NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Moving Toward a Clean Energy Future

National University of Singapore

November 3, 2010

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Laboratory Director

Energy Challenges

Achieving a Sustainable Energy Economy

*Requires a National Energy Grand Challenge**

Lead Coordinated RD3E Strategy in Sustainable Energy

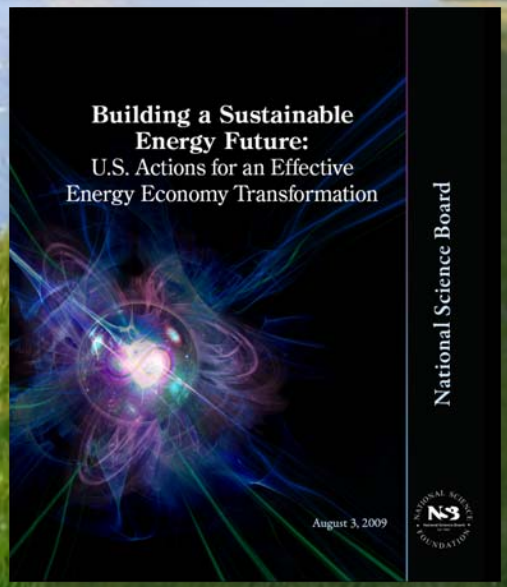
Boost R&D Investment

Construct Essential Policies & Market Conditions

Support Education & Workforce Development

Lead Globally

Promote Public Awareness & Action



* Recommendations of the National Science Board Task Force on Sustainable Energy

Our Energy System

Supply & Conversion

Oil 40%

Coal 23%

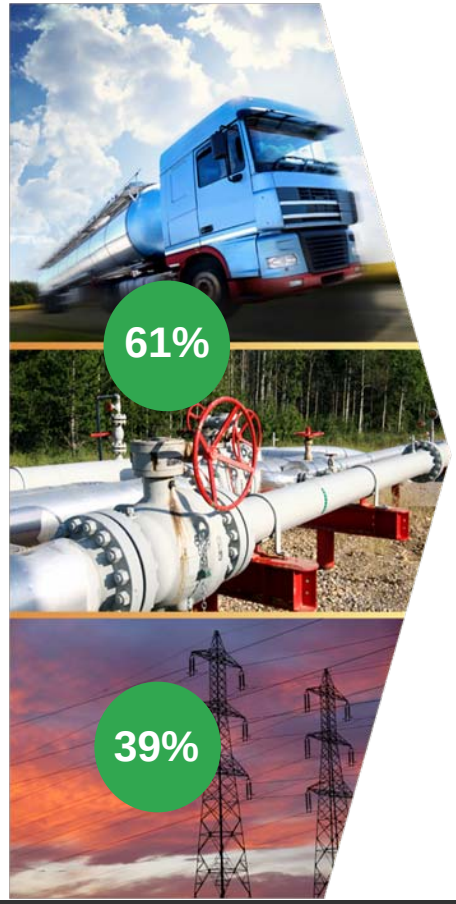
Natural Gas 23%

Nuclear 8%

Hydro
Wind
Solar
Biomass
Geothermal
6%

100 Quads

Transmission & Distribution



Utilization

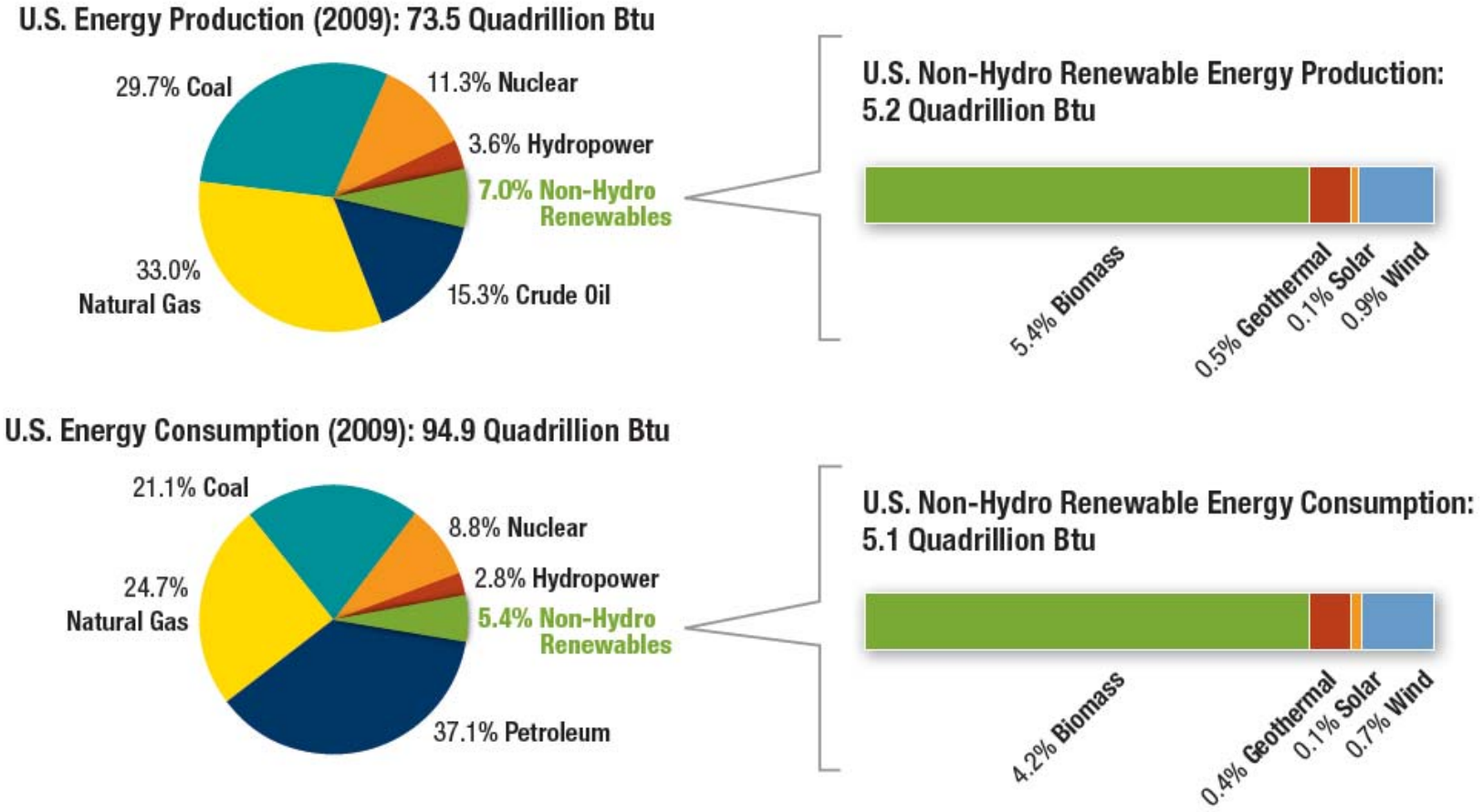
27%

40%

33%

Lost energy as inefficiencies – 62%

U.S. Energy Production and Consumption (2009)



Source: EIA; full references are provided starting on p. 123.

Note: Because hydropower is considered a conventional source of energy, it is accounted for separate from other new renewable sources of energy. Energy consumption is higher than energy production due to oil imports.

Source: NREL, *2009 Renewable Energy Data Book* http://www.nrel.gov/docs/fy10osti/48178.pdf

The New U.S. National Priorities

- Invest $150B in alternative energy over 10 years
- Create green jobs with clean, efficient American energy
- Double production of alternative energy in three years – enough to power 6 million homes
- Upgrade the efficiency of more than 75% of federal buildings and two million private homes
- Put one million PHEVs on U.S. roads by 2015
- Reduce CO_2 emissions by 80% below 1990 levels by 2050
- Transform our economy with science and technology

G8Website/ANSA Photo: Alessandro Di Meo

U.S. Energy and Environmental Priorities

Clean Energy Jobs ◆ Energy Security ◆ Reduce Carbon Emissions

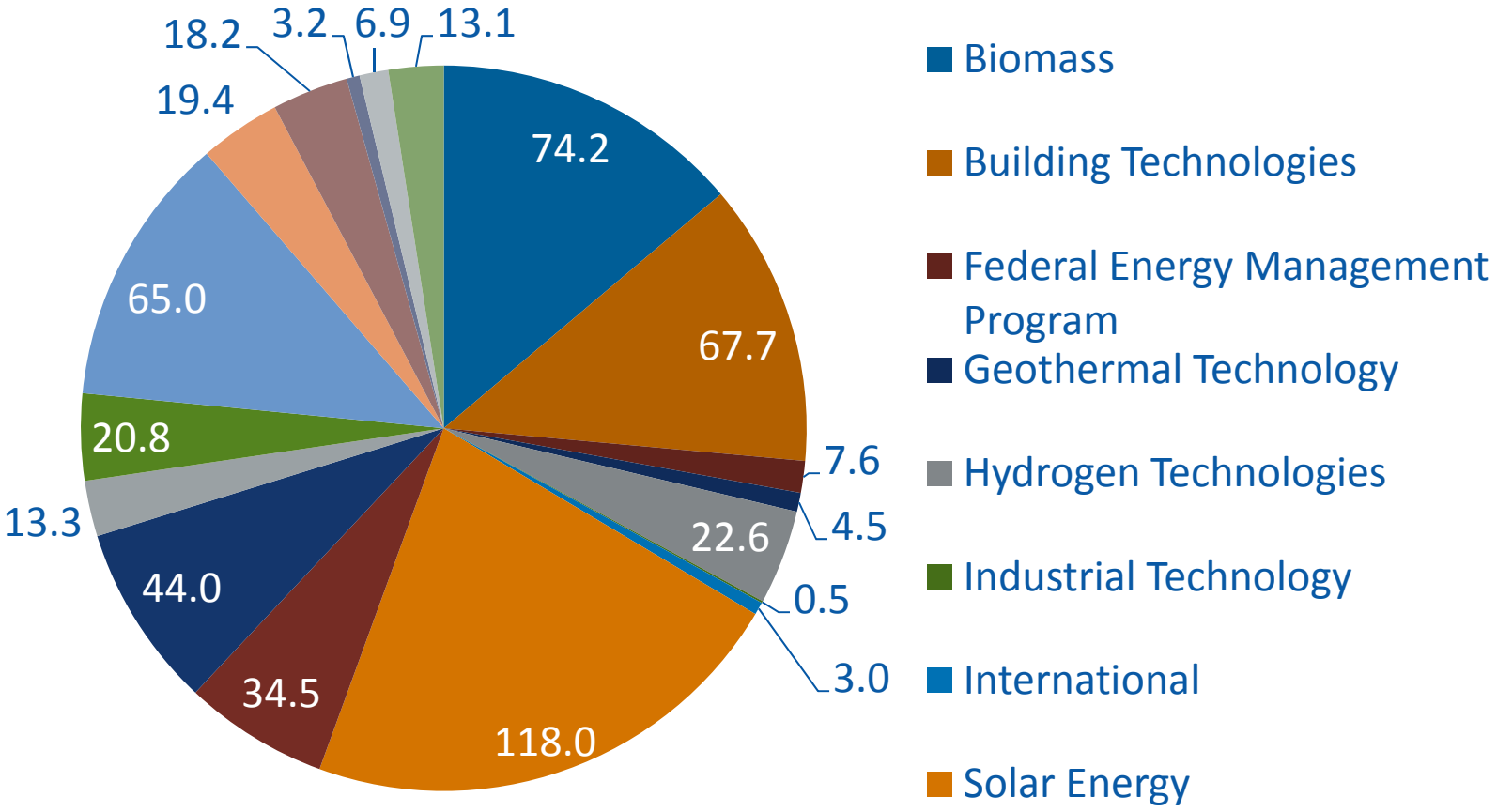
U.S. DOE Fiscal Year 2011 Budget Request:

- **Renewable Energy Technology Research**
  - **Solar: $302M (22.4% increase)**
  - **Wind: $123M (53% increase)**
  - **Geothermal: $55M (25% increase)**
- **Renewable Energy Project Development**
  - **Energy credit subsides**
  - **Energy manufacturing tax credit**
- **Supporting Science**
  - **Energy Innovation Hubs**
  - **Advanced Research Projects Agency**
  - **Energy Frontier Centers**
- **Education and Workforce Development**

G8Website/ANSA Photo: Alessandro Di Meo

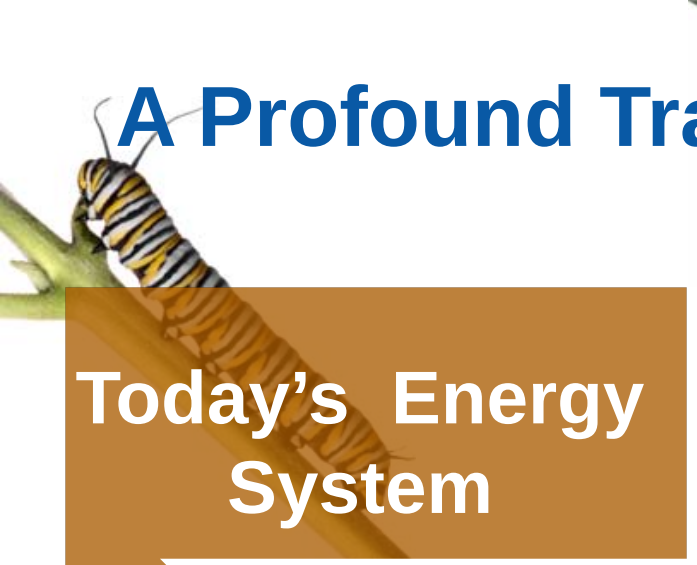
NREL FY2010 Funding by Program

FY2010 received $536.5M



Updated 10/10

A Profound Transformation is Required



Today's Energy System

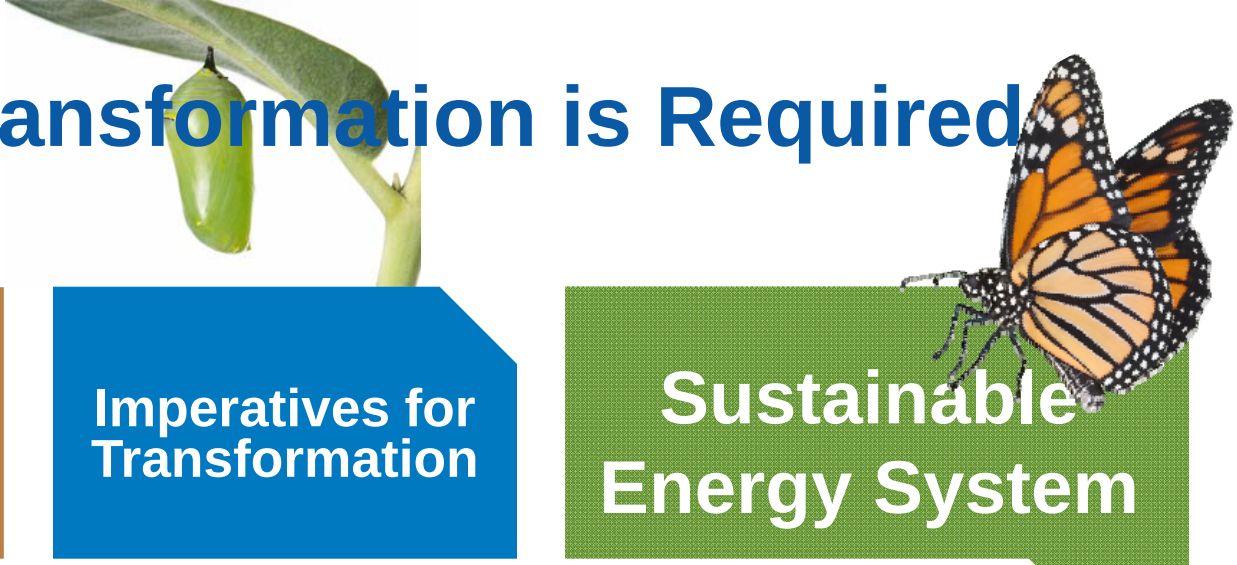
- Dependent on foreign sources
- Subject to price volatility
- Increasingly unreliable
- 2/3 of source energy is lost
- Produces 25% of the world's carbon emissions

Imperatives for Transformation

DEFINE THE END STATES

REDUCE NEW TECHNOLOGY RISK

ACCELERATE ADOPTION



Sustainable Energy System

- Carbon neutral
- Efficient
- Diverse supply options
- Minimal impact on resources
- Creates sustainable jobs
- Accessible, affordable and secure

Energy is a means to an end, not an end in itself

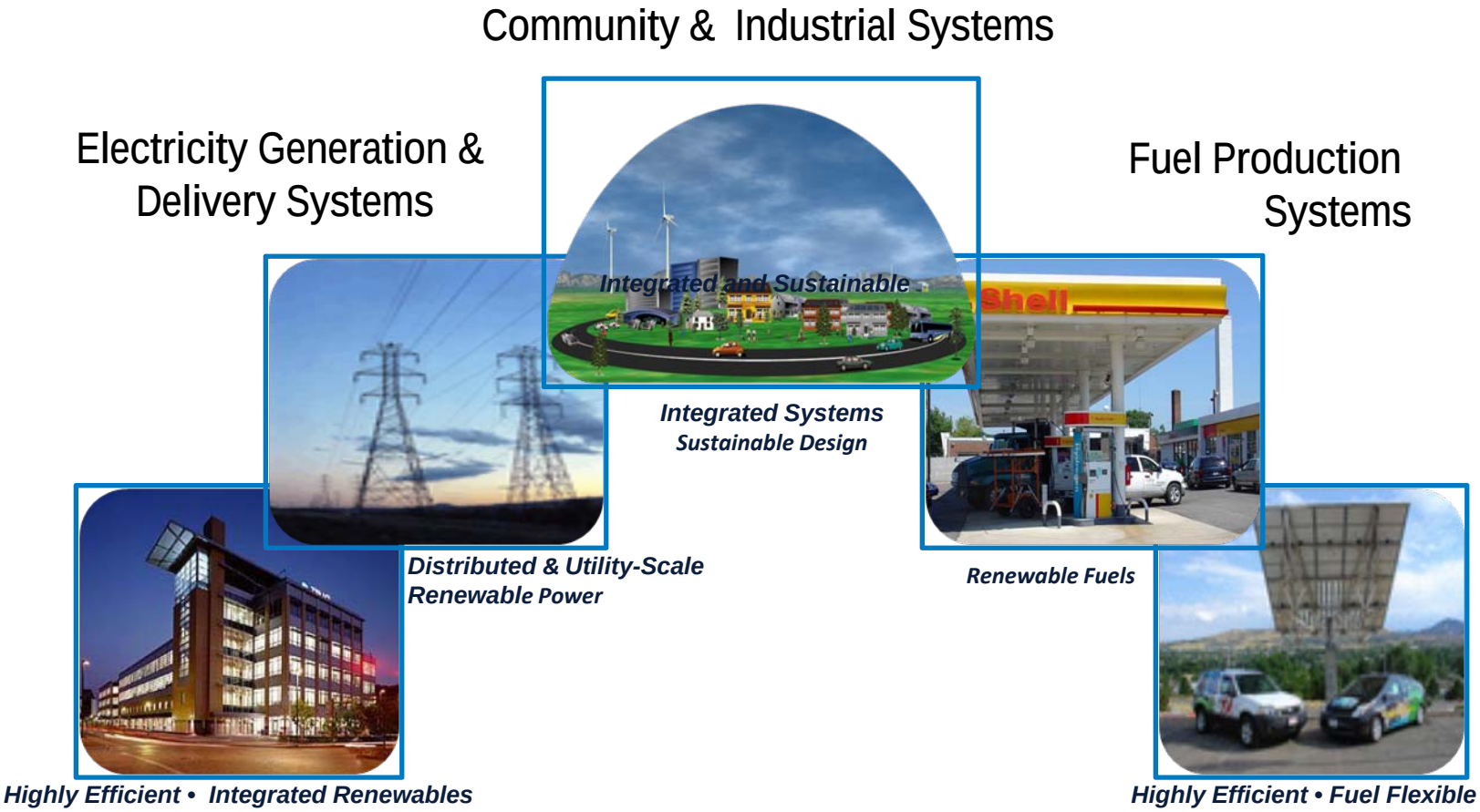
Heat and power for where we live and work

Sustainable Electricity System

Fuel and power for mobility and access

Sustainable Transportation System

Need a Sustainable "System of Systems"



Near-Term Impact: Harvest Past R&D Energy Investments

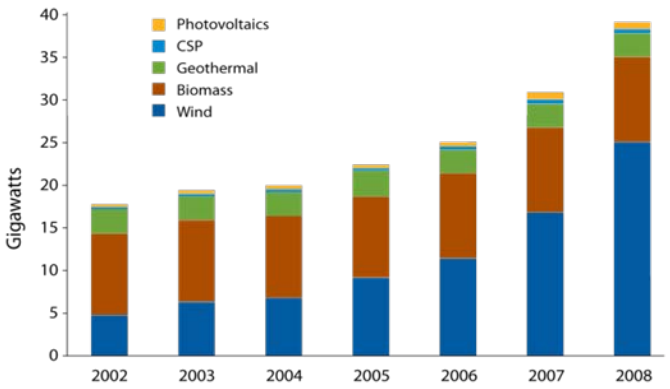
Remove Barriers to Broad Deployment

- Fuels Economic Recovery
- Creates Jobs

NREL Provides Data, Tools and Technical Assistance

- Educate and inform
- Develop codes and standards
- Inform policy options, program design, and investment choices
  - Resource Assessment
  - Technology Analysis
  - Policy Analysis

U.S. Renewable Electricity Installed Nameplate Capacity



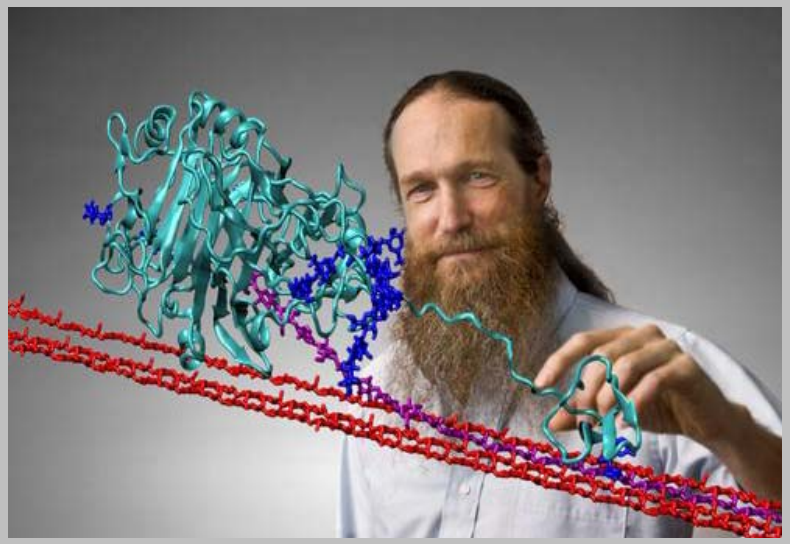
Source: EIA Annual Energy Outlook 2009 Early Release

Mid-Term Impact: Accelerate Next-Generation Technology to Market

- NREL Focus on Technology and Systems Development
- Unique Partnering Facilities
- Testing and Validation Capabilities

Long-Term Impact: Requires Breakthrough/ Translational Science

Translational science at NREL focuses on renewable energy and energy efficiency innovations that will most benefit the nation in practical applications.

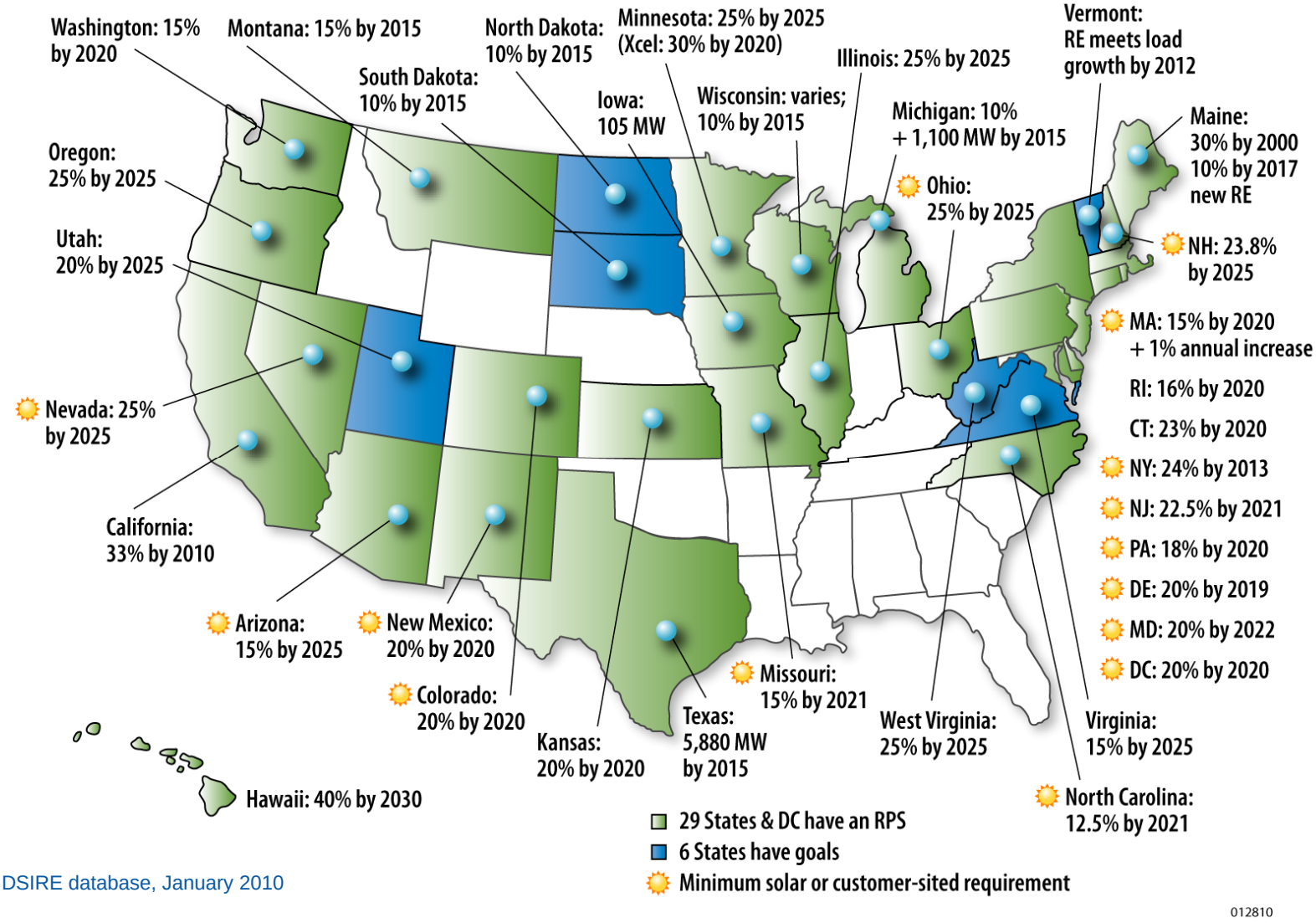


Michael Crowley, a senior scientist with the Chemical and Biosciences Center, created an animated model of Cel7A, nature's primary enzyme for decaying plants.

NREL: Managing the science-to-technology interface

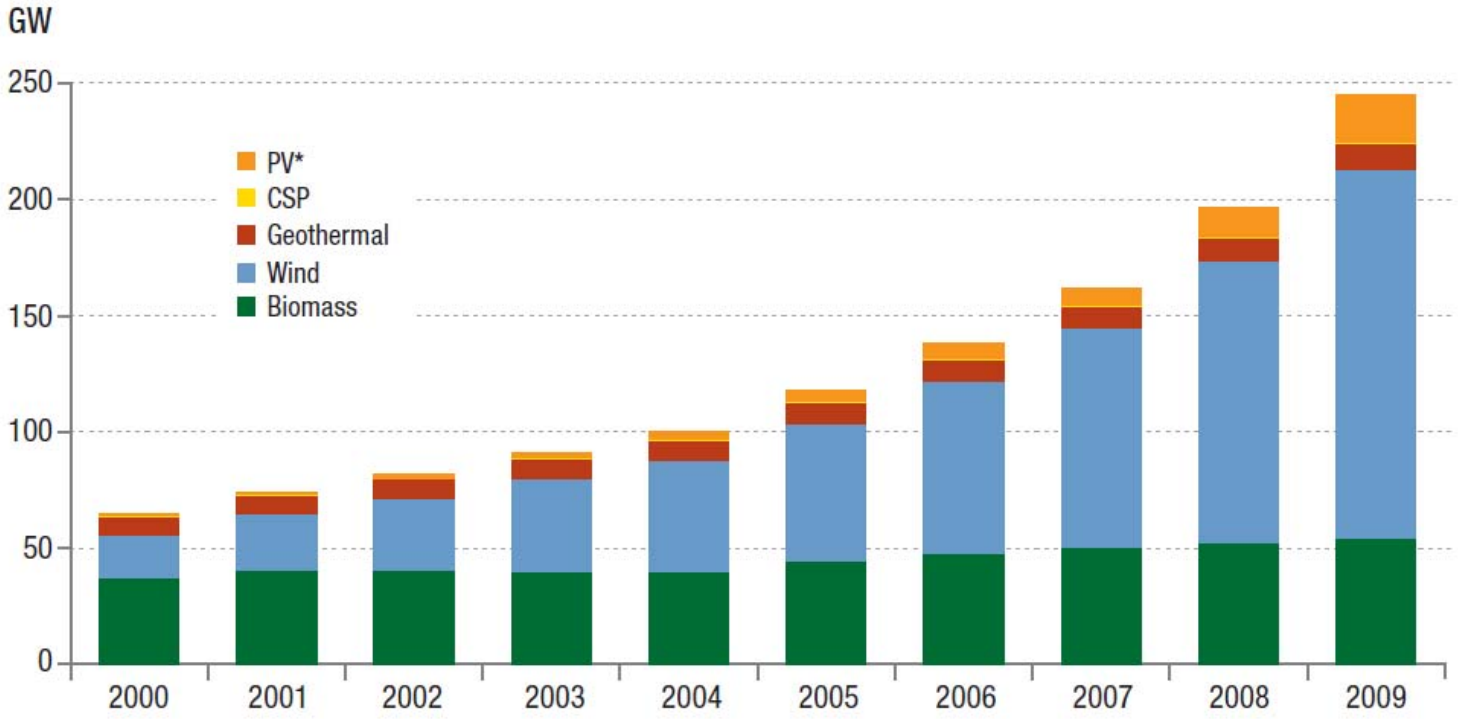
State Policy Framework

Renewable Portfolio Standards



Source: DSIRE database, January 2010

Renewable Electricity Generating Capacity Worldwide (excluding hydropower)

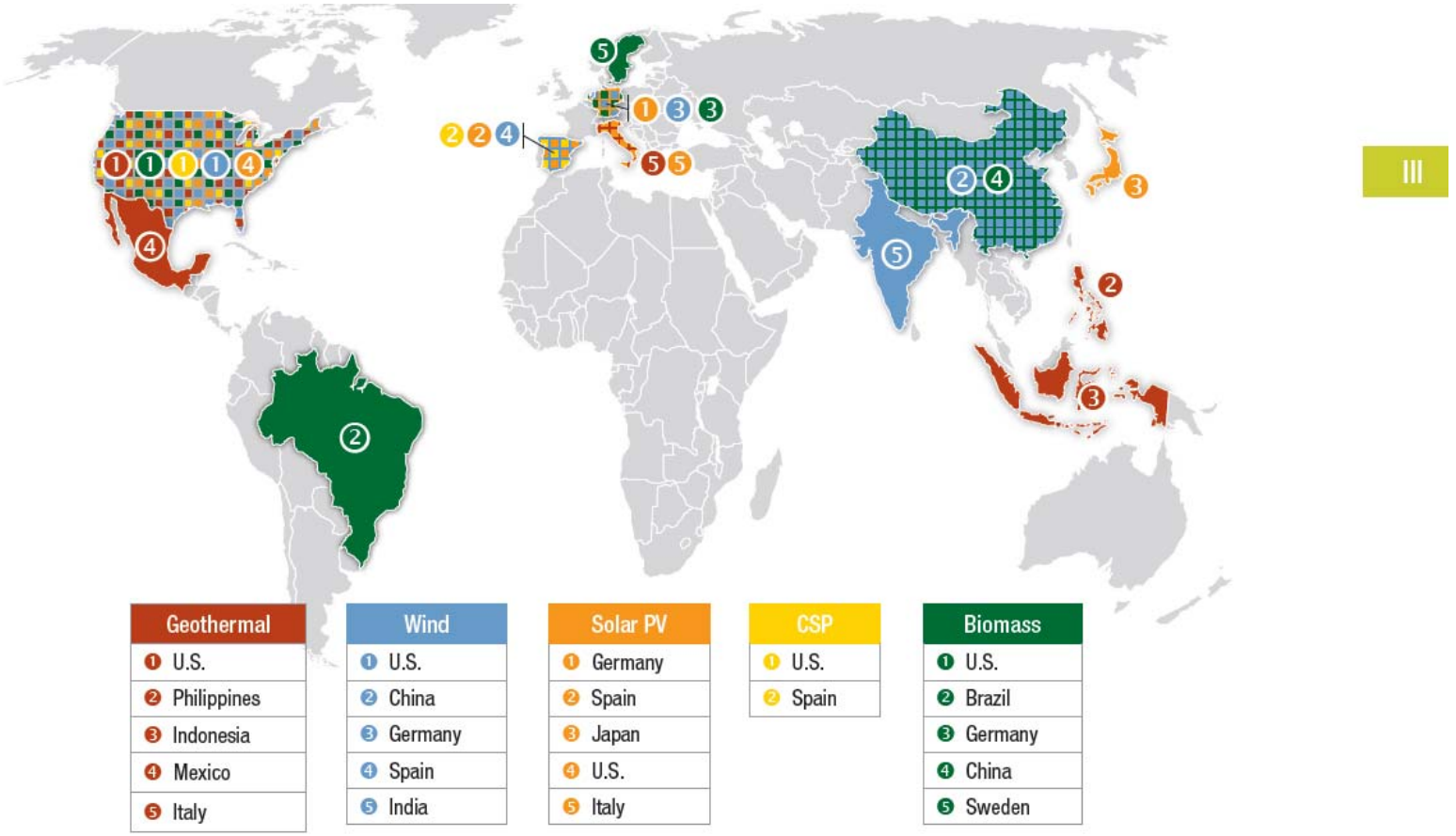


*Grid-tied capacity.

Sources: REN21, GWEC, GEA, SEIA, EIA

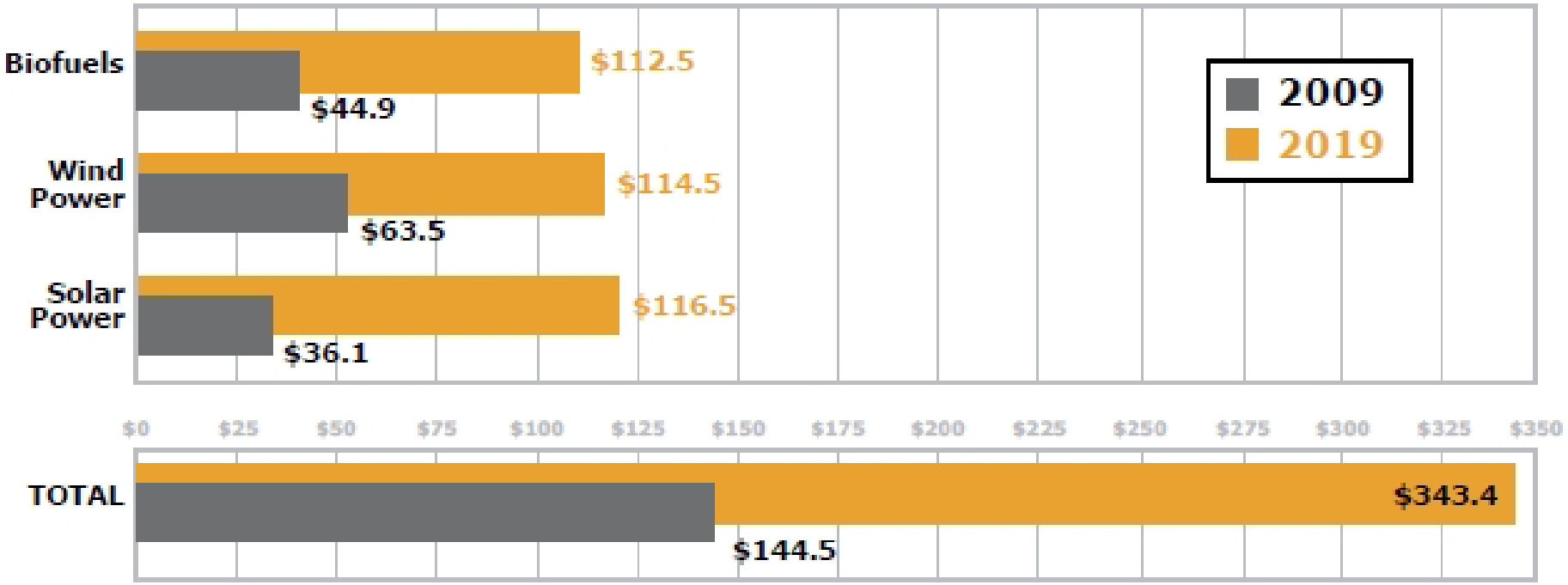
Source: NREL, *2009 Renewable Energy Data Book* http://www.nrel.gov/docs/fy10osti/48178.pdf

Top Countries with Installed Renewable Electricity by Technology (2009)



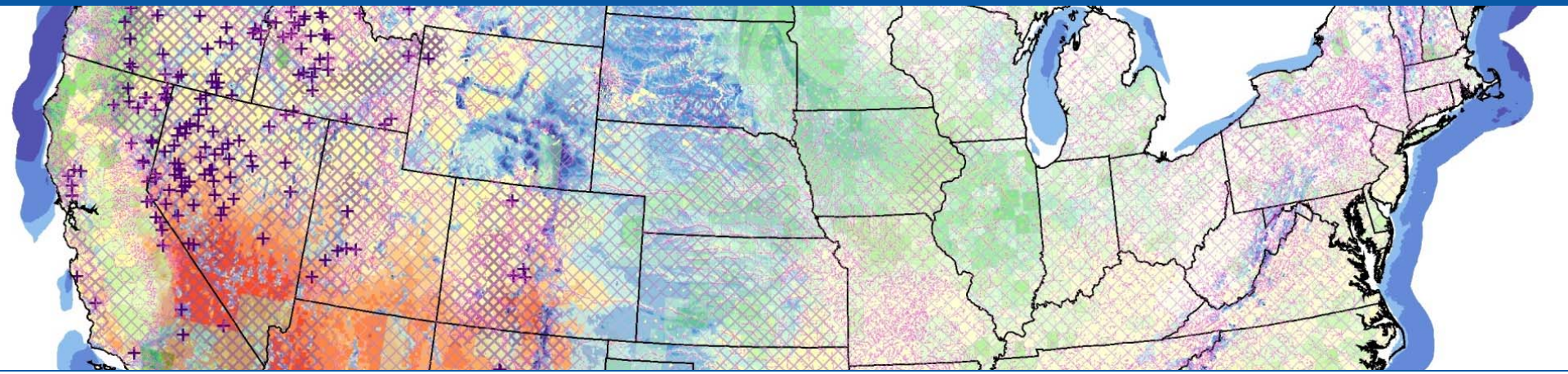
Source: NREL, *2009 Renewable Energy Data Book* http://www.nrel.gov/docs/fy10osti/48178.pdf

Global Clean-Energy Projected Growth 2009-2010 ($ billions)

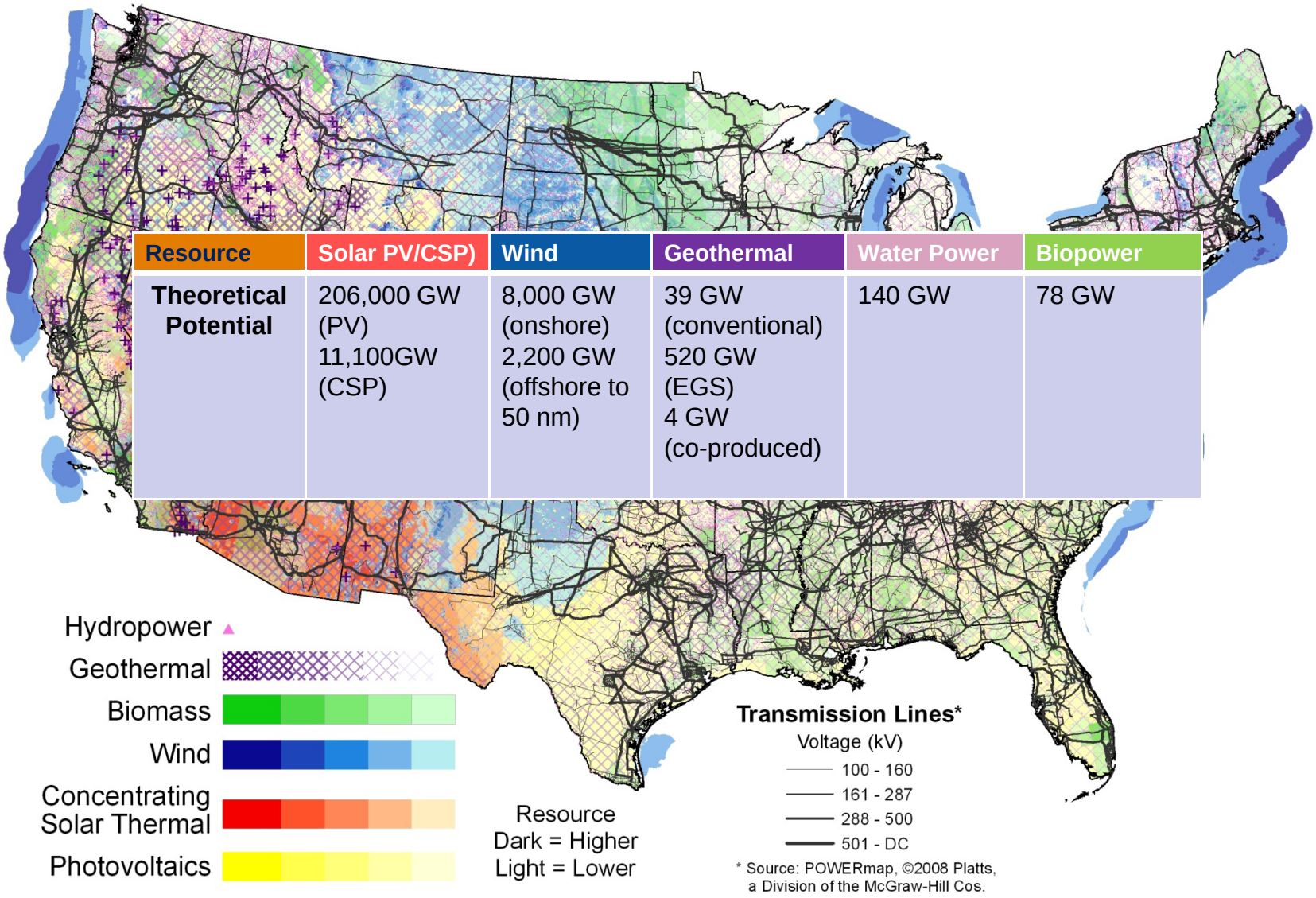


Source: Clean Edge, Inc., *Clean Energy Trends 2010* http://www.cleanedge.com/reports/reports-trends2010.php

Resource Potential



U.S. Renewable Resources



Resource	Solar PV/CSP)	Wind	Geothermal	Water Power	Biopower
Theoretical Potential	206,000 GW (PV) 11,100GW (CSP)	8,000 GW (onshore) 2,200 GW (offshore to 50 nm)	39 GW (conventional) 520 GW (EGS) 4 GW (co-produced)	140 GW	78 GW

Energy Efficiency

Buildings

Status U.S. Buildings:

- 39% of primary energy
- 71% of electricity
- 38% of carbon emissions

DOE Goal:

- Cost effective, marketable zero energy buildings by 2025
- Value of energy savings exceeds cost of energy features on a cash flow basis

NREL Research Thrusts

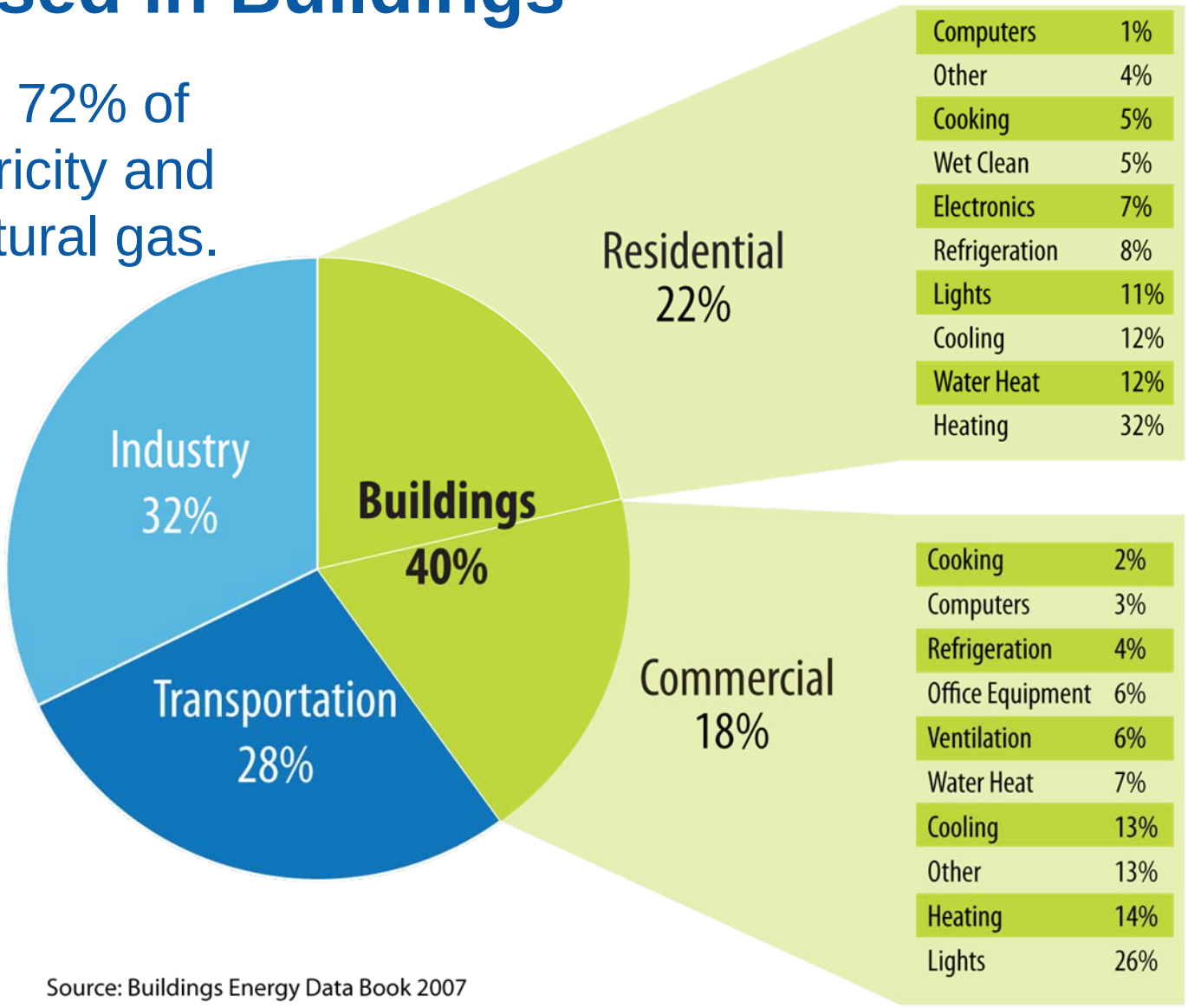
- Whole building systems integration of efficiency and renewable features
- Computerized building energy optimization tools
- Building integrated PV

Updated 7/09

Energy Used in Buildings

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

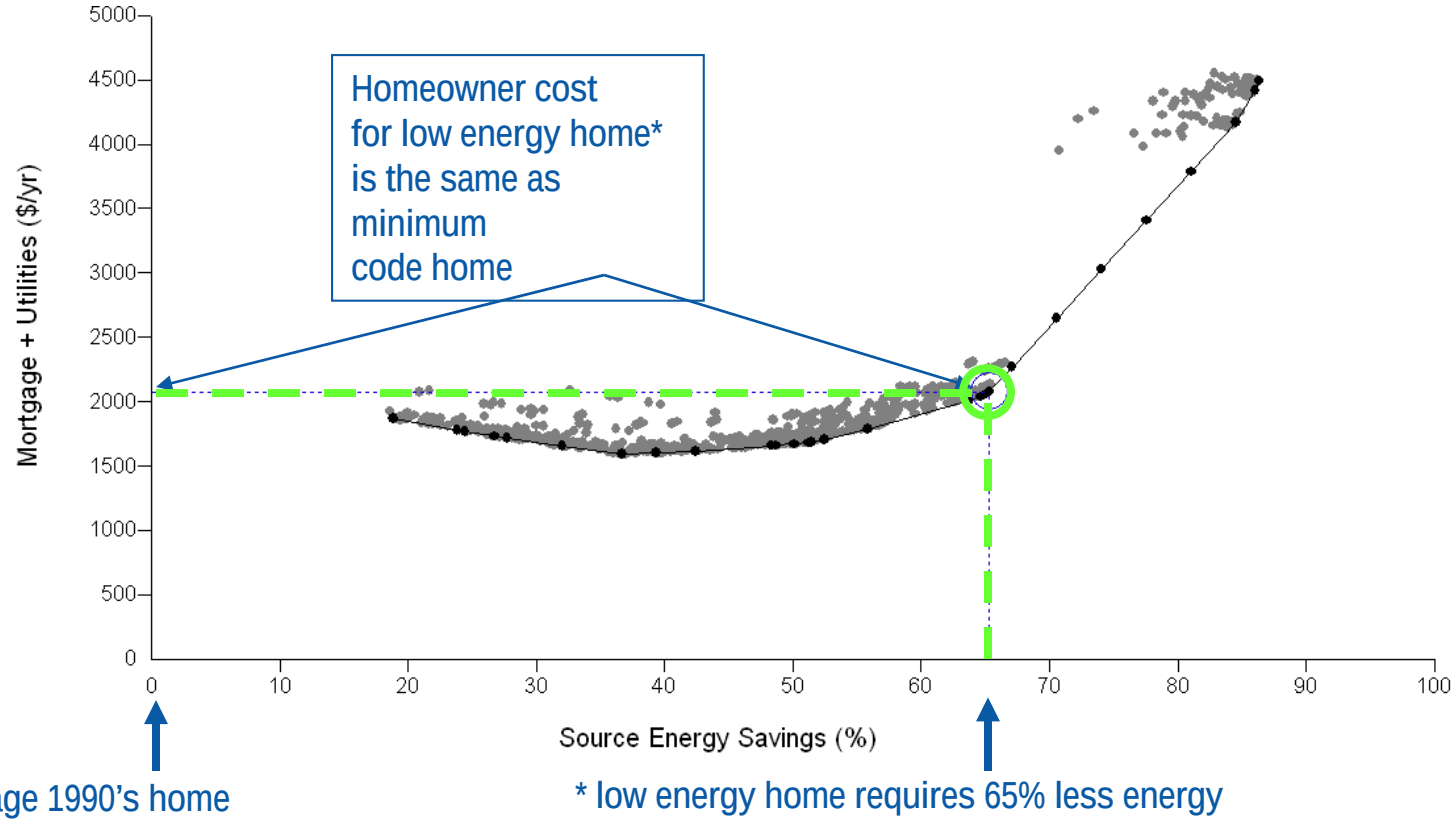
100.7 Quads of Total Use, 2005



Source: Buildings Energy Data Book 2007

Net-Zero Energy Homes That Are Cashflow Neutral

- NREL Analysis using BEOpt software for Boulder,CO climate



Example taken from the "GEOS" Neighborhood. Courtesy of Wonderland Hills Development, Boulder Colorado

Technology for Cost Effective Zero Energy Buildings

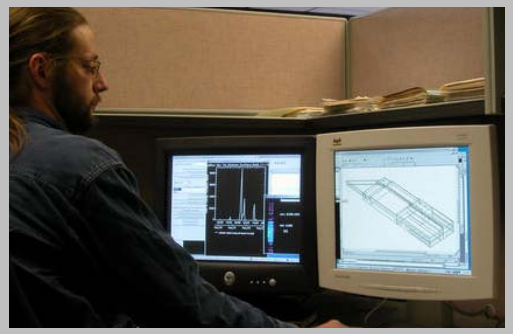
NREL Zero Energy Habitat House

BIPV Products & PV-T Array

Compressorless Cooling

Electrochromic Windows

Polymer Solar Water Heaters



Computerized optimization & simulation Tools

The Laboratory of the Future

Energy efficient workspace….requires new occupant behavior

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

Removing personal Space Heater saves 1500 Watts

Laptop 30 Watts

Desktop Computer (Energy Star) 300 Watts

Multi-function Devices 100 Watts (continuous)

Removing Desktop Printers Saves ~460 Watts/Printer

Renewable Electricity Supply

Wind Energy

The Siemens 2.3 MW turbine at NREL is among the largest land-based turbines deployed in the United States

Current Status (2009)

- 35 GW of installed capacity
- 1.8% of total U.S. electricity generation
- 10 GW added in 2009, representing over 39% of new domestic electricity generation capacity
- Cost 6-9¢/kWh at good wind sites

Cost goals by 2020

- Utility-scale, low-wind-speed, land-based, Class 4 wind regimes– reduce unsubsidized cost to 8.0 cents/kWh
- Shallow water, offshore, Class 6 wind regimes—reduce unsubsidized cost to 13.0 cents/kWh.

Major Technology Directions

- Wind Turbine System and Component Reliability
- Wind Resource Modeling and Forecasting
- Grid Integration
- Offshore Wind /Small Wind Siting and Testing

Updated 10/10

Wind Energy Technology

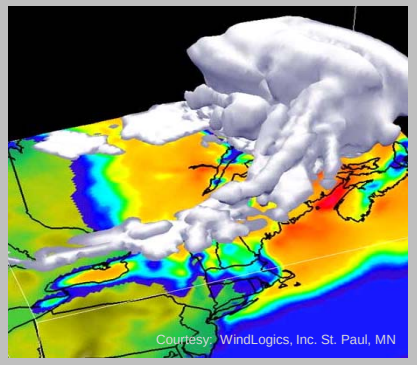
US Wind Resource Exceeds Total Electrical Demand

Offshore Wind

Innovative Tall Towers

Advanced Blades

Giant Multi-megawatt Turbines

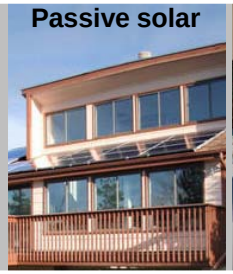


Wind Forecasting


Horns Rev Offshore Wind Farm
North Sea, Denmark
Photo used by permission of Uni-Fly A/S

Applications of Solar Heat and Electricity

Solar Thermal



Photovoltaics (PV)

Concentrating Solar Power (CSP)

Distributed Generation, on-site or near point of use

Centralized Generation, large users or utilities

- Transportation
- Residential & Commercial Buildings
- Industrial

Solar Energy

Current U.S. Status:

Photovoltaics

- 1,500 MW installed solar photovoltaic (PV) capacity
- Cost 16.5¢/kWh*

Concentrating Solar Power

- 422 MW installed capacity
- Cost 13.5¢/kWh*

Cost goals:

- PV: 7-13 ¢/kWh by 2020, 6-10 ¢/kWh by 2030
- CSP: 8-14 ¢/kWh by 2020, 6-12 ¢/kWh by 2030**

Major Technology Directions

Photovoltaics

- Thin-film cells/modules & scale-up
- Nanomaterials enabled technologies
- Advanced manufacturingg techniques
- Improved reliability
- Closing gaps between cell & module efficiencies

Concentrated Solar Power

- Low-cost, high-performance thermal storage
- Advanced absorbers, reflectors, and heat transfer fluids
- Next generation solar concentrators

Grid integration, systems performance and reliability

Updated 10/10

*Source: Navigant Consulting Inc, July 2010. Assumes federal & state incentives.

**CSP assumes trough technology.

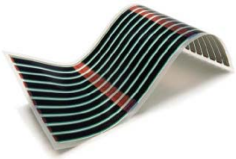
PV Conversion Technology Portfolio

Market-Competitive Targets

Market Sector	Current U.S. Market Price Range (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8-16.7	23-32	13-18	8-10
Commercial	5.4-15.0	16-22	9-12	6-8
Utility	4.0-7.6	13-22	10-15	5-7

Thin Films (aSi)

Advancing amorphous and wafer replacement crystal silicon film solar cells on low-cost substrates



Organic PV

Customizing molecules, substrates, and deposition techniques to yield ultra low-cost modules

Next Generation

Investigating advanced concepts aimed at delivering revolutionary performance improvements

Crystalline Silicon

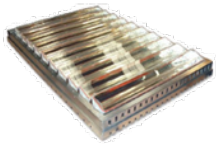
Developing higher efficiency devices and lower cost processing methods for traditional silicon cells

Crosscut

Synergistic technologies, evaluation approaches, and process engineering approaches applicable across multiple absorber materials and processes

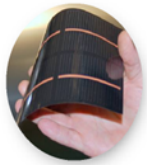
Concentrating PV

Combining new, lower cost multijunction cells and innovative optical packages



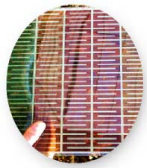
Thin Films (CIGS)

Supporting the manufacture of non-vacuum processes and transferring record efficiency device performance into large area commercial modules



Dye-Sensitized Cells

Advancing the efficiency and stability of inexpensive dye-based solar cells with novel nanostructures



Building Integrated PV

Creating module form factors aimed at dramatically reducing or eliminating solar installation costs

Geothermal

Current Status in the U.S.

- 3,153 MWe installed, 6443 MWe under development
- Cost 5-8¢/kWh with no PTC
- Capacity factor typically > 90%, base load power

Long Term Potential

- Recent MIT Analysis shows potential for 100,000 MW installed Enhanced Geothermal Power systems by 2050, cost-competitive with coal-powered generation

Updated 1/2010

Geothermal

NREL Research Thrusts

- DOE lead for Low Temperature R&D
  - Oil/gas coproduction of electricity, direct use, geothermal heat pumps
- Analysis to define pathways for broad commercial impact of geothermal systems
- R&D in advanced power conversion systems
- Systems engineering/integration

DOE's Future Energy Cost Goals

- Near term: Hydrothermal sites at 5¢/kWh
- Longer term: Enhanced geothermal systems, huge resource at 5-10¢/kWh with mature technology

Drilling rig on South Table Mountain, testing for installation of geothermal heat pump showcase system at NREL.

Biomass Power

Current Status in the U.S.

- 2007 capacity – 10.5 GWe
  - 5 GW Pulp and Paper
  - 2 GW Dedicated Biomass
  - 3 GW MSW and Landfill Gas
  - 0.5 GW Cofiring
- 2004 Generation – 68.5 TWh
- Cost – 8-10¢/kWh

Potential

- Cost – 4-6¢/kWh (integrated gasification combined cycle)
- 2030 – 160 TWh (net electricity exported to grid from integrated 60 billion gal/yr biorefinery industry)

Biofuels

Biofuels

Current Status (2009):

U.S. produced 10.8 billion gallons of ethanol and 0.5 billion gallons of biodiesel

- 210 commercial corn ethanol plants
- 150 biodiesel refineries
- 26 cellulosic ethanol demonstration plants

Cost goal:
Cellulosic ethanol—cost parity with gasoline by 2012

Major Technology Directions:

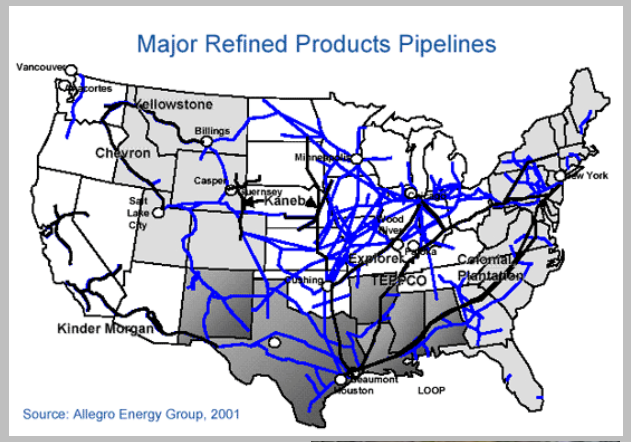
- **Foundational Science:** Enzymes, fermentation, understanding biomass and cell composition
- **Feedstocks**: Sustainable feedstock production systems
- **Pretreatment & Conversion R&D:** Biochemical and thermochemical conversion processes
- **Advanced Biofuels and Algae**: Broadening RD&D beyond cellulosic ethanol to address "drop in" and high-energy content fuels from algae and other biomass resources

Updated 10/10

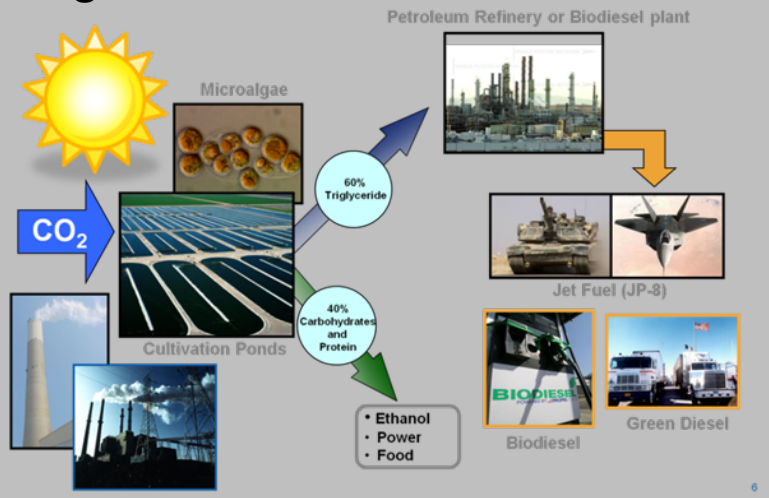
Why Follow-On Generations?

Advanced Biofuels – "beyond ethanol"

- Higher energy density/suitability
- Better temp and cold start ability
- Energy and tailored feedstocks
- Infrastructure compatibility



Algae



Fuel Cells/Hydrogen

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Major Technology Directions

- Renewable H_2 production
- H_2 storage
- Fuel cells
- Safety/codes/standards
- Integration of H_2-electricity systems
- Technology validation

Current U.S. Status

- >200 fuel cell vehicles on the road
- ~60 hydrogen fueling stations
- Commercial fuel cell electric vehicle launch expected in 2015
- Fuel cells having market success in forklift and backup power applications
- > 2000 fuel cells shipped by U.S. companies in 2009
- 9 million metric tons of H_2 produced annually for a variety of uses

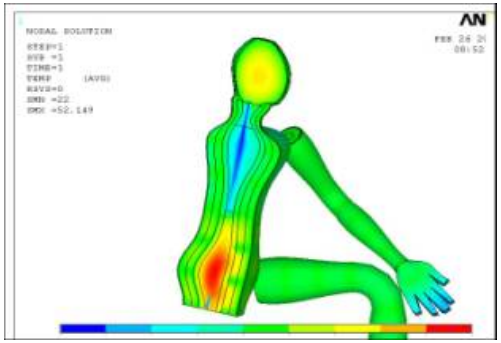
Alternative Vehicles

Current U.S. Status

- 129 million light duty gas/diesel vehicles
- 98 million heavy duty gas/diesel trucks
- 1 million hybrid electric vehicles

NREL Research Thrusts

- **Fuels utilization**
  - Advanced fuels chemistry and testing
  - Engine-fuels interactions
- **Component technologies**
  - Advanced lithium ion batteries
  - Battery thermal management
- **Advanced power electronics**
- **Vehicle ancillary loads reduction**
  - Advanced heating & cooling
  - Vehicle thermal management
- **Electric vehicle-to-grid interface**



Updated 1/10

Smart Grid/Grid Integration

Current U.S. Status

- **The Grid**
  - 30,000 transmission paths; >180K miles of transmission lines
  - 14,000 transmission substations
  - Distribution grid connects substations to over 100 million loads
- **Utility Sector**
  - 3,170 traditional electric utilities (239 investor-owned, 2,009 publicly owned, 912 consumer-owned rural cooperatives, and 10 Federal electric utilities)

Artist Rendering of the Energy System Integration Facility

NREL Research Thrusts

- **DG Interconnection Standards**

  IEEE Standards Development

  Standards Testing and Validation
- **Smart-Grid Data Hub**
- **RE Grid Integration**
  - Power Electronics for Interconnection monitoring and control
  - Grid-to-vehicle interface

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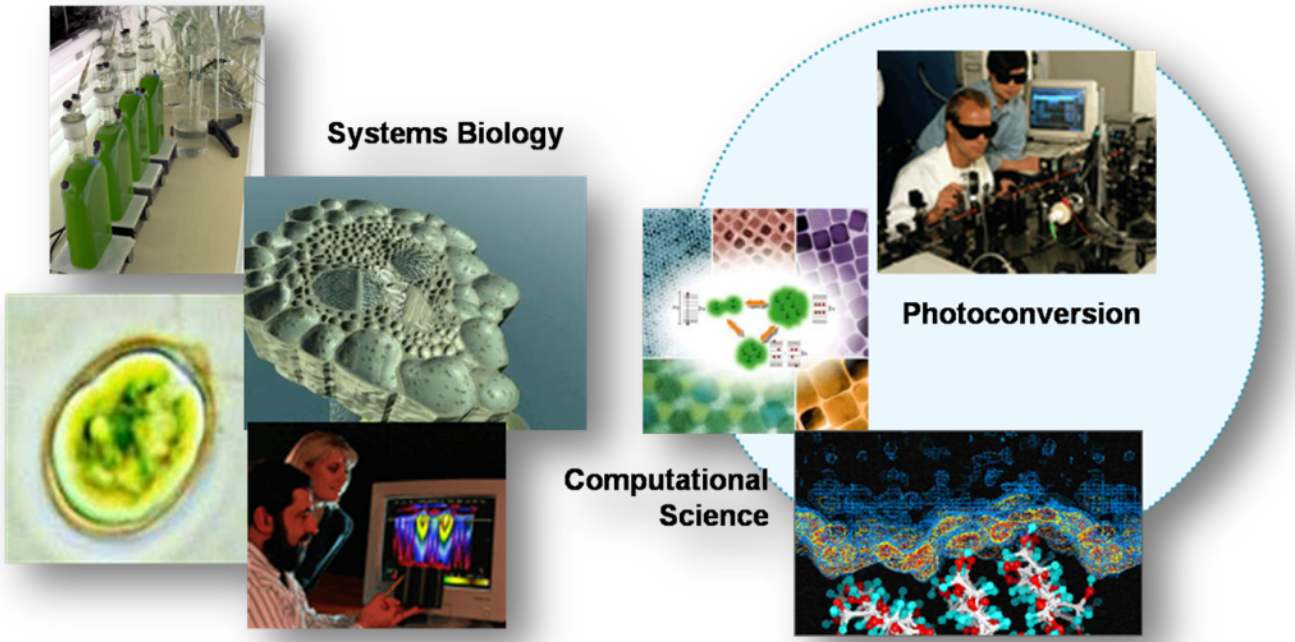
New Directions

Commitment to Breakthrough Innovation



Managing the science-to-technology interface

An Integrated Approach is Required

Making Transformational Change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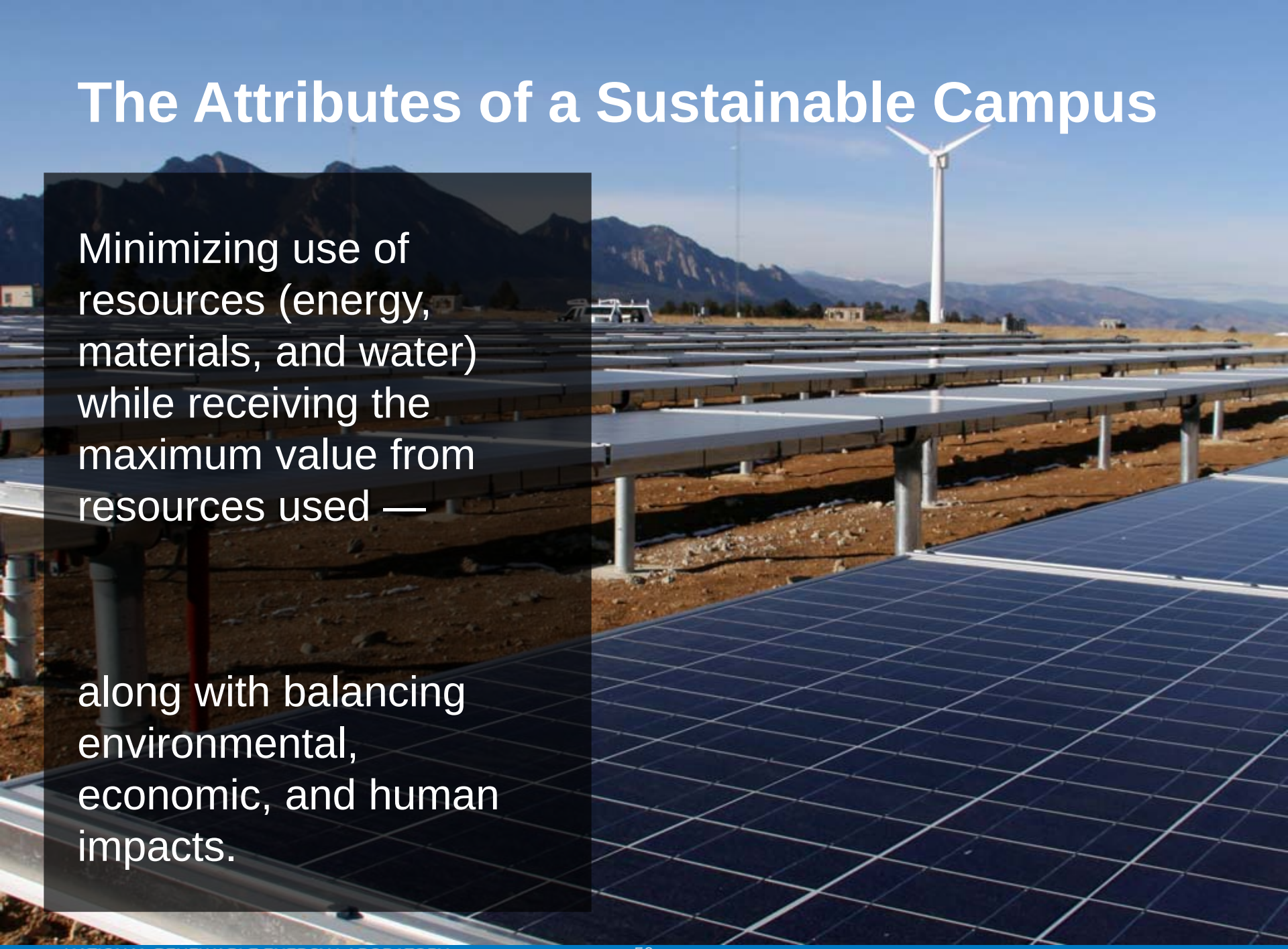
Sustainable Campus

The Attributes of a Sustainable Campus



Minimizing use of resources (energy, materials, and water) while receiving the maximum value from resources used —

along with balancing environmental, economic, and human impacts.

Current NREL Renewable Energy Picture

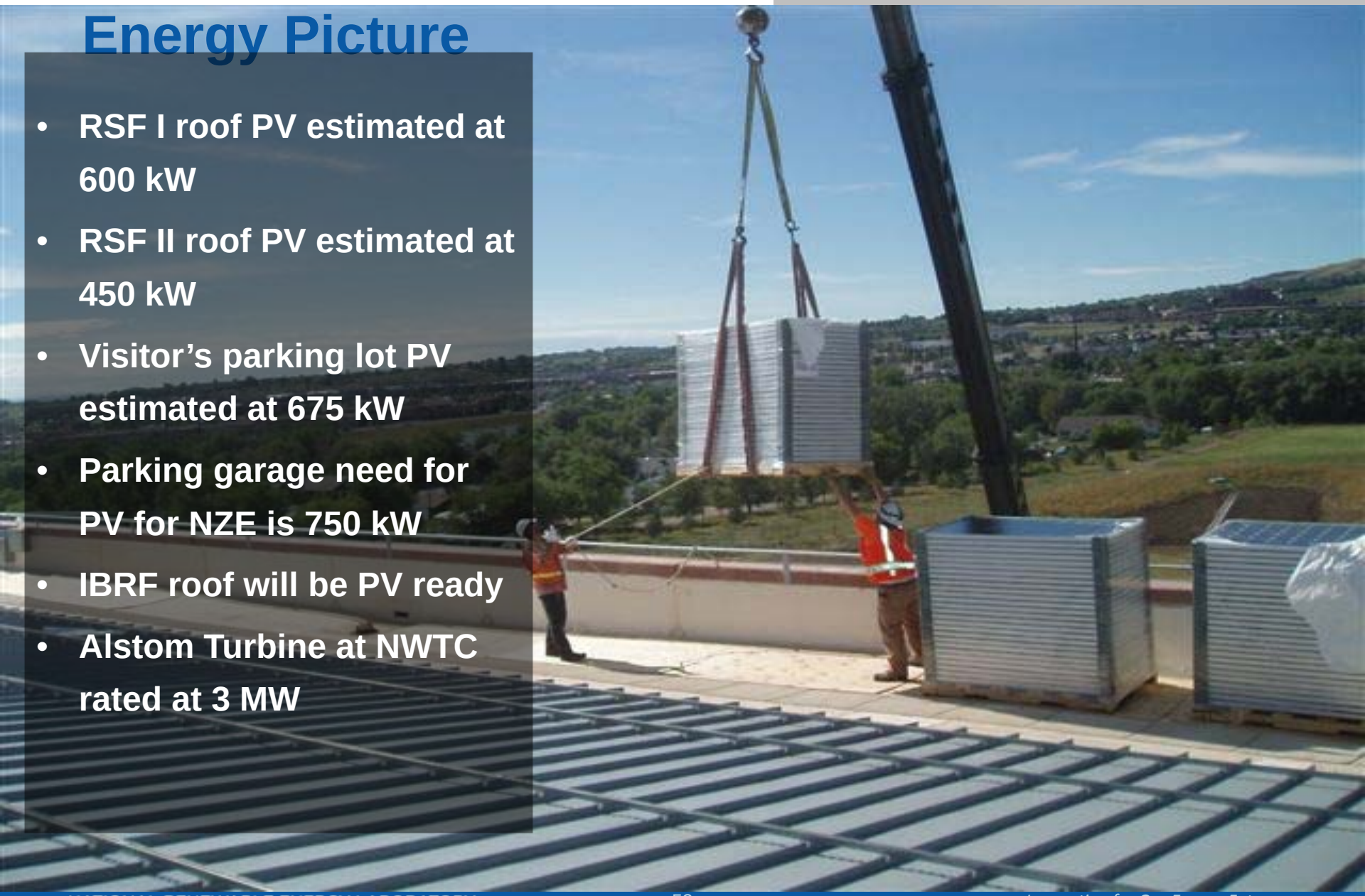
Total Current Onsite Renewable Power Generation Capacity—

greater than 8 MW

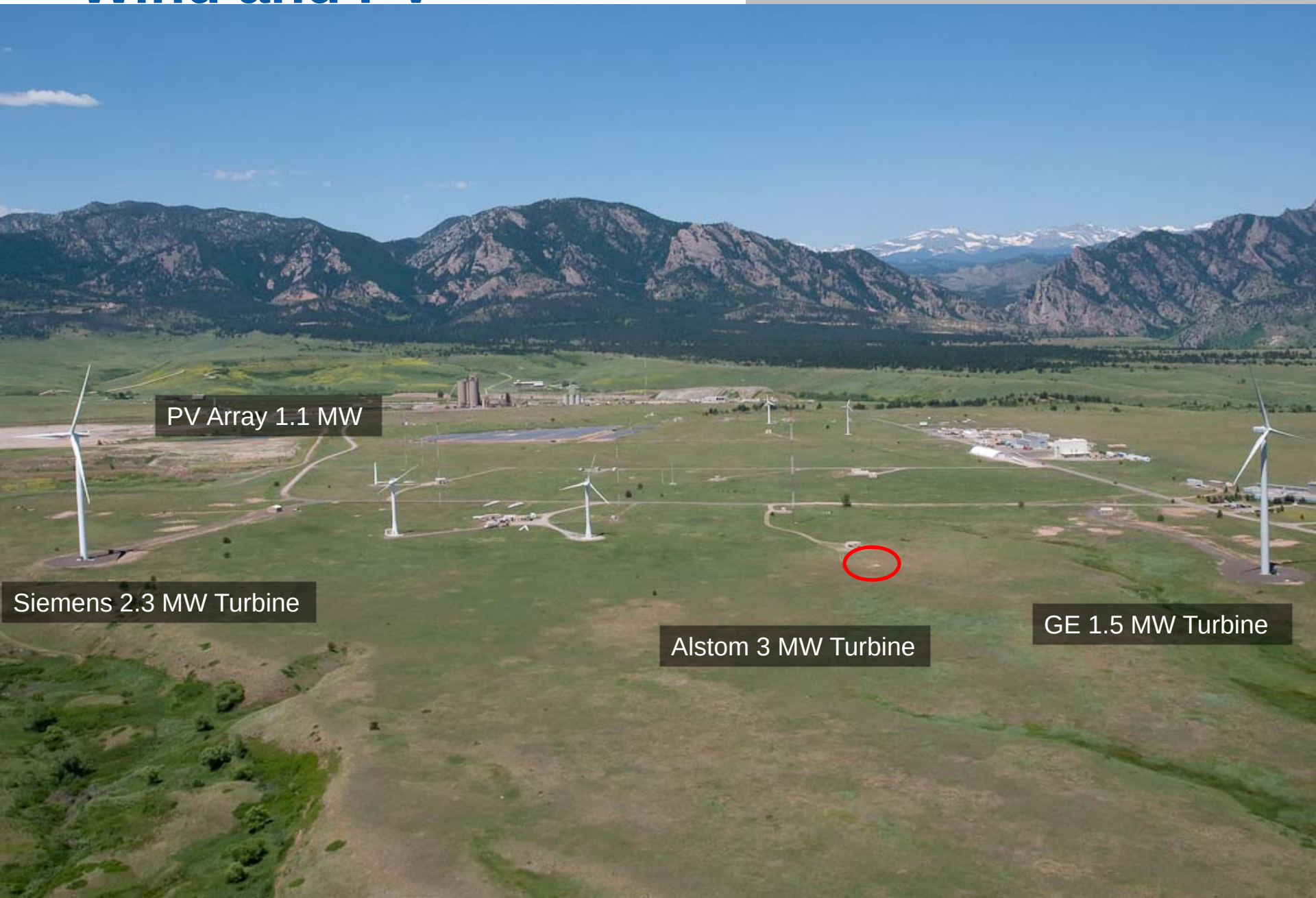
- Mesa Top array is rated at 720 kW
- S&TF array is rated at 118 kW
- NWTC PV is approx. 1.1MW
- GE turbine is rated at 1.5 MW
- Siemens turbine is rated at 2.3 MW
- RFHP is rated at 2.5 MW thermal output

NREL Future Renewable Energy Picture

- RSF I roof PV estimated at 600 kW
- RSF II roof PV estimated at 450 kW
- Visitor's parking lot PV estimated at 675 kW
- Parking garage need for PV for NZE is 750 kW
- IBRF roof will be PV ready
- Alstom Turbine at NWTC rated at 3 MW



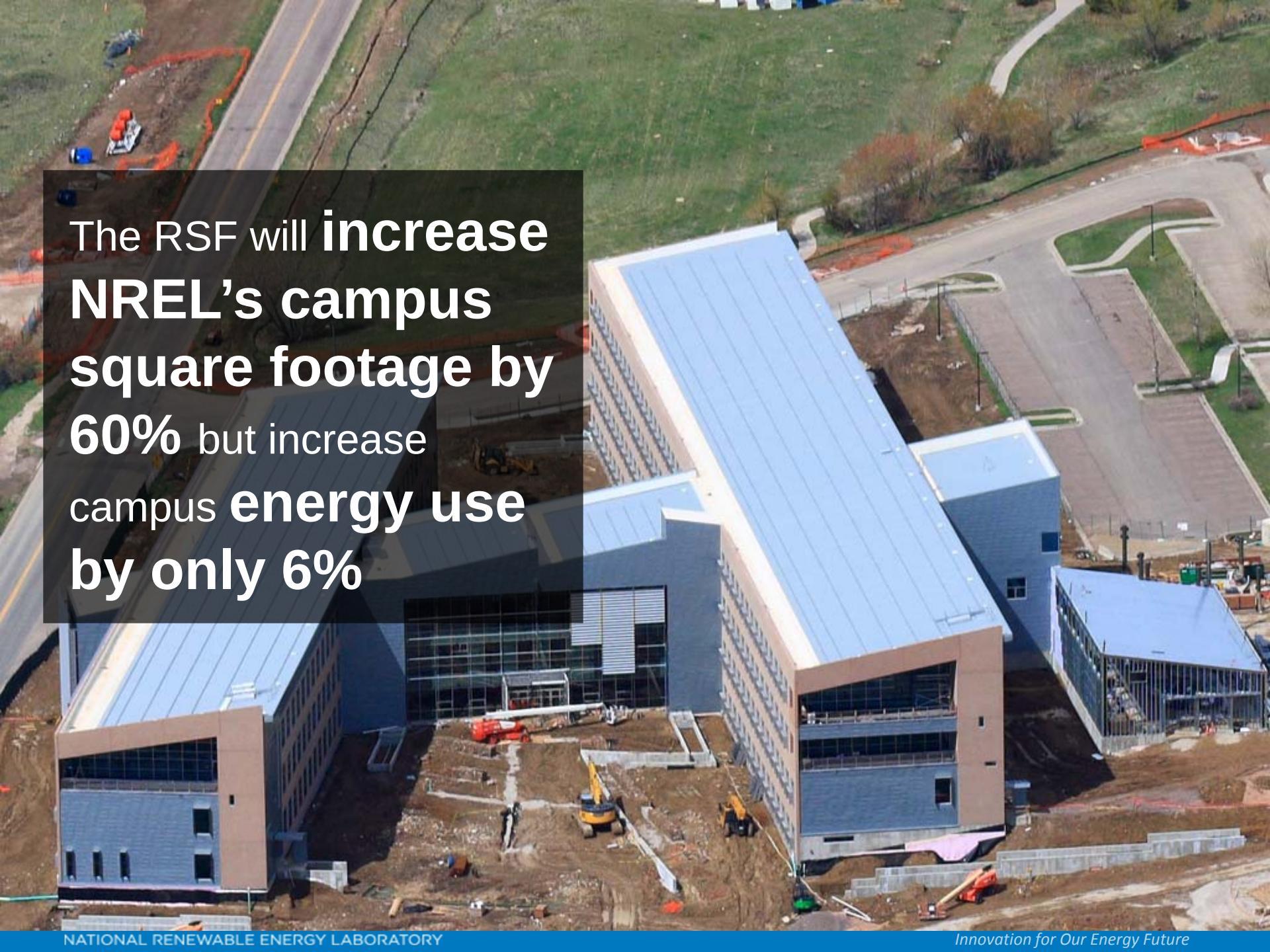
Wind and PV

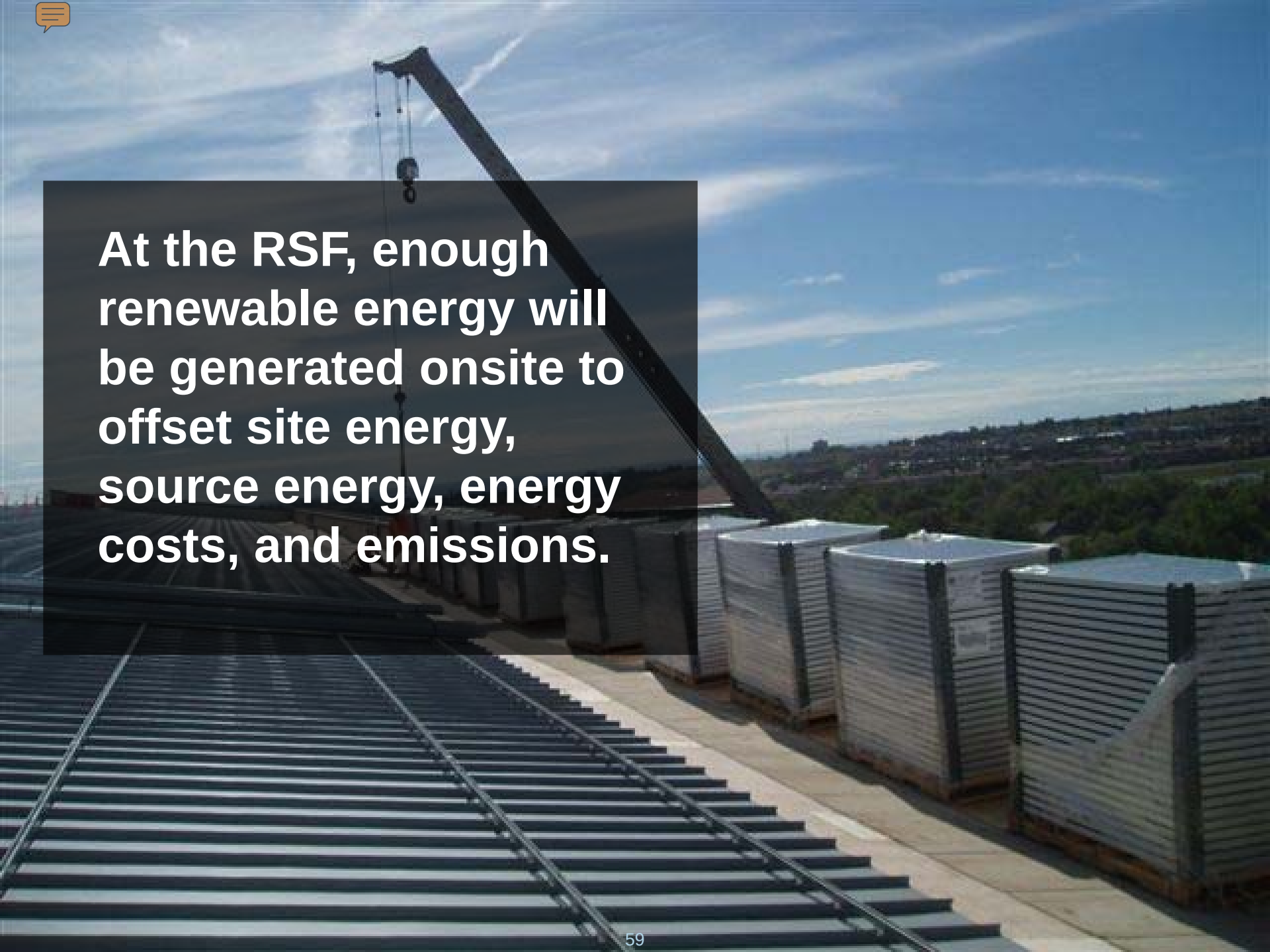

PV Array 1.1 MW
Siemens 2.3 MW Turbine
Alstom 3 MW Turbine
GE 1.5 MW Turbine


Mesa Top PV
array = 720 kW

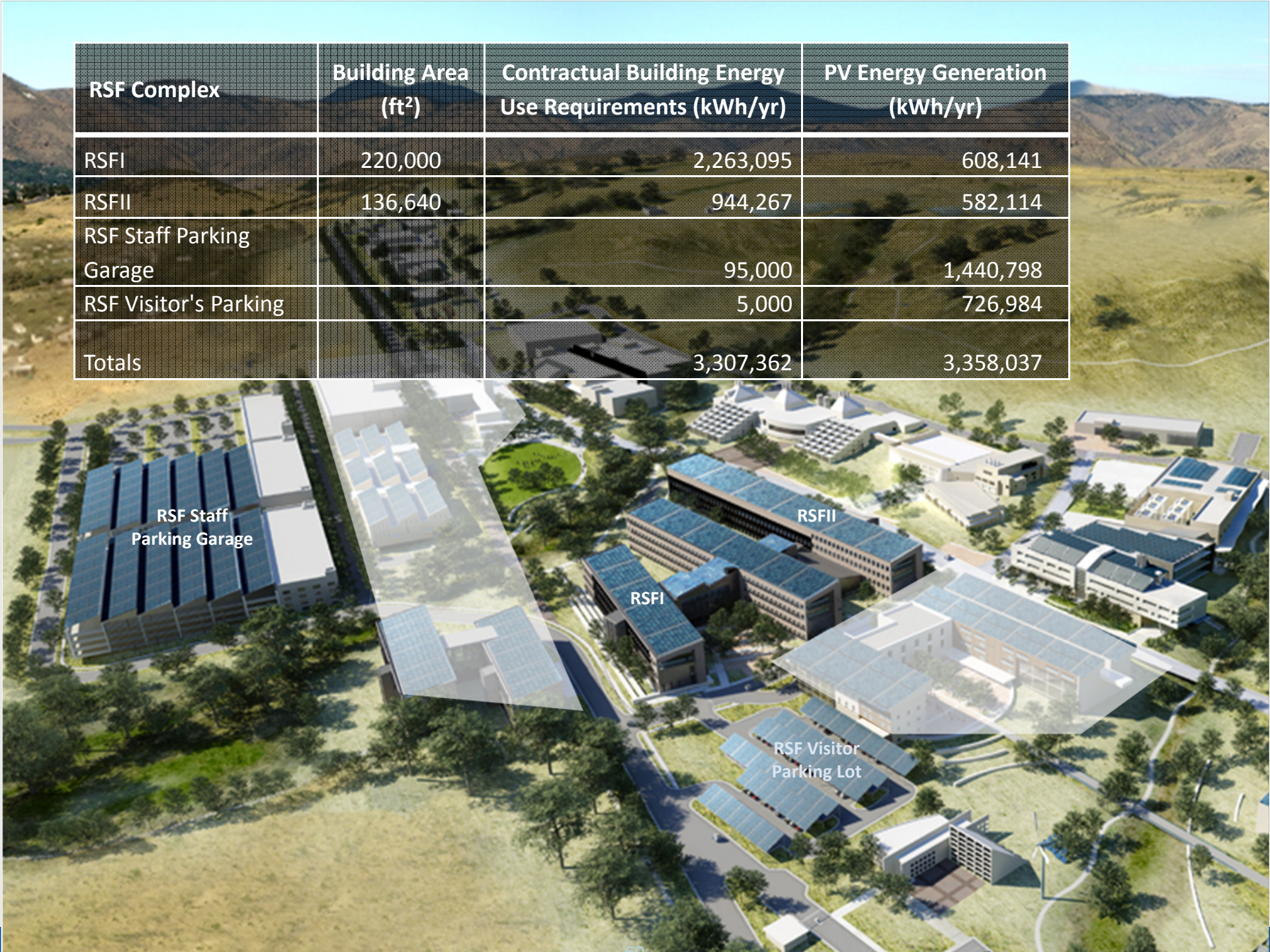

S&TF array
= 118 kW


Renewable Fuels Heating Plant
displaces
4.8 million Btu of
natural gas usage


The RSF will **increase NREL's campus square footage by 60%** but increase campus **energy use by only 6%**


At the RSF, enough renewable energy will be generated onsite to offset site energy, source energy, energy costs, and emissions.

RSF Complex	Building Area (ft^2)	Contractual Building Energy Use Requirements (kWh/yr)	PV Energy Generation (kWh/yr)
RSFI	220,000	2,263,095	608,141
RSFII	136,640	944,267	582,114
RSF Staff Parking Garage		95,000	1,440,798
RSF Visitor's Parking		5,000	726,984
Totals		3,307,362	3,358,037



Energy efficient workspace….requires new occupant behavior

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

Removing personal Space Heater saves 1500 Watts

Laptop 30 Watts

Desktop Computer (Energy Star) 300 Watts

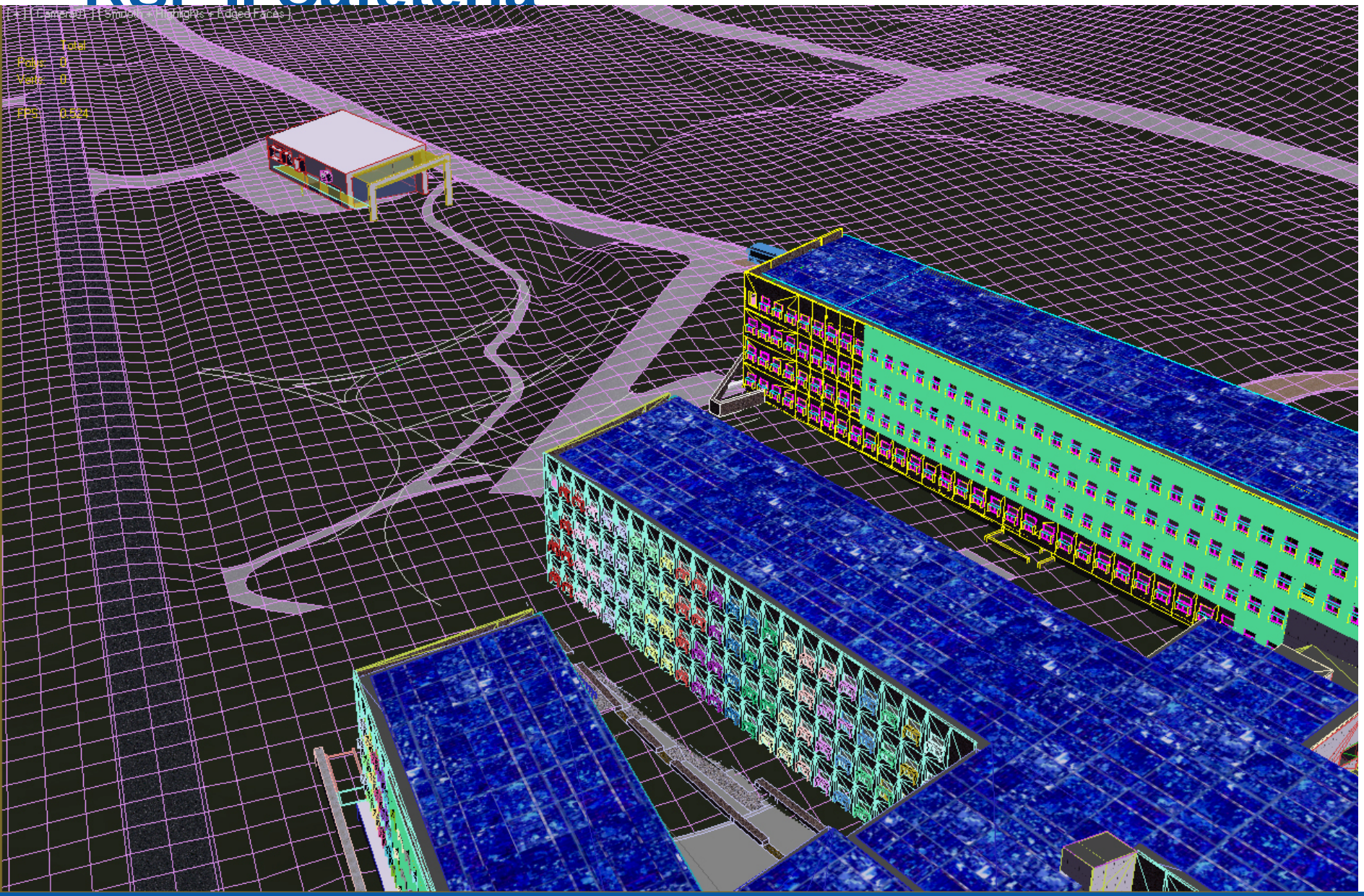
Multi-function Devices 100 Watts (continuous)

Removing Desktop Printers Saves ~460 Watts/Printer

Research Support Facility II

- An additional wing to the RSF for $68 million
- Completion Fall of 2011
- Approximately 150,000 additional square feet
- House approximately 550 staff
- LEED Platinum (in combination with RSF I)
- Associated infrastructure and parking
- Cafeteria of approximately 12,000 square feet

RSF II Cafeteria



Laboratory Projects

Research Support Facilities
- $80 million

Research Support Facilities II
- $68 million

Integrated Biorefinery Research Facility Stage I
- $20 million

Integrated Biorefinery Research Facility Stage II
- $13.5 million

Renewable Energy, Supporting Site Infrastructure
- $19.2 million

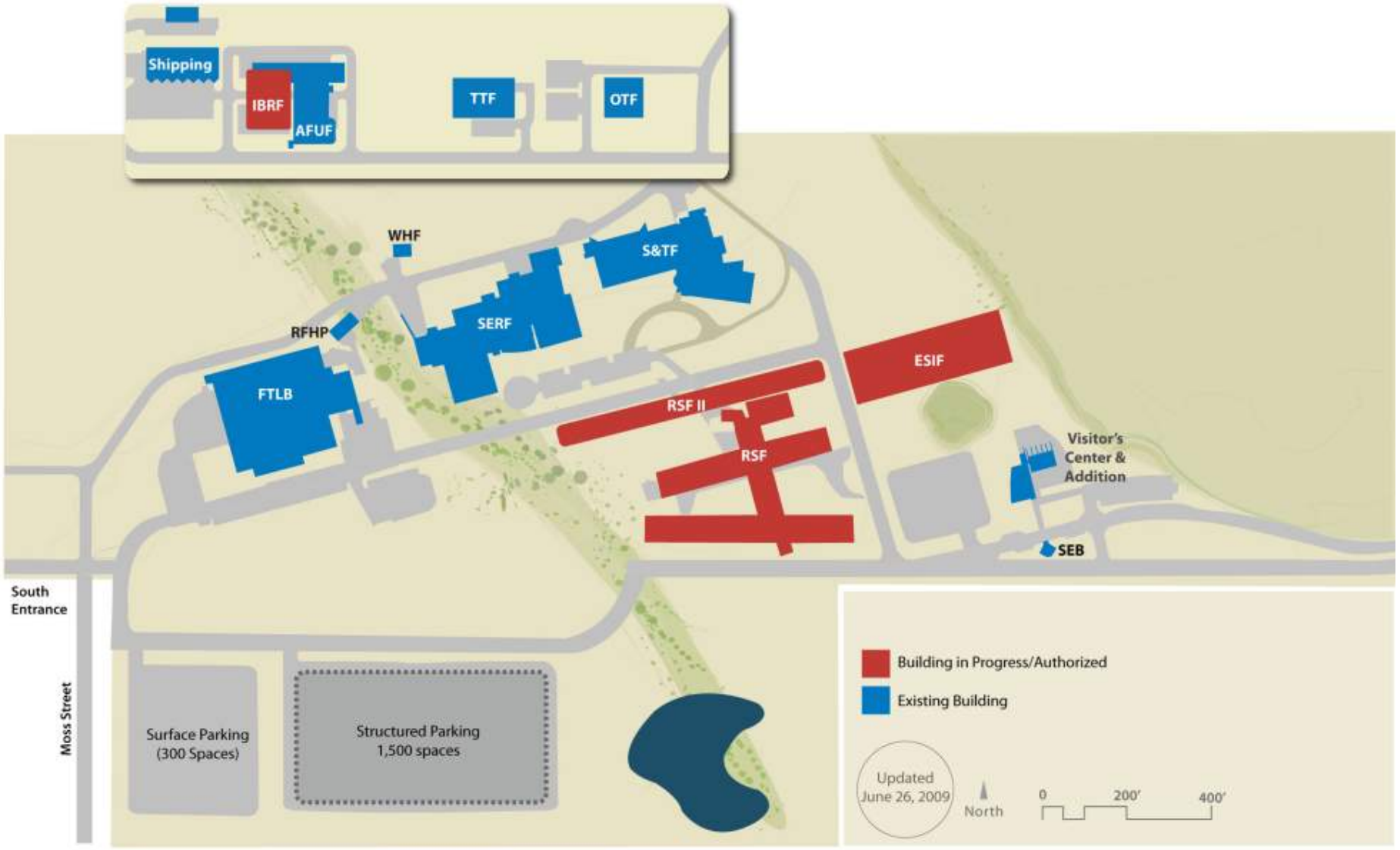
Energy Systems Integration Facility
- $135 million ($95.5 million funded, final increment of funding in FY11 Pres. Budget)

Ingress/Egress
- $44 million

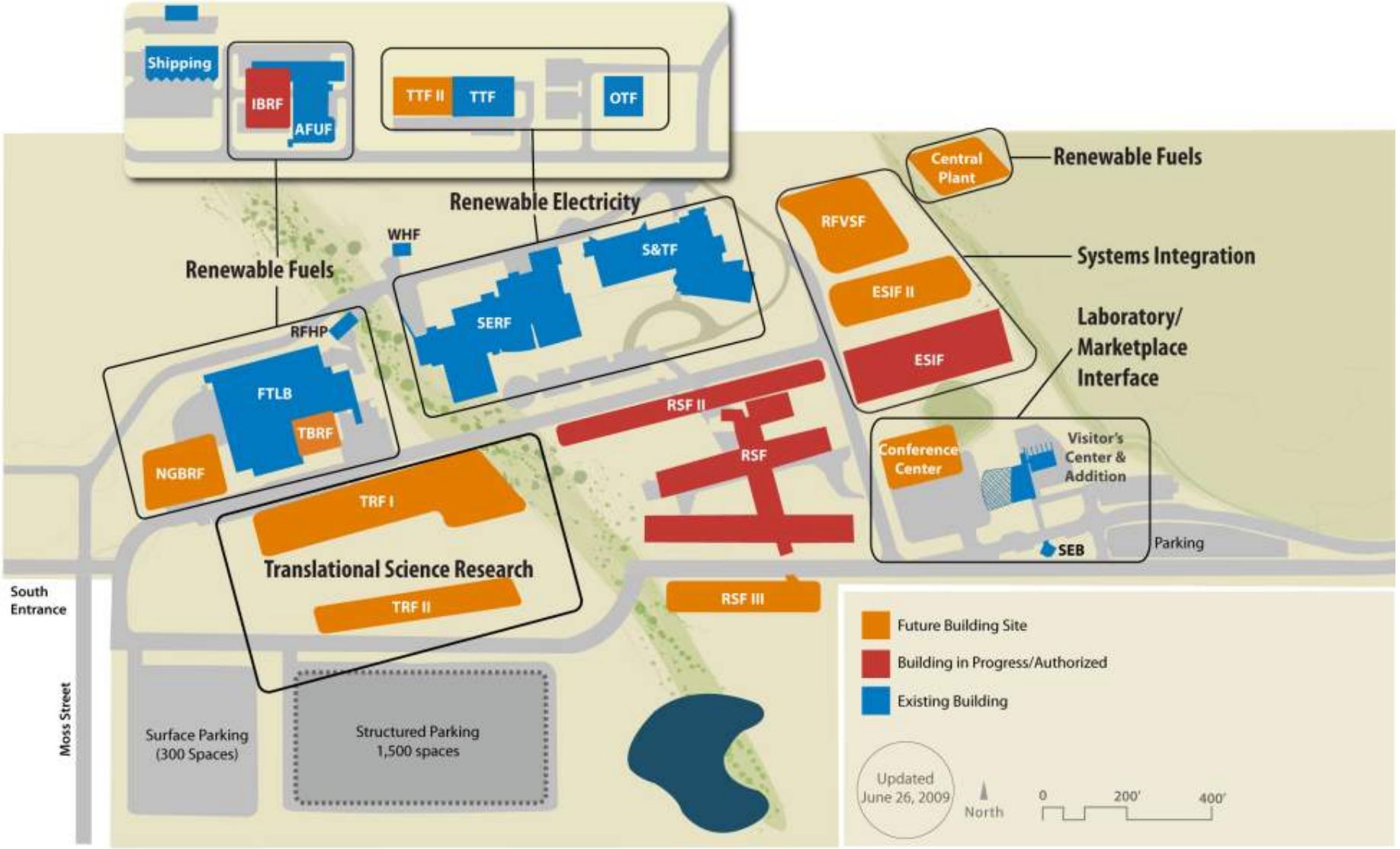
STM Infrastructure Zone 1
- $7.324 million

STM Infrastructure Zone 2
- $13.0 million

STM Buildings in Progress 2009-2011



At Buildout 2020



Science and Technology Highlights

- Silver nanohole arrays show enhanced optical absorption
- First demonstration of a stable quantum dot solar cell
- New, unique, and rigorous theoretical model for electron-hole pair multiplication processes
- Demonstrated novel approach to depositing lithium metal atoms
- Reversible melting demonstrated in silica-coated silver nanoparticles
- Novel transparent conducting barriers (coatings) have potential to decrease costs