NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Innovation in the Energy Sector: the Role of Energy Efficiency & Renewable Energy

NSF CMMI Research and Innovation Conference 2011

January 5, 2011

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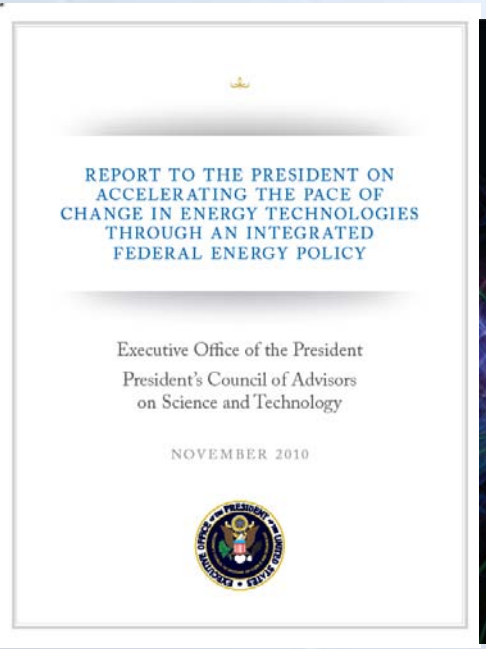
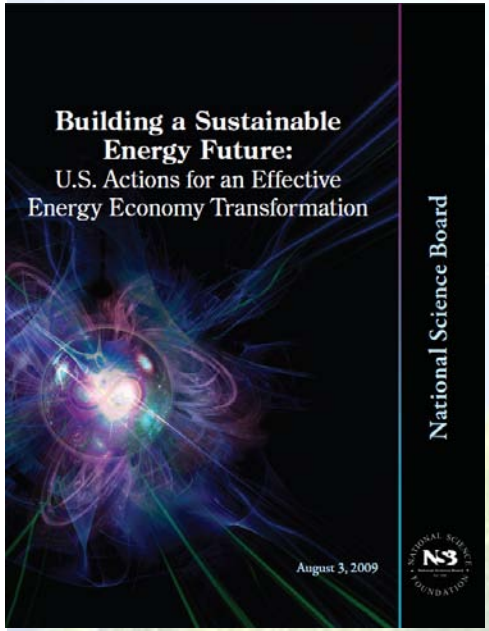
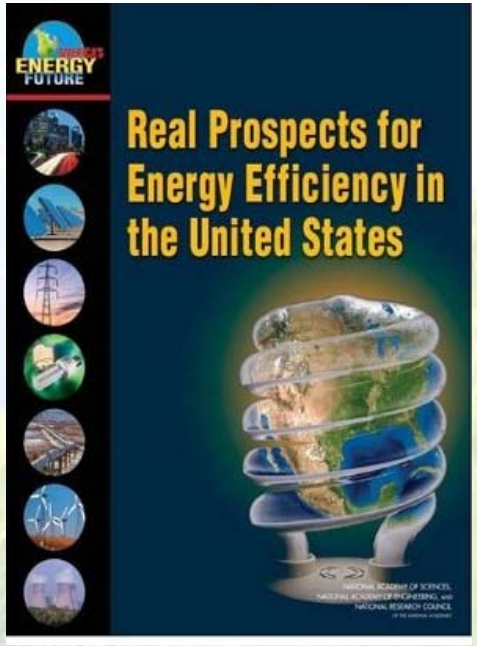
Laboratory Director

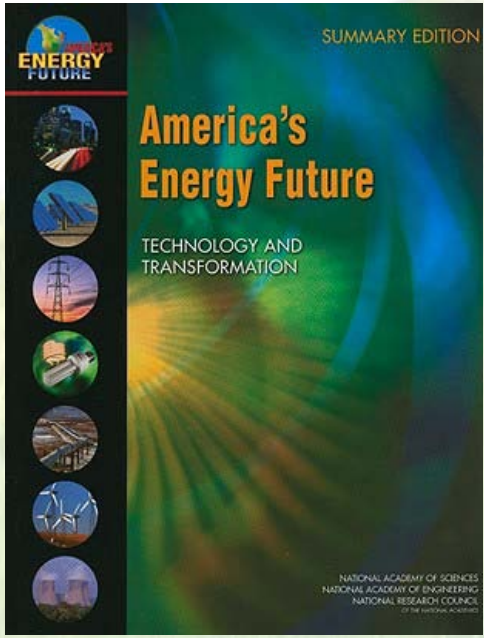
Energy Challenges

Consensus…





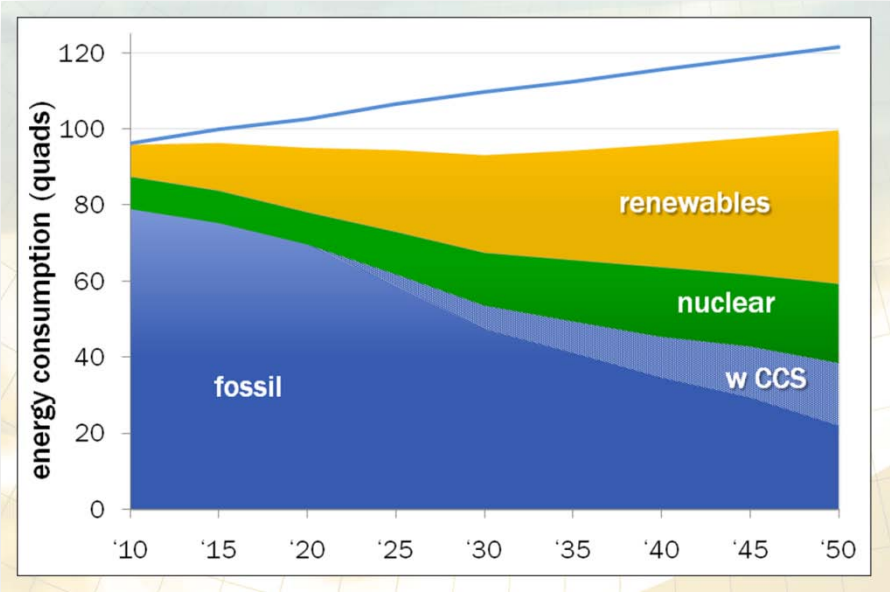




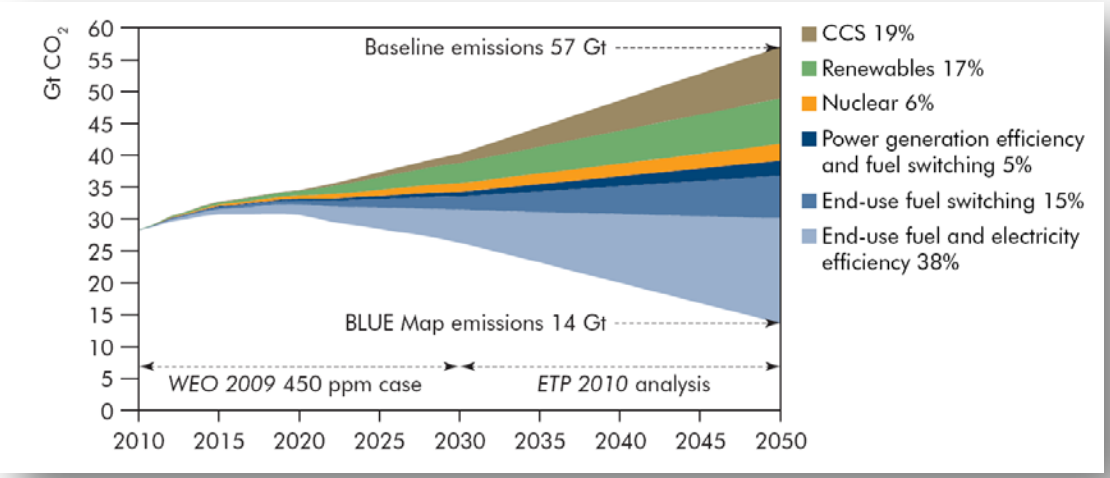
- ***Increase R&D Investment***
- ***Align Public Policy with Nat'l Priorities***
- ***Accelerate Adoption and Diffusion***

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 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

Reaching This Goal Will Require a Sustainable Energy System

Community & Industrial Systems

Integrated Systems
Sustainable Design

The Built Environment

Highly Efficient •
Integrated Renewables

Transportation Systems

Highly Efficient • Fuel Flexible

Distributed & Utility-Scale Renewable Power

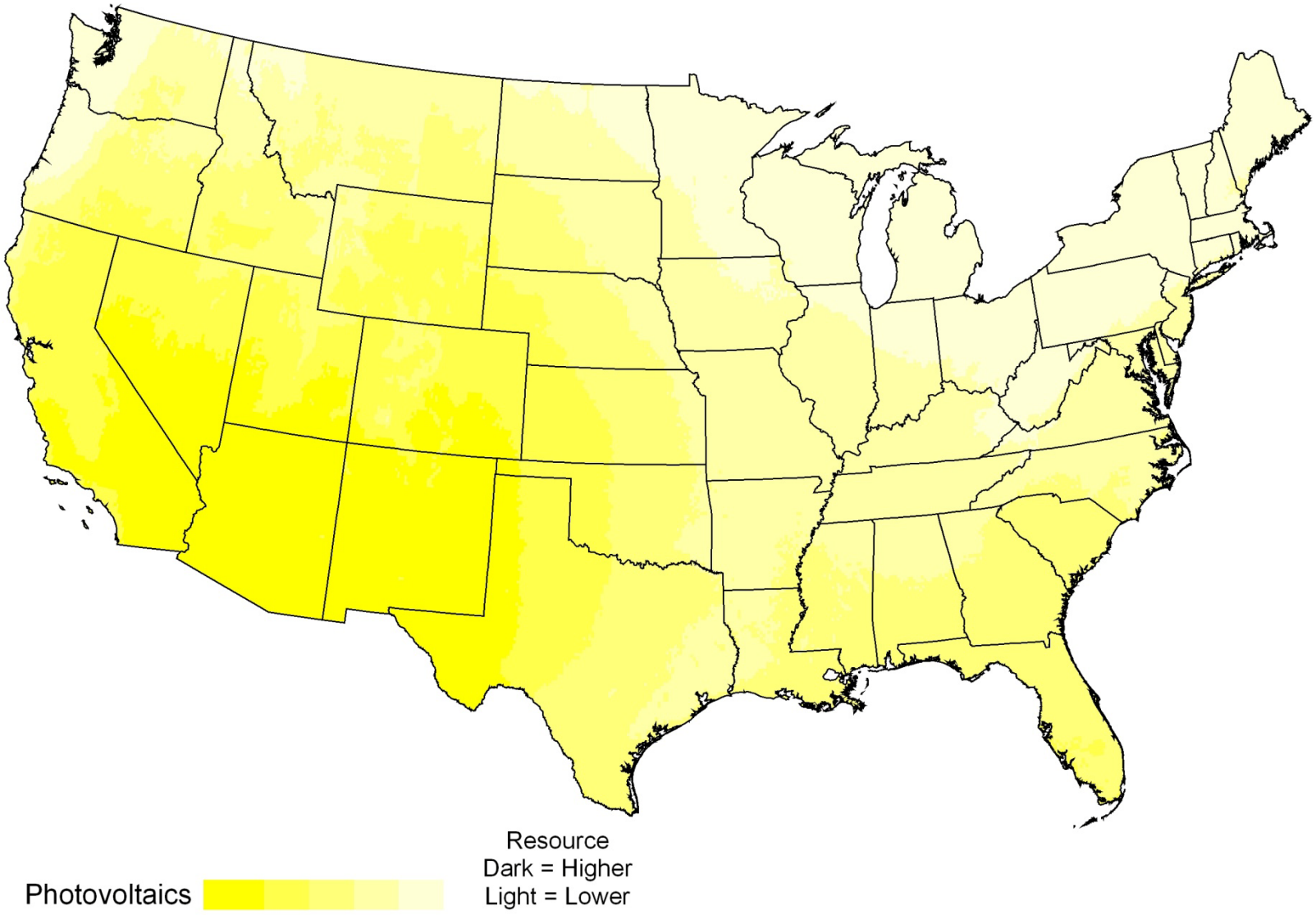
Electricity Generation & Delivery Systems

Renewable Fuels

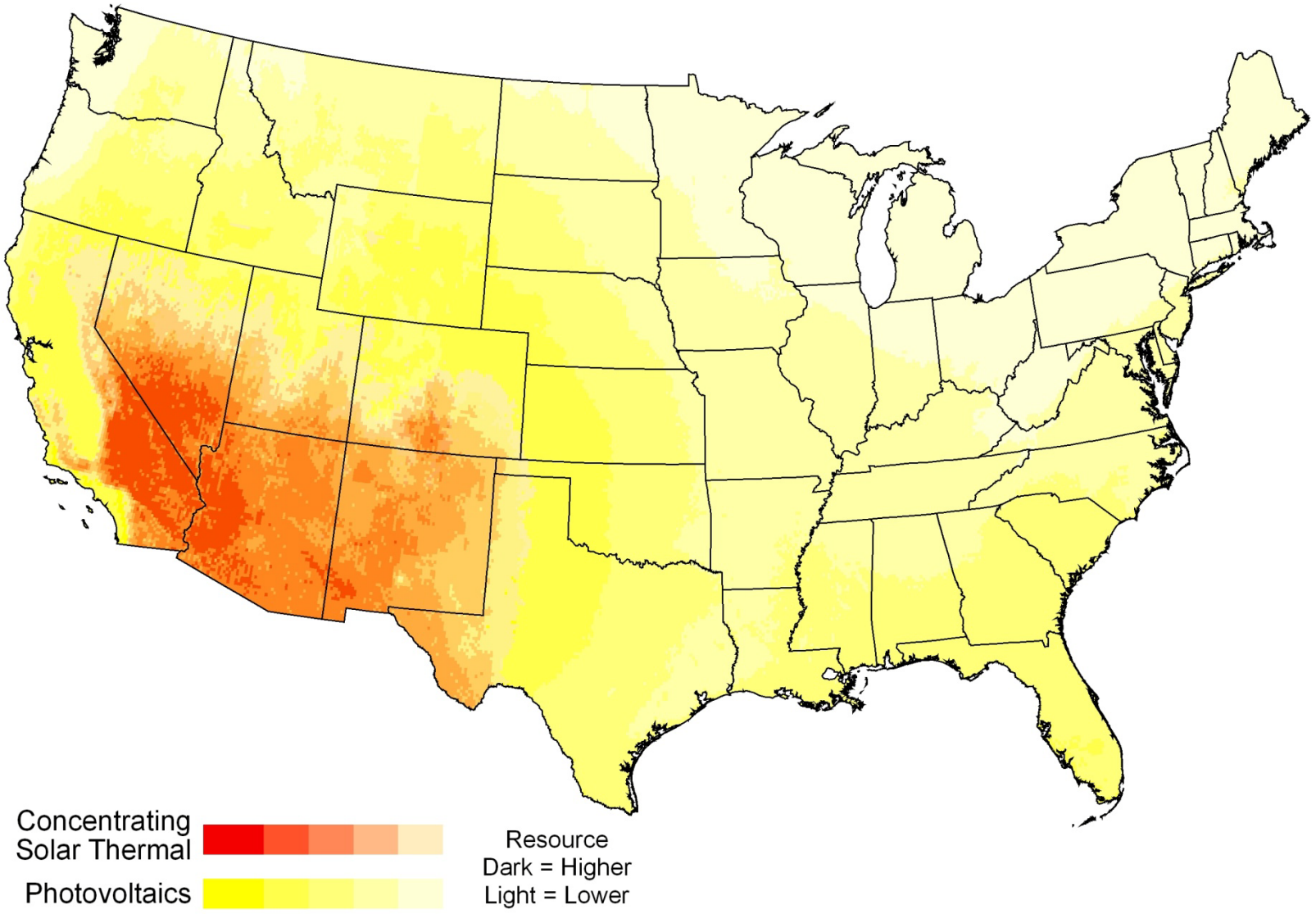
Fuel Production Systems

Renewable Energy Innovation

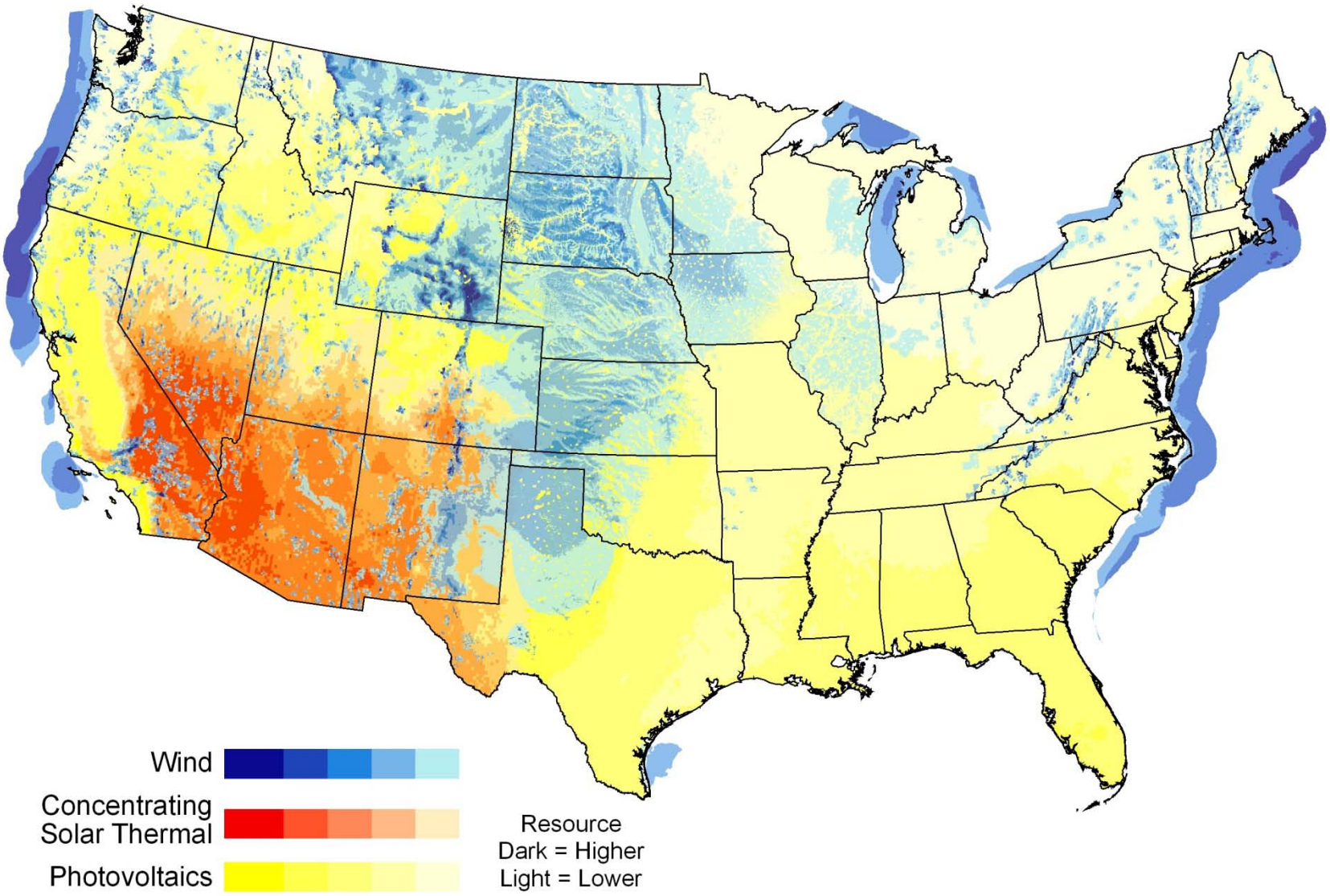
U.S. Renewable Resources



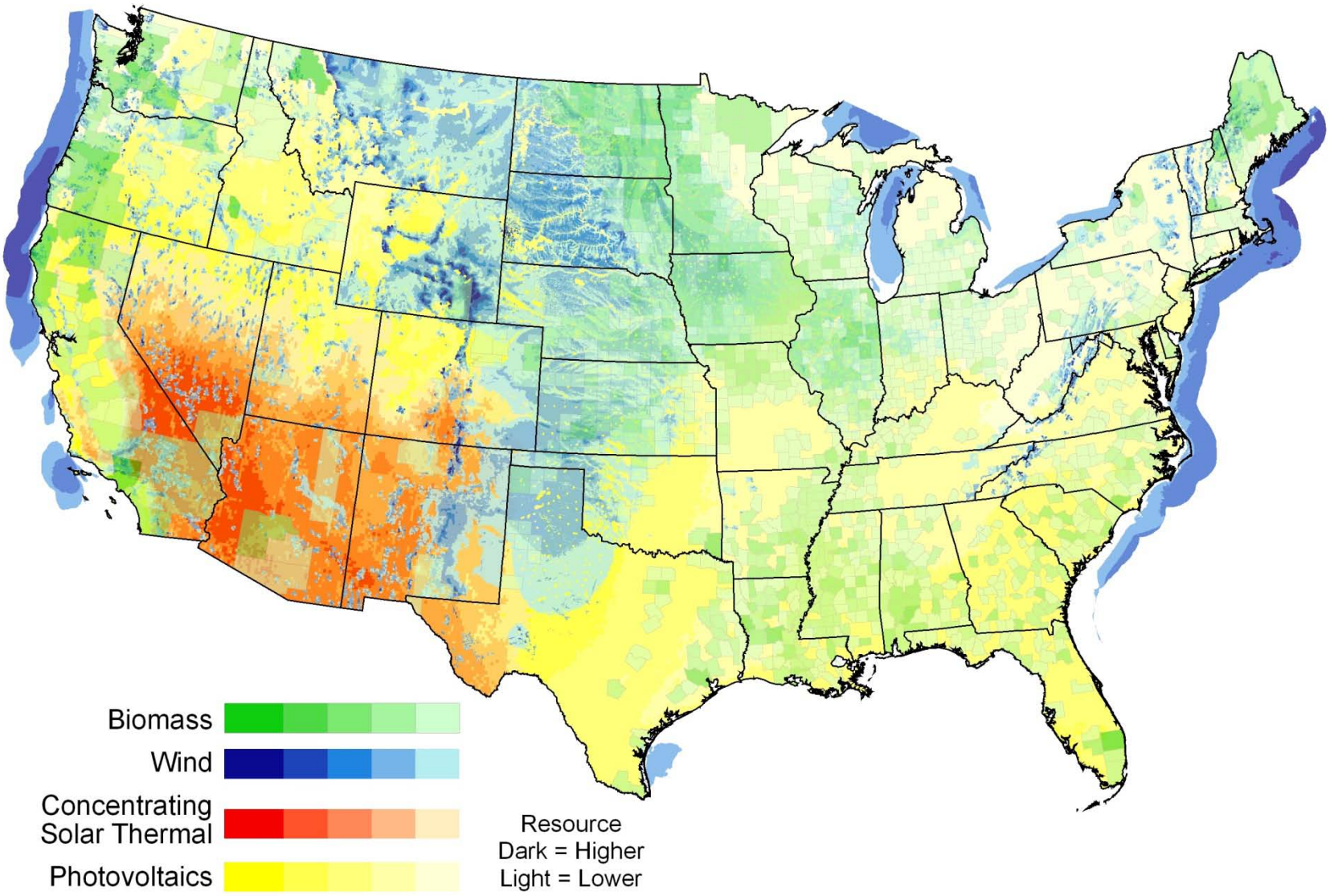
U.S. Renewable Resources



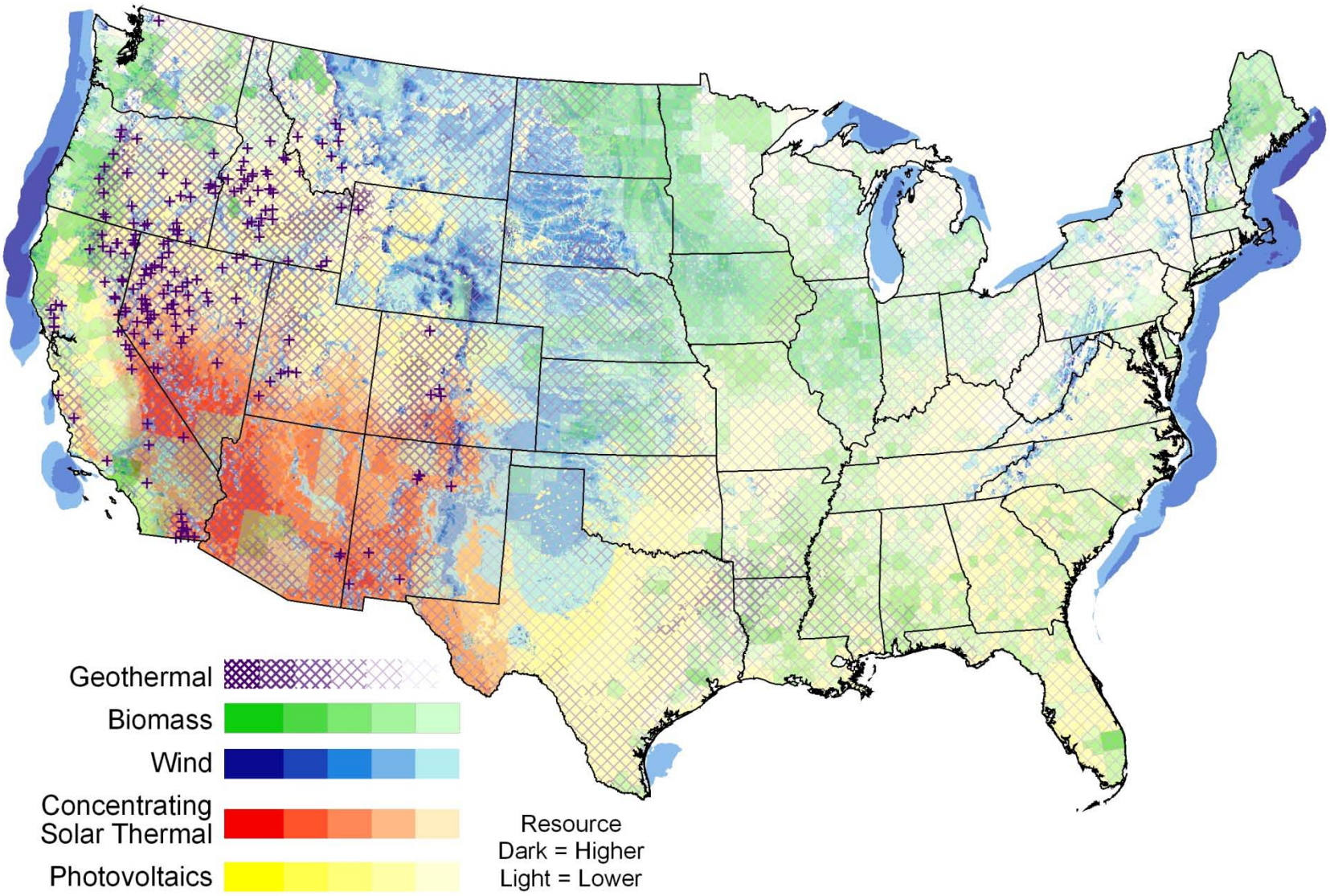
U.S. Renewable Resources



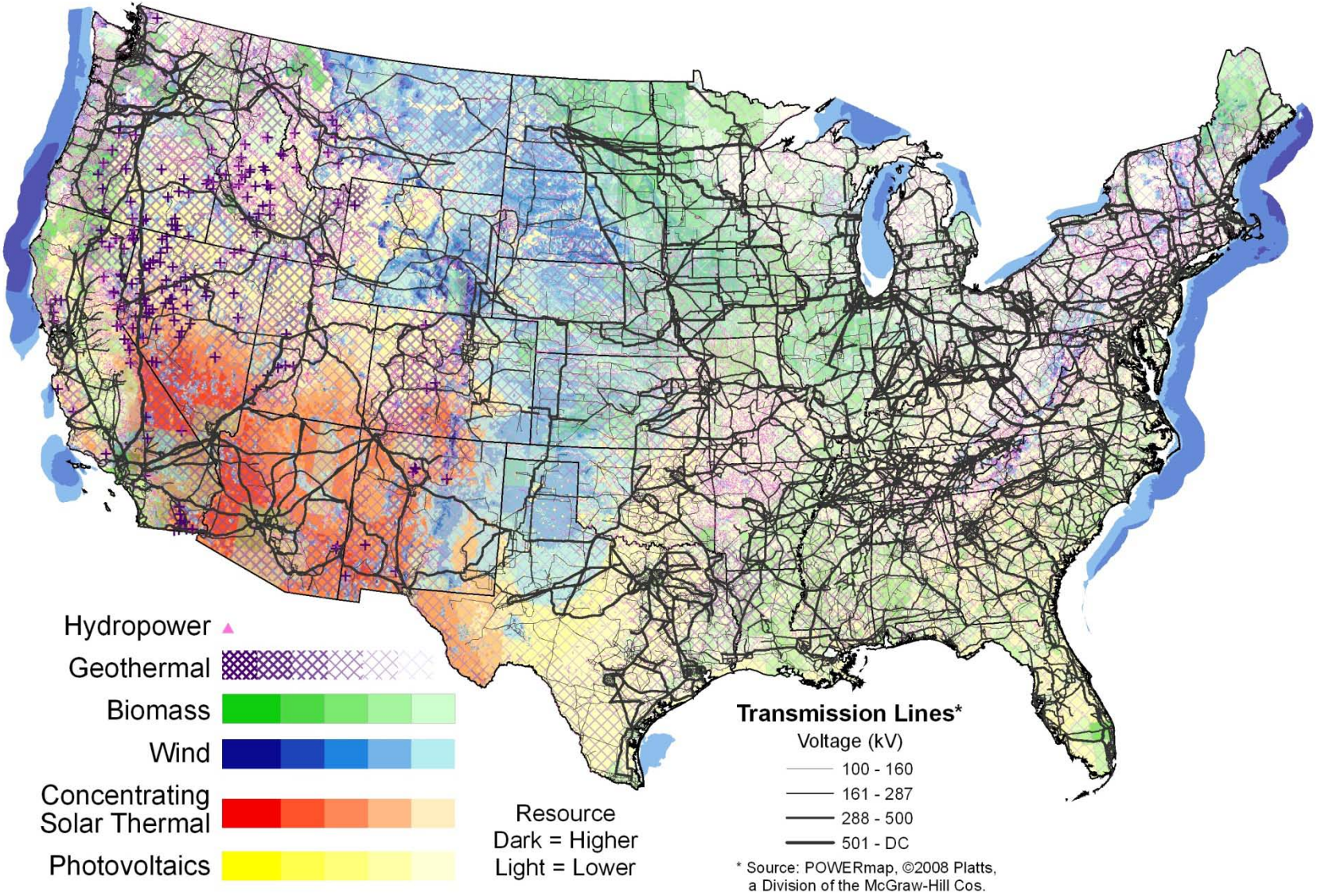
U.S. Renewable Resources



U.S. Renewable Resources

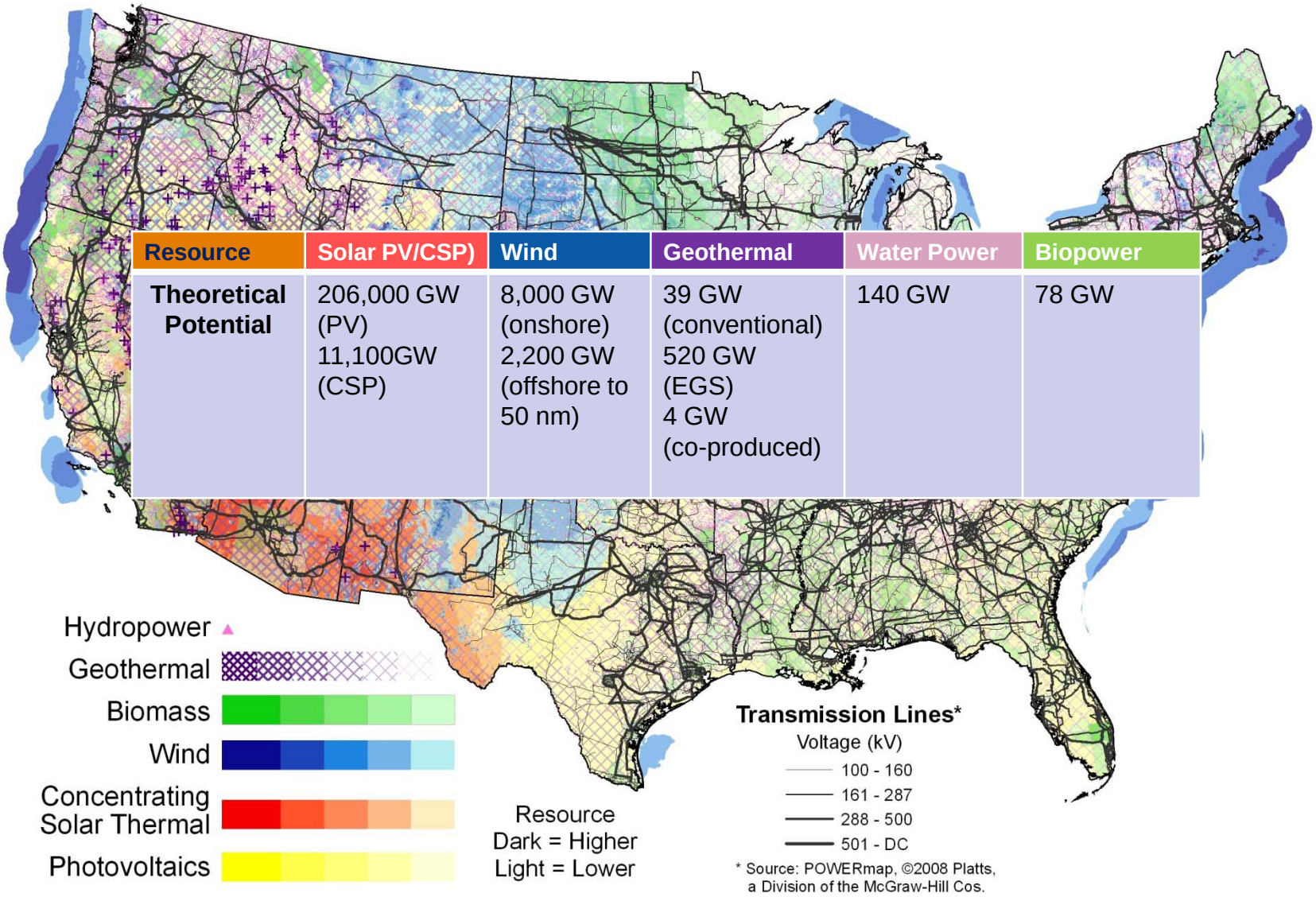


U.S. Renewable Resources



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



A Decade of Real Progress

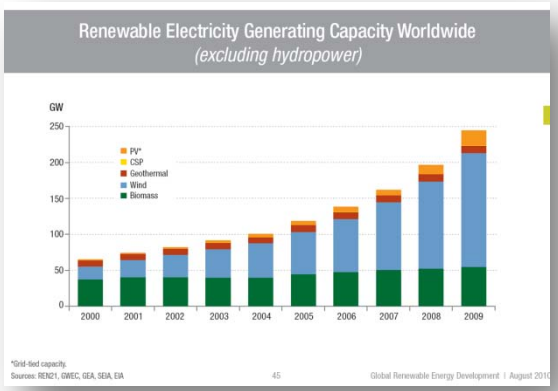
Wind power increased from **1,000 MW to 10,000 MW/year**

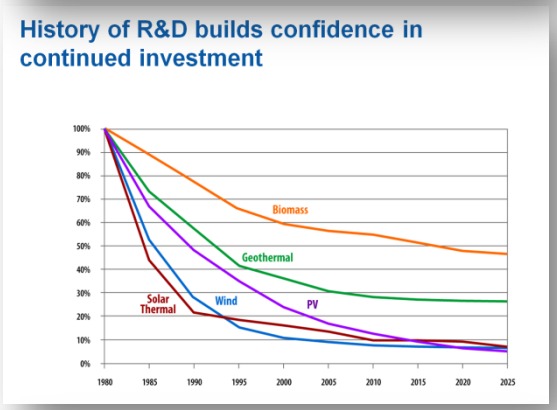
Solar PV went from **25 MW to 500 MW/year**

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.





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

Buildings Innovation

High Performance Buildings

BIPV Products & PV-T Array

Compressorless Cooling

Electrochromic Windows

Polymer Solar Water Heaters

Computerized optimization & simulation Tools

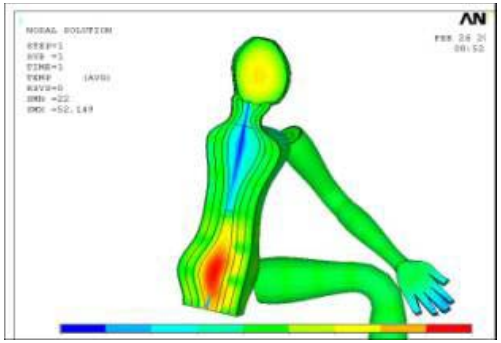
Advanced Vehicles

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

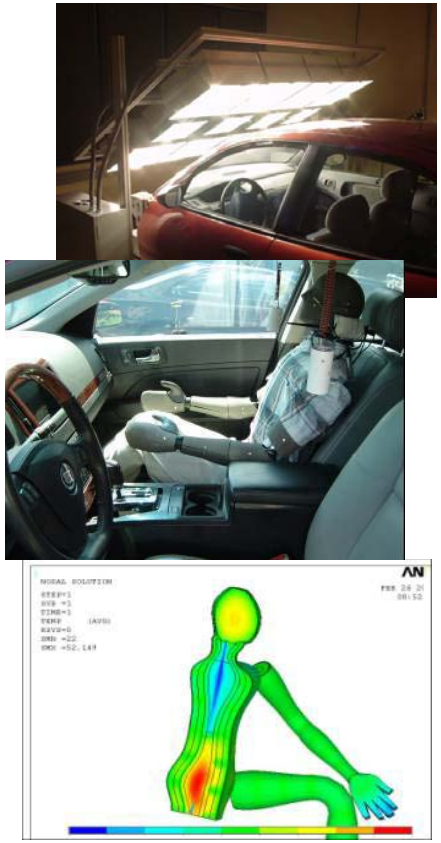
Advanced Vehicles Innovation

Energy Storage

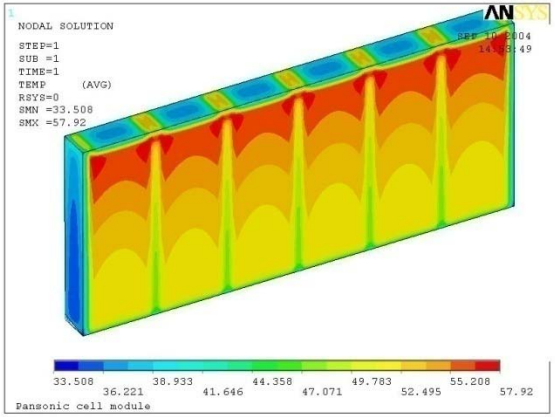
Batteries & UltraCaps

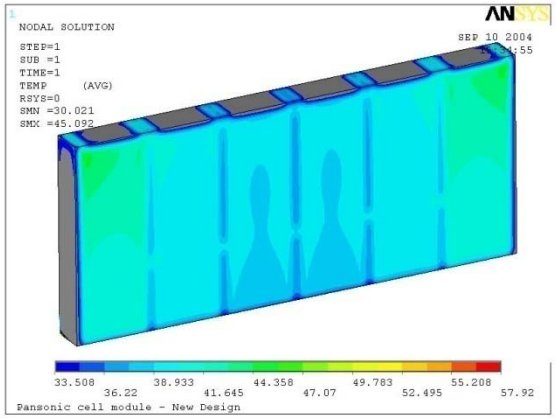
Advanced Power Electronics

Vehicle Ancillary Loads Reduction



Before → **After**





Wind Energy

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

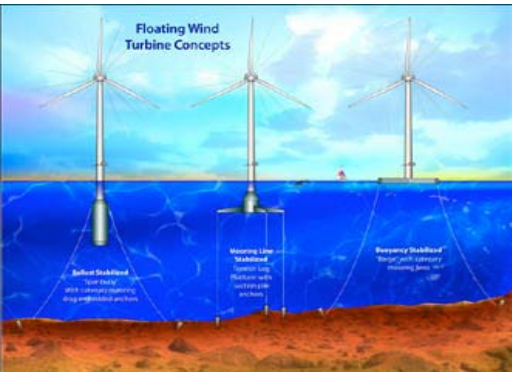
- Utility-scale, low-wind-speed, land-based, Class 4 wind regimes– reduce unsubsidized cost to 8.0 cents/kWh
- Shallow water, offshore, Class 6 wind regimes—reduce unsubsidized cost to 13.0 cents/kWh.

Major Technology Directions

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

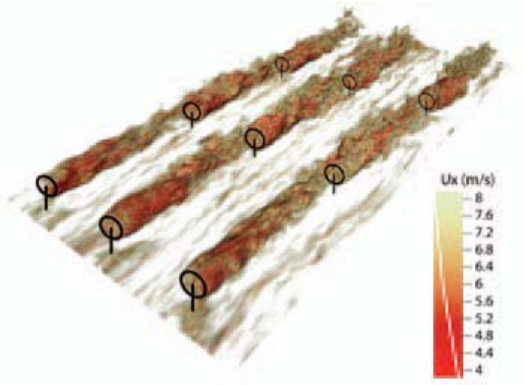
Updated 10/10

Wind Innovation



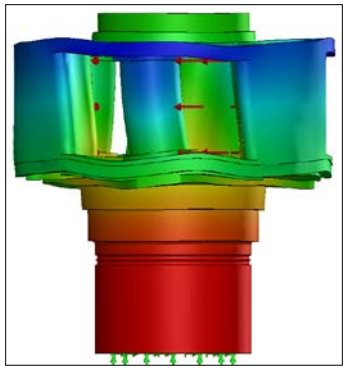
What: New complex modeling and analysis tool for offshore floating wind turbine concepts.

Impact: Will enable wind turbine designers to develop competitive offshore technologies capable of harvesting the vast offshore wind resources found farther from shore.



What: High-fidelity large-eddy simulation model that predicts the performance of large wind plants with a high degree of accuracy.

Impact : Will increase the performance of large wind plants, reduce the cost of wind energy, and save wind plant developers millions of dollars in lost revenue.



What: Improve gearbox reliability and find process gaps.

Impact : Will provide industry with broad analytical and reliability testing for optimum compliant wind turbine designs, saving money and increasing capacity.

Solar Energy

Solar Energy

Current U.S. Status:

Photovoltaics

- 1,677 MW installed solar photovoltaic (PV) capacity
- Cost 16.5¢/kWh*

Concentrating Solar Power

- 431 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 manufacturing 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

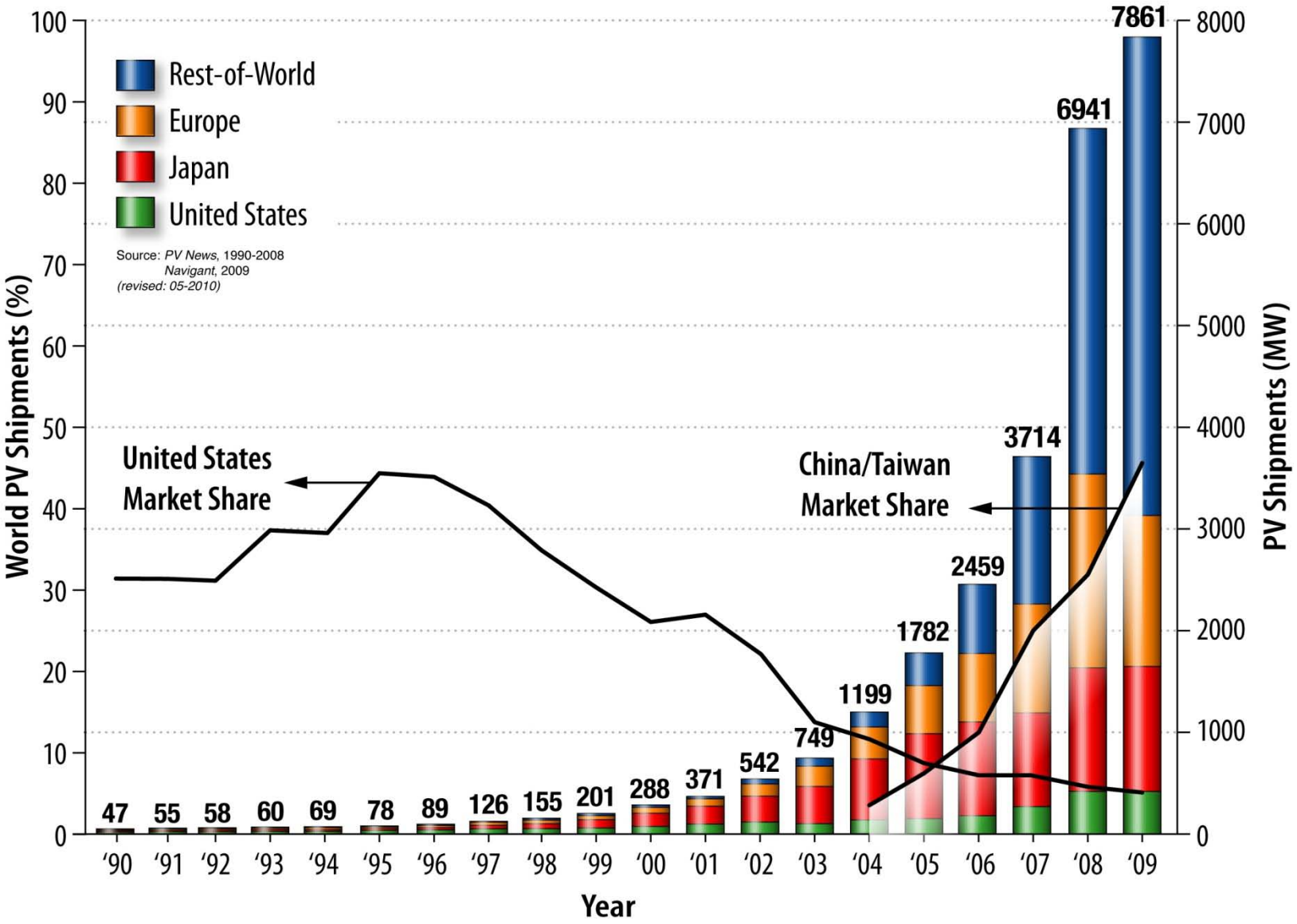
Grid integration, systems performance and reliability

Updated 1/11

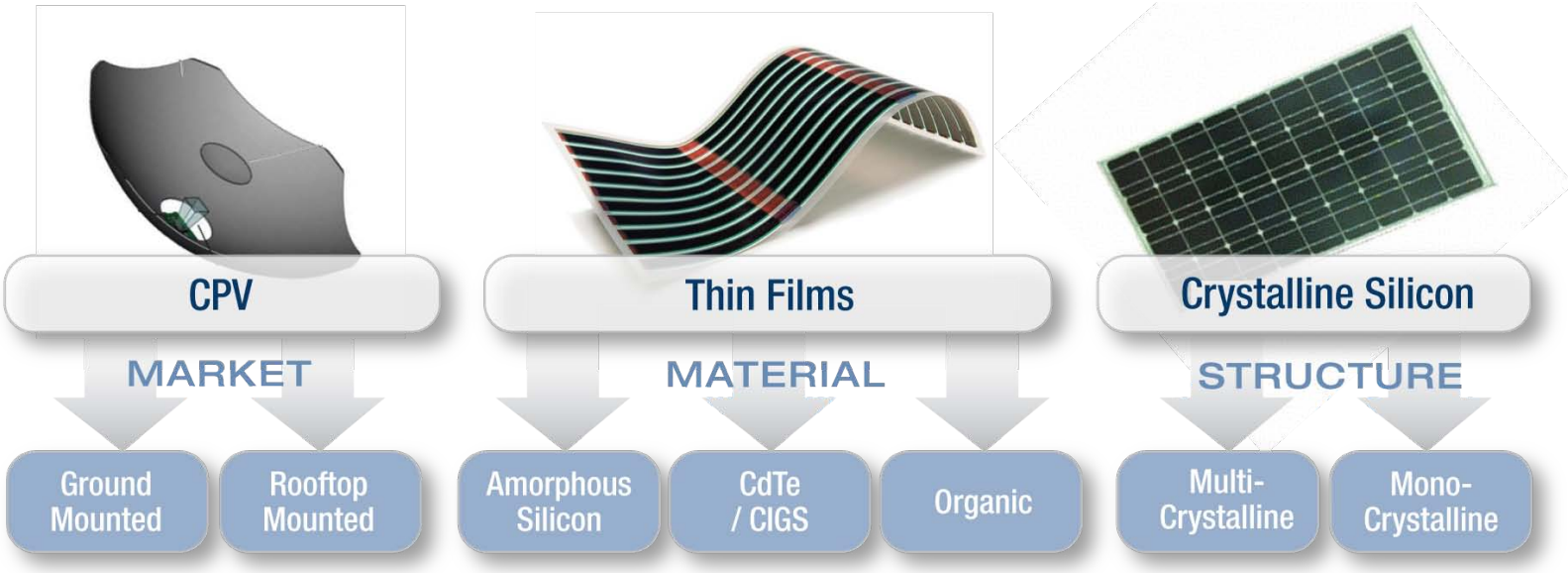
*Source: Navigant Consulting Inc, July 2010. Assumes federal & state incentives.

**CSP assumes trough technology.

Manufacturing Shifts to Asia

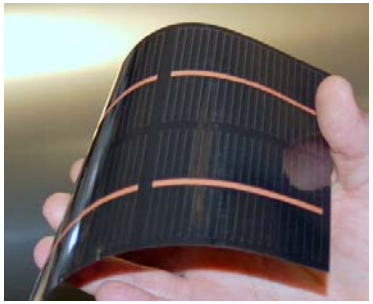


Pursuing a Range of Promising PV Technologies

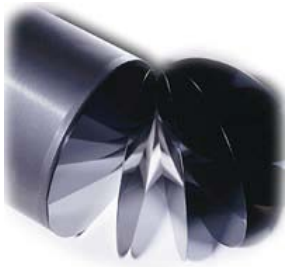


20x-100x

500x



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

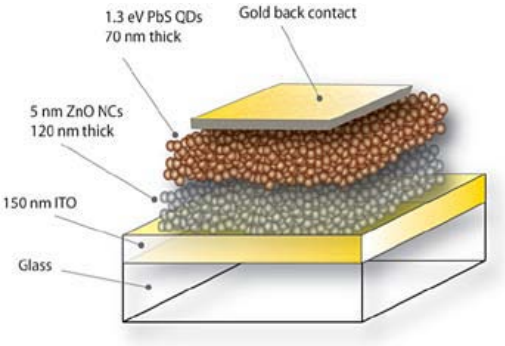


c-Si ~ 180 um

Solar Innovation

What: Improved Transparent Conducting Oxides Boost Performance of Thin-Film Solar Cells

Impact: These coatings improve the commercial prospects of thin-film PV.



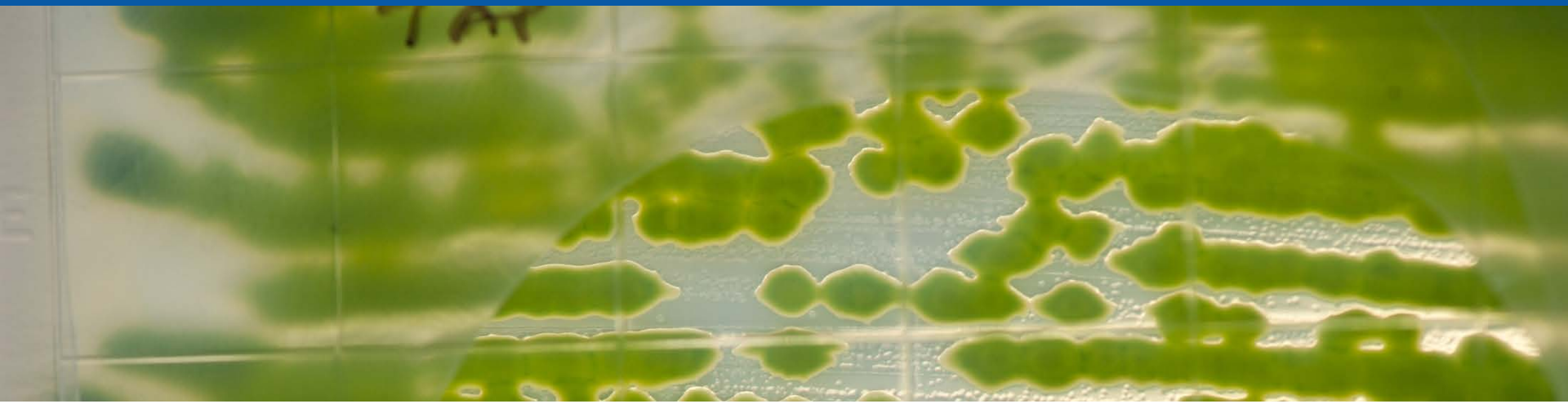
What: First All Quantum Dot Photovoltaic Cell; Demonstrates Stability, Performance in QDs

Impact : The two-electrons-from-one-photon bonus exhibited by a stable quantum dot device could lead to a dramatic increase in the conversion efficiency into electricity in solar cells.

What: Using thin-film PV to generate lower-cost PV electricity (in dollars per watt).

Impact : Development of cadmium telluride (CdTe) and other thin-film photovoltaic (PV) technologies will enable the U.S. to capture a significant share of the worldwide PV market.

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

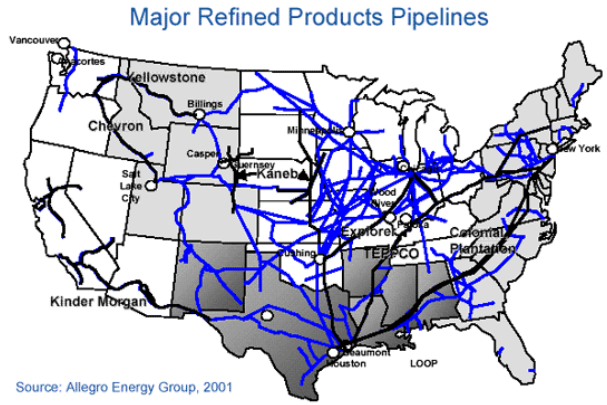
Cost goal:
Cellulosic ethanol—cost parity with gasoline by 2012

Major Technology Directions:

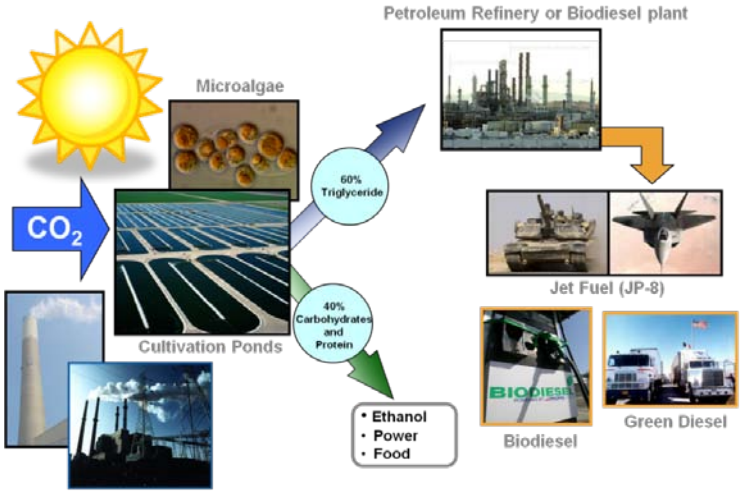
- **Foundational Science:** Enzymes, fermentation, understanding biomass and cell composition
- **Feedstocks**: Sustainable feedstock production systems
- **Pretreatment & Conversion R&D:** Biochemical and thermochemical conversion processes
- **Advanced Biofuels and Algae**: Broadening RD&D beyond cellulosic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

Updated 10/10

Why Follow-On Generations?



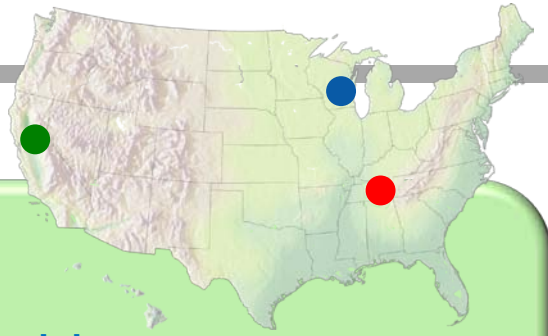
Algae



Advanced Biofuels – "beyond ethanol"

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

Bioenergy Research Centers



University of Wisconsin

GLBRC
Great Lakes Bioenergy Research Center

- Plant fiber breakdown
- Increase plant production of starches and oils
- Biofuels sustainability

Lawrence Berkeley National Laboratory

jbei
Joint BioEnergy Institute

- "Model" crops of rice and *Arabidopsis*,
- Microbial-based synthesis of fuels beyond ethanol.

Oak Ridge National Laboratory

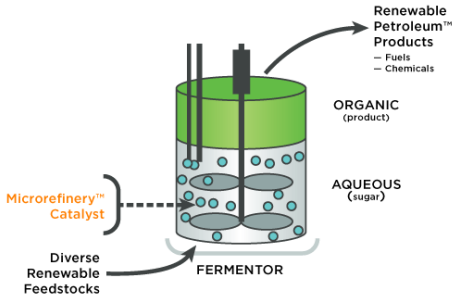
BESC
BioEnergy Science Center

- Resistance of plant fiber to breakdown into sugars
- Potential energy crops poplar and switchgrass.

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



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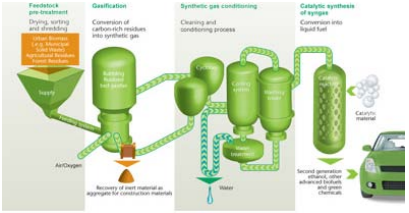
AMYRIS

Chemical Catalytic Conversion



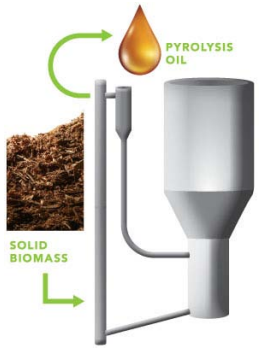
VIRENT
IT'S ABOUT TIME

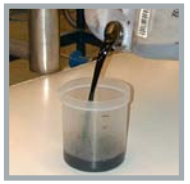
RENTECH®

ClearFuels®
TECHNOLOGY, INC.

Enerkem

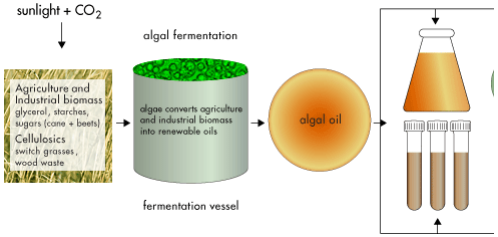
Pyrolysis/Bio-Oil Pathways





Envergent
TECHNOLOGIES
A Honeywell Company

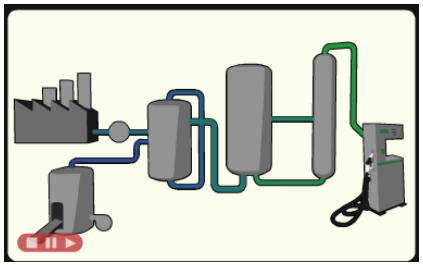
Heterotrophic Algae Conversion



solazyme®

MARTEK
life enriched.™

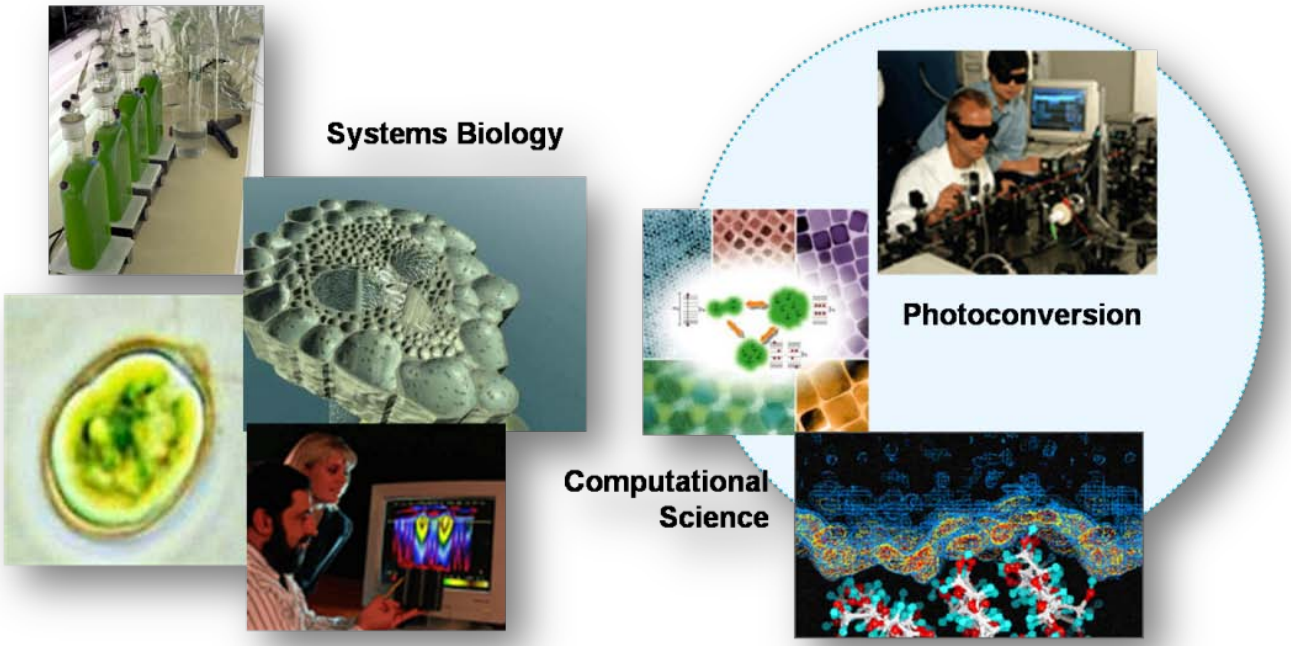
Hybrid Conversion Technologies



LanzaTech

coskata

Commitment to Breakthrough Innovation



Managing the science-to-technology interface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