NREL
NATIONAL RENEWABLE ENERGY LABORATORY




Smart Grid Research at NREL

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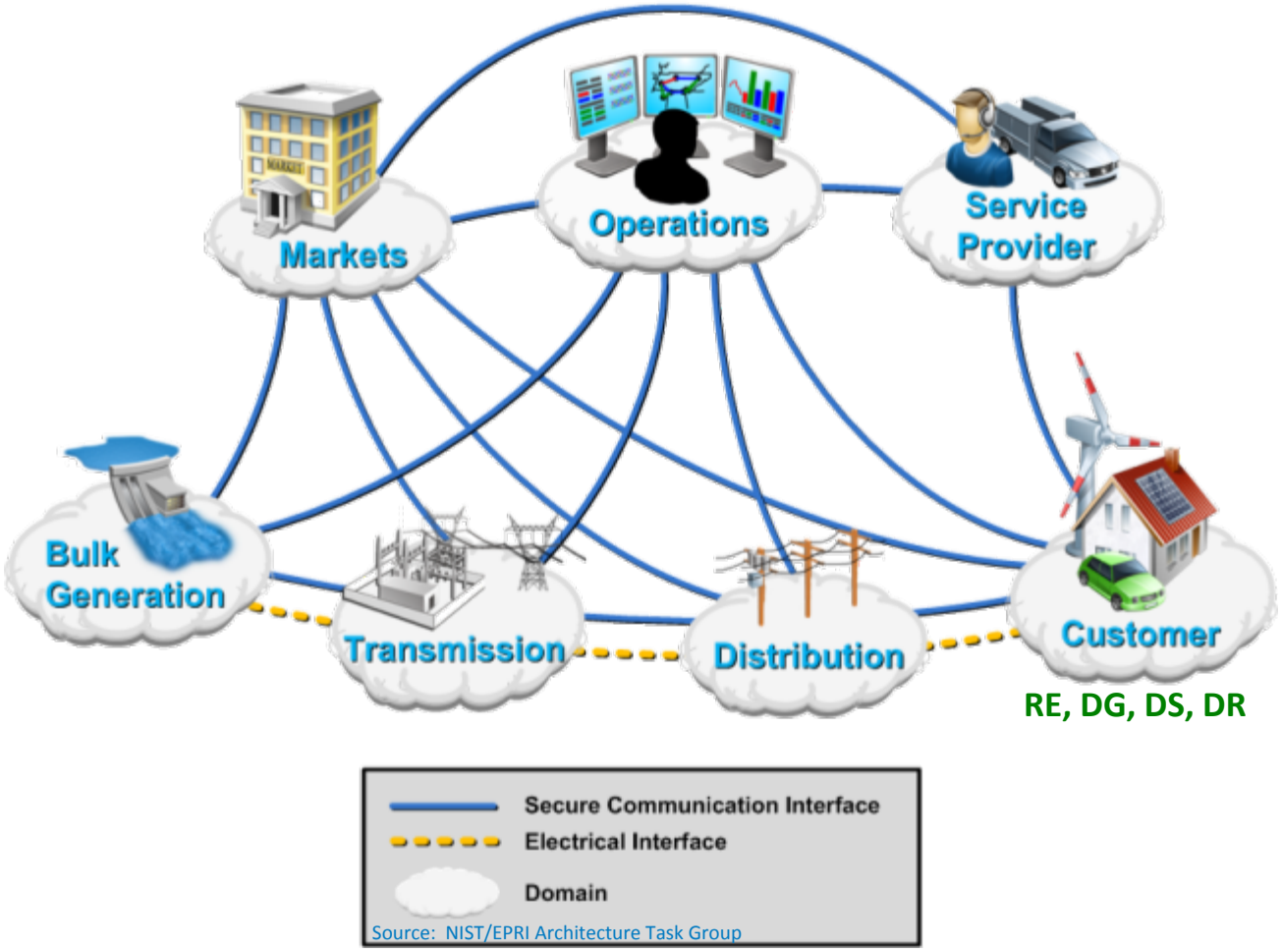
What is the Smart Grid?



The **Smart Grid** is the electricity production and delivery system along with consumption *integrated* with communications and information technology

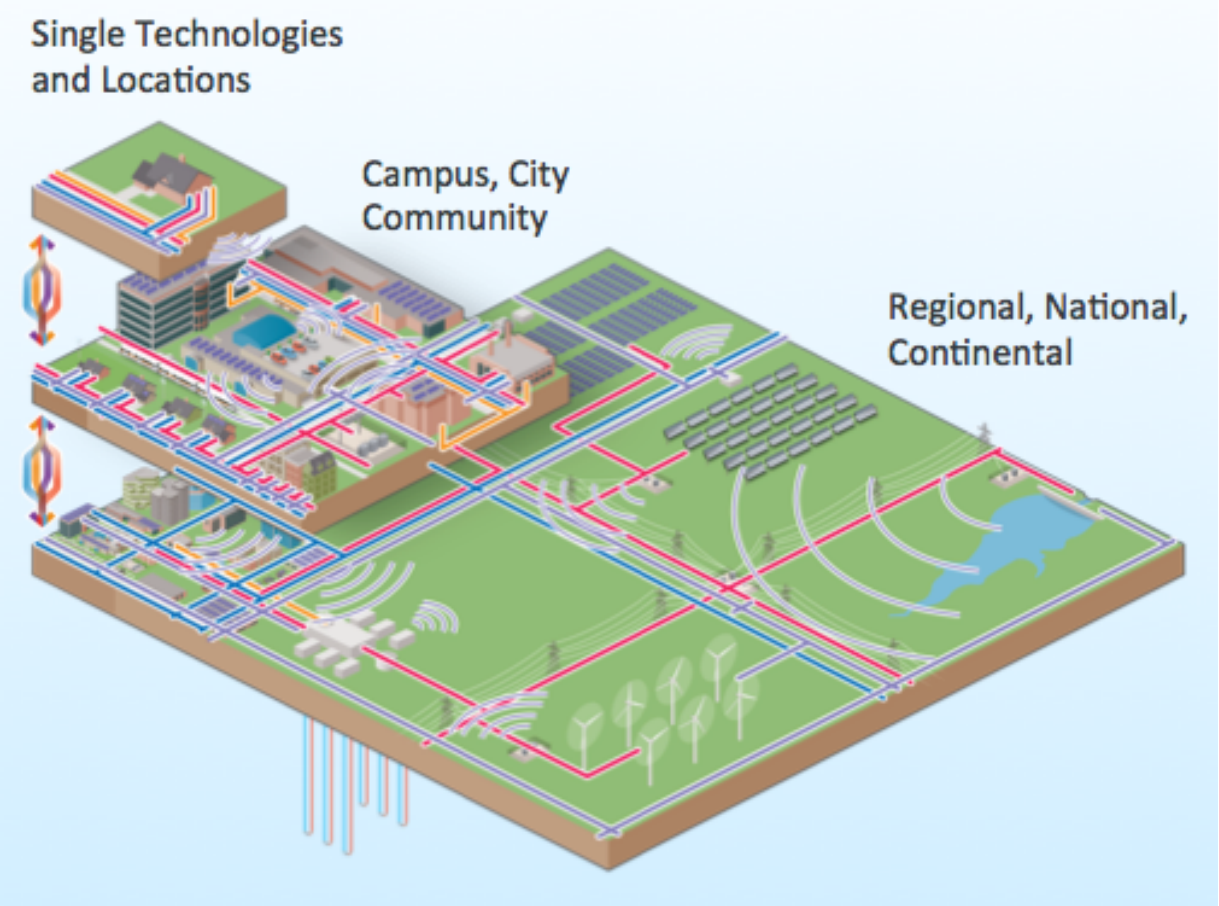
The **Smart Grid** is an automated, widely distributed energy delivery network characterized by a **two-way flow of electricity and information**, capable of monitoring and responding to changes in everything from power plants to customer preferences to individual appliances.

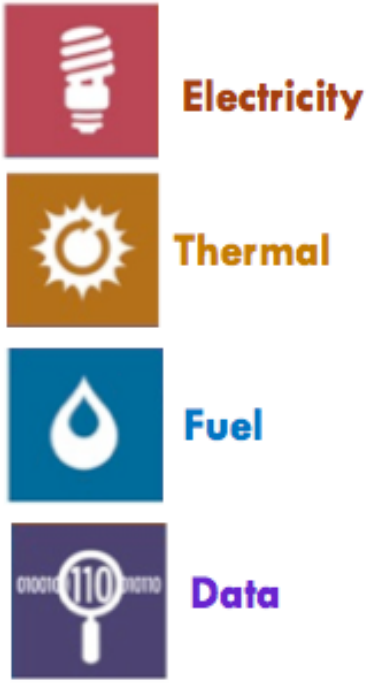
Smart Grid R&D at NREL

- Development of Smart Grid Interoperability Standards (IEEE 2030) and Interconnection Standards (IEEE 1547)
- Integration of High Penetration of Renewables and Distributed Generation (Modeling, Simulation, Testing, and Analysis)
- Advanced Distribution System Operations (Microgrids and Intentional Islands)
- Control, Testing and Evaluation of dispatchable generation, loads and energy storage (V2G, GridAgents, and Energy Storage Testing)
- Development of Conformance Test Protocol for Smart Grid Technologies (Interoperability and Operations)
- Analysis of Smart Grid Projects www.smartgrid.gov

Energy Systems Integration – The Concept

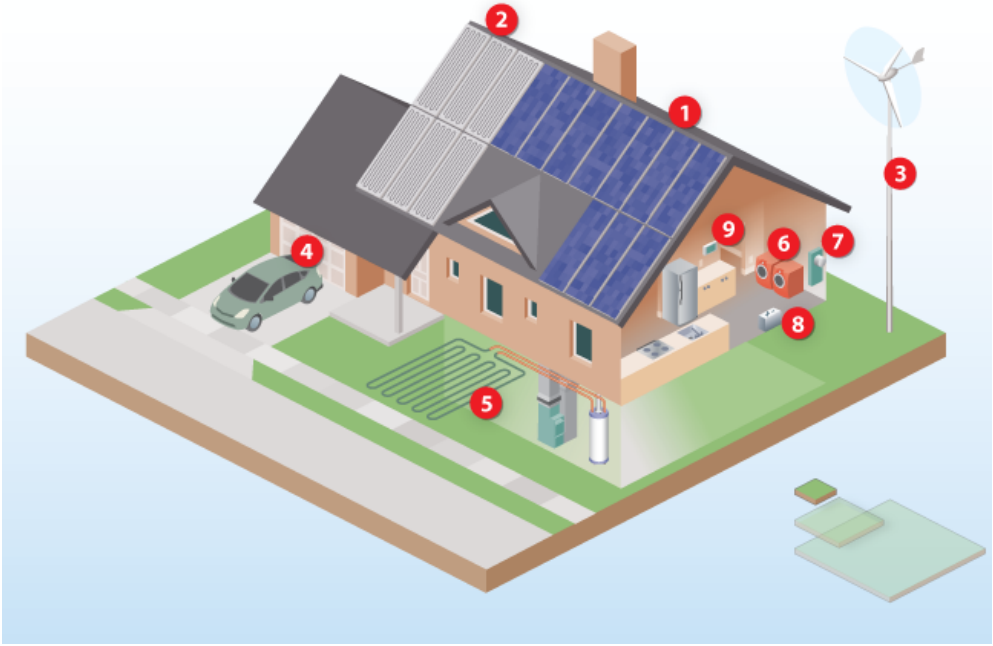
ESI has a broader vision: Highly integrated, flexible, and efficient systems that enable utilization of clean energy sources while maintaining reliability at an affordable cost





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

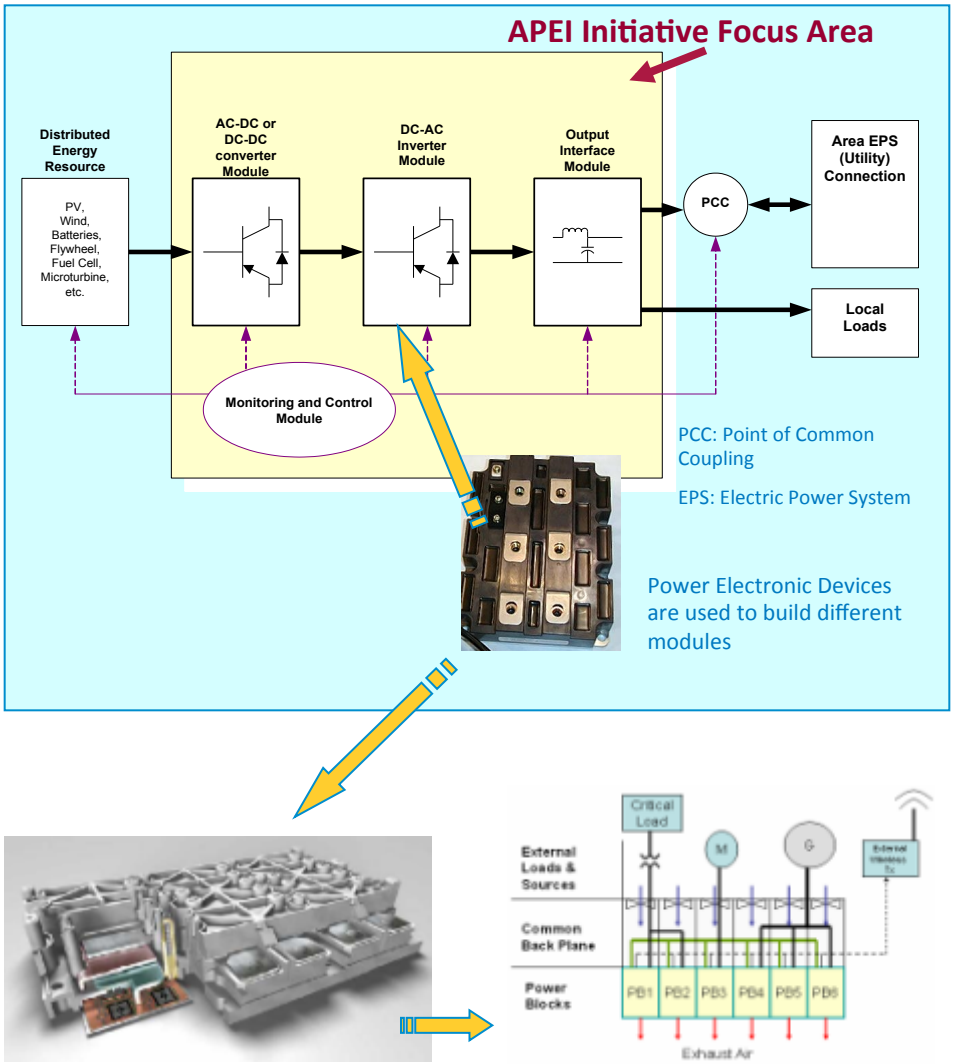


- **Multiple lines allow users to "plug and play"**

Smart Distributed Energy Interfaces

Advanced Power Electronics Interfaces

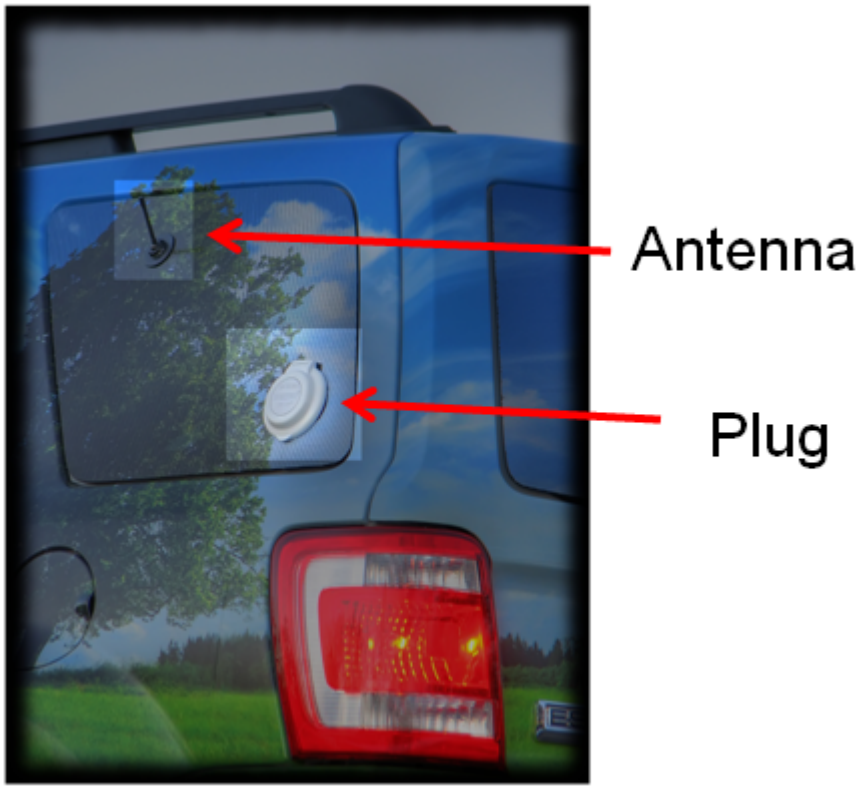
- NREL is working with the California Energy Commission and several industry partners to develop a standardized, highly integrated, **modularized power electronic interconnection technologies** that will come as close as possible to "plug-and-play" for distributed energy resource (DER) platforms.
- The 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.



V2G Testing and Applications

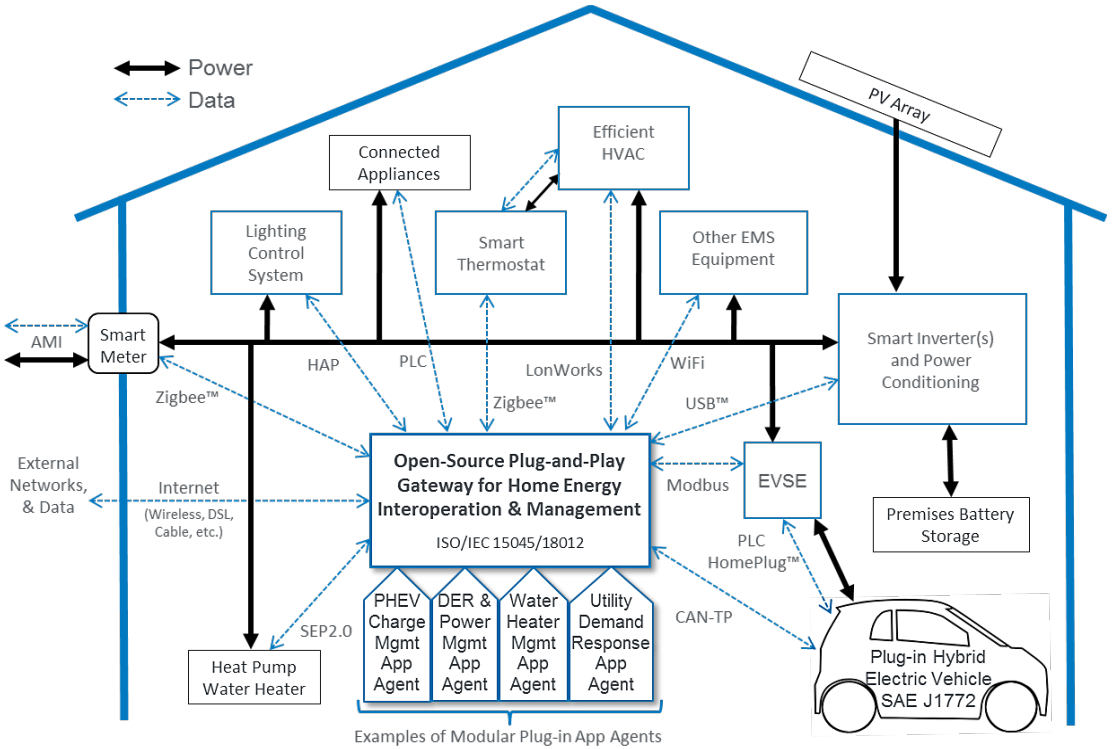
NREL conducts testing EV and PHEVs for Vehicle-to-Grid (V2G) application

Developing Standard test protocol for V2G



Replication at Scale: Systems

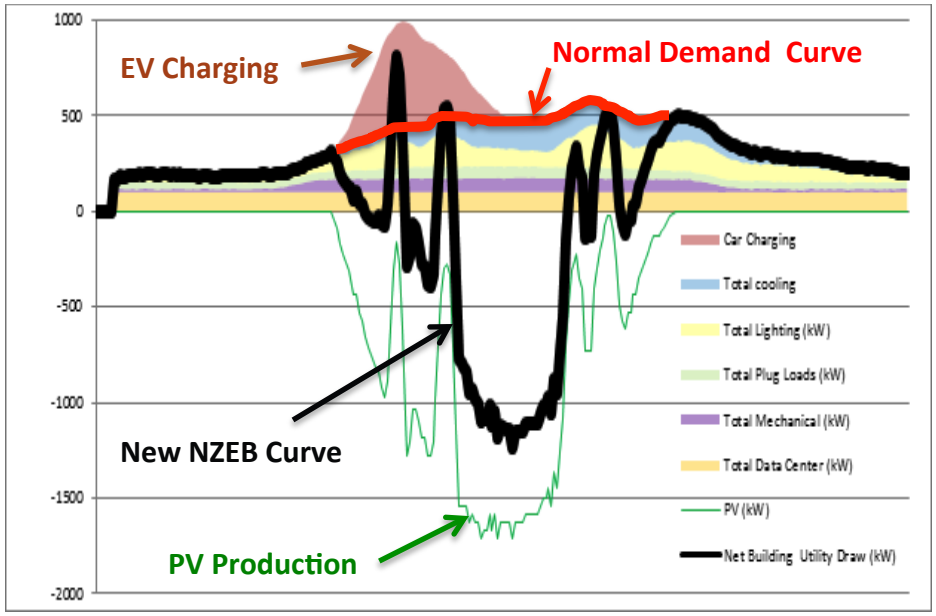
- **NREL-PNNL Smart-Grid Integration Project**
  - Connect devices in ESIF and HIL with GridLab-D modeling and signals
- **Interoperability & Smart Building Controllers**
  - Testing and evaluating of home and commercial building controllers
- **Smart Appliance Suites**
  - Testing and evaluation of smart appliances for demand response and grid services



Smart Grid Simulation at Scale

- **NZEB for Grid Services**
  - RSF and other NREL campus data is being collected and could be used to identify opportunities to reduce total energy use and/or reduce peak load and provide grid services with Xcel Energy

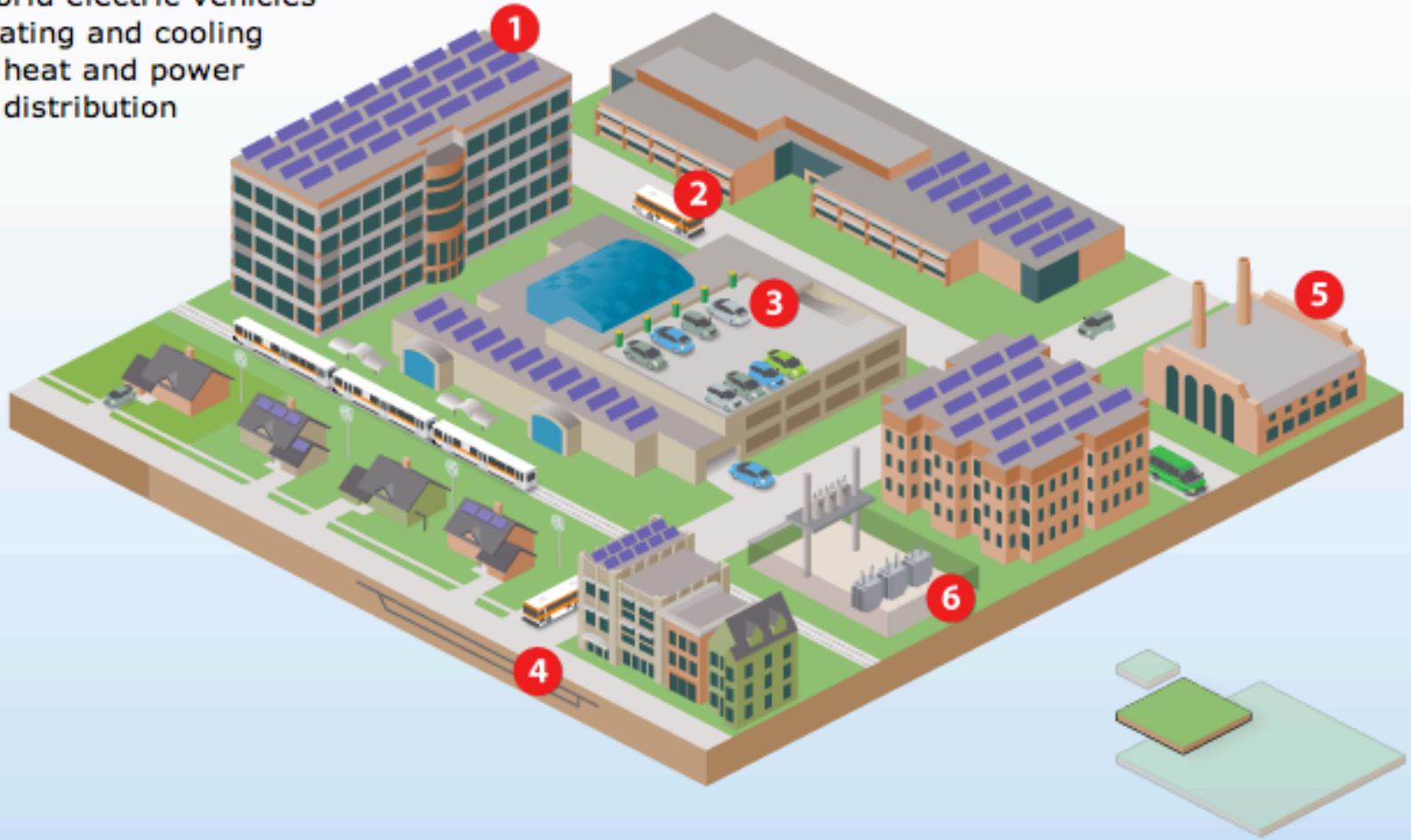
NZEB significantly changes demand profile



Campus, Community, and City Scale

Technologies

1. Photovoltaics
2. Fleets and mass transit
3. Plug-in hybrid electric vehicles
4. District heating and cooling
5. Combined heat and power
6. Electricity distribution



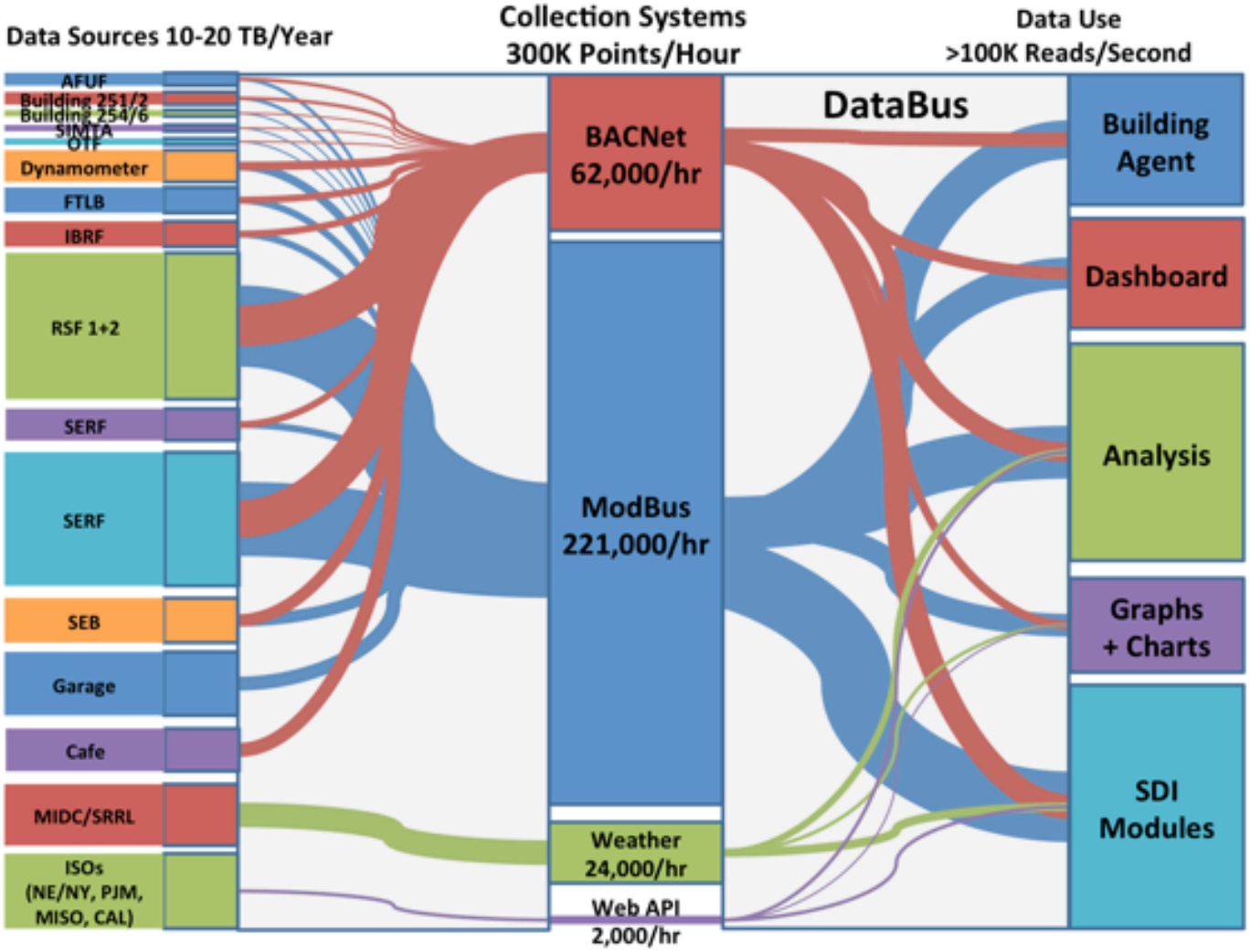
NREL Campus - Energy DataBUS

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)

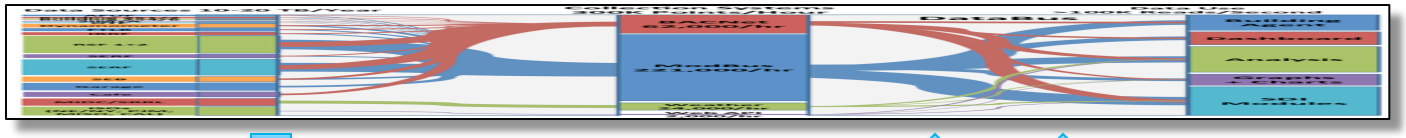
Push and pull into to app layer



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

NREL Campus Energy - Apps

Energy DataBUS – Data Collection and Analytics

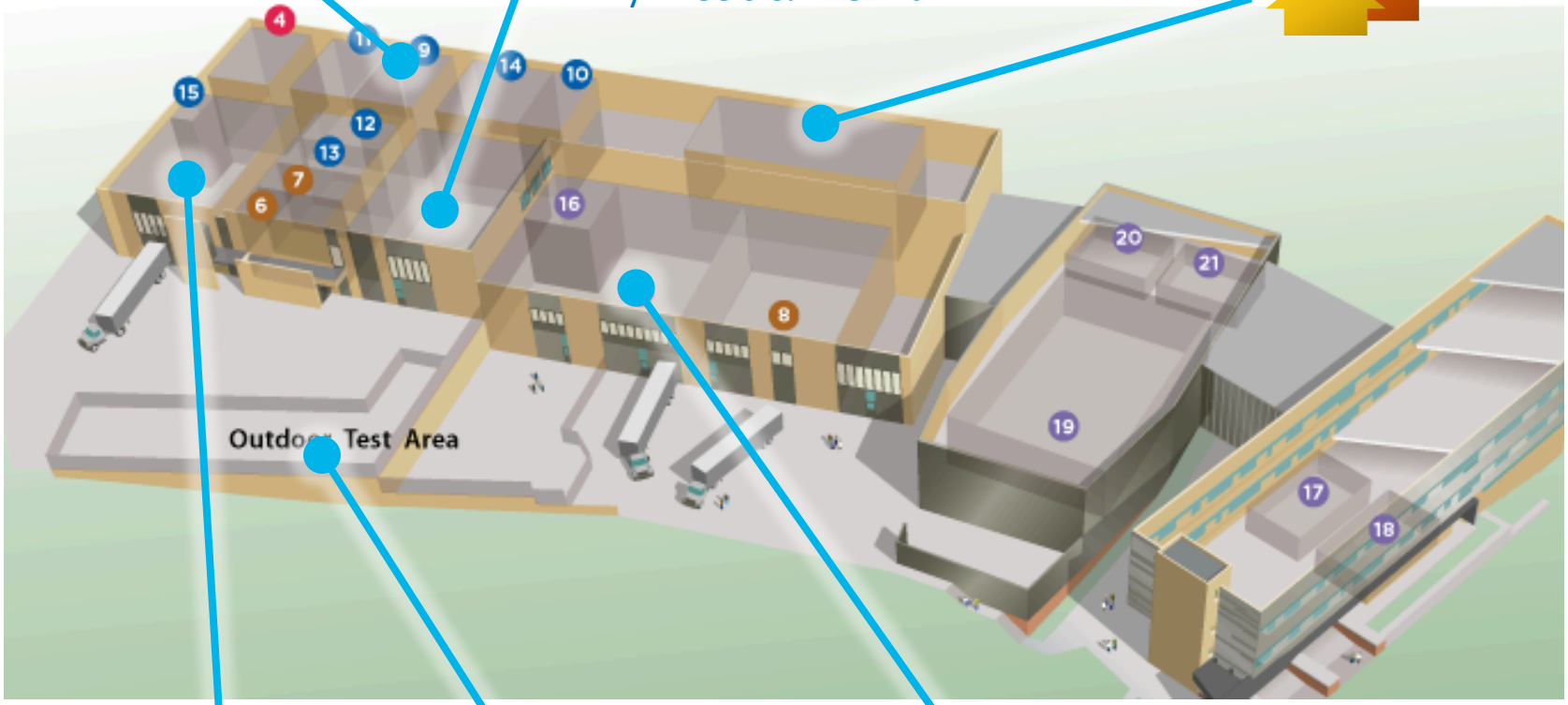


Campus Energy Dashboard

Engaging Occupants with Building Agent

Campus Energy Control and Optimization

Replication at Scale: Microgrid & Area



Microgrid Projects

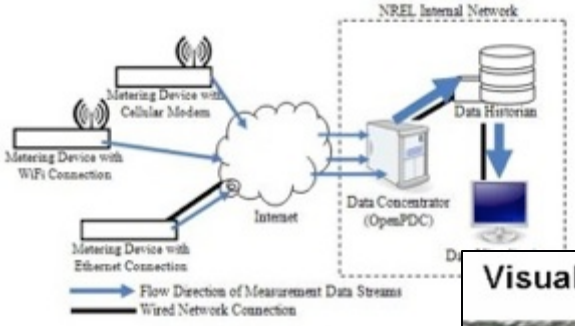
- Development of IEEE 1547.4 – Microgrid Standard
- Portland General Electric (PGE)
- Sacramento Municipal Utility District (SMUD)
- Santa Rita Jail Microgrid
- SPIDERS – DoD high reliability microgrids
- Other US DoD Bases – microgrids for high reliability

Regional, National, Continental Scale

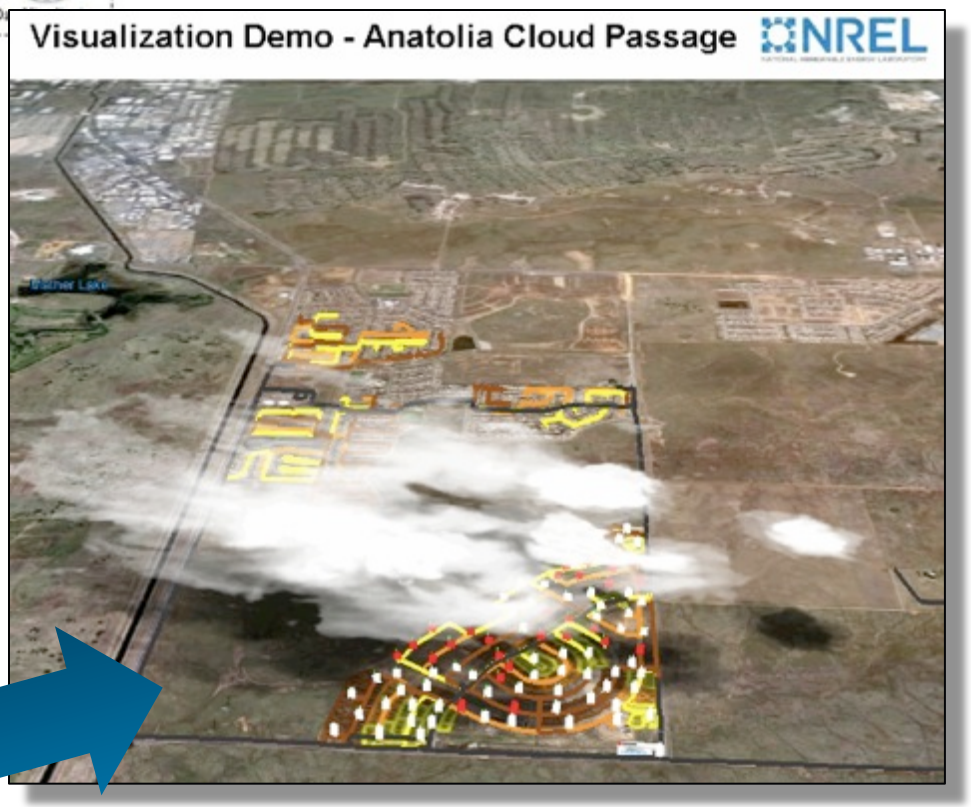
Technologies

1. Solar energy
2. Wind energy
3. Geothermal energy
4. Hydroelectric power
5. Nuclear energy
6. Fossil-fuel energy
7. Electricity transmission

Energy System Visualization



NREL is working with SMUD on visualizing impact of DG deployments



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*

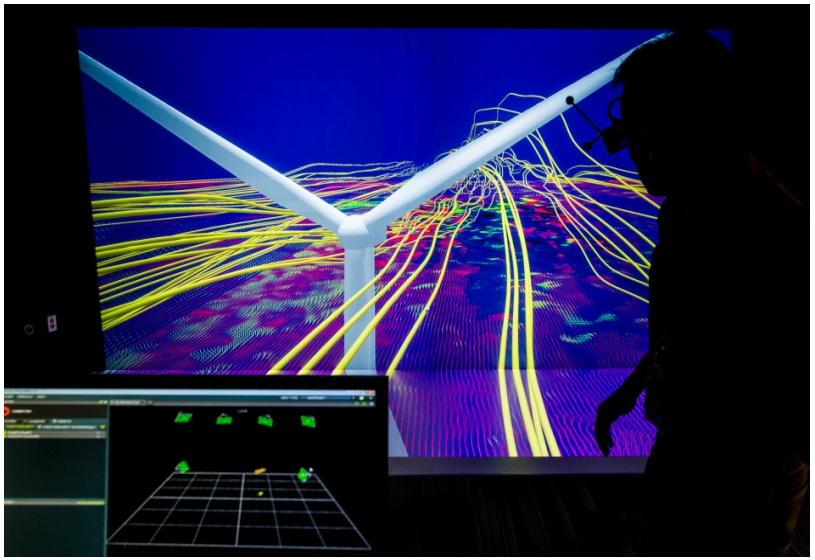
NREL NATIONAL RENEWABLE ENERGY LABORATORY | ENERGY SYSTEMS INTEGRATION FACILITY

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

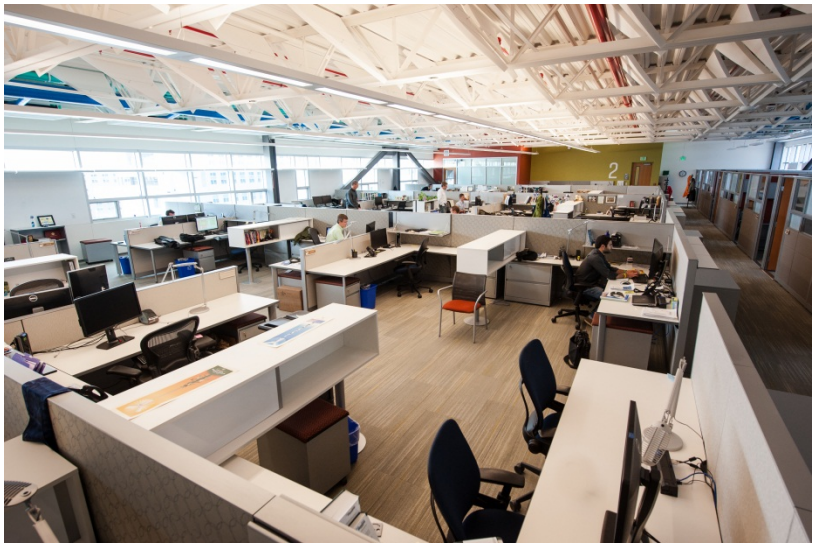
- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation
- Flexible interconnection points for electricity, thermal, and fuels
- Medium voltage (15kV) microgrid test bed
- Virtual utility operations center and visualization rooms
- Smart grid testing lab for advanced communications 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

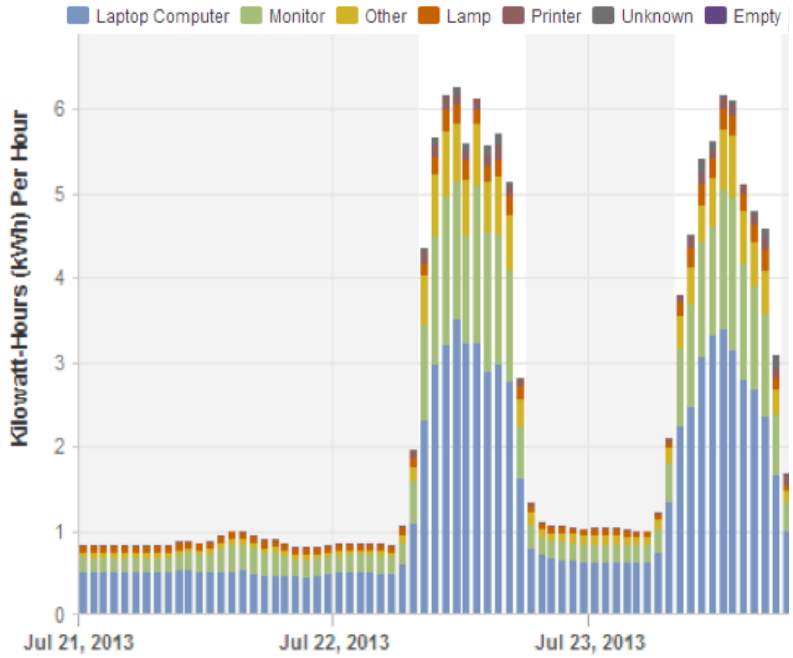


ESIF Office Area

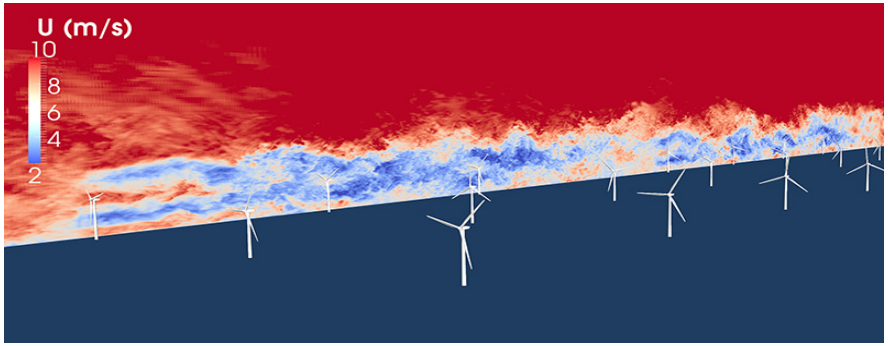
- Integrated Energy Efficiency into Design and Operations
- High use of daylight
- Natural use of ventilation through operable windows
- Uses about 25% national average for energy in office space
- Installed Enmetric plug load control system
- Collecting circuit level load information in office area

Enmetric Plug Load Controller





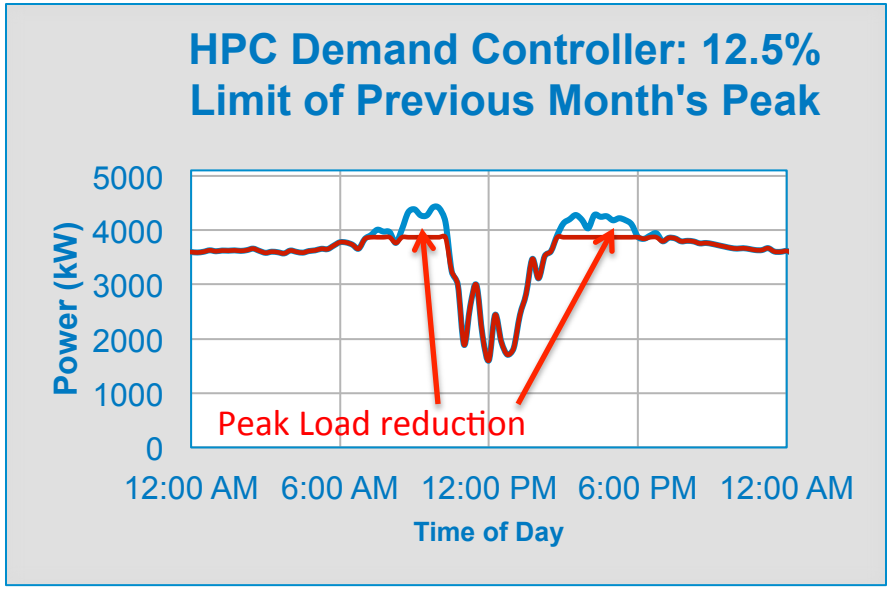
ESIF - High Performance Computing



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

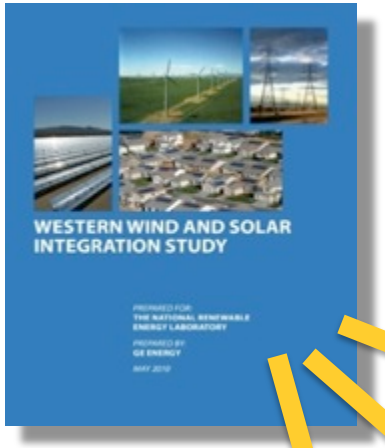
- High performance computing provides a multi-faceted basis for simulating future integrated energy innovations that would otherwise be too expensive, too lengthy, too dangerous, or otherwise impossible to study by direct experimentation.
- HPC also has integrated energy control and waste heat capture



ESIF - Energy System Simulated Operations

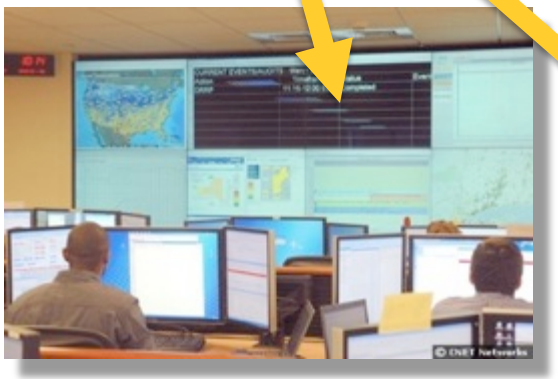
A Flight Simulator for Energy System Operators

"connecting integration studies to operations"

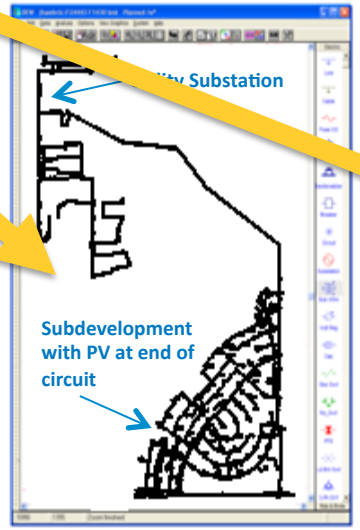


Operations techniques development for:

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



Transmission



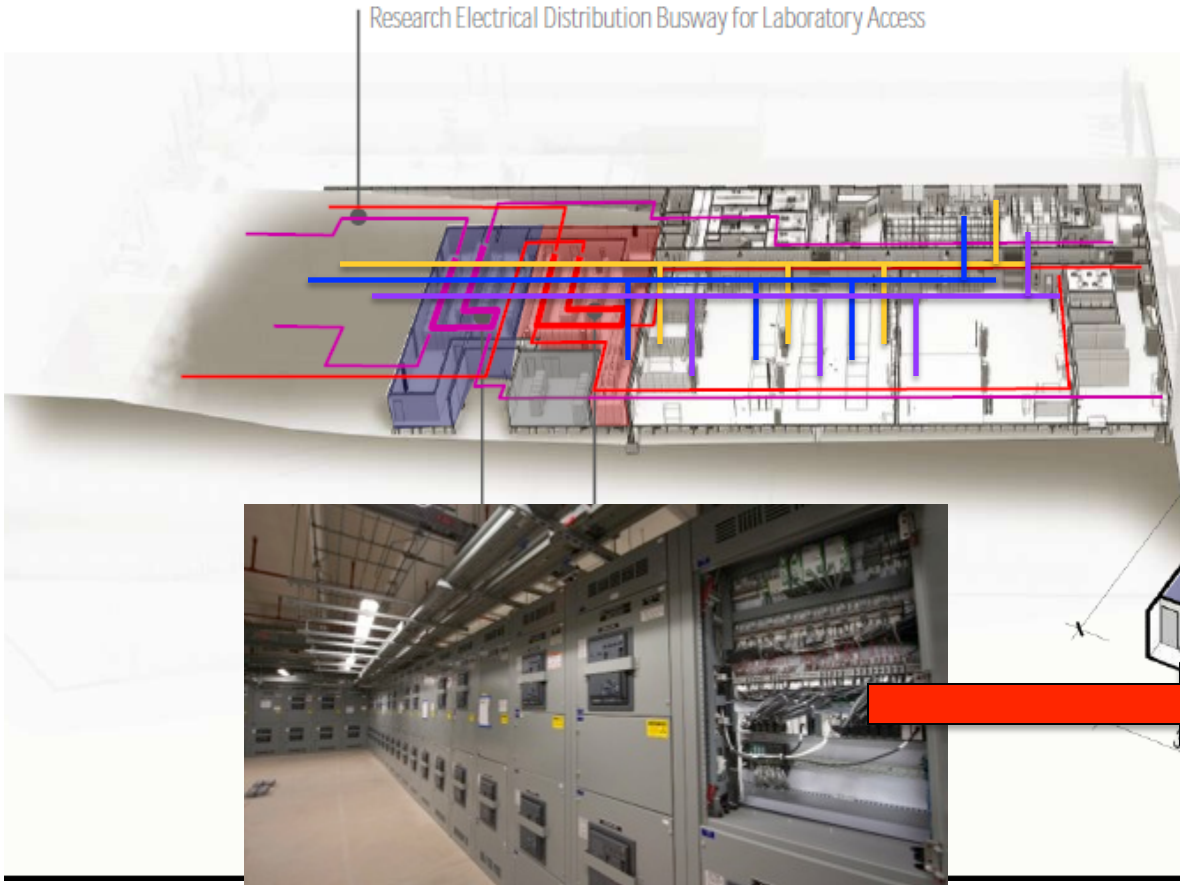
Distribution

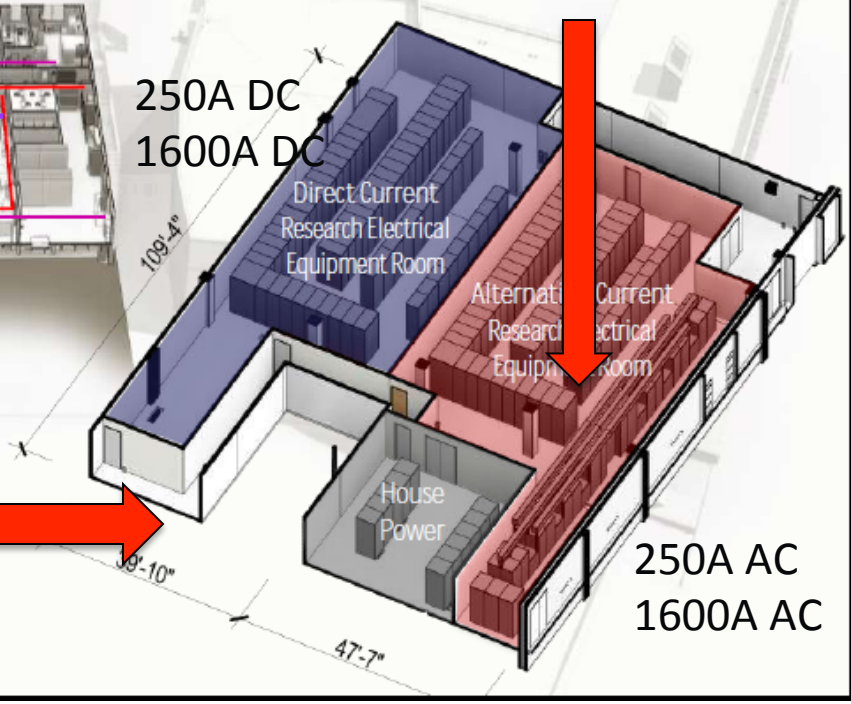
Campus Energy Dashboard

ESIF 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)

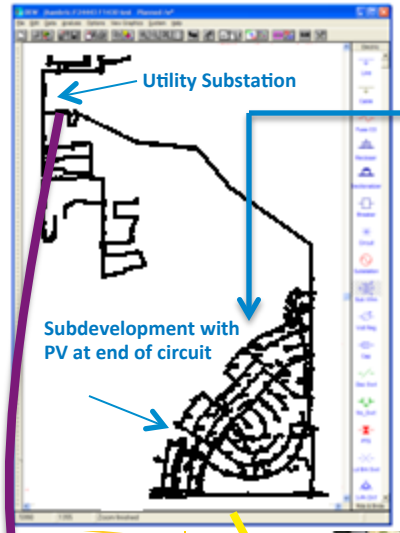
1MW Grid Simulator





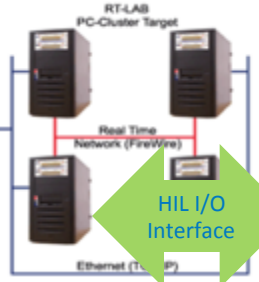
Hardware-in-the-Loop: Connecting Experiments to Simulations

Simulation validated with real field data



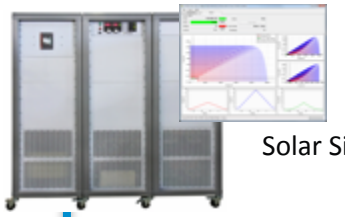
Simulation and Visualization at ESIF

Visualization Interface



HIL I/O Interface

Actual hardware at ESIF



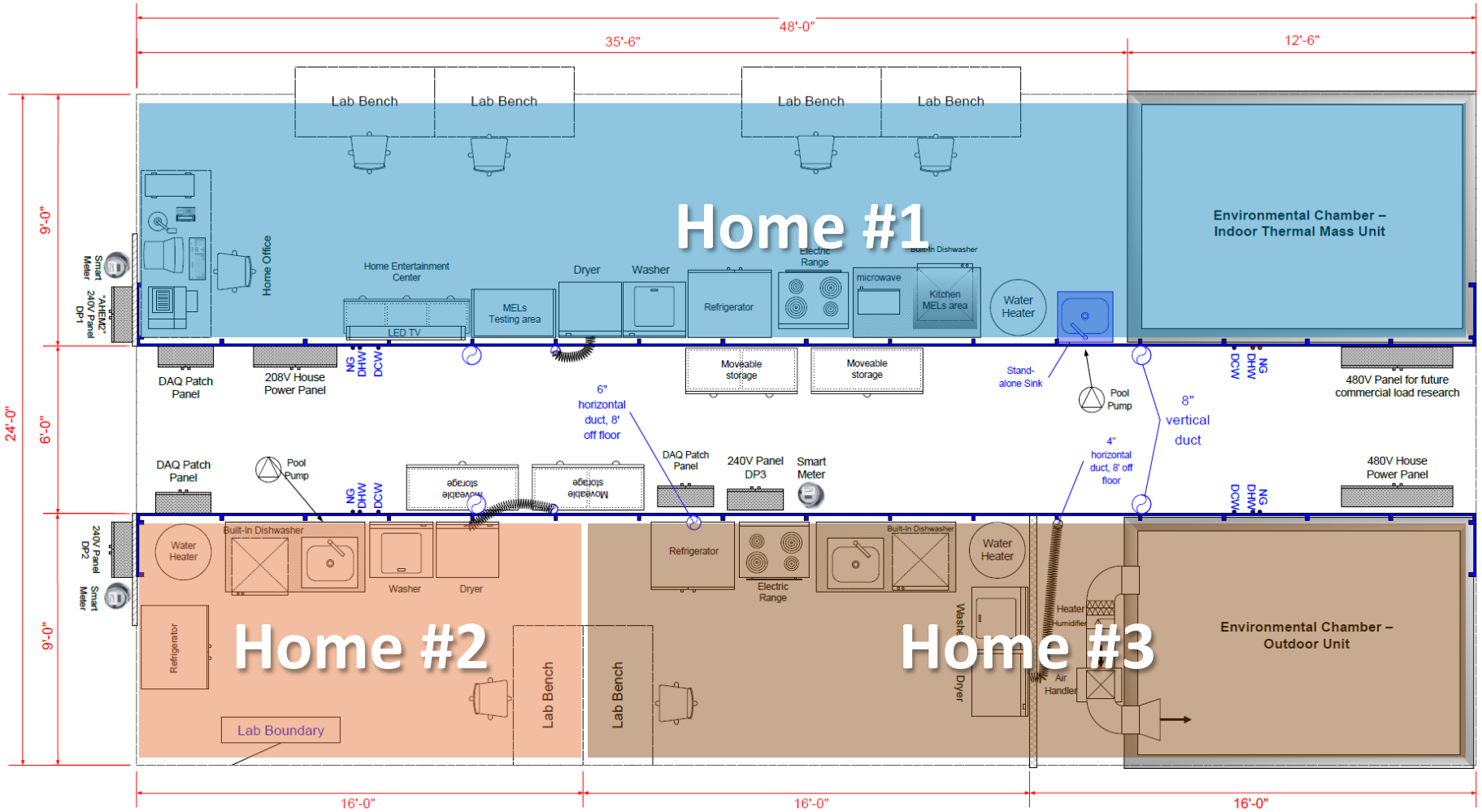
Solar Simulator

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

Replicated into Larger Simulation

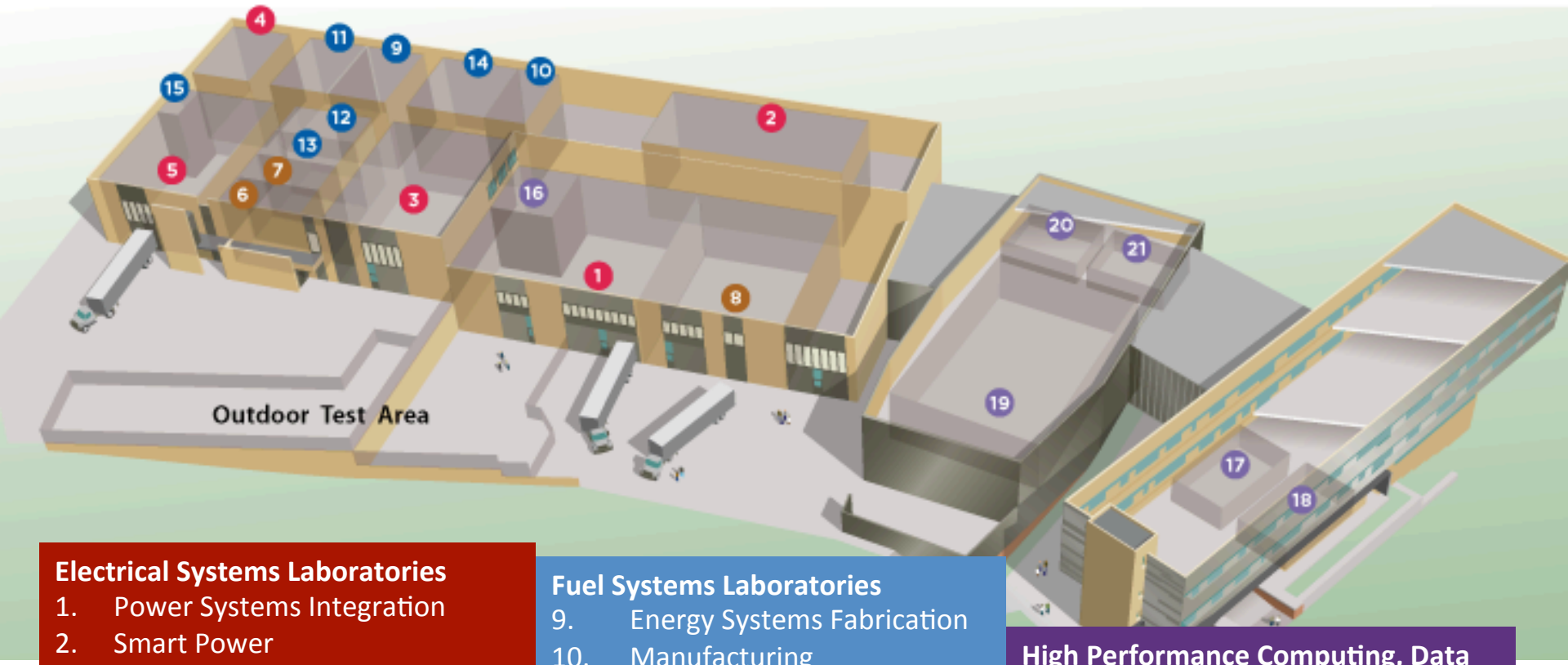
Simulation loop closed with actual hardware

Smart Grid Simulation at Scale



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

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 – 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

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

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

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

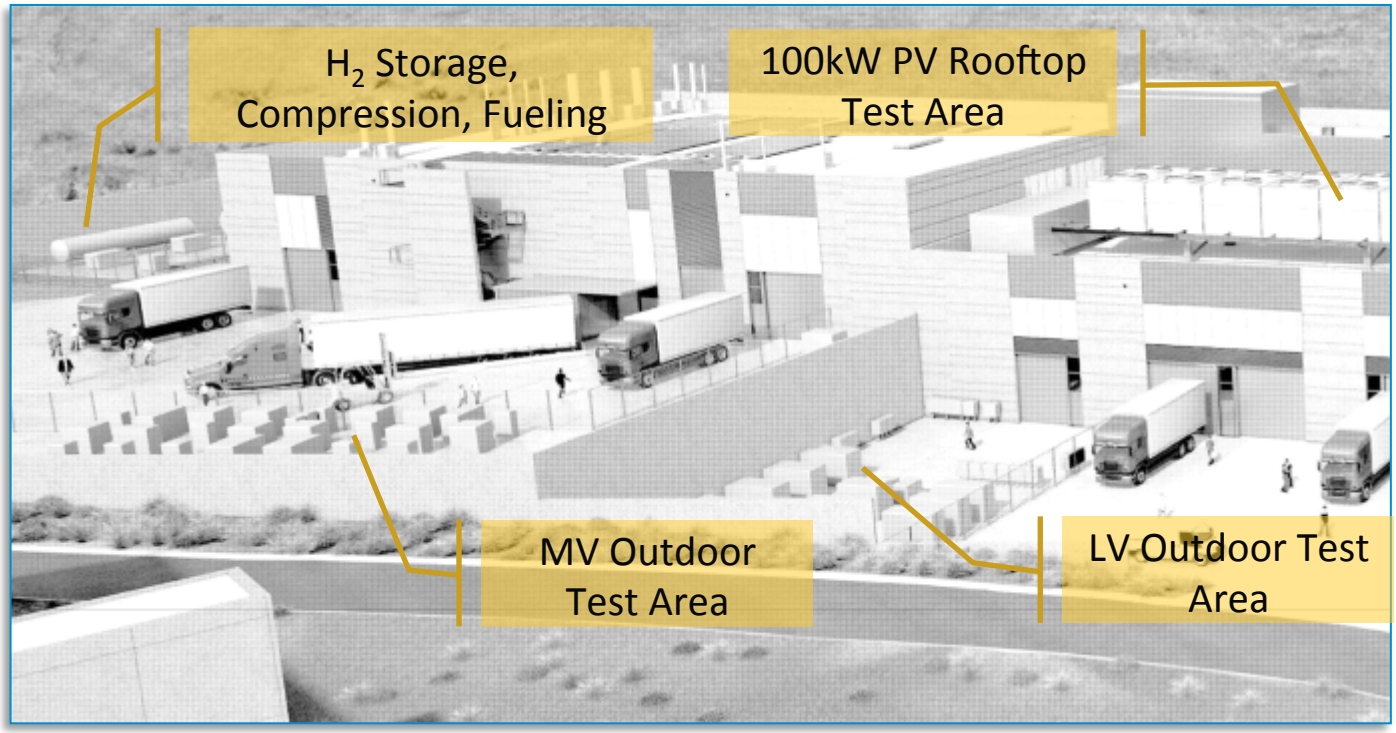
- Provides a safe environment for conducting high voltage surge testing and high current short circuit tests on equipment

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 –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

Director – Energy Systems Integration
National Renewable Energy Laboratory

http://www.nrel.gov/esi