

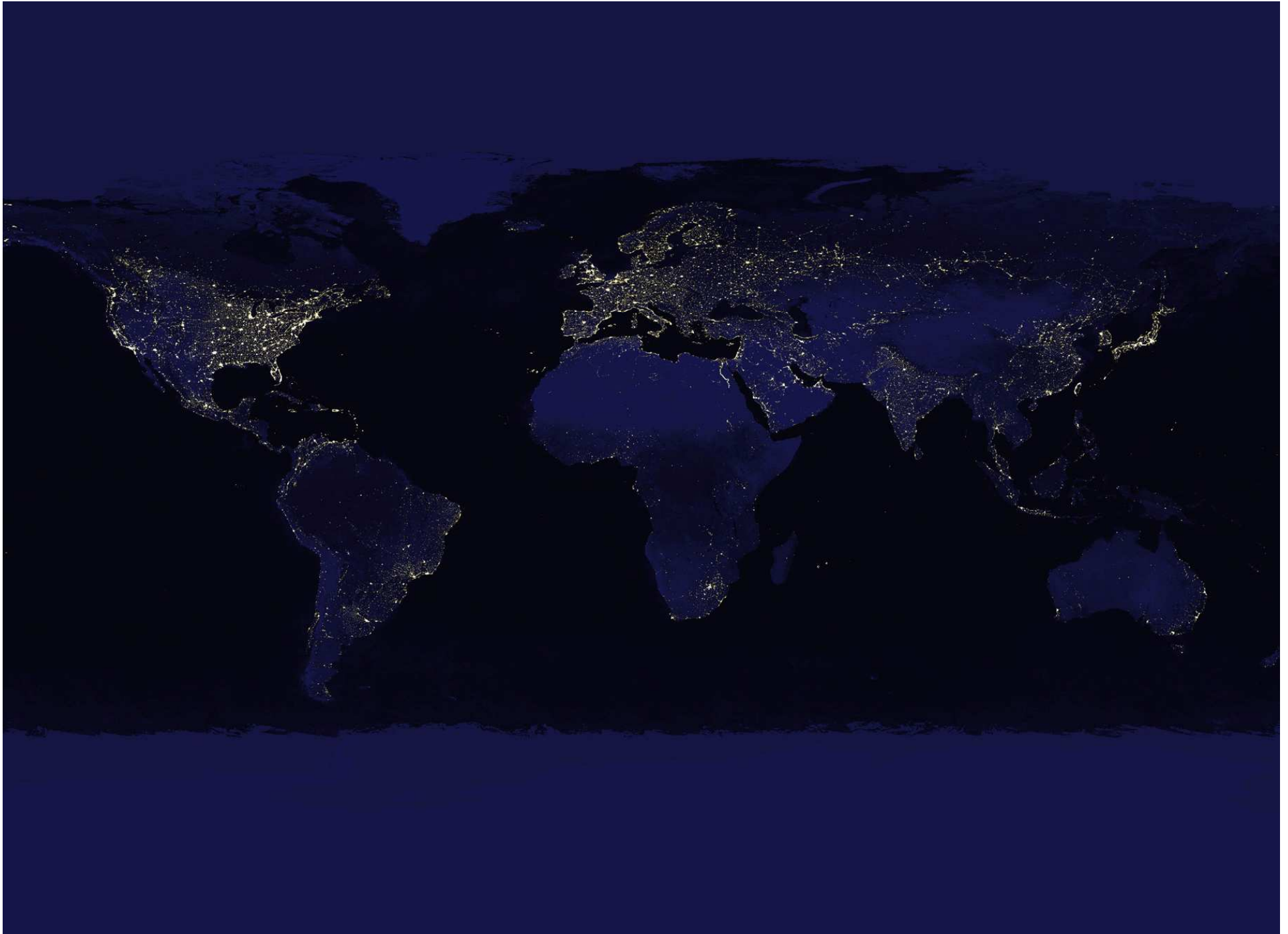
Leading the Way to a Clean Energy Future

The Transition to Renewable Energy

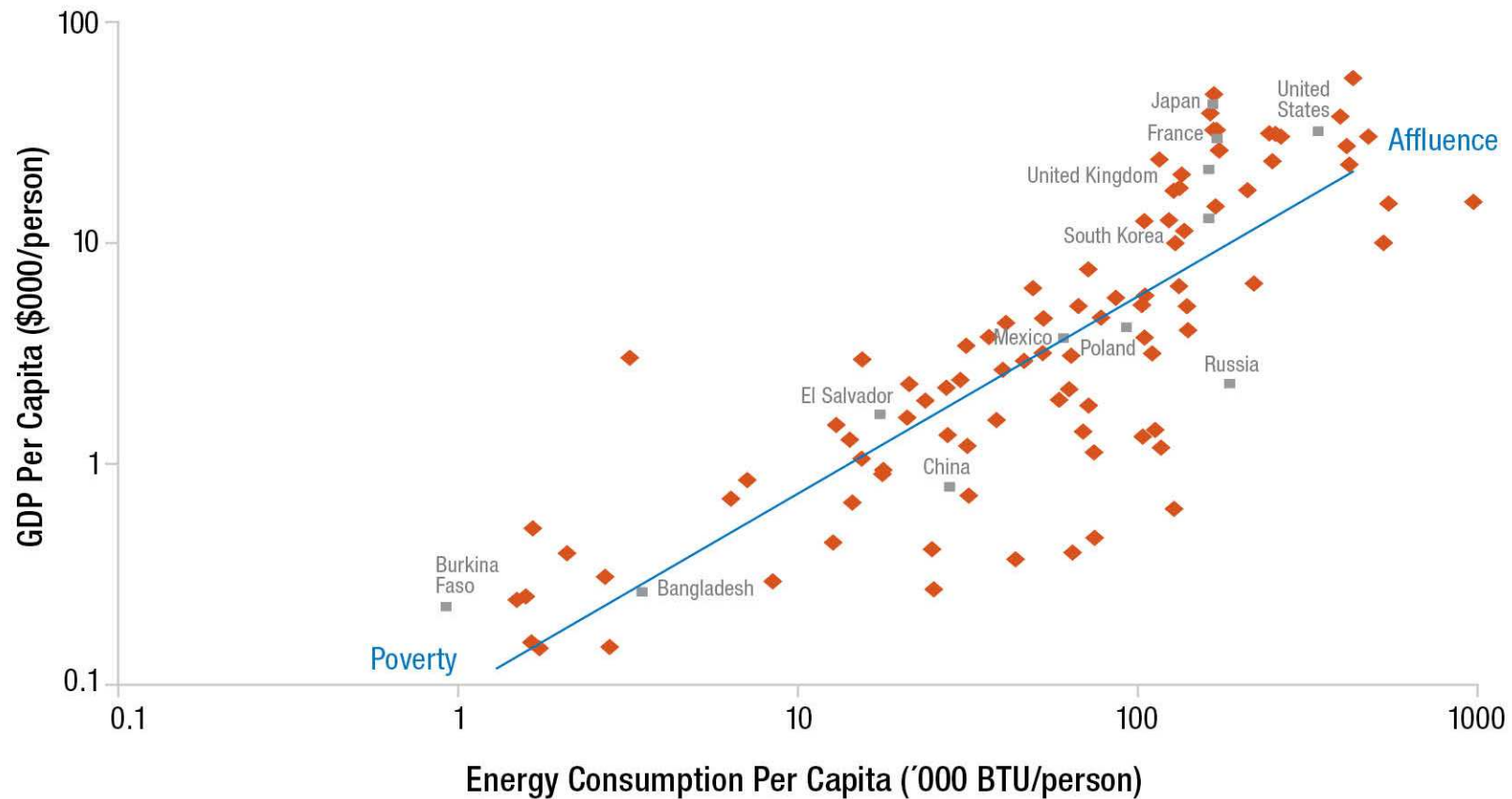
OSHER

David Warner, NREL Public Affairs Office

October 14, 2015

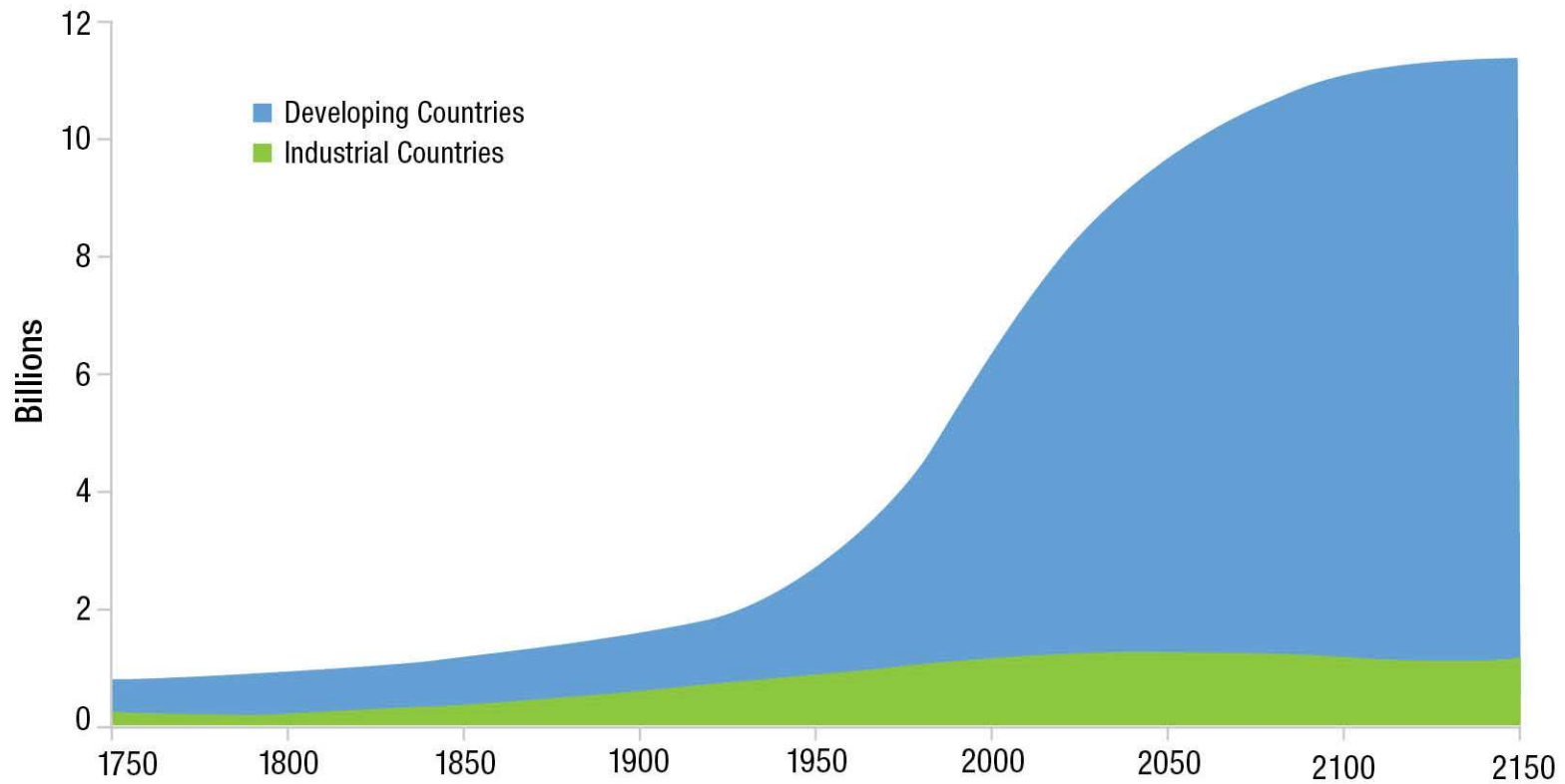


Energy Use and Gross Domestic Product



Source: Energy Information Administration, International Energy Annual 2000 Tables E1, B1, B2;
Gross Domestic Product per capita is for 2000 in 1995 dollars. Updated May 2002.

World Population Growth (1750–2150)



How Long Does It Take To Add A Billion People?

Number of years required to add one billion people to the population of the Earth with current projections into the future

| Population | Year Achieved | Years Required |
|------------|---------------|----------------------|
| 1 Billion | 1800 | All of Human History |
| 2 | 1930 | 130 |
| 3 | 1960 | 30 |
| 4 | 1974 | 14 |
| 5 | 1987 | 13 |
| 6 | 1998 | 11 |
| 7 | 2009 | 11 |
| 8 | 2021 | 11 |
| 9 | 2035 | 14 |
| 10 | 2054 | 19 |
| 11 | 2093 | 39 |

Humanity's Top Ten Problems for next 50 years

1. Energy
2. Water
3. Food
4. Environment
5. Poverty
6. Terrorism & War
7. Disease
8. Education
9. Democracy
10. Population

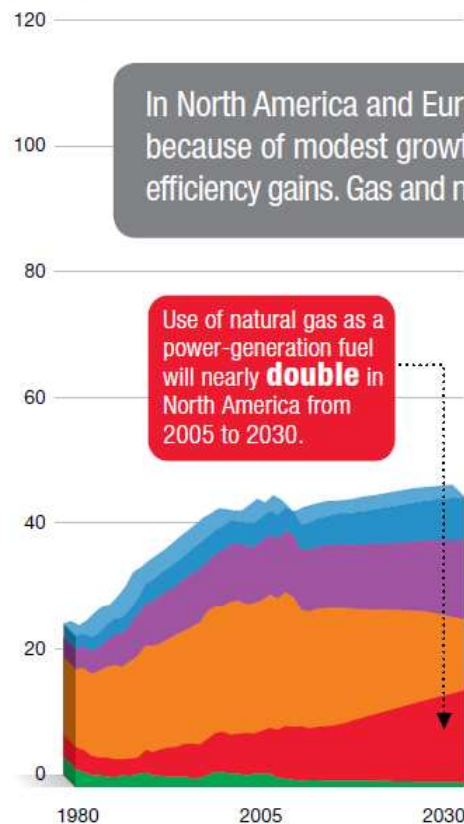


Source: Nobel laureate, Richard Smalley

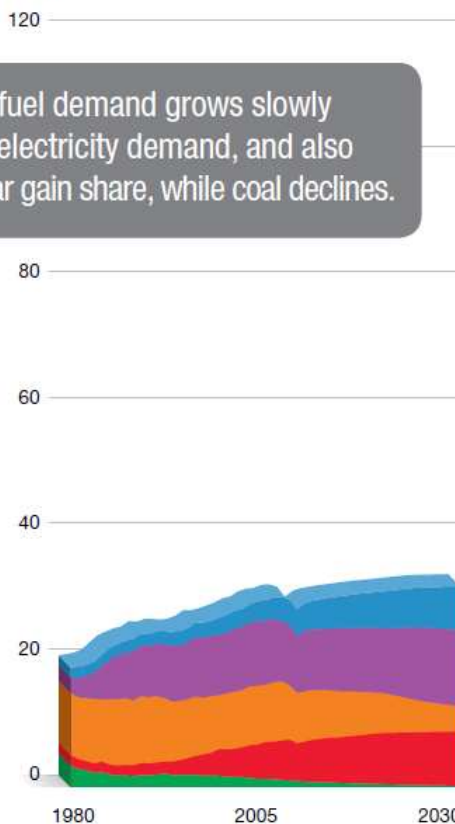
Many expect electricity demand to grow faster than renewable energy generation

Power generation by fuel

Quadrillion BTUs
North America

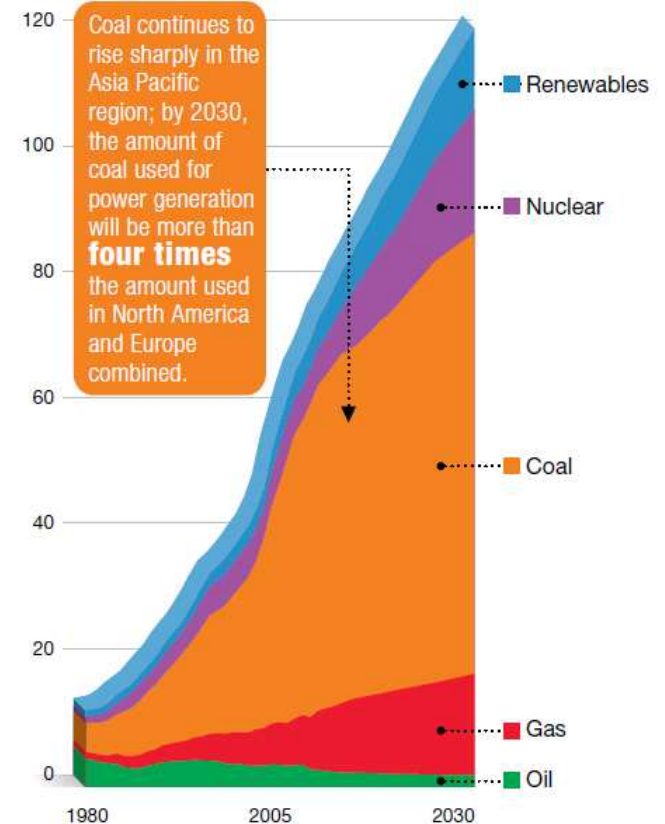


Europe



In North America and Europe, fuel demand grows slowly because of modest growth in electricity demand, and also efficiency gains. Gas and nuclear gain share, while coal declines.

Asia Pacific



Source: ExxonMobile
http://www.exxonmobil.com/corporate/files/news_pub_eo_2010.pdf

The Outlook for Energy: A View to 2030 31

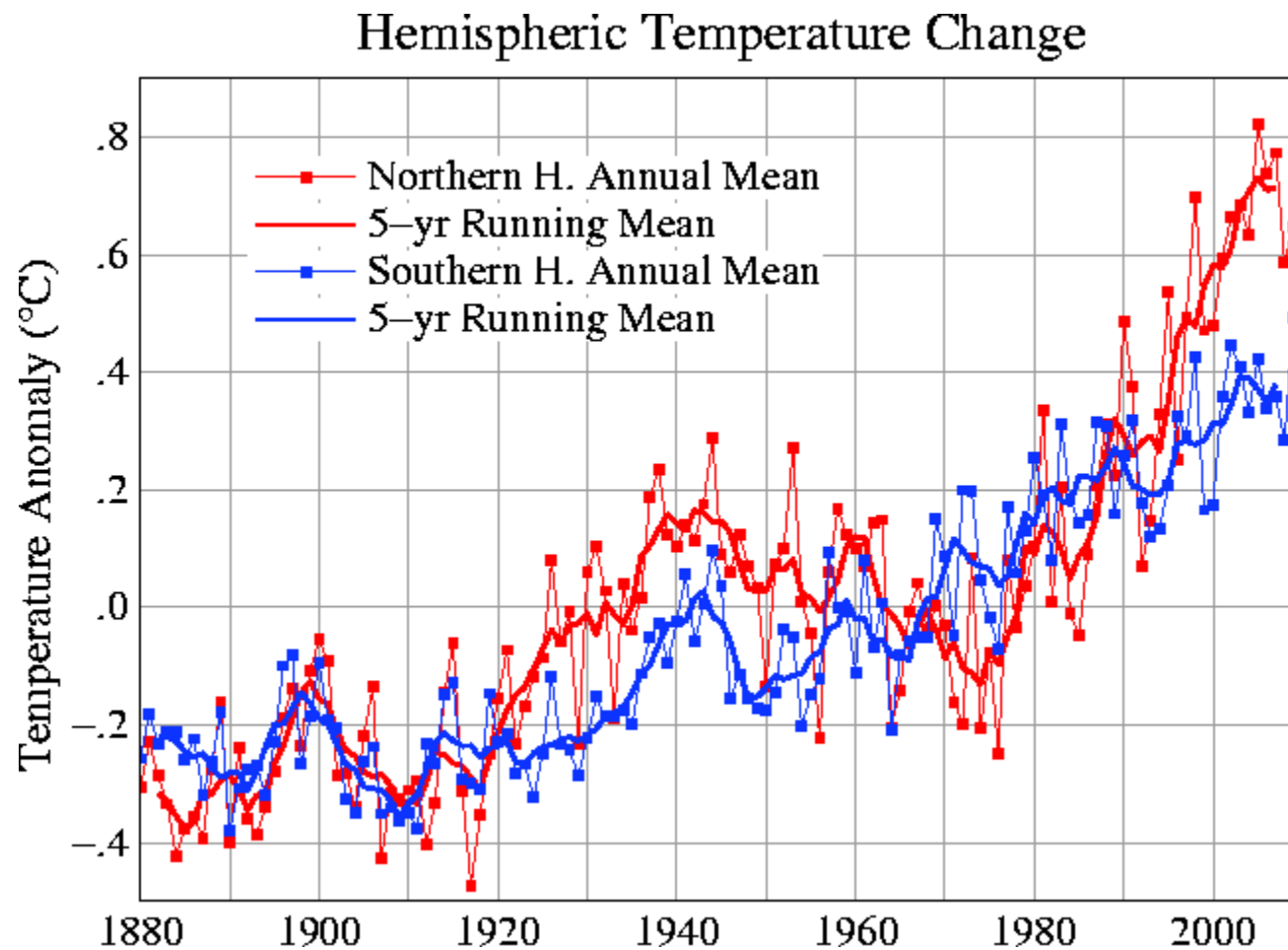
Impact of Exponential Growth

| Annual Growth Rate | Lifetime of Resource in Years | | | | | | |
|--------------------|-------------------------------|----|-----|-----|------|------|--------|
| 0%* | 10 | 30 | 100 | 300 | 1000 | 3000 | 10,000 |
| 1% | 9.5 | 26 | 69 | 139 | 240 | 343 | 462 |
| 2% | 9.1 | 24 | 55 | 97 | 152 | 206 | 265 |
| 3% | 8.7 | 21 | 46 | 77 | 115 | 150 | 190 |
| 4% | 8.4 | 20 | 40 | 64 | 93 | 120 | 150 |
| 5% | 8.1 | 18 | 36 | 56 | 79 | 100 | 124 |
| 6% | 7.8 | 17 | 32 | 49 | 69 | 87 | 107 |
| 7% | 7.6 | 16 | 30 | 44 | 61 | 77 | 94 |
| 8% | 7.3 | 15 | 28 | 40 | 55 | 69 | 84 |
| 9% | 7.1 | 15 | 26 | 37 | 50 | 62 | 76 |
| 10% | 6.9 | 14 | 24 | 34 | 46 | 57 | 69 |

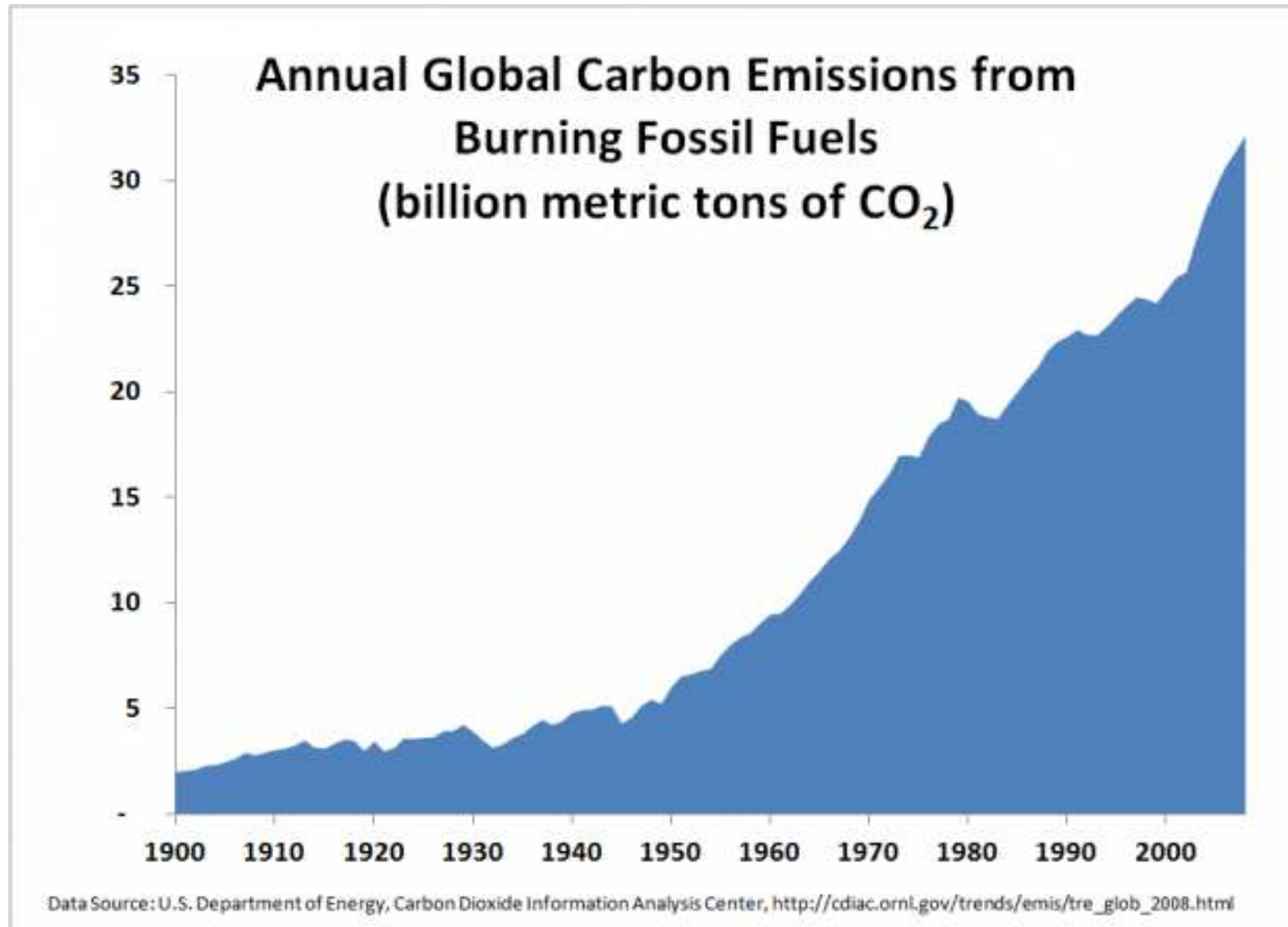
* 0% annual growth = "at current rate of consumption"

Lifetimes of non-renewable resources for different rates of growth of consumption. Except for the left column, all numbers are lifetimes in years.

Global Temperatures

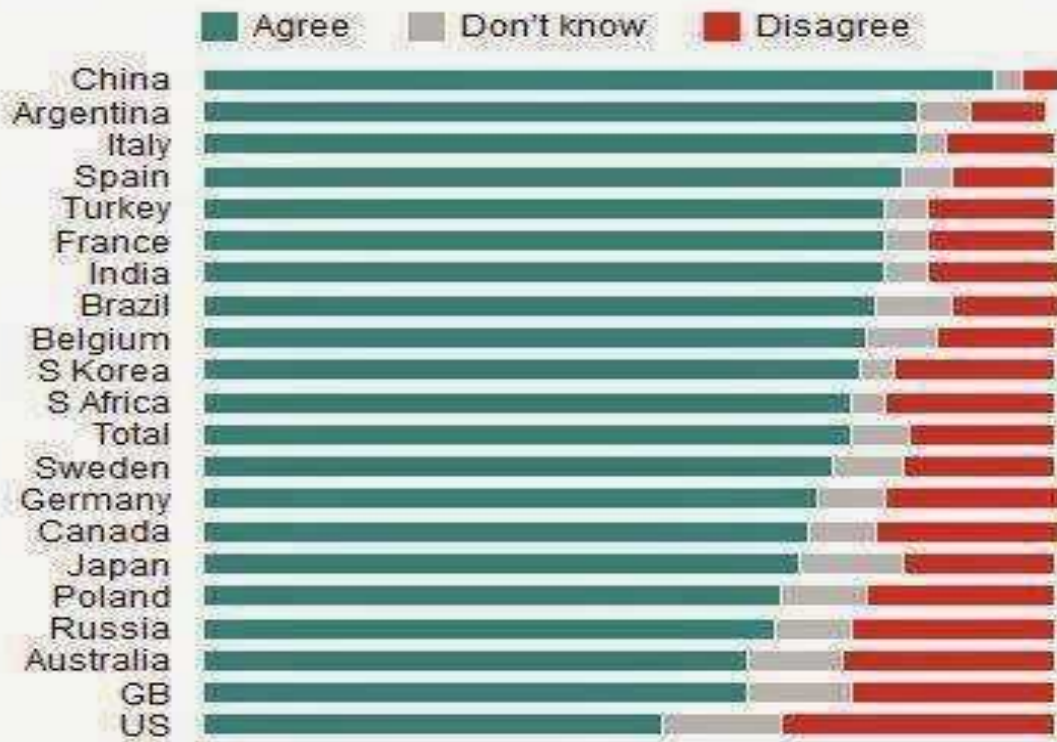


Global Carbon Emissions



Perceptions by country

To what extent do you agree or disagree? The climate change we are currently seeing is largely the result of human activity



National Energy Imperatives





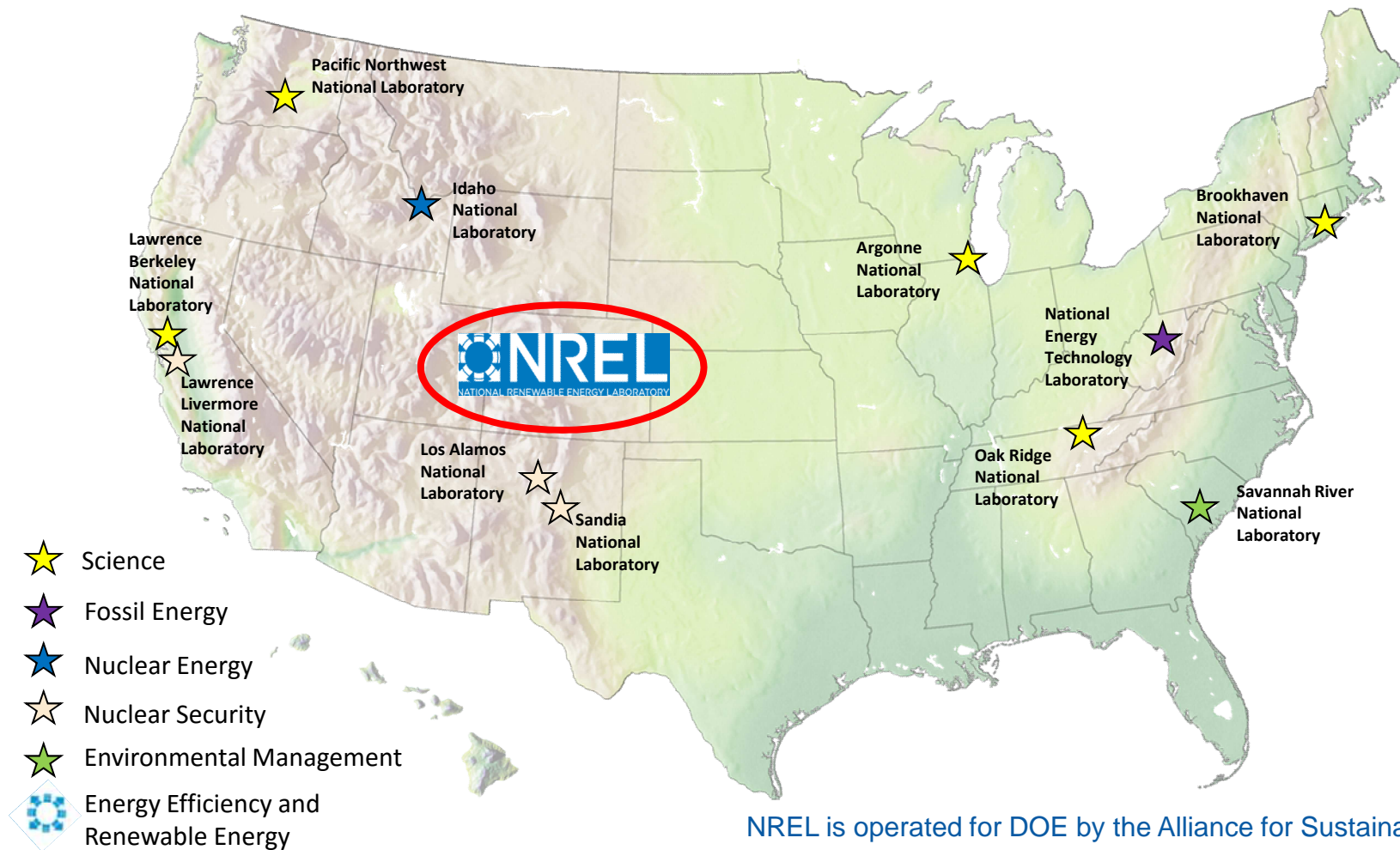
Laboratory Snapshot

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

U.S. Department of Energy National Labs

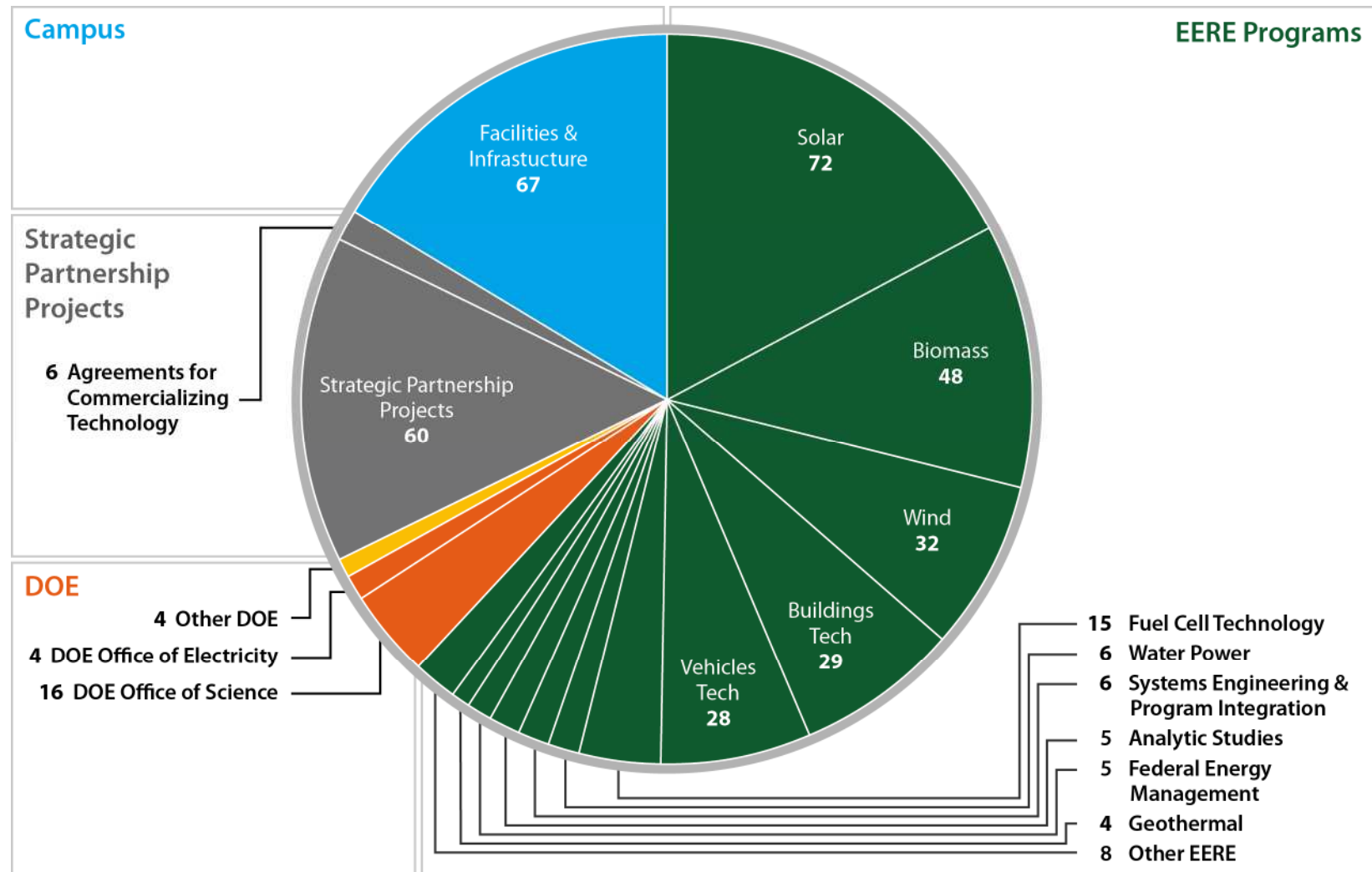
NREL is the only DOE National Laboratory that is wholly dedicated to renewable and energy efficient technologies



NREL is operated for DOE by the Alliance for Sustainable Energy
(Midwest Research Institute and Battelle Memorial Institute)

Major Programs & Funding

FY15 Spend Plan as of June, 2015: ~ \$415 M

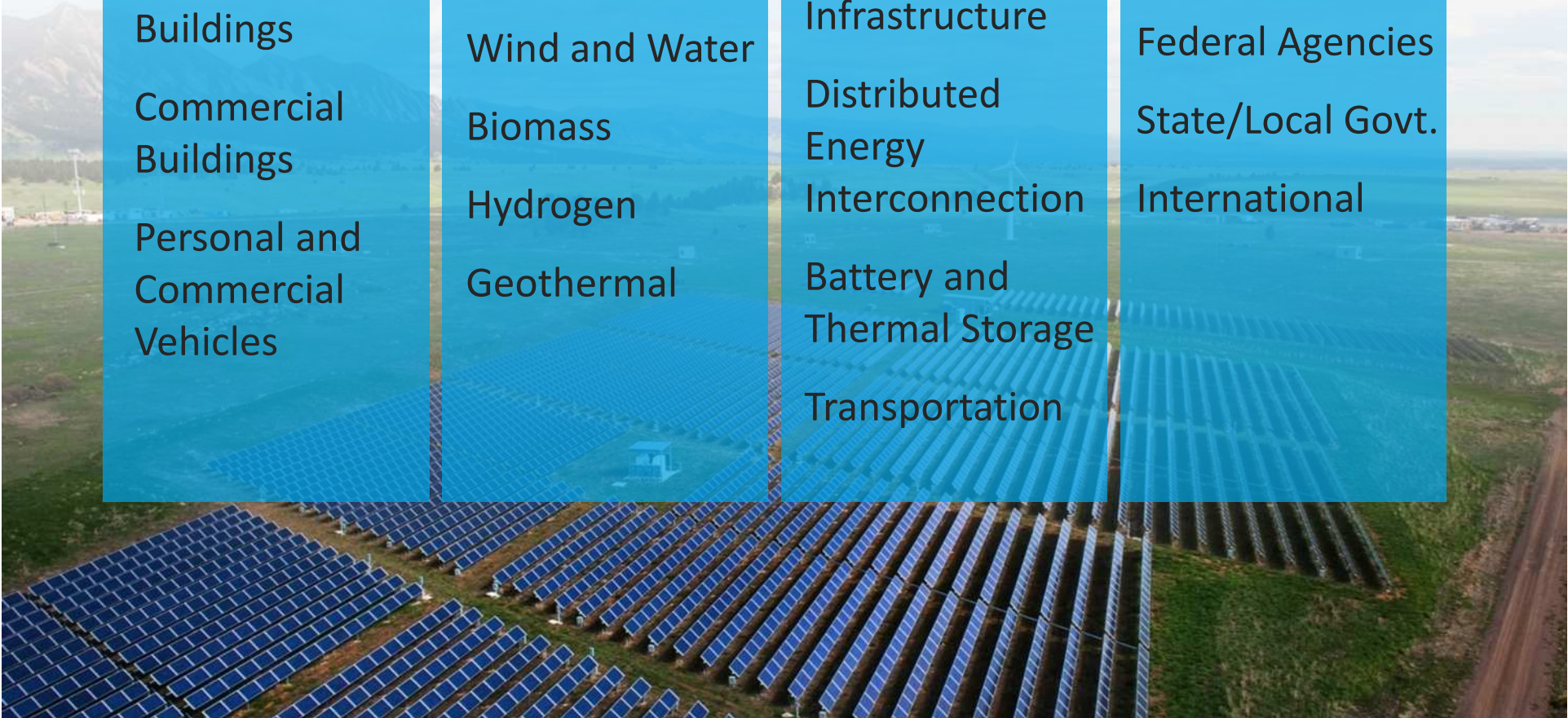


NREL's Impacts on the Colorado Economy

- **\$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

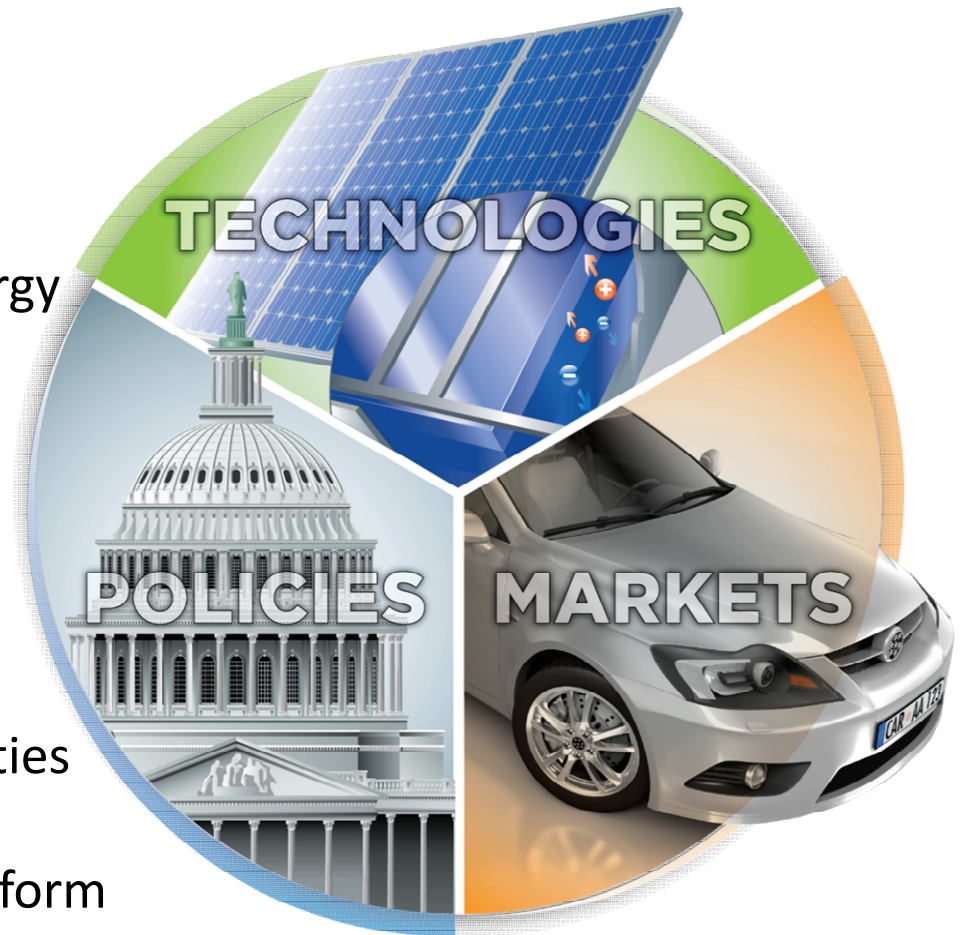


| Energy Efficiency | Renewable Energy | Systems Integration | Market Focus |
|---|--|---|--|
| Residential Buildings Commercial Buildings Personal and Commercial Vehicles | Solar Wind and Water Biomass Hydrogen Geothermal | Grid Infrastructure Distributed Energy Interconnection Battery and Thermal Storage Transportation | Private Industry Federal Agencies State/Local Govt. International |

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



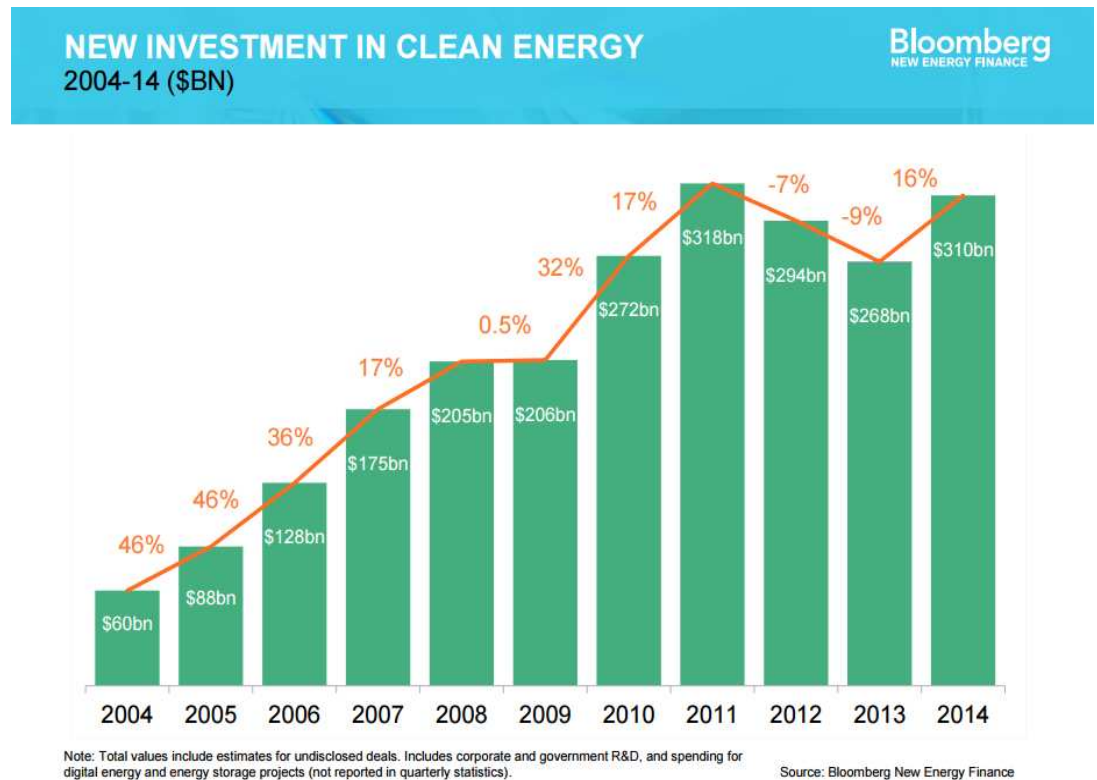
Industry Collaboration



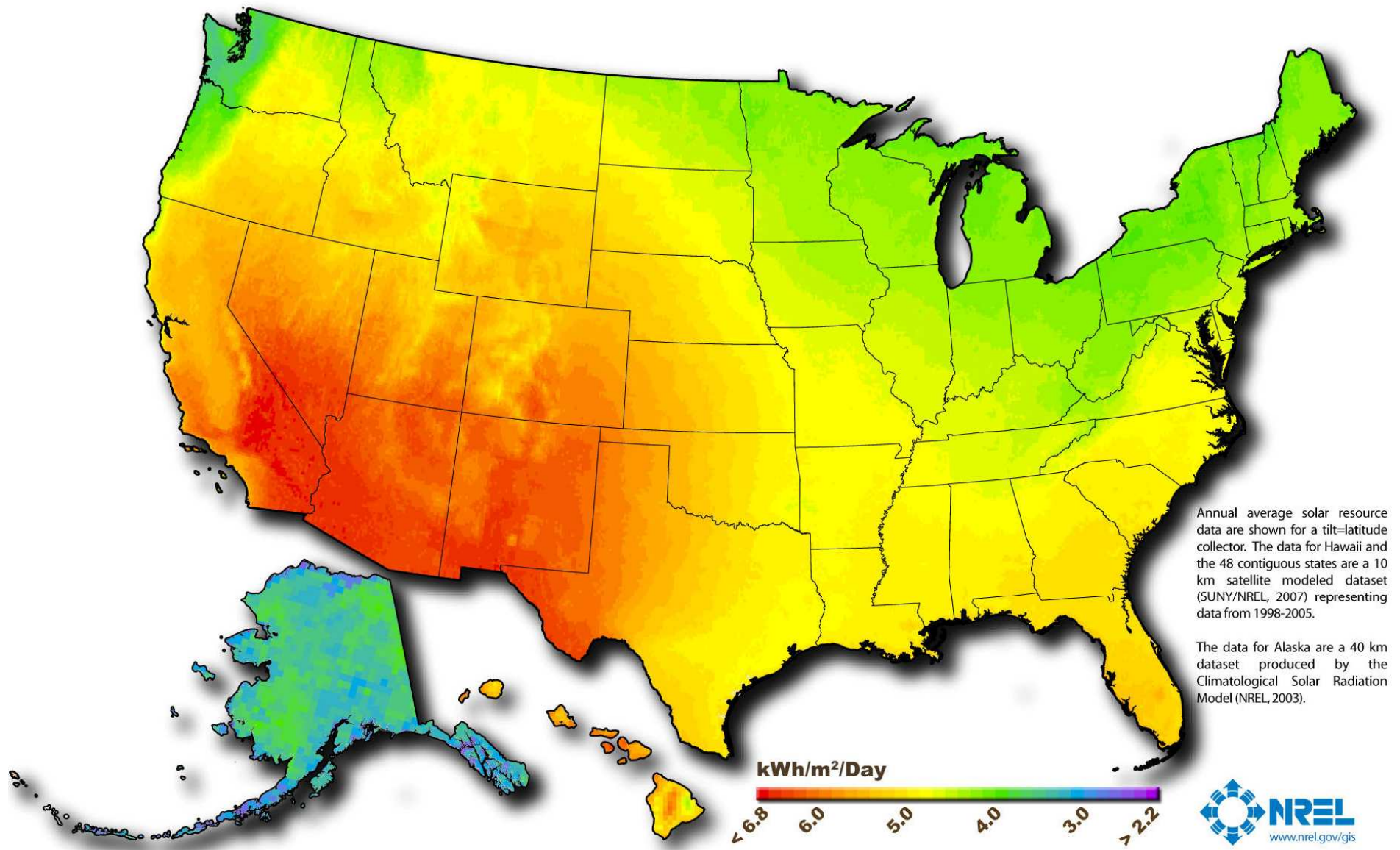
Challenges to Success

Energy Market Barriers

- Inconsistent public policy
- Outdated infrastructure
- Lack of knowledge
- Limited private investment
- Global renewable industry investment increased from 2013 to 2014



U.S. Photovoltaic Solar Resource



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 20,000 MW installed capacity
- More than 6,000 MW in 2014

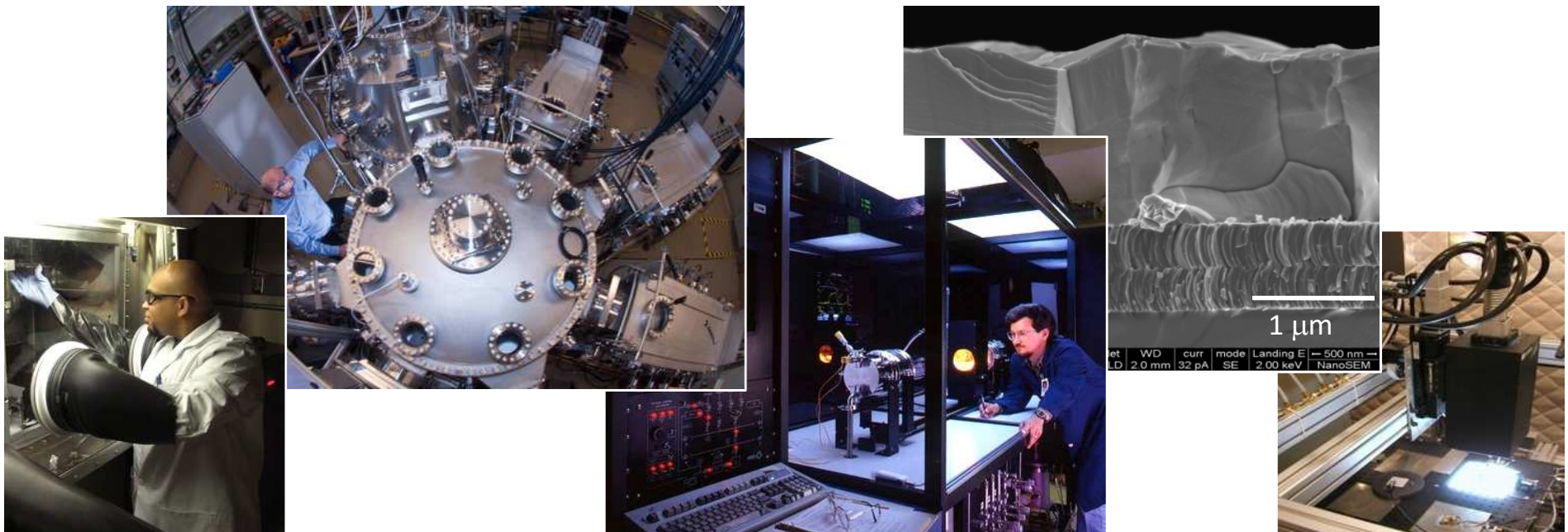
Source: U.S. Department of Energy, IEA,
Photo: 8.22-megawatt Alamosa, Colo., PV solar plant

PV R&D at NREL



Extensive Capabilities and PV Experience Under One Roof

*Material Synthesis • Device Processing • Device Design •
Device Modeling • Measurements & Characterization •
A Highly Trained Technical Staff*



Next-Generation PV Power

- Quantum-dot (QD)-based solar cells
 - QDs are nanoscale spheres of semiconducting material
 - QDs have the potential to dramatically increase the efficiency of solar cells, perhaps doubling it in some cases
 - NREL built the first all-QD solar cell in 2011 using lead sulfide QDs
- Plastic solar cells, which may incorporate QDs
- Perovskite solar cells, which have rocketed to high efficiencies during just a few years of research



SOLAR



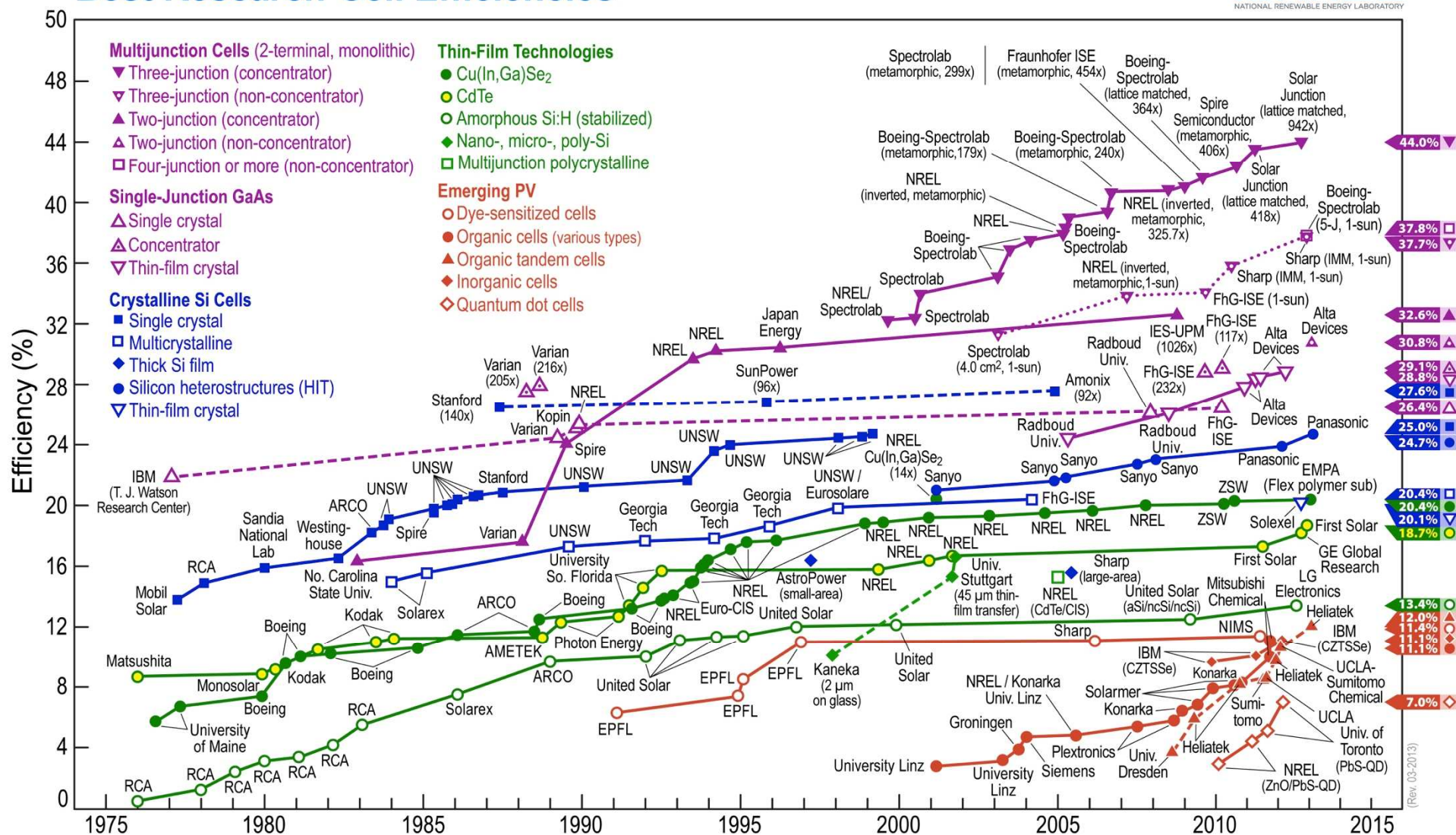
Helping Solar Manufacturers

- From 2000 to 2014, U.S. market share in the solar photovoltaic (PV) industry slipped from 30% to about 2%, driving a need for manufacturers to cut costs
 - NREL developed a simple chemical etch that causes silicon to absorb almost all light and avoids expensive antireflection coatings
 - NREL devised a tool to measure detailed PV performance in less than a second, making it feasible to test every cell on a manufacturing line
 - NREL's Optical Cavity Furnace uses light during processing to heat solar cells, leading to higher efficiencies and more uniform temperatures

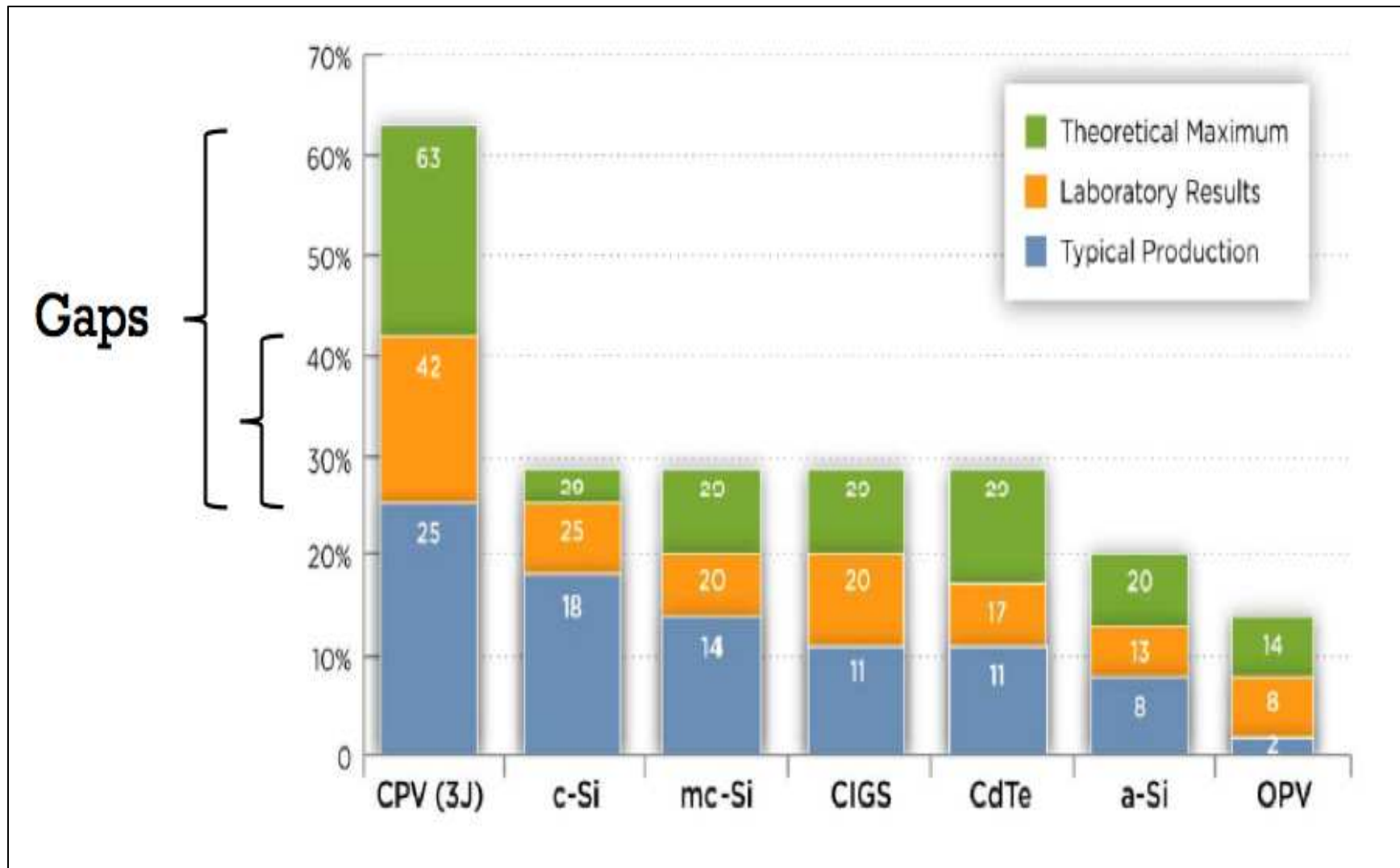
Best Research Cell Efficiencies



Best Research-Cell Efficiencies



Closing the gaps



US PV Market - Historic



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



BrightSource 392 MW Ivanpah Power Tower

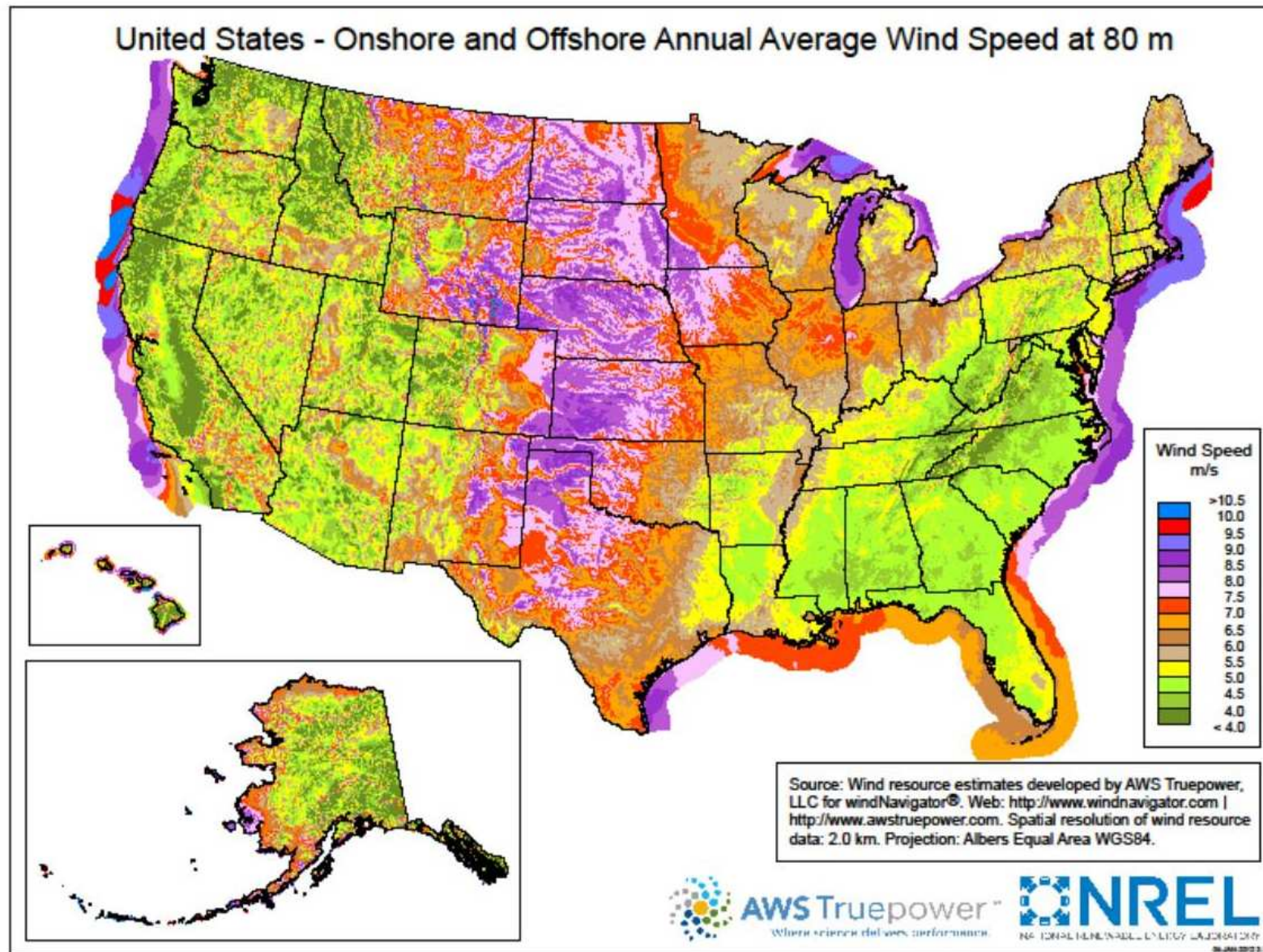
California/Nevada Border

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

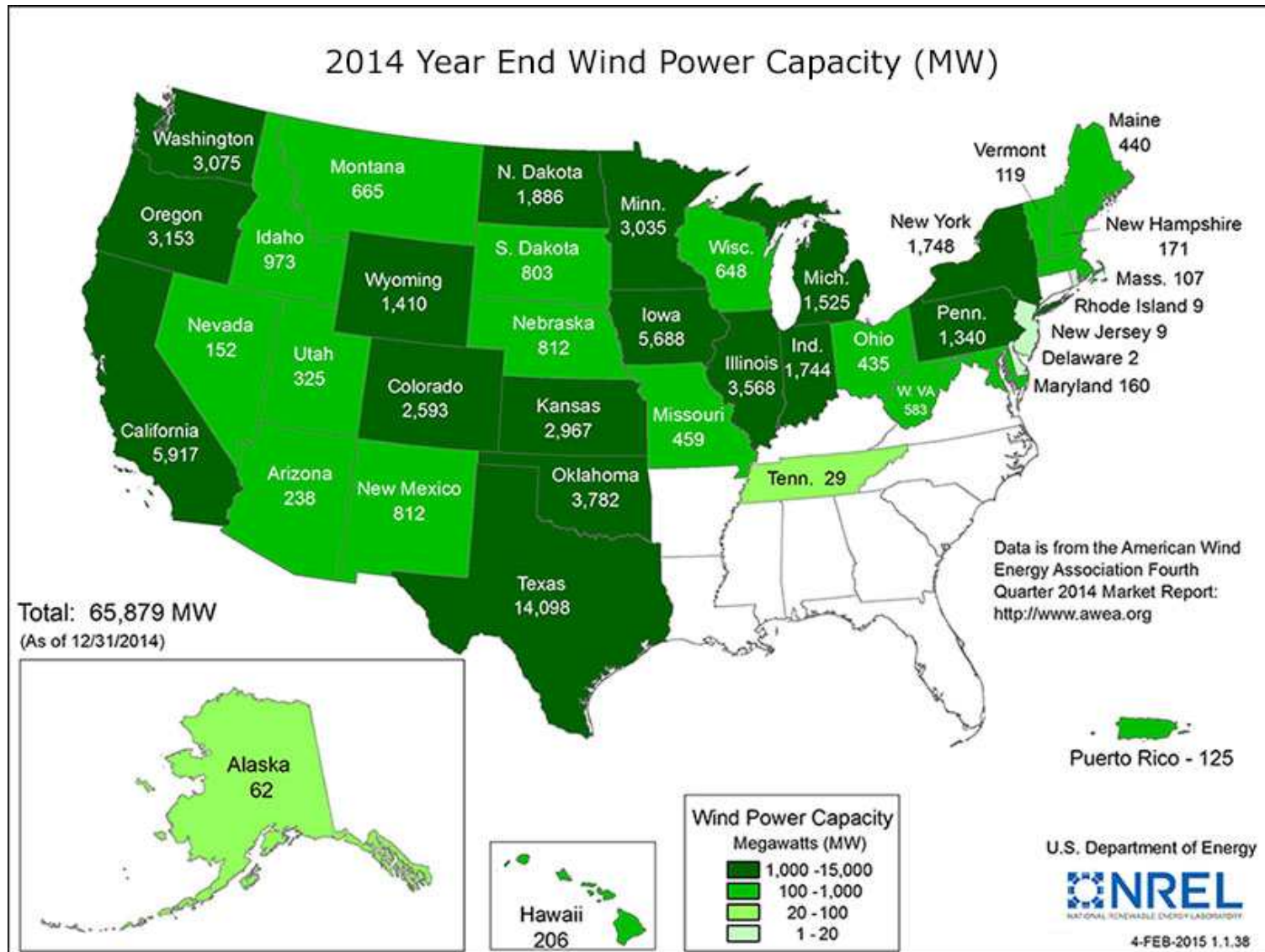
- 20% of the nation's electricity supply



*With no Production Tax Credit

Source: U.S. Department of Energy, American Wind Energy Association, Updated December 8, 2008

US Wind Installations



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



- 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

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

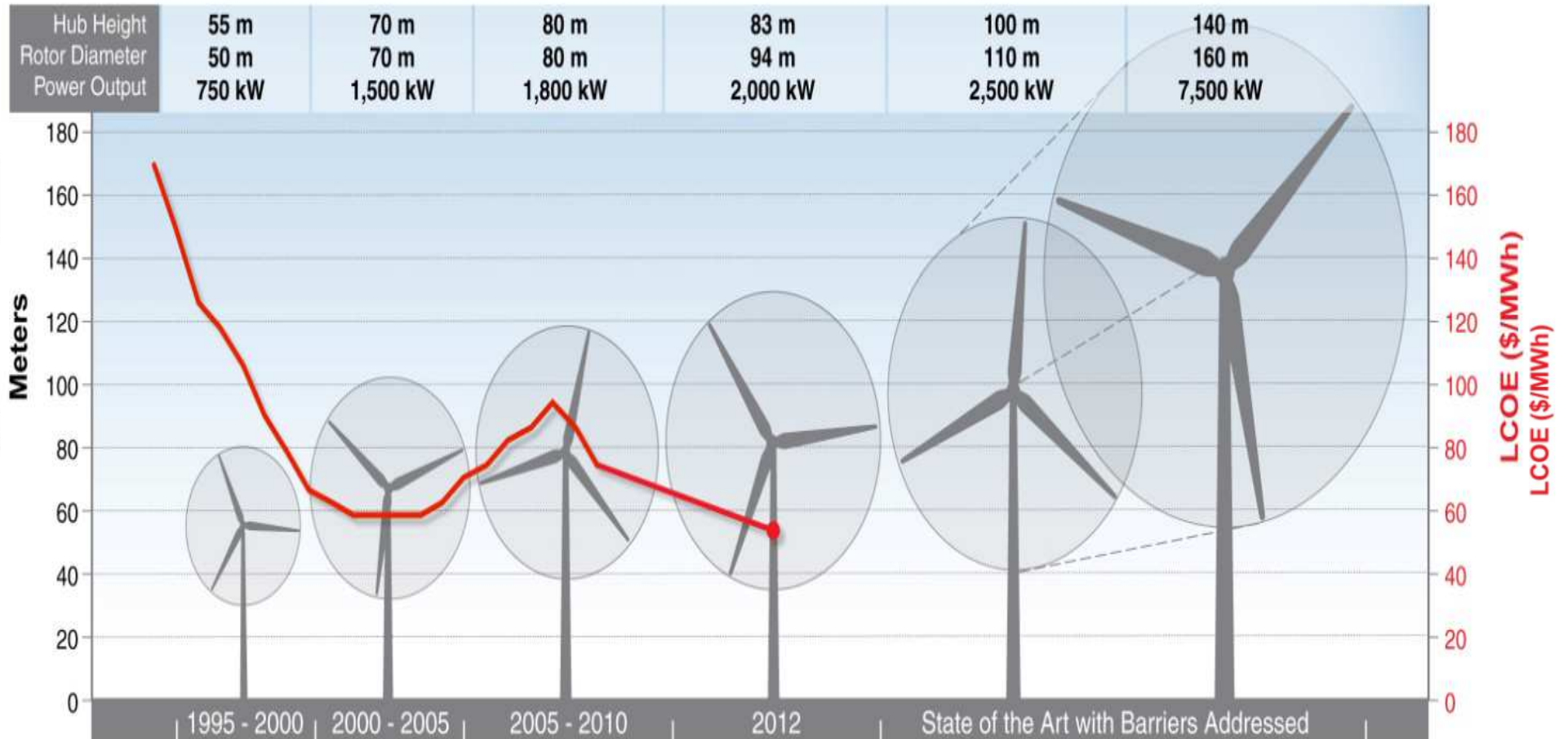


Drivetrain, Blade, and Full-System Testing

- NREL operates two of the few multimegawatt wind-energy-specific dynamometers in the world
- Integrated electrical and structural dynamics testing analyze impacts and interactions between utility-scale technologies and transmission grid
 - Multimegawatt dynamometers
 - 7-MW controllable grid interface
 - Utility-scale wind turbines
 - Multimegawatt storage systems
- Patented blade testing system removes need for costly hydraulic equipment



Turbines are getting larger



There is a limit on land



Photo from Martin Fischer, SSP Technology

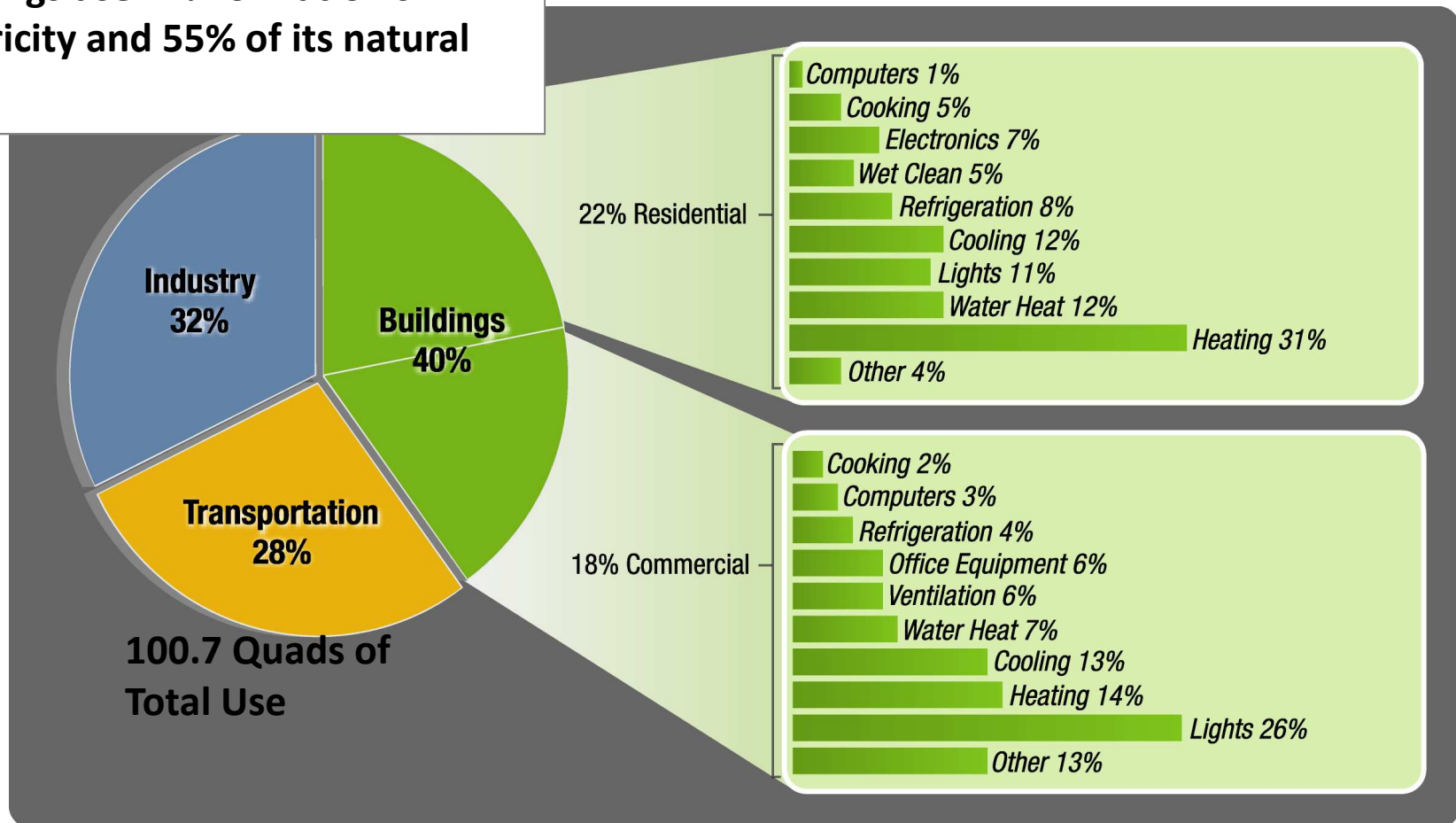
Horns Rev Offshore Wind Farm North Sea, Denmark



- 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



BUILDINGS

RSF Key Design Strategies

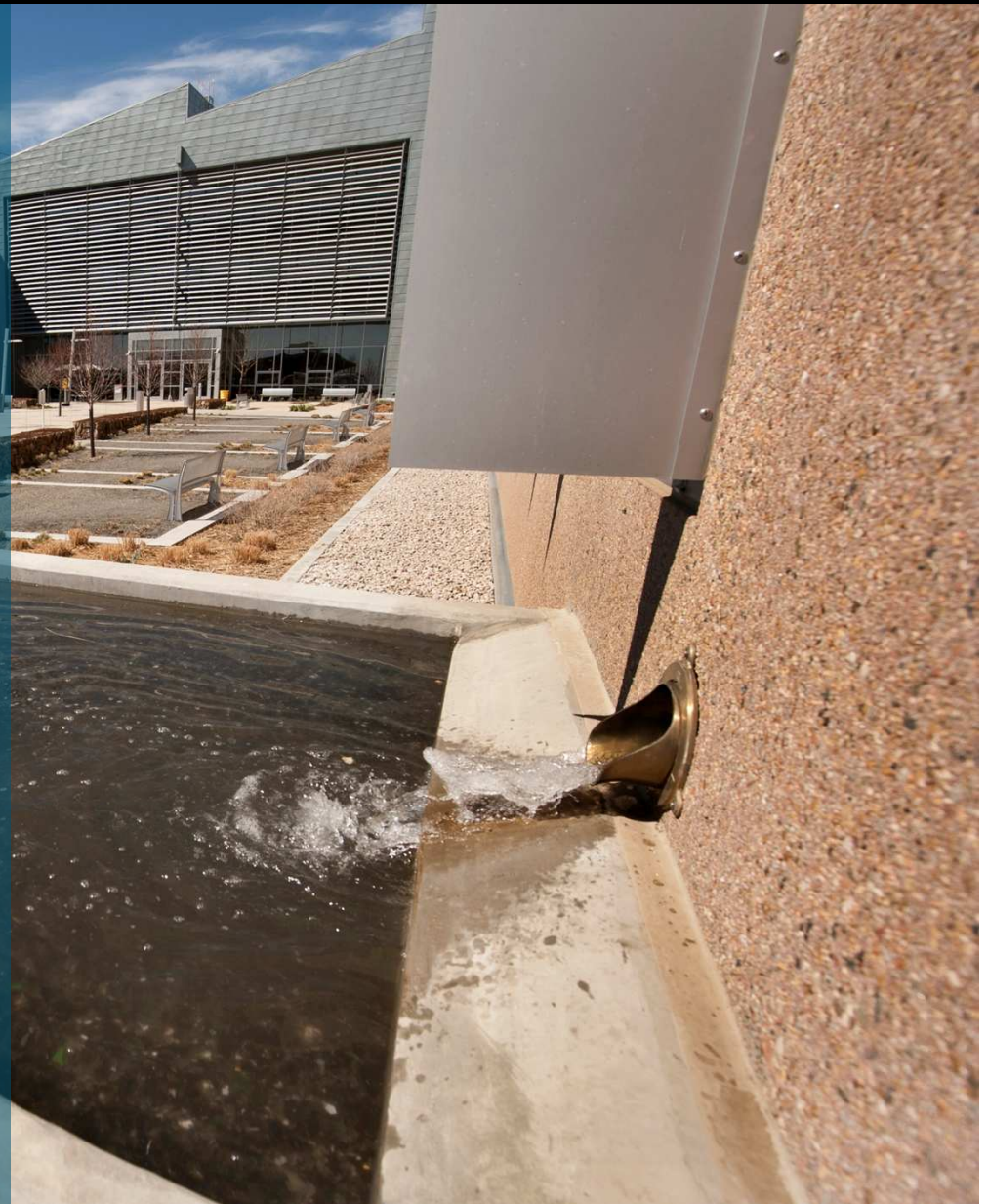
- Optimal orientation and office space layout
- Fully daylit office wings with high-performance electrical lighting
- Continuous insulation precast wall panels with thermal mass
- Operable windows for natural ventilation
- Radiant heating and cooling
- Outdoor air preheating
 - Transpired solar collector
 - 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

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.



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



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



BUILDINGS

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

iGo Power Smart Towers

Reduces "vampire" energy use

VOIP phones 2 Watts

Laptop
30 Watts

Desktop Computer (Energy Star)
300 Watts

Removing personal Space Heater
saves 1500 Watts

Multi-function Devices
100 Watts (continuous)

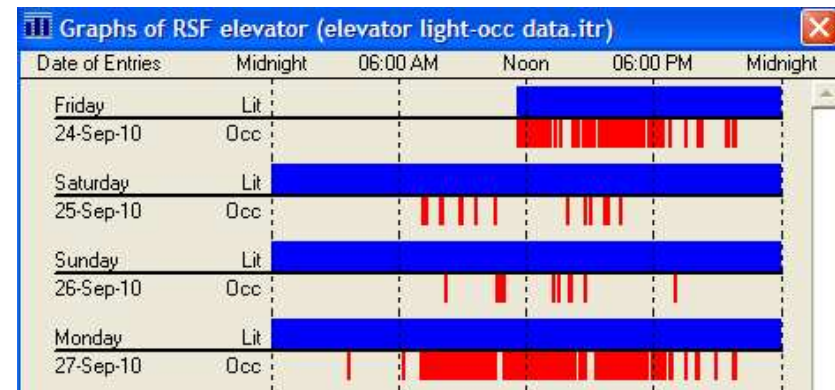
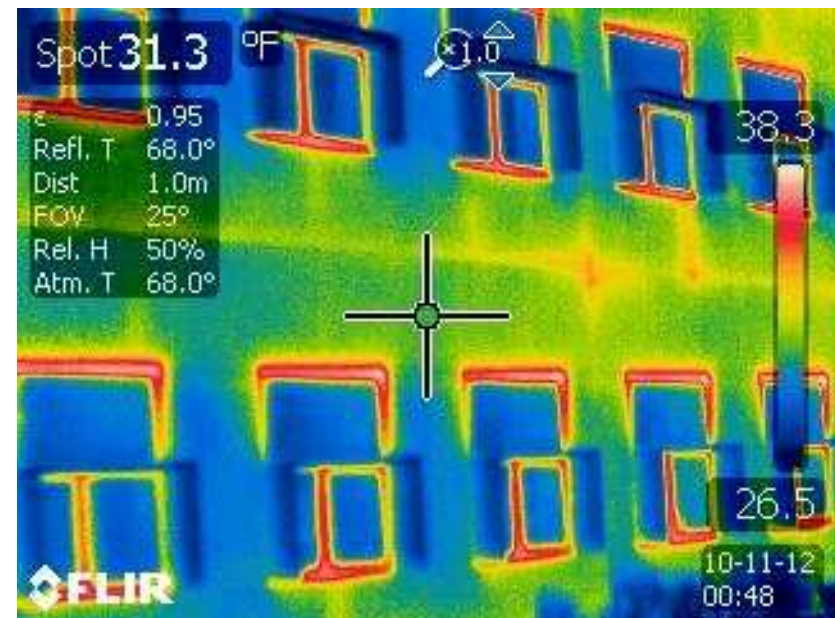


Removing Desktop
Printers Saves
~460 Watts/Printer

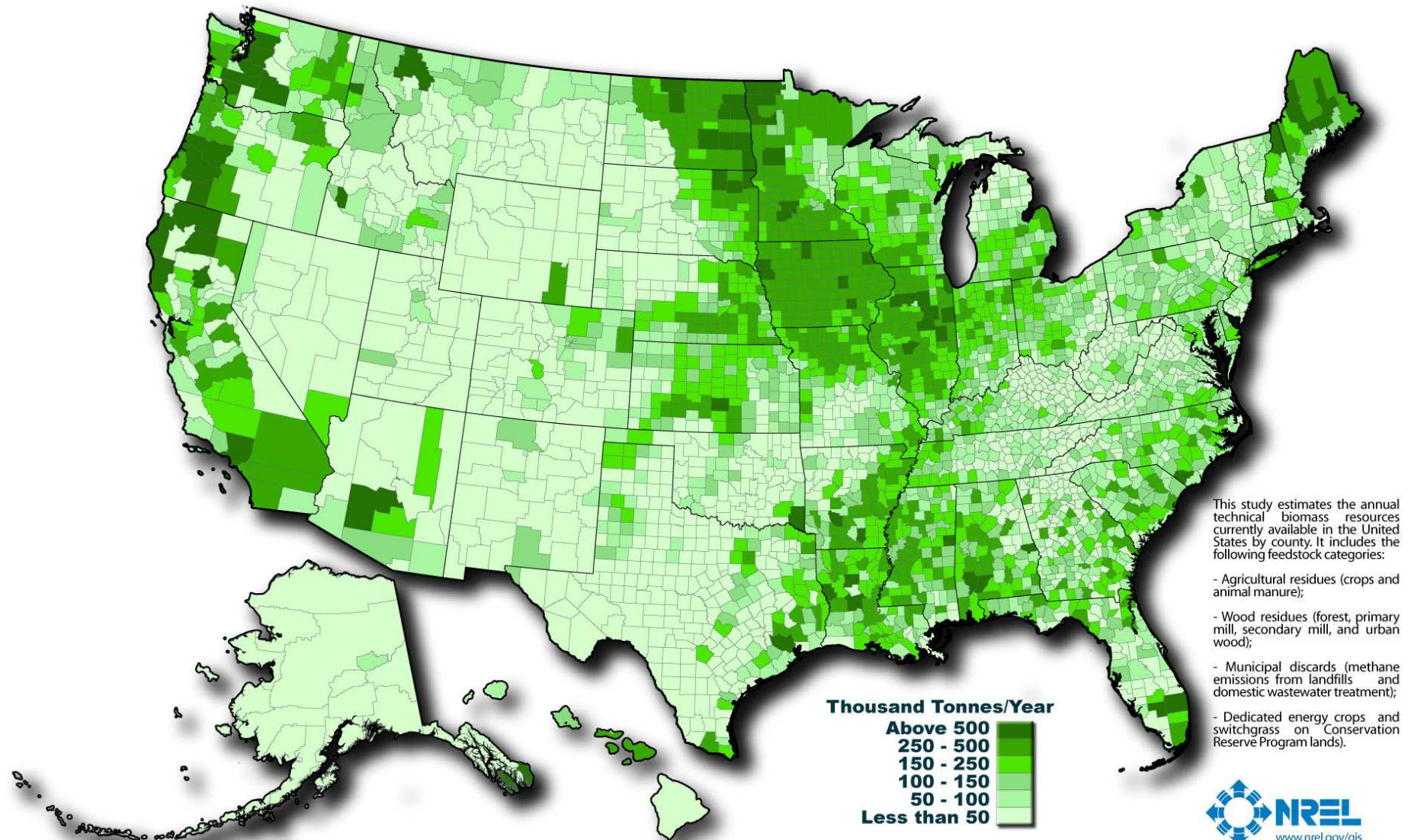
Energy Usage and Data

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



U.S. Biomass Resource



Author : Billy Roberts - October 20, 2008

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
 - Collaborated on biomass characterization, pretreatment, and process integration research
 - Exceeded enzyme cost-reduction goal by 10x
- Newly discovered enzymes promise further cost cuts

BIOENERGY

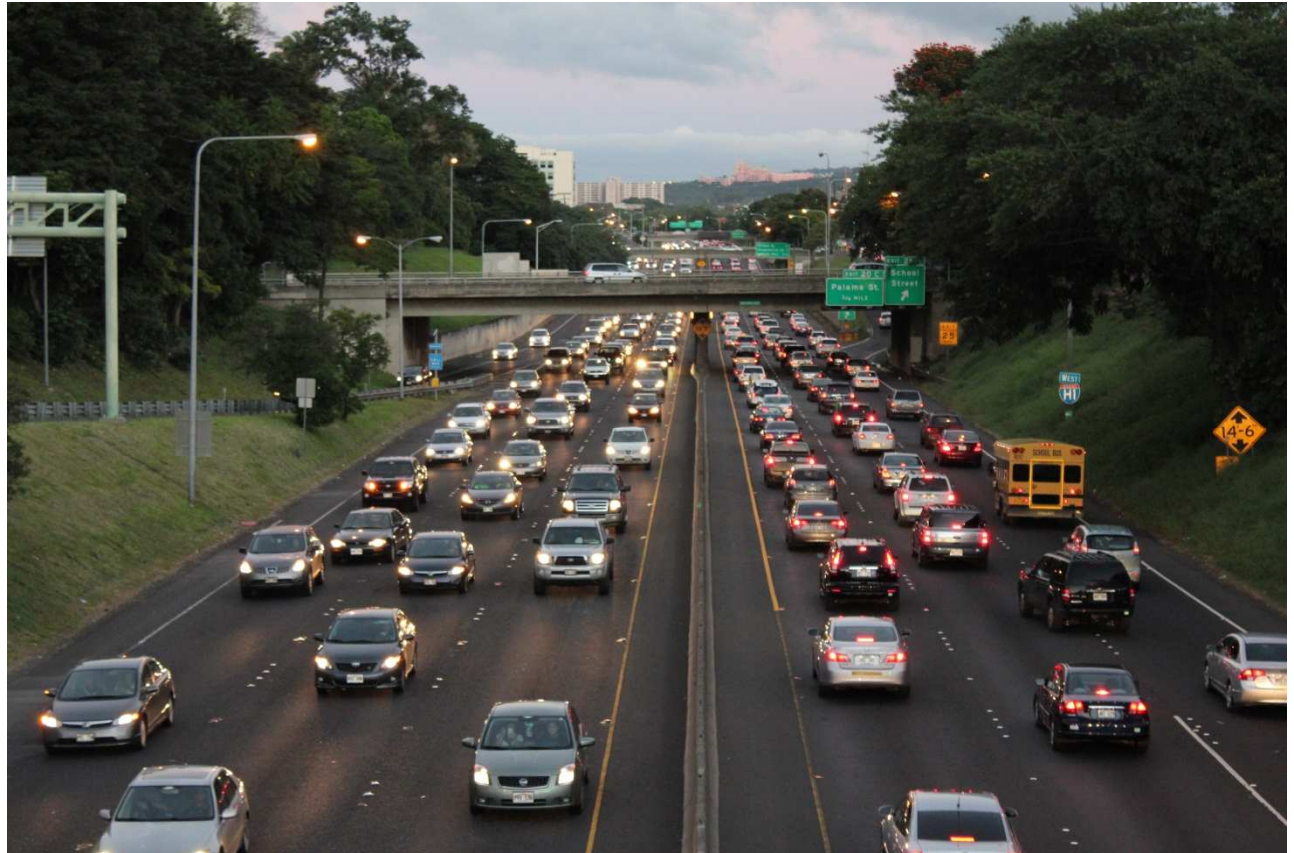
Renewable Fuel Heat Plant



- 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





Transportation

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

Sustainable Transportation

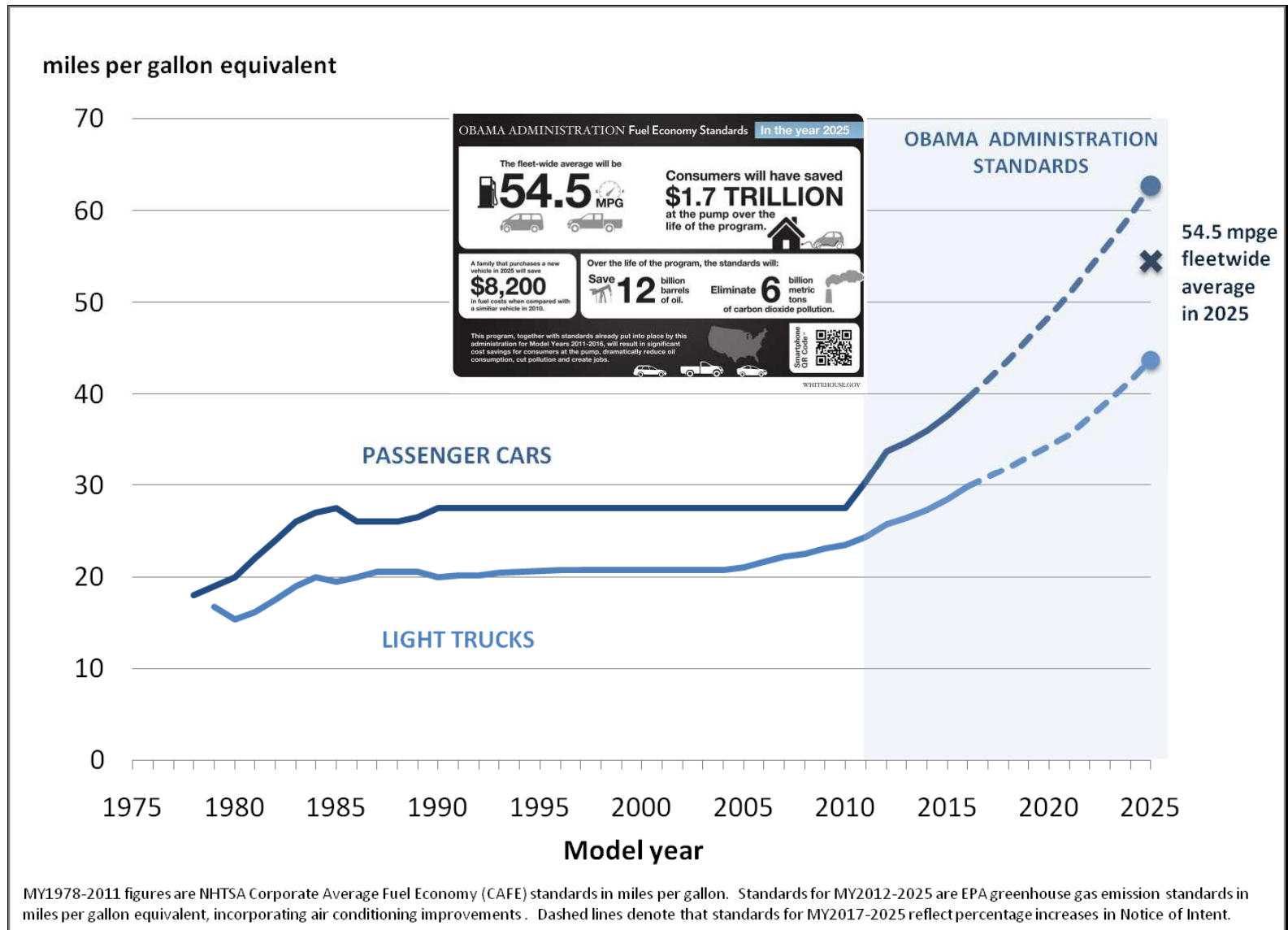
NREL's transportation RD&D accelerates widespread adoption of energy-efficient vehicles and clean alternative fuels with:

- Computer-aided engineering tools to design better electric vehicle batteries faster
- Platooned trucks that demonstrate ~6.4% fuel savings
- Recruitment of more than 200 businesses for the Workplace Charging Challenge
- Climate control configurations to reduce electric vehicle energy use by ~66.5%
- R&D 100 Award-winning calorimeters that provide the most accurate measurement of battery thermal performance



TRANSPORTATION

Light Duty Vehicle Fuel Economy Standards, 1978-2025

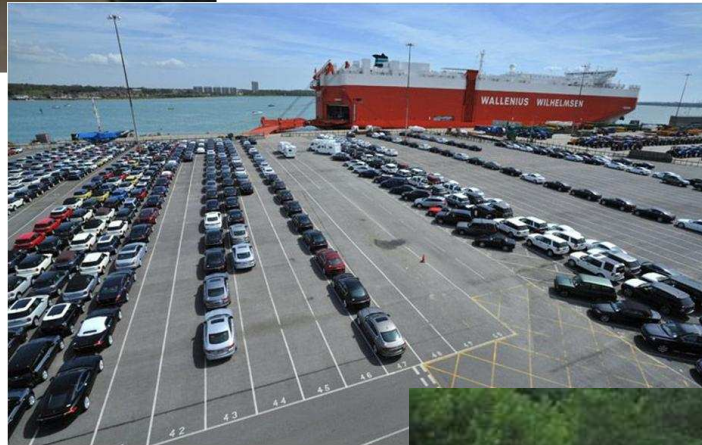


How Long Will it Take to Replace the U.S. LDV Fleet?



**240 Million
Light Duty
Vehicles**

**16 Million
Sales/Year**



**15 Years
to Replace
LDV Fleet**





Analyses, Models, and Tools

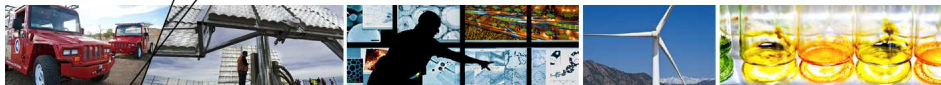
- NREL analyzed high penetrations of renewable energy in the eastern and western U.S. power grids for benefits, impacts, and mitigation strategies
- For solar photovoltaic manufacturing, NREL modeling tools identify cost improvements and assess competitive advantages
- The OpenEI website links and shares energy data worldwide
- NREL's System Advisor Model determines the economic value of proposed solar, wind, and geothermal projects

ANALYSIS

High-Penetration Renewables



Renewable Electricity Futures: *Exploration of up to 80% renewable electricity penetration in the United States*



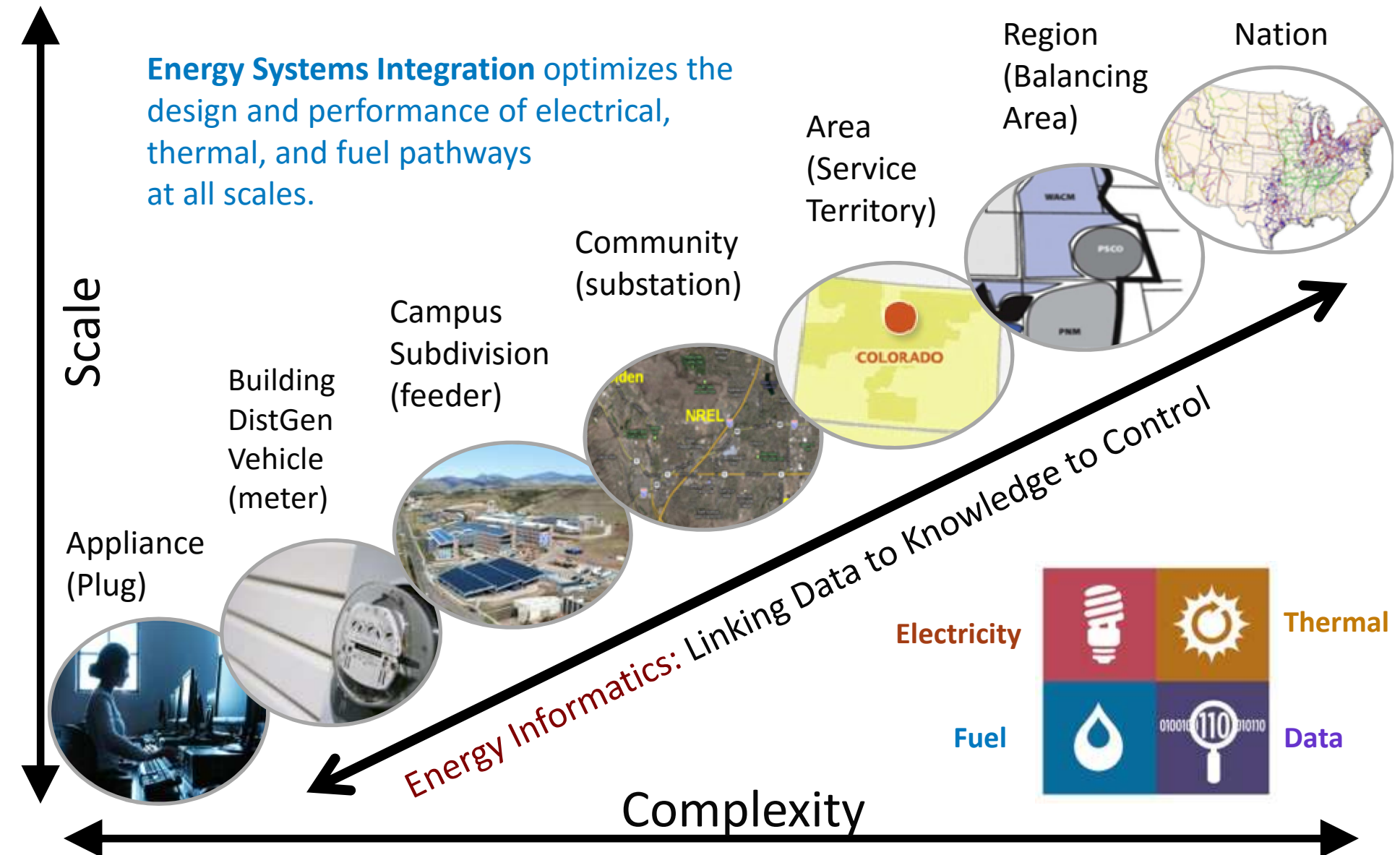
Maureen Hand, NREL
Ed DeMeo, RECS Inc.
Donna Hostick, PNNL
Trieu Mai, NREL
C. Adam Schlosser, MIT

World Renewable Energy Forum
Denver, Colorado
May 17, 2012

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.


New study on the feasibility of renewable energy providing up to 80% of electricity in the U.S. by 2050.

Energy Systems Integration Continuum



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

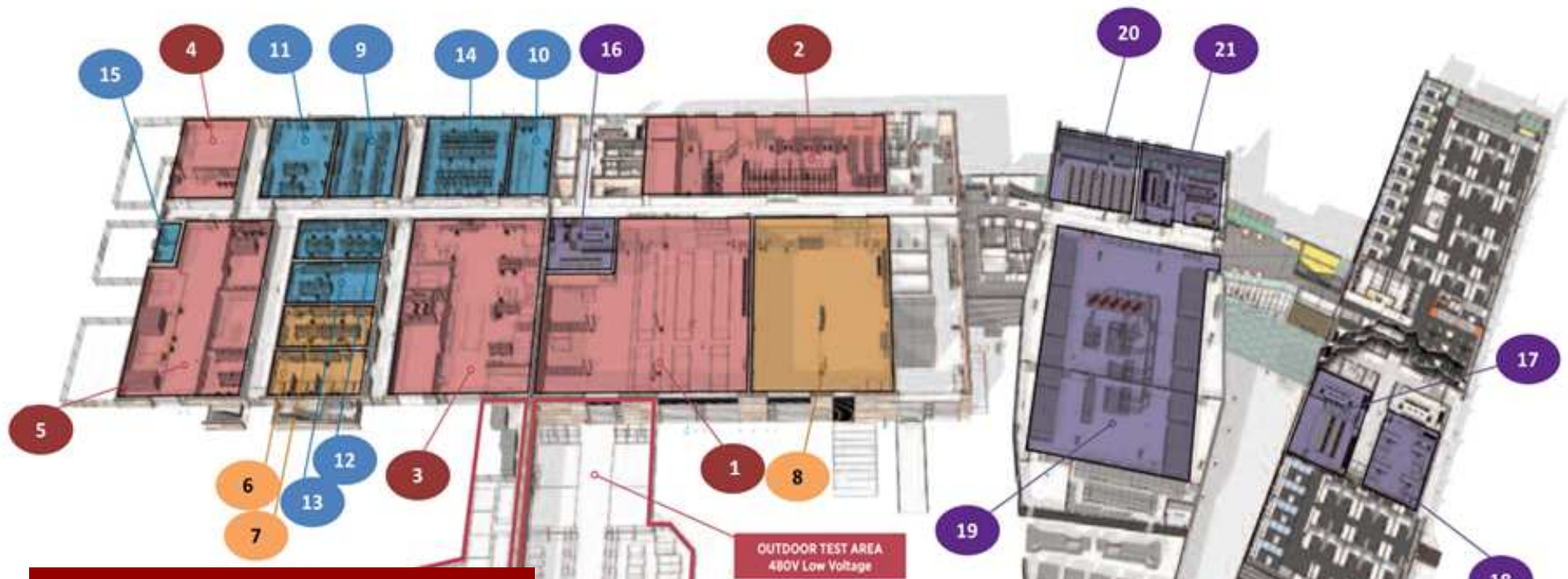


Energy Systems
Integration

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

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

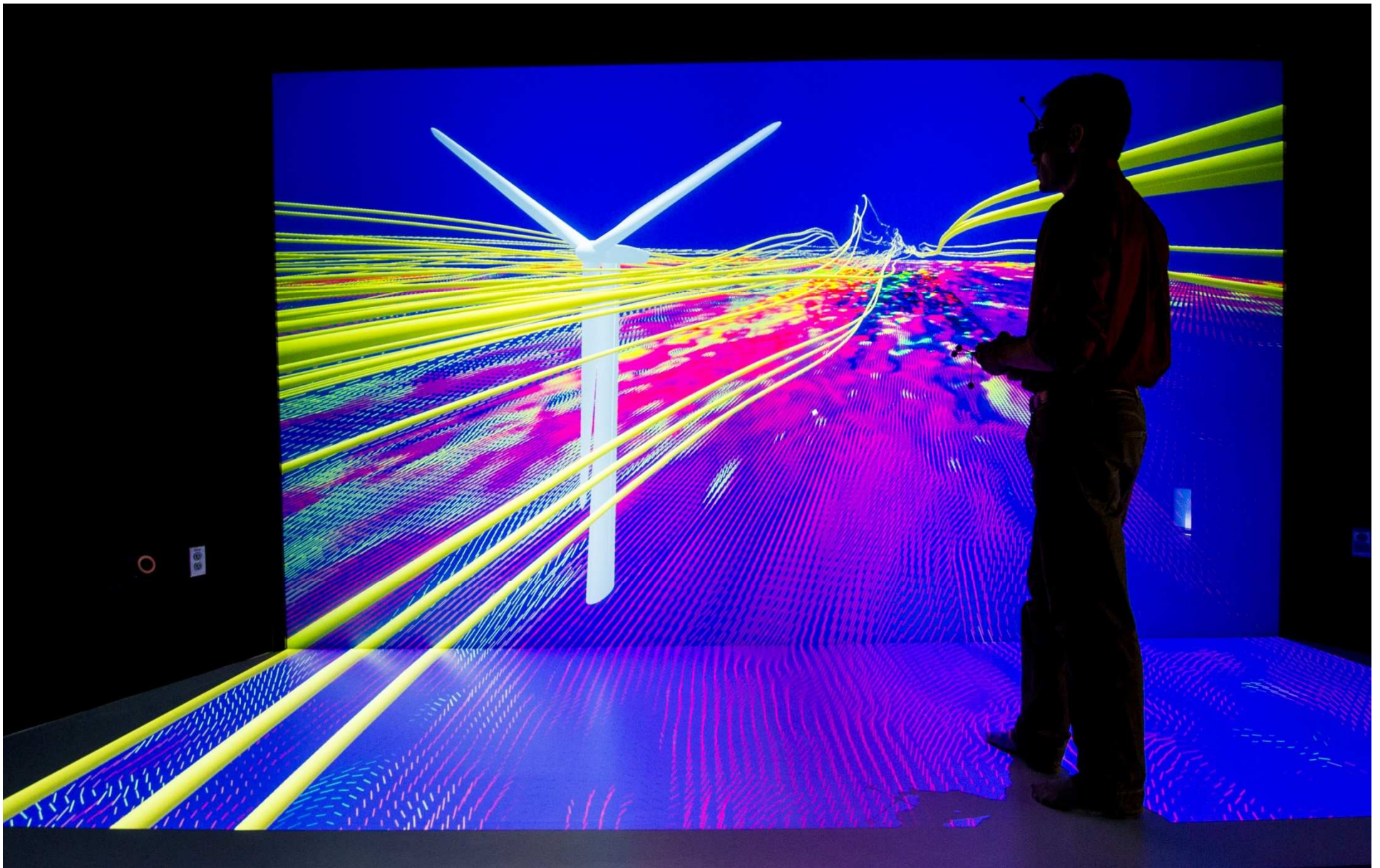
High Performance Computing, Data Analysis, and Visualization

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

Petaflop Computing Capability



2-D and 3-D Imaging





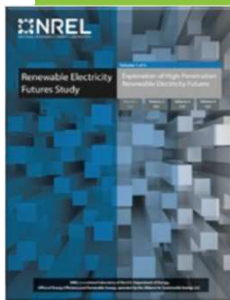
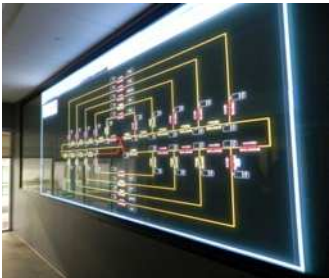
For more than 37 years, NREL has delivered innovation impact enabling the emergence of the U.S. clean energy industry.



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

NREL's Energy Vision

A clean, resilient and reliable energy system that contributes to economic prosperity, national security, and environmental quality



High Performance Buildings

Research Support Facility

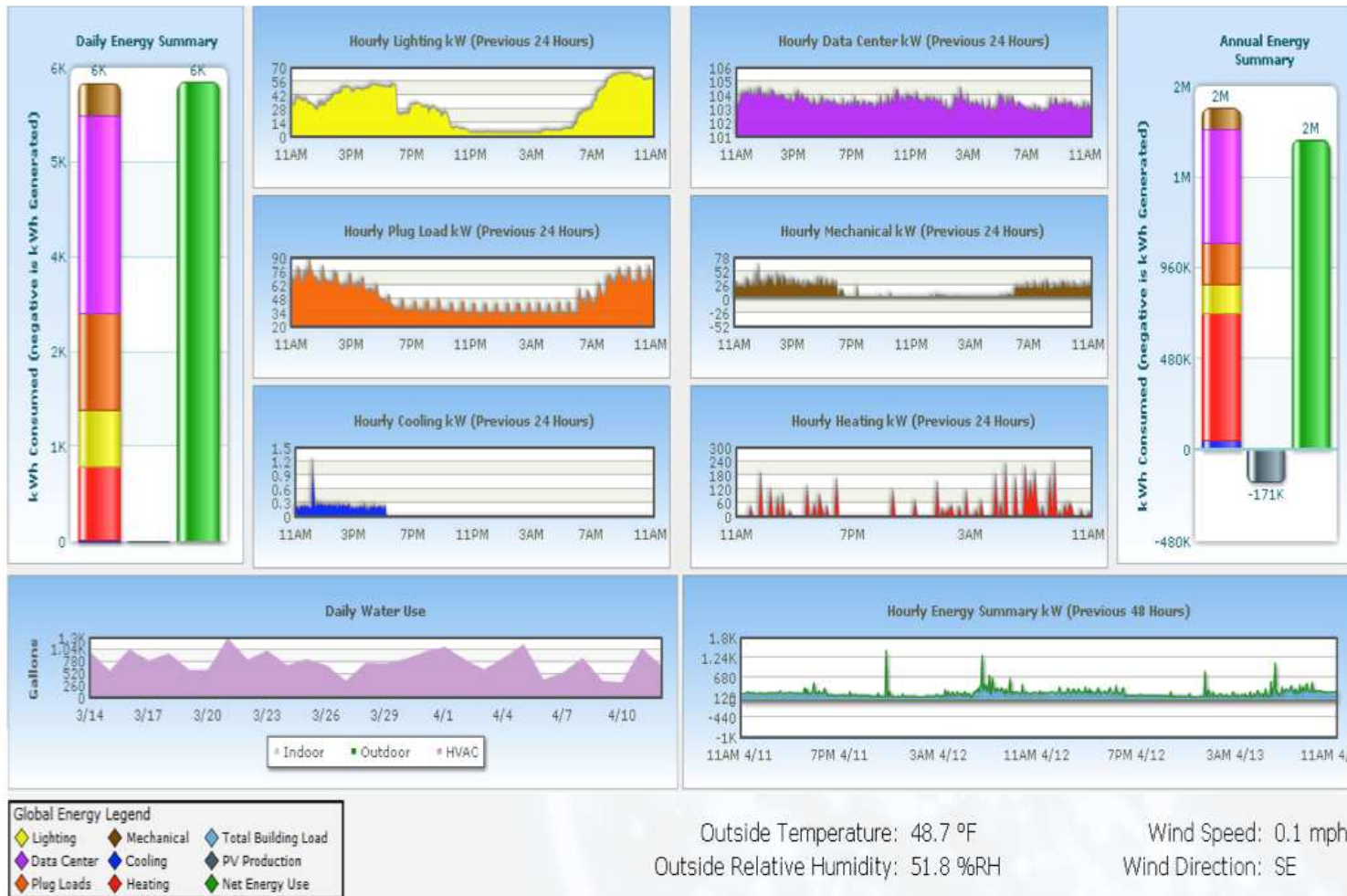
- Prototype for the future of large-scale ultra high energy efficient buildings
- Changing the views of the commercial building industry
- Zero energy buildings are doable and affordable

Not a concept, but a reality



Energy Monitoring

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



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



TRANSPORTATION