NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Moving Toward a Clean Energy Future

Presented to the Weizmann Institute

February 23, 2011

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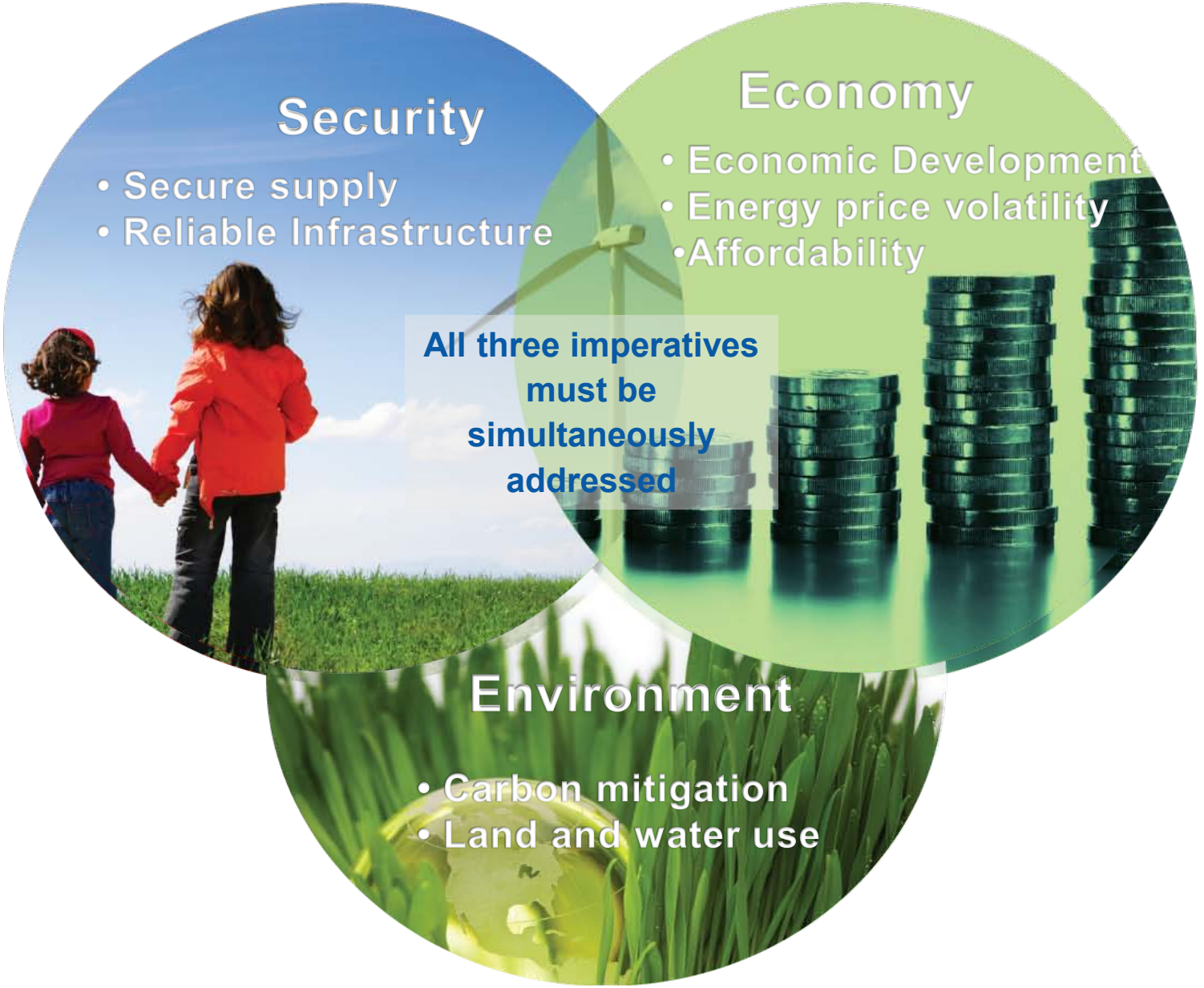
Laboratory Director

Energy Challenges



Our Energy System

Supply & Conversion

Oil 37%

Coal 21%

Natural Gas 23%

100 Quads

Nuclear 9%

Hydro
Wind
Solar
Biomass
Geothermal
8%

Transmission & Distribution

Utilization

28%

40%

32%

Lost energy as inefficiencies – approximately 60%

Updated: 2/11

Achieving a Sustainable Energy Economy

*Requires a National Energy Grand Challenge**

Lead Coordinated RD3E Strategy in Sustainable Energy

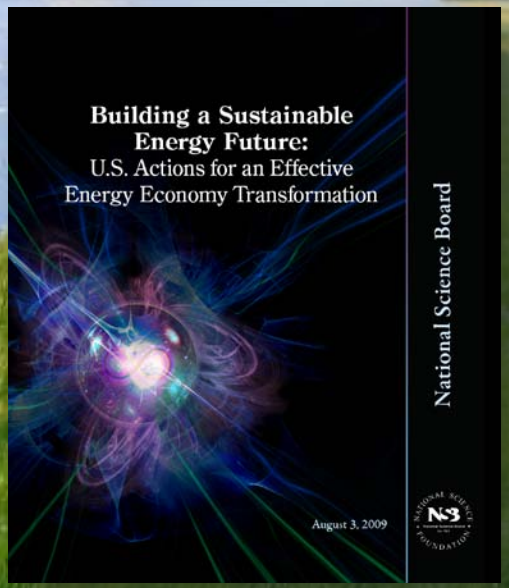
Boost R&D Investment

Construct Essential Policies & Market Conditions

Support Education & Workforce Development

Lead Globally

Promote Public Awareness & Action

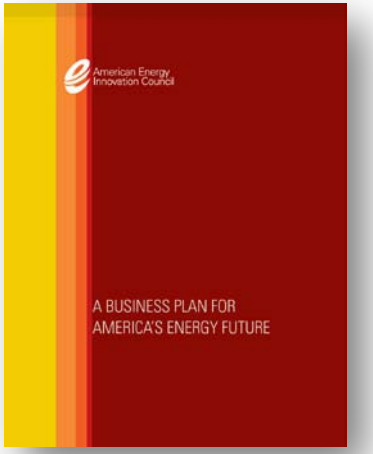


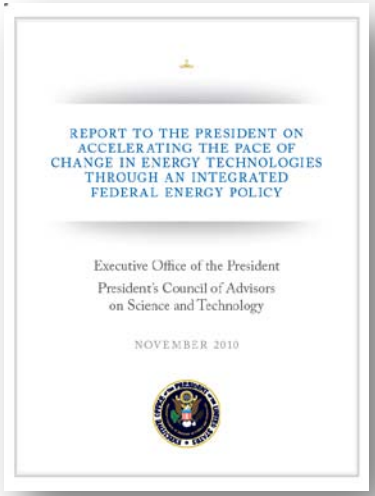
* Recommendations of the National Science Board Task Force on Sustainable Energy

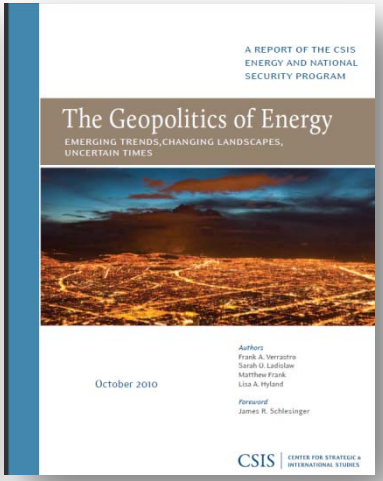
External Perspectives on Energy

Common themes

- Need a national energy strategy
- Significantly increase funding for energy RDD&D to match scale of problem
- Need a balanced portfolio (no "silver bullet" solutions)
- New mechanisms are needed (especially to address translation, adoption & diffusion)
- Need cross Federal agency coordination







e.g., PCAST, American Energy Innovation Council, Harvard Report on Transforming the Energy Economy, CSIS

A Profound Transformation is Required

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

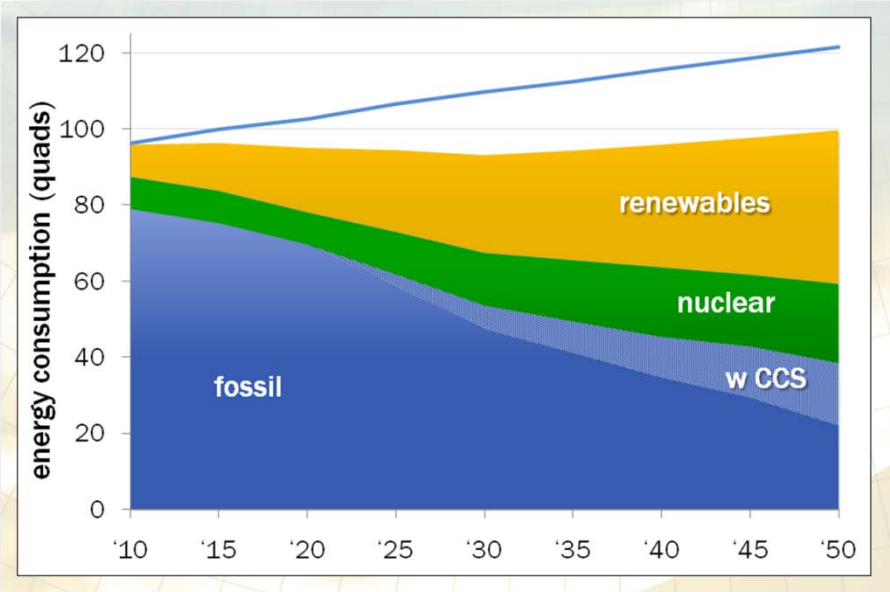
TRANSFORMATION

Sustainable Energy System

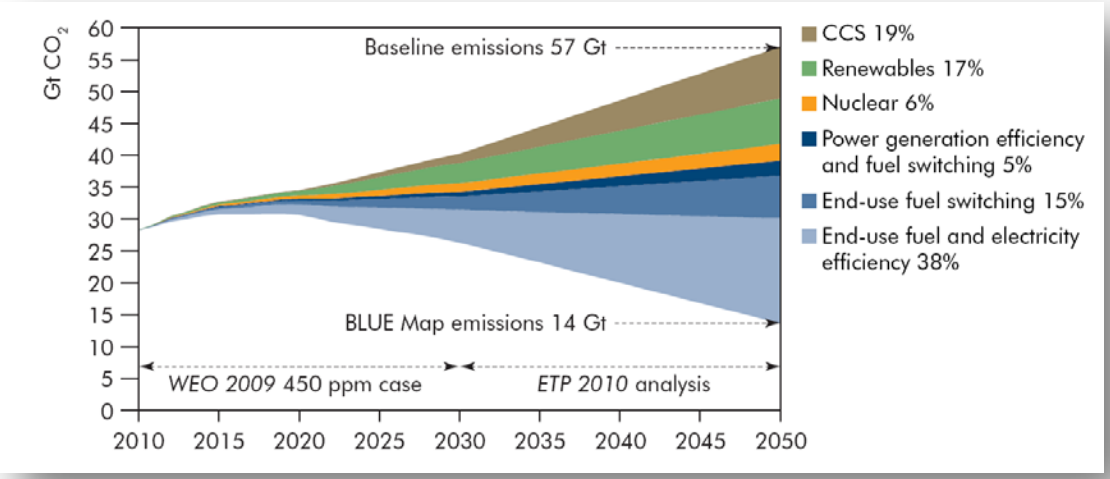
- Carbon neutral
- Efficient
- Diverse supply options
- Sustainable use of natural resources
- Creates American jobs
- Accessible, affordable and secure

And a Path Forward

STEP—Medium Case Total Energy



Key Technologies for Reducing CO2 Emissions Under the BLUE Map Scenario



2050 national goal:
Oil use reduced to <15% of current levels,
CO_2 emissions cut by >80%

Source: International Energy Agency, *Energy Technologies Perspectives 2010*

A Decade of Real Progress

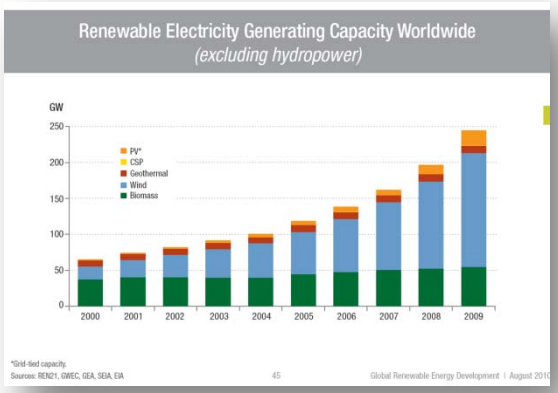
Wind power increased from **1,000 MW to 10,000 MW/year**

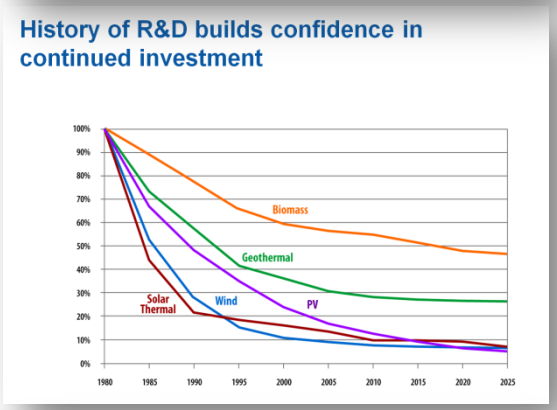
Solar PV went from **20 MW to nearly 600 MW/year**

Biofuels emerged as a **major national and global industry**

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

Renewable energy grew from $1B/year to a **$20B/year market** in the U.S.





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

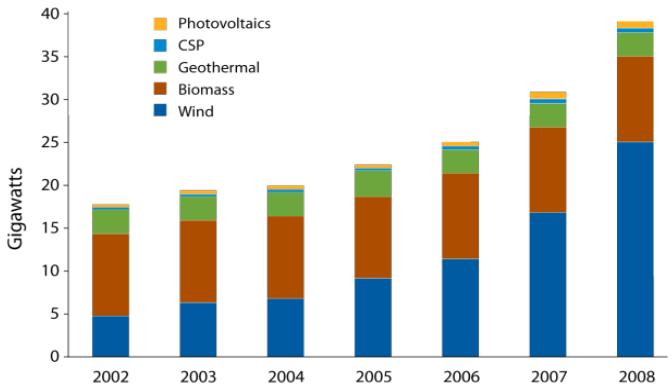
Remove Barriers to Broad Deployment

- 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



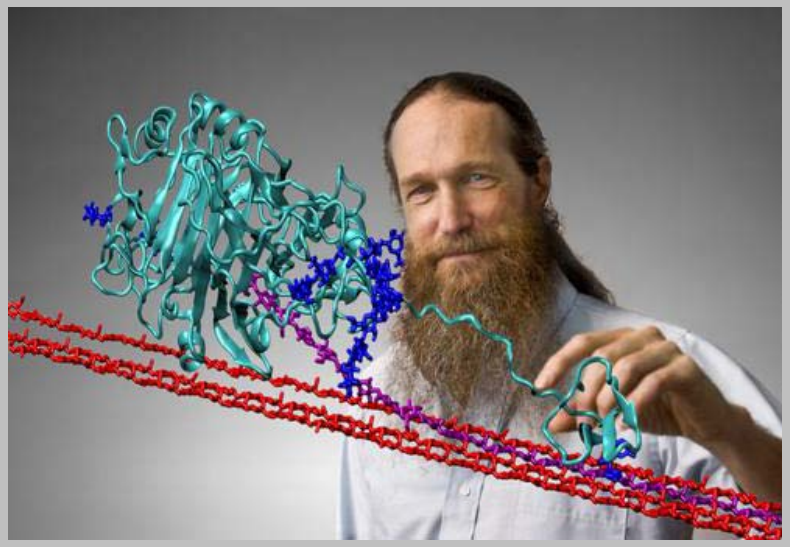
Source: EIA Annual Energy Outlook 2009 Early Release

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

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

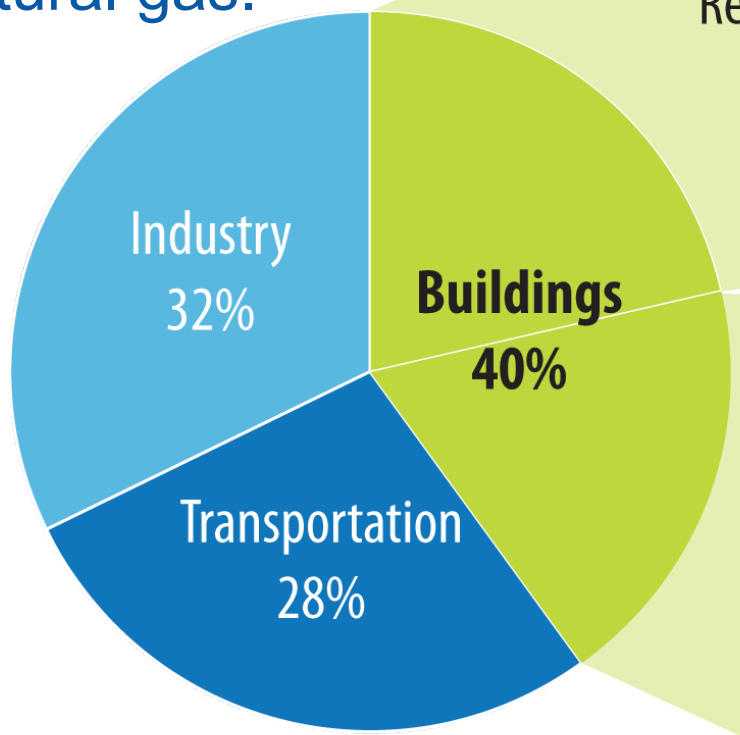
NREL Research Thrusts

- 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

Residential 22%

Computers	1%
Other	4%
Cooking	5%
Wet Clean	5%
Electronics	7%
Refrigeration	8%
Lights	11%
Cooling	12%
Water Heat	12%
Heating	32%

Commercial 18%

Cooking	2%
Computers	3%
Refrigeration	4%
Office Equipment	6%
Ventilation	6%
Water Heat	7%
Cooling	13%
Other	13%
Heating	14%
Lights	26%

Source: Buildings Energy Data Book 2007

Technology for Cost Effective Zero Energy Buildings

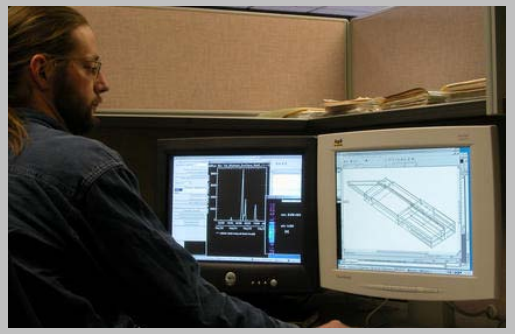
NREL Zero Energy Habitat House

BIPV Products & PV-T Array

Compressorless Cooling

Electrochromic Windows

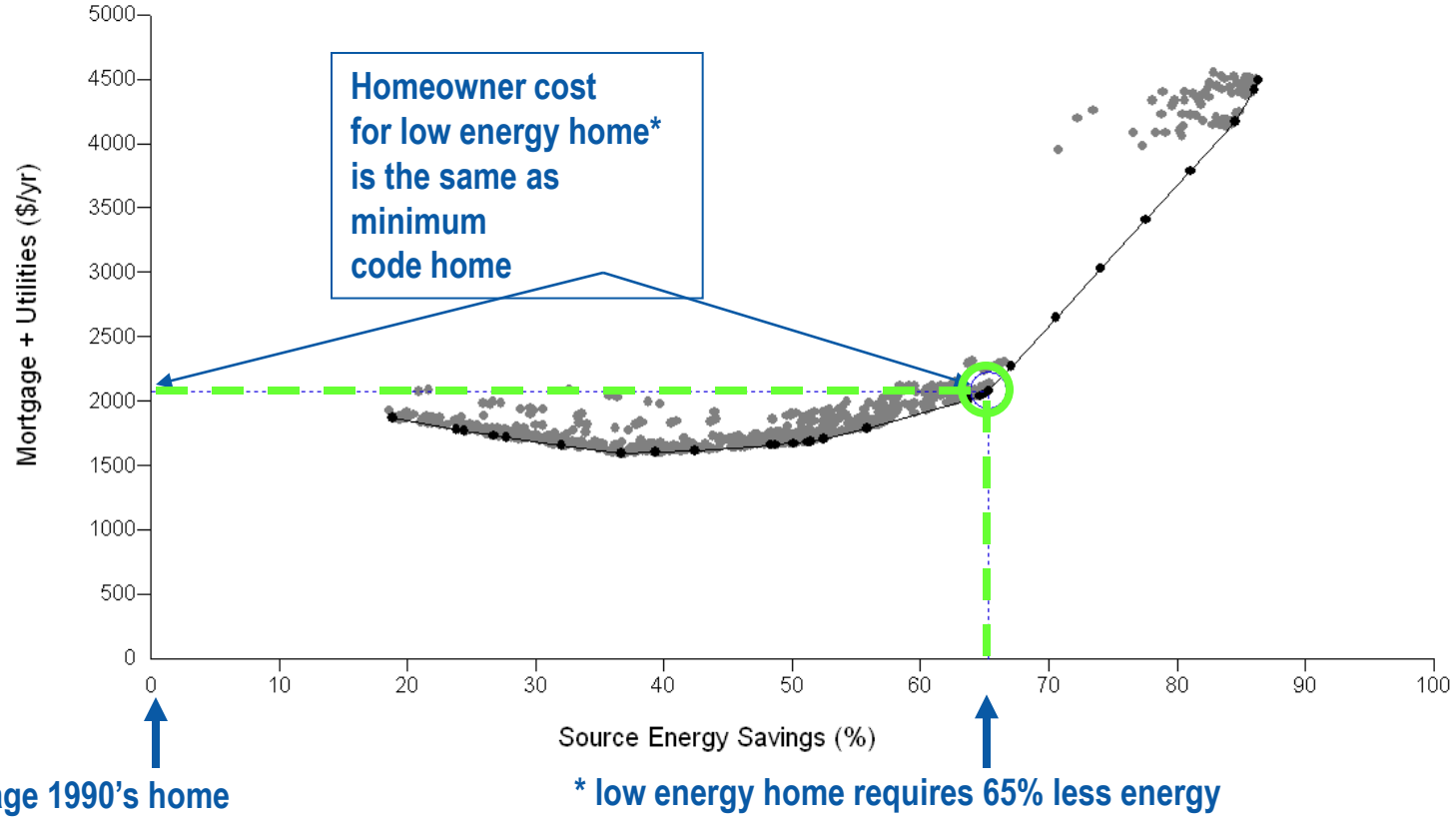
Polymer Solar Water Heaters



Computerized optimization & simulation Tools

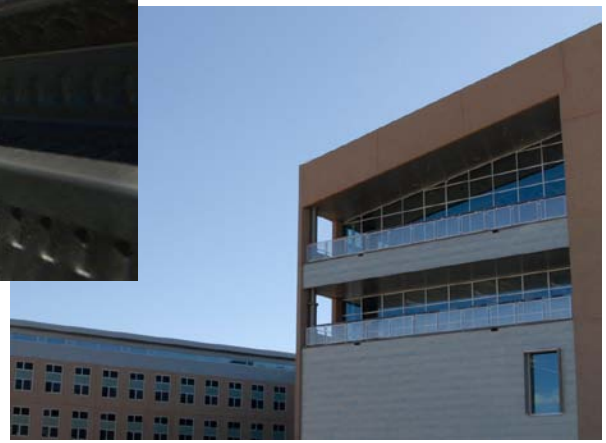
Net-Zero Energy Homes That Are Cashflow Neutral

- NREL Analysis using BEOpt software for Boulder,CO climate



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

NREL's Research Support Facility – Ultra High Efficiency in Practice



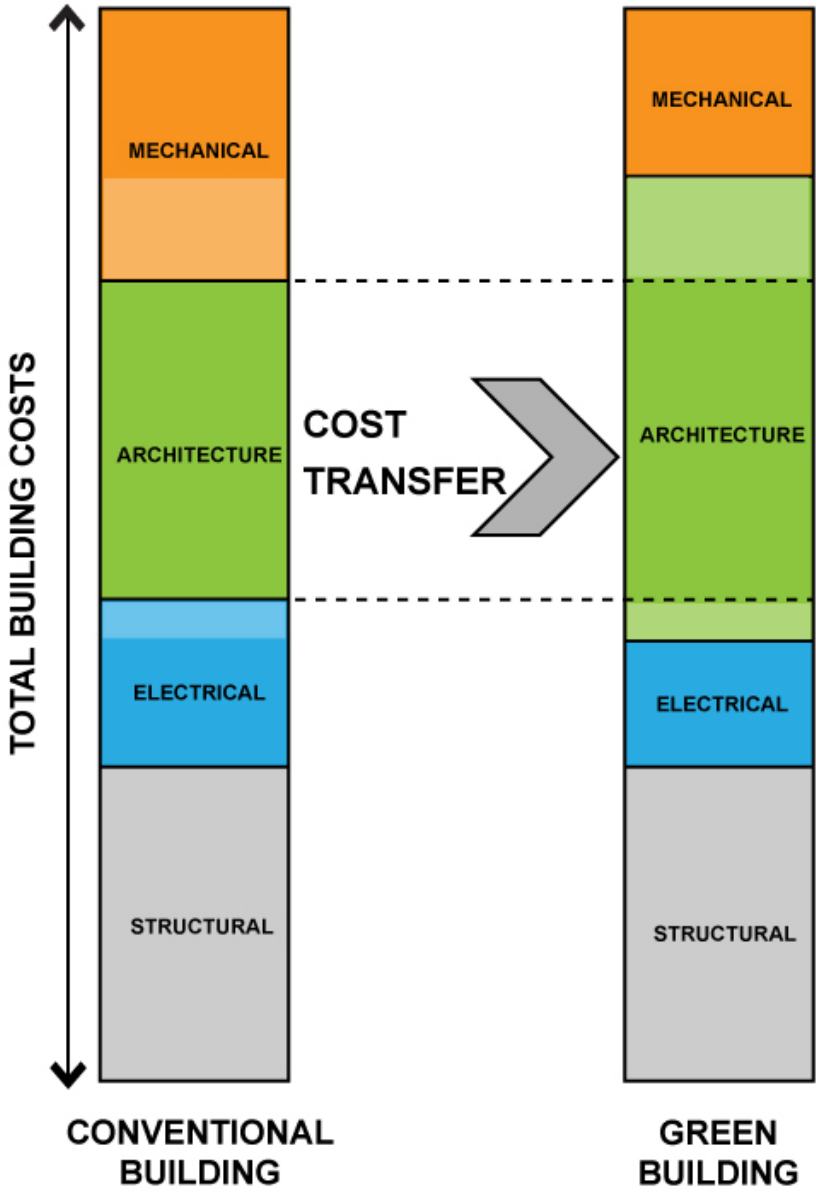
Will achieve LEED Platinum rating but will use 50% less energy than if it were built to current commercial codes

Is a living laboratory where researchers use real-time building performance data to study building energy use.

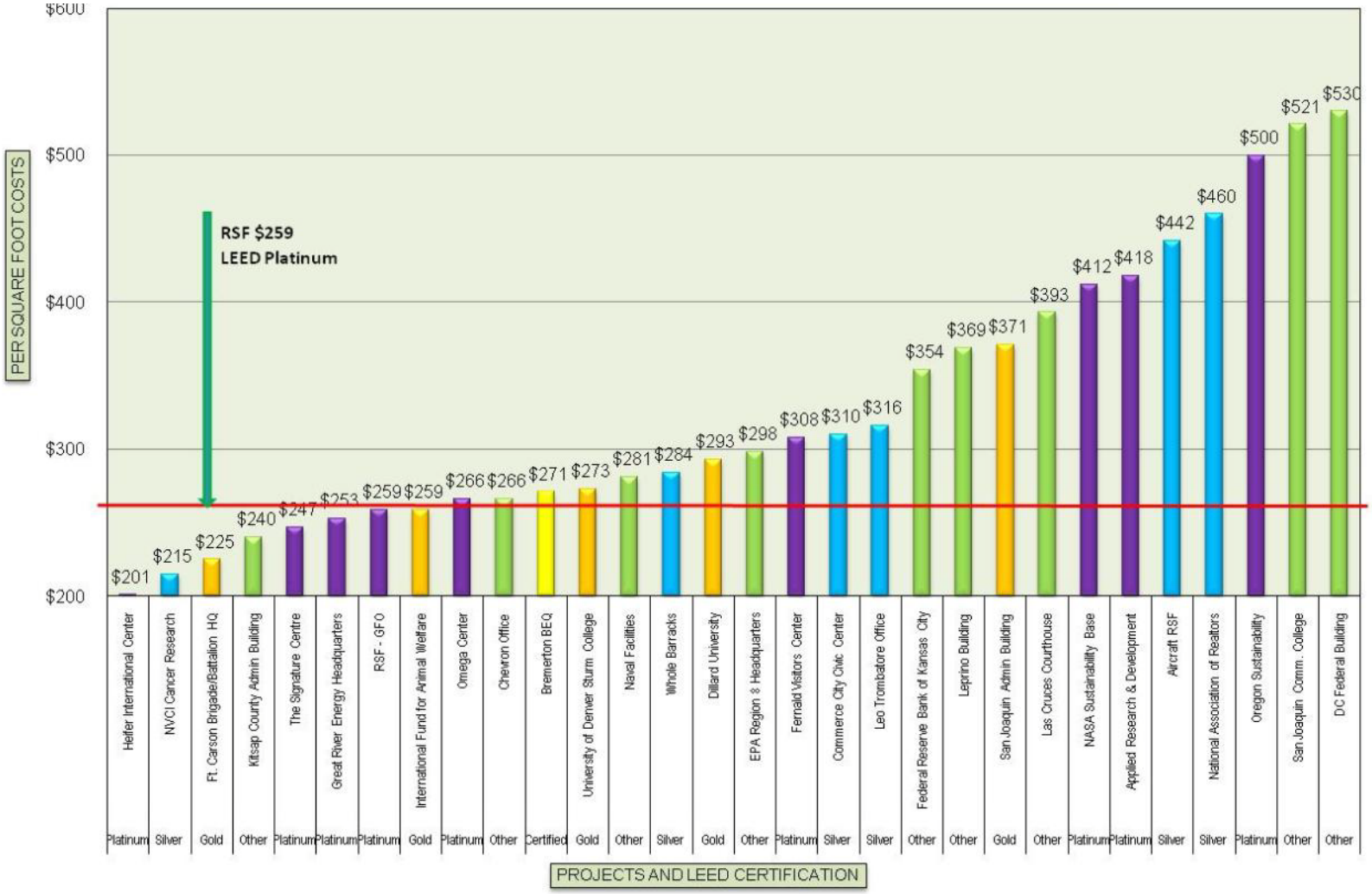
Integrated Design

Cost Transfer

Transfer costs from mechanical and electrical systems to building architecture



Commercial Construction Buildings Costs
By cost per square foot



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

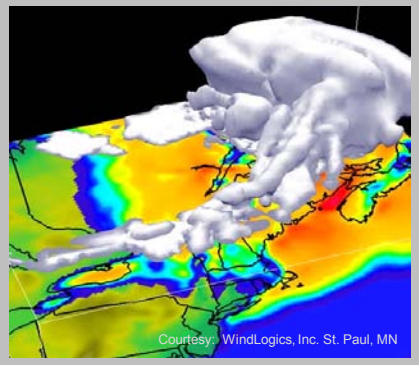
US Wind Resource Exceeds Total Electrical Demand

Offshore Wind

Innovative Tall Towers

Advanced Blades

Giant Multi-megawatt Turbines

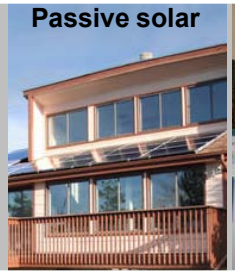


Wind Forecasting


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

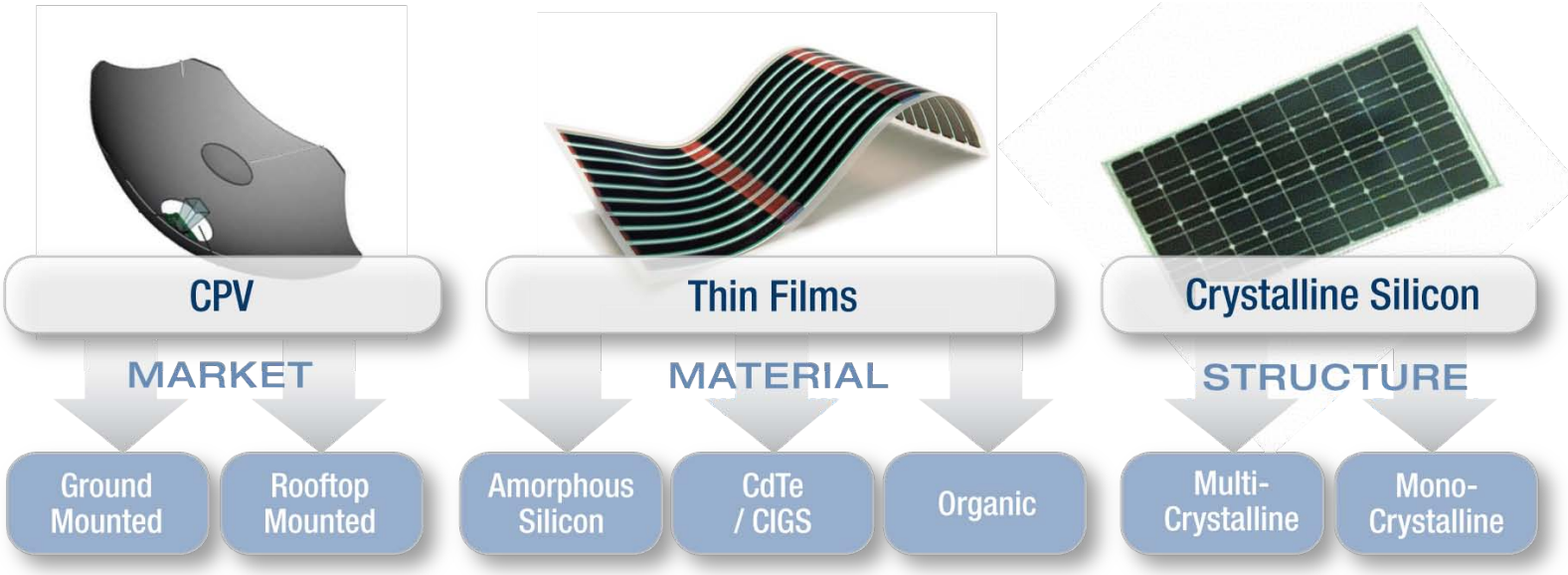
Grid integration, systems performance and reliability

Updated 10/10

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

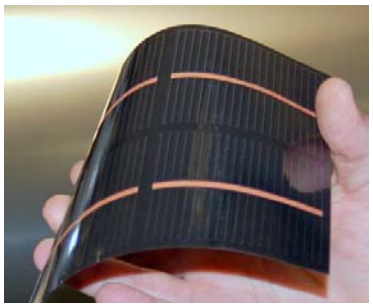
**CSP assumes trough technology.

Pursuing a range of promising PV technologies…

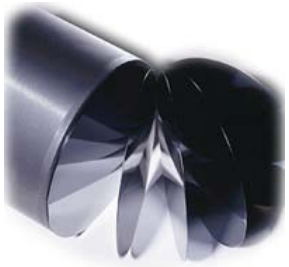


20x-100x

500x



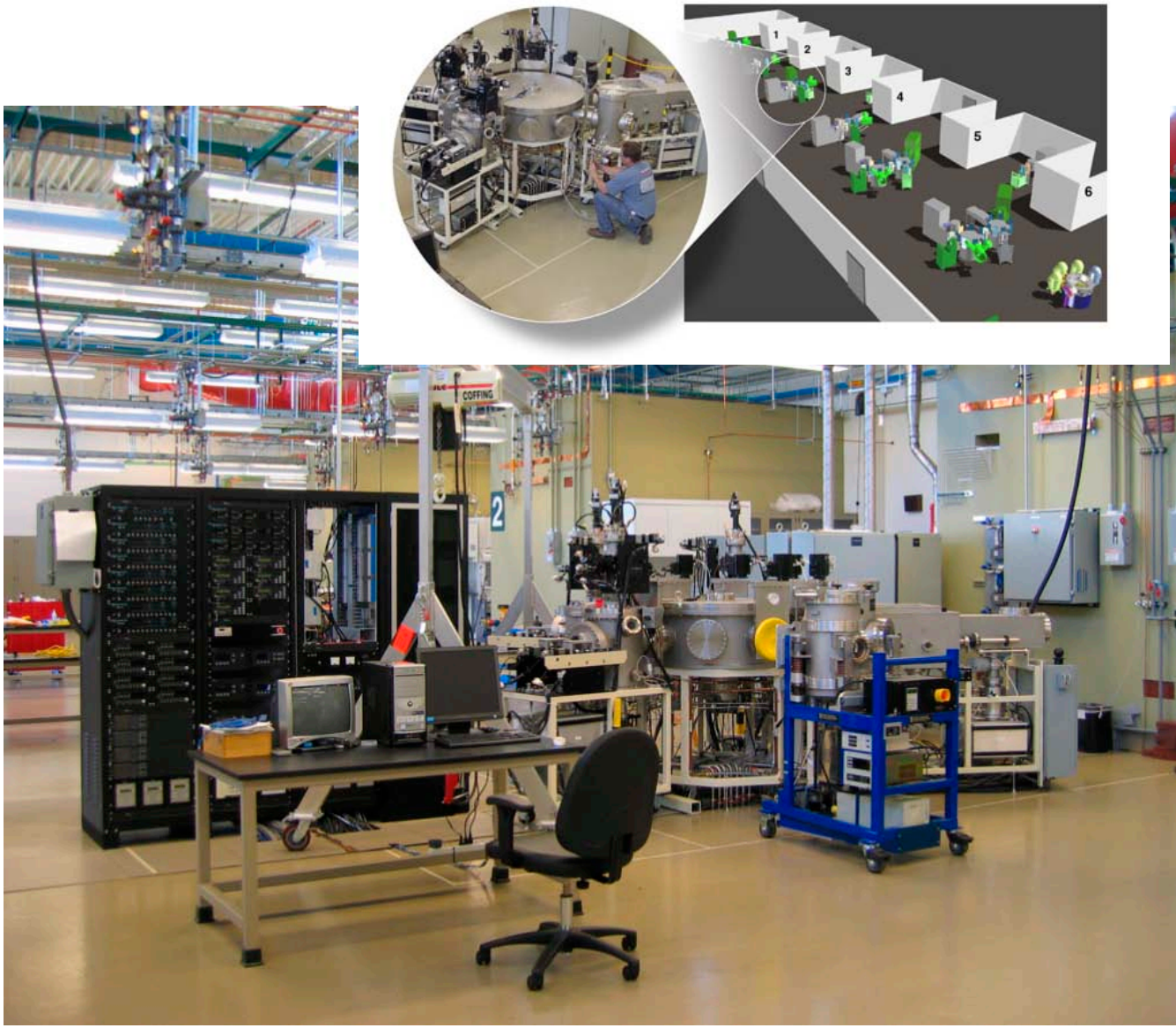
Cu(In,Ga)Se_2 ~ 1-2 um



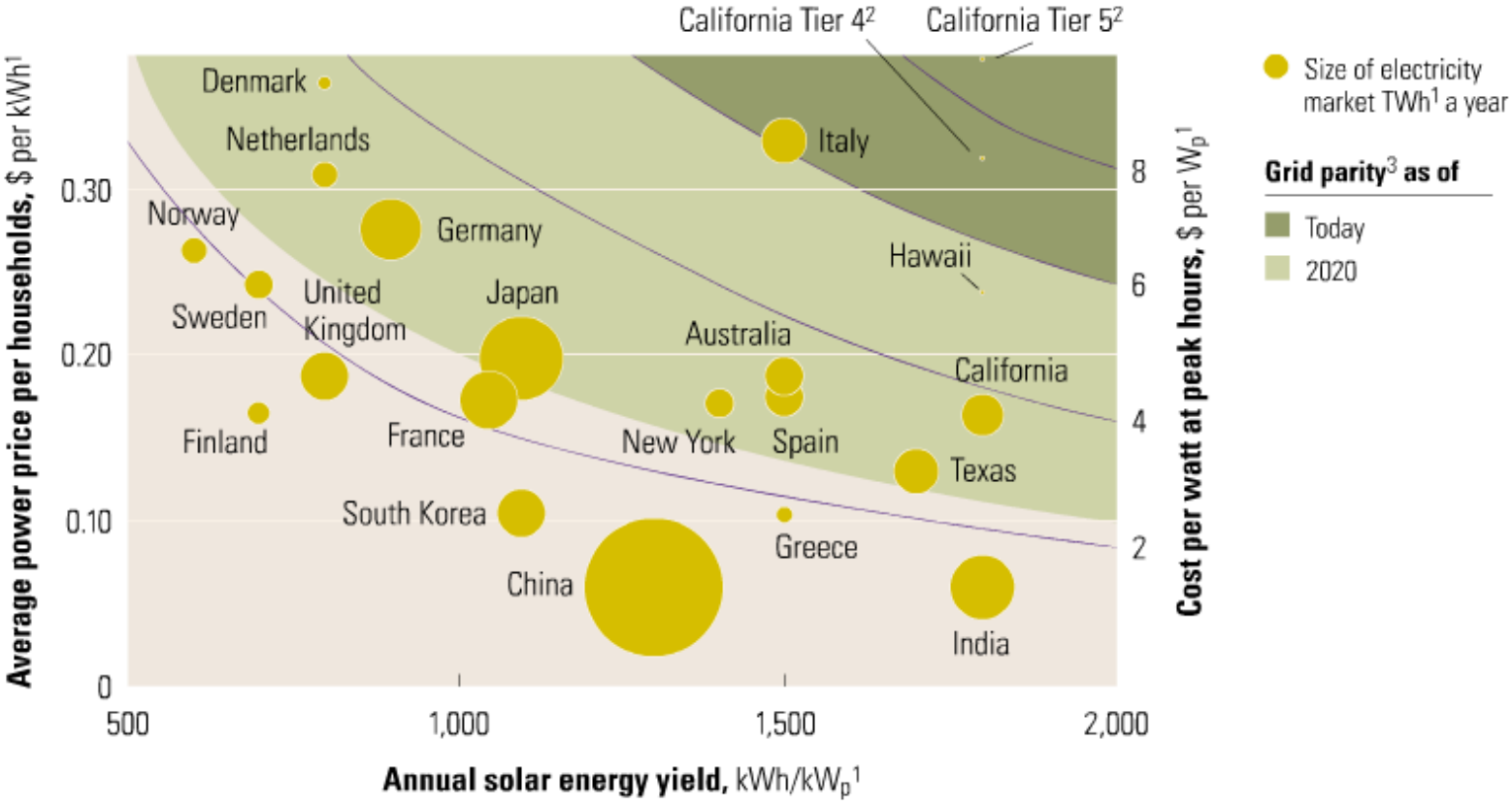
c-Si ~ 180 um

Process Development and Integration Laboratory

The PDIL brings together technical experts from NREL, the solar industry, and universities to access unique process development and integration capabilities.



Growing Competiveness of Solar



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

Source: McKinsey Quarterly, June 2008

Biopower

Current Status:

10.8 GWe capacity

- 5 GW pulp and paper
- 2 GW dedicated biomass
- 3 GW municipal solid waste/landfill gas
- 0.5 GW cogeneration

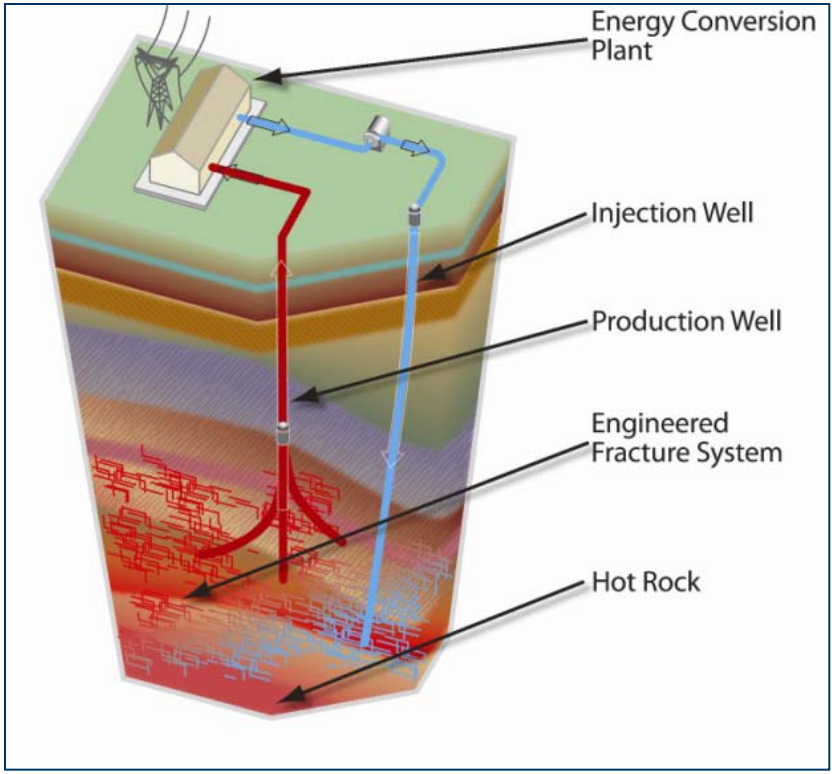
Cost: 8-10¢ /kWh

Major Technology Directions: Proposed focus on large-scale power

- Optimized biochar fuel,
- Feedstock logistics and sustainability
- Fuel characteristics and feed methods,
- Flue gas clean-up
- Power generation and integration with other biomass uses, such as integrated biorefineries.

Updated 9/10

Geothermal



Current Status

- 3,000 MWe installed; about 6,000MWe under development
- Conventional Geothermal ~5-8¢/kWh
- Enhanced Geothermal Systems potential > 100 GW by 2050

Major Technology Directions

- Enhanced Geothermal Systems (EGS)
- Conventional hydrothermal, co-produced power from oil and gas wells and low-temperature resources.
- Resource potential

Updated 9/10

Water Power

Current Status

Conventional hydropower:

- Remaining potential is large (>50 GW), but difficult to access

Ocean power: Early development stages

- U.S. wave & current resource estimated at 51 GW of extractable energy

Major Technology Directions

- Resource assessment
- Support increased production from existing dams and pumped storage
- Marine and hydrokinectic device development, testing, and demonstration

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:

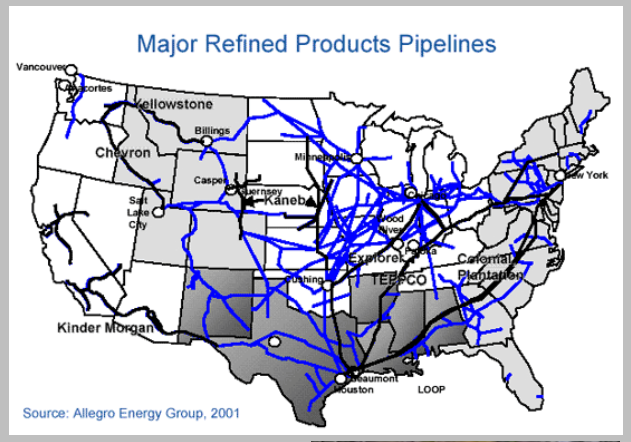
- **Foundational Science:** Enzymes, fermentation, understanding biomass and cell composition
- **Feedstocks**: Sustainable feedstock production systems
- **Pretreatment & Conversion R&D:** Biochemical and thermochemical conversion processes
- **Advanced Biofuels and Algae**: Broadening RD&D beyond cellulosic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

Updated 10/10

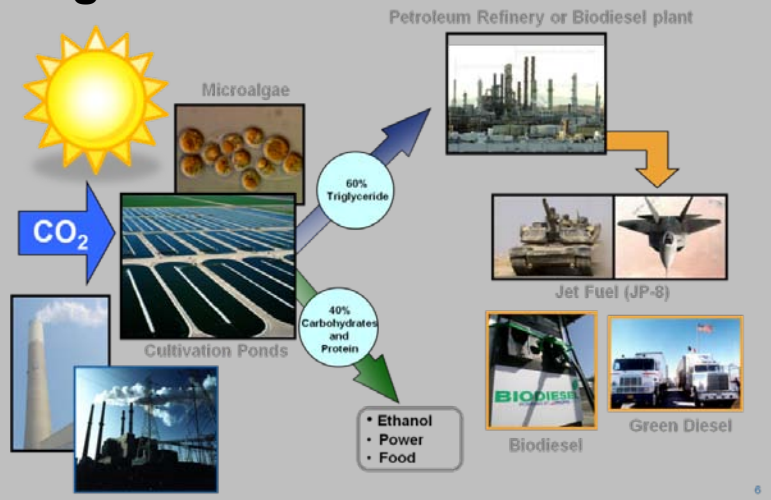
Why Follow-On Generations?

Advanced Biofuels – "beyond ethanol"

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



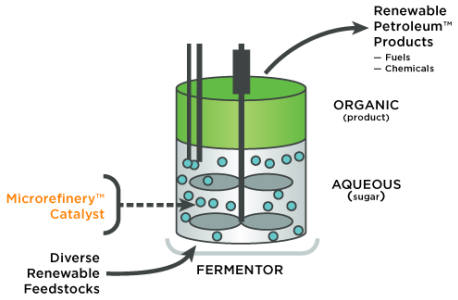
Algae



Innovative Adv Biofuels Processes

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



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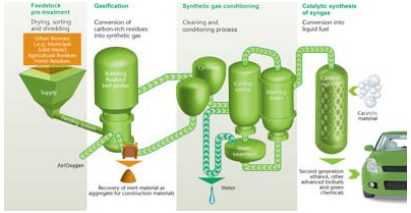
AMYRIS

Chemical Catalytic Conversion



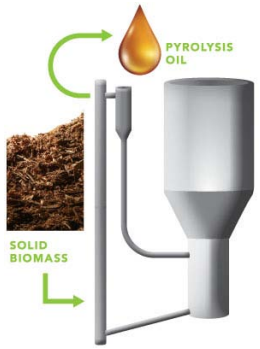
VIRENT
IT'S ABOUT TIME

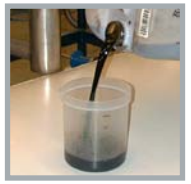
RENTECH®

ClearFuels®
TECHNOLOGY, INC.

Enerkem

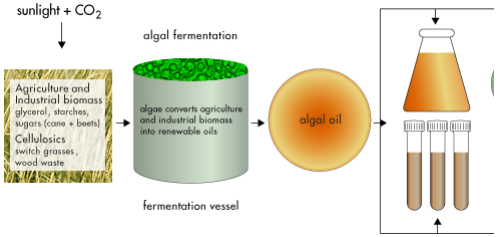
Pyrolysis/Bio-Oil Pathways





Envergent
TECHNOLOGIES
A Honeywell Company

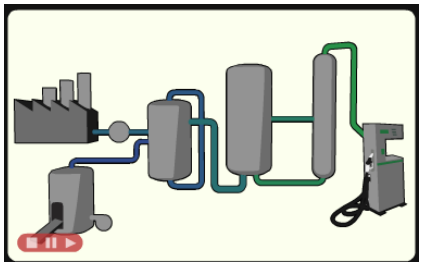
Heterotrophic Algae Conversion



solazyme®

MARTEK
life enriched.™

Hybrid Conversion Technologies



LanzaTech

coskata

Sustainable Transportation

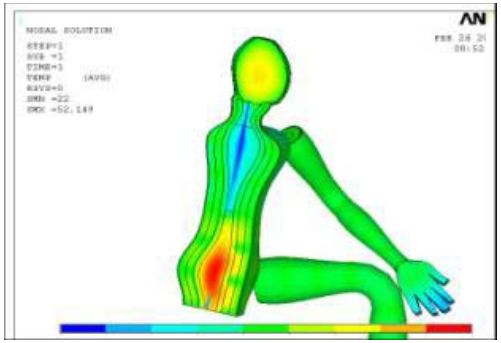
Alternative Vehicles

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

Plug-In Hybrid Electric Vehicles (PHEV)

Status:
- PHEV-only conversion vehicles available
- OEMs building prototypes, and several about to come to showrooms
- NREL PHEV Test Bed

NREL Research Thrusts
- Energy storage
- Advanced power electronics
- Vehicle ancillary loads reduction
- Vehicle thermal management
- Utility interconnection
- Vehicle-to-grid

Key Challenges
- Energy storage – life and cost
- Utility impacts
- Vehicle cost
- Recharging locations
- Tailpipe emissions/cold starts
- Cabin heating/cooling
- ~33% put cars in garage

Updated January 2010

Fuel Cells/Hydrogen

Updated 9/10

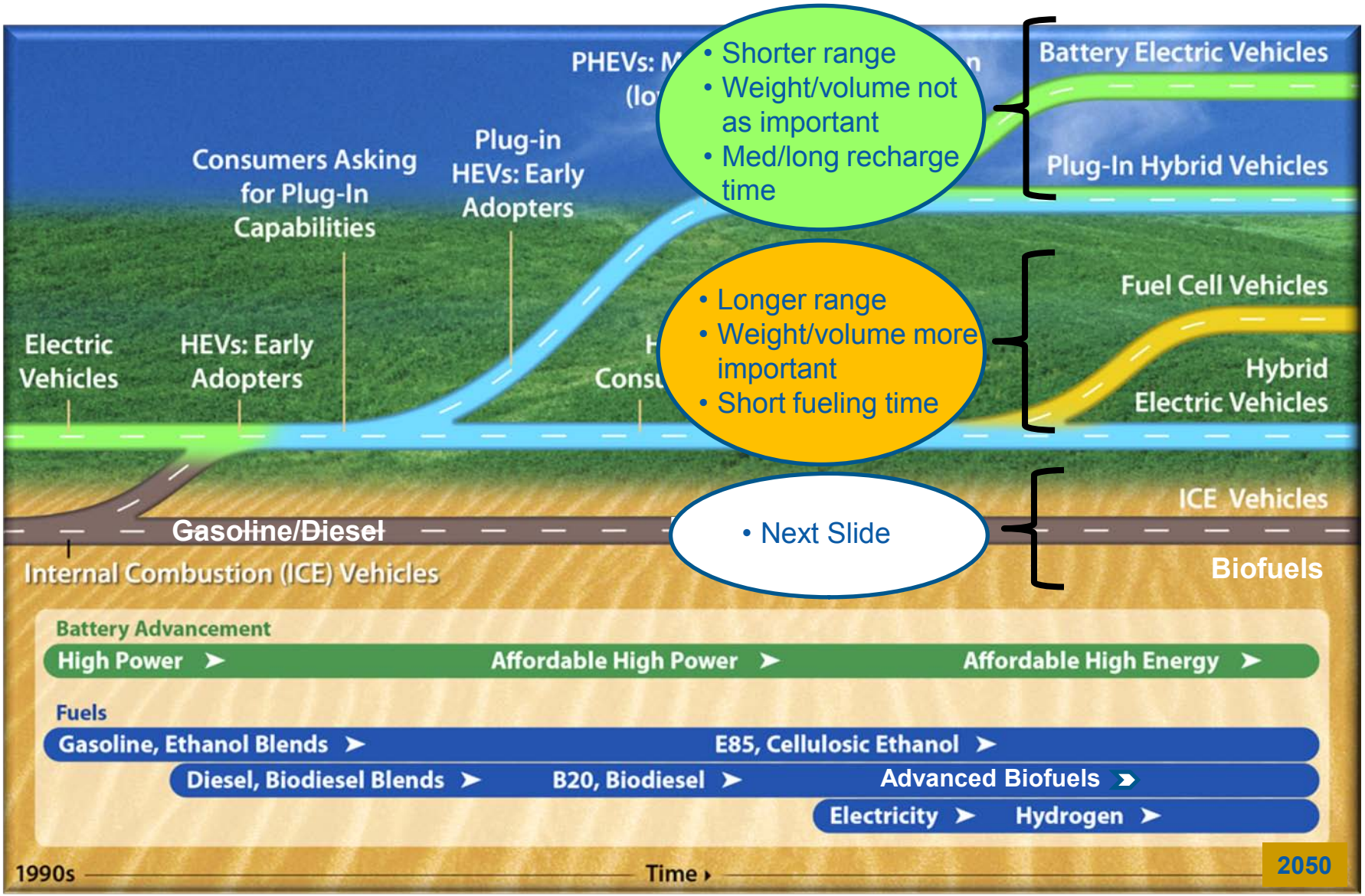
Major Technology Directions

- 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

2050 U.S. Big Picture – Road/Auto & Truck



New Directions

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

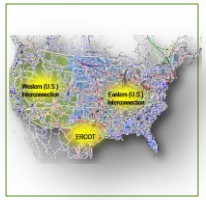
Updated 9/10

Smart Grid is the Key Enabler to Grid Modernization

Renewable Integration – *Addressing variability of large-scale wind and solar generation*

Energy Storage – *Providing regulation and load shaping*

Load Management – *Making consumer demand an active tool in reducing the peak*



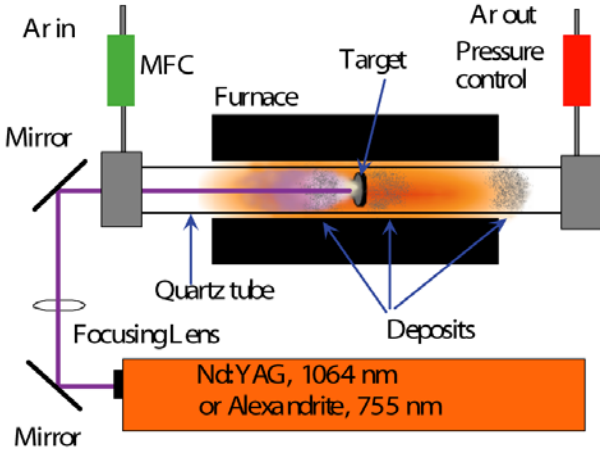
System Transparency – *Seeing and operating the grid as a national system in real-time*

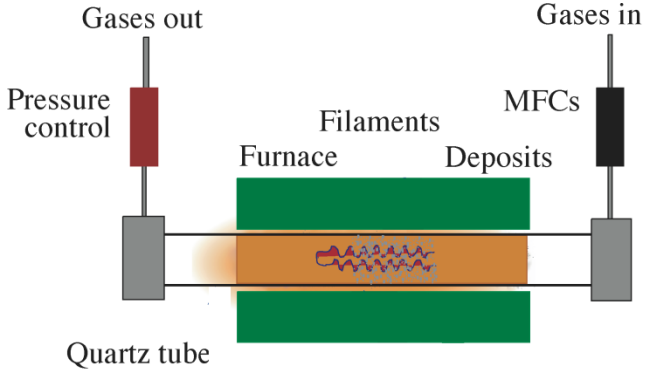
Cyber Security and Physical Security –*Securing the physical infrastructure and two-way communication and data exchange*

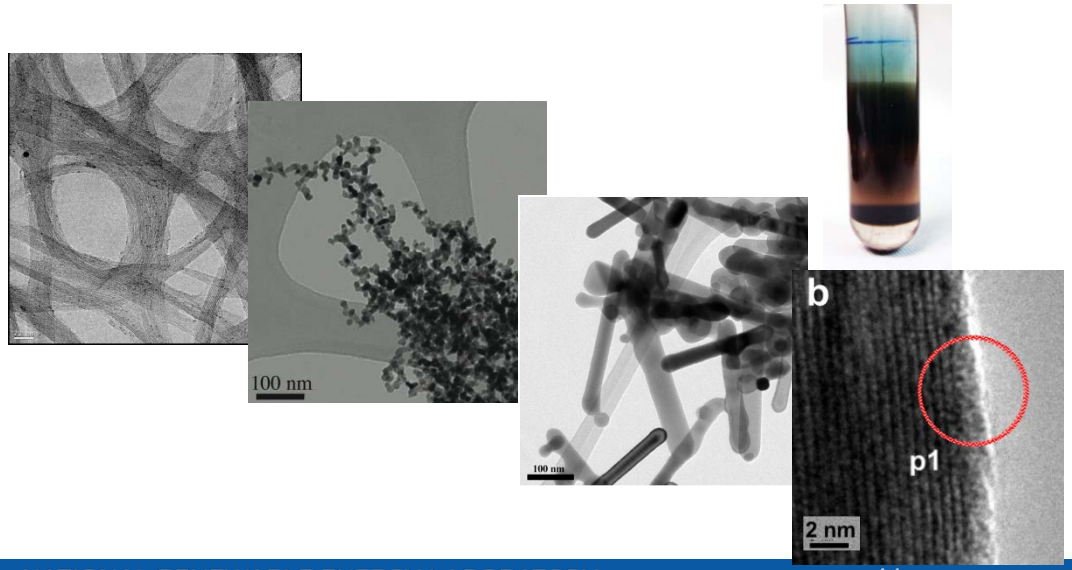
Nanostructured Materials Development for Renewable Energy and Energy Efficiency

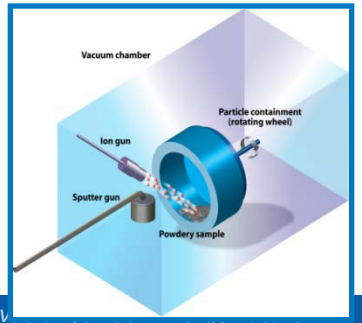
State-of-the-art synthesis and characterization to create novel materials for a range of energy related applications for EERE programs

- **Batteries:** develop novel electrolytes and metal oxides for cathodes and anodes
- **Thermal storage:** nanofluids and phase change materials
- **Hydrogen storage**
- **Electrochromic** Windows
- **Fuel Cells:** develop novel electrolytes and catalysts

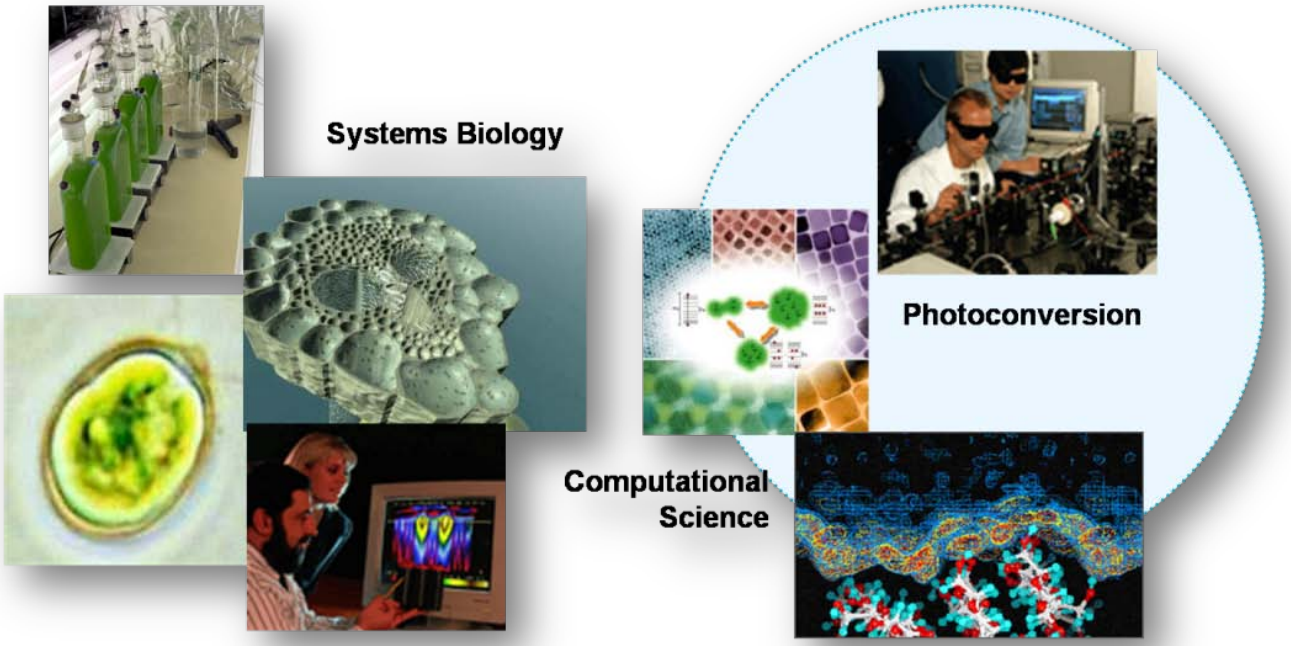








Commitment to Breakthrough Innovation



Managing the science-to-technology interface

Making Transformational Change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