NREL
NATIONAL RENEWABLE ENERGY LABORATORY

U.S. DEPARTMENT OF ENERGY

DOE's Energy Systems Integration Facility at NREL

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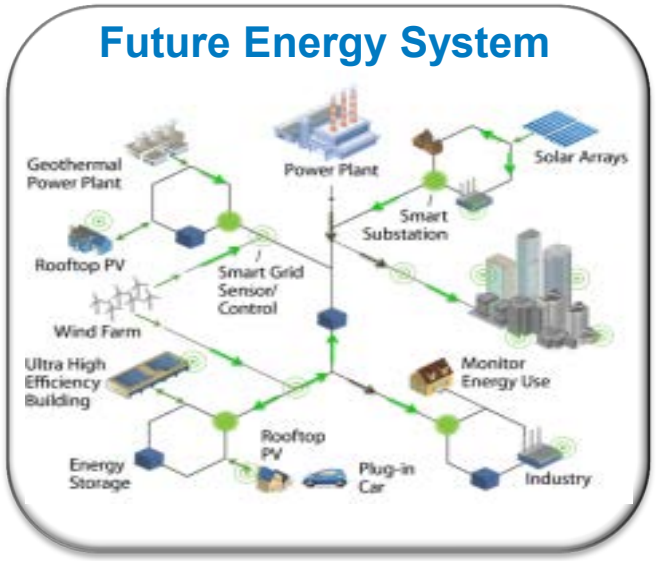
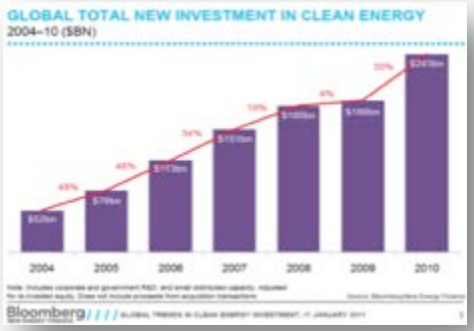
Current Situation

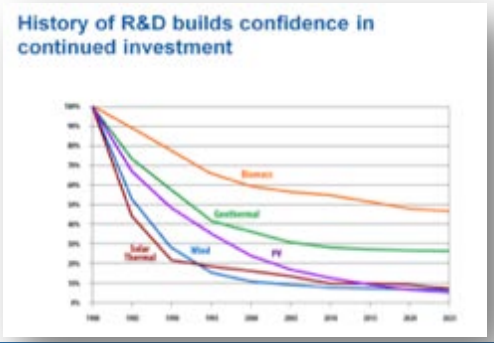
A Decade of Rapid Change

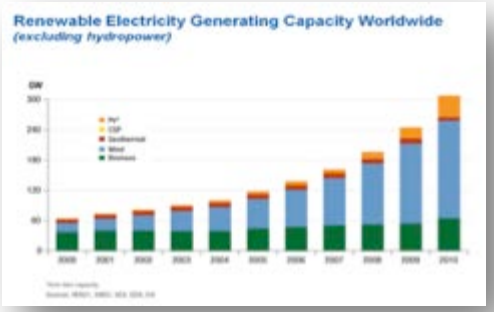
- Increase in energy productivity
- Rapid growth in clean energy capacity
- Growth in U.S. clean energy investment - from $1B/year to a $34B/year
- Turnover of electric capacity and vehicle fleets to natural gas

As Clean Energy Scales and Diversity in Generation and Use Grows, Systems Challenges Emerge



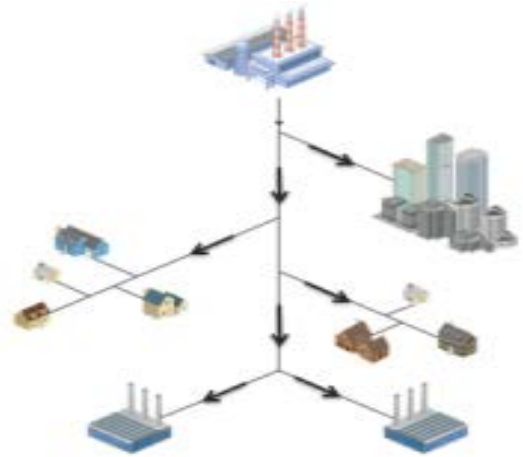




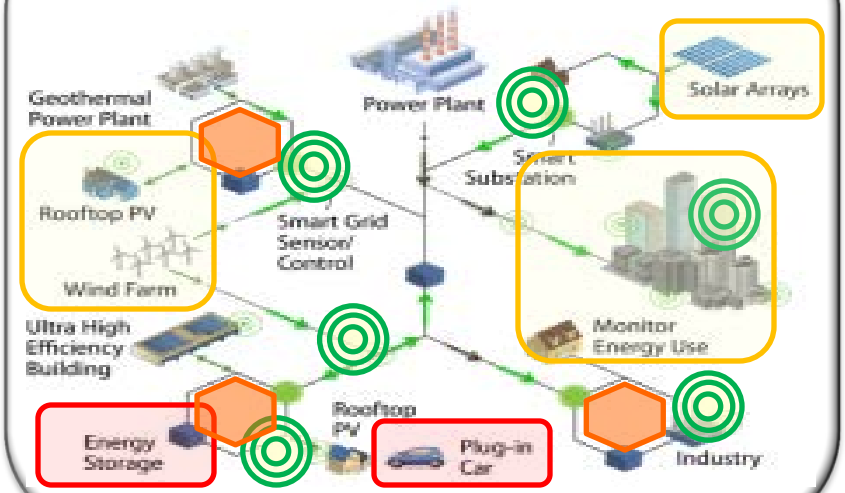


Why Energy Systems Integration?

Current Energy Systems



Future Energy Systems



Reducing investment risk and optimizing systems in a rapidly changing energy world

- Increasing penetration of variable RE in grid
- Increasing ultra high energy efficiency buildings and controllable loads
- New data, information, communications and controls
- Electrification of transportation
- Integrating energy storage (stationary and mobile) and thermal storage
- Interactions between electricity/thermal/fuels
- Increasing system flexibility and intelligence

Energy Systems Integration

Energy Production and Delivery

Electricity

Fuel

End-Use and Efficiency

Buildings

Transportation

Energy Systems Integration

optimizes the design and performance of electrical, thermal, and fuel pathways at all scales

Energy Systems Integration Continuum

Energy Systems Integration optimizes the design and performance of electrical, thermal, and fuel pathways at all scales.

Scale

Appliance (Plug)

Building DistGen Vehicle (meter)

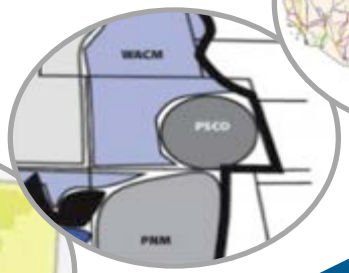
Campus Subdivision (feeder)

Community (substation)

Area (Service Territory)

Region (Balancing Area)

Nation



Energy Informatics: Linking Data to Knowledge to Control

Complexity

Electricity

Thermal

Fuel

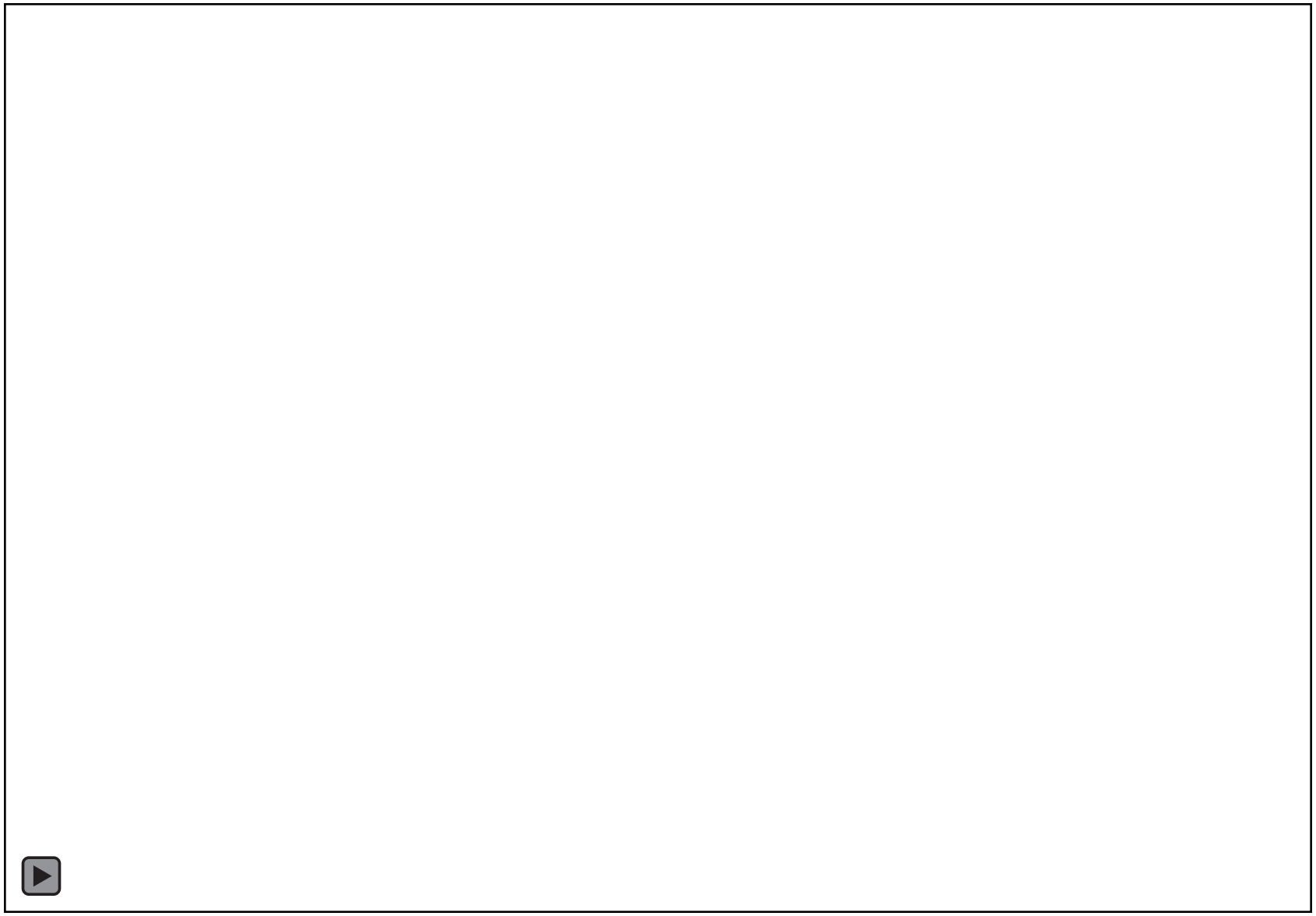
Data

DOE's Energy Systems Integration Facility (ESIF) at NREL

- DOE's largest R&D facility (182,500 ft^2) at NREL
- Space for 200 NREL staff and research partners
- A unique national asset to conduct RD&D of integrated energy systems
- On track for LEED Platinum
- World's most efficient data center (PUE <1.06)

Addressing the challenges of integrating clean energy technologies into the energy systems infrastructure at all scales

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

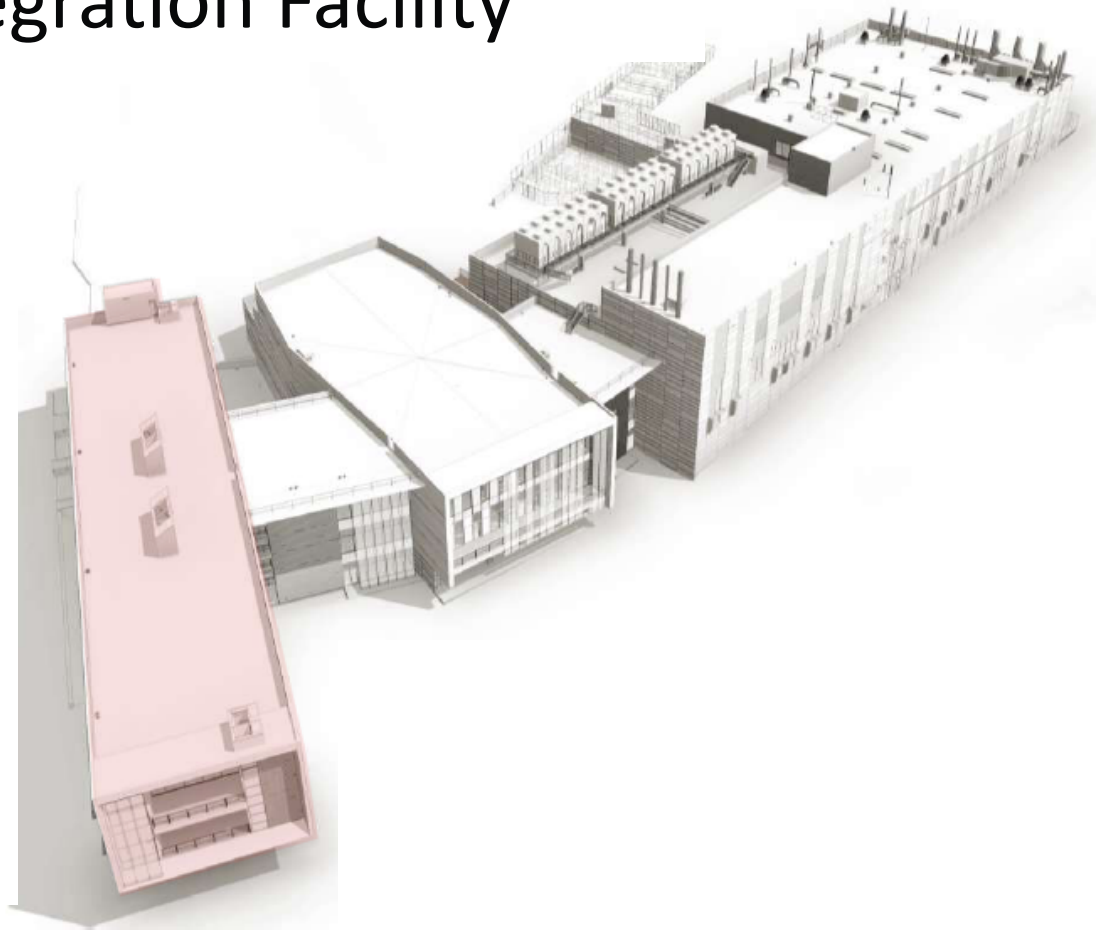


ESIF - Office Area

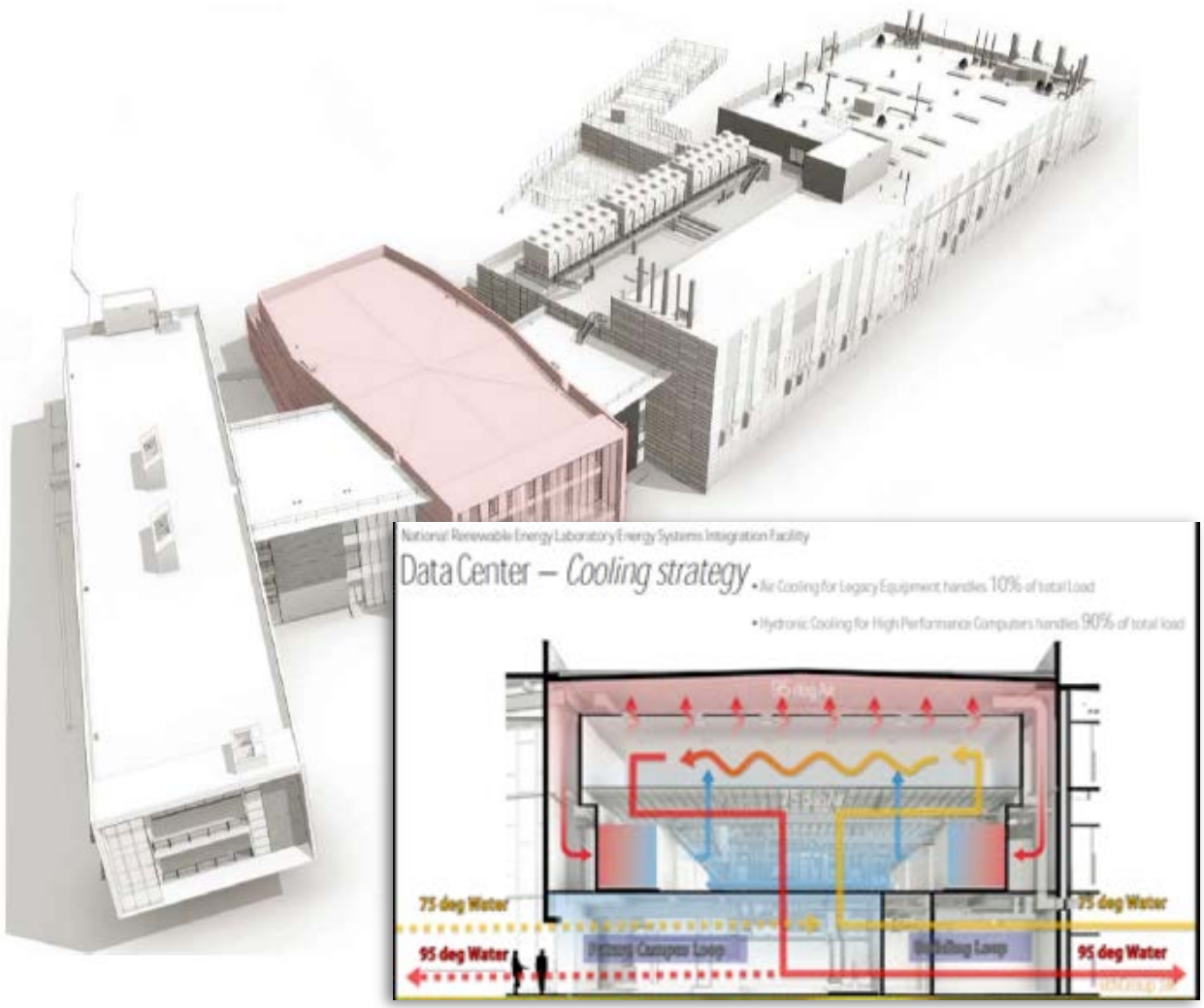
National Renewable Energy Laboratory
Energy Systems Integration Facility

Office Space

- Energy Target (Site EUI): 26.7 kBtu/sf/yr
- National Average Site EUI: 90 kBtu/sf/yr (CBECS)
- Energy Efficiency over National Average (w/server): 74%
- Energy Efficiency over National Average (w/out HPC): 87%



ESIF - High Performance Computing Data Center



Showcase Facility

- Use evaporative rather mechanical cooling.
- Waste heat captured and used to heat labs & offices.
- World's most energy efficient data center, PUE 1.06!

20 year planning horizon

- 5 to 6 HPC generations.

Energy Data Hub

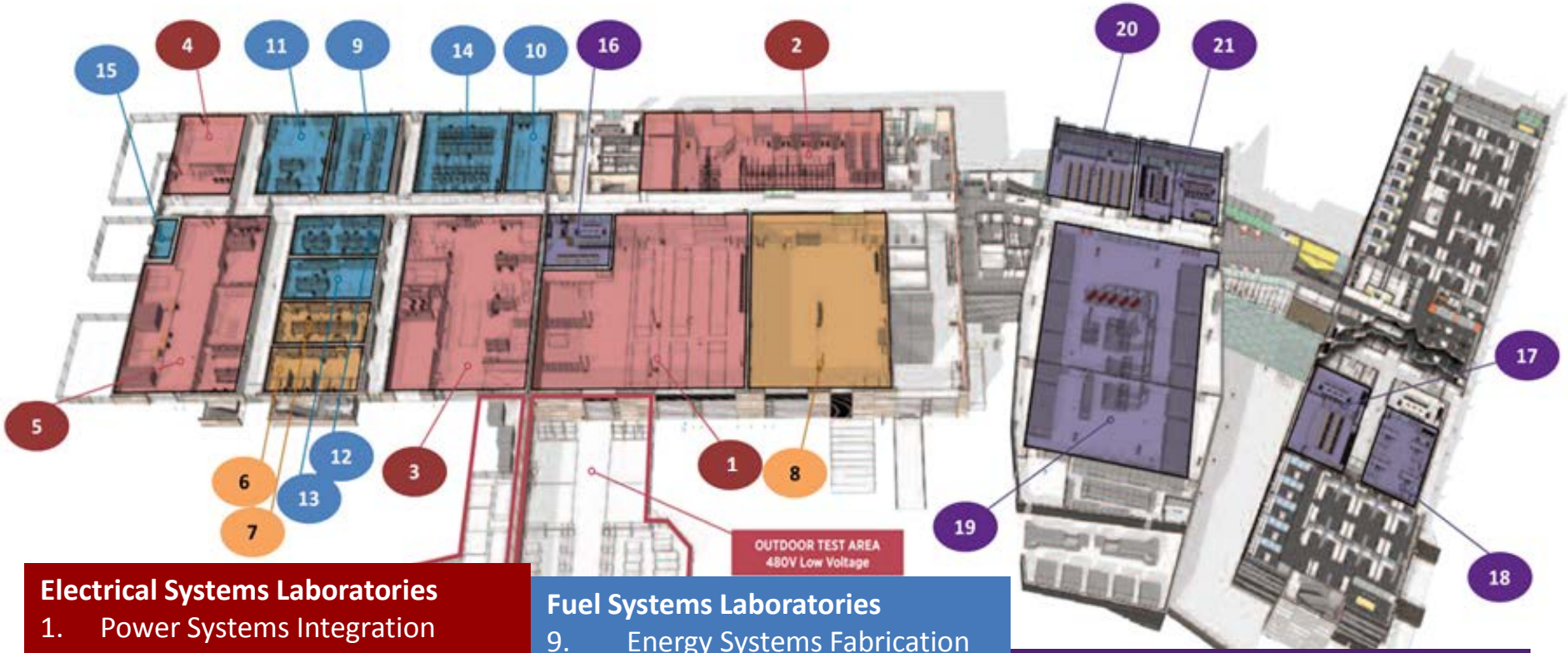
- Data mgmt, mining, analytics
- Smartgrid.gov
- High frequency data from technology deployment

Insight Center

- Scientific data visualization
- Collaboration and interaction.

PUE = Power Usage Effectiveness

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

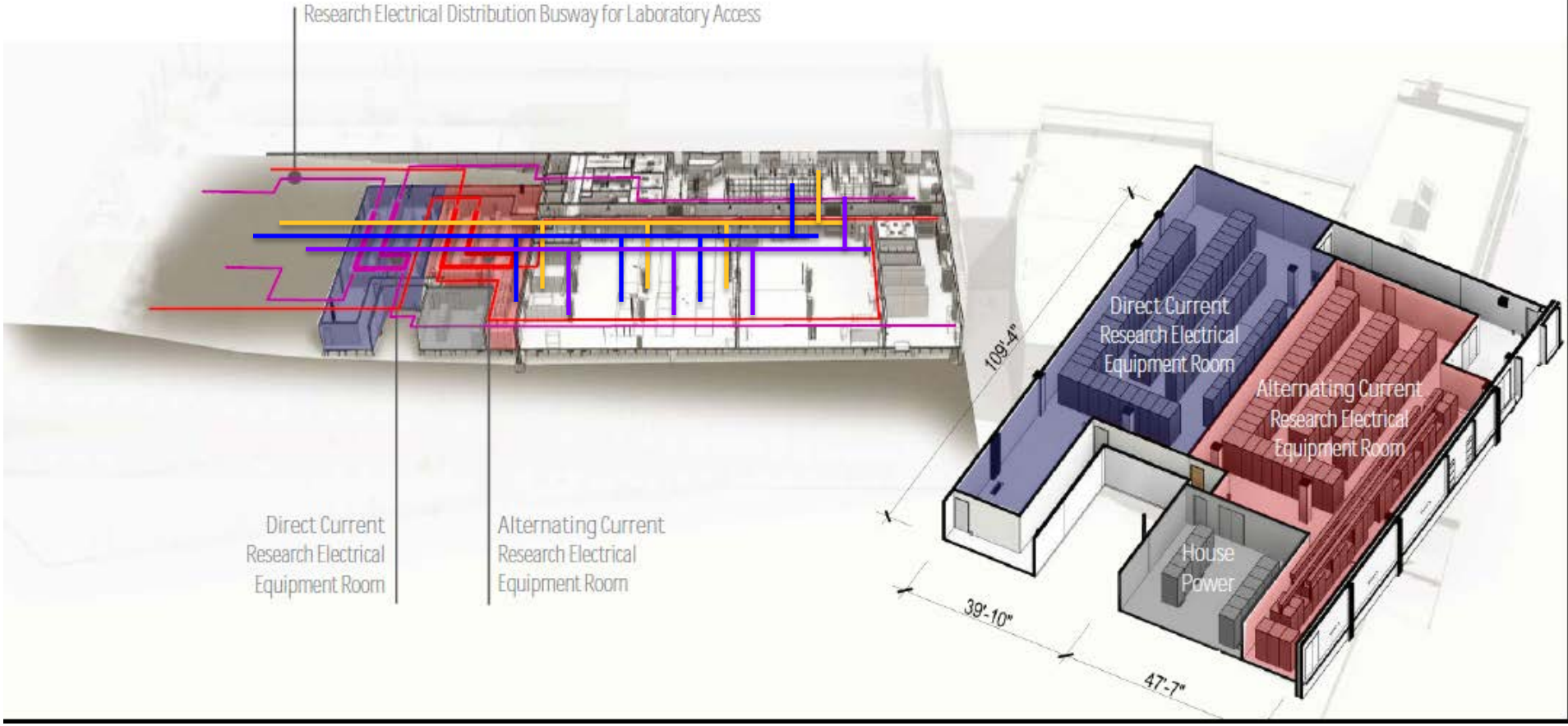
High Performance Computing, Data Analysis, and Visualization

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 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) Bus

- Energy System Research At Scale
- 1.5 MW Single Source REDB
- MW-Scale Micro Grid Simulation



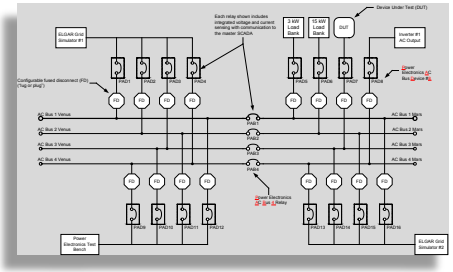
ESIF Labs - Interior

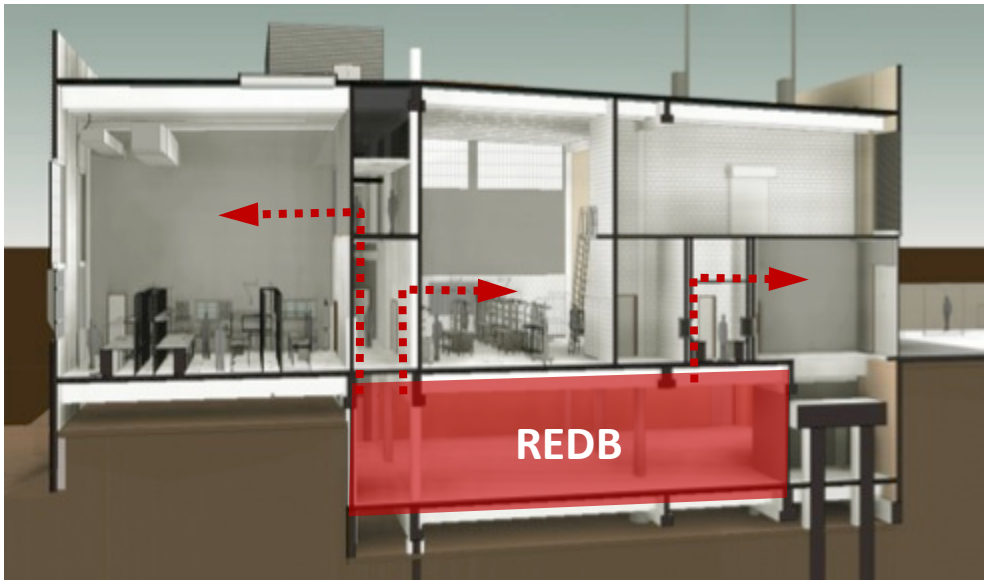
Smart Power Lab

Energy Systems Integration Lab

ESIF's Unique Advanced Capabilities

- Multiple parallel research electrical distribution busses (REDB) at MW power level with grid and load simulation.





- Flexible interconnection points for electricity, thermal, and fuels to multiple labs.
- Medium voltage (15kV) microgrid test bed.
- Extensive selection of existing distributed energy systems and high power PV and wind simulation.

ESIF – Power Systems Integration Lab

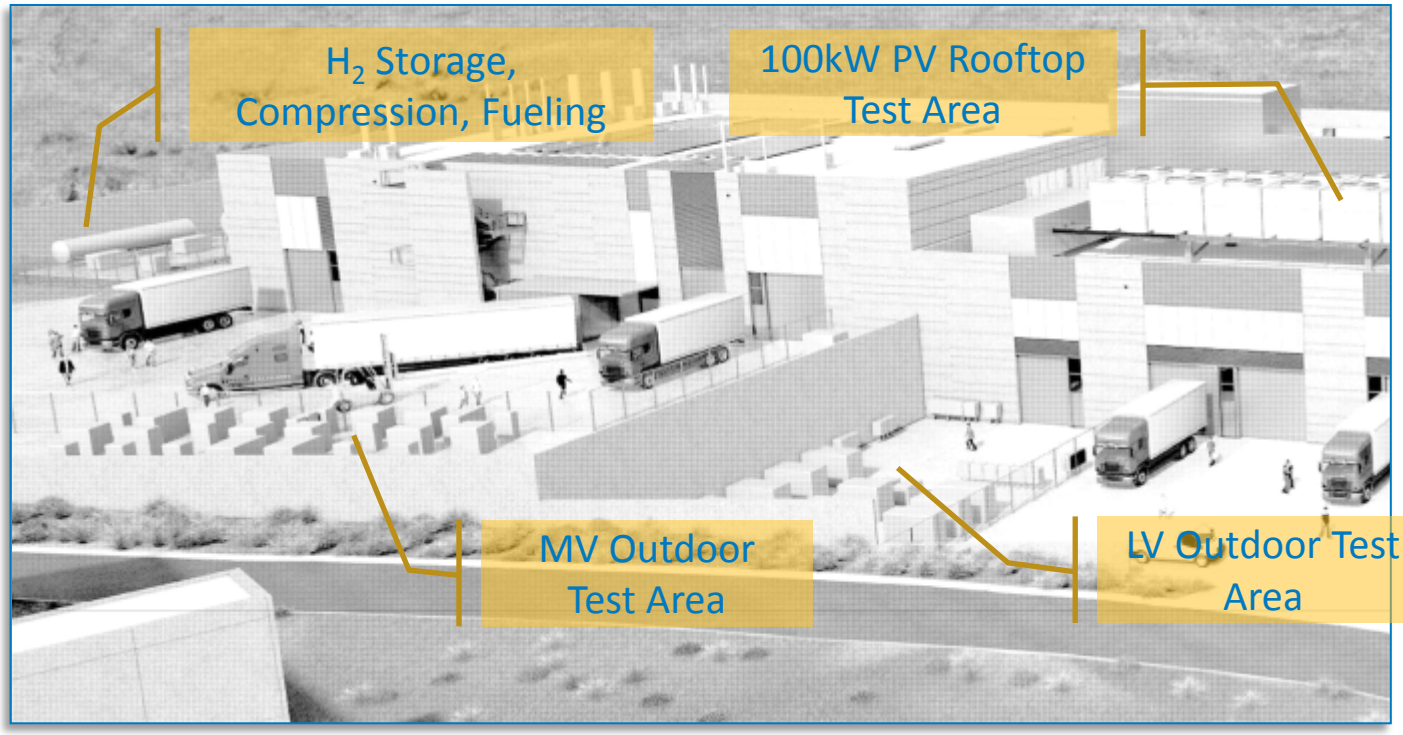
Lab Functions

- Research of large-scale electrical equipment and operating configurations
- House infrastructure for DG research (electricity-REDB, thermal, and fuels)

Major Laboratory Equipment included in building capital

- Grid simulator (4x270kW, 690Vac, 400Vdc, DC-800Hz)
- AC load banks (4x250kW, Wye, 50W load step)
- SCADA Data Collection and Control System
- Research Chiller/Boiler (750 MBH boiler, 60ton chiller)
- Hardware-in-the-Loop Simulator (Opal-RT)
- Bidirectional DC supplies (2x250kW, 0-900V)

ESIF –Outdoor Test Areas



ESIL Major Lab Equipment

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

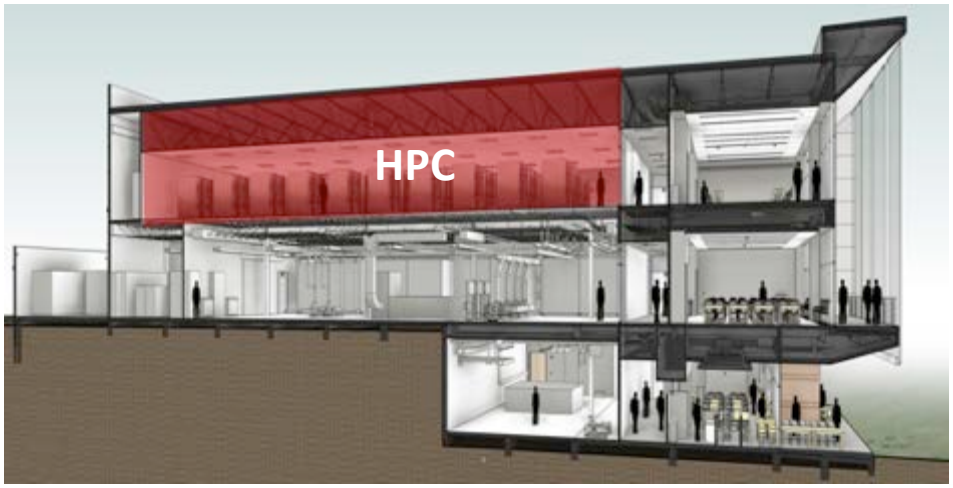
MV Major Lab Equipment

- 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

ESIF's Unique Advanced Capabilities



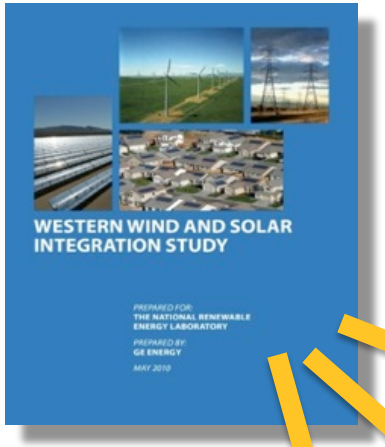
- Petascale HPC and data management system in showcase energy efficient data center.

- Virtual utility operations center and visualization rooms to understand impact of high penetration variable renewables, electric vehicle, and energy efficiency deployments.
- Interconnectivity to external field sites for data feeds and model validation.

ESIF - Energy System Simulated Operations

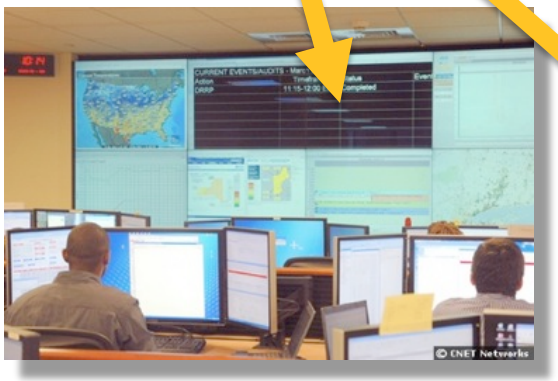
A Flight Simulator for Energy System Operators

"connecting integration studies to operations"

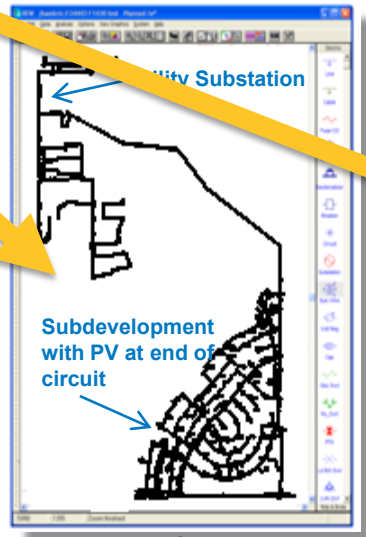


Operations techniques development for:

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



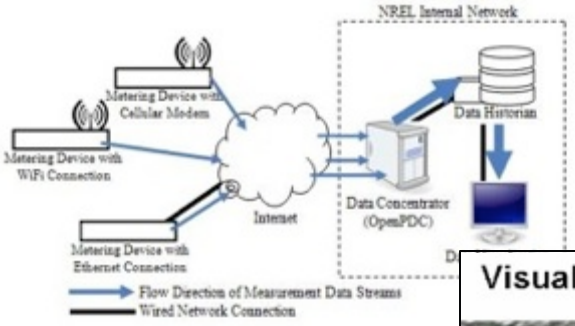
Transmission



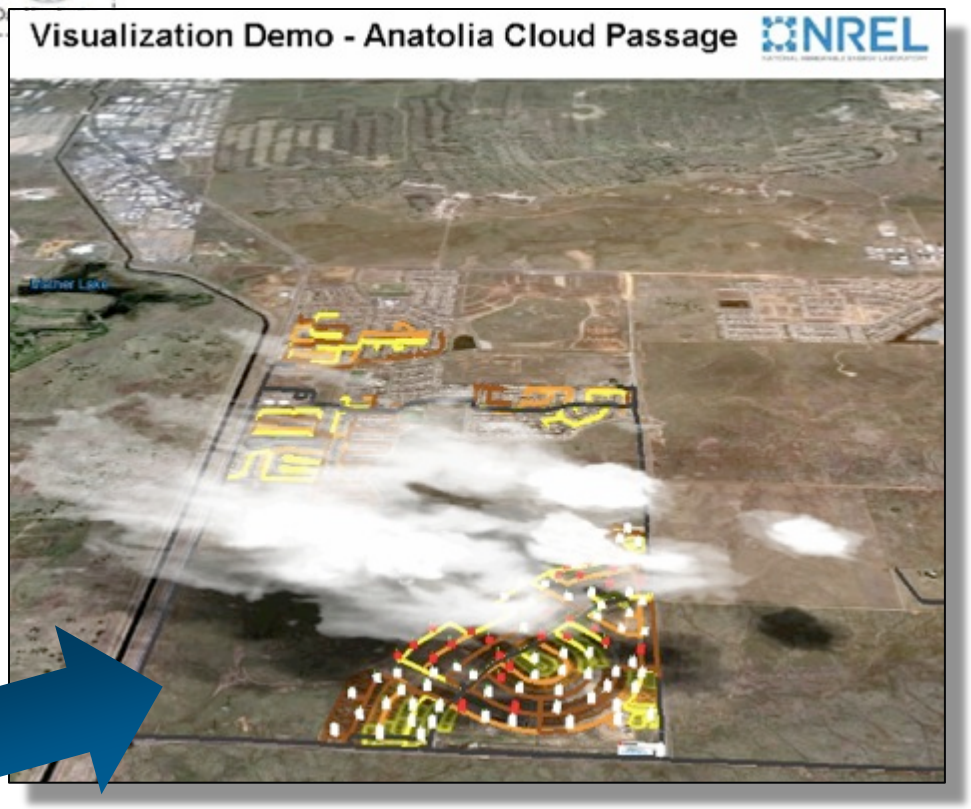
Distribution

Campus Energy Dashboard

ESIF - Energy System Visualization

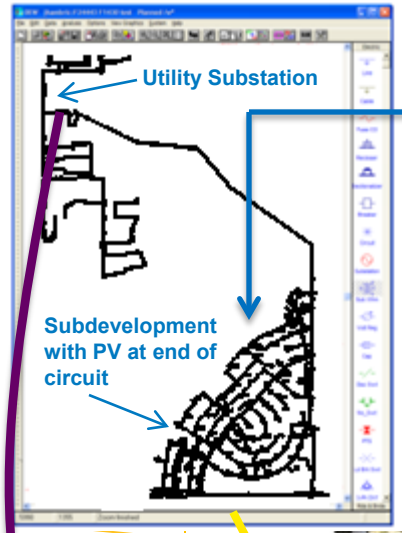


NREL is working with SMUD on visualizing impact of DG deployments



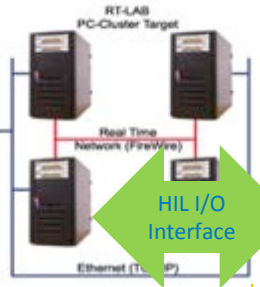
ESIF - Hardware-in-the-Loop (HIL)

Simulation validated with real field data



Simulation and Visualization at ESIF

Visualization Interface



HIL I/O Interface

Actual hardware at ESIF

Replicated into Larger Simulation

Simulation loop closed with actual hardware

ESIF System Integration Capabilities

Energy System Research and Development Across Technologies

Solar and Wind

- RE integration
- Power electronics
- Building integration
- Thermal and PV system optimization

Grid Planning and Operations

- Transmission and Distribution Systems
- Smart Grid Technologies
- Microgrids
- Standards

Energy Storage

- CSP Thermal Storage
- Utility scale batteries
- Distributed storage

Buildings

- Sensors and controls
- Design and integration
- Modeling and simulation
- Big Data warehousing and mining
- System integration

Fuel Cells and Hydrogen

- H_2/electric interfaces
- RE electrolyzers
- Storage systems
- Standards
- Fuel cell integration
- Fueling systems

Advanced Vehicles

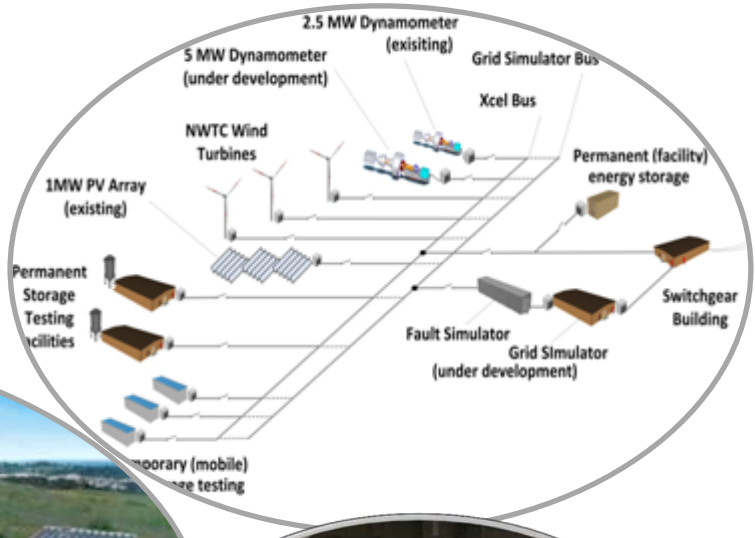
- Plug-in-hybrids and vehicle-to-grid
- Battery thermal management
- Power electronics

Full systems interface evaluation for integration of electricity, fuels, thermal, storage, and end-use technologies

DOE's Energy Systems Integration Facilities at NREL

A unique national asset for energy systems integration R&D, testing, and analysis at various scales

NWTC – 2MW+



DERTF
1kW-200kW

ESIF
1kW-2MW

EVSEs

TTF

VTIF

RSF

Creating a Leading Competency

System Models & simulations

- Scalable, dynamic models
- Rich regional detail

Measured & Modeled data

- Common Data Platform
- Robust Measured Performance Data Sets

Energy Systems Modeling

Energy Systems, Components, & Controls

Energy Systems Informatics

Experiment, Test & Validate

Energy system Innovations

- Interfaces & Controls
- Materials
- Test Methods
- Hybrid Systems & Storage

Experimental facilities

- MW-Scale HIL Capability (ESIF)
- Field Testing Capabilities
- Partnering Model

Suppliers — *Design* — *Prototype* — *Demonstrate* — *Deploy* — **Users**

Thank you

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For more information: http://www.nrel.gov/esi/