Deployment of Renewable Energy Resources at Speed and Scale

University of Arizona

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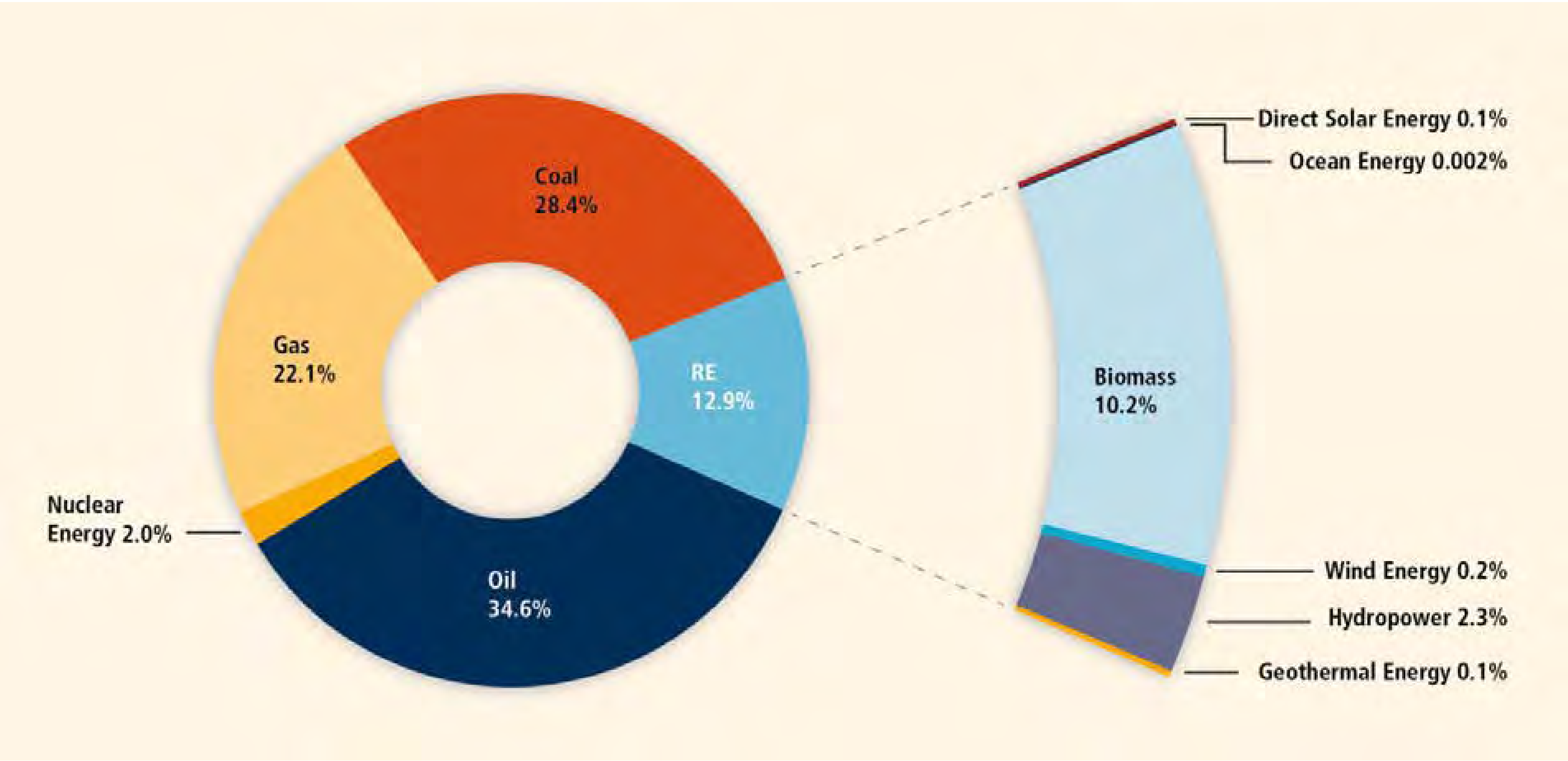
National Energy Imperatives

"When we put a priority on renewable energy we address job creation, we address climate change, women's empowerment and food security. Sustainable energy cuts across nearly every major challenge we face today and will face in the future."

—U.N. Secretary General Ban Ki-moon at NREL, August 25, 2011

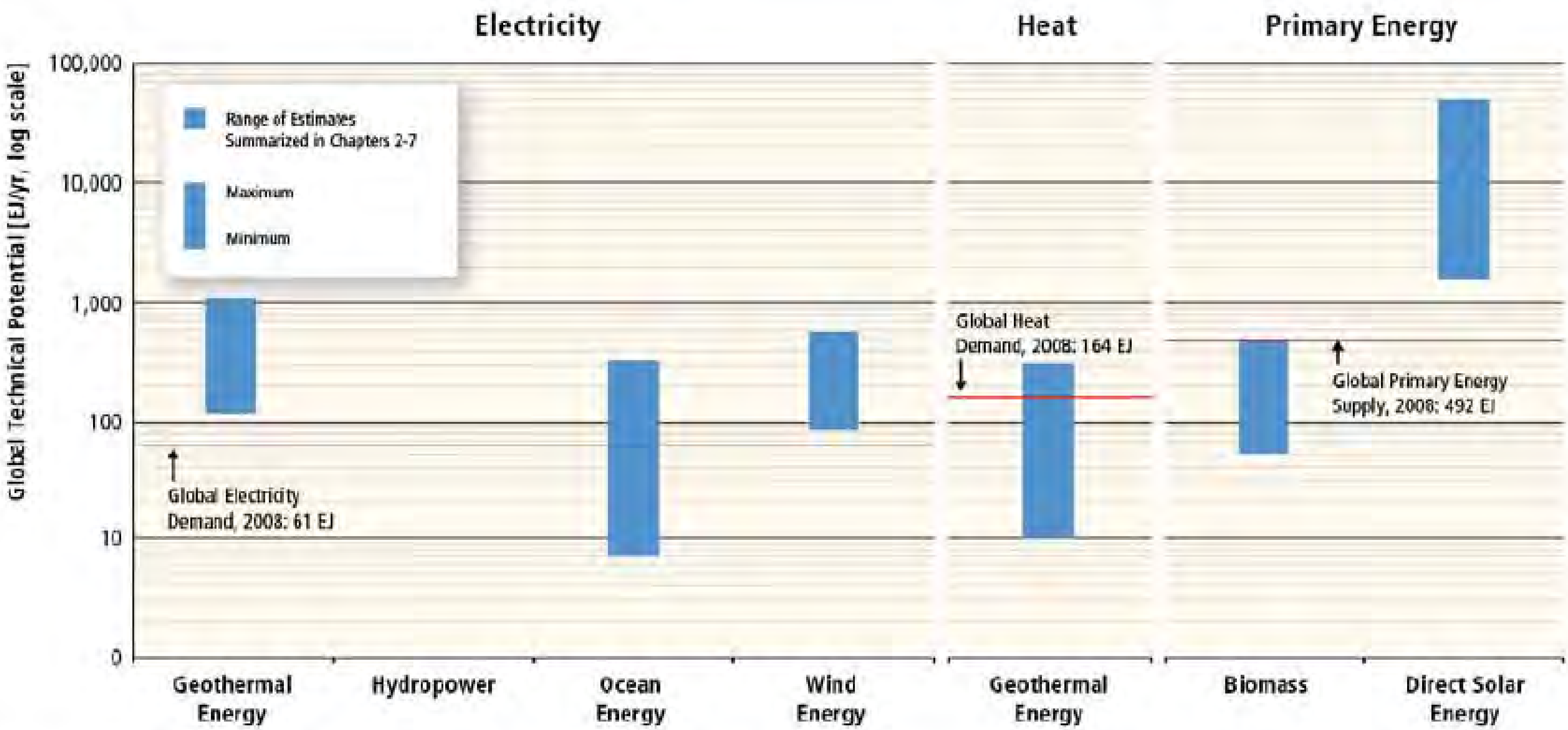
The global context

Shares of energy sources in total global primary energy supply in 2008



Source: IPCC Special Report Renewable Energy Sources (SRREN)

Ranges of global technical potentials of RE sources

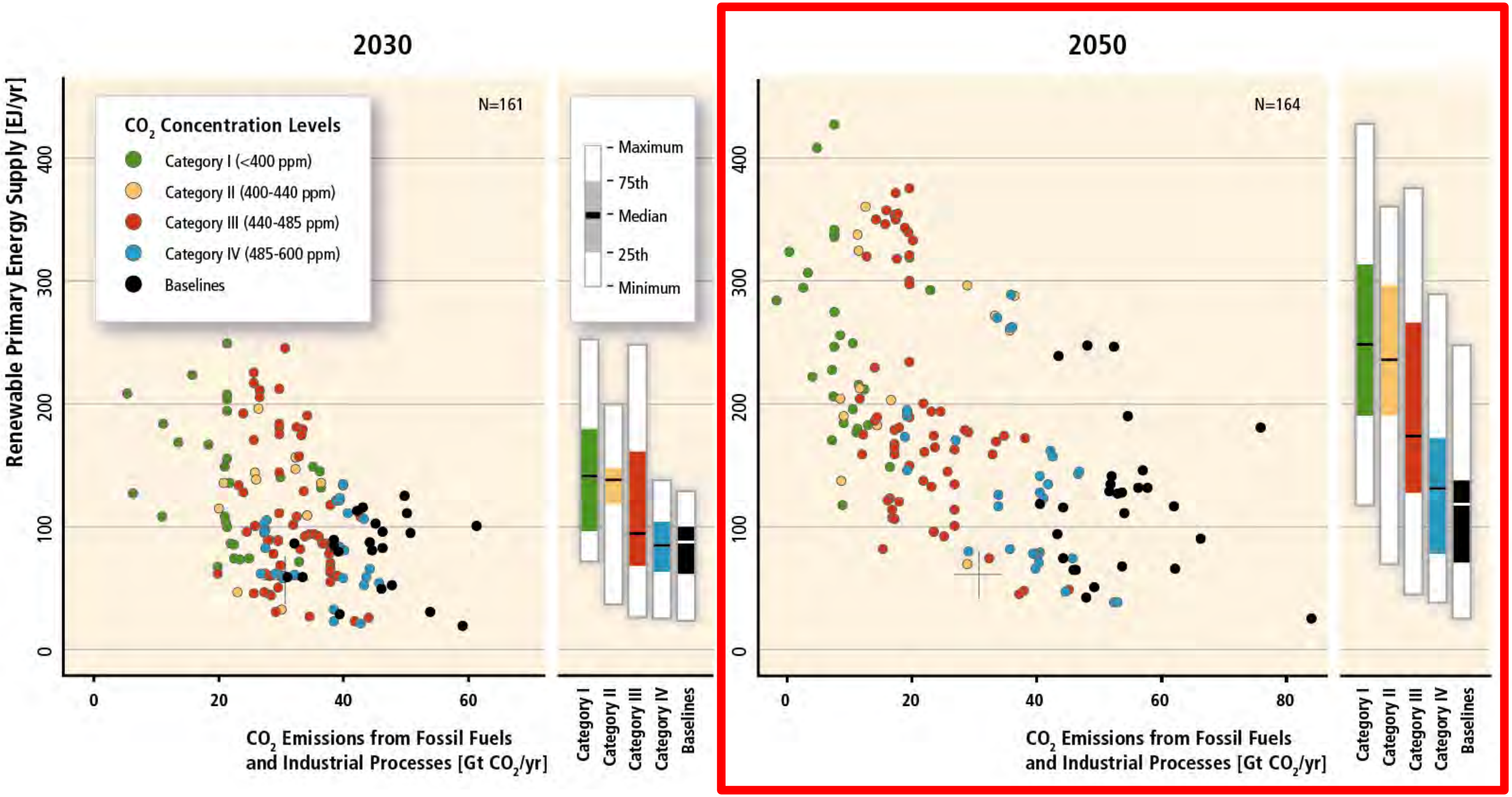


Range of Estimates of Global Technical Potentials

	Geothermal Energy (Electricity)	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy (Heat)	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

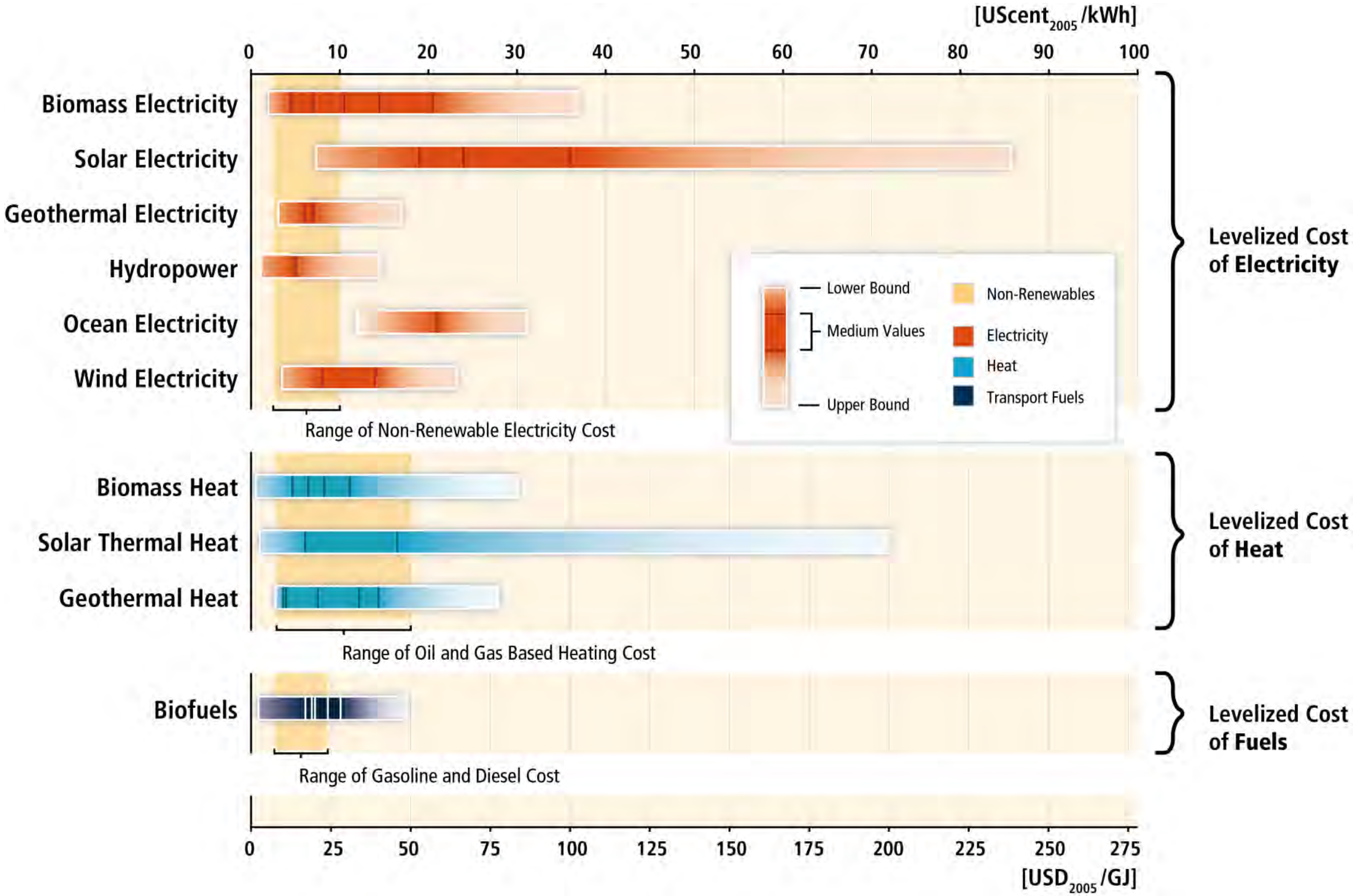
Source: IPCC Special Report Renewable Energy Sources (SRREN)

Global RE primary energy supply from 164 long-term scenarios versus fossil and industrial CO_2 emissions



Source: SRREN SPM, Figure SPM.9

RE costs are still higher than existing energy prices, but in various settings RE is already competitive



Top Countries with Installed Renewable Electricity by Technology (2010)

Geothermal	Wind	Solar PV	CSP	Biomass
1 U.S.	1 China	1 Germany	1 Spain	1 U.S.
2 Philippines	2 U.S.	2 Spain	2 U.S.	2 Brazil
3 Indonesia	3 Germany	3 Japan		3 Germany
4 Mexico	4 Spain	4 Italy		4 Spain
5 Italy	5 India	5 U.S.		5 India

Sources: REN21, GWEC, SEIA/GTM

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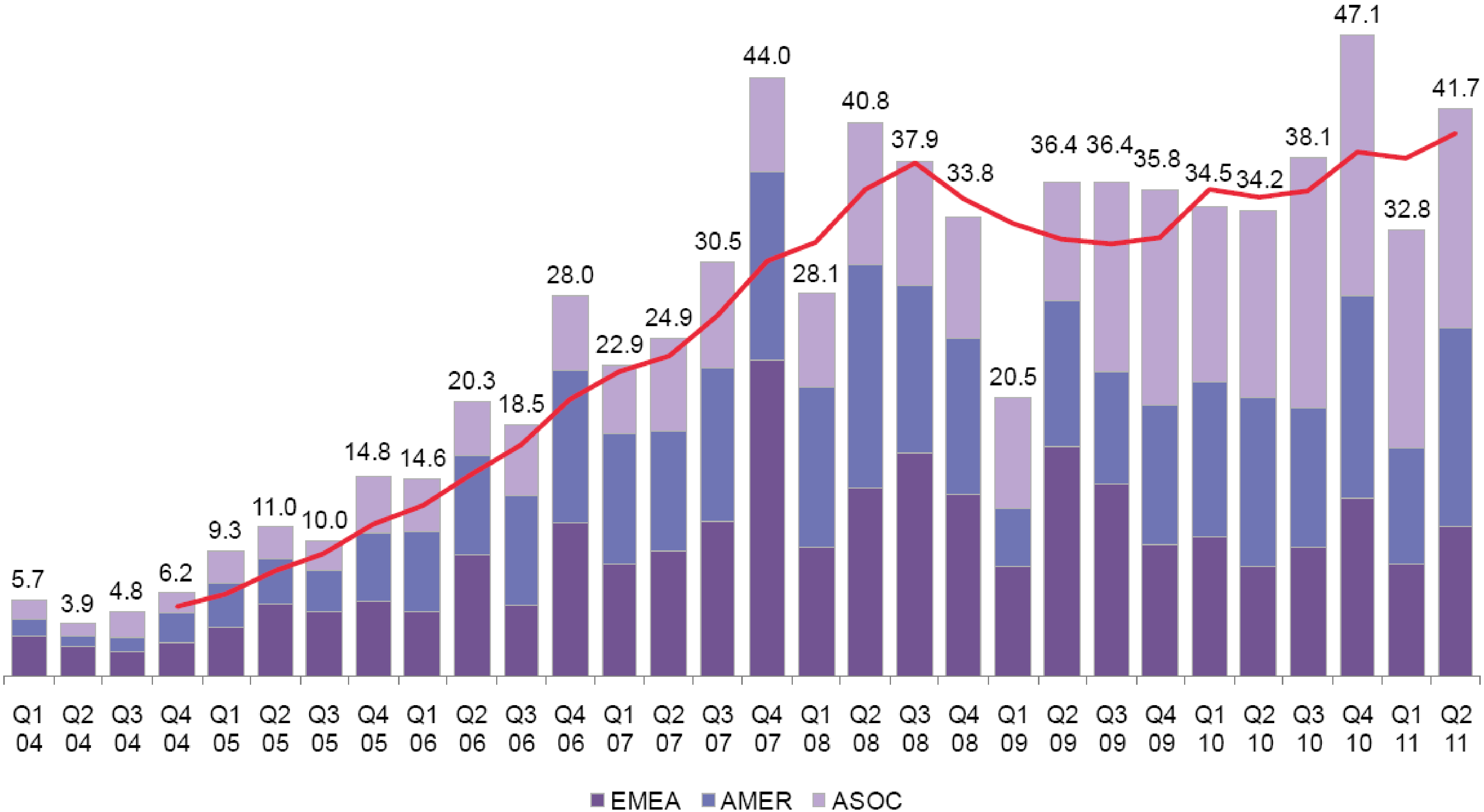
Global Renewable Energy Development | August 2011

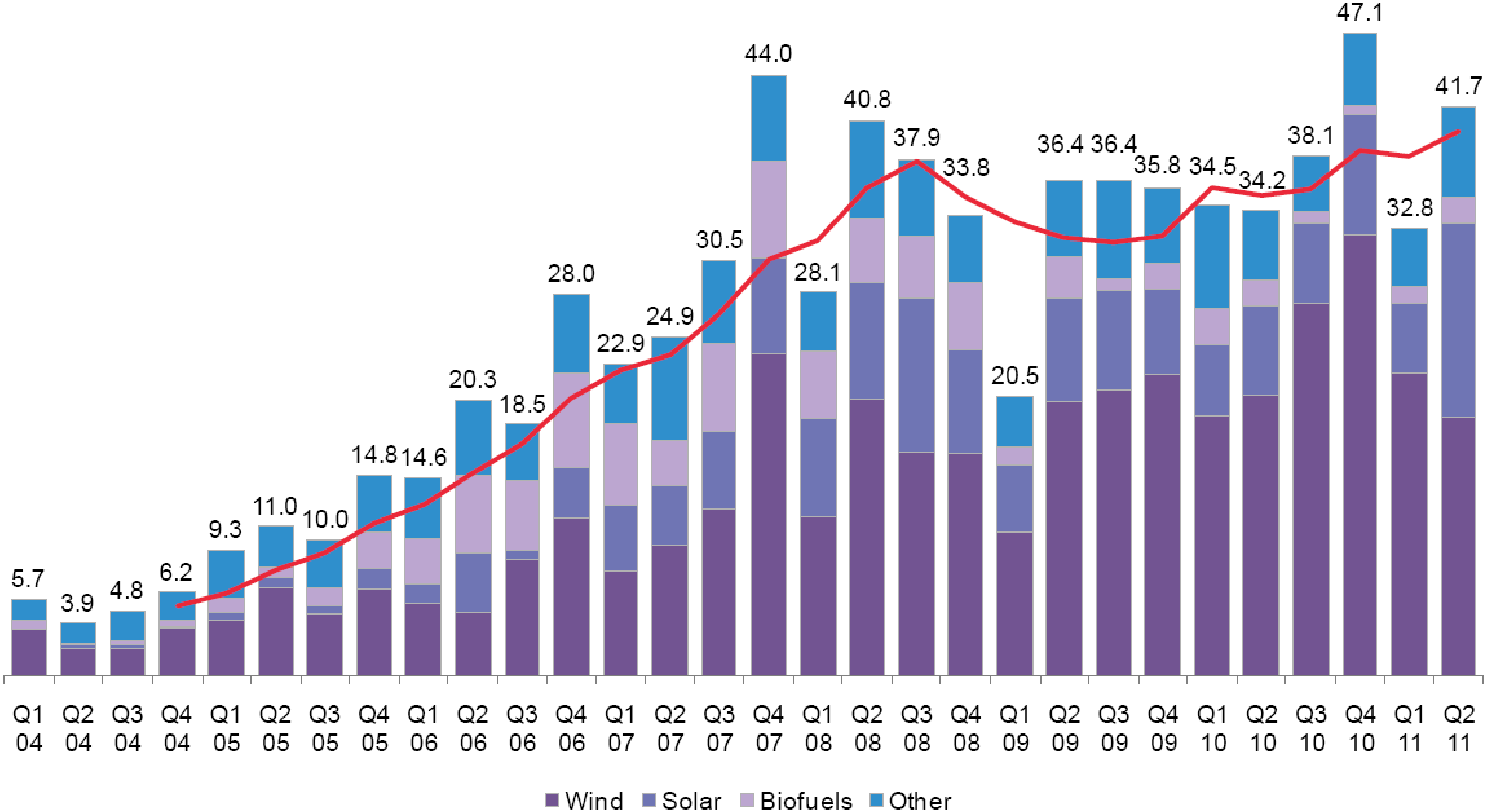
New Financial Investment in Clean Energy by Region Q1 2004-Q2 2011 ($Bn)



Note: Excludes corporate and government R&D, and small distributed capacity. Not adjusted for re-invested equity

Source: Bloomberg New Energy Finance

New Financial Investment in Clean Energy by Sector Q1 2004-Q2 2011 ($Bn)

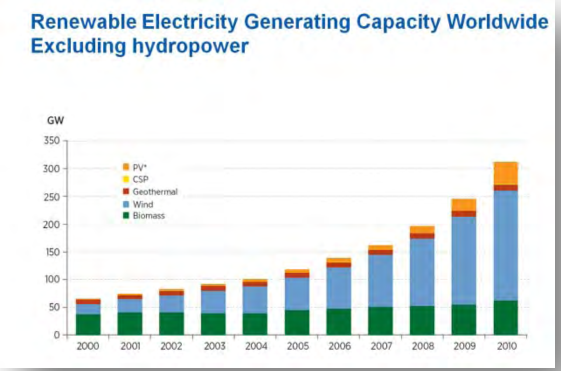


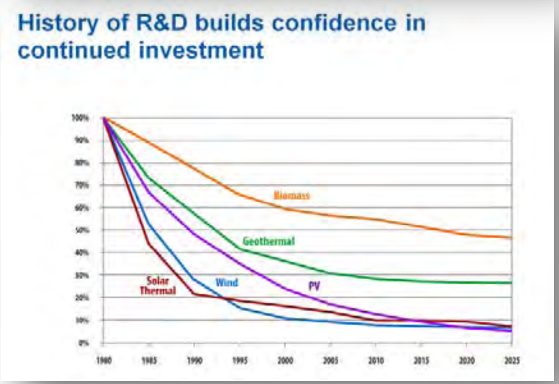
Note: Excludes corporate and government R&D, and small distributed capacity. Not adjusted for re-invested equity

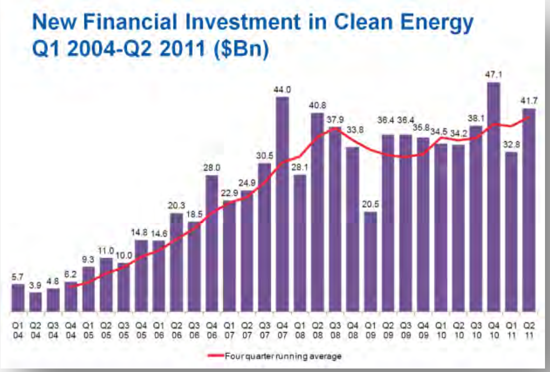
Source: Bloomberg New Energy Finance

The Role for Clean Energy—A Decade of Real Progress

- **Wind power capacity increased by more than a factor of 10 to more than 200 GW.**
- **Solar PV global installed capacity grew by factor of almost 30 to about 35 GW in 2010.**
- **Biofuels emerged as a major global industry (~28 billion gallons/year)**
- **LEED-certified commercial buildings grew to more than 10,000**
- **Costs have been significantly reduced and are approaching grid parity**
- **Clean energy grew from $1B/year to a $211B/year market**







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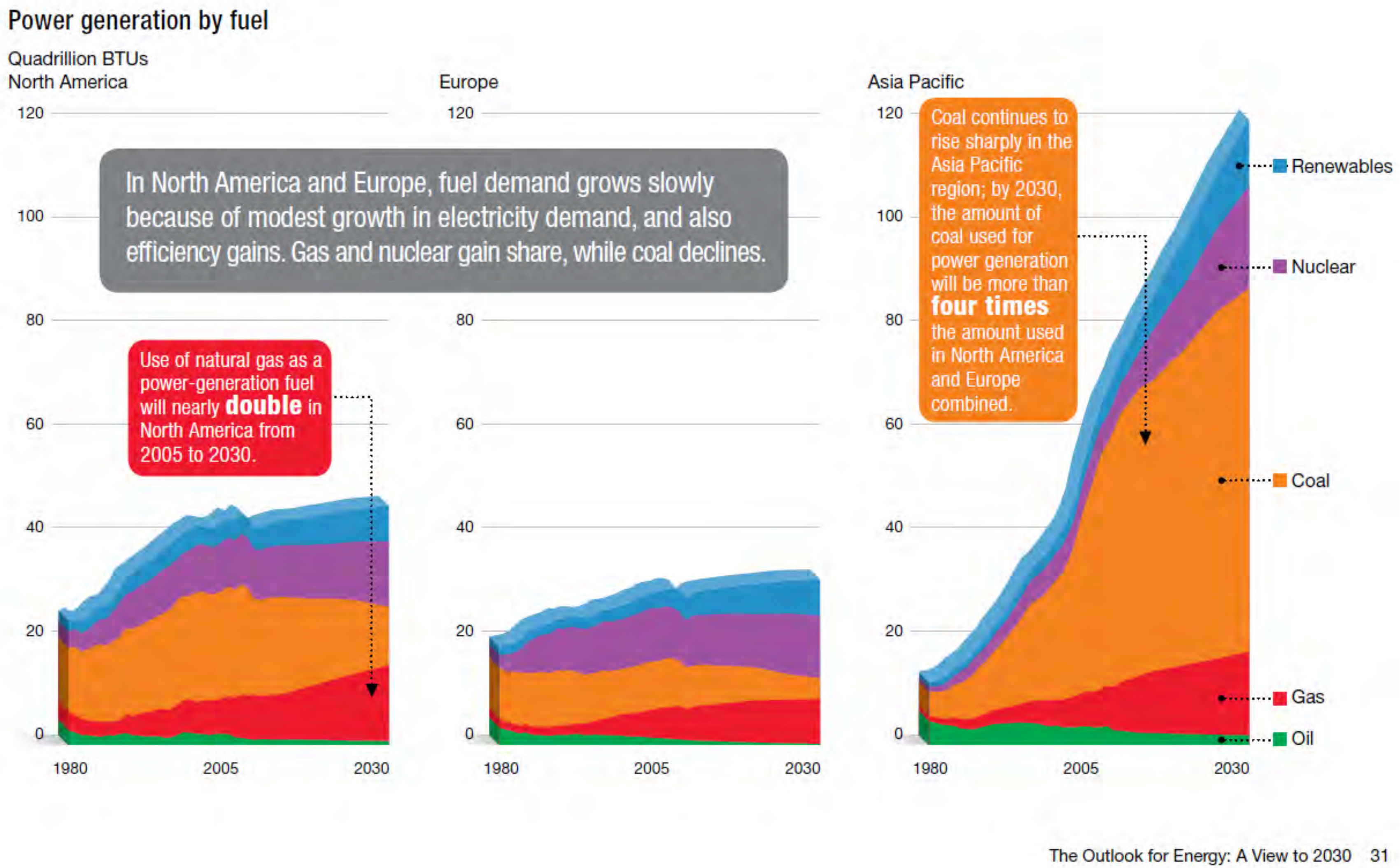
IEA 2011 *Clean Energy Progress Report*

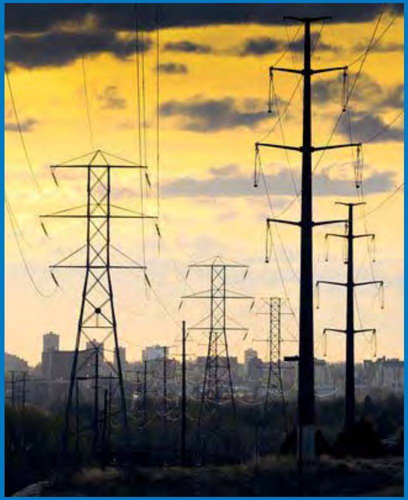
"While 19.5% of global electricity in 1990 was produced from renewable sources, this share fell to 18.5% in 2008."

Many expect electricity demand to grow faster than renewable energy generation



For decades we have known our energy system is unsustainable.

Why is this so hard?



"But even under conservative projections, we face a future of critical shortages and handicaps. By the year 2000, a United States population of 300 million – nearly doubled in 40 years – will need far greater supplies of farm products, timber, water, minerals, fuels, energy, and opportunities for outdoor recreation." (February 23, 1961)

"Let this be our national goal: At the end of this decade, in the year 1980, the United States will not be dependent on any other country for the energy we need to provide our jobs, to heat our homes, and to keep our transportation moving." (January 30, 1974)

"I am proposing a program which will begin to restore our country's surplus capacity in total energy. In this way, we will be able to assure ourselves reliable and adequate energy and help foster a new world energy stability for other major consuming nations." (January 15, 1975)

"This intolerable dependence on foreign oil threatens our economic independence and the very security of our nation. " (July 15, 1979)

"We will continue supportive research leading to development of new technologies and more independence from foreign oil. " (Feb. 18, 1981)

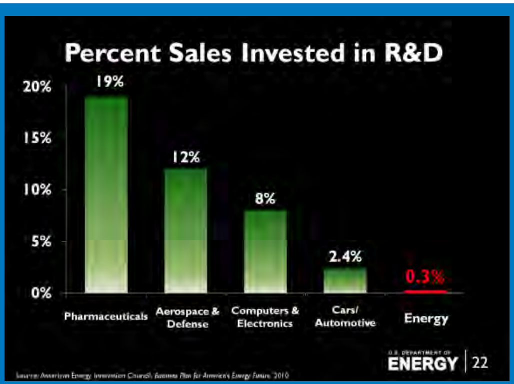
"There is no security for the United States in further dependence on foreign oil." (August 18, 1988)

"We need a long-term energy strategy to maximize conservation and maximize the development of alternative sources of energy. " (June 28, 2000)

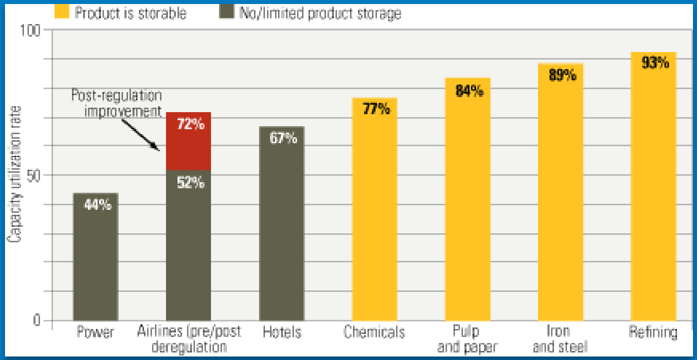
"This country can dramatically improve our environment, move beyond a petroleum-based economy, and make our dependence on Middle Eastern oil a thing of the past." (January 31, 2006)

"For decades, we have known the days of cheap and accessible oil were numbered…. Now is the moment for this generation to embark on a national mission to unleash America’s innovation and seize control of our own destiny." (June 15, 2010)

Energy Sector Challenges



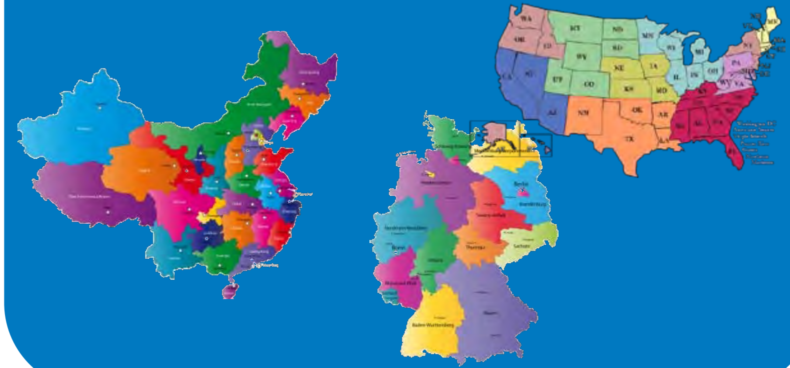
R&D Investment Drives Innovation



Asset Utilization

Capital Intensive with Long Life Cycles

National Strategies Driving Energy Market



A Profound Transformation is Required

Today's U.S. Energy System	Sustainable Energy System

TRANSFORMATION

Today's U.S. Energy System

- Dependent on foreign sources
- Subject to price volatility
- Increasingly vulnerable energy delivery systems
- 2/3 of source energy is wasted
- Produces 25% of the world's carbon emissions
- Role of electricity increasing

Sustainable Energy System

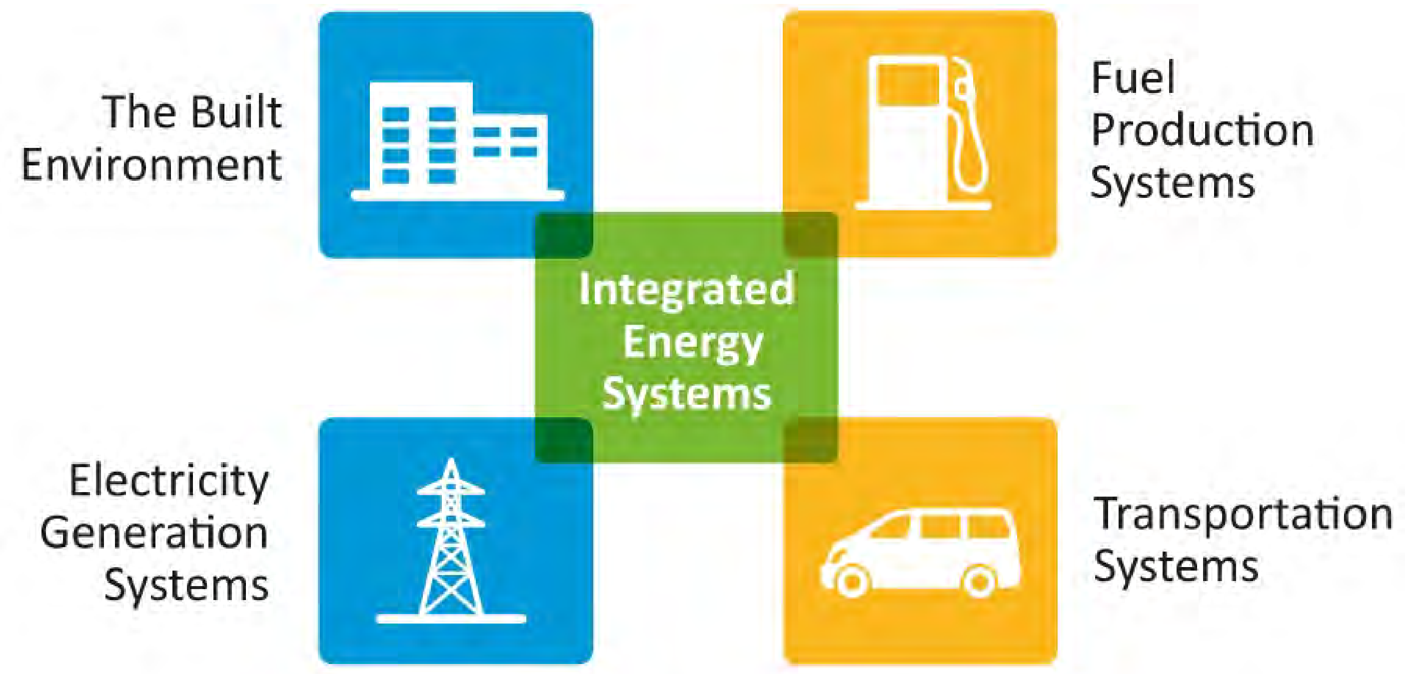
- Carbon neutral
- Efficient
- Diverse supply options
- Sustainable use of natural resources
- Creates American jobs
- Accessible, affordable and secure

Vision for the Energy System

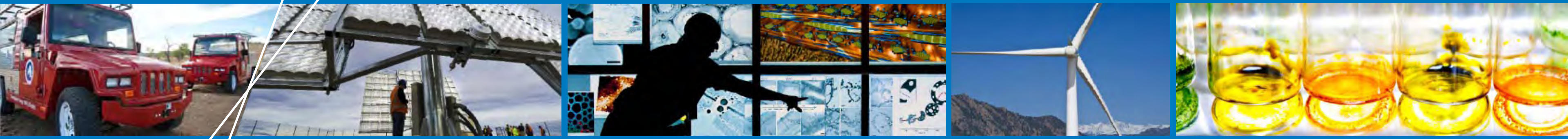
By 2050, we will have a clean and sustainable energy system that contributes to economic prosperity, enhances national security, and maintains environmental quality

2050 Energy System Target

Oil use is reduced to **15%** of current levels, CO_2 reduced by **80%**

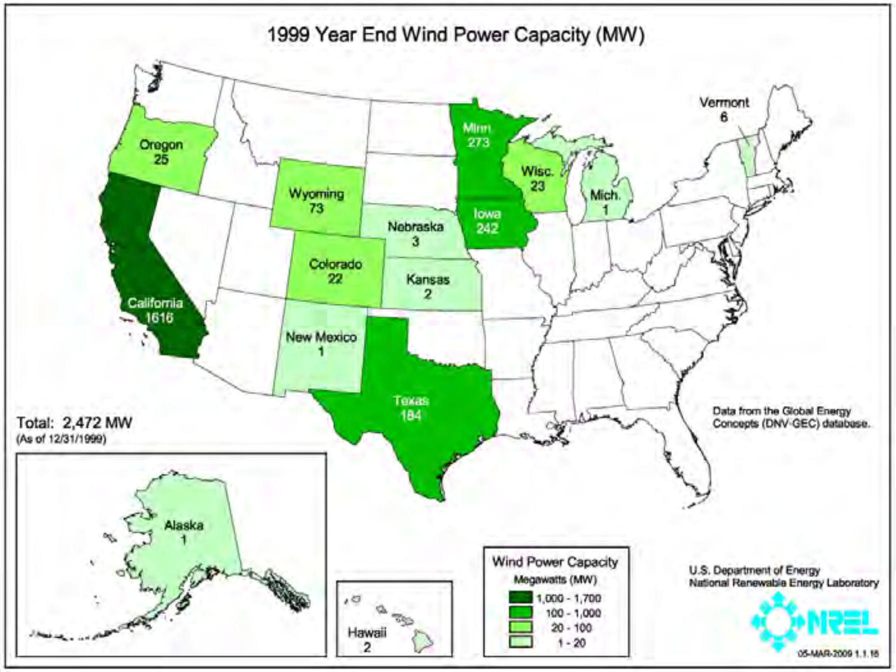


The Promise of the Technology



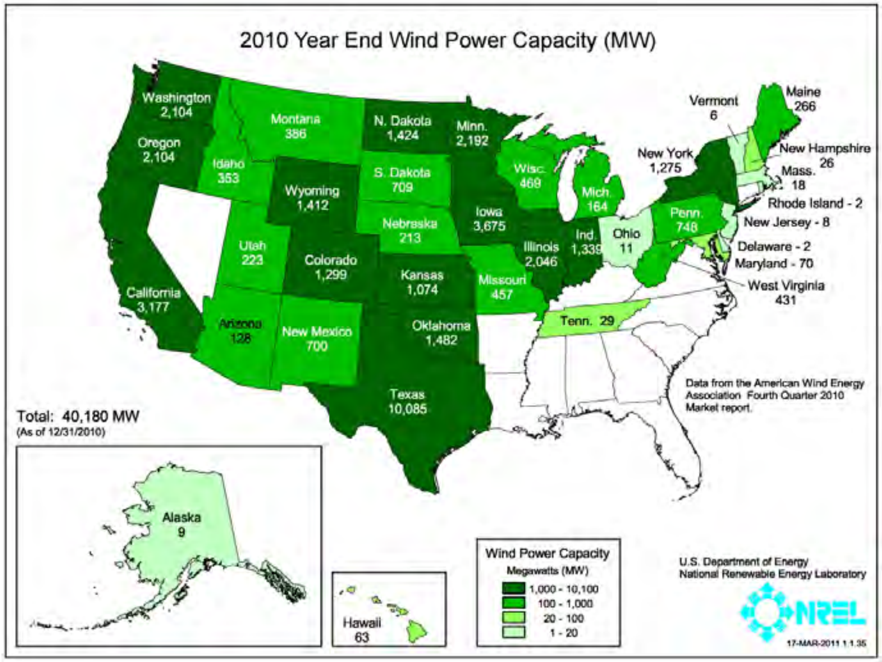
Wind Power

Wind energy: state of the technology



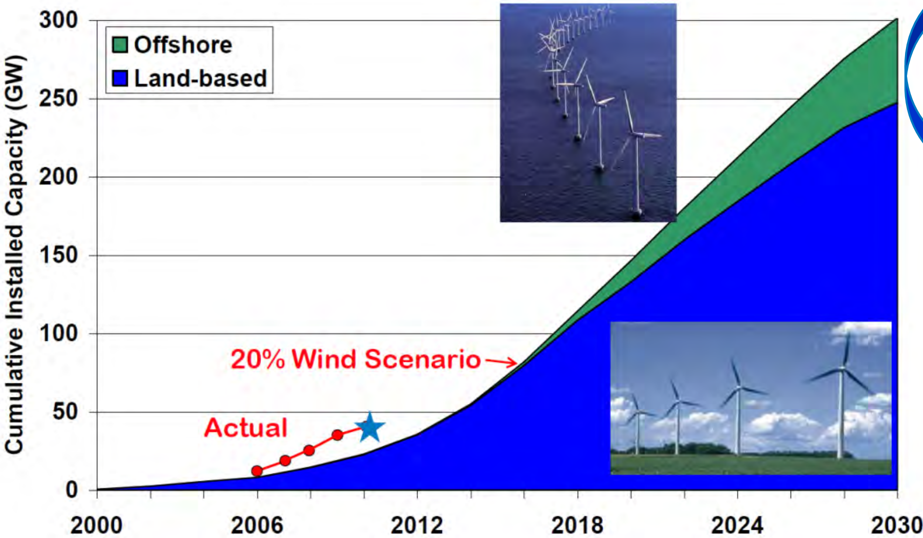
- U.S. installed capacity = 42.4 GW (6/2011)
- 38 of 50 states have utility-scale wind with 14 states > 1,000 MW installed
- 7.4 GW currently under construction
- Over 35,600 commercially operating wind turbines > 1 MW in capacity
- U.S. wind percentage of electricity = 2.3%
  - IA = 15%, ND = 12%, MN: = 10%

- Costs: 7-10 cents/kWh LCOE*
- Installed wind project cost = $2,155/kW
- 1.5-3.0 MW commercial turbines are typical
- 10 MW prototype machines in development
- Direct drive generators more common
- Variable speed and grid-friendly operation
- Technologies targeting offshore wind markets



* Estimate for utility-scale wind, class 4 wind sites, no subsidies

Wind energy: national goals/targets



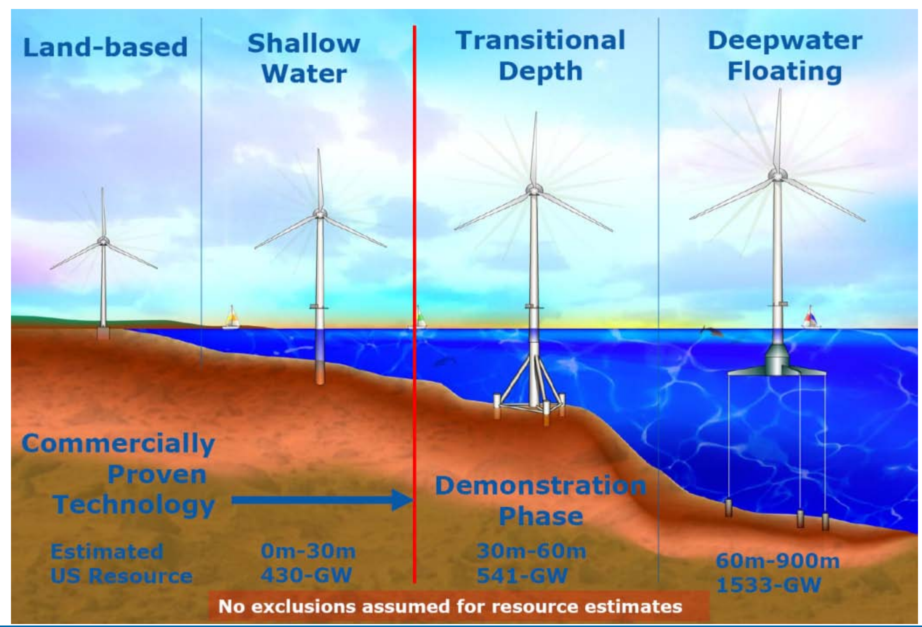
Administration goals: By 2035, 80% of America's electricity will come from clean energy sources

DOE/EERE strategic goals: Reduce energy-related greenhouse gas emissions by 17% by 2020 and 83% by 2050, from a 2005 baseline

Wind Program strategic goals: Technology development to reduce wind unsubsidized LCOE to be competitive with coal and natural gas

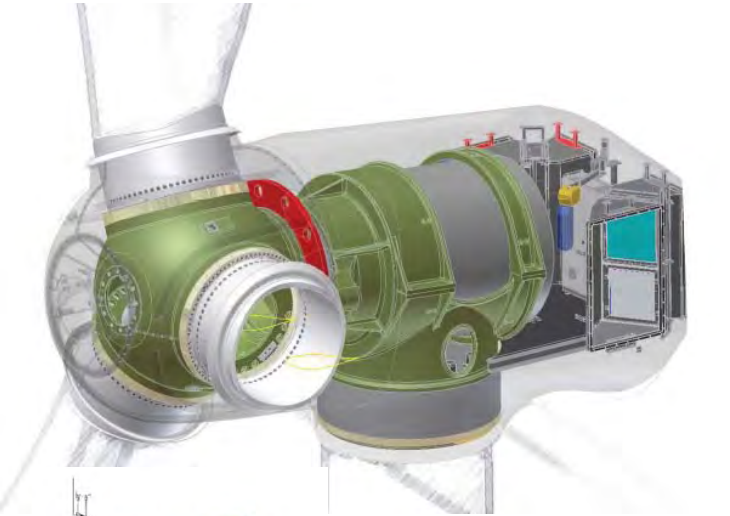
RDD&D Thrusts to Realize National Goals:

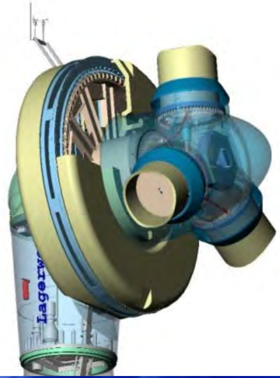
- Reduce cost of wind energy – improve performance & reliability, decrease capital costs
- Integrate large amounts of wind with electric grid – expand transmission, improve wind forecasting, increase flexibility of grid operation
- Leverage geographic and technological diversity
- Address barriers to large-scale deployment – siting, radar interference, wildlife, permitting
- Expand domestic supply chain and workforce
- Enable informed decision-making

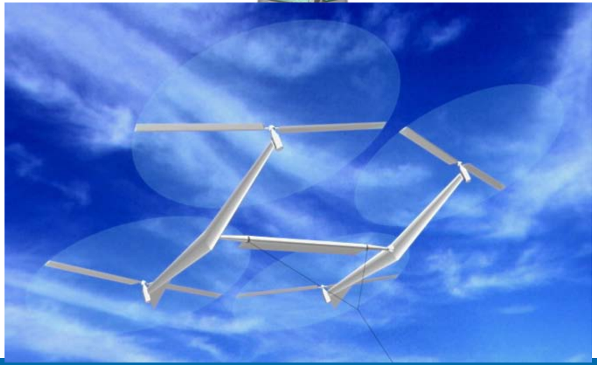


Innovative new wind technologies

- Modular large components – blades, drivetrains, and tall towers
- Advanced drivetrain power conversion systems – superconducting direct drive generators
- Flexible, ultra-large rotors and systems
- Active controls for structural load reduction, improved wind plant performance, and grid-friendly operation
- Floating offshore wind turbines
- Airborne wind power systems







Wind Energy Technology

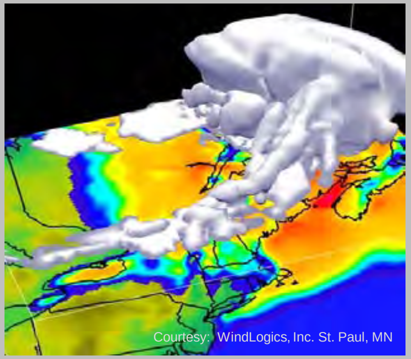
US Wind Resource Exceeds Total Electrical Demand

Offshore Wind

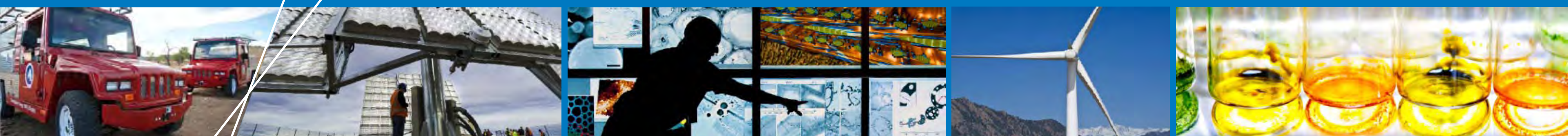
Innovative Tall Towers

Advanced Blades

Giant Multi-megawatt Turbines



Wind Forecasting



Solar Power

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 Electricity: *State of the Technology*

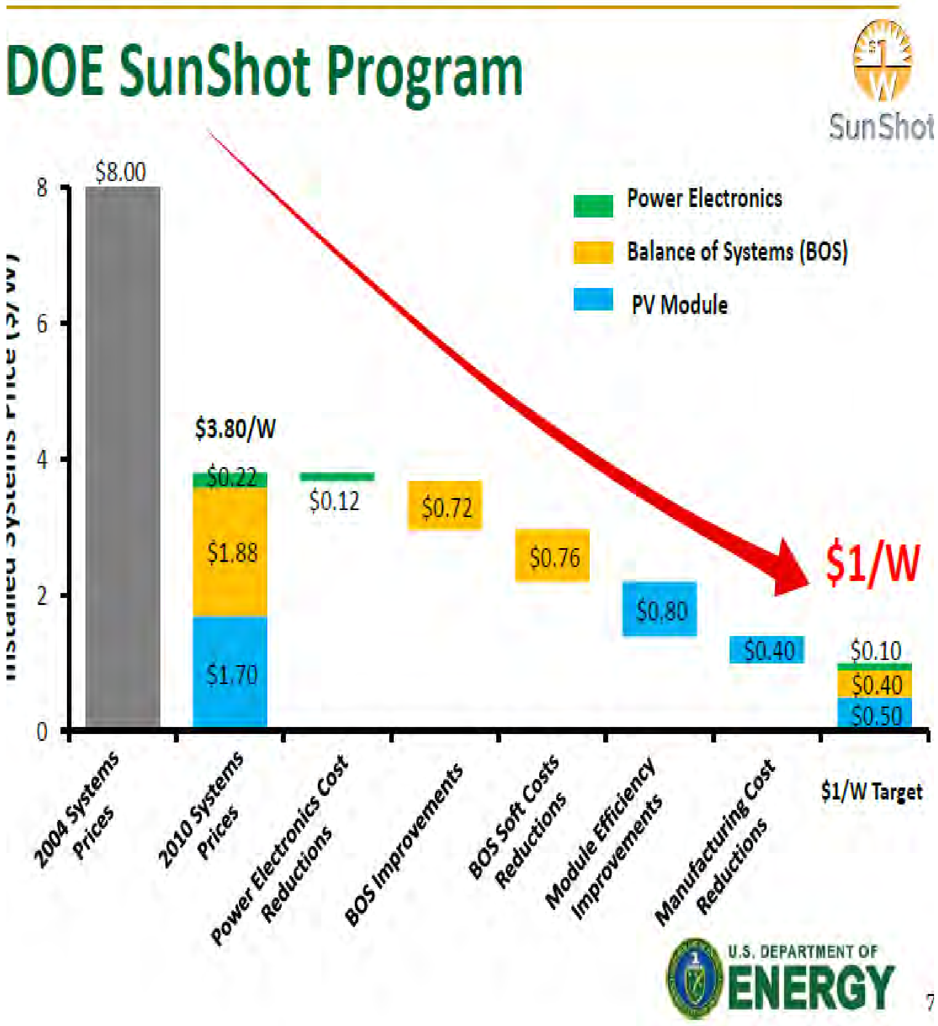
- Photovoltaics (PV)
- Market: Residential; Commercial,
- Utility. Geographically diverse.
- 1 kW to 250 MW > GW
- U.S. Capacity: 2.4 GW
- U.S. Forecast: 10+ GWs in pipeline.
- Costs. $4 to $8/W :*LCOE 10 to 20¢/kWr.
- Technologies: Conversion; thin-films, crystalline silicon. Storage; battery.

- *With various incentives; e.g. the FTC.

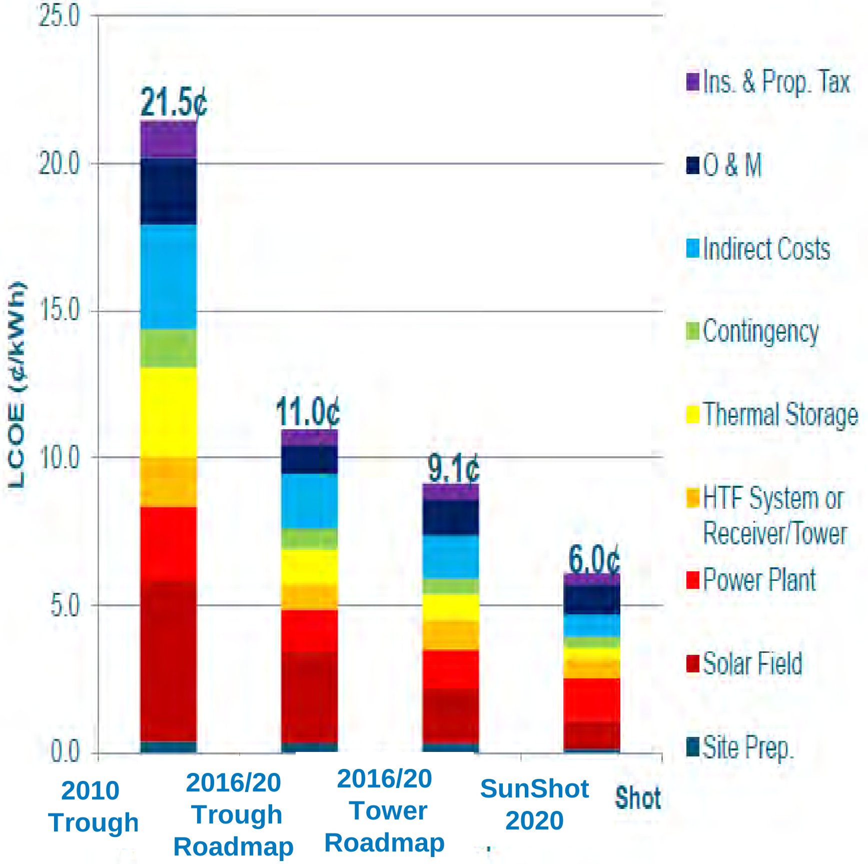
- Solar Thermal Electric (CSP)
- Market: Commercial; Utility.
- Geographically confined to “sun bowls”.
- 25 MW to 250 MW > GWs
- U.S Capacity: 0.5 GW.
- U.S. Forecast: 10+ GWs in pipeline.
- Costs. $4 to $8/W :*LCOE 12 to 20 ¢/kWr.
- Technologies. Conversion; parabolic troughs, central receivers, dish. Storage; thermal, up to 15 hours.

Solar Electricity: R&D Thrusts

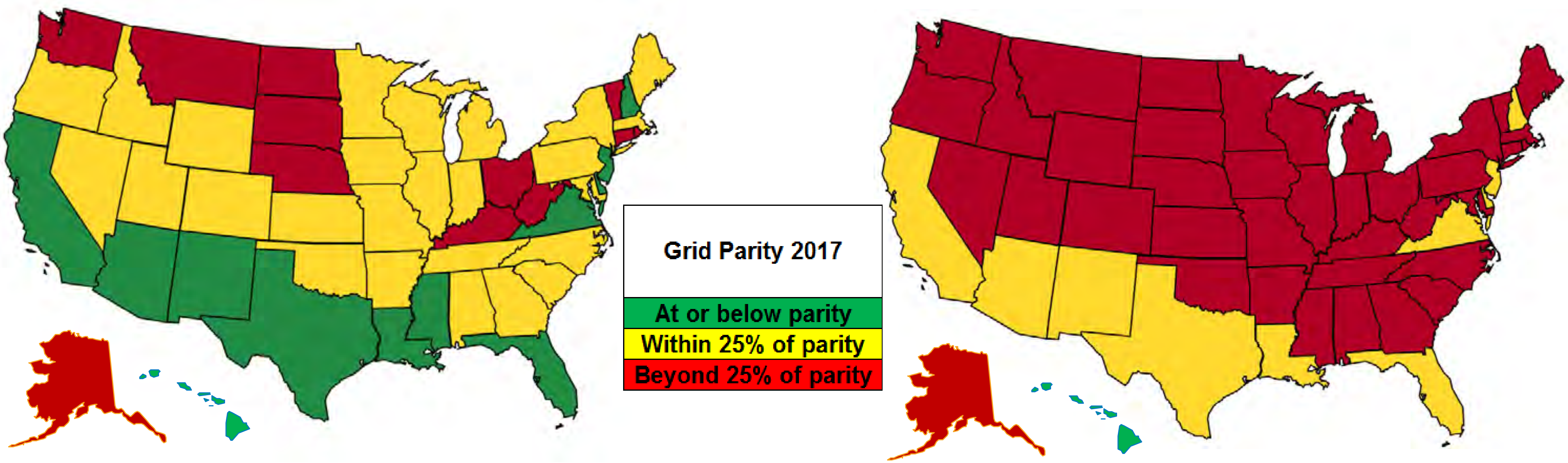
Photovoltaics



CSP



Grid Parity with $1 / Watt



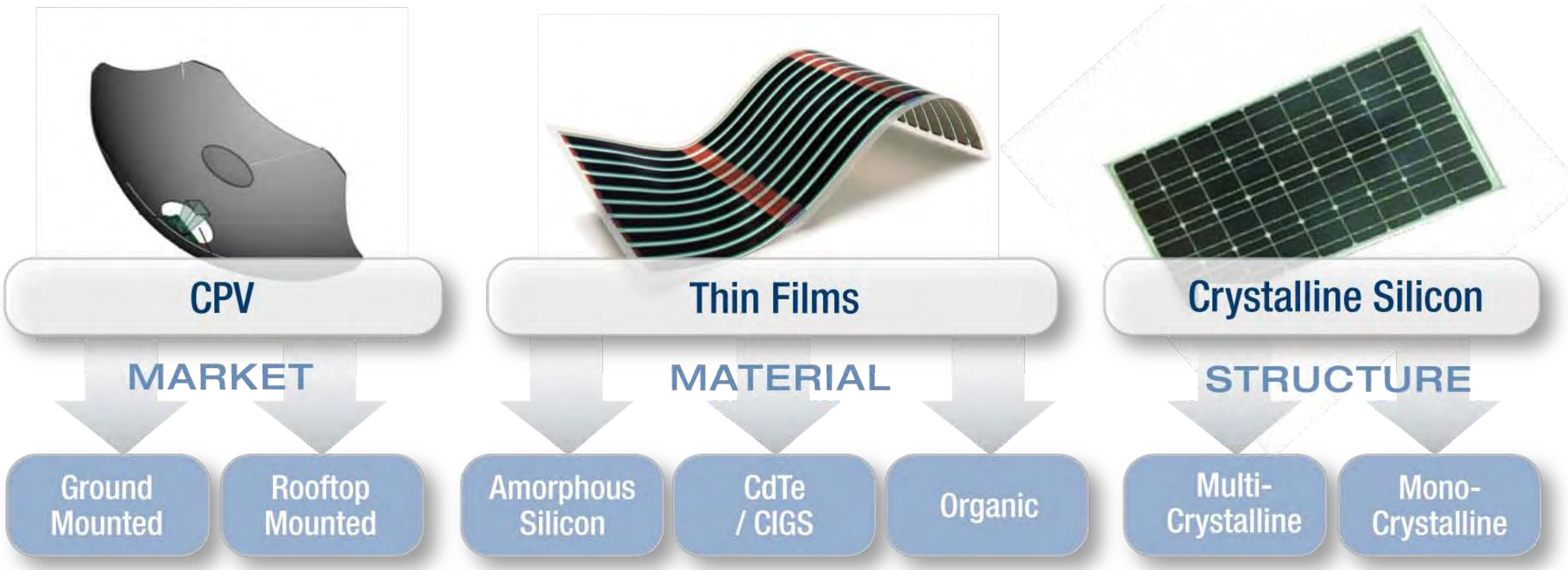
$1 / Watt Scenario

Current Projection

- Assumes no Federal, State, Local, and Utility incentives
- Assumed an installed system size of 20 MW, and an 86% conversion factor between DC and AC module capacity.
- Utilized weighted average wholesale electricity prices from the 2008 EIA-861 Data. The data were escalated to 2017 prices based on an annual electricity escalation rate of 1%.

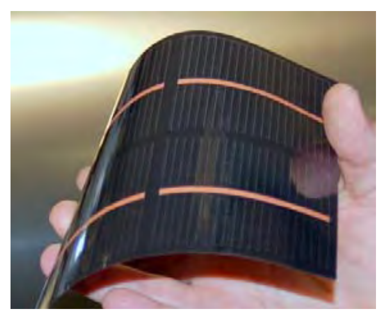
- Current projection for utility scale PV is assumed to be $2/Watt by 2017.

Pursuing a Range of Promising PV Technologies

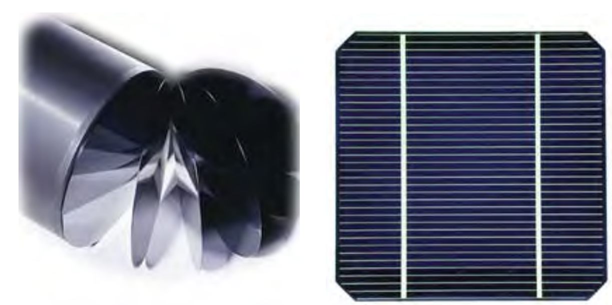


20x-100x

500x



$Cu(In,Ga)Se_2$ ~ 1-2 um



c-Si ~ 180 um

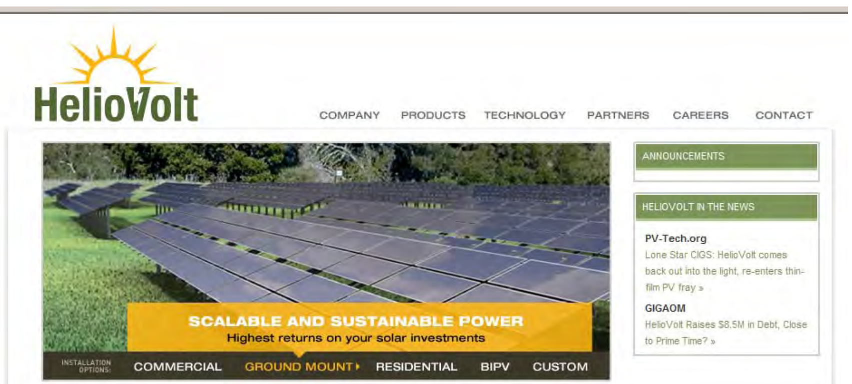
Market Relevant Process Innovation

"Black Silicon" Nanocatalytic Wet-Chemical Etch

2010 R&D 100

Flash Quantum Efficiency System

2011 R&D 100



Revolutionary CIGS thin-film manufacturing process using inket printing

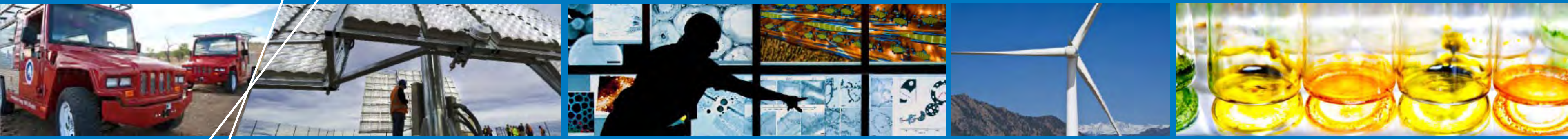
HelioVolt

R&D 100

2008

Silicon Ink
NREL Incubator Project

2011 R&D 100



Biofuels

Biofuels

Current Status:

U.S. produced 13 billion gallons of ethanol and 0.5 billion gallons of biodiesel (2010):

Biorefineries:

- 219 commercial corn ethanol plants
- 180 biodiesel refineries
- 26 cellulosic ethanol demonstration plants

Cost goal:

Cellulosic ethanol—cost parity with gasoline by 2012

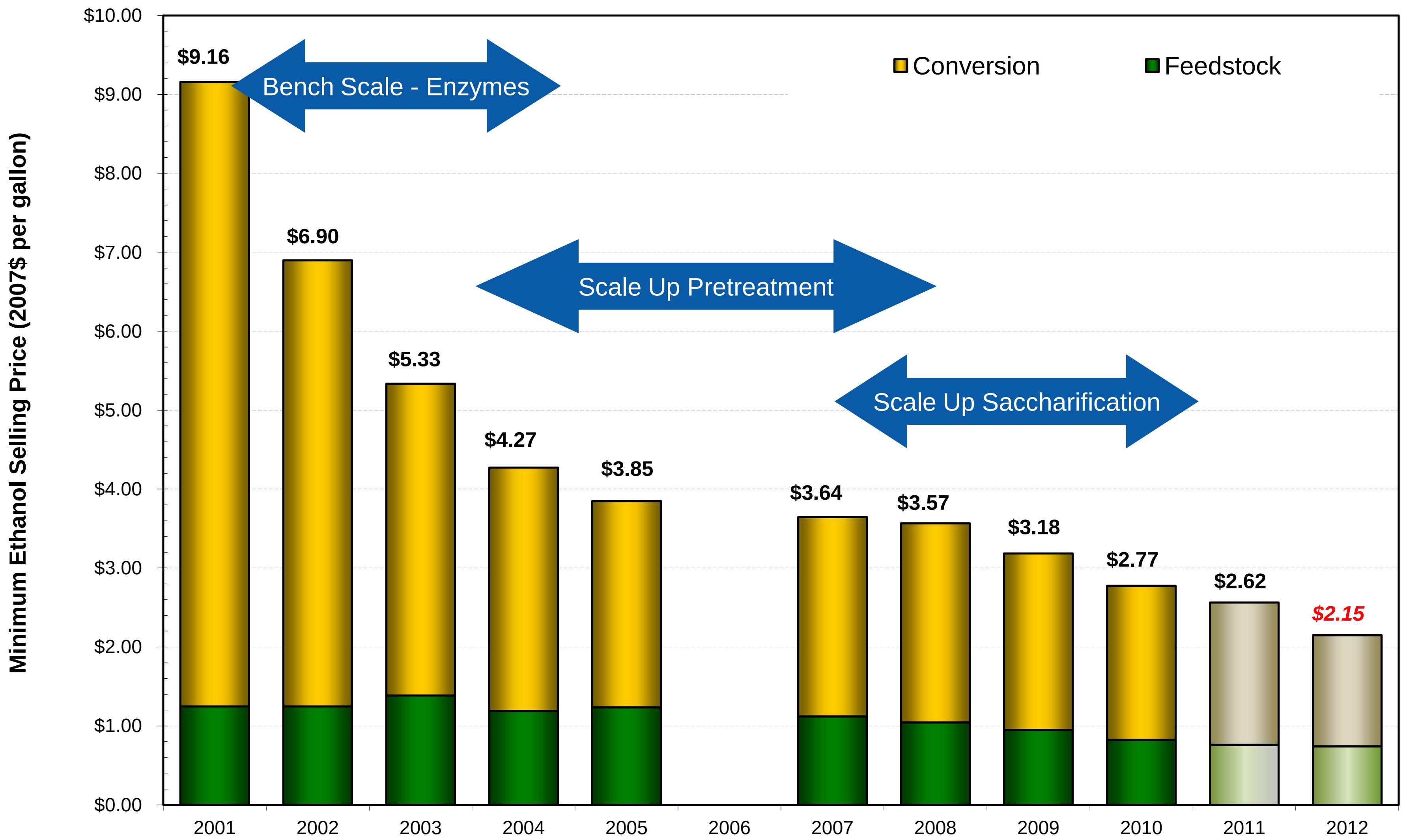
Major Technology Directions:

- **Foundational Science: Enzymes, fermentation, understanding biomass and cell compostion**
- **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**

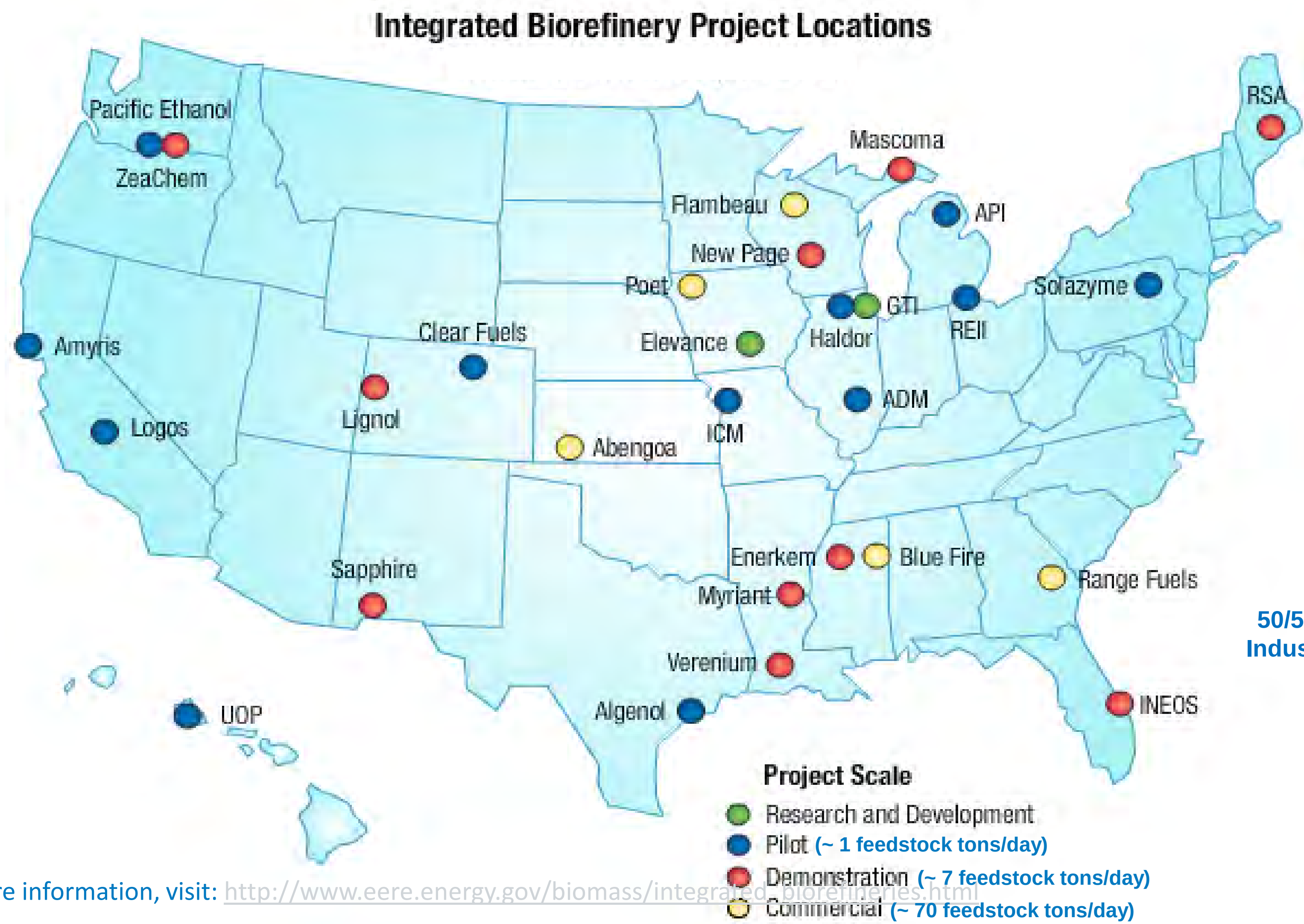
Updated 8/22/11

Updated 8/11

Biochemical Conversion: *State of Technology*



Locations of the 28 Integrated Biorefinery Projects



50/50 funded by Industry and DOE

For more information, visit: http://www.eere.energy.gov/biomass/integrated_biorefineries.html

Transportation Biofuels Evolution

Near-Term Biofuels
Low-carbon, non-petroleum fuel for the 200+ million ICE vehicles the U.S. will still have for decades to come – primarily ethanol

Longer-Term Biofuels
Low-carbon, non-petroleum fuel for hybrids/plug-ins and for transportation needs that may not be suitable for electric drive – advanced biofuels

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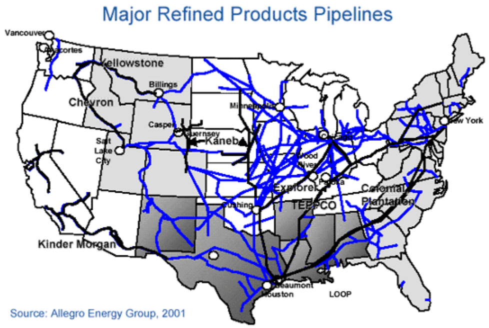
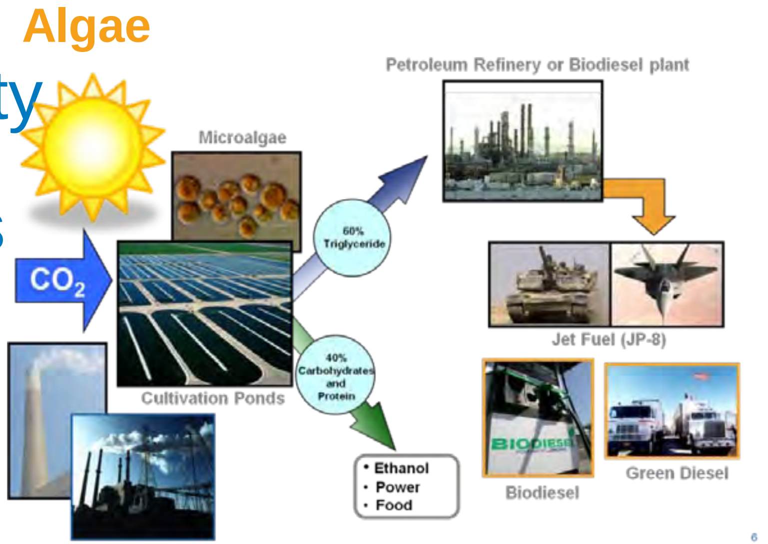
Why Follow-On Generations?



"Advanced Biofuels" – moving beyond ethanol

- Higher energy density/suitability
- Infrastructure compatibility
- Better temp and cold start ability
- Energy and tailored feedstocks
- **Also called:**
  - Drop-in Biofuels
  - Hydrocarbons
  - Infrastructure-compatible Biofuels

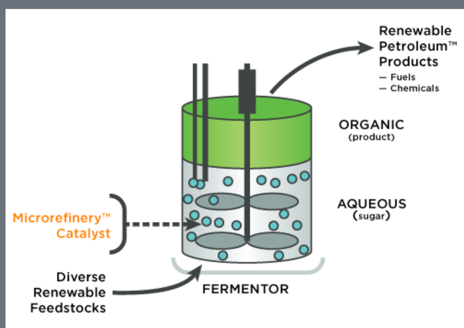


Updated 8/22/11

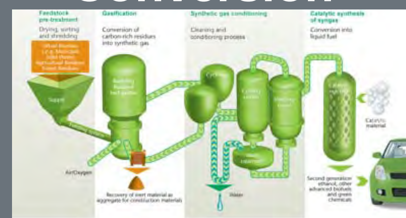
Biofuels Innovation

New conversion technologies are being developed, offering the possibility of revolutionary, high volume methods for producing biofuel hydrocarbon fuels for our trucks, trains, ships, and aircraft . . .

Biological Conversion

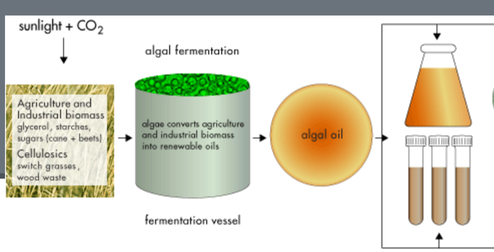


Chemical Catalytic Conversion

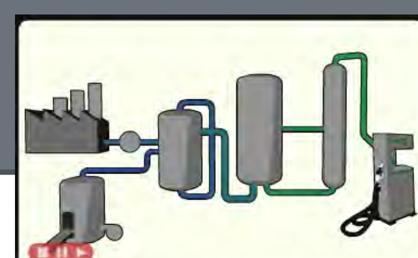


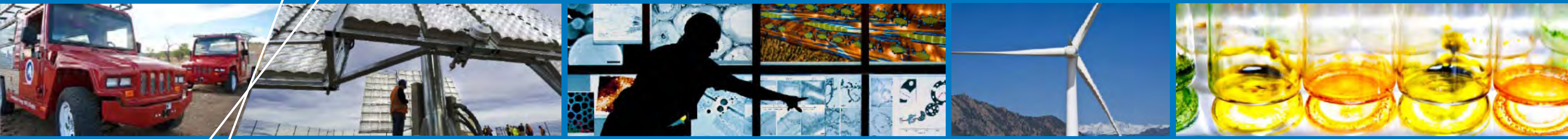
Pyrolysis/Bio-Oil Pathways

Heterotrophic Algae Conversion



Hybrid Conversion Technologies

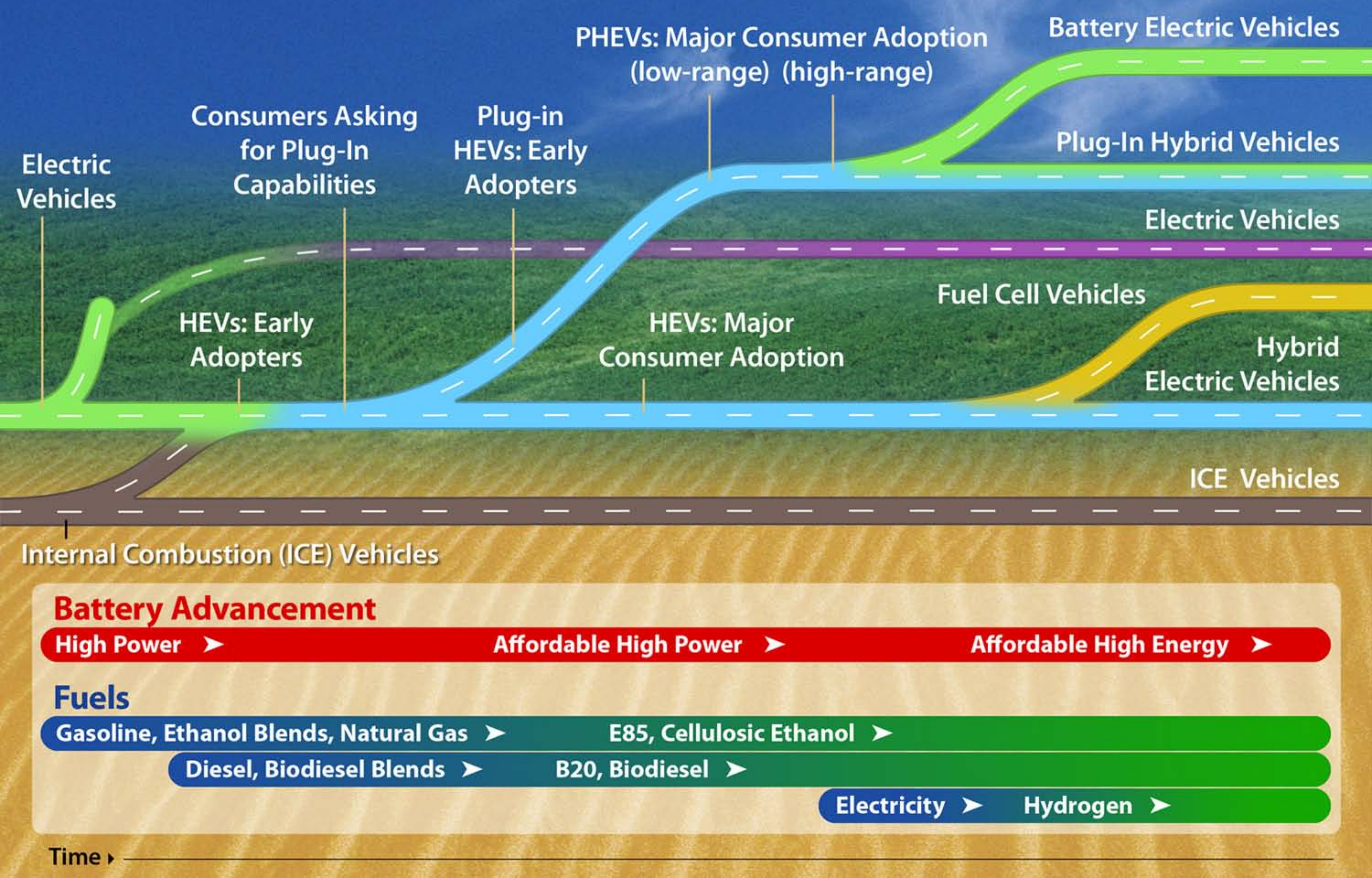




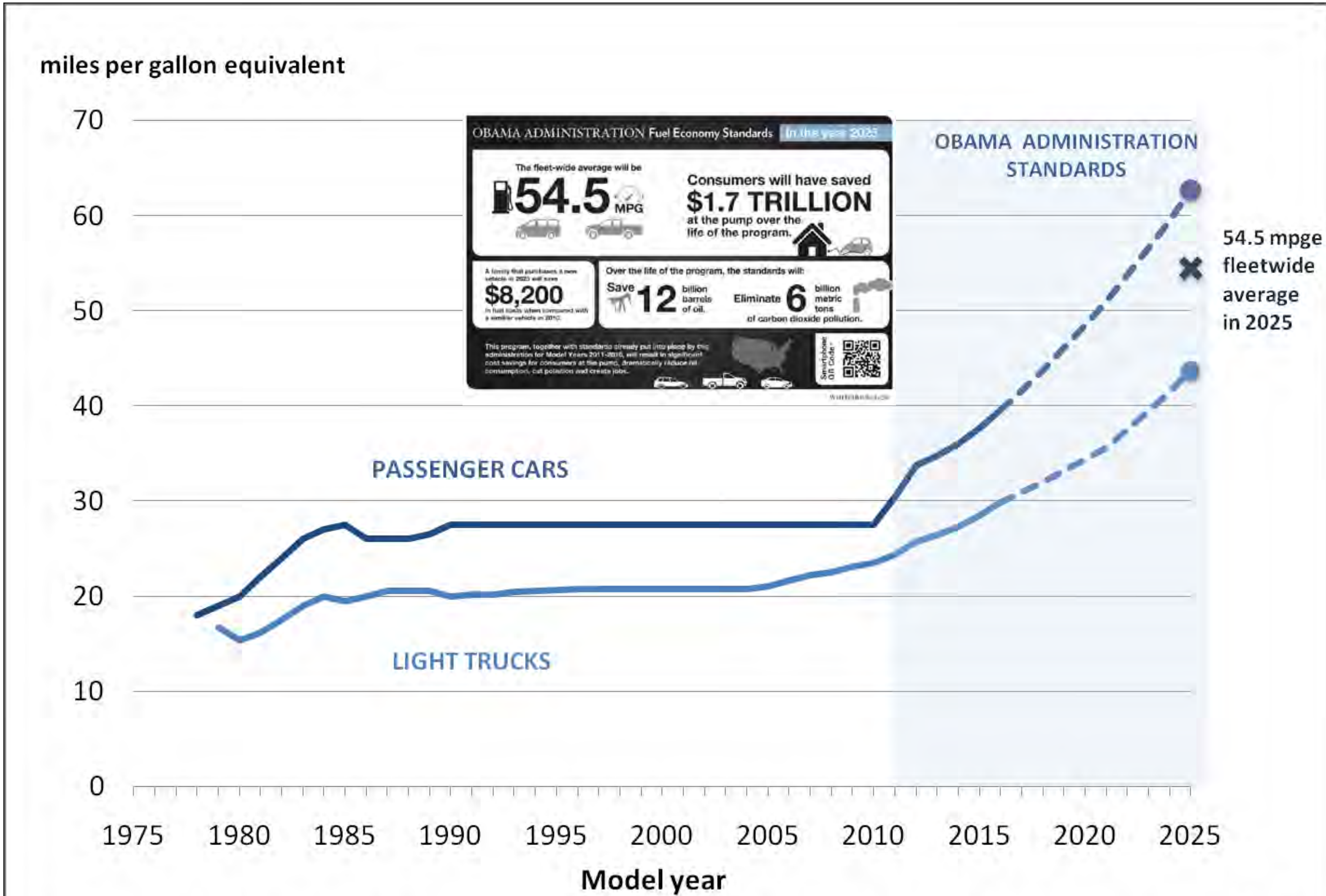
Vehicles

Vision of Future Transportation

National Renewable Energy Laboratory • Concept - Ahmad Pesaran • Illustration - Dean Armstrong • NREL/GR-540-40698



Light Duty Vehicle Fuel Economy Standards, 1978-2025



MY1978-2011 figures are NHTSA Corporate Average Fuel Economy (CAFE) standards in miles per gallon. Standards for MY2012-2025 are EPA greenhouse gas emission standards in miles per gallon equivalent, incorporating air conditioning improvements. Dashed lines denote that standards for MY2017-2025 reflect percentage increases in Notice of Intent.

Portfolio of technologies leading to 54.5 mpg

Degree of electrification (Power electronics & Energy Storage)

Start/stop

Regenerative braking

Low rolling resistance tires

Electric powered steering

Electric infrastructure

Light weighting

8 speed transmissions

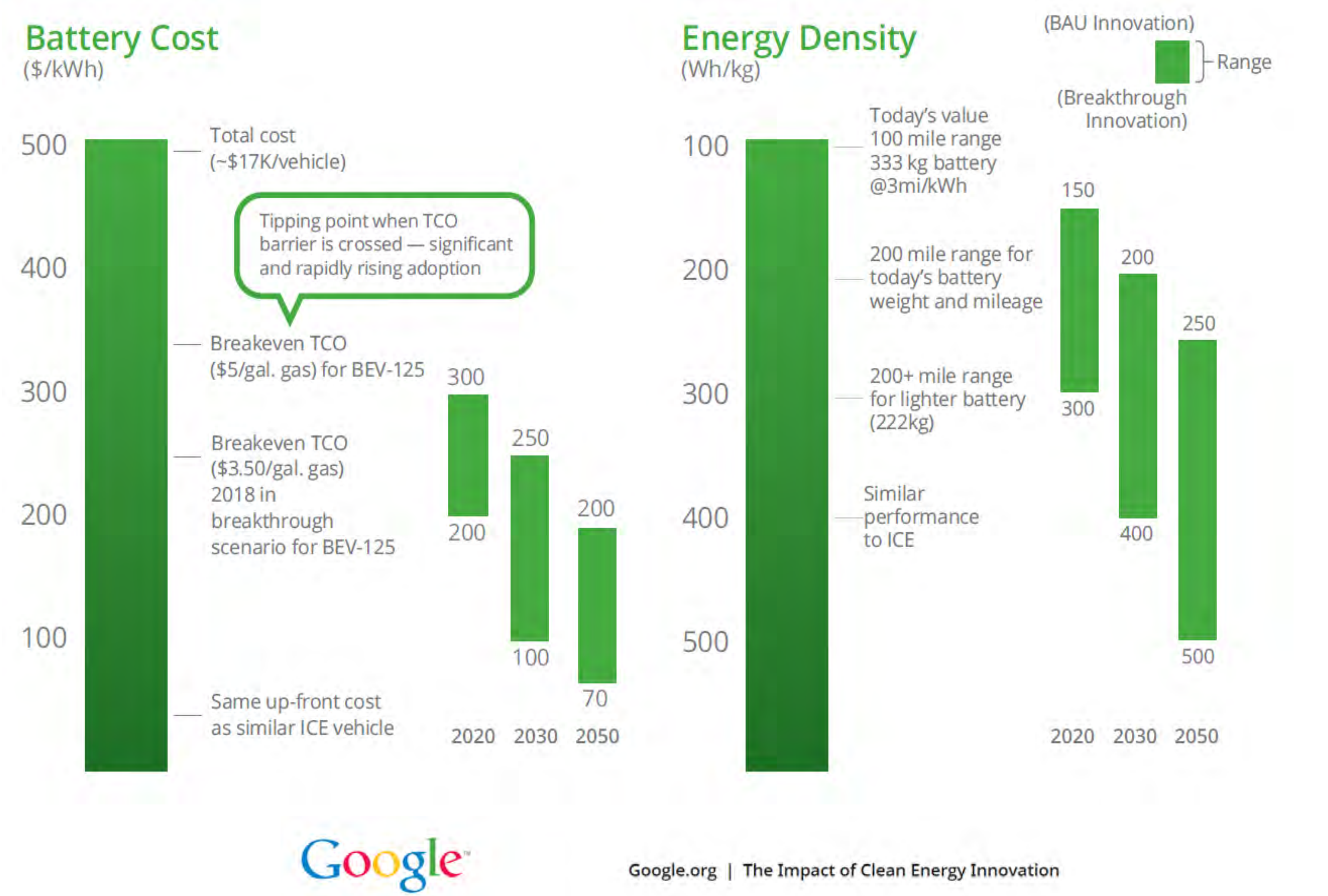
Turbocharging, direct fuel injection, advanced combustion

Variable cylinder mgmt

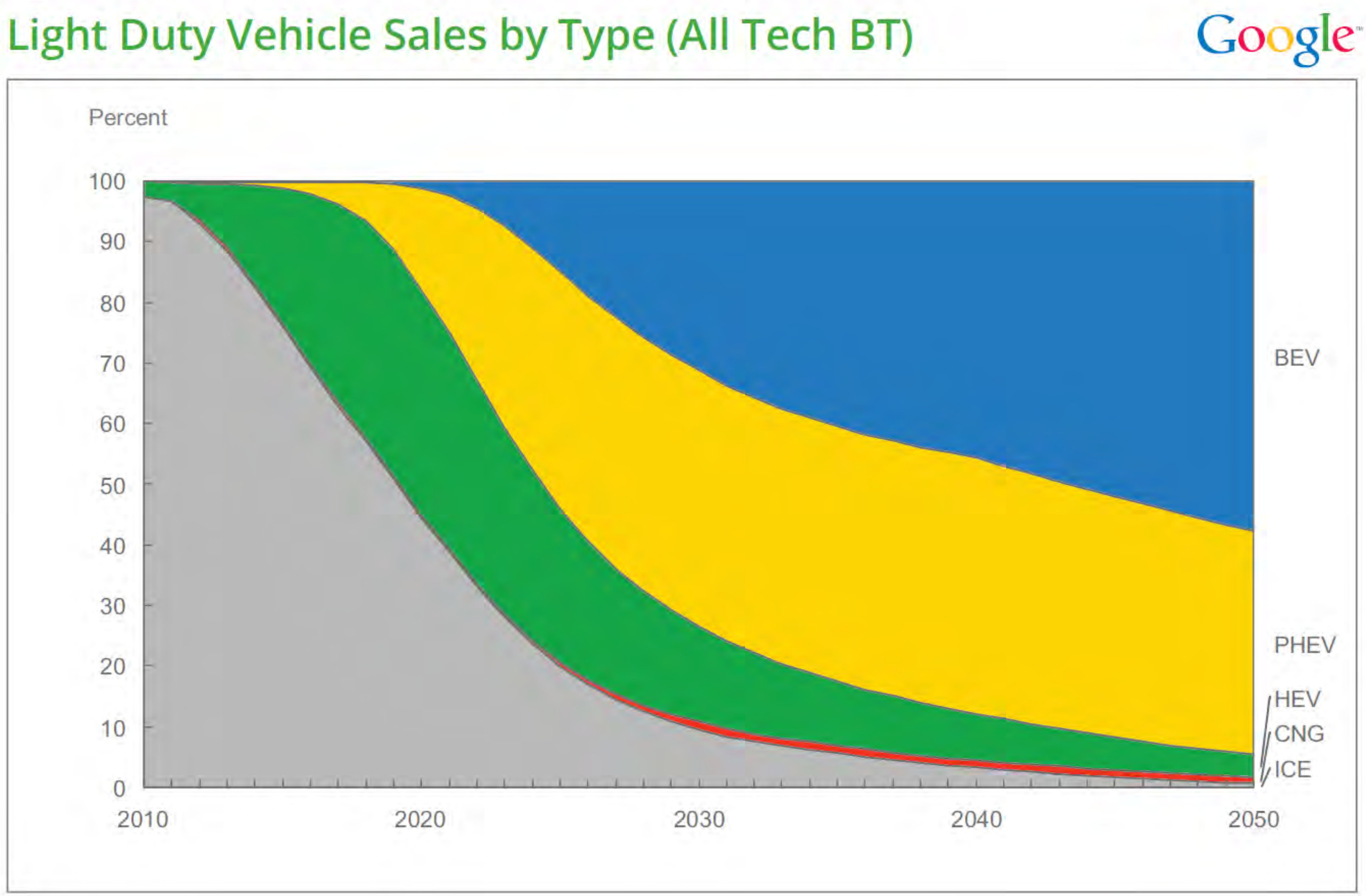
Improved aerodynamics

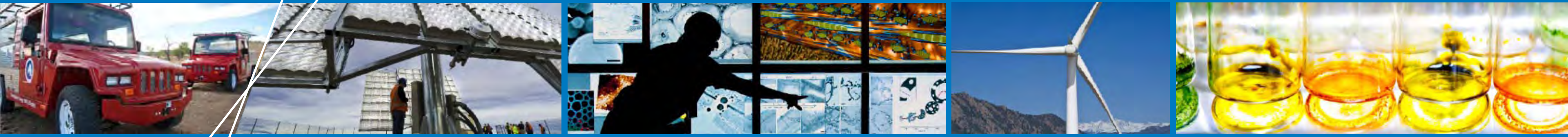
Diesel powered & or Alternative Fuels, H2 etc

One example: Battery cost tipping points



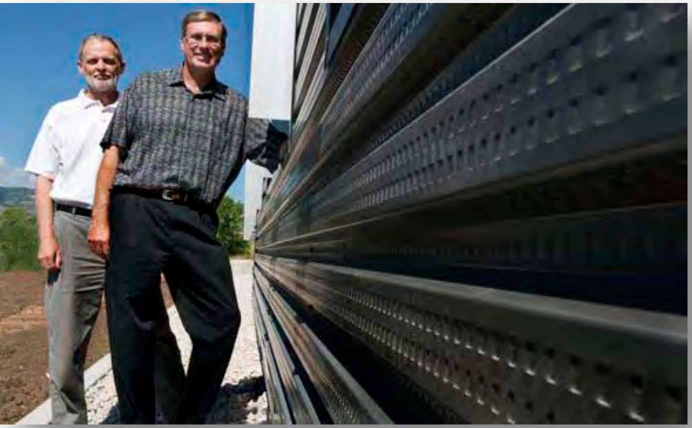
Many projections as to how the mix will change over time



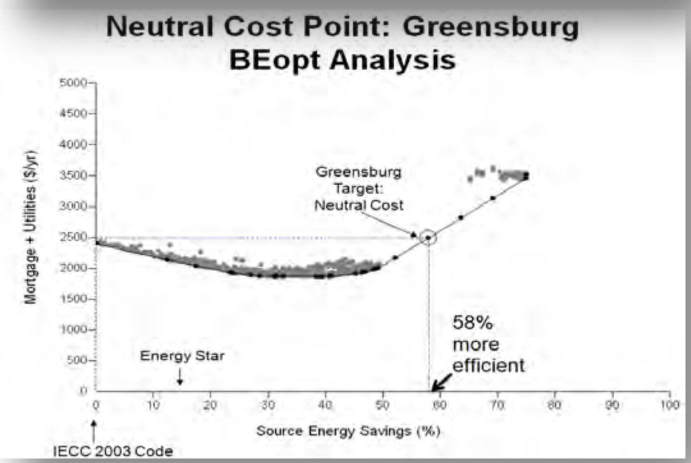


Buildings

Buildings



- **Current Status**
- **U.S. Buildings**
  - **39% of primary energy**
  - **71% of electricity**
  - **38% of carbon emissions**

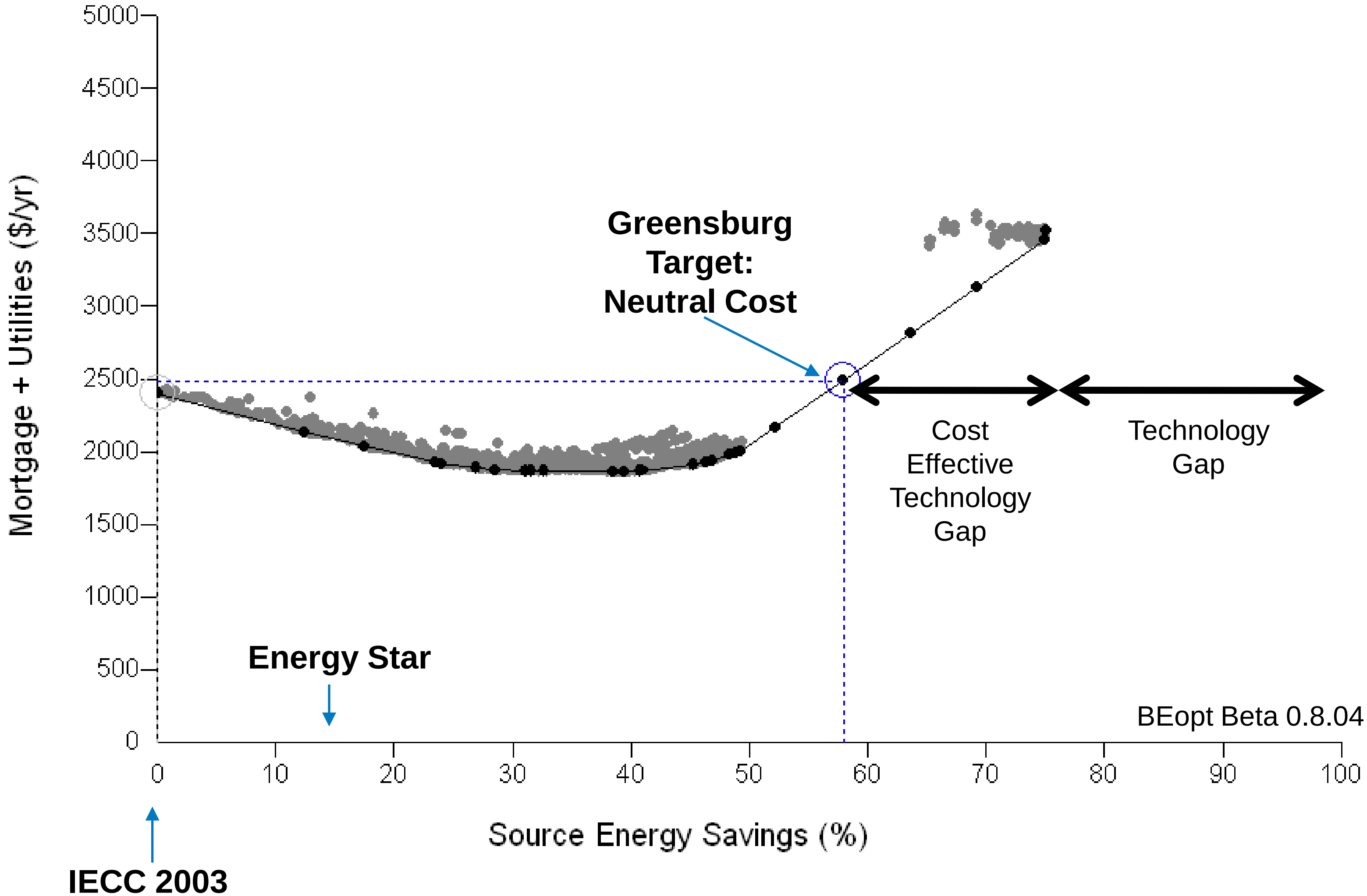


Major Technology Directions

Whole building systems integration

- Computerized building energy optimization tools
- Advanced HVAC (Heating Ventilating and air conditioning)
- Cost effective ultra energy efficient retrofits and new buildings

Neutral Cost Point: Greensburg BEopt Analysis



(2000 ft2, 2-story, 16% window to floor area ratio, unconditioned basement)

Buildings Innovation

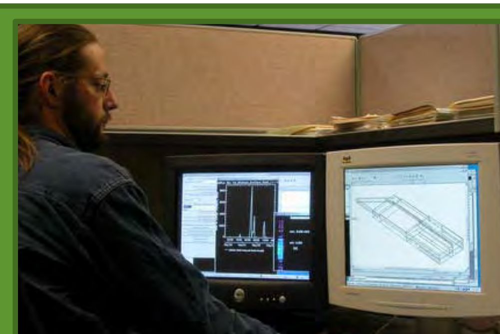
High Performance Buildings

BIPV Products & PV-T Array

Compressorless Cooling

Electrochromic Windows

Polymer Solar Water Heaters



Computerized optimization & simulation Tools

The Vision

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)

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

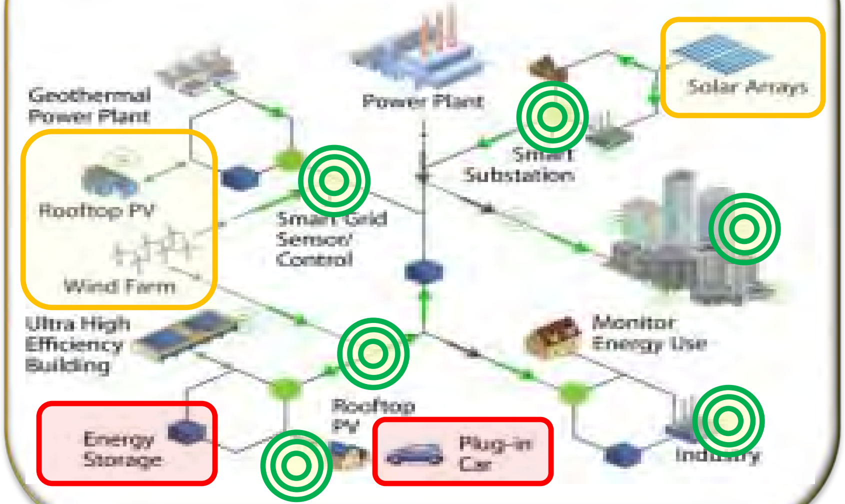
Artist Rendering of the Energy System Integration Facility

Updated 9/10

Why Energy Systems Integration?

Current Energy Systems

Future Energy Systems



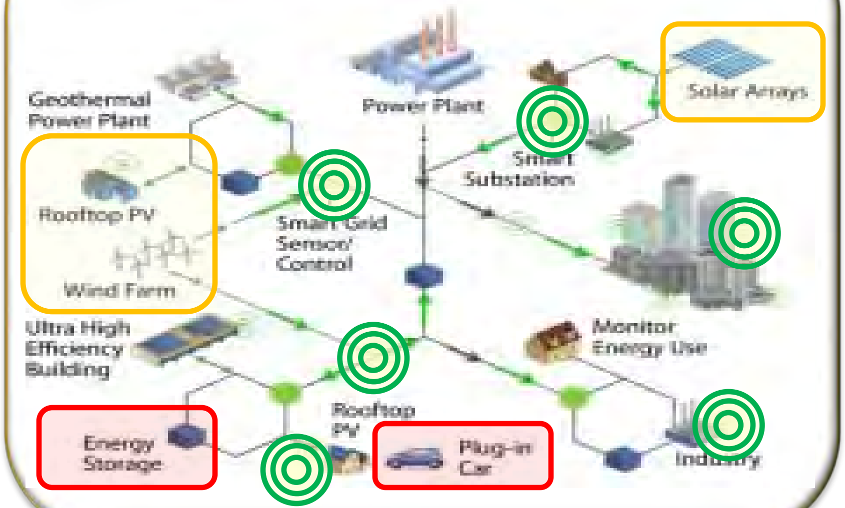
New Challenges – Need to tackle difficult problems

- Increasing penetration of variable RE in grid
- New communications and control models
- Electrification of transportation
- New energy technologies and services integrating energy storage
- Increasing system flexibility
- Understanding interactions between electricity/thermal/fuels

Why Energy Systems Integration?

Current Energy Systems

Future Energy Systems



New Challenges – Need to tackle difficult problems

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NREL PV Grid Integration Activities

NREL is working with Utilities, System Integrators, Universities and other National Laboratories to help integrate higher levels of PV into the electric power grid

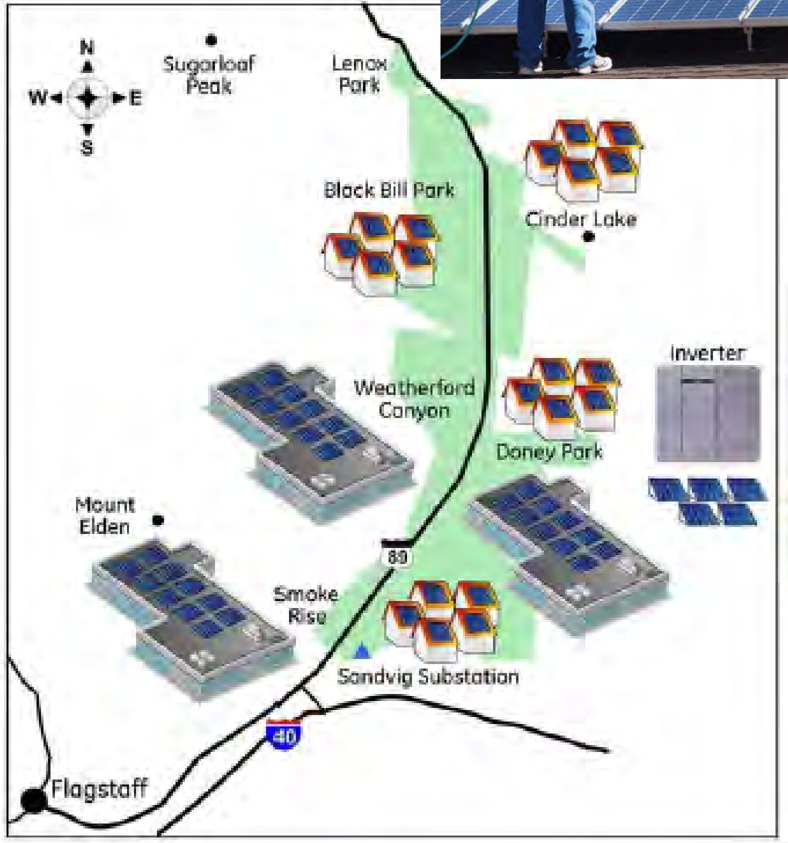
- **Distribution Integration**
  - Monitoring real-world high penetration cases
  - Developing and validating models and simulations
  - Updating integration approaches and standards
- **Transmission Integration**
  - Collecting and validating field data
  - Conducting operational analysis and optimization
  - Developing models for new technologies
  - Integrating into transmission expansion planning

Utility Partners

- Southern California Edison (SCE)
- Sacramento Municipal Utility District (SMUD)
- Xcel Energy (Colorado)
- CPS Energy (San Antonio)
- Arizona Public Service (APS)
- Kauai Island Electric Cooperative (KIUC)
- Maui Electric Company (MECO)
- FPL/NextEra
- Sempra Energy

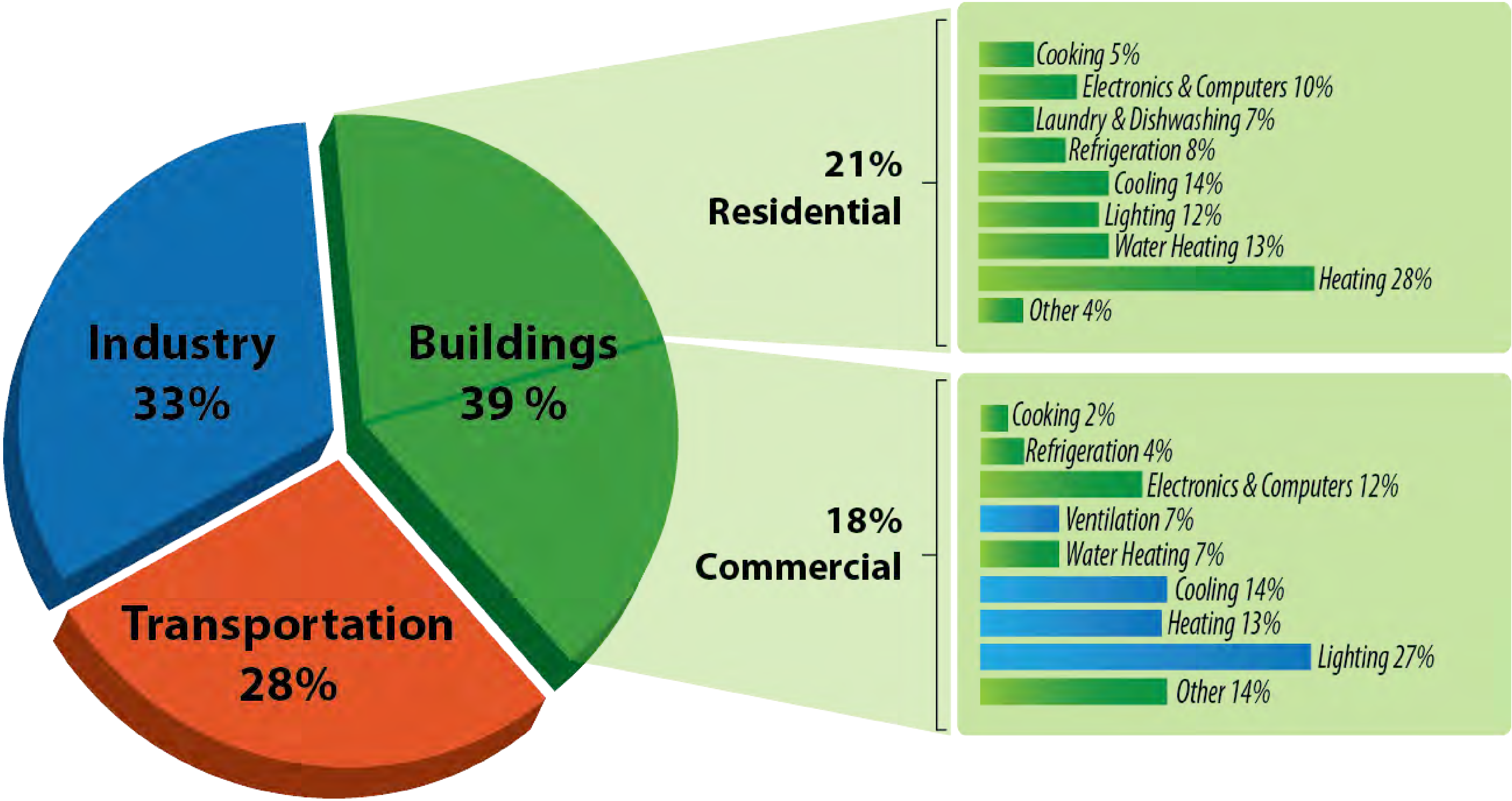
Arizona Public Service

- APS is conducting a unique pilot project in Flagstaff, AZ designed to increase the deployment of renewable energy, especially distributed energy from solar panels.
- Study the effects of large amounts of distributed PV on a utility feeder and it’s associated customers
- Create and validate models to describe the interactions between weather/PV/feeder equipment and operations
- Identify technical and operational modifications that could be deployed in future feeder designs.



NREL Research Support Facility: A glimpse into the future

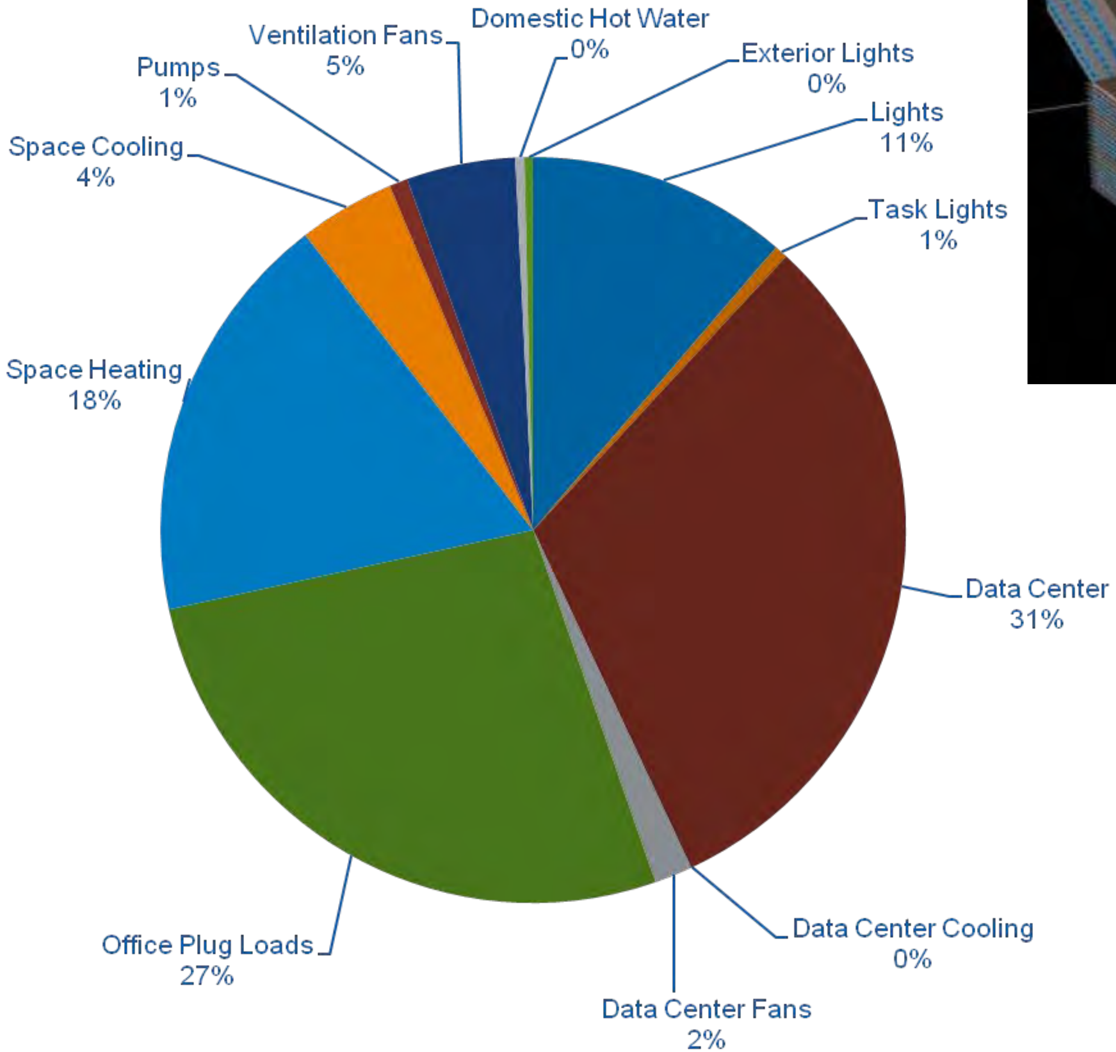
Energy Consumption in the U.S.

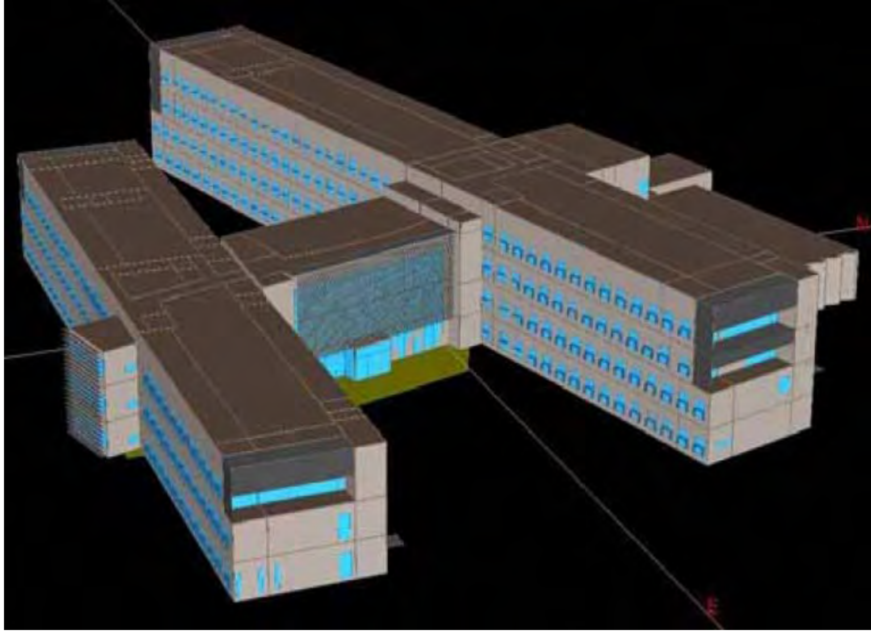


Source: Buildings Energy Data Book, 2006

Energy Modeling

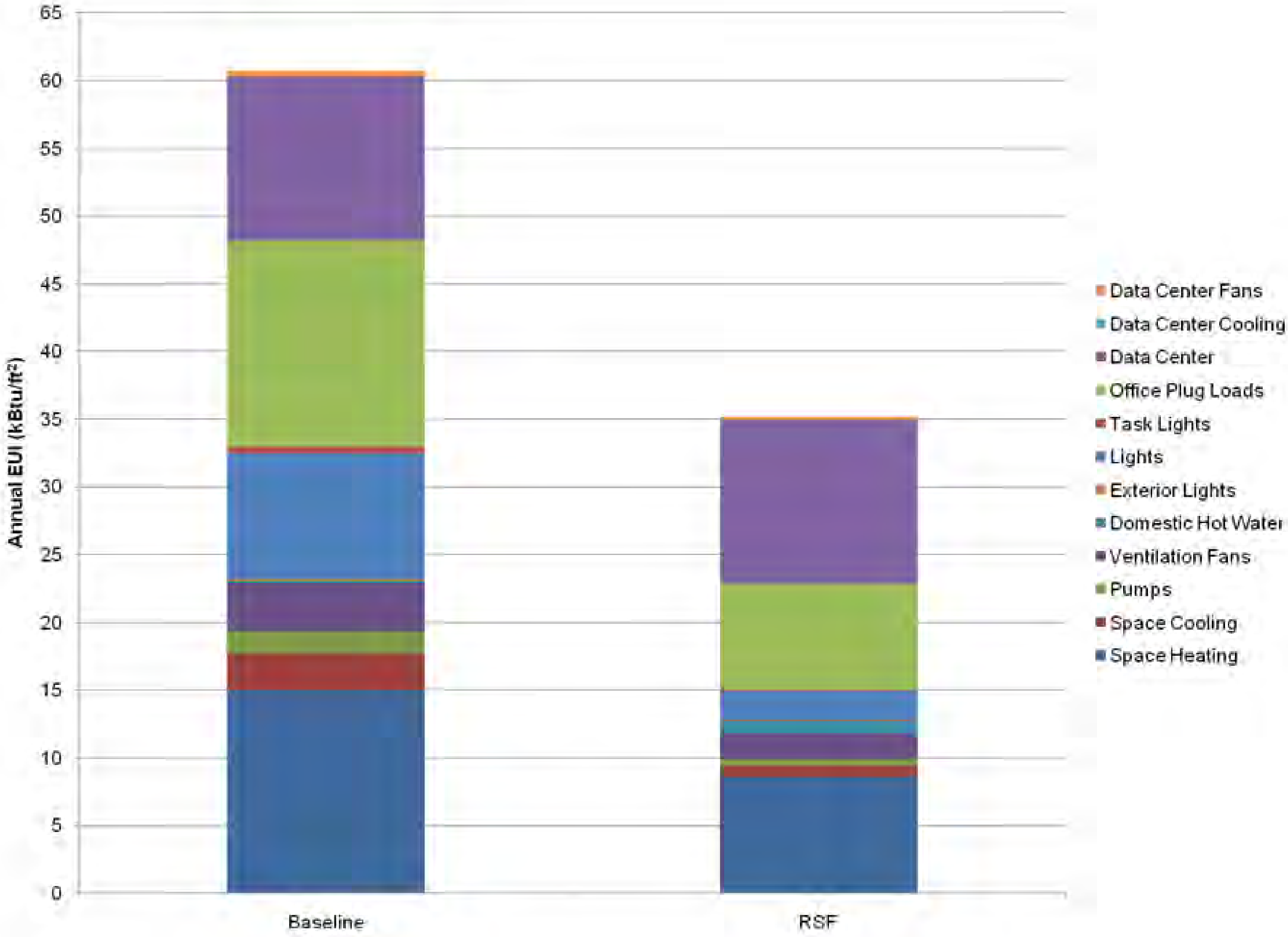
NREL RSF Energy Use Breakdown





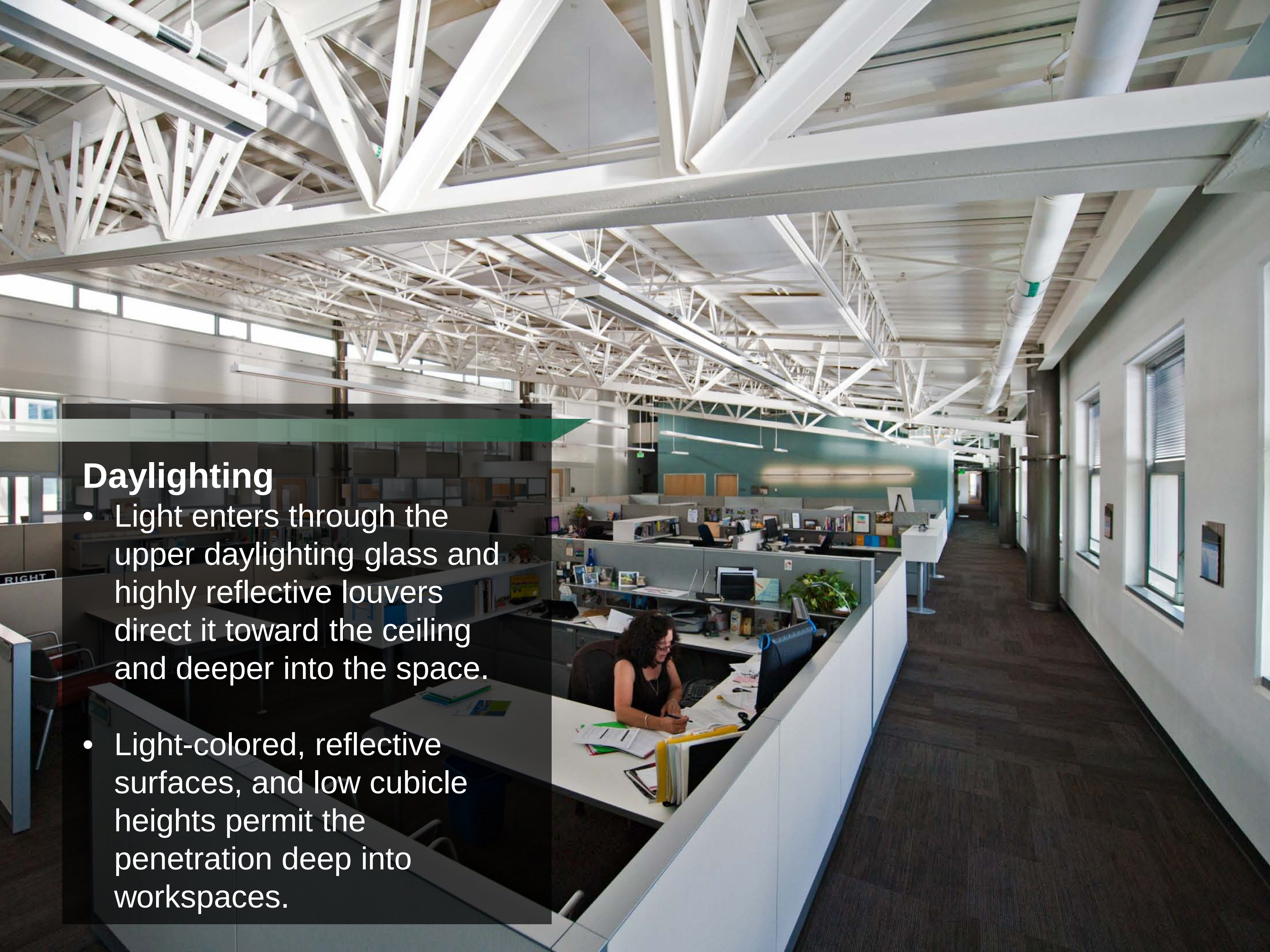
End Use	kBtu/ft²
Lights	3.85
Task lights	0.19
Data center	10.60
Data center cooling	0.01
Data center fans	0.55
Office plug loads	9.16
Space heating	6.11
Space cooling	1.42
Pumps	0.27
Ventilation fans	1.61
Domestic hot water	0.13
Exterior lights	0.12

NREL RSF Annual Energy Consumption Comparison



Daylighting

- Two long 60-foot wide wings with east-west orientation
- Design reduces electrical lighting



Daylighting

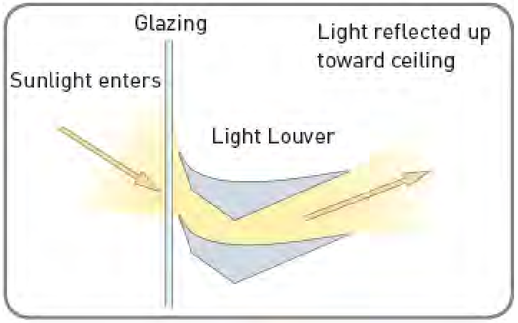
- Light enters through the upper daylighting glass and highly reflective louvers direct it toward the ceiling and deeper into the space.

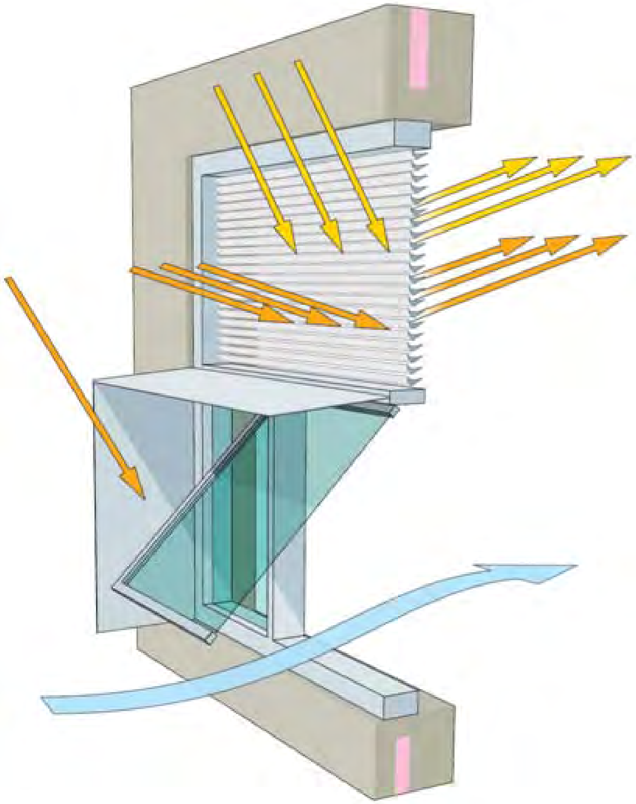
- Light-colored, reflective surfaces, and low cubicle heights permit the penetration deep into workspaces.

Daylighting: Light Louvers

A light louver daylighting system reflects sunlight to the ceiling, creating an indirect lighting effect.

Fixed sunshades limit excess light and glare.





Thermal Mass

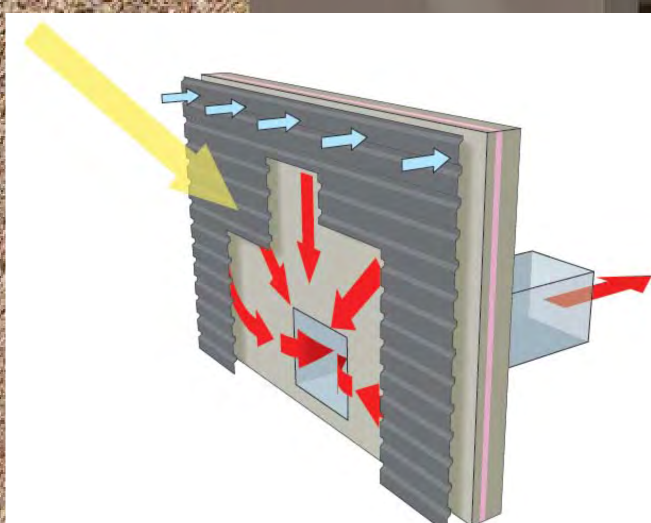
- Incorporates many passive heating and cooling techniques.

- Pre-cast thermal mass wall – 3” concrete, 2” rigid insulation, 6” concrete – helps moderate internal temperatures year round.

- Nighttime purges in summer months trap cool air inside, keeping temperatures comfortable for the warm summer days.

NREL-developed transpired solar collector

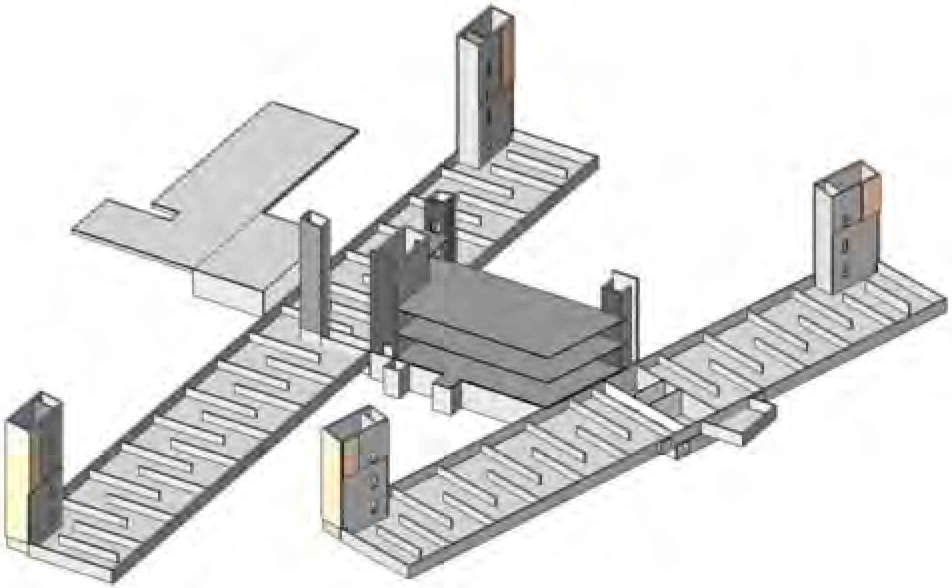
- Metal sheet perforated with small holes
- Fans pull air through the holes on sunny winter days to preheat building air
- During colder weather, air heated by the transpired solar collectors is stored in the labyrinth



Labyrinth

Labyrinth Thermal Storage

- Massive, staggered concrete structures in the basement crawl space stores thermal energy to provide passive heating and cooling of the building.

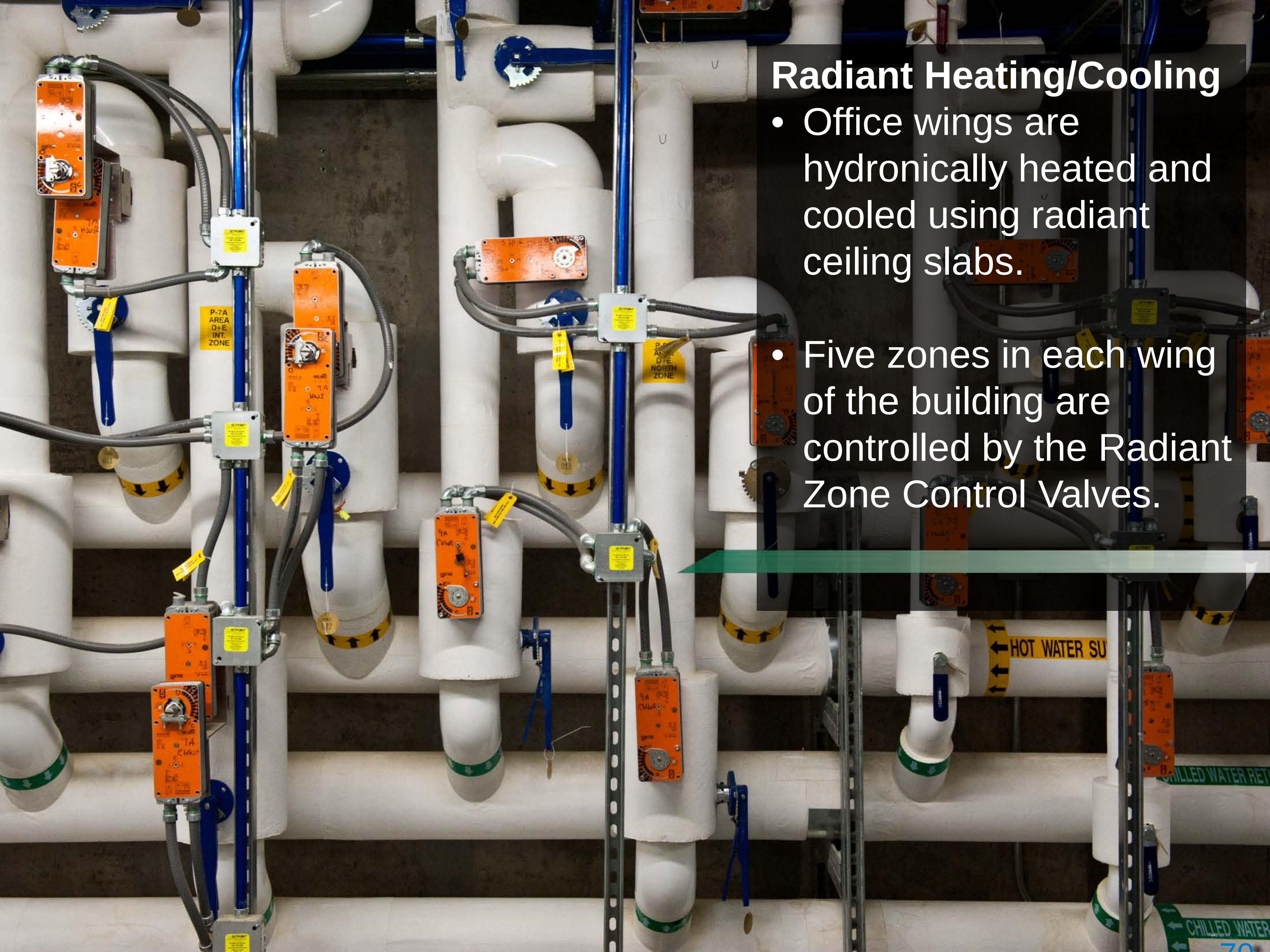


Triple-glazed windows with individual overhangs maximize daylighting and minimize glare, as well as heat loss and gain.

Window Technologies

The west elevation windows feature NREL-developed **electrochromic technology** in which the windows tint in response to a small electric current, reducing heat gain in the afternoon hours.

Thermochromic windows on the eastern balcony windows react to temperature change and have glass resistant to heat transfer.



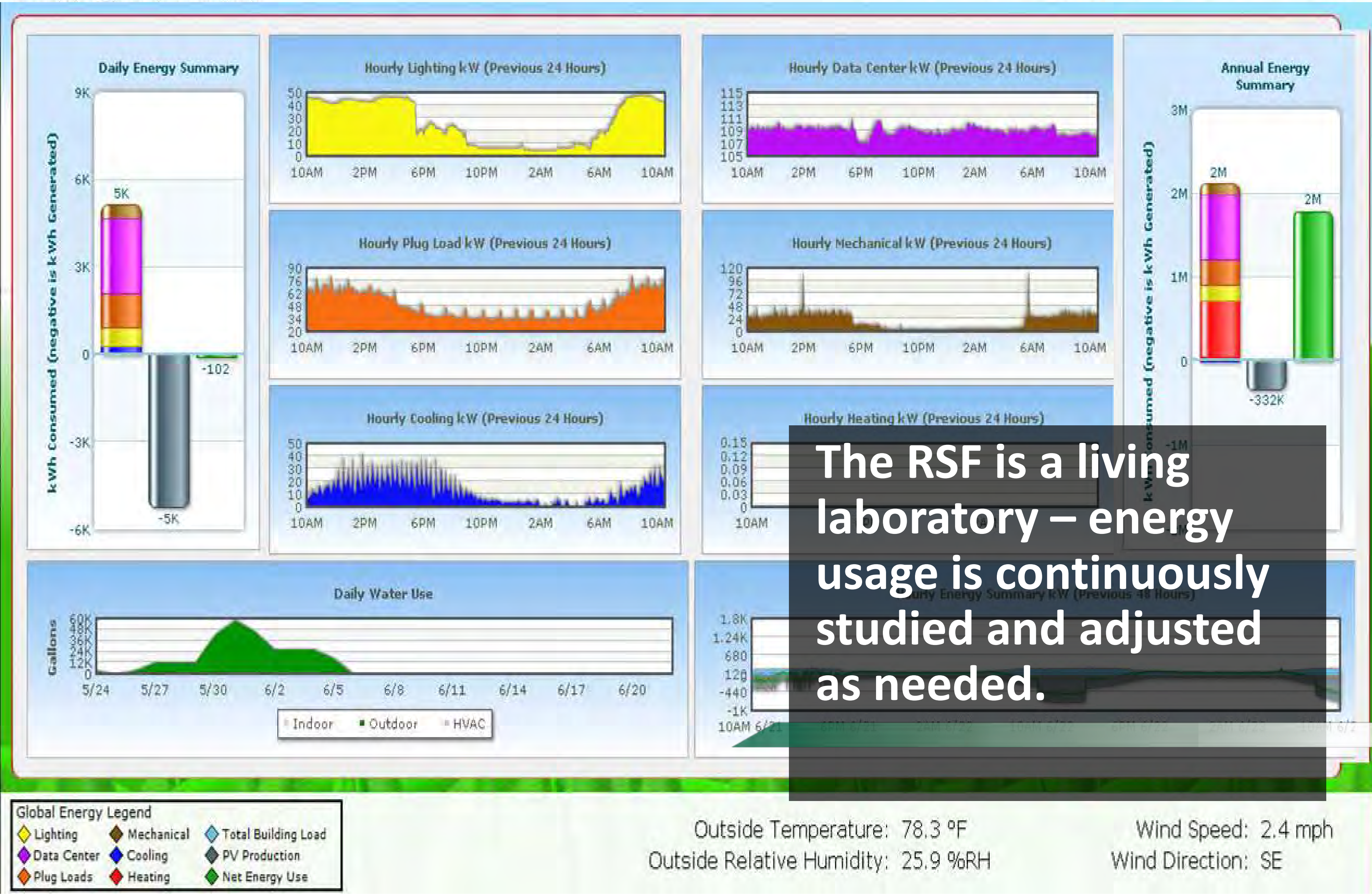
Radiant Heating/Cooling

- Office wings are hydronically heated and cooled using radiant ceiling slabs.

- Five zones in each wing of the building are controlled by the Radiant Zone Control Valves.

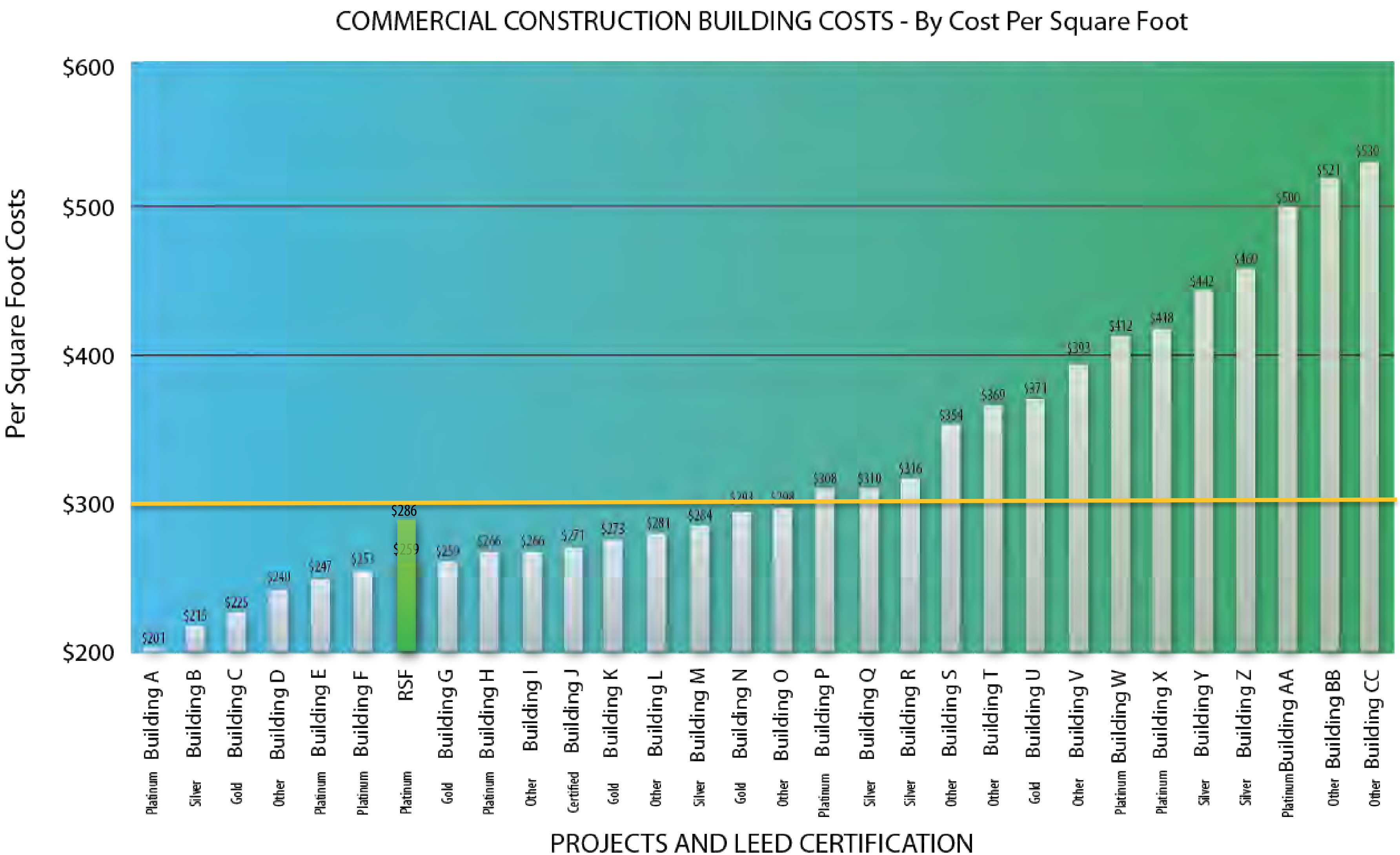
RSF Net Zero Energy PV Arrays

RSF Energy Monitoring



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

Construction Costs



A glimpse into the future

If all commercial buildings operated in this fashion, the percent renewable energy contribution to the energy mix would be a game changer.

To achieve this vision, we must…

- Invent the future we desire
- Invest in innovation
- Improve access to capital
- Partner on a global scale

NREL

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