NREL Overview
Climate Change Educators Workshop
David Warner, NREL Public Affairs Office
June 26, 2015
Laboratory Snapshot

Only National Laboratory Dedicated Solely to Energy Efficiency and Renewable Energy

- Leading clean-energy innovation for more than 35 years
- 1,721 employees with world-class facilities
- Campus is a living model of sustainable energy
- Owned by the Department of Energy
- Operated by the Alliance for Sustainable Energy
NREL is the only DOE National Laboratory that is wholly dedicated to renewable and energy efficient technologies.
Major Programs & Funding

FY14 Spend Plan by NREL Program as of 9/30/14 — ~ $380M
NREL’s Impacts on the Colorado Economy

• $831 million boost to Colorado’s economy
• In total, 6,200 jobs in Colorado
• Key Colorado business sector – 17,000 clean energy jobs
• Contracts with 329 Colorado companies
  • $414 million in total value
  • $ 75.3 million paid last year
• CRADAs – 23 Colorado companies
• TSAs – 24 Colorado companies
• PV Incubator helps companies reach full-scale production
• Industry Growth Forum – since 2003, VCs invested $3.4 billion

Source: University of Colorado Leeds School of Business
# Scope of Mission

<table>
<thead>
<tr>
<th>Energy Efficiency</th>
<th>Renewable Energy</th>
<th>Systems Integration</th>
<th>Market Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Buildings</td>
<td>Solar</td>
<td>Grid Infrastructure</td>
<td>Private Industry</td>
</tr>
<tr>
<td>Commercial Buildings</td>
<td>Wind and Water</td>
<td>Distributed Energy</td>
<td>Federal Agencies</td>
</tr>
<tr>
<td>Personal and Commercial</td>
<td>Biomass</td>
<td>Interconnection</td>
<td>State/Local Govt.</td>
</tr>
<tr>
<td>Vehicles</td>
<td>Hydrogen</td>
<td>Battery and Thermal Storage</td>
<td>International</td>
</tr>
<tr>
<td></td>
<td>Geothermal</td>
<td>Transportation</td>
<td></td>
</tr>
</tbody>
</table>

- **Energy Efficiency**
  - Residential Buildings
  - Commercial Buildings
  - Personal and Commercial Vehicles

- **Renewable Energy**
  - Solar
  - Wind and Water
  - Biomass
  - Hydrogen
  - Geothermal

- **Systems Integration**
  - Grid Infrastructure
  - Distributed Energy
  - Interconnection
  - Battery and Thermal Storage
  - Transportation

- **Market Focus**
  - Private Industry
  - Federal Agencies
  - State/Local Govt.
  - International
National Energy Imperatives

Security
- Ensuring resilient and reliable energy systems

Environment
- Protecting resources and environmental quality

Economy
- Affordability while stimulating manufacturing and jobs
NREL’s Solutions Role

Reducing Investment Risk

• Integrating technology at scale

• Enabling basic and applied clean energy technology innovation

• Accelerating technology market introduction and adoption

• Encouraging collaboration in unique research and testing partnering facilities

• Providing analysis and expertise to inform decisions and catalyze market adoption
Industry Collaboration
U.S. Photovoltaic Solar Resource

Annual average solar resource data are shown for a tilt=latitude collector. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

Author: Billy Roberts - October 20, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Solar – Photovoltaics

Status in U.S.

PV

- More than 16,000 MW installed capacity
- More than 6,000 MW in 2014

Source: U.S. Department of Energy, IEA.
Photo: 8.22-megawatt Alamosa, Colo., PV solar plant.
PV R&D at NREL

PV Technologies
- Thin Film PV (CIGS / CdTe / CZTS)
- III-V
- OPV/TCO
- Silicon

PV Cross-Cutting R&D
- Measurements & Characterization
- Module Reliability & Systems Engineering

Extensive Capabilities and PV Experience Under One Roof
- Material Synthesis • Device Processing • Device Design • Device Modeling • Measurements & Characterization • A Highly Trained Technical Staff
Closing the gaps
US PV Market - Historic

![Diagram showing annual PV installations and weighted average system price from 2000 to 2013.]

<table>
<thead>
<tr>
<th>Year</th>
<th>Residential (MW)</th>
<th>Non-Residential (MW)</th>
<th>Utility (MW)</th>
<th>Total (MW)</th>
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<td>0</td>
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<td>2011</td>
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<td>1,072</td>
<td>1,803</td>
<td>2,847</td>
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<tr>
<td>2013</td>
<td>792</td>
<td>1,112</td>
<td>2,847</td>
<td>4,751</td>
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</tbody>
</table>

Sources: GTM Research/SEIA and Lawrence Berkeley National Laboratory
Solar Research

- Concentrating Solar Power (CSP)
- Low cost high performance storage for baseload markets
- Advanced absorbers, reflectors, and heat transfer fluids
- Next generation solar concentrators
- 1,000 MW installed and 1,000 MW with signed PPAs

Photo courtesy of SkyFuel, Inc
Abengoa 250 MW Solana Plant with 6 hrs Storage
Arizona
Environmental measures:
• Solar field is not graded
• Air-cooled condenser reduces water consumption by over 90%
US Wind Resource
Wind

Today’s Status in U.S.
- 65 GW installed capacity

Long Term Potential
- 20% of the nation’s electricity supply

* With no Production Tax Credit
US Wind Installations

2014 Year End Wind Power Capacity (MW)

Total: 65,879 MW
(As of 12/31/2014)

Data is from the American Wind Energy Association Fourth Quarter 2014 Market Report:
http://www.awea.org

U.S. Department of Energy
NATIONAL RENEWABLE ENERGY LABORATORY
National Wind Technology Center
Wind

Wind Research

• Improved performance and reliability
• Blade and gear box testing
• Utility grid integration
Airfoil and Turbine Research

• NREL-patented airfoil designs improved blade efficiency and simplified over-speed controls, helping launch the wind industry

• Drivetrain and blade testing improved turbine reliability and lowered costs

• Aerodynamic and structural models guided U.S. industry product development

• On-going research in reliability, efficiency, and controls for multi-megawatt wind turbines and entire wind farms; also developing offshore system technologies
Blade Testing Facilities

New Large Blade Test Facility:

- Boston, MA with Massachusetts Technology Collaborative
- Static and Fatigue tests of blades up to 90 m
- NREL staff to operate facility

- NREL has developed and patented advanced blade testing
- NREL supports R&D blade testing for DOE and industry
- Supporting development of new blade test facilities worldwide
Drivetrain Testing

• 2.5 MW Dynamometer
  – Commissioned 1999
  – Steady use by industry
  – Used in R&D activities
  – Key facility for Gearbox Reliability Collaborative
  – Basic shaft load capability added in FY2010

• Dynamometer Upgrade
  – $10M Recovery Act funding
  – New 5 MW driveline
  – Robust shaft loading system
  – Commissioned in 2013
Turbines are getting larger

- **Hub Height**
  - 55 m: 750 kW
  - 70 m: 1,500 kW
  - 80 m: 1,800 kW
  - 83 m: 2,000 kW
  - 100 m: 2,500 kW
  - 140 m: 7,500 kW

- **Rotor Diameter**
  - 50 m: 70 m
  - 70 m: 80 m
  - 80 m: 94 m
  - 110 m: 160 m

- **Power Output**
  - 750 kW
  - 1,500 kW
  - 1,800 kW
  - 2,000 kW
  - 2,500 kW
  - 7,500 kW

- **Meters**
  - 1995 - 2000
  - 2000 - 2005
  - 2005 - 2010
  - 2012
  - State of the Art with Barriers Addressed

- **LCOE ($/MWh)**
There is a limit on land

Photo from Martin Fischer, SSP Technology
Horns Rev Offshore Wind Farm
North Sea, Denmark

• Photo used by permission of Uni-Fly A/S
Energy Used in Buildings

Buildings use 72% of nation’s electricity and 55% of its natural gas.

Source: Buildings Energy Data Book 2007
Buildings research

• Whole building systems integration of efficiency and renewable features
• Computerized building energy optimization tools
• Zero energy buildings
Highly Efficient Office Buildings

- DOE/NREL Research Support Facility is a model for sustainable commercial buildings
- Uses 50% less energy than conventional office buildings
- Incorporates NREL inventions in energy efficiency and renewable power
- Draws on onsite solar power for all annual power needs
- LEED Platinum rating
High Performance Buildings

Research Support Facility
• Prototype for the future of large-scale ultra high energy efficient buildings
• Changing the views of the commercial building industry
• Zero energy buildings are doable and affordable

Not a concept, but a reality
RSF Key Design Strategies

• Optimal orientation and office space layout
• Fully daylit office wings with high-performance electrical lighting
• Continuous insulation precast wall panels with thermal mass
• Operable windows for natural ventilation
• Radiant heating and cooling
• Outdoor air preheating
  - Transpired solar collector
  - Data Center waste heat
  - Exhaust air heat recovery
  - Crawl space thermal storage
• Aggressive plug load control strategies
• Data Center outdoor air economizer with hot aisle containment
• Roof top- and parking lot-based PV
RSF Key Design Strategies

Transpired Solar Collector

- Passive heating technology developed at NREL
- Pre-heats incoming air
- Captures up to 80% of the energy from sunlight striking the collector
RSF Key Design Strategies

Reclaimed Materials

• Aggregate in the foundations and slabs came from the demolition of Denver’s previous airport.

• Crushed recycled glass used in the storm water management basins outside the building.

• Reclaimed natural gas piping serves as support for the building.

• The lobby and other common areas feature beetle-kill pine from Western forests.
Electrochromic Windows

- NREL discovery led to development of electronic “tintable” window glass

- Variable light transmittance of 5% - 70% helps keep buildings cool in summer and warm in winter

- Operating voltage of a flashlight battery

- Installed on NREL’s Research Support Facility

- Ongoing research to make windows turn clearer when untinted, change tinting faster, and reject more heat – possibly including an add-on coating for retrofits
Energy Efficient Workspace

- 24” LCD Energy Efficient Monitors
  18 Watts
  Typical 19”-24” Monitors
  30-50 Watts

- Sensor-controlled LED task lights
  3 Watts
  Fluorescent task lights
  35 Watts

- Laptop
  30 Watts

- Desktop Computer (Energy Star)
  300 Watts

- iGo Power Smart Towers
  Reduces “vampire” energy use

- VOIP phones
  2 Watts

- Removing personal Space Heater
  saves 1500 Watts

- Multi-function Devices
  100 Watts (continuous)
  Removing Desktop Printers
  Saves ~460 Watts/Printer
Energy Monitoring

The RSF is a living laboratory—energy usage is continuously studied and adjusted as needed.
Energy Usage and Data

What are we monitoring? EVERYTHING!

- Lighting
- Heating
- Cooling
- Plug Loads
- Data Center
- Day lighting
- Mechanical System Power Density
- Outdoor Air Temperature
- Monthly End Use Energy Consumption
- Elevator Lighting
- PV Output
This study estimates the annual technical biomass resources currently available in the United States by county. It includes the following feedstock categories:

- Agricultural residues (crops and animal manure);
- Wood residues (forest, primary mill, secondary mill, and urban wood);
- Municipal discards (methane emissions from landfills and domestic wastewater treatment);
- Dedicated energy crops and switchgrass on Conservation Reserve Program lands.

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. See additional documentation for more information at http://www.nrel.gov/docs/fy06osti/39181.pdf
Biomass research

- The biorefinery and cellulosic ethanol
- Solutions to under-utilized waste residues
- Energy crops
- Next generation of “Drop-in” hydrocarbon biofuels
Lowering the Cost of Biofuels

• Cellulosic ethanol prices are tied to the cost of enzymes used to convert biomass into fermentable sugars

• NREL partnered with Novozymes and Genencor to engineer new low-cost enzyme production
  o Collaborated on biomass characterization, pretreatment, and process integration research
  o Exceeded enzyme cost-reduction goal by 10x

• Newly discovered enzymes promise further cost cuts
Renewable Fuel Heat Plant

- Wood heating plant
- 10,000 million BTU
- Displaces 50% of STM’s campus natural gas usage
Transportation research

- HEV Test bed
- Advanced power electronics
- Vehicle ancillary loads reduction
- Energy storage
- Utility interconnection
- Vehicle-to-grid
Vehicle Efficiency Research - ADAM

- Built ADAM, the “sweaty, shivering” manikin to measure human thermal comfort in cars
- Air conditioning consumes 7 billion gallons of gasoline annually - 10% of imported crude oil
- NREL researchers goal is to reduce fuel used for air conditioning
- ADAM used by most major car manufacturers to test new efficient cooling systems
Advanced Vehicle Technology

• More efficient vehicles and advanced technologies are a key part of achieving deep cuts in U.S. petroleum use

• NREL is collaborating to develop software tools that will improve and accelerate vehicular battery design

• NREL's innovative Isothermal Battery Calorimeters perform precise thermal measurements on batteries and packs

• NREL's Vehicle Testing and Integration Facility puts vehicles through a thermal workout to evaluate energy-saving and comfort-optimization strategies

Miles per gallon equivalent

Model year


Passenger cars

Light trucks

54.5 mpge fleetwide average in 2025

MY 1978-2011 figures are NHTSA Corporate Average Fuel Economy (CAFE) standards in miles per gallon. Standards for MY 2012-2025 are EPA greenhouse gas emission standards in miles per gallon equivalent, incorporating air conditioning improvements. Dashed lines denote that standards for MY 2017-2025 reflect percentage increases in Notice of Intent.
How Long Will it Take to Replace the U.S. LDV Fleet?

240 Million Light Duty Vehicles

16 Million Sales/Year

15 Years to Replace LDV Fleet
Analyses, Models, and Tools

• NREL analyzed high penetrations of renewable energy in the eastern and western U.S. power grids for benefits, impacts, and mitigation strategies

• For solar photovoltaic manufacturing, NREL modeling tools identify cost improvements and assess competitive advantages

• The OpenEI website links and shares energy data worldwide

• NREL’s System Advisor Model determines the economic value of proposed solar, wind, and geothermal projects
High-Penetration Renewables

New study on the feasibility of renewable energy providing up to 80% of electricity in the U.S. by 2050.
Energy Systems Integration optimizes the design and performance of electrical, thermal, and fuel pathways at all scales.

Energy Systems Integration: Linking Data to Knowledge to Control

Complexity

Region (Balancing Area)

Area (Service Territory)

Community (substation)

Campus Subdivision (feeder)

Building DistGen Vehicle (feeder)

Appliance (Plug)

Electricity

Thermal

Data

Fuel
Energy Systems Integration Facility

• NREL's Energy Systems Integration Facility (ESIF) integrates electric, thermal, and fuel systems with high-performance modeling and simulation capabilities

• The ESIF offers megawatt-scale hardware-in-the-loop testing with actual or simulated electrical devices, a supervisory control and data acquisition system, and unique analysis and visualization tools

• Energy systems integration brings together the wide range of energy carriers—electricity, thermal sources, and fuels—with other infrastructures, such as water and transportation, to work together optimally
Energy Systems Integration Facility
ESIF Laboratories

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

**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

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

**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
Petaflop Computing Capability
2-D and 3-D Imaging
NREL’s Energy Vision

A clean, resilient and reliable energy system that contributes to economic prosperity, national security, and environmental quality
For more than 35 years, NREL has delivered innovation impact enabling the emergence of the U.S. clean energy industry.

For more information please visit our website at www.nrel.gov.