PV: Global Perspective for a Sustainable Future

September 5, 2011

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Laboratory Director

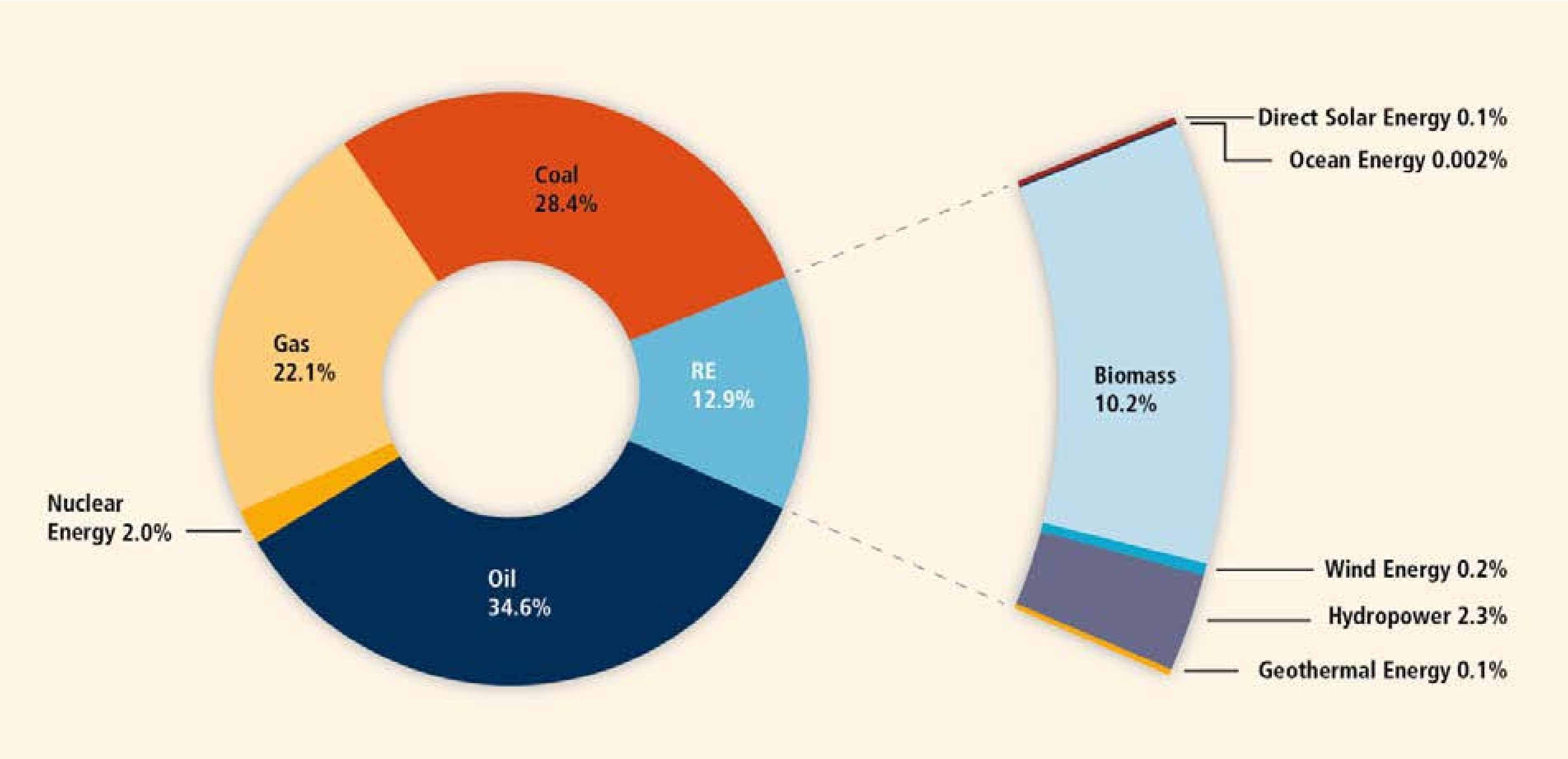
Energy Challenges

"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

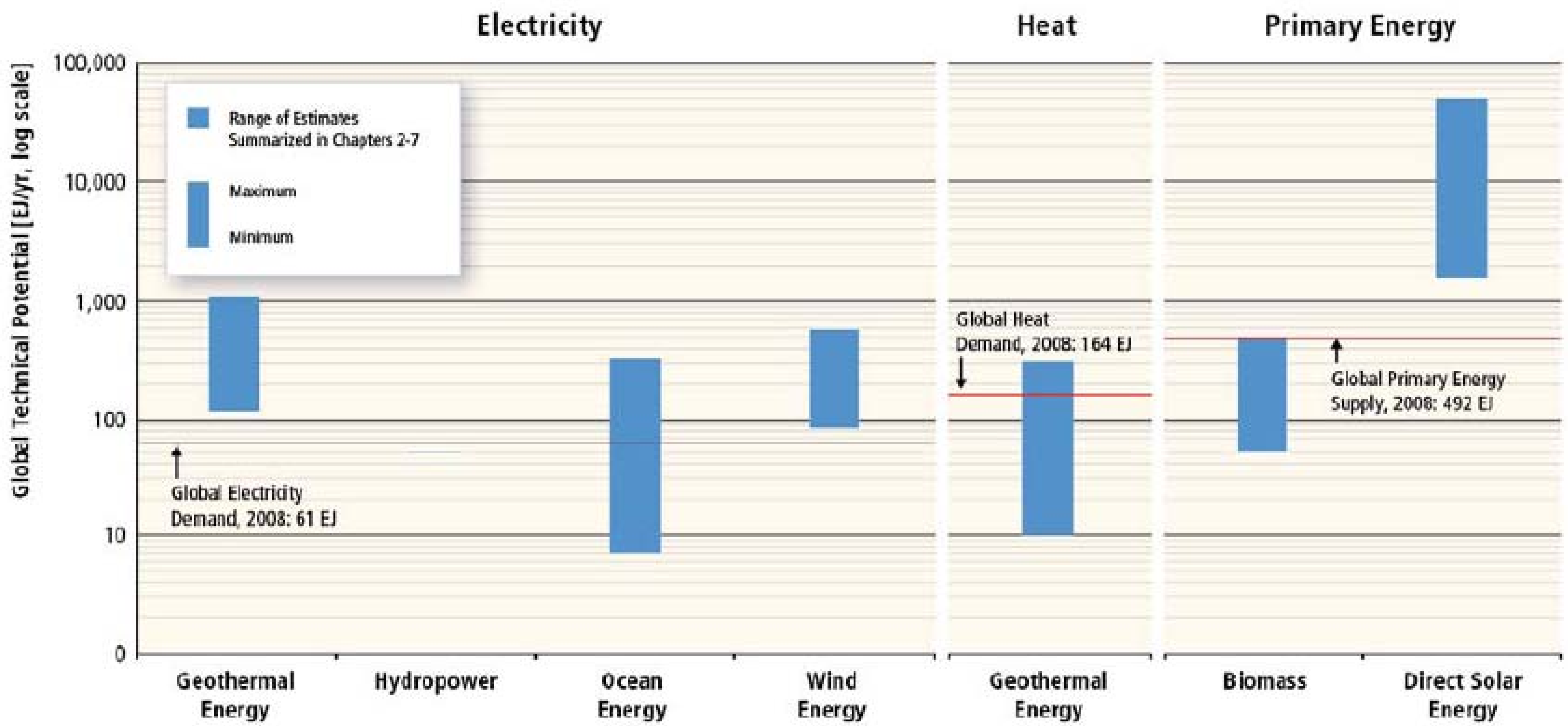
The global context

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	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy	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)

Top Countries with Installed Renewable Electricity by Technology (2010)

III

Geothermal
1 U.S.
2 Philippines
3 Indonesia
4 Mexico
5 Italy

Wind
1 China
2 U.S.
3 Germany
4 Spain
5 India

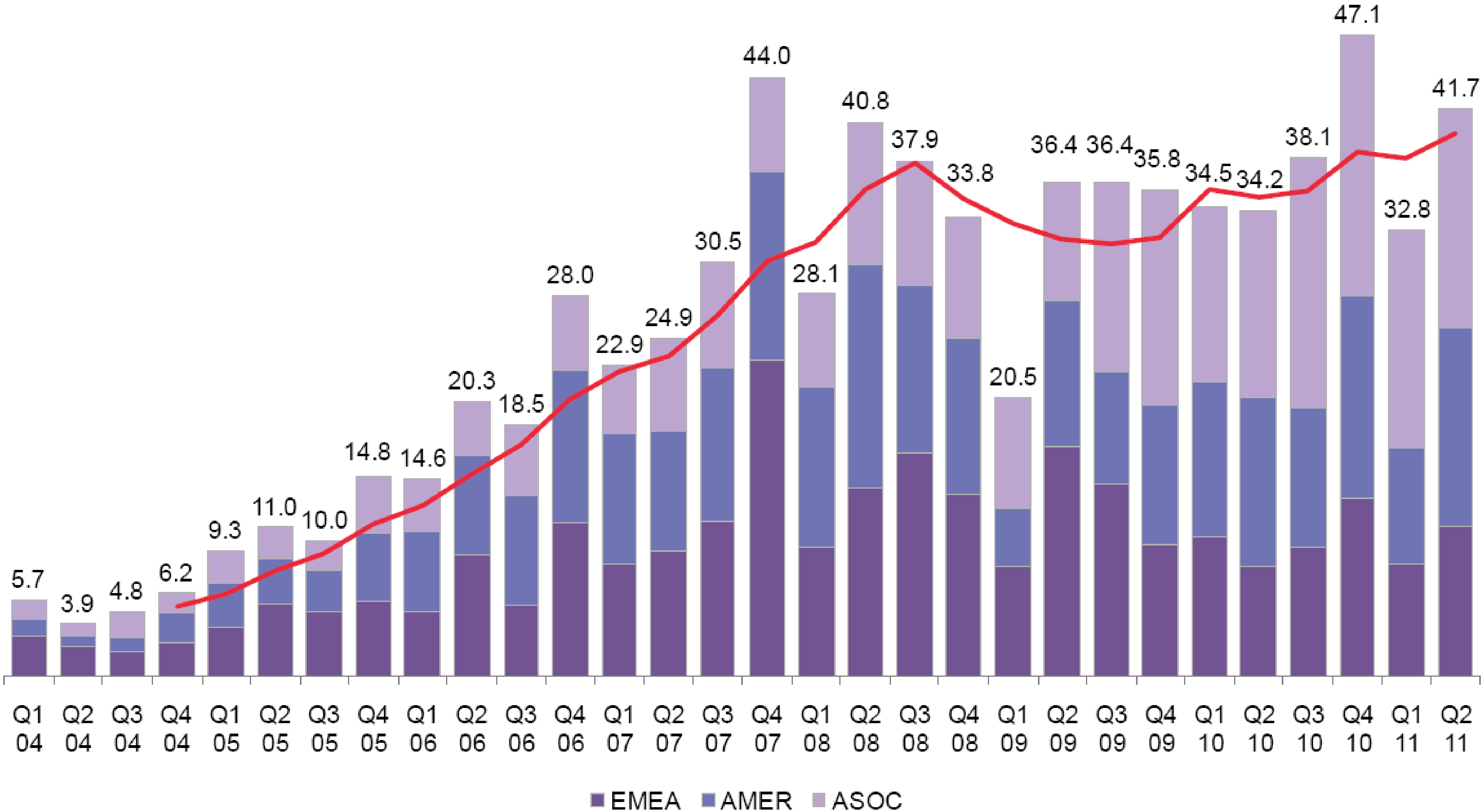
Solar PV
1 Germany
2 Spain
3 Japan
4 Italy
5 U.S.

CSP
1 Spain
2 U.S.

Biomass
1 U.S.
2 Brazil
3 Germany
4 Spain
5 India

Sources: REN21, GWEC, SEIA/GTM

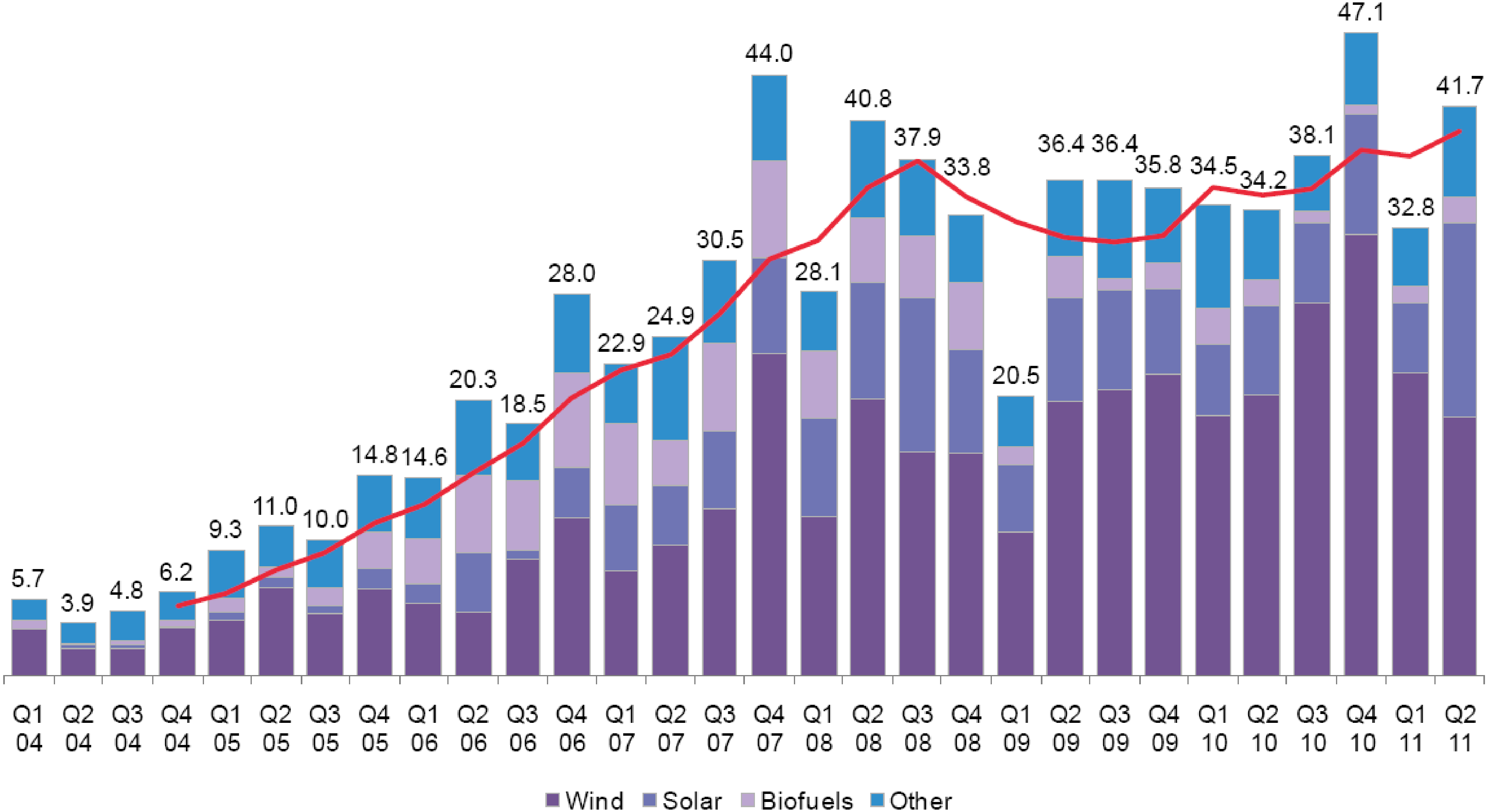
New Financial Investment in Clean Energy by Region Q1 2004-Q2 2011 ($Bn)



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.**

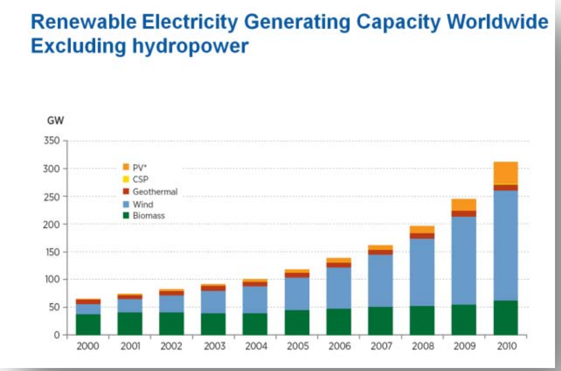
Solar PV global installed capacity **grew by factor of almost 30** to about 35 GW in 2010.

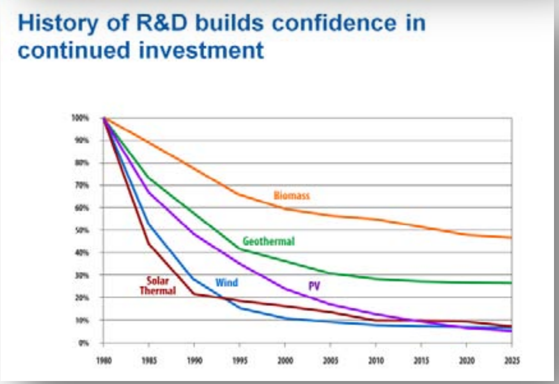
Biofuels emerged as a **major global industry** (~28 billion gallons/year)

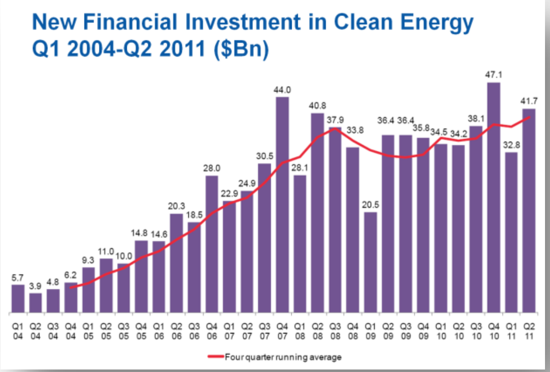
LEED-certified commercial buildings grew to more than 10,000

Costs have been significantly reduced and are **approaching grid parity**

Clean energy grew from $1B/year to a **$211B/year market**

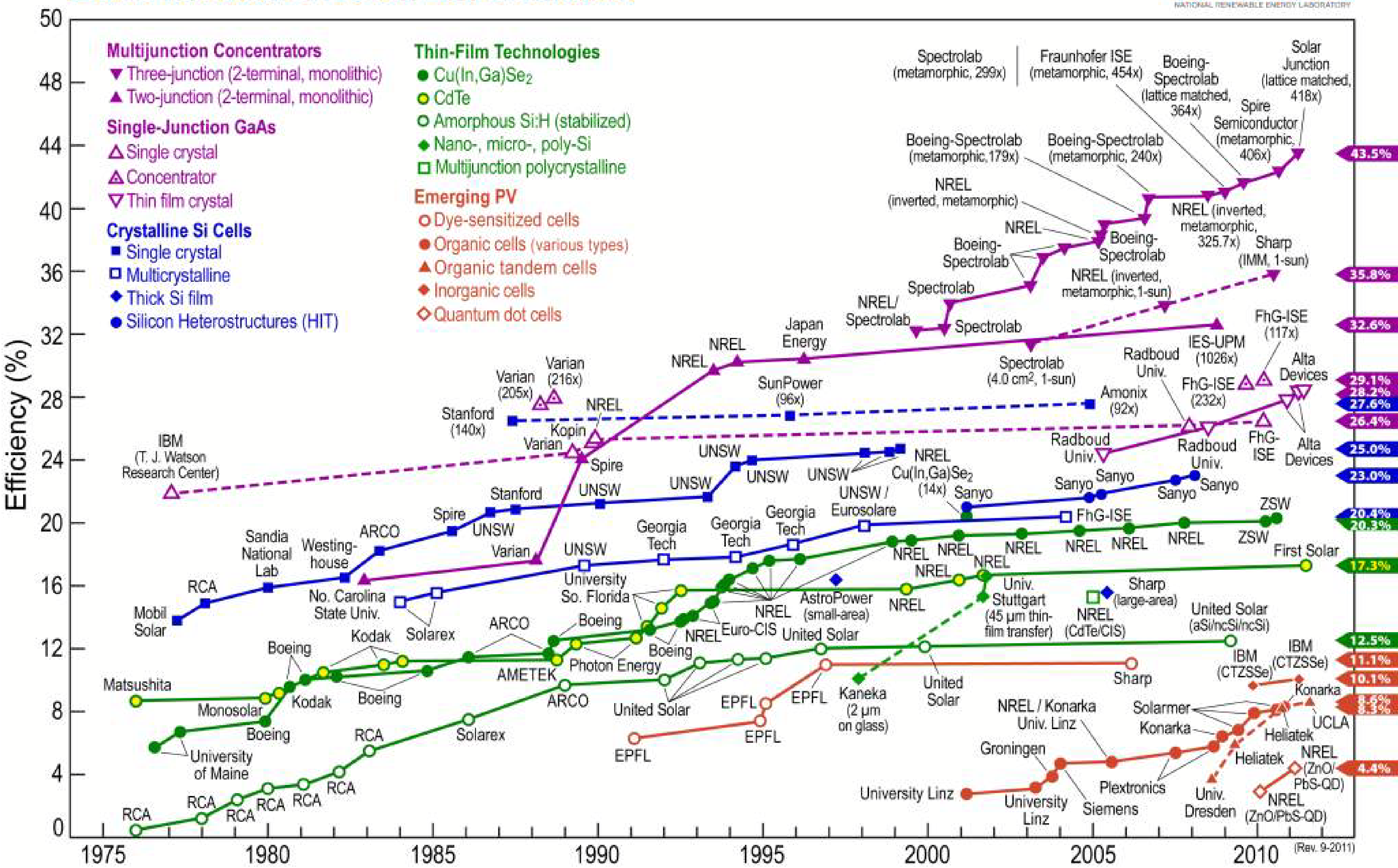




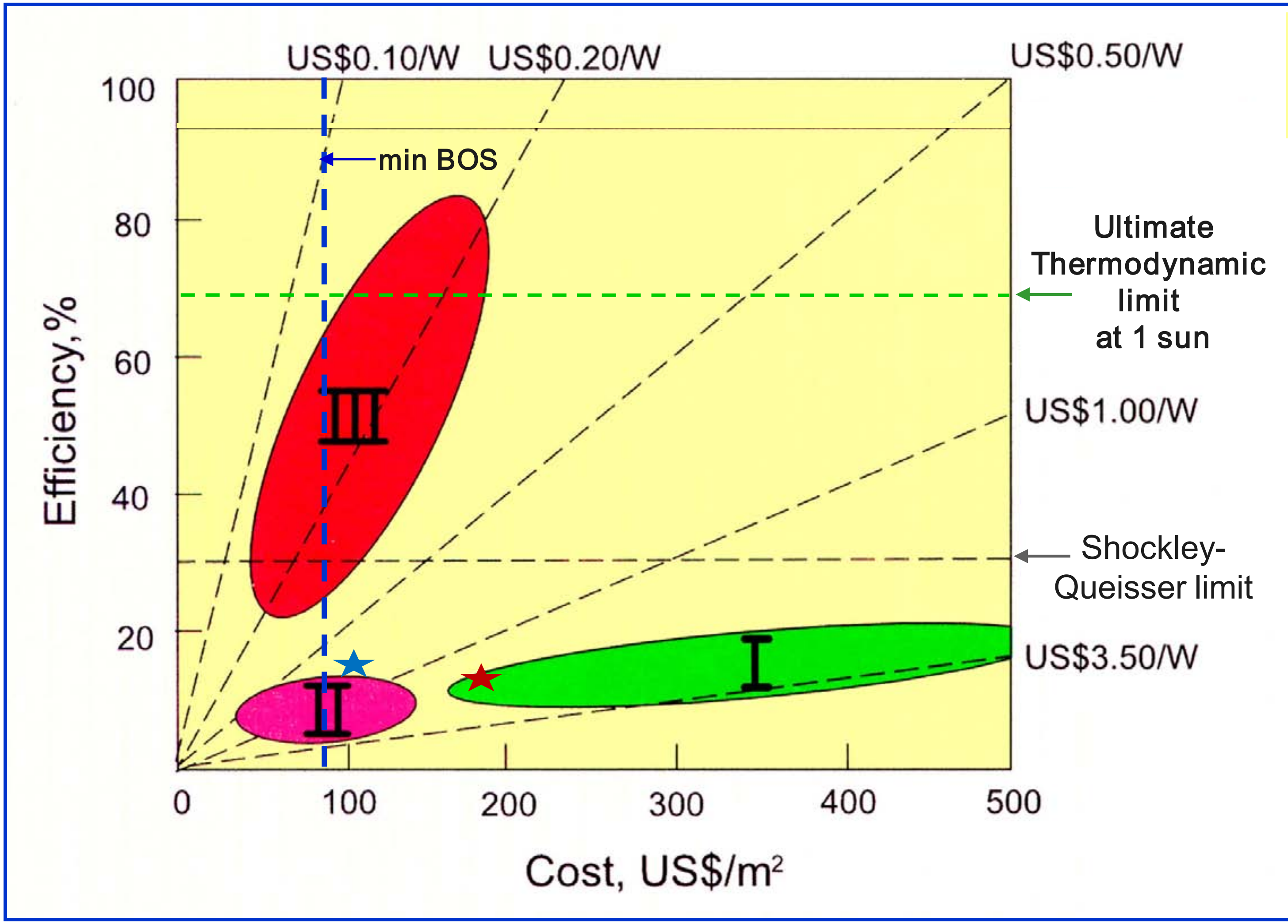


The promise of the technology

Best Research-Cell Efficiencies



PV Power Costs as Function of Module Efficiency and Areal Cost
3rd Generation PV: Beyond 1$/watt



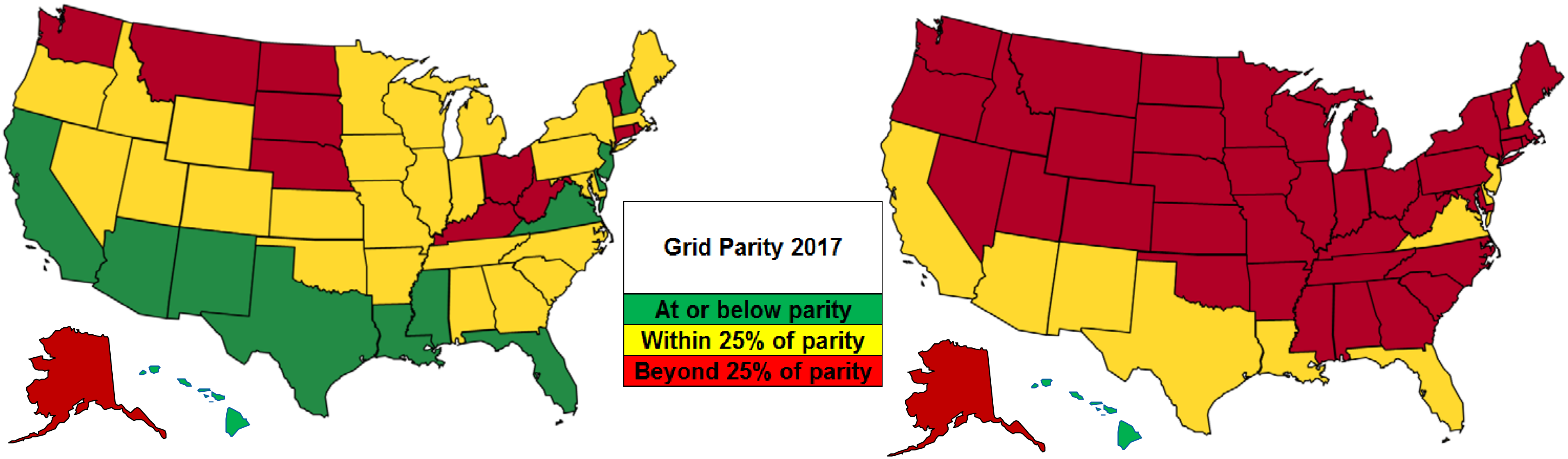
$\$/W_p = (\$/m^2)/(W/m^2)$

$\$/kWh \approx 0.05 \times \$/W_p$

★ 2011-Thin Si
★ 2011-CdTe

For PV or PEC to provide a major fraction of C-free energy required for electricity and fuel, power cost needs to be <u>equivalent to coal</u> (2-3 cents/kWh—module cost of $0.20-0.30/W)

Grid Parity with $1 / Watt



$1 / Watt Scenario

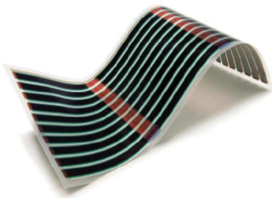
Current Projection

- 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.

PV Conversion Technology Portfolio

Thin Films (aSi)

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

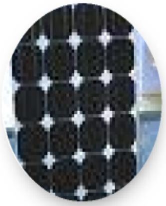


Organic PV

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

Next Generation

Investigating advanced concepts aimed at delivering revolutionary performance improvements

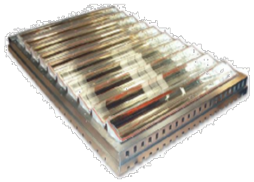


Crystalline Silicon

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

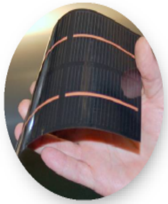
Concentrating PV

Combining new, lower cost multijunction cells and innovative optical packages



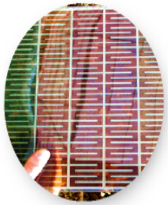
Thin Films (CIGS)

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

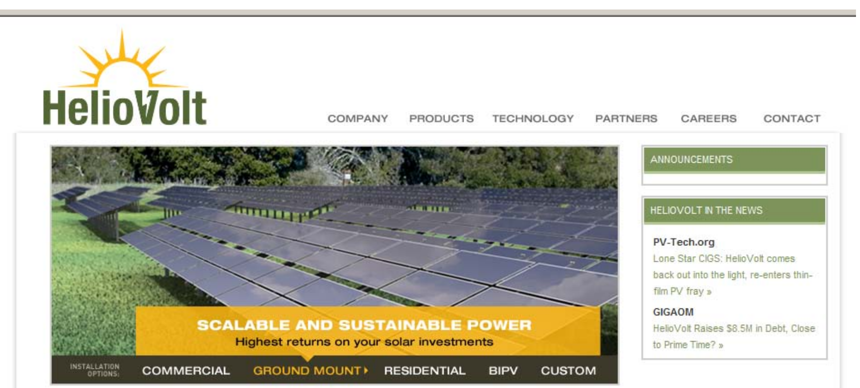
Market Relevant Process Innovation

"Black Silicon" Nanocatalytic Wet-Chemical Etch

R&D 100 2010

Flash Quantum Efficiency System

R&D 100 2011



Revolutionary CIGS thin-film manufacturing process using inket printing

HelioVolt

R&D 100

2008

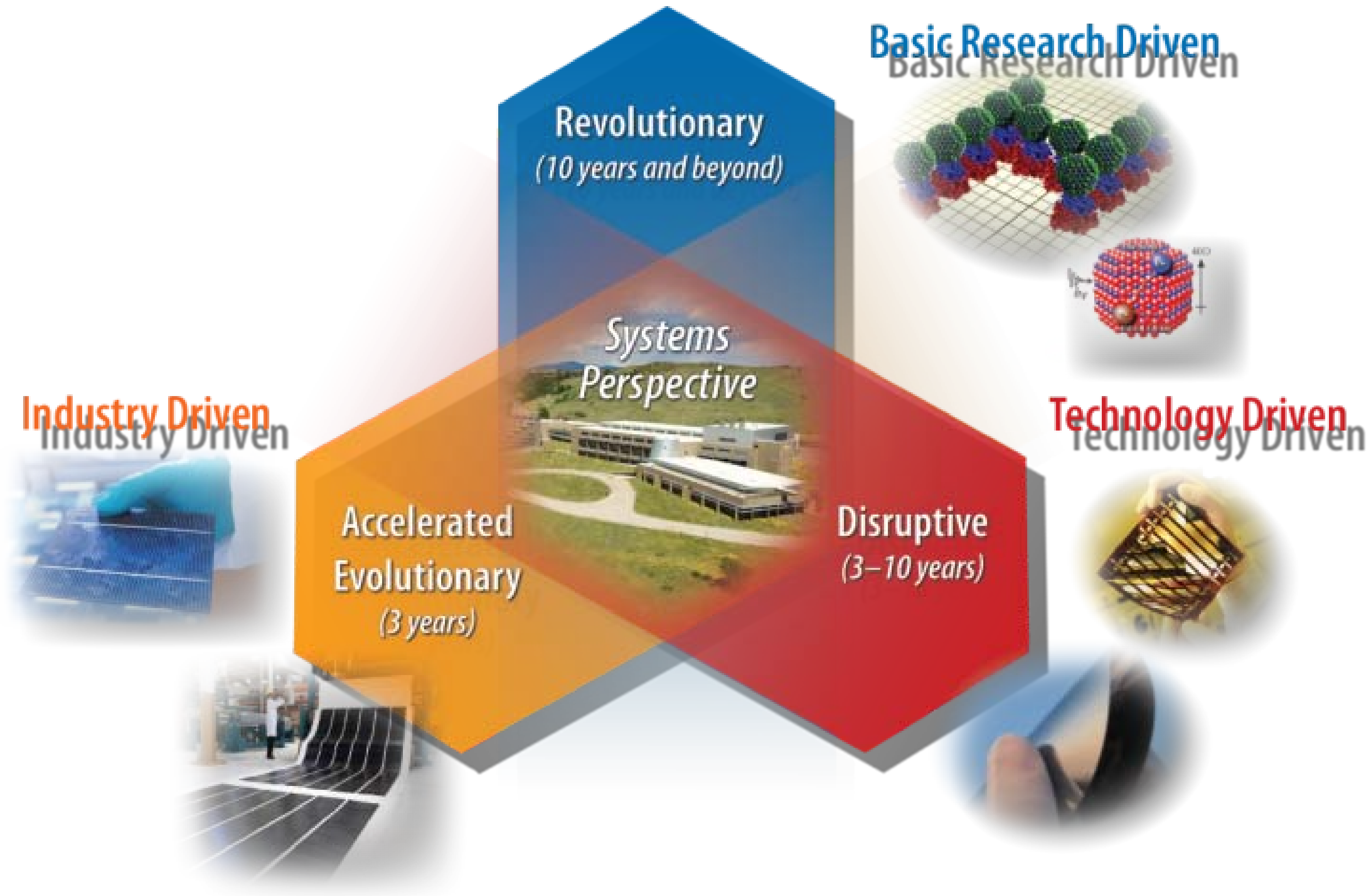
Silicon Ink
NREL Incubator Project

R&D 100 2011

innovation Impact: Partnering is Key

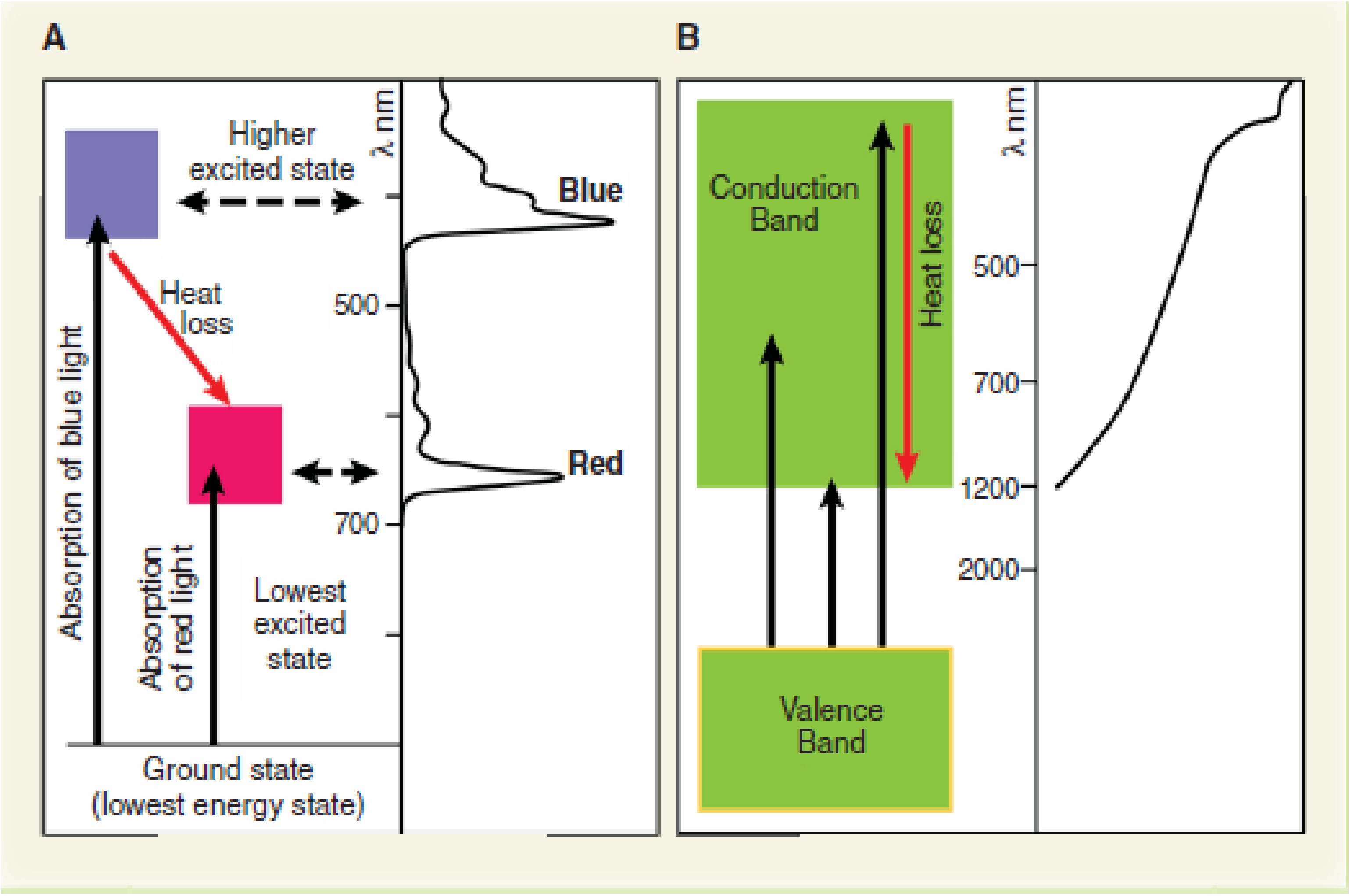
GE
Bank of America
ABENGOA SOLAR
ALSTOM
RF MICRO·DEVICES
JM JOHNSON MATTHEY
AMPULSE
PHOTON SOLAR POWER The Art of The Sun
HelioVolt
FedEx
JCPenney
1366 TECHNOLOGIES
Walmart Save money. Live better.
GLOBAL SOLAR
SIEMENS
SkyFuel
bp
Ascent SOLAR
OPTONY Solar for Life™
novozymes®
BERGEY WINDPOWER
SPECTROLAB A BOEING COMPANY
LOCKHEED MARTIN
DOW
labsphere®
Eskom
Xcel Energy℠
KONARKA®
DELPHI
Clipper®
IBERDROLA
JOHN DEERE
Coolerado®
orion
OPTIMA® BATTERIES THE ULTIMATE POWER SOURCE™
regency centers www.regencycenters.com
CALPINE®
RAYOVAC®
PLANAR™
QUANTUM SPHERE™
Ford
GENENCOR® A Danisco Division
DAIMLERCHRYSLER
BEST BUY
CATERPILLAR®
MiaSolé Thin-film solar
PardeeHomes Where smart solutions live.
AWS Truewind

Breakthough/Translational Science

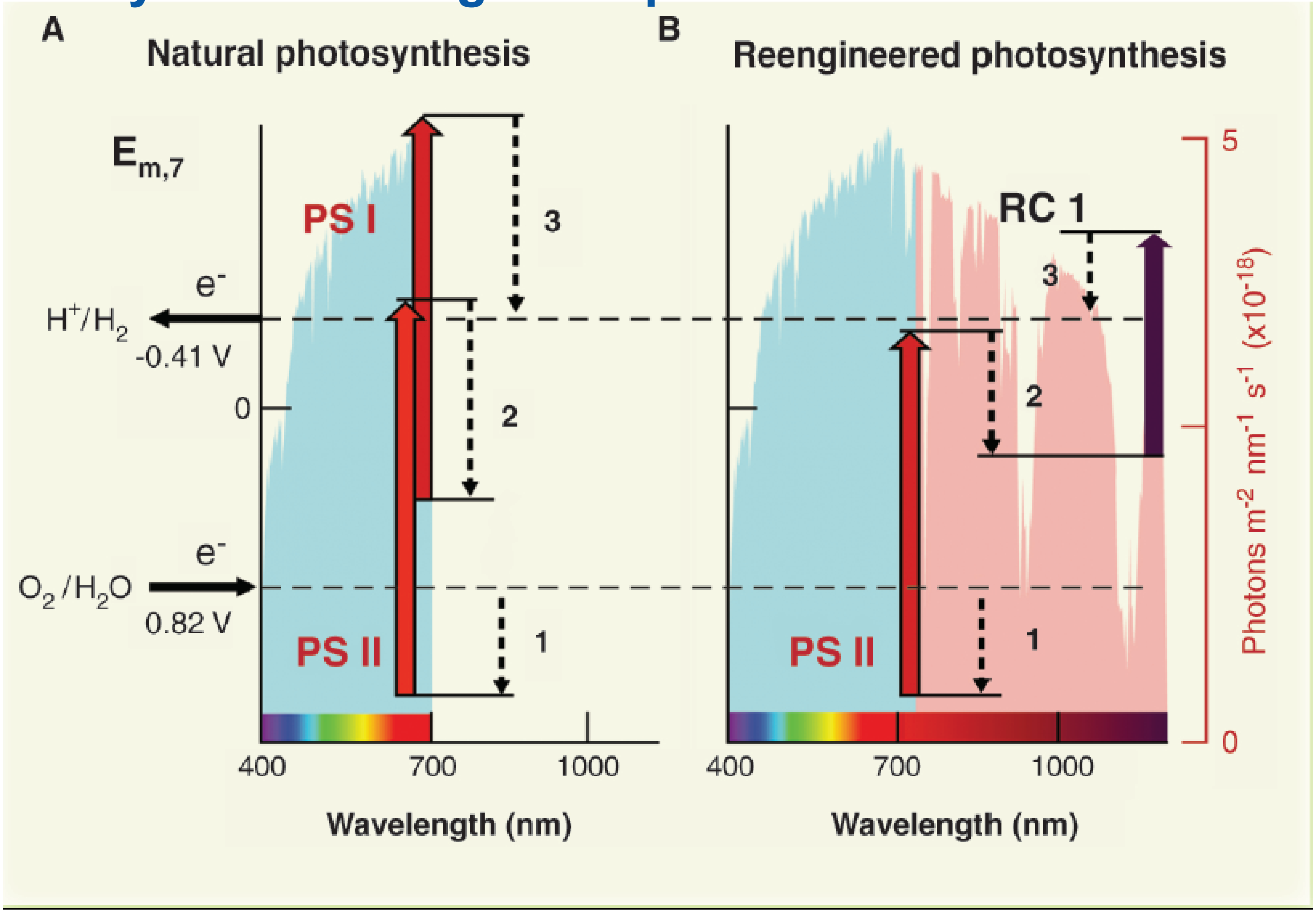


Absorption Properties

Chlorophyll Silicon



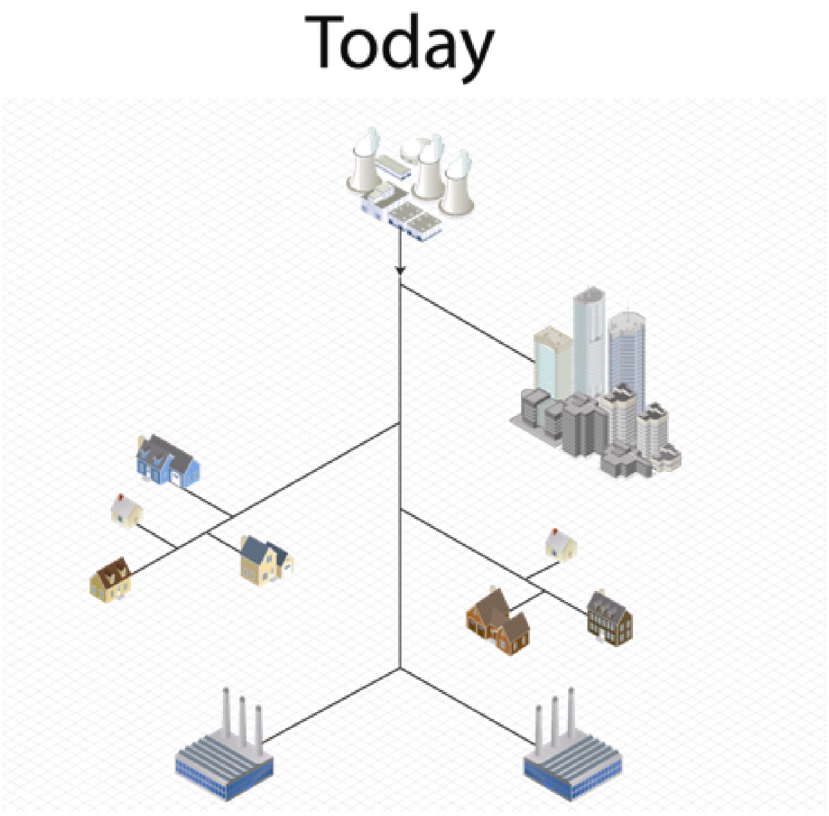
How to Enhance Efficiency of Biological Photosynthesis using Principles of Multi-Junction PV

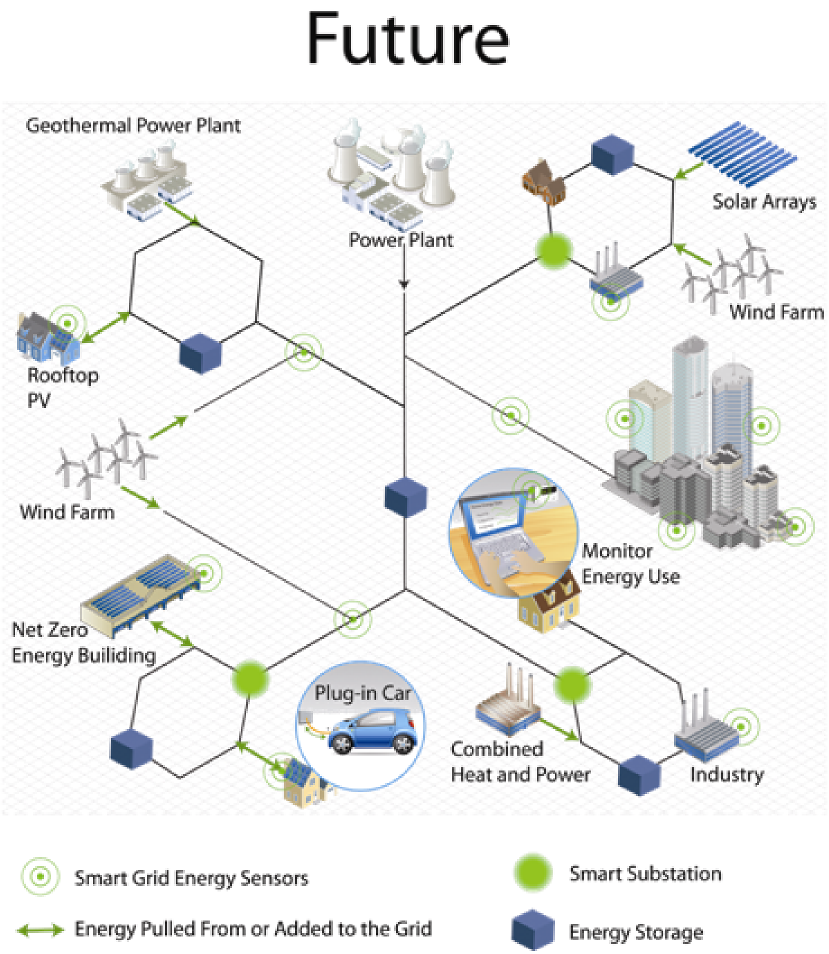


Science ***332*****, 805 (2011) (18 authors)**

The vision: Optimizing the role of solar energy

Realizing the Potential: Renewable Energy Systems Integration





Applications of Solar Heat and Electricity

Solar Thermal

Passive solar

Hot water

Photovoltaics (PV)

Concentrating Solar Power (CSP)

Distributed Generation, on-site or near point of use

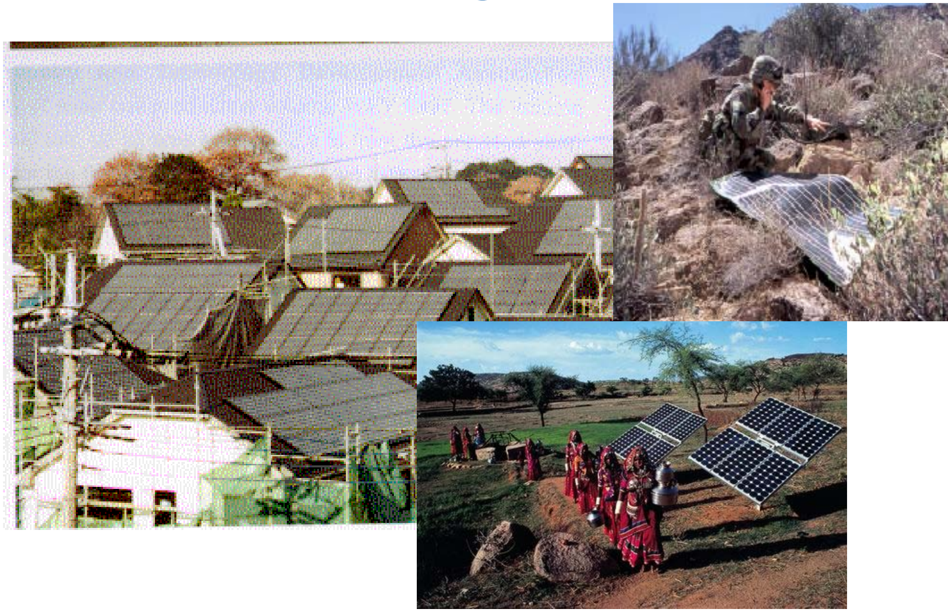
Centralized Generation, large users or utilities

- Transportation
- Residential & Commercial Buildings
- Industrial

Photovoltaics – Solar Electricity

Photovoltaics (PV)

- Direct conversion of sunlight to electricity



Advantages

- Modular (mW to many MW)
- No (or few) moving parts
- Noise and pollution free
- Reliable; low operating costs
- Abundant, indigenous resource ($30,000 \text{ km}^2$ PV for 800 GW)

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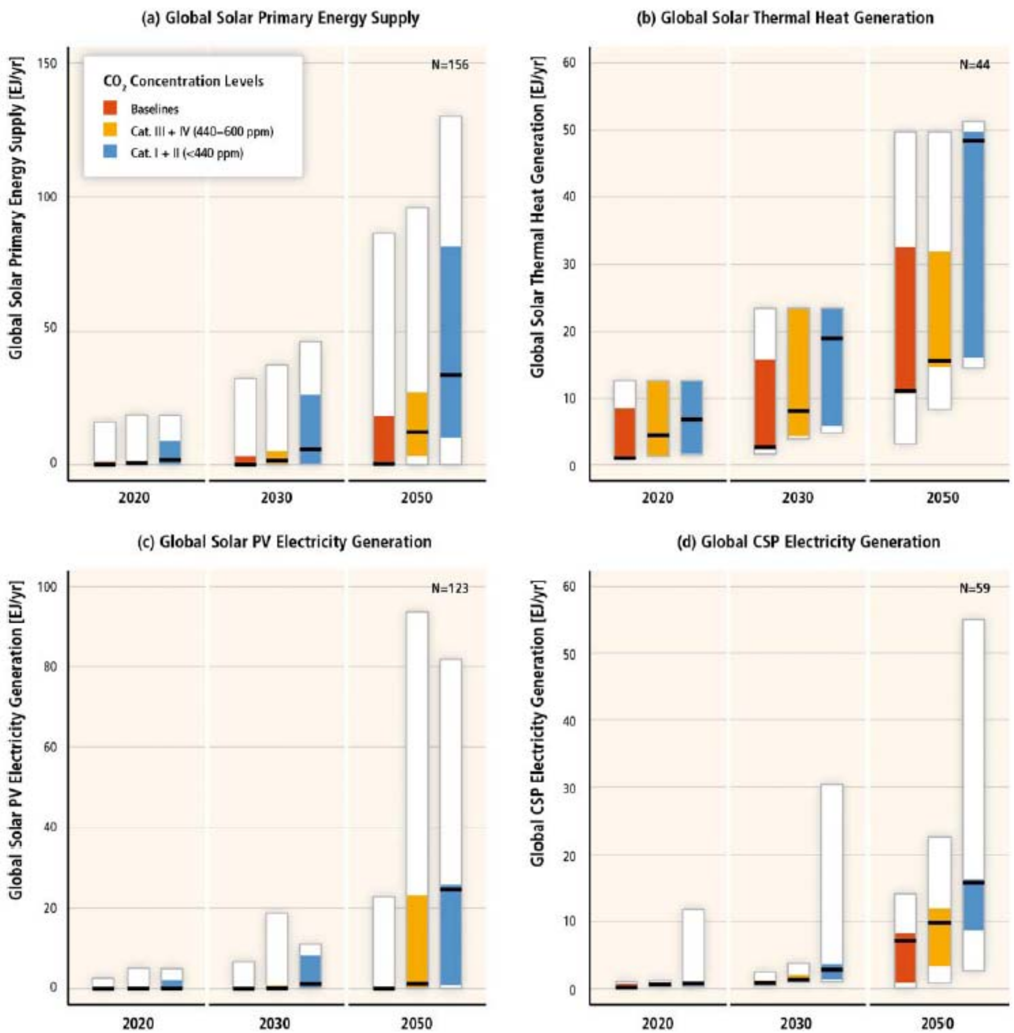
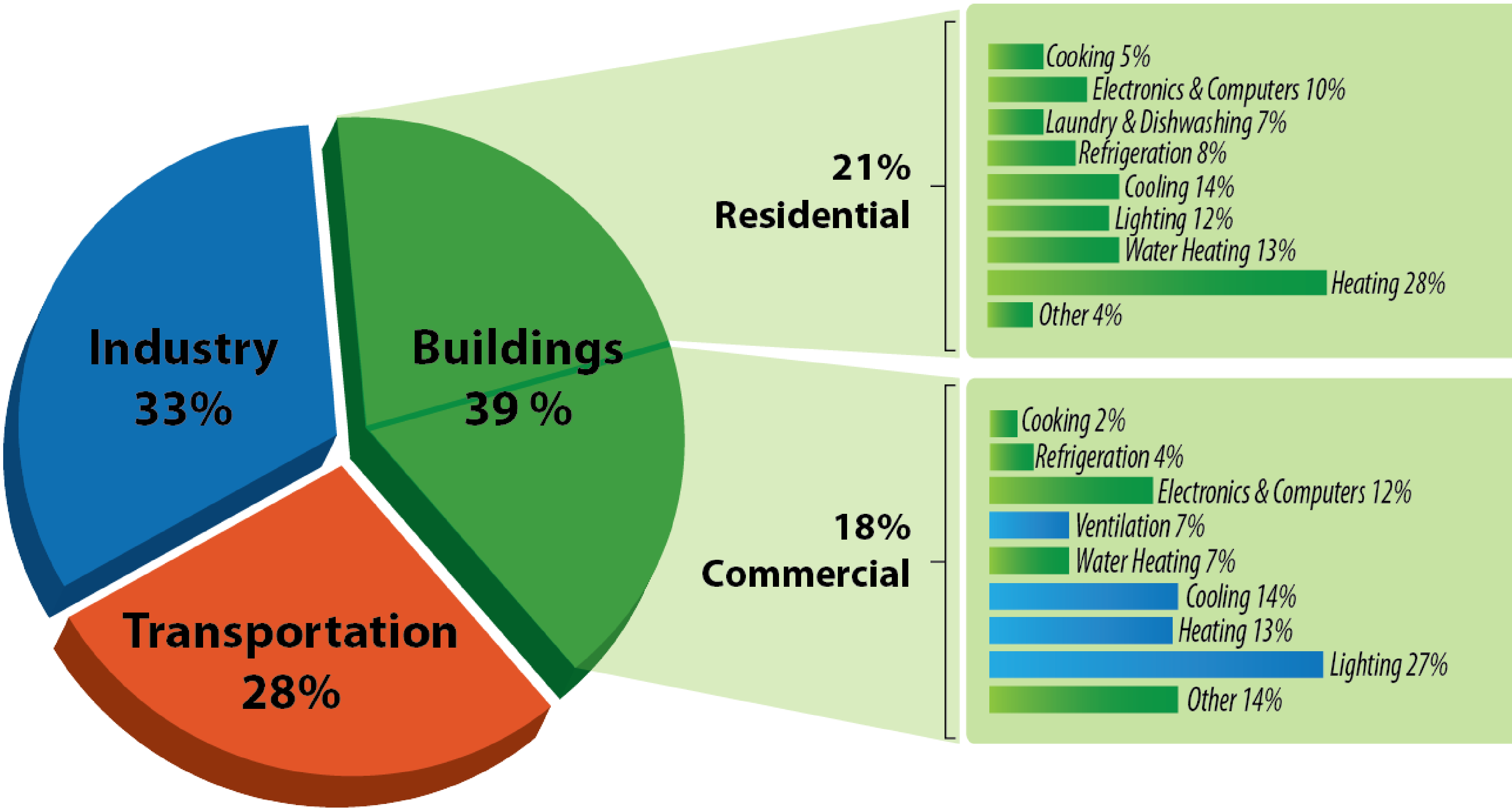
Global solar supply and generation in long-term scenarios



Source: IPCC Special Report Renewable Energy Sources (SRREN)

Energy Consumption in the U.S.

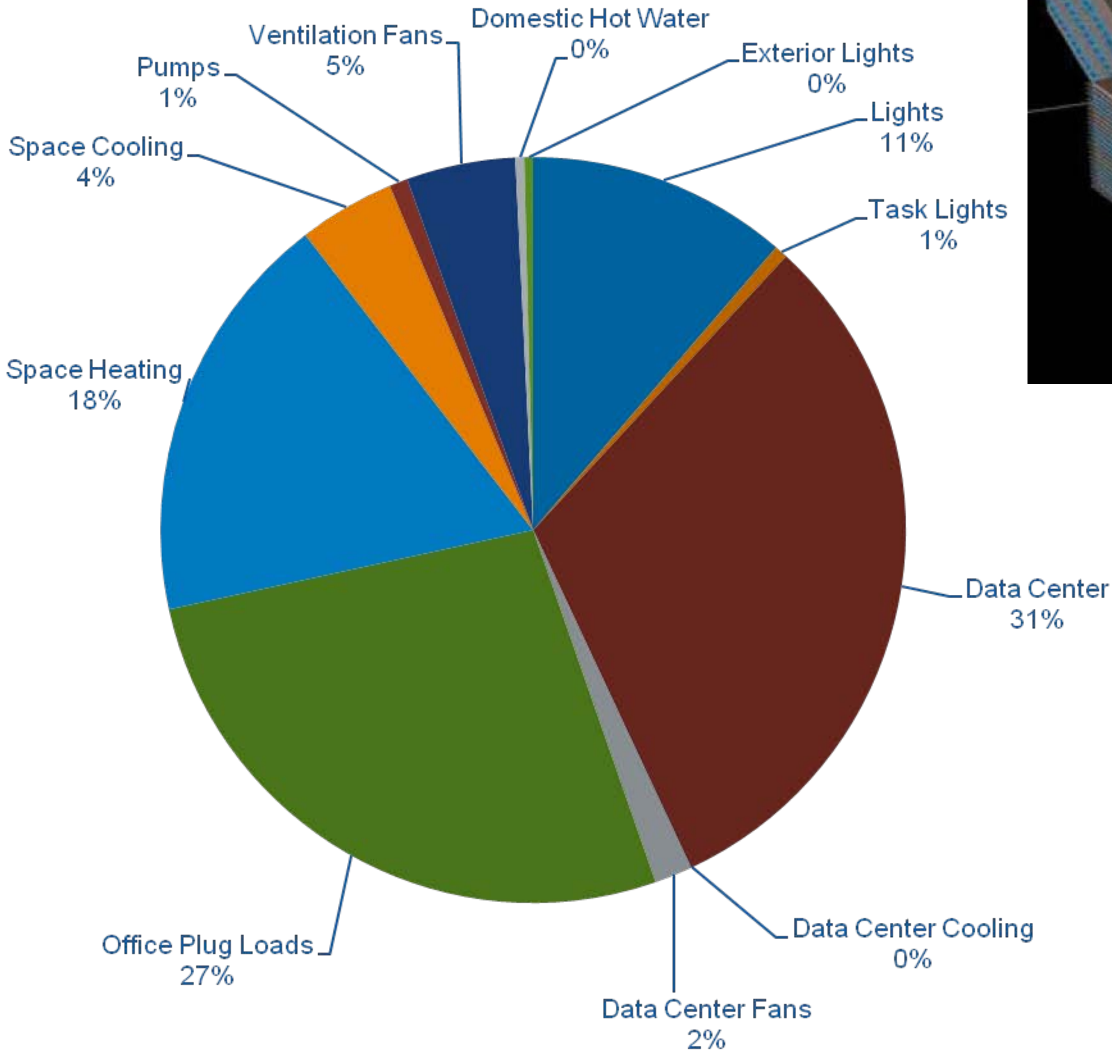


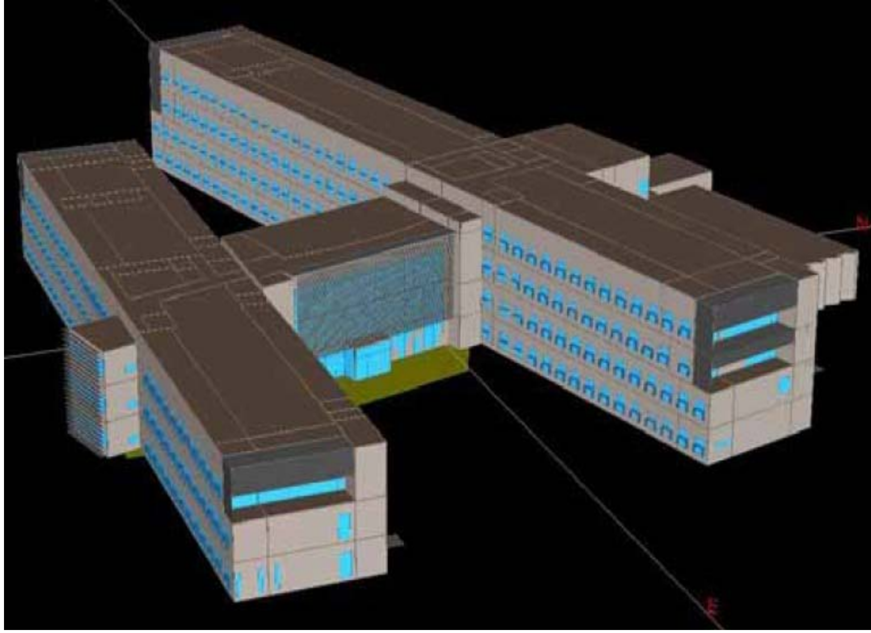
Source: Buildings Energy Data Book, 2006

NREL Research Support Facility

Energy Modeling

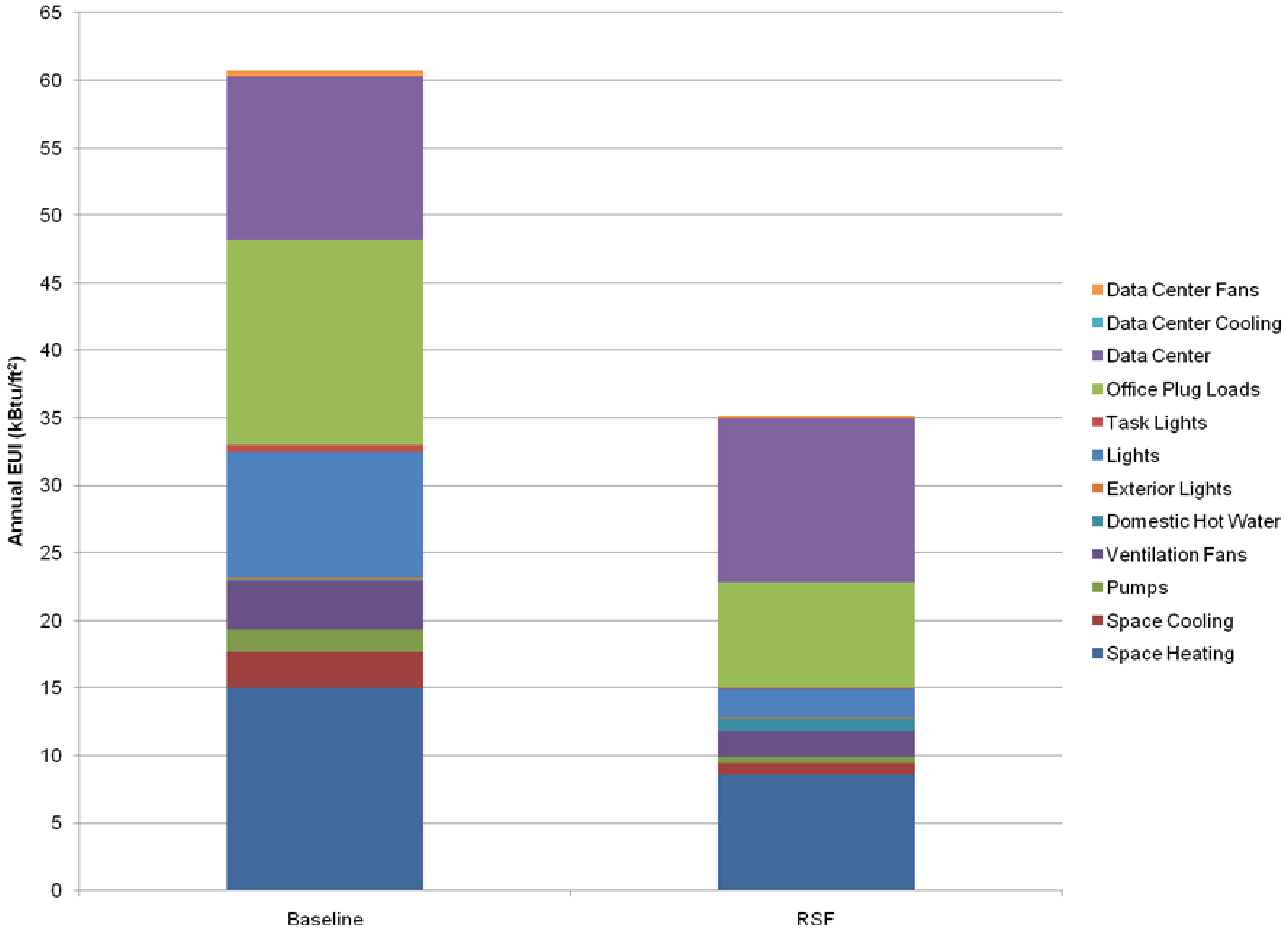
NREL RSF Energy Use Breakdown





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



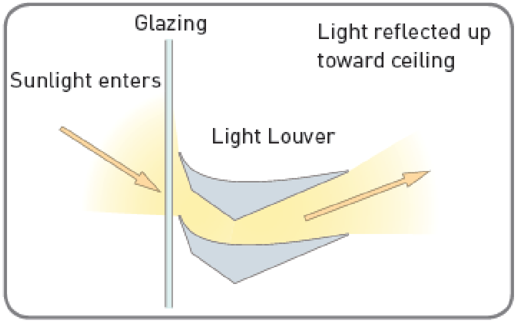
Daylighting

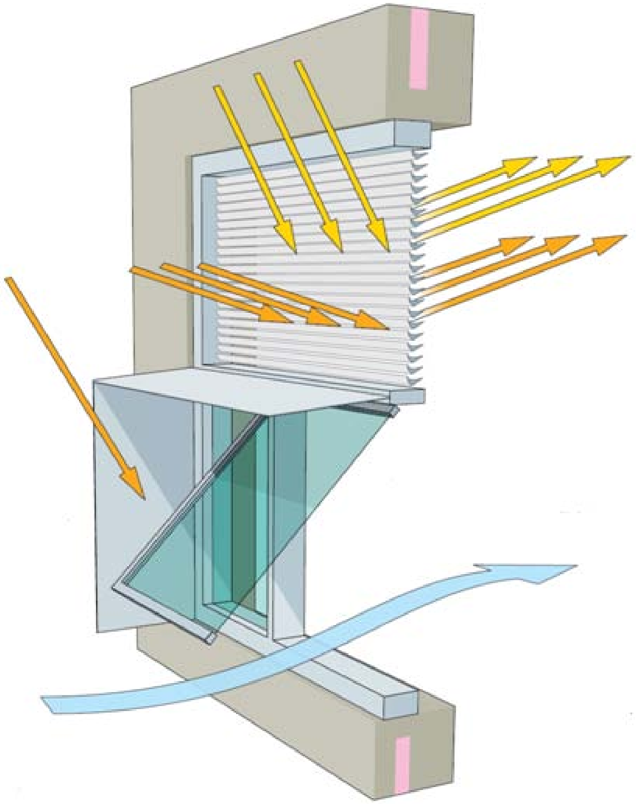
- Two long 60-foot wide wings with east-west orientation
- Design reduces electrical lighting

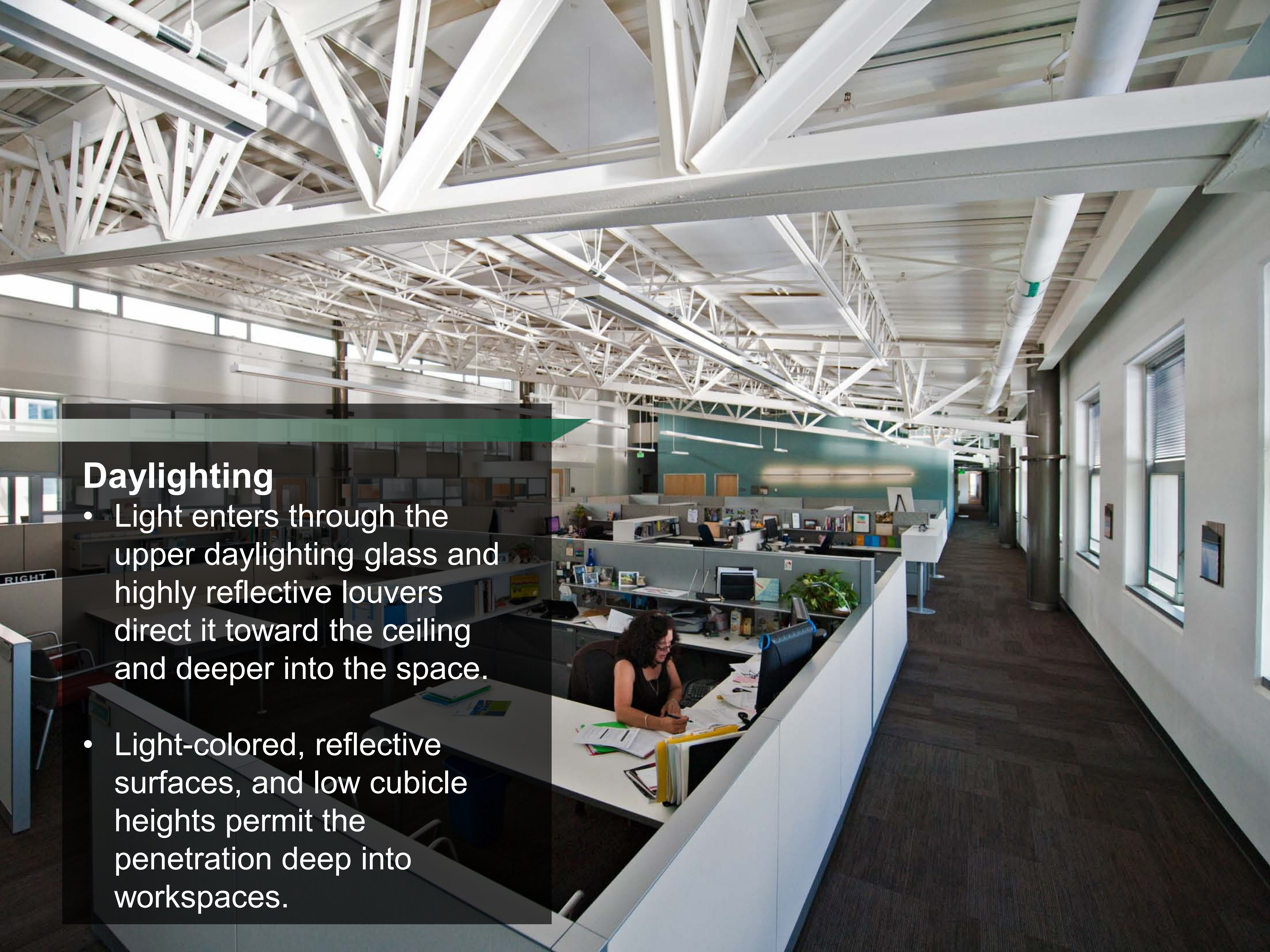
Daylighting: Light Louvers

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

Fixed sunshades limit excess light and glare.







Daylighting

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

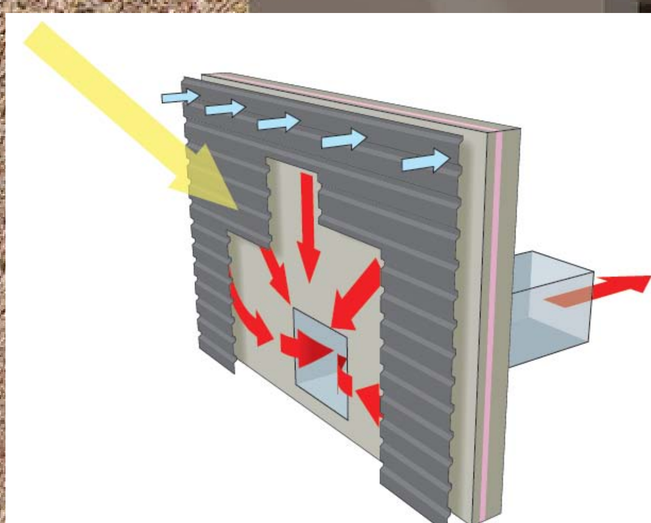
- Light-colored, reflective surfaces, and low cubicle heights permit the penetration deep into workspaces.

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

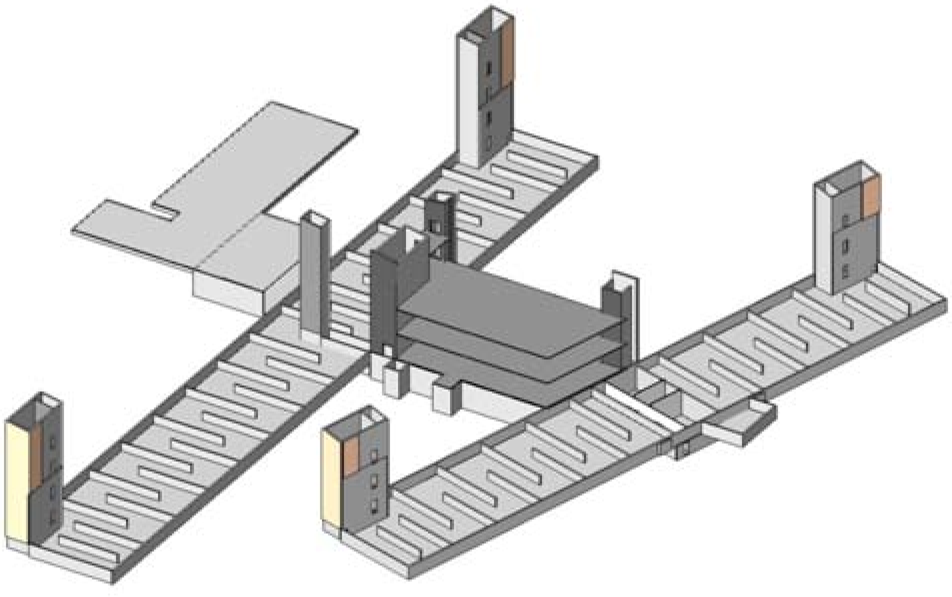
- Metal sheet perforated with small holes
- Fans pull air through the holes on sunny winter days to preheat building air
- During colder weather, air heated by the transpired solar collectors is stored in the labyrinth



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.



Natural Ventilation

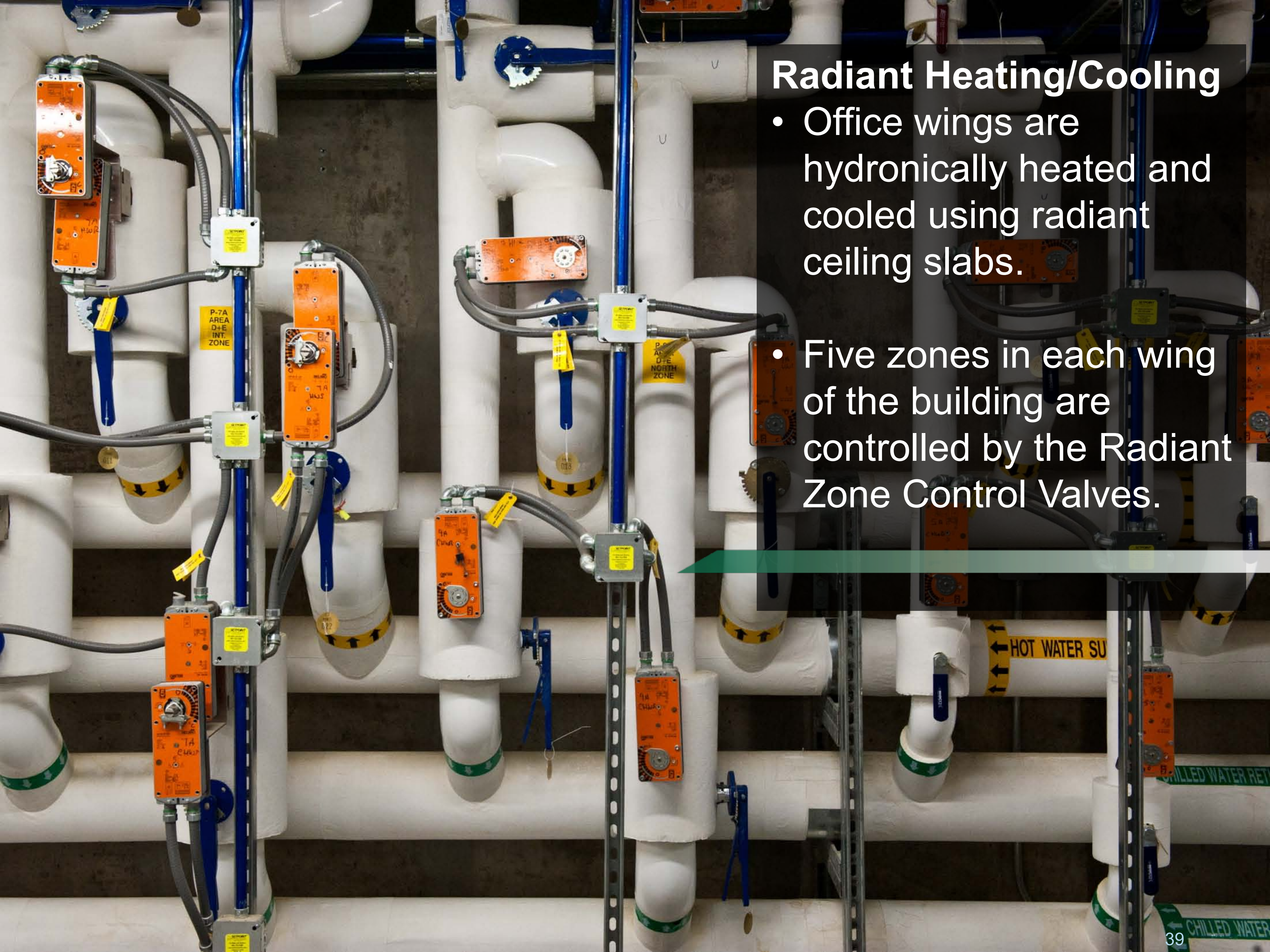
- During mild weather, operable windows allow for natural ventilation.
- Automatic windows are controlled and operated primarily to support nighttime precooling.
- Occupants are notified when conditions allow for manual windows to be opened.

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.



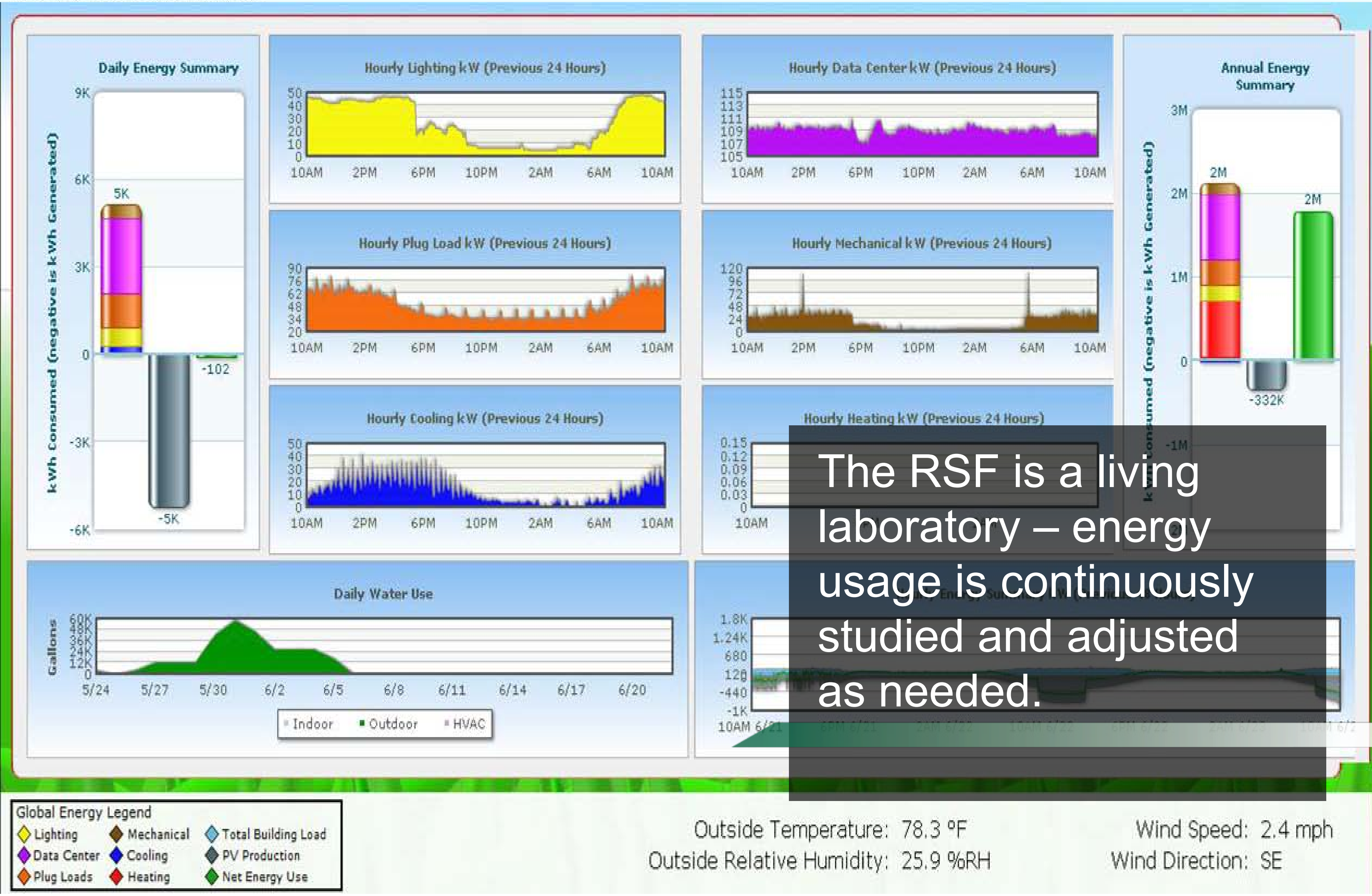
Radiant Heating/Cooling

- 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

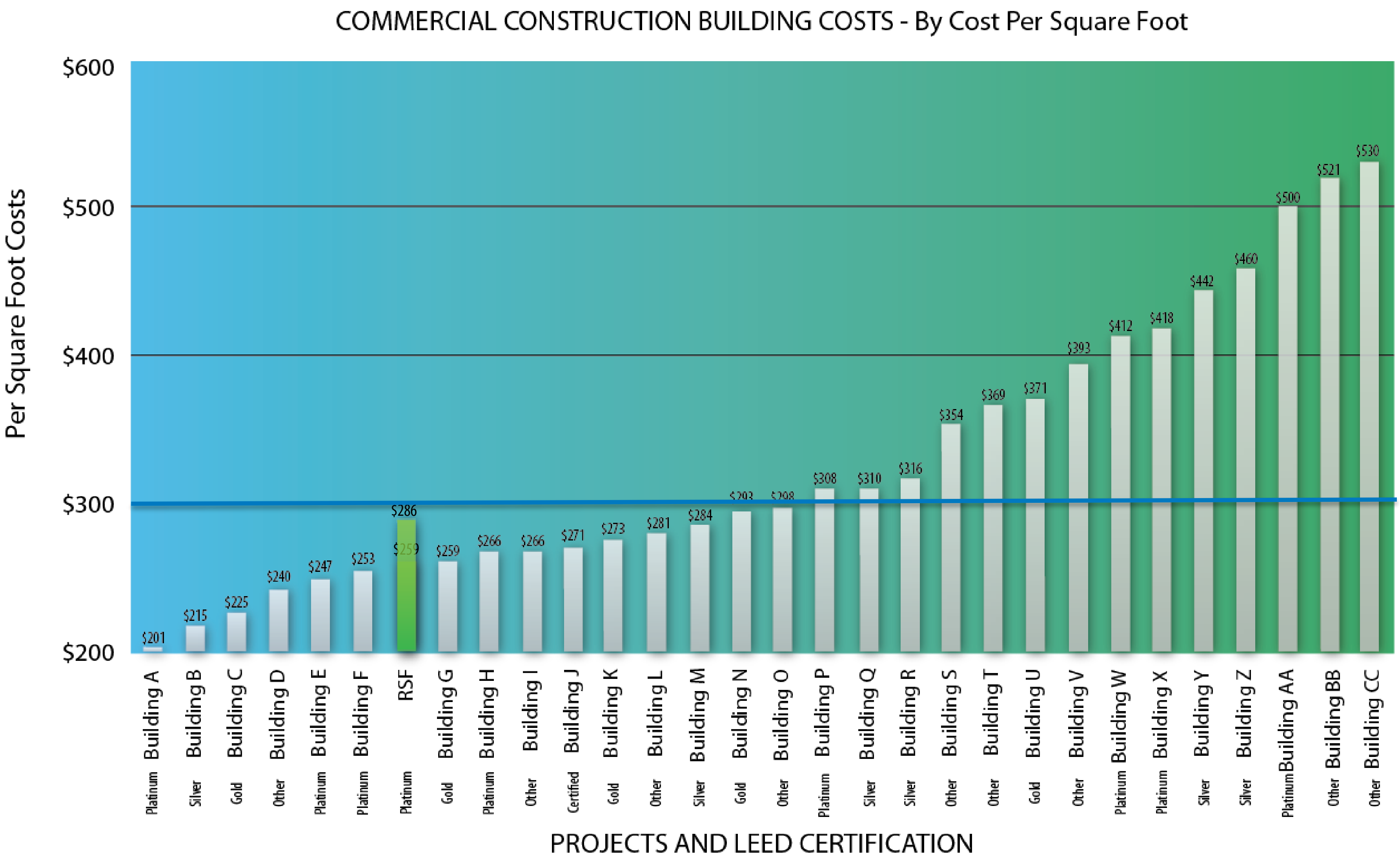


The RSF is a living laboratory – energy usage is continuously studied and adjusted as needed.

A glimpse into the future

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

Construction Costs



To achieve this vision, we must…

- Invent the future we desire
- Invest in innovation
- Partner on a global scale

NREL

NATIONAL RENEWABLE ENERGY LABORATORY

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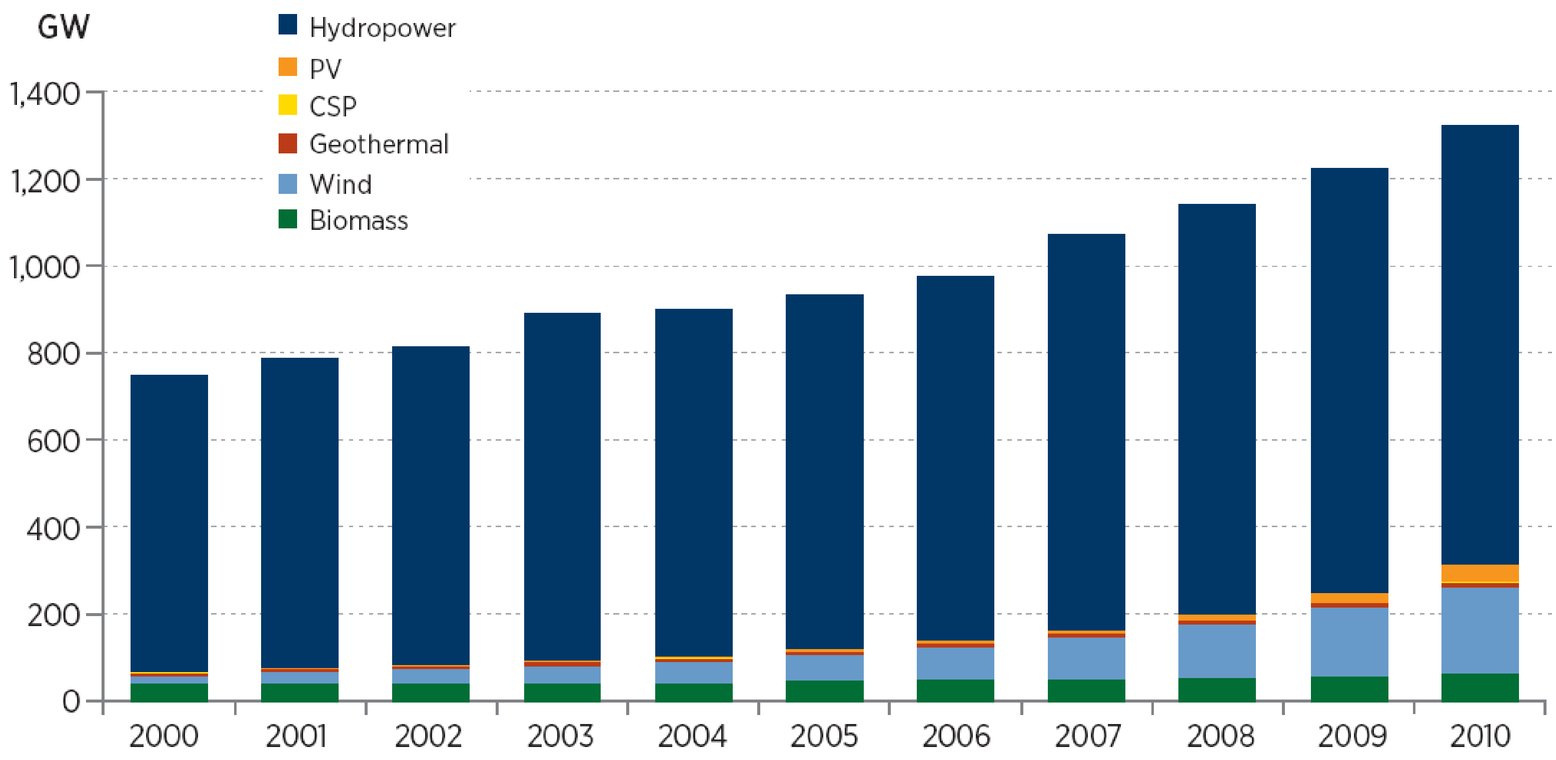
May 2011

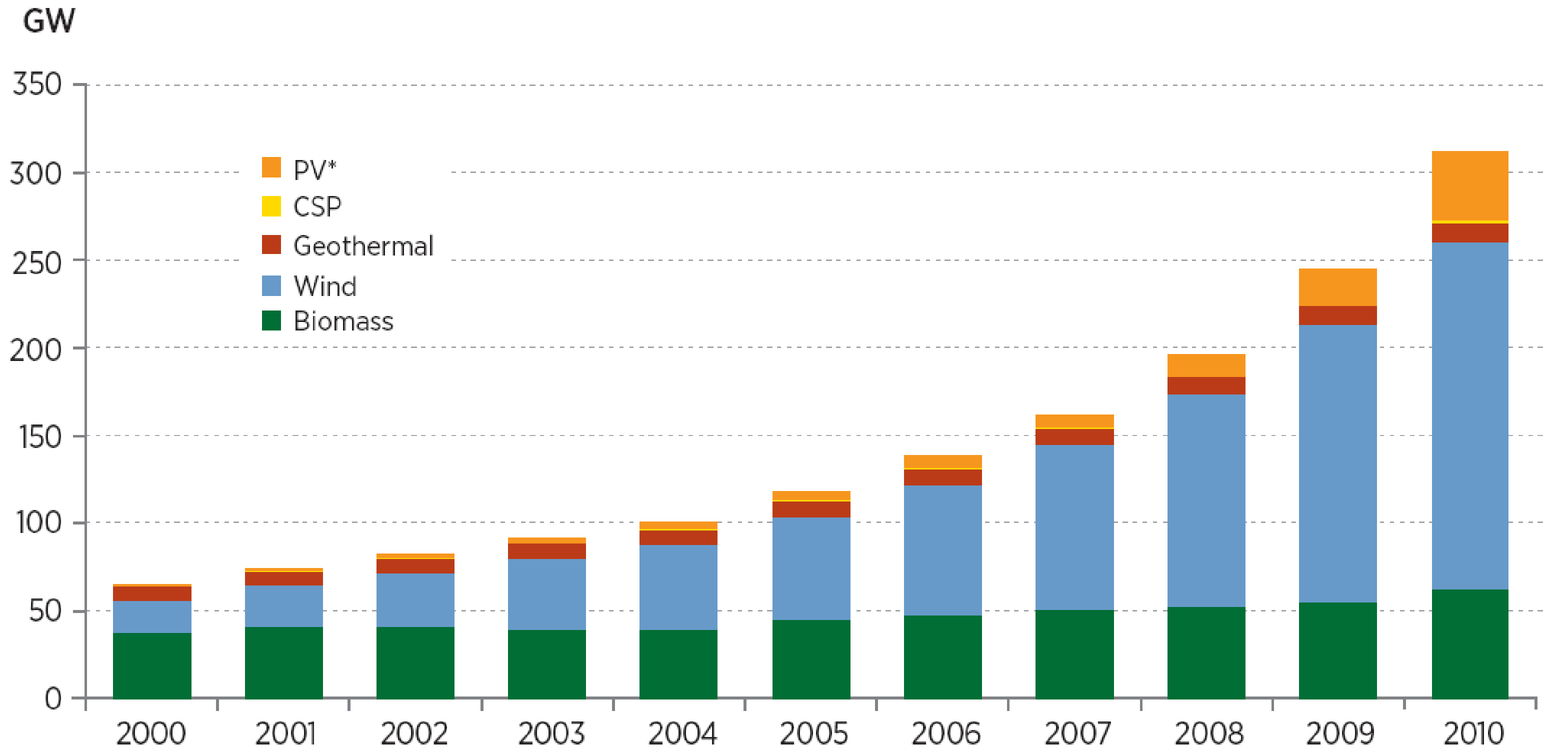
Backup Slides

Renewable Electricity Capacity Worldwide Including hydropower



Sources: REN21, GWEC, GEA, EIA, SEIA/GTM

Renewable Electricity Generating Capacity Worldwide Excluding hydropower



*Grid-tied capacity.

Sources: REN21, GWEC, GEA, EIA, SEIA/GTM

World Renewable Cumulative Electricity Capacity Percent Increase from the Previous Year

III

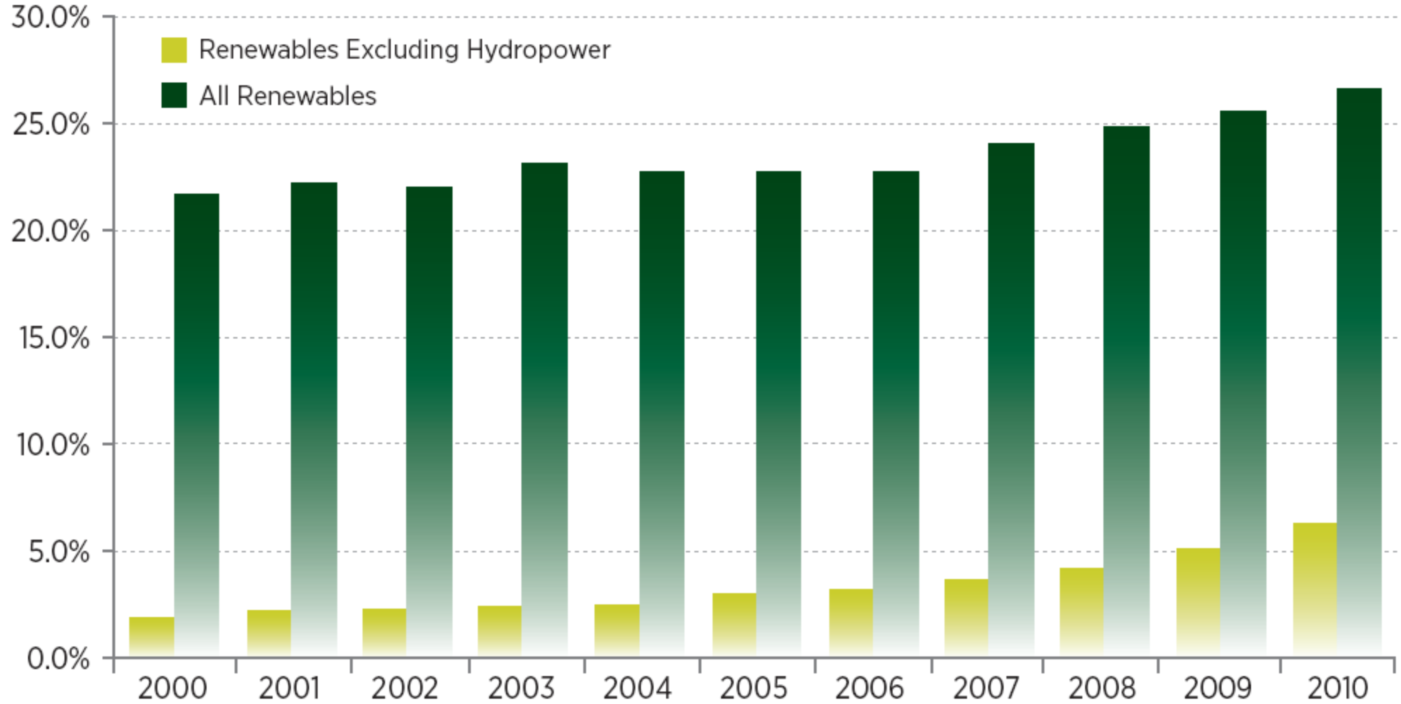
	Hydro	Solar PV	CSP	Wind	Geothermal	Biomass	Renewables without Hydro	All Renewables
2000	0%	22%	0%	31%	0%	6%	11%	1%
2001	5%	29%	0%	33%	0%	8%	15%	6%
2002	2%	33%	0%	29%	2%	0%	11%	3%
2003	9%	25%	0%	29%	9%	-3%	11%	9%
2004	1%	33%	0%	20%	0%	0%	10%	1%
2005	2%	38%	0%	23%	4%	13%	18%	4%
2006	2%	32%	0%	25%	3%	7%	17%	4%
2007	9%	5%	5%	27%	0%	6%	17%	10%
2008	4%	71%	14%	29%	4%	4%	22%	6%
2009	4%	62%	22%	31%	7%	4%	25%	7%
2010	3%	90%	83%	25%	3%	15%	27%	8%

- annual decrease | annual increase +

Sources: REN21, GWEC, GEA, EIA, SEIA/GTM

Renewables Share of Total Electricity Capacity Worldwide

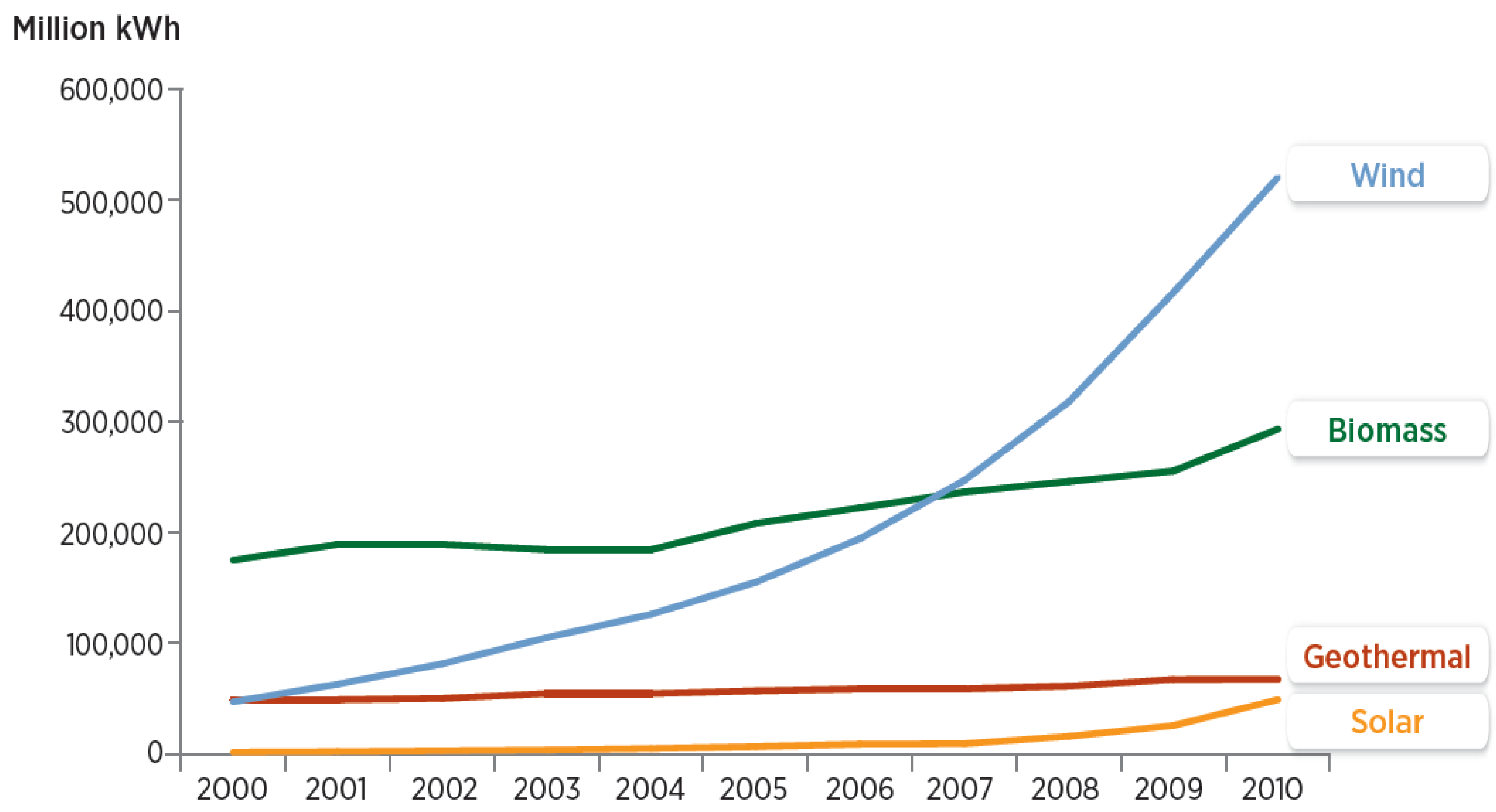
III



Sources: REN21, GWEC, GEA, EIA, SEIA/GTM

Renewable Electricity Generation Worldwide by Technology (2000-2010)

III

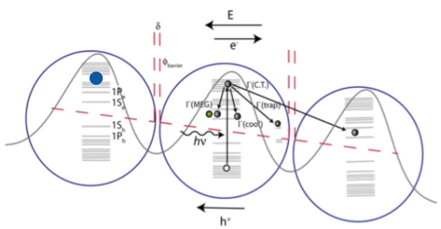


Generation derived using capacity factors of 14% for PV, 30% of wind, 70% for geothermal, 54% for biomass, 25% for CSP, and 41% for hydro.

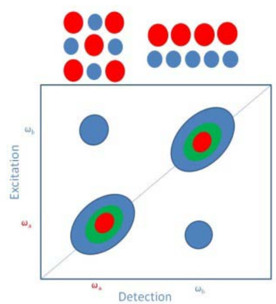
Sources: REN21, GWEC, GEA, EIA, SEIA/GTM

Chemistry and Nanoscience of Solar Photoconversion

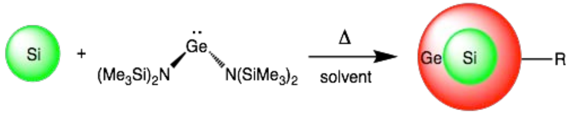
- Understand primary exciton dynamics in nanoscale structures
- Probe energy transfer, charge transport and reactivity at nanostructured interfaces
- Investigate integrated nanoscale energy conversion systems



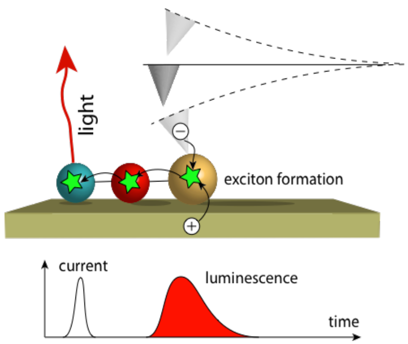
Nanocrystal Assemblies



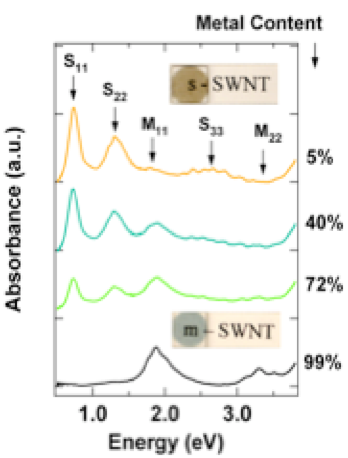
Advanced Spectroscopy



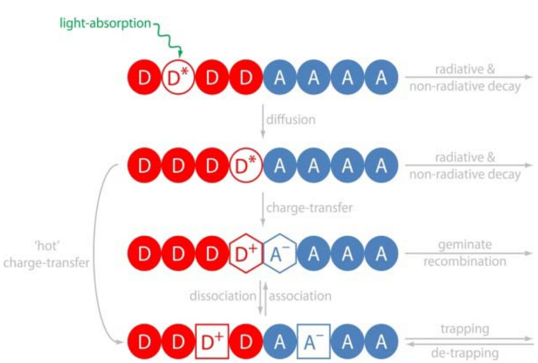
Nanoscale Synthesis



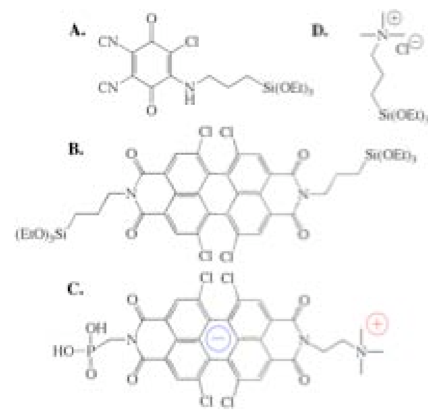
Imaging



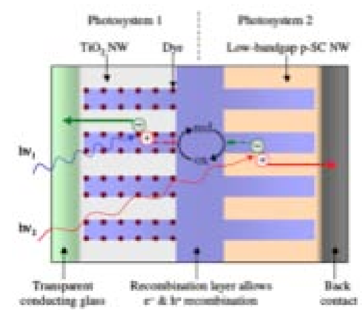
Carbon Nanotubes



Conjugated Polymers

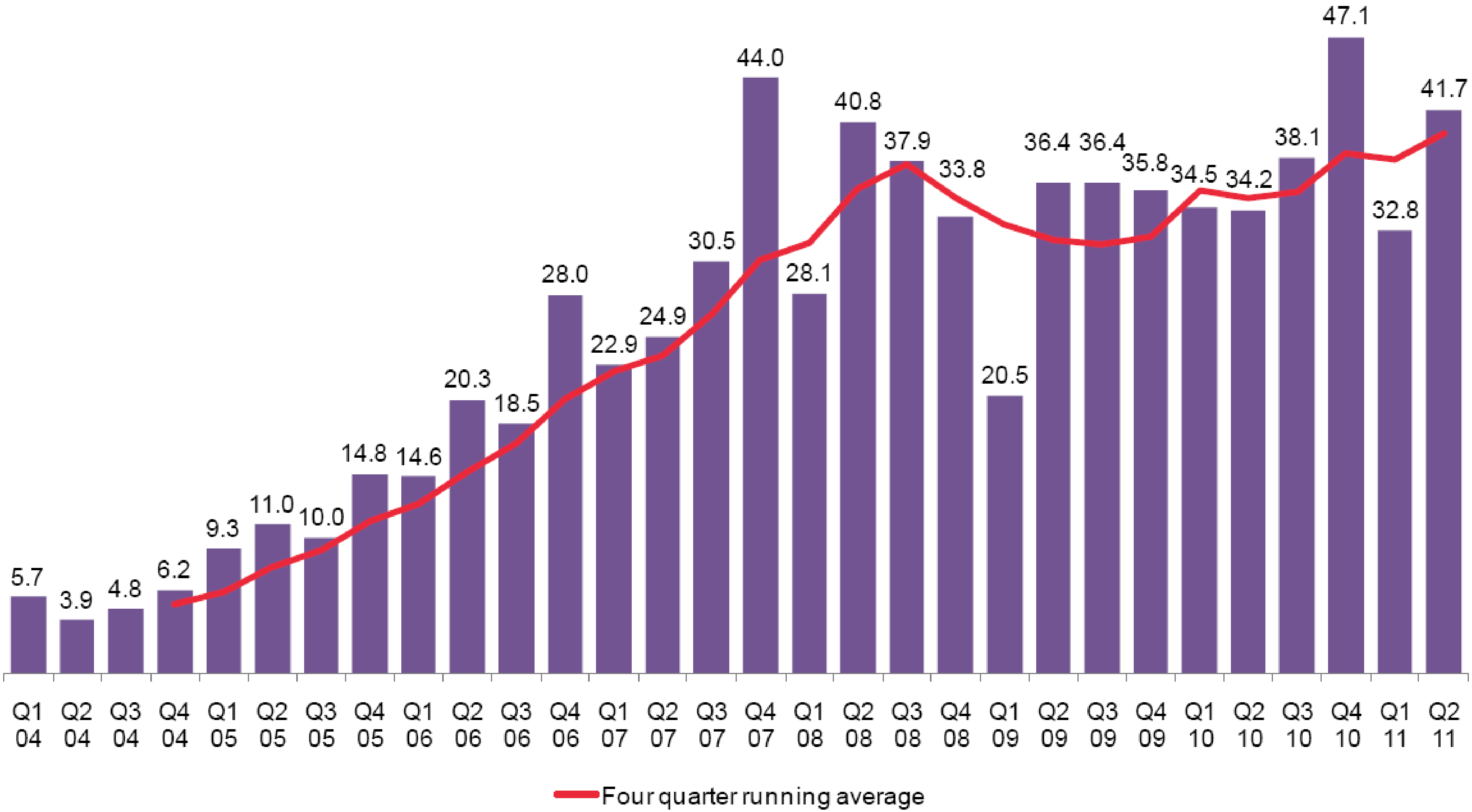


Excitonic Semiconductors



Sensitized Nanostructures

New Financial Investment in Clean Energy 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