catalysts, thin-film and gas diffusion electrodes, and membrane electrode assemblies.

Lab functions

- Supports fuel cell and electrochemical cell related research
- Fuel Cell MEA fabrication and characterization
- Wet chemical synthesis and fabrication of materials and device components

Major Lab Equipment

- Hot press
- Vacuum table
- Vapor Sorption Workstation
- Workstation EGA (evolved gas analysis)

ESIF – Manufacturing Lab

The Manufacturing Laboratory features a web line suitable for use in developing and validating quality control techniques for manufacturers of low temperature and high temperature fuel cells. Capabilities support initial proof-of-concept studies through prototype system development and in-line validation.

Lab functions

- Continuous web processing (roll-to-roll) equipment and various diagnostic measurement platforms.
- Develops rapid and non-destructive quality-control techniques to help manufacturer's scale-up production while maintaining quality.
- Evaluates and develops diagnostic systems for in-line quality control of fuel cell membrane electrode assembly components.

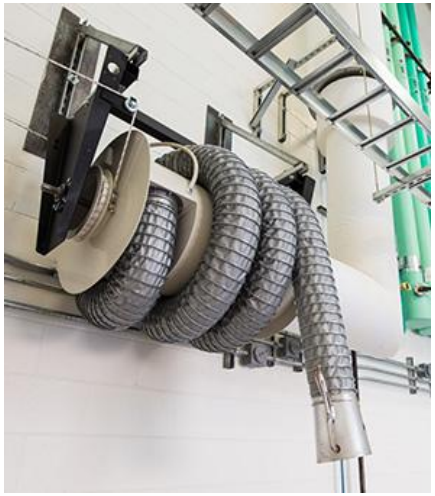
Major Lab Equipment

- Continuing Processing Line
- Unwind/Wind Modules
- Optical Diagnostic Test Platform
- Process/Instrumentation Modules

ESIF – Materials & Electrochemical Characterization Labs

The Materials & Electrochemical Characterization laboratories use advanced diagnostic tools for material characterization on fuel cell materials.

The **Materials Characterization Laboratory** covers multiple analytical operations, with the overall goal of troubleshooting synthetic materials or process streams to improve performance.



The **Electrochemical Characterization 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.

Currently the labs are focused on fuel cells, however many of the fabrication and characterization capabilities apply to other energy storage devices, such as batteries.

ESIF – Energy Systems Sensor Lab

The Energy Systems Sensor Laboratory tests hydrogen and its use for the development of codes and standards in order to take the current technology to the level it needs to be in the future.

Lab functions

- 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.

Major Lab Equipment

- SSTL Sensor Test Apparatus
- Walk-in Fume Hood
- National Instruments Data Acquisition System
- Circulating Cooler
- Precision Digital Mass Flow Controllers

ESIF – Fuel Cell Development and Test Lab

The Fuel Cell Development and Test Laboratory supports fuel cell research and development projects through in-situ fuel cell testing. Testing capabilities include single-cell fuel cells and fuel cell stacks.

Lab functions

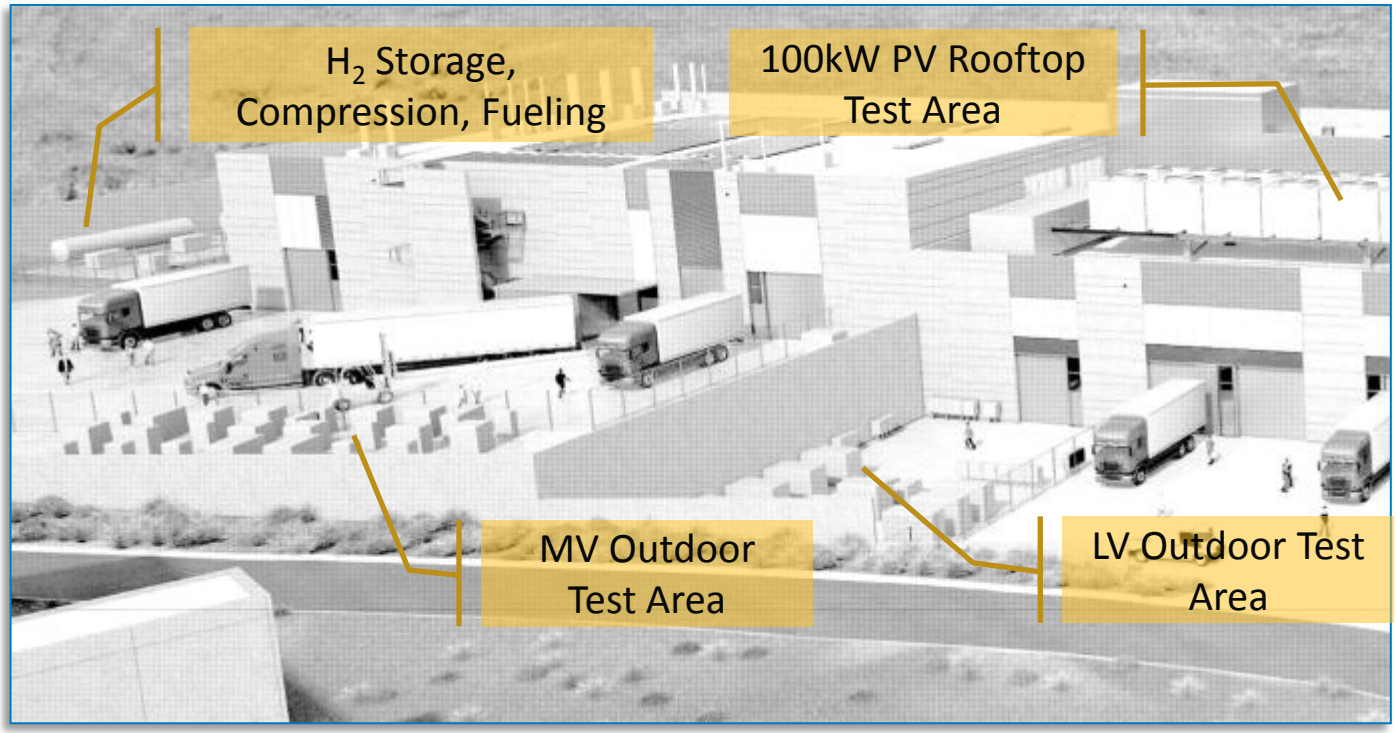
- Bench top testing of Fuel Cells and Fuel Cell Stacks.
- Thermochemical, electrochemical, and thermomechanical analysis of fuel cell MEA materials.

Major Lab Equipment

- Single cell and segmented cell fuel cell test stations
- Microelectrode workstation
- Environmental chamber for membrane mechanical testing
- Calibration equipment
- Spatial testing capabilities using 121-channel 50cm2 segmented cell system or multi-channel potentiostat
- Comprehensive host of state-of-the-art fuel cell diagnostics

ESIF –Outdoor Test Areas

The outdoor test areas at the ESIF allow for testing either at 480 Volts or 13.2 kiloVolts



ESIL Major Lab Equipment

- H_2 storage vessels
- H_2 IC engine testing
- H_2 Vehicle fueling station

MV Major Lab Equipment

- 1MVA 13.2kV to 480 Y-Y transformers
- Connections to REDB, Utility

LV Major Lab Equipment

- 80kW and 125kW Gensets
- 100kW, 250kW load banks
- Capstone Microturbine
- Connections to REDB

Thank you

Ben Kroposki

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National Renewable Energy Laboratory

http://www.nrel.gov/esi