THE RIGHT TOOL AT THE RIGHT TIME

Energy Systems Integration Facility at the National Renewable Energy Laboratory
Golden, Colorado

2014 Lab of the Year

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ESIF's Super Computer, "The Peregrine" and NREL's Computational Science Center Director, Steve Hammond

Data Entry List

Project Name:
Energy Systems Integration Facility

Project Location: Golden, Colorado

Project Owner:
Department of Energy's
National Renewable Energy Laboratory

Date of Completion: April 2013

Total Gross Size (ft2/m2): 182,500 GSF

Total Construction Cost: $98,590,459

Total Project Cost: $135,000,000

Cost Per ft^2: $540/sf

Net to Gross ft^2 Ratio:
63% (Excluding Data Center)

Client Contact:
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Golden Colorado,
303-384-7617, brian.larsen@nrel.gov

Overall Facility Areas

Office:	**43,750 GSF**
Data Center:	**26,750 GSF**
Collaboration & Viz Center:	**23,900 GSF**
High Bay Lab:	**88,100 GSF**
Total:	**182,500 GSF**

Submitter
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MEP Engineer (Laboratory)
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Data Entry List 1

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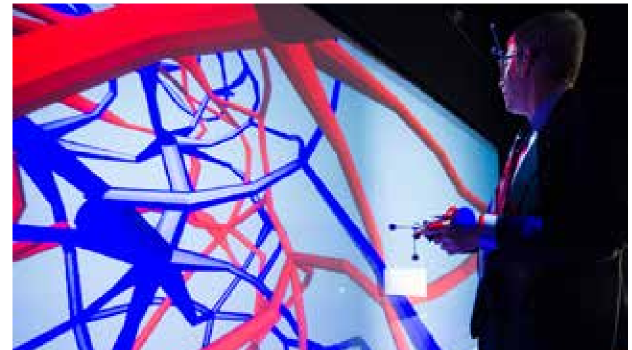
ESIF's Insight Visualization Theatre


ESIF's Fuel Cell Test and Development Lab


Bird's Eye View of Smart Power Laboratory from Tour Route

Executive Summary

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View of ESIF from Protected Arroyo

> **Our National Laboratories are a national treasure that help America's entrepreneurs and innovators to accelerate the development of new technologies, 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**

Executive Summary

Urbanization, modernization, and economics are placing ever-increasing demands on systems around the world to squeeze more out of less. Energy systems have evolved from small, local, single-service systems (e.g., the steam engines that powered the Industrial Revolution) into highly integrated, continental systems that deliver energy services through renewable, nuclear, and fossil sources but also electrical, thermal, and fuel pathways that convert and deliver energy to our homes and businesses. The complexity of the system is also increasing with the integration between other systems—such as data and information networks and water systems—that traditionally have not been linked with energy.

Without an all-inclusive approach to this comprehensive problem, there is significant danger that local optimizations may produce a solution that is far from a global or societal optimum. Conversely, universal optimization may lead to a "brittle" solution that risks reliability or security. Further, a sense of urgency must be maintained as transformation continues, and piecemeal changes may be difficult to reverse once established.

Opportunities exist to capture co-benefits and improve the overall efficiency of our energy system. Through a more holistic approach, efficiency can be increased using technologies such as combined heat and power and waste heat utilization. Properly designed improvements can also enhance reliability, security, and flexibility. **Enter the National Renewable Energy Laboratory's Energy Systems Integration (ESI) initiative**.

ESI optimizes the design and performance of electrical, thermal, and fuel systems at different but interrelated scales, ranging from individual homes and businesses to communities and cities to regional and national infrastructures. NREL's approach builds on research in the integration of complex "systems of systems" to design energy structures that are optimized at smaller levels and can be aggregated to improve energy pathways at any scale. This focus will allow NREL to better understand and make use of potential co-benefits that increase energy reliability and performance, reduce cost, and minimize environmental impacts.

Project Goals:

Integrate safety into every phase of the project including design, construction and anticipated use.

- ✔ SCADA system allows for central monitoring, control of events and early detection system for potential safety issues
- ✔ No other construction project on NREL's campus achieved more superior safety ratings then the ESIF project. construction and anticipated use.

Artfully incorporate energy efficient and sustainable building design strategies and technologies into this one of a kind high tech facility.

- ✔ HPC data center will save approximately $1 million in annual operating cost compared to a traditional data center.
- ✔ ESIF achieved all 56 LEED® points applied for and the facility is 40% more energy efficient than the baseline building performance rating per ASHRAE/IESNA Standard 90.1-2004.

Create a national showcase of high performance building design for this project type.

- ✔ International magnet for high-profile visitors. Ground breaking one of a kind research and testing.

Accommodate the REDB, which is a specialized electrical distribution bus network which interconnects laboratories and experiments to test equipment.

- ✔ The REDB functions as the ultimate power integration "circuit" capable of utilizing multiple AC and DC buses that connect multiple sources of energy and inter-connecting laboratories and experiments to test and simulate equipment.

NREL and its partners recognize the growing importance of ESI as a critical multidisciplinary, multifaceted research and development area that will underpin the energy system of the future. This requires tapping **newly developed integration facilities, such as NREL's Energy Systems Integration Facility** (ESIF) located on Golden, Colorado, that combine hardware testing at proper scale with simulation environments that can link the energy pathways. Through ESIF, NREL is developing a competency to allow the empirically driven refinements of systems integration simulations, operations, and controls to inform future energy system architecture, policy, and investments. These tools, along with a commitment to understanding integration at any scale, **will allow NREL to shape the energy system of the future.**

The 182,500 sf facility's architectural significance is represented by a first-of-its-kind design and unique merging of three distinct and very specialized components. A ultra-green workplace, a high performance computing data center, and 14 highly sophisticated high-bay laboratory spaces with outdoor test areas all work in tandem to advance NREL's sustainable mission. To construct such a unique facility the design build team, which was charged to meet or exceed the client's goals for energy performance, applied technology to deliver the project in a highly collaborative and accelerated pace while maintaining the strictest standards of quality and safety.

Home to 200 scientists and engineers, the ESIF 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 is built in accordance with the U.S. Green Buildings Council's standards and achieved LEED Platinum Certification.

For the ESIF project, DOE/NREL employed a performance-based design-build process. In this methodology, the owner does not rely on plans and specifications to describe the scope of the project. Instead, the owner focuses on the problem(s) to be solved, the targets to be met, and leaves the solutions to the design-build team to work out. This delivery method allocates control and accountability differently - in that the owner sets a firm price for the project, establishes program and performance requirements, prioritizes these requirements in a request for proposals (RFP), and then invites design-build teams to propose innovative solutions that best achieve the prioritized requirements.

Project Goals:

Advance data center design and energy efficiency through state of the art technologies that will serve as a valuable example that could be replicated.

- ✔ The HPCDC contains a petaflop scale supercomputer capable of large-scale modeling and simulation. Not only is it one of the fastest computing system dedicated to renewable energy technologies in the world, it is also one of the most energy efficient data centers in the world.

Achieve an annualized Power Use Effectiveness (PUE) of 1.06 or lower and an annualized Energy Use Effectiveness (EUE) of 0.9 or lower for the HPCDC.

- ✔ The HPCDC operates a projected 1.06 Power Use Effectiveness (PUE), making it one of the most energy efficient data centers in the world.

Provide offices and shared common spaces for a minimum of 200 constant staff. Conference rooms, visualization centers, interaction areas and guest offices will facilitate collaboration between NREL's private, academic and public sector partners.

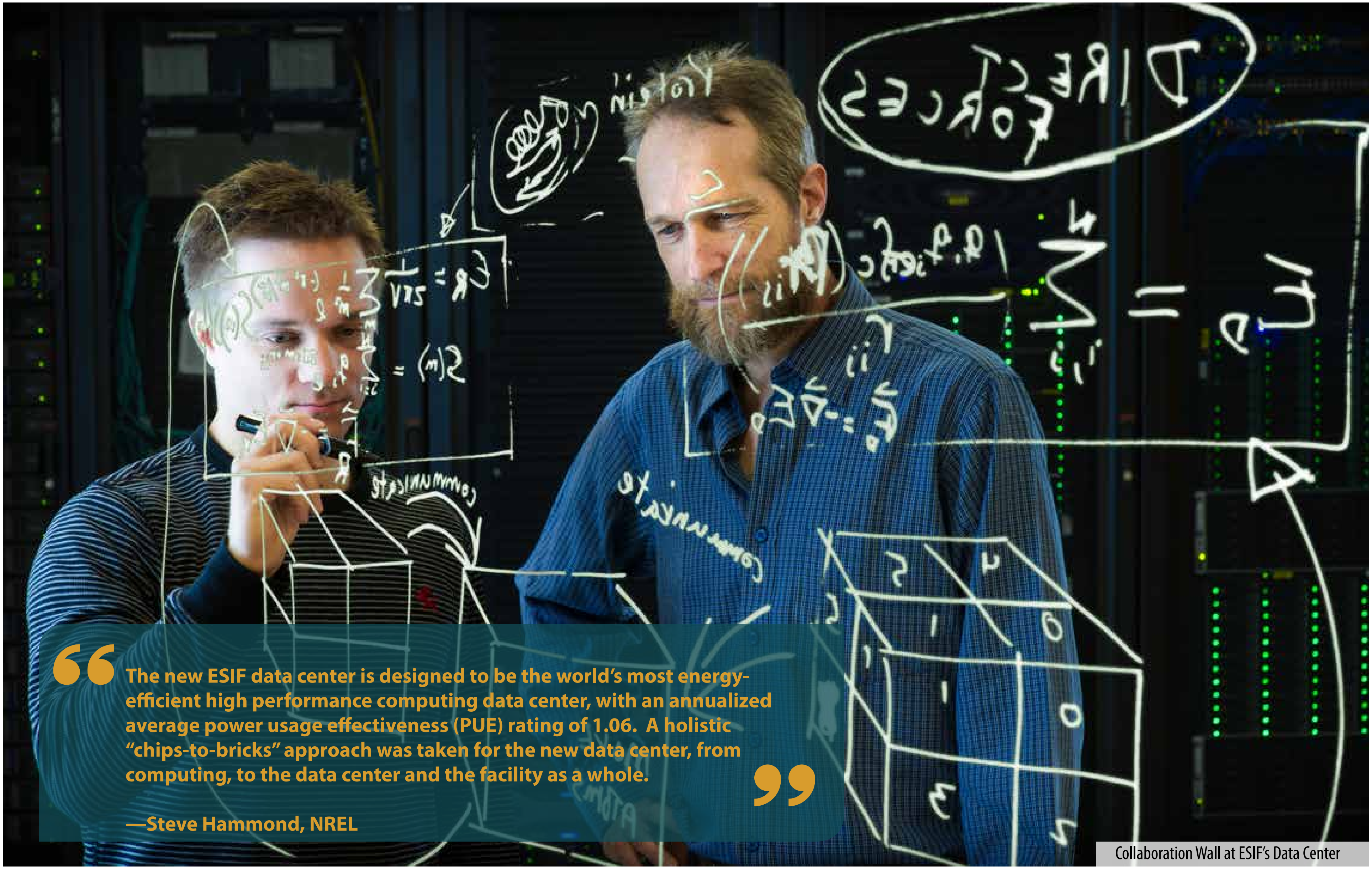
- ✔ The ESIF creates a one of a kind magnet for international talent and industry collaboration

Achieve an energy target of 25 kBtu/sf/year for the office environment.

- ✔ The office environment consumes 74% less energy than the national average for office buildings at 23.0 kBTU/sf/yr.

Accommodate tour groups but not impact research.

- ✔ The tour route was elevated above the laboratories—to ensure minimal disturbance—and views down were coordinated with overhead lab services, ductwork and unistrut systems to maintain lines of sight.



> **“The new ESIF data center is designed to be the world’s most energy-efficient high performance computing data center, with an annualized average power usage effectiveness (PUE) rating of 1.06. A holistic “chips-to-bricks” approach was taken for the new data center, from computing, to the data center and the facility as a whole.”**
>
> **—Steve Hammond, NREL**

Collaboration Wall at ESIF’s Data Center

The Right Time – Why Energy Systems Integration?

Urbanization, modernization, and economics are placing ever-increasing demands on systems around the world to squeeze more out of less. Energy systems have evolved from small, local, single-service systems (e.g., the steam engines that powered the Industrial Revolution) into highly integrated, continental systems that deliver energy services through renewable, nuclear, and fossil sources but also electrical, thermal, and fuel pathways that convert and deliver energy to our homes and businesses. The complexity of the system is also increasing with the integration between other systems—such as data and information networks and water systems—that traditionally have not been linked with energy.

The challenge continues as building large-scale infrastructure (e.g., high-voltage transmission) is increasingly difficult in many parts of the world, and technology improvements are simultaneously driving growth in local generation. Furthermore, existing energy systems, which are typically capital-intensive and designed to last decades, are suffering from aging infrastructure and costly upgrades. **In fact, the International Energy Agency's World Energy Outlook 2011 predicts that $35 trillion will be invested in energy infrastructure over the next 25 years.** This astounding number proves the need to optimally integrate and control these resources across multiple scales—from the local level to the global energy system—in order to diminish the significant dangers of under- or over-investing based on weak assumptions and increased uncertainty.

Amidst all the advancements and complexities, the current energy system is still required to, at a minimum, maintain current levels of efficiency, resiliency, and sustainability and this is becoming increasingly harder to manage. **For example, in the United States alone, more than one-half of the energy generated is wasted by inefficient systems.** As the intricacy of the energy system increases, the challenges of maintaining stable, reliable, and economic operation become more difficult.

The ongoing transformation of the global energy system poses fundamental challenges to the creation of robust energy systems. **Meeting the growing demand for energy is one of the most complex and challenging issues of our time.**

ESIF's Outdoor Test Area. Partnership with Toyota

Without an all-inclusive approach to this comprehensive problem, there is significant danger that local optimizations may produce a solution that is far from a global or societal optimum. Conversely, universal optimization may lead to a “brittle” solution that risks reliability or security. Further, a sense of urgency must be maintained as transformation continues, and piecemeal changes may be difficult to reverse once established.

Opportunities exist to capture co-benefits and improve the overall efficiency of our energy system. Through a more holistic approach, efficiency can be increased using technologies such as combined heat and power and waste heat utilization. Properly designed improvements can also enhance reliability, security, and flexibility. **Enter the National Renewable Energy Laboratory’s Energy Systems Integration (ESI) initiative.**

ESIF Continues NREL’s Research on Parabolic Trough Solar Collectors

Gas Manifold Corridor for Cell Testing in ESIF’s Fuel Cell Test and Development Lab

ESIF Conducts Research at the National Wind Technology Center

> "ESIF is a dynamic facility with many mission critical functions including high bay labs capable of utility scale research, a high-performance computer and datacenter as well as an office wing for 200 researchers"
>
> —Drew Detamore, NREL

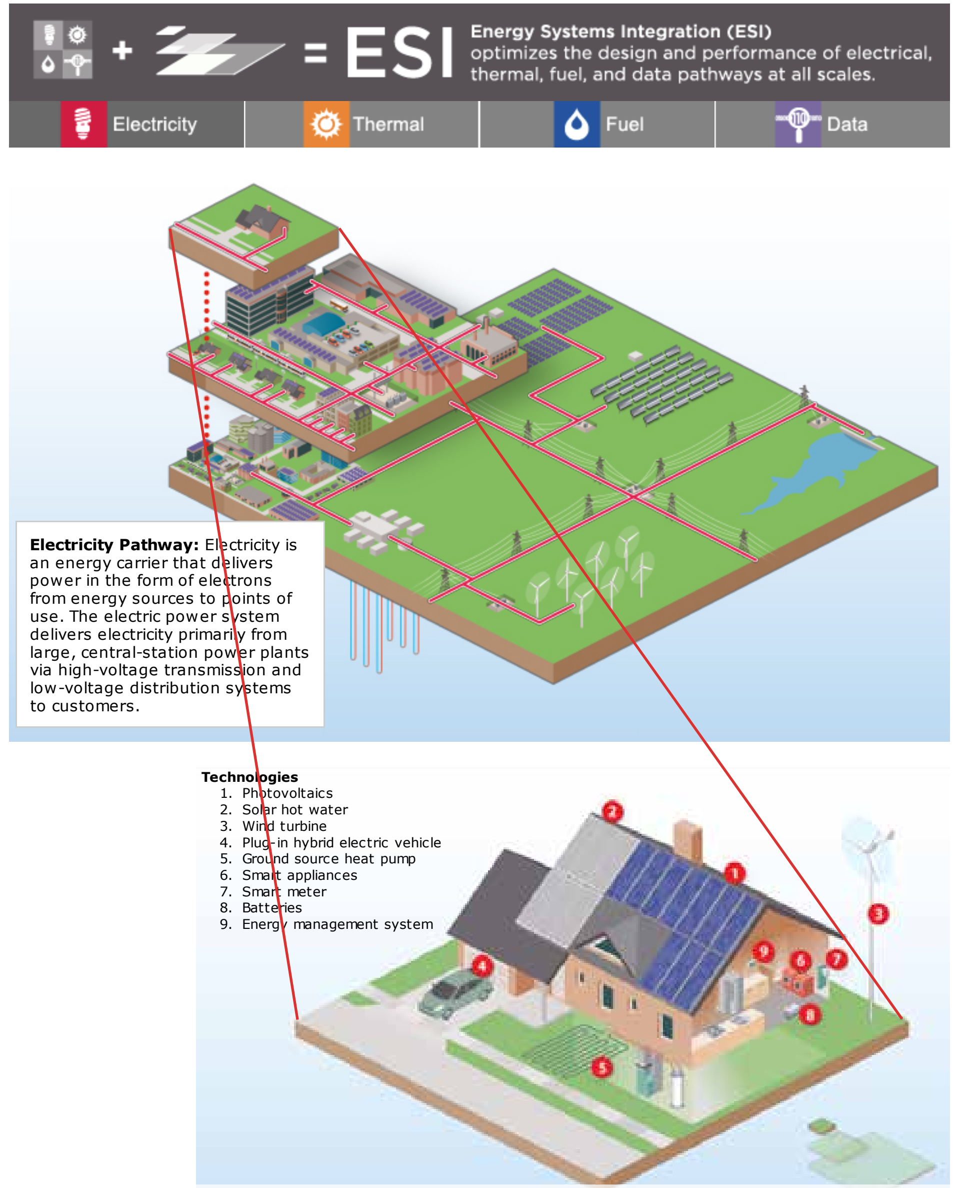
Industry Partnerships at ESIF's Energy Storage Laboratory

The Right Tool – What is Energy Systems Integration?

ESI optimizes the design and performance of electrical, thermal, and fuel systems at different but interrelated scales, ranging from individual homes and businesses to communities and cities to regional and national infrastructures. NREL's approach builds on research in the integration of complex "systems of systems" to design energy structures that are optimized at smaller levels and can be aggregated to improve energy pathways at any scale. This focus will allow NREL to better understand and make use of potential co-benefits that increase energy reliability and performance, reduce cost, and minimize environmental impacts.

NREL and its partners recognize the growing importance of ESI as a critical multidisciplinary, multifaceted research and development area that will underpin the energy system of the future. **This requires tapping newly developed integration facilities, such as NREL's Energy Systems Integration Facility** (ESIF) located in Golden, Colorado, that combine hardware testing at proper scale with simulation environments that can link the energy pathways. Through the ESIF, NREL is developing a competency to allow the empirically driven refinements of systems integration simulations, operations, and controls to inform future energy system architecture, policy, and investments. This facility and the tools it houses, along with a commitment to understanding integration at any scale, **will allow NREL and its partners to shape the energy system of the future.**

Research capabilities at the 182,500 sf ESIF provide a holistic view of the electric power system through hardware-in-the-loop testing at the low- to megawatt-scale power capability giving NREL, and its partners, the opportunity to evaluate how technologies will work together in a real world environment. This one-of-a-kind mega-watt scale testing will be done through the facility's unique capabilities, advanced laboratories and NREL's strategic partnerships.



Education and Outreach for ESIF from NREL/Department of Energy

Unique Capabilities

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

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 Supervisory Control and Data Acquisition (SCADA) system, and petascale computing, the ESIF allows researchers and NREL partners to visualize complex systems simulations and operations in a completely virtual environment.

ESIF's Super Computer, "The Peregrine"

High Performance Computing Data Center (HPCDC)

In addition to high-tech collaboration and visualization rooms, the ESIF includes 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 petaflop scale system 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 one of the fastest computing systems dedicated to energy efficiency and renewable energy technologies in the world, it is also one of the most energy efficient data centers in the world, operating at a power usage effectiveness (PUE) rating of 1.06 or better.

Research Electrical Distribution Bus (REDB) and SCADA systems

Integrated throughout the ESIF, the 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 the 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 altogether provide a variety of electricity, thermal power, and fuel type connections.

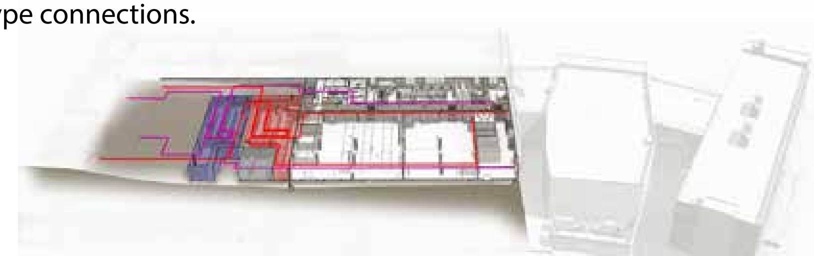


Diagram of the Research Electrical Distribution Bus

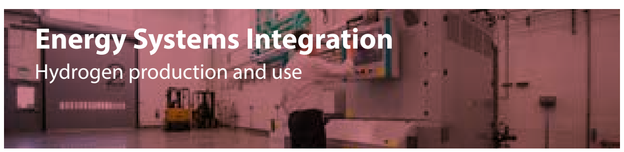
Electricity Laboratories


Power Systems Integration
Large-scale distributed energy systems


Smart Power
Smart technologies and energy management


Energy Storage
Integration of energy storage systems


Electrical Characterization
High voltage equipment testing


Energy Systems Integration
Hydrogen production and use

Thermal Laboratories


Thermal Systems
Utility scale thermal storage

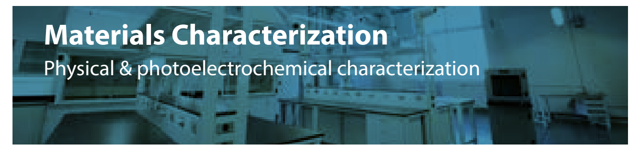

Thermal Storage Materials
Material transfer & storage

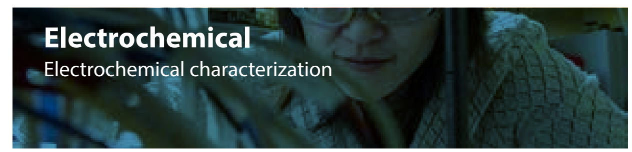

Optical Characterization and Thermal Systems
Solar concentration devices

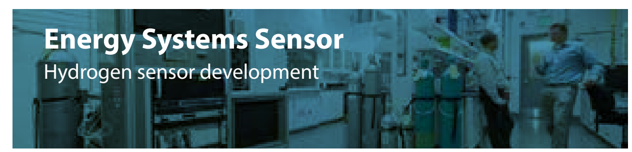
Fuel Laboratories


Energy Systems Fabrication
Fuel cell component manufacturing

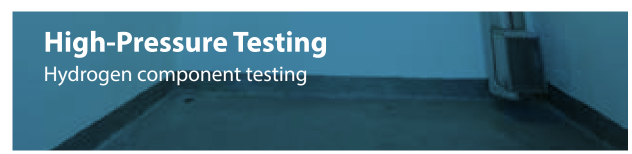

Manufacturing
Fuel cell component production


Materials Characterization
Physical & photoelectrochemical characterization


Electrochemical
Electrochemical characterization


Energy Systems Sensor
Hydrogen sensor development


Fuel Cell Development
In-situ fuel cell testing


High-Pressure Testing
Hydrogen component testing

Click Here to See Video Descriptions of ESIF's 15 One of a Kind Laboratories!

Partnerships

NREL recognizes the importance of working with a wide range of energy stakeholders that include, but are not limited to, utilities, system integrators, technology developers, state energy departments, state regulators, universities, standards organization certification labs, government agencies and other national laboratories. NREL developed the ESIF with those users in mind. Partners can come in and develop technologies in NREL's laboratories as multidisciplinary exerts work side-by-side. This allows for the validation of all technologies from concept to commercialization and reduces the risk of adoption. **There isn't another place in the country—or the world—to research system integration, plug it in and see if it works at a variety of scales.** This uniqueness will provide value to our society and advance industry and all aspects of the world's energy system.

The ESIF is not intended to be a facility in isolation. The research happening within is much more effective with external stakeholders and other laboratories, universities, industries, and utilities, all working together. For example NREL is now collaborating with Toyota Motor Engineering & Manufacturing to find new and better ways to integrate into the power grid. Scientists and engineers at the ESIF and NREL's Vehicle Testing and Integration Facility are using 20 Toyota Prius plug-in hybrid electric vehicles (PHEVs) to develop and explore ways to prepare grid operators and energy infrastructure to accommodate the growing U.S. electric vehicle fleet. Toyota has relocated the PHEVs to the ESIF's Medium Voltage Outdoor Test Area (MVOTA), which provides easy interconnection and testing alternatives for grid integration hardware. The project will provide confirmation on the levels at which vehicle loads become significant to distribution grid power quality challenges and will lead to foundational strategies for monitoring and control throughout the grid.

As a high profile facility of national importance, the architecture of the ESIF expresses leadership in the development of renewable and integrated energy systems. It is a living/working laboratory of the technological development which it houses. In order to design and construct the nation's first facility of this type it took an integrated design build team who understood the advanced and unique nature of the science happening within and who would deliver the project at a highly collaborative and accelerated pace while maintaining the strictest standards of quality, safety and energy efficiency.

President of Iceland and Foreign Dignitaries

> **The SmithGroupJJR design team was able to effectively work with facility users to refine the program requirements and in many cases exceeded our expectations. Overall, the project met the schedule milestones established at award.**
>
> **—Brian Larsen, NREL**

Entry View from NREL's Adjacent Research Support Facility

Design Overview

Charged with addressing the twin challenges of an aging energy grid and increasing consumer demand for renewable energy, NREL tasked the design build team of JE Dunn and SmithGroupJJR to create a facility to test and deploy next-generation technologies and advancements in power production and electrical infrastructure. And since the goal is sustainability for the nation's energy supply—research, development and megawatt-scale testing of transmission and distribution-level components for future supply and demand systems—plans for the ESIF needed to integrate clean and sustainable energy sources and management. The facility must lead by example. To do this, the design build team collaborated with NREL to bring their vision to life.

ESIF is Designed to Accommodate Daily Tours of 20–30 Guests

Aerial View of ESIF and NREL's Growing Research Campus

The 182,500sf facility's architectural significance is represented by a first-of-its-kind design and unique merging of three distinct and very specialized components. An ultra-green workplace, a high performance computing data center, and 14 highly sophisticated high-bay laboratory spaces with outdoor test areas all work in tandem to advance NREL's sustainable mission. To construct such a unique facility the design build team applied technology to deliver the project in a highly collaborative and accelerated pace while maintaining the strictest standards of quality and safety.

Home to 200 scientists and engineers, the ESIF 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 is built in accordance with the U.S. Green Buildings Council's standards and achieved LEED Platinum Certification.

Challenging Site and Topography:

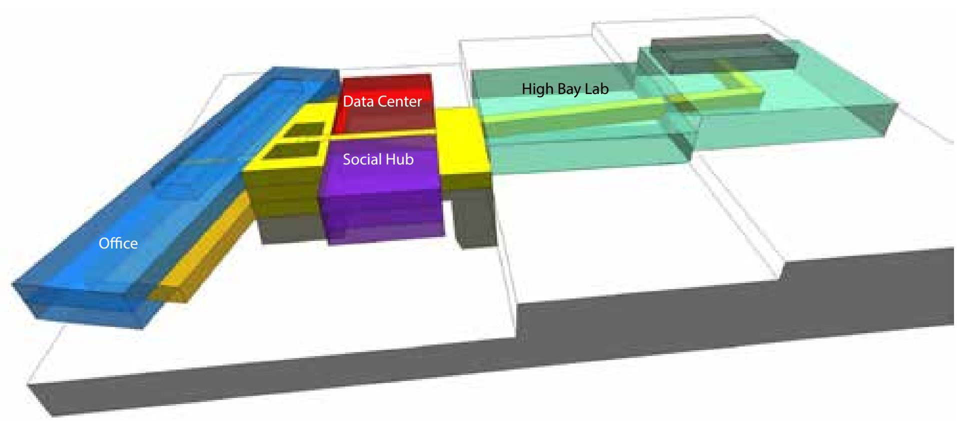
The specific site for ESIF is 4.2 acres and is bound on the east by the natural arroyo and it's 75' setback to preserve natural habitat environment. Two access drives bound the site on the south and west, while the steep slope of the Front Range of the Rocky Mountain South Table Mountain offers a difficult topography in which to build a large facility, which also requires large outdoor test areas. The 45 foot elevation change from north to south created a challenging design opportunity in terms of flexibility, accessibility and balancing functionality of the facility with the cost of excavation.

The design solution optimizes these constraints to create an intuitive and legible circulation and way finding system throughout this complex facility. The stacking of the interior program and the site are perfectly melded to step up the site three times (16' each). This provides direct access to the interior research spaces at each level, allows research activities to flow outdoors and provides service access for the movement of large equipment.

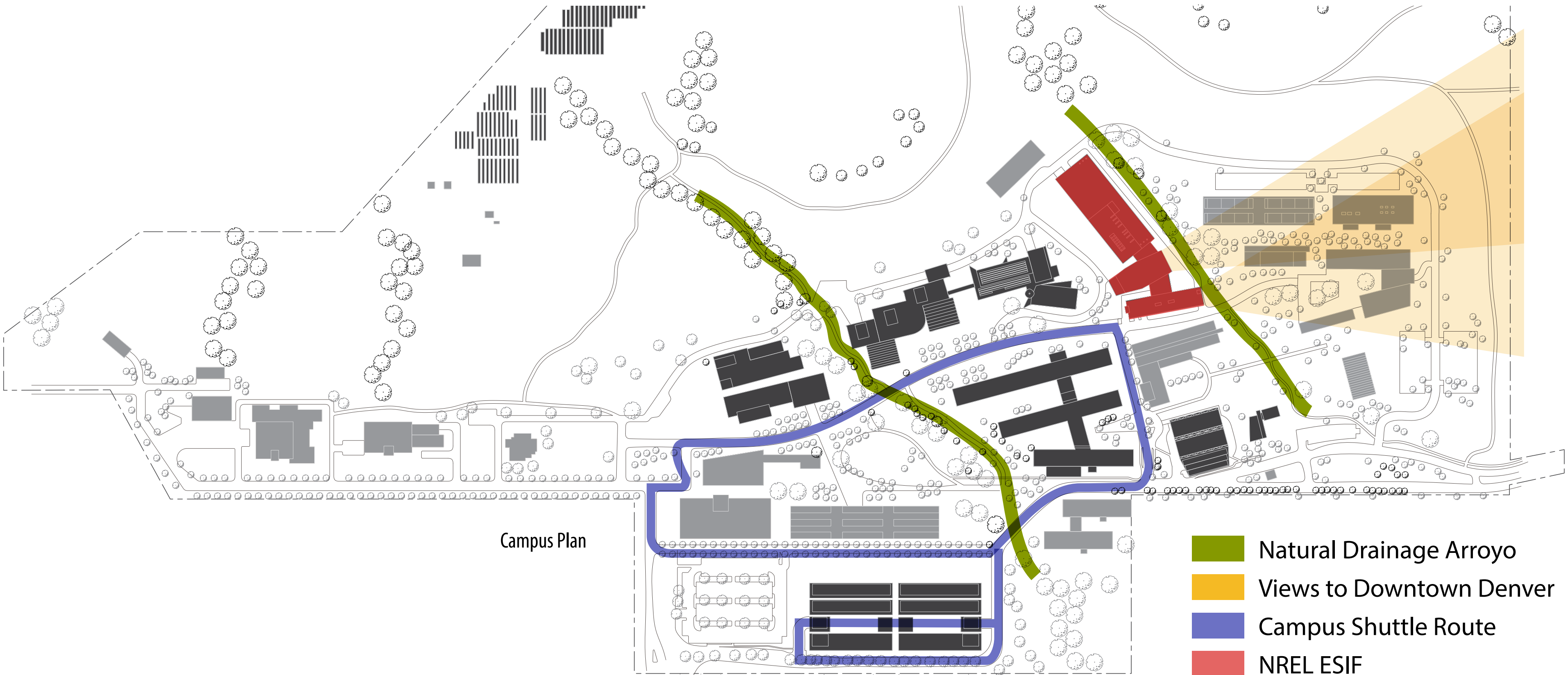
The site presented a challenge from the beginning as it was constrained on all sides by a protected arroyo, the Rocky Mountains, and the NREL campus. However, the design of the ESIF celebrates the natural beauty of its surroundings. Visual and physical connectivity to the outdoors was a primary driver in the design and all common vertical circulation, conferencing and break rooms, and balconies are east facing to frame the views of the natural arroyo and downtown Denver.

Not only is ESIF one of the most sustainable research facilities in the world, but its ground breaking research is highly visible nationally and internationally with significant demand for tours from the public and private industry. An elevated tour corridor allows visitors a safe bird's eye view of the laboratories, while offering researchers 24/7 operation and separation from disturbances. The design strategically highlights the data center and its associated systems, provides visual access to the office, and creates gallery space in the lobby for NREL to showcase its research.

Campus Master Plan



Planning/Stacking Diagram



Campus Plan

View from ESIF to Downtown Denver

Habitat Preservation at ESIF

NREL's Pedestrian Oriented Campus

Part of the Family. Example for Future Generations:

The overall NREL campus is comprised of a variety of material types but there is an overlying unity to its architecture based on the master plan. The ESIF blends seamlessly into the NREL campus vocabulary while simultaneously elevating NREL's architectural brand and energy mission through a strategic integration of appropriate sustainable strategies with high quality and low maintenance products.

The project's energy goals required the design build team to re-think conventional construction and engineering paradigms, while eloquently placing this significant structure into the campus context. From a materiality standpoint, the team looked to embrace and advance many of the campus' existing materials while utilizing the highest performing exterior envelope assemblies possible.

The project is a one-of-a-kind, futuristic mixture of an ultra-green workplace, energy efficient high performance data center, and experimental energy laboratories. Each of the three elements received its own identity and presence within the design whole. The design is fully borne out of the specific functionality of its internal program. Clearly delineated in the massing of the facility is each of the major project components: the high-bay, the data center, the office; all functioning independently and as part of the whole facility. These elements are not embellished; they are a direct representation of their function and purpose.

The office block is the front door and public face of the facility, while the data center and social hubs are centrally located both functionally and within the infrastructure. The high bay laboratory spaces are farthest away from the office and social spaces to maintain safety and effectively contribute to the ESIF's overall sustainability mission.

The office portion is defined by a cantilevered two story metal-clad structure that creates the main entry atrium. The design of the structure addresses stringent setback requirements and eliminated impact on the arroyo by floating above it. The office is clad with metal panels, which reflect the architectural theme on campus, with a pre-cast concrete base. Horizontal and vertical shading elements balance solar gain with day lighting goals. The main entry acts as a knuckle that links the office to the data center portion of the ESIF.

The data center is clad in a darker articulated metal panel than the office to differentiate it, while preserving campus continuity. The data center is strategically fused to the "Insight Center," which is where researchers and partners can visualize experiments being performed in the labs. Another 'knuckle' with restrooms, vertical circulation and causal interaction space, attaches the data center to the large pre-cast concrete clad high bay laboratory spaces.

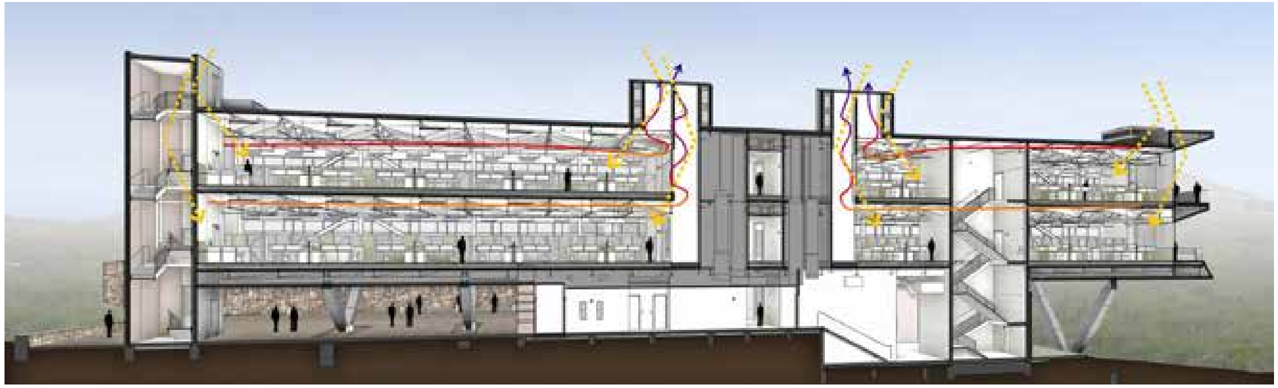
Holistic Systems Design and the Highly Calibrated Envelope:

Appropriate Solar Orientation, Access to Views, Daylight Harvesting and Natural Ventilation

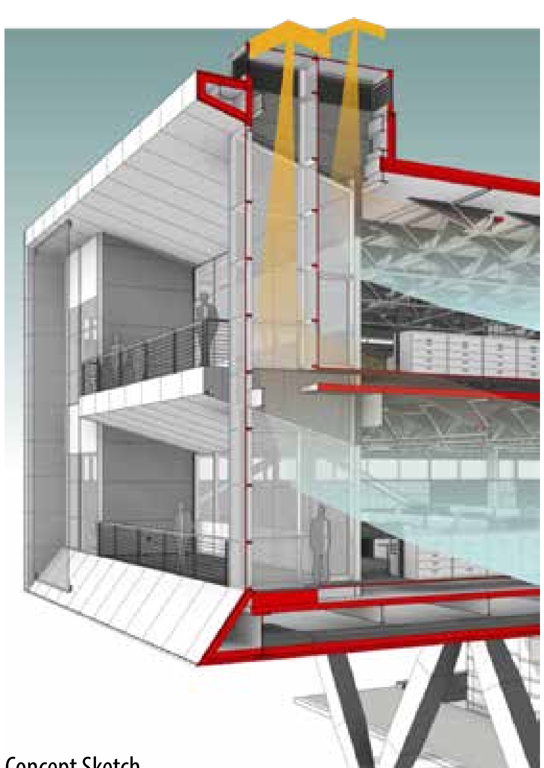
These critical strategies are intertwined and dependent on each other at multiple levels. The site planning strategy balances each of these strategies with the primary axis for the office and HPCDC/social hub being east-west. Each of the three main programmatic volumes is also separate from each other in order to provide day lighting, views and opportunity for natural ventilation for each and every space. The narrow depth of the office maximizes daylight penetration and access to views.

Daylight & Convection Shafts

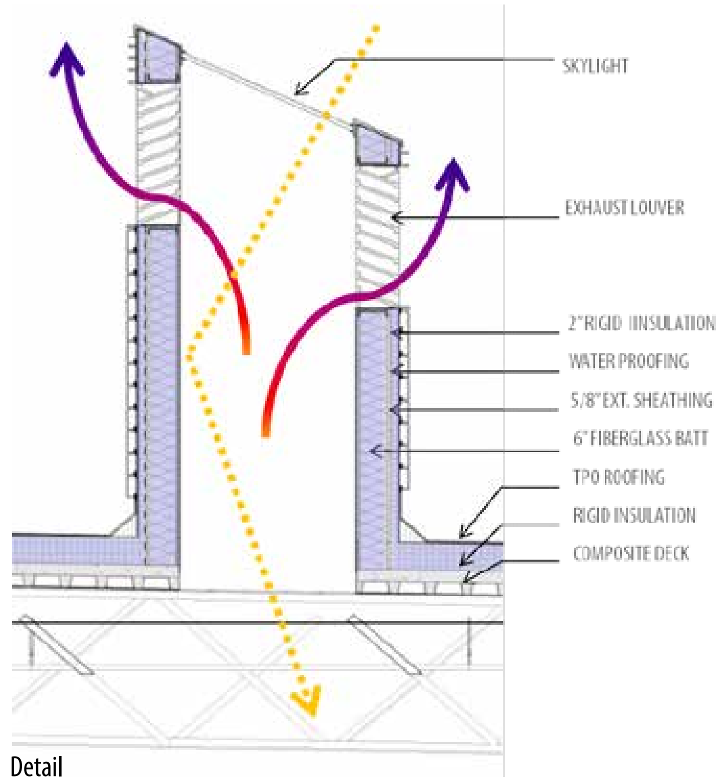
Four two-story shafts skim heat loads from the two levels of office space while harvesting diffuse daylight simultaneously. Solar powered exhaust fans assist natural convective stack effect reducing the overall load on the mechanical system.



Office Cross Section. Daylight and Convection Shafts



Concept Sketch



Detail

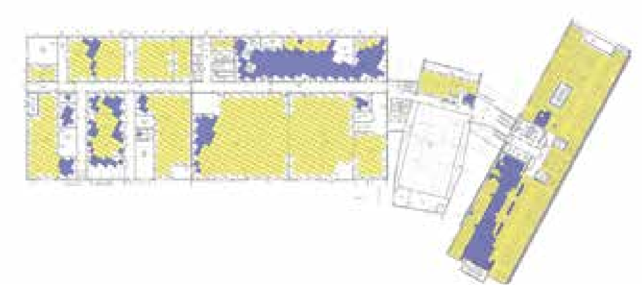
Holistic Systems Design and the Highly Calibrated Envelope:

Super-Insulated Rain Screen Roof / Wall System

R-20 wall and R-40 roof insulation were provided to minimize heat transfer and thermal bridging while the insulation was installed outboard of the vapor barrier. Supporting members and fasteners were mocked up to substantiate performance of the proposed system during construction.

Passive and Active Shading and Daylight Strategies Intertwined

While glazing configuration, sizing and locations balance solar gain, daylighting and views, additionally numerous shading and daylighting elements supplement these passive strategies. Horizontal shading louvers block overhead southern sun, while perforated vertical fins block morning and afternoon exposure. On the eastern facades, stainless steel mesh 'curtains' are hung to allow for views while blocking more than 50% of all solar exposure.



Daylighting Design Allows Lights to be Off From 10am to 2pm Daily

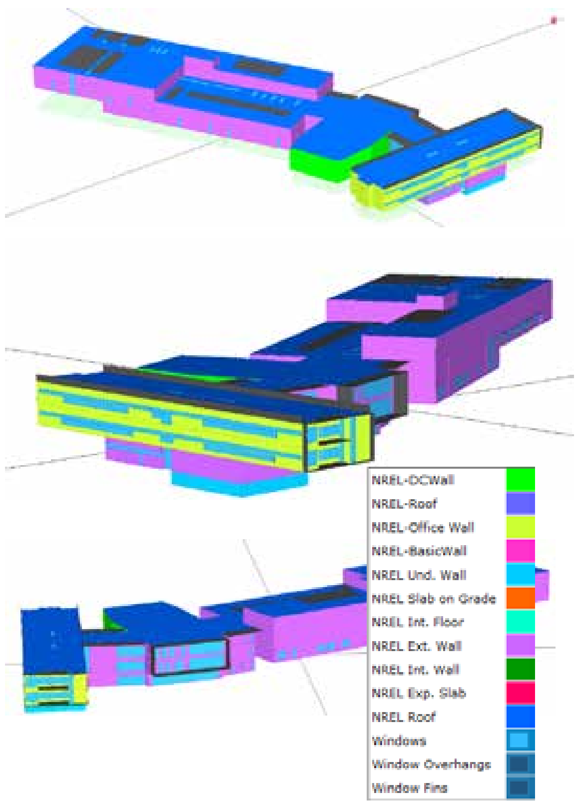
Exterior Active Shading Elements at Office Building

Exterior Active Shading Elements at High Bay Laboratory

Stainless Steel Mesh 'Curtains' at Social Hub

Uber-Collaborative Process

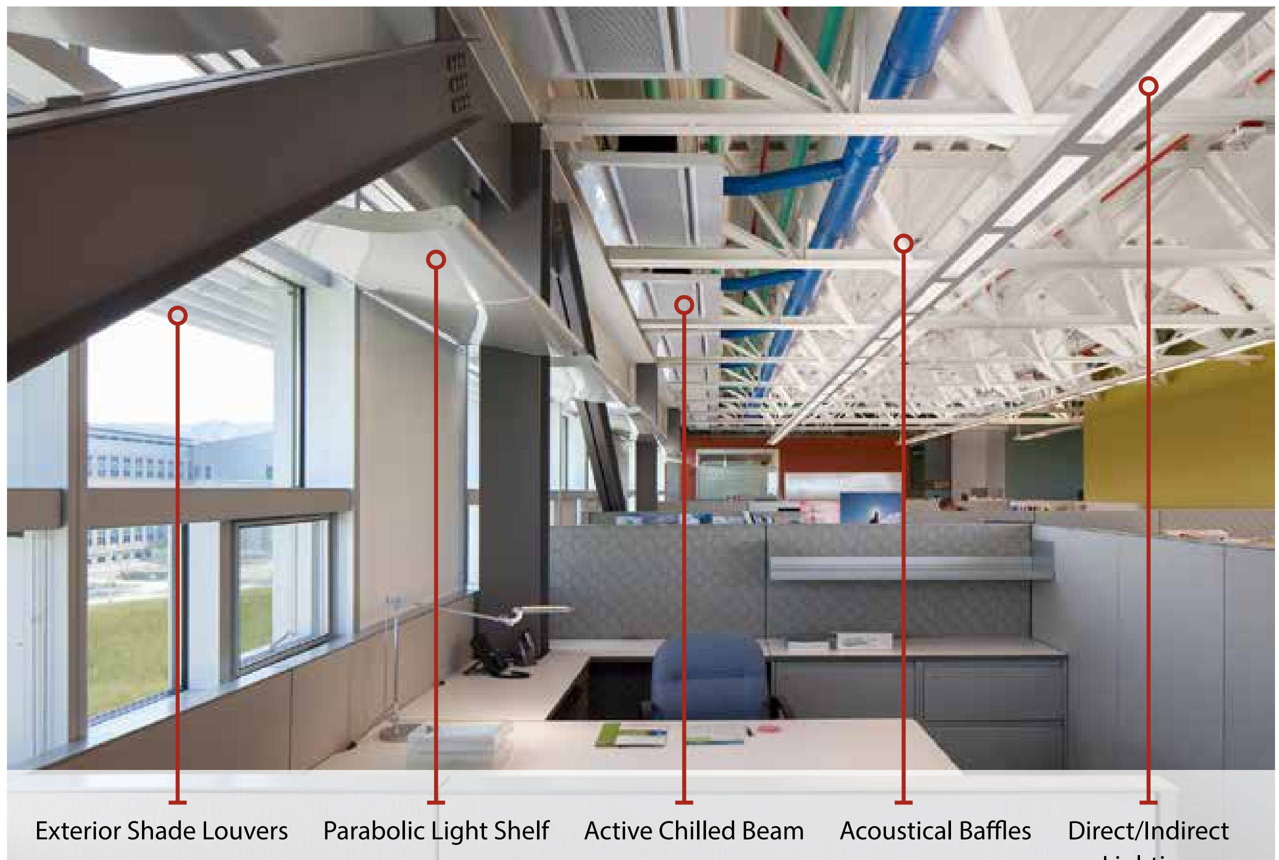
The 25 kBtu/sf energy requirement for the office required a highly collaborative and iterative design process. The ratio of wall to window as well as the location, size and distribution of fenestration was determined by the team after numerous simulations and iterations.



Energy Modeling Iterations

Integrated Parabolic Light Shelf with Light Bouncing Acoustical Baffles

Internal parabolic light shelves are installed between vision glazing and high clerestory glazing, 'throwing' light deep into the floor plates. These elements are designed to be removable as new products become available and that NREL will do testing on. The light shelves are coupled with a poetically composed acoustical baffle system that is suspended from steel trusses. This double strategy allows the spaces to be acoustically designed to meet the client's criteria while amplifying daylighting distribution and quality to the work surface.



Open Office Environment

Innovative Use of Glazing Technology

Four different glass types in different areas of the office with highly calibrated specifications maximize views and daylight harvesting while mitigating glare. These glass types were evaluated for their light transmission, shading coefficient, and U-value. The south facade vision glazing is a Low-E vision glass with 63% transmittance, while the south clerestory glazing is maximized in area but treated with switchable electro chromatic glass giving staff the ability to 'black it out' manually at certain times of the year or day. On the north facade where access to ambient daylighting is highest, insulated glass panels with 83% transmittance is installed to capture the highest light levels from that direction. Vision glazing on the north facades received low-E glazing with 63% transmittance. This effort was aimed at increasing staff satisfaction while driving down demand for artificial lighting. ESIF is designed to have the lights off from 10am to 2pm each day.

Entry Canyon and Breezeway

North Facing Glazing at Office Building

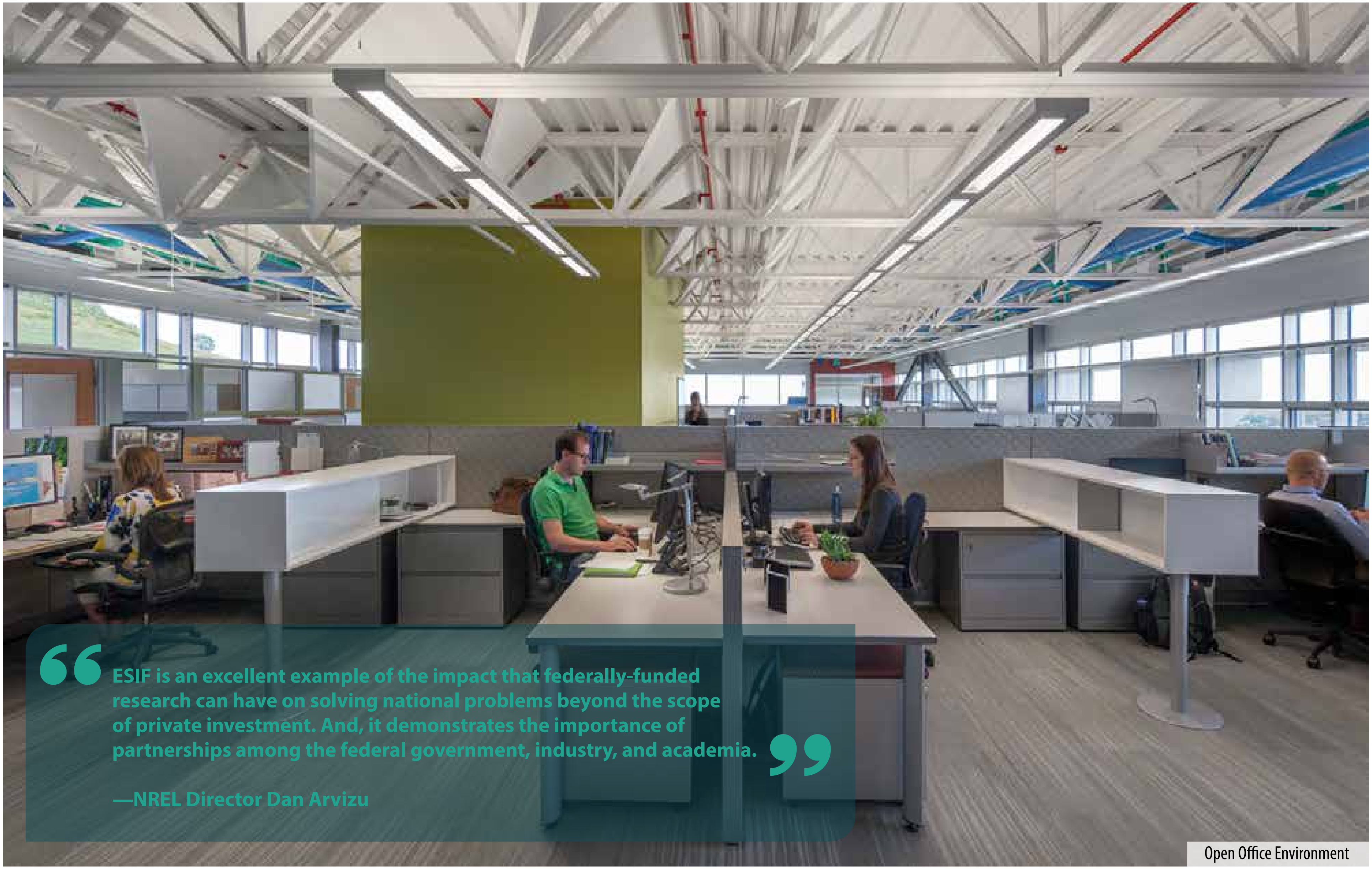
Daylight and Views to Arroyo from High Bay Laboratory

Four Glazing Types- Office Building	
South Office Vision	62% Transmission (Anti-Glare Coating)
South Office Clerestory	Switchable Electrochromatic
North Office Vision	62% Transmission
North Office Clerestory	83% Transmission

"It was a challenge from the start to not only make the facility energy efficient, but to go beyond everyone's expectations and achieve LEED® Platinum."

—Drew Detamore, NREL's deputy director of SITE Operations

ESIF's Office Building



"ESIF is an excellent example of the impact that federally-funded research can have on solving national problems beyond the scope of private investment. And, it demonstrates the importance of partnerships among the federal government, industry, and academia."

—NREL Director Dan Arvizu

Open Office Environment

NREL | ENERGY SYSTEMS INTEGRATION FACILITY

U.S. DEPARTMENT OF ENERGY

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, 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 and Thermal Systems
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

Laboratory Planning:

The planning for the ESIF laboratories began as an internal discussion with NREL personnel. This dialogue reviewed the mission needs statement and the 13 competencies that the facility must be able to accommodate. The 13 competencies are:

1. Renewable resource characterization
2. Renewable systems operations and analysis support
3. Integrated testing and field validation of components
4. Simulation and development of system controls
5. Analyzing storage systems
6. Advanced energy computing capability
7. Renewable electricity production and hydrogen synergies
8. Buildings system integration
9. Market and integration analysis
10. Economic validation
11. Market competitiveness of zero energy buildings
12. Codes and standards
13. Combined heat and power

Approximately six months were spent examining these competencies and identifying the specific activities and tasks associated with each based on a bottoms-up approach. As an example, Renewable Systems Operations and Analysis Support, was broken into several activities. One, for example, was to analyze distributed renewable energy systems. Each activity was broken down into specific tasks. So for this example, the tasks included collecting renewable systems performance data and optimizing renewable system technoeconomic operations. By breaking each competency into specific activities and tasks, the requirements for space, equipment, and staff were determined at the lowest level. This methodology was conducted for all **13 competencies and resulted in a total of 48 activities and 118 tasks.** This information led to the development of 15 unique laboratories across three main research categories, which are electrical, thermal and fuel.

Tour Route

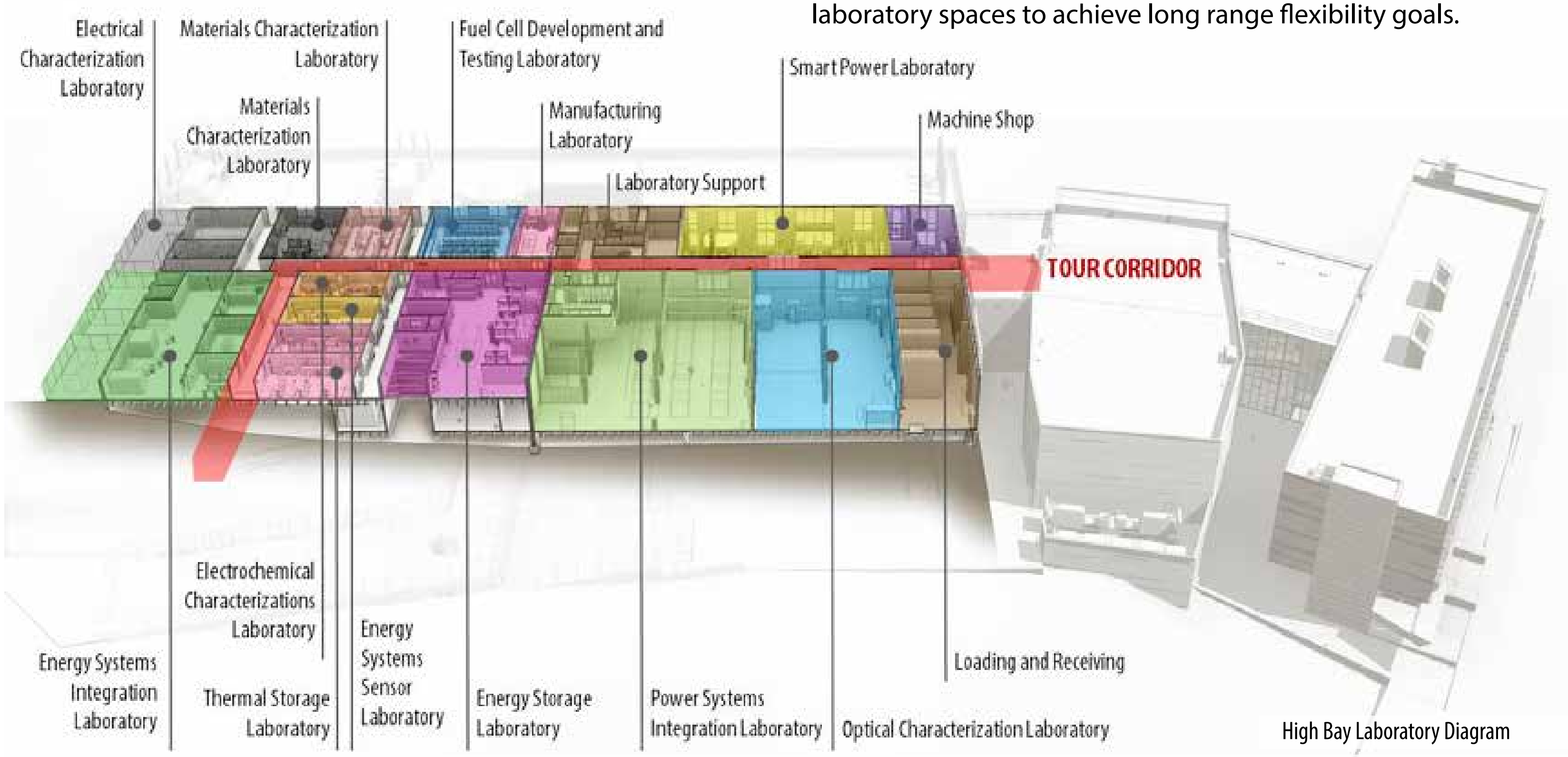
The following aspects drove the specific arrangement of research spaces along the laboratory block:

- hazard level
- chemical quantities
- hydrogen availability
- research type
- required adjacencies
- site conditions
- truck access
- special equipment
- high bay volume
- exterior test areas

The culture at NREL is that they only spend the time in the laboratory that is necessary and work from their office when able. To maximize safety within the facility, the high-hazard laboratories were carefully planned furthest away the office, data center and collaboration areas. Those laboratories containing higher chemical quantities were grouped together on level three at the far end of the site with lower quantities on level two more adjacent to other building areas. Lab areas requiring central hydrogen gas were arranged near the hydrogen production laboratory and storage area to reduce distribution length and hazard exposure. Appropriate placement of each research laboratory type within this organizational overlay required evaluation of individual hazard levels and accommodation of the required adjacencies (both internal and external). The 45 foot slope and available access points of the site required the design build team to intentionally locate elements along the grade. Locations of high bay laboratories, exterior test areas and spaces requiring direct 18-wheel truck access were specifically selected to accommodate site typography and align with other objectives.

Woven throughout the lab areas is the tour corridor, which gives visitors a glimpse into laboratory areas from a safe vantage point. Providing the best possible experience for guests and research personnel required careful integration of facility requirements with viewing needs. To avoid interference with research, the tour route was elevated above the laboratories. Views from the tour corridor down into the laboratory spaces were coordinated with overhead lab services, ductwork and unistrut systems to ensure that lines of sight were maintained. In instances where privacy was required, moveable systems for shielding views are provided. The resulting space offers direct views of the science and provides the necessary separation to ensure safety and uninterrupted research.

NREL closely collaborates with industry on technologies that not only benefit these partners but the entire United States as well. The notion that research conducted at the ESIF would change over time was a driving force behind the nature of the laboratory spaces. For example, utilization of the planning module allows for easier space reallocation over time. Moveable casework systems provide the ability to quickly adapt laboratories to meet changing requirements. Upgrading structural systems in select areas provides the ability to add floors in the future to spaces currently utilized as high bay. Careful placement of utilities and other fixed equipment removes potential barriers to change and provides a framework appropriate for conducting research that has yet to be considered. Providing non-circulation service corridors to support high chemical laboratories enables laboratory spaces to achieve long range flexibility goals.



High Bay Laboratory Diagram

Safety:

The safety philosophy for the ESIF is based upon evaluating leading indicators as opposed to lagging indicators. The safety strategy started over a year prior to the start of construction. The design build team endeavored to incorporate many elements of Safety by Design and the CDC's Prevention Through Design into multiple aspects of the building design, construction and operation. From placement of the program components based on hazard, to inclusion of built-in safety elements like continuous parapets and fall protection devices, to secure, flexible components like unistrut cast into all the precast roof double-tees. Safety started in design.

Lab Safety / Hazard Avoidance

NREL's passion for laboratory safety extends from the bench to the facility and the larger campus. Above and beyond the building codes and standards that a typical project must adhere to, the ESIF project was required to comply with **over 250 codes and standards that were specifically mandated to the design build team.** The compliance review team included numerous design build personnel, NREL Environmental Health & Safety personnel as well as third party oversight groups. The project underwent independent reviews for compliance with both International Building Codes and National Fire Protection Association codes and standards. Notes from these independent reviews were then evaluated as a group and the most stringent interpretations were then selected for facility design.

A comprehensive Fire/Life/Safety study was performed to identify conditions requiring specific attention. Acknowledged in the report were the types of materials to be used in the facility, storage and handling requirements, quantities, associated fire control systems and special hazards that are unique to NREL's facilities. This information was reviewed by facility and design build team personnel to determine specific hazard mitigation safeguards required to ensure that the science conducted inside the facility could be undertaken in the safest manner possible.

ESIF's Power Systems Integration Lab

The resulting hazard mitigation strategy is comprised of multiple layers of systems put in place to create a safe environment. Those include:

- Careful compartmentalization of material works to effectively limit the amount of chemicals exposed to any single fire event
- Utilization of service corridors for chemical transport and storage minimizes the possibility that a mishap will jeopardize facility occupant safety or egress
- Providing a second means of egress from laboratory helps building evacuation in the greatest range of events
- Self-imposed hazard occupancy and class 1 division 2 classifications provide an elevated level of protection at hydrogen production and component testing spaces
- Locating blast relief doors away from critical areas allows this vital protection system to function in the safest manner possible
- Providing the SCADA system overlay to all laboratory areas, which allows for central monitoring and control of events and serves as an early detection system for potential issues.

Construction Safety

Months before contractors came on board, a safety management plan was established so that a highly skilled safety consultant could help improve the safety program for the design and construction of the ESIF. The program informed employees of the Department of Energy's strict safety requirements, environmental regulations and quality expectations. The DOE and NREL expect their construction project teams to strive two levels above OSHA compliance, which they term as Superior Safety Performance.

In construction, the project's safety system was comprised of multiple administrative controls to prevent injuries. Contractors were selected based upon their safety program. Prior to being permitted to work on the project each day, each subcontractor was required to provide a detailed Plan of the Day (POD) and Activity Hazard Analysis (AHA). The superintendents and safety staff evaluated over 5,600 POD/AHAs during the project.

Of the 82 weekly safety audits conducted, the JE Dunn construction team achieved 32 superior safety ratings and 33 excellent safety ratings. No other project on NREL's campus has achieved more superior safety ratings then the ESIF project.

ESIF's Hydrogen Sensor Test Lab

The Design Incorporates Elements of Safety by Design and Prevention Through Design

Sustainable Design Intent and Innovation:

As a reflection of the groundbreaking research for which it supports, the ESIF building contains several one-of-a-kind innovative design strategies that take green research facilities to a whole new level. **This innovative facility houses some of the most advanced and unique technologies in the world and raises the bar for research facilities.** The ESIF incorporates the best in energy efficiency, environmental performance, and advanced controls using a "whole building" integrated design approach.

The High Performance Computing Data Center (HPCDC) contains a petaflop scale supercomputer capable of large-scale modeling and simulation. Not only will it be the fastest computing system dedicated to 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) of 1.06 or better and using 100% evaporative-based cooling, it features warm water liquid cooling and return water heat capture for re-use in the labs and office.

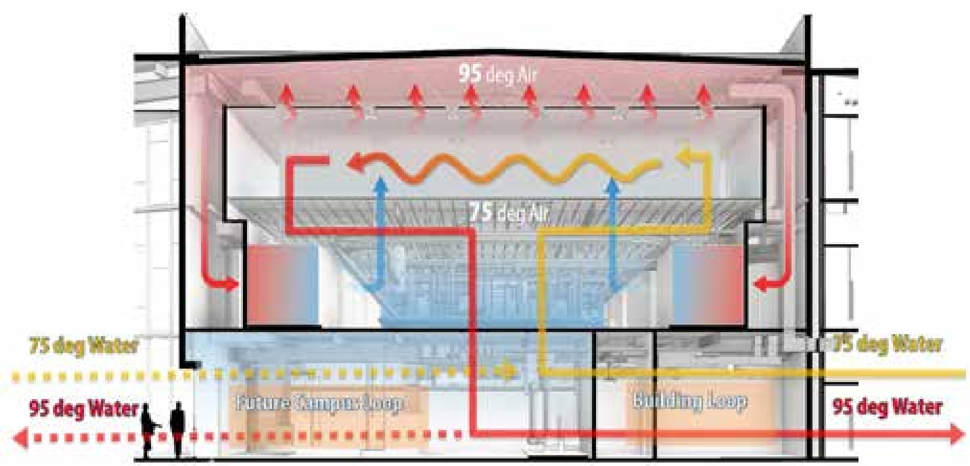
Energy Performance Achievements

Office Building- 26.7 kBtu/sg/yr- (23 achieved)

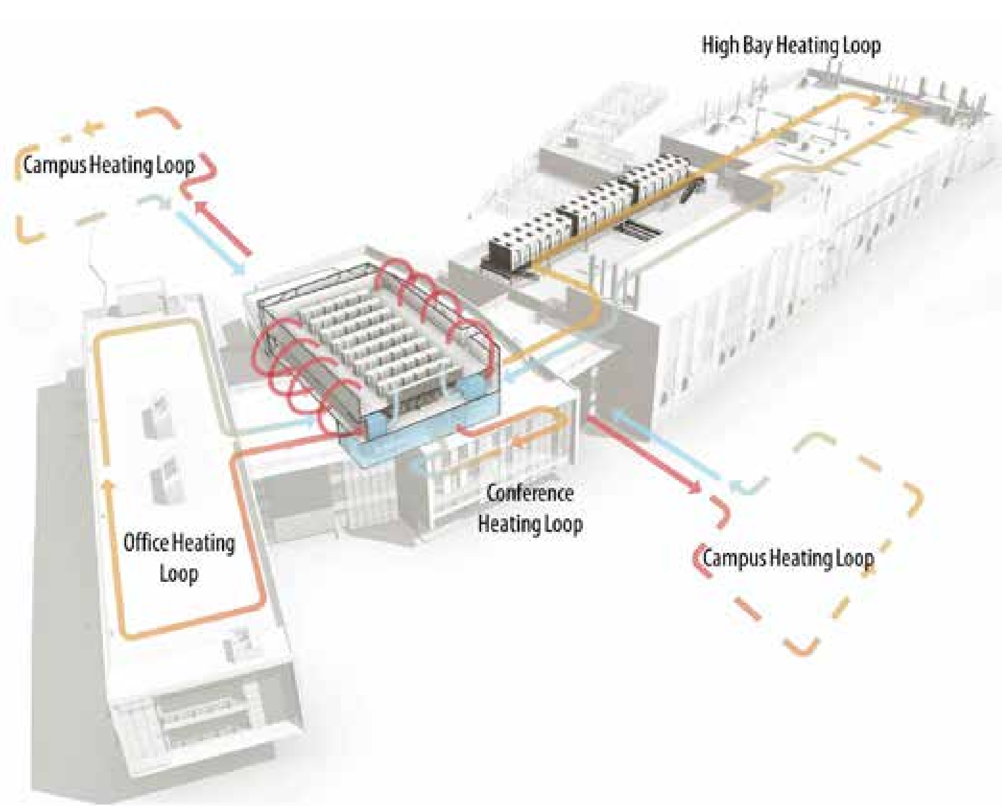
Data Center- (PUE) of 1.06 or less, (EUE) of 0.9 with a goal of 0.6

Lab Building- 30% lower than ASHRAE

LEED Platinum



Data Center Sectional and Waste Heat Diagram

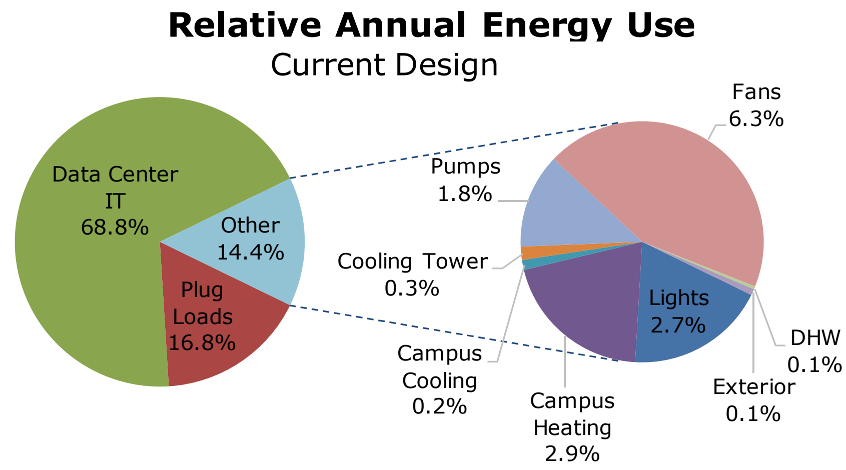


Waste Heat Diagram

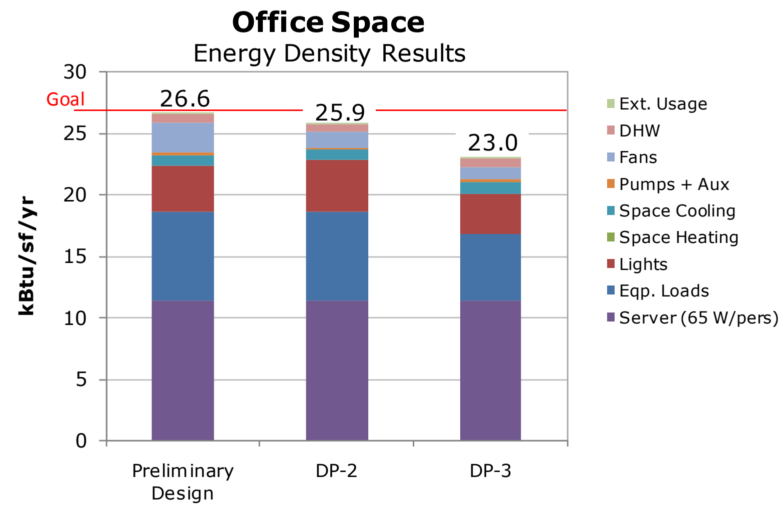
The office building boasts a highly calibrated envelope, daylighting harvesting and delivery devices, low velocity active chilled beams, and under floor air ventilation with operable windows and convection shafts. This results in staggeringly low energy consumption (EUI) of 23.0 kBTU/sf/yr, which is 74% below the national average for office buildings.

The laboratories are unique in their plug and play research capabilities. At the core of these capabilities is the Research Electrical Distribution Bus (REDB). The REDB is the ultimate power integration grid capable of utilizing multiple AC and DC buses that interconnect laboratories and experiments. Never before attempted at this scale, the REDB can interconnect up to 1 megawatt of experimental power generating equipment, making it the largest of its kind in the world. It is electronically connected to laboratories and experiments with a specially adapted Supervisory Control and Data Acquisition software system (SCADA). The SCADA provides high resolution data output to a central control room with a wall-sized visualization screen allowing researchers to monitor and manipulate experiments in real time. This allows ESIF to raise the bar for sustainable laboratories by managing and harvesting process and electrical energy from experiments and transferring it to other laboratories and building systems for simultaneous use/reuse.

NREL estimates that leveraging the energy efficient HPC data center will save approximately **$1 million in annual operating cost** compared to a traditional data center. The cost savings are due to a potential $800,000 electrical energy savings and $200,000 thermal energy savings from reuse of the return water heat to heat ESIF.



Facility Energy Analysis Identifies High Energy Use Space Types for Optimization



Office Energy Density Analysis Informs Overall Systems Design

Engineering and Energy Efficiency:

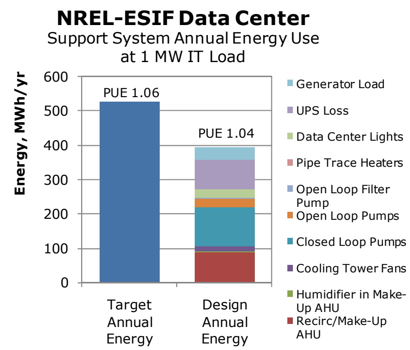
The building's three major components – high bay laboratories, high performance computing data center, and offices – utilize distinct and complementary energy efficiency strategies to increase the overall energy efficiency of the facility. The systems employed at this facility are focused on both energy efficiency and recovery.

High performance computing data centers consume large amounts of power and have correspondingly large amounts of heat rejection. To maximize efficiency at this facility, the HPCDC utilizes liquid-cooled servers, allowing heat to be captured in the form of water with minimal fan energy. Complementing this approach, cooling of the HPCDC is achieved through evaporative cooling (no compressor-based cooling required). The HPCDC operates at a projected 1.04 Power Use Effectiveness (PUE), making it one of the most energy efficient data centers in the world. The design approach for HPCDC resulted in additional opportunities for energy recovery to other facility programs.

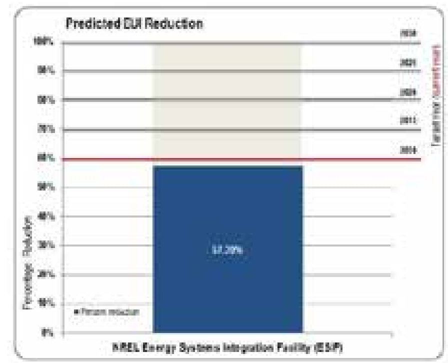
Heat from the HPCDC is captured in the form of 95°F water. Instead of rejecting this heat into the environment, it is reused to provide heat to the office areas and to precondition make-up air for the high bay laboratories. As the data center grows, there is also provision to export this heat to other buildings on campus.

In addition to HPCDC heat recovery for ventilation air, the high bay laboratories utilize evaporative cooling and optimized laboratory exhaust systems. The laboratory exhaust systems are variable-volume, minimizing the amount of exhaust (and associated ventilation air) required to maintain environmental conditions. Wind tunnel testing was utilized to optimize exhaust stack heights and discharge velocities. These values were then calibrated to a weather station on the building, allowing for a reduction in discharge velocity and exhaust fan energy based on wind speed and direction. Extensive daylighting combined with sophisticated lighting monitoring and controls allows for additional reductions in lighting energy.

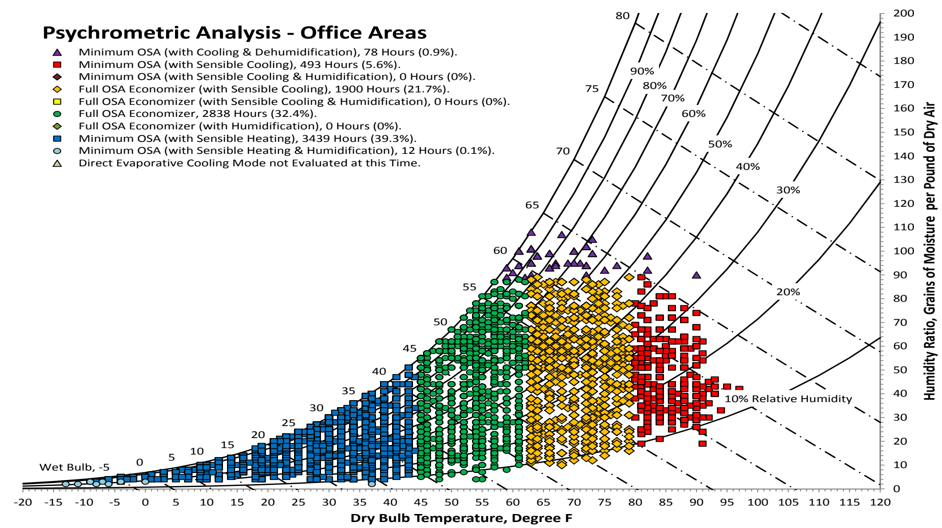
ESIF achieved all 56 LEED® points applied for and the facility is 40% more energy efficient than the baseline building performance rating per ASHRAE/IESNA Standard 90.1-2004. It becomes 46.2% more efficient with the addition of a 720 kW photovoltaic solar array located on nearby South Table Mountain.



Data Center Load Profile Optimizes Energy Performance



2030 Challenge PEUI

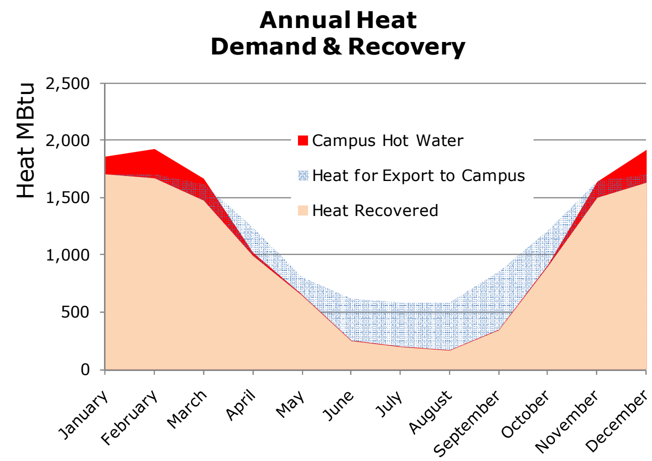


Hourly Weather Analysis for Golden, Colorado Informs Mechanical Systems Approach

The office area is heated entirely by return water heat from the HPCDC. Active convective heat transfer chilled beams provide both heating and cooling along the building perimeter. An underfloor displacement air ventilation system utilizes an outside air economizer for interior cooling, natural convection, and increased ventilation effectiveness. A natural ventilation mode reduces the ventilation system to a minimum while opening ventilation shafts high in the space. Occupants are notified via email to open windows as needed for both natural and cross ventilation modes. Natural ventilation mode is enabled by the building weather station and based on outside air temperature and wind speed. Daylighting and lighting strategies are used to minimize lighting energy and the associated heat generated in the space. The ESIF is designed to have the lights off from 10am to 2pm each day.

In support of the NREL's goal to demonstrate energy efficient buildings with lower impact on the natural environment, the facility was to be a Leadership in Energy and Environmental Design (LEED™) Gold certified laboratory building as defined in the US Green Buildings Council LEED™ rating system. The building design exceeded expectations and received a Platinum certification in late 2013. It is the highest certified facility of its type with a high performance computing data center.

Transforming the nation's energy infrastructure is a tall order and arguably the most significant challenge facing our country today. The breakthrough energy technologies and interconnection solutions that NREL and its industry partners will develop and test in this dedicated facility will be critical to transforming the nation's energy infrastructure at an unprecedented rate, bringing with it a secure and sustainable energy future to the United States.



Building Systems Take Advantage of Data Center Waste Heat Recovery

Building Systems and Energy Performance are Described at ESIF's Main Lobby

The Right Now – Successes at the Energy Systems Integration Facility 6

> Our focus is what the building must do, not what it must be.… A big thing about this building is its flexibility
>
> —Brian Larsen, NREL

Highly Flexible Process Infrastructure at ESIF's Power Systems Integration Lab

Since the completion of the ESIF in early 2013 the building was dedicated as the newest DOE user facility by Energy Secretary Ernest Moniz, has seen countless high-profile visitors, began breaking ground on one of a kind research and testing and won numerous awards.

Energy Secretary Moniz Headlines ESIF Dedication

Along with Assistant Secretary for Energy Efficiency and Renewable Energy David Danielson and other key energy officials, Secretary Moniz visited NREL to dedicate the ESIF as the nation's first facility to help both public and private sector researchers scale up promising clean energy technologies. The dedication formally introduced the ESIF as the latest DOE user facility—and the only one in the nation focused on utility-scale clean energy grid integration.

"Strong partnerships between our national laboratories and America's private industry, academia, and entrepreneurs will help reduce the effects of climate change, increase the production of clean energy, and accelerate the development of new technologies," said Secretary Moniz. "The Energy Department has been at the forefront of large-scale computation and modeling, and new NREL supercomputing capabilities will support the groundbreaking science and innovation we need to address the effects of global climate change and pave the way to a cleaner, more sustainable energy future."

Who's Who on the ESIF Visitor List

Not only is the ESIF securing important partnerships from organizations like Toyota and the U.S. Army, it is attracting high-profile visitors, including:

- University of Michigan
- Federal Utility Partnerships
- Toshiba
- CSIRO
- Ron Loveland, Energy Advisor to the Welsh Government
- Karla Olsen, Deputy Communications Director, DOE
- House Energy and Water Appropriations Staff
- Assistant Secretary Pat Hoffman, OE-1, DOE
- San Diego Gas & Electric
- Asetek
- DOE Advanced Scientific Computing Research (ASCAR)
- Barry MacColl, GM of Research, Testing and Development, Sustainability Division, Eskom
- Sandia National Laboratories

Secretary of Energy Ernest Moniz Speaks at ESIF's Dedication Ceremony

Unique Research: NREL Demonstrates the ESIF's Power Hardware-in-the-Loop Capability

Leveraging the ESIF's megawatt-scale power capacity to take ESI research to the next level, NREL researchers and operations staff have successfully demonstrated the power hardware-in-the-loop (PHIL) testing capability in the ESIF. PHIL allows simulated electrical grids to be connected to physical devices such as photovoltaic (PV) inverters to test advanced device controls and functionality at full power—and determine whether their integration changes the landscape of the grid. The PHIL testing capability is made possible by key infrastructure in the ESIF, which includes a programmable 1-megawatt AC grid simulator, a 1-megawatt PV simulator, and a 1-megawatt load bank connected through the ESIF's Research Electrical Distribution Bus (REDB).

Earlier this year, NREL researchers worked with industry partner Advanced Energy (AE) to complete evaluation of an AE 500-kilowatt PV inverter's advanced grid support features. NREL researchers are now working on testing this same inverter when connected to a simulated real-world electric distribution system using PHIL techniques. This will allow for evaluation of the inverter's advanced grid support features and their impact on an electric distribution system prior to field deployment on an actual distribution system.

This November, a first step towards this goal was completed when the 500-kilowatt inverter was connected to a simulation of a simplified distribution system, allowing testing of the inverter's response to a simulated grid islanding event. NREL researchers will continue working with AE to complete this full PHIL evaluation using a real-world distribution system model in 2014. This testing capability allows electric utilities and manufacturers to partner together and "bring their own circuit" to NREL to demonstrate and test new, potentially game-changing innovations in a controlled laboratory environment—revealing the effects of these technologies on the distribution system while posing no risk to the utilities or their customers.

And the Award Goes to…the ESIF

The ground breaking research at the ESIF is expected, but winning awards is just an added bonus. The ESIF and the science happening within have earned numerous awards, which range from design to computing to delivery method awards, since its completion. The list includes:

- Associated General Contractors of Colorado, ACE Awards - 2013 Jack Mincher People's Choice Award – General Contractor
- Associated General Contractors of Colorado, ACE Awards - 2013 Bronze Award of Merit – Best Building Project – GC (Over $70 Million)
- Design Build Institute of America, Rocky Mountain Region - RMR 2013 Design-Build Award Industrial/Process/Research Facilities
- Design Build Institute of America, Rocky Mountain Region -RMR 2013 Design-Build Award Best Overall Project
- American Institute of Architects, Arizona Chapter – 2013 Arizona Public Service Energy Award
- American Institute of Architects, Arizona Chapter - Salt River Pima Sustainable Award
- Engineering News Record Southwest - Best Project: Government/Public Building -- Merit Award
- HPCwire – 2013 Editor's Choice Award: Best Application of Green Computing in HPC

ESIF's Smart Power Laboratory

A Protective Canopy and Entry Breezeway Provide Shelter from the Elements. Golden's Extreme Weather Conditions Vary from Extreme Heat to Winter Blizzards

Energy Systems Integration Facility – The Right Tool At the Right Time

“We have everything here in this facility. And it really allows industry to come in and perform testing that they will not be able to do anywhere else in the world.”

—Kevin Harrison, NREL Senior Engineer