Energy Efficiency & Renewable Energy: Challenges, Opportunities, Impacts

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Understanding Federal R&D Impact
Thomson-Reuters
Washington, DC
March 19, 2013

Overview

Challenges

- **Economy**—economic development and growth; energy imports
- **Security**—foreign energy dependence, energy availability
- **Environment**—local (particulates, water), regional (acid rain), global (GHGs)

What role can EE & RE serve in meeting these Challenges?

- Efficiency: Buildings, Industry, Transport
- Renewable Fuels
- Renewable Electricity

What role can Evaluation serve?

- Peer Review
- Impact Evaluation

Speed and Scale

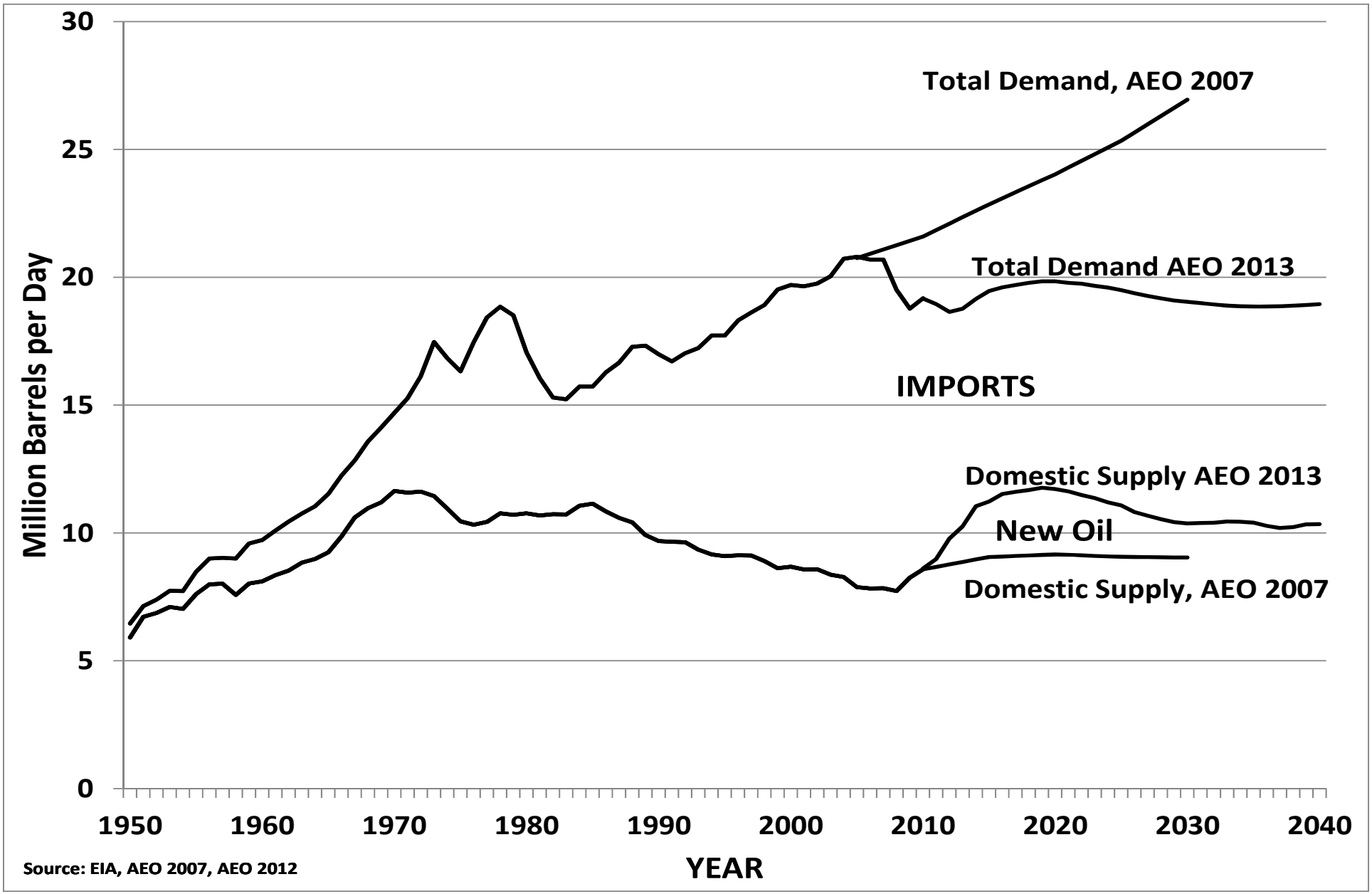
The Oil Problem

Nations that **HAVE** oil (% of Global Reserves*)	
Saudi Arabia	26%
Iraq	11
Kuwait	10
Iran	9
UAE	8
Venezuela	6
Russia	5
Mexico	3
Libya	3
China	3
Nigeria	2
U.S.	**2**

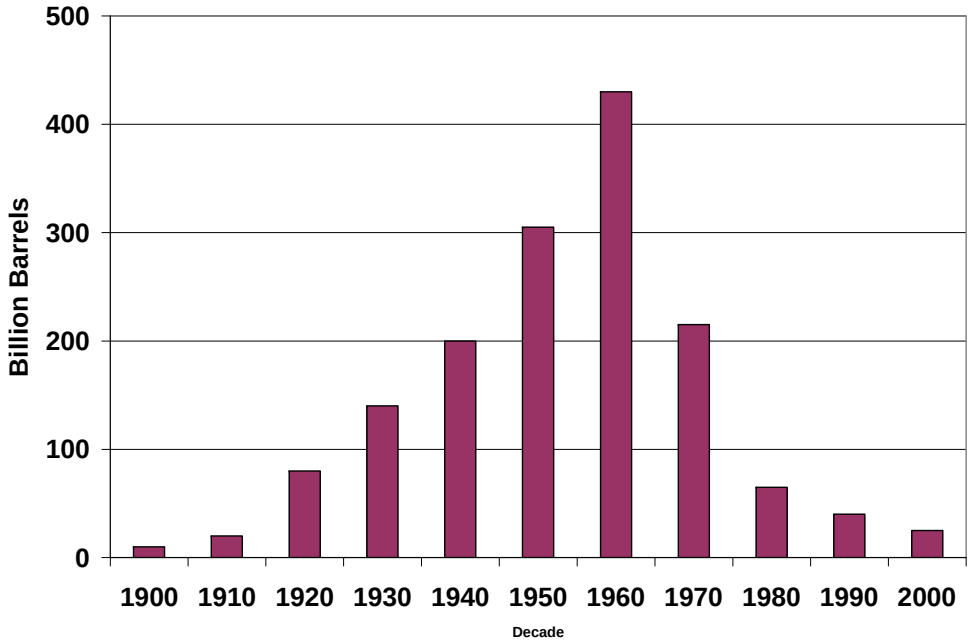
Nations that **NEED** oil (% of Global Consumption)	
U.S.	**24. %**
China	8.6
Japan	5.9
Russia	3.4
India	3.1
Germany	2.9
Canada	2.8
Brazil	2.6
S. Korea	2.6
Mexico	2.4
France	2.3
Italy	2.0
Total	85 MM Bbl/day

Source: EIA International Energy Annual; *Conventional Oil

Oil Supply and Demand?

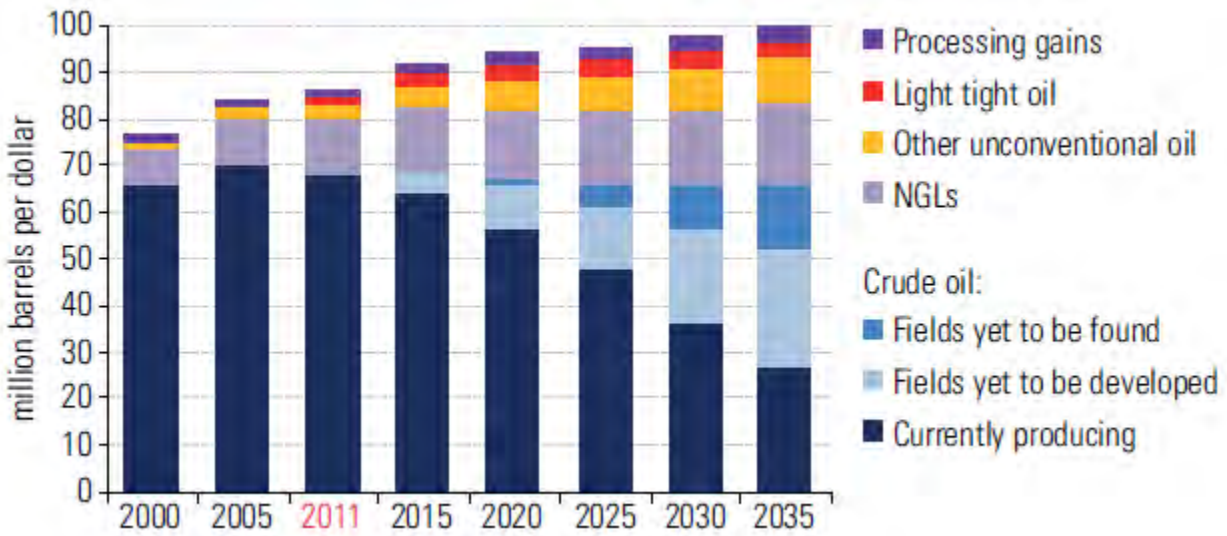


Resources and Supply Projections

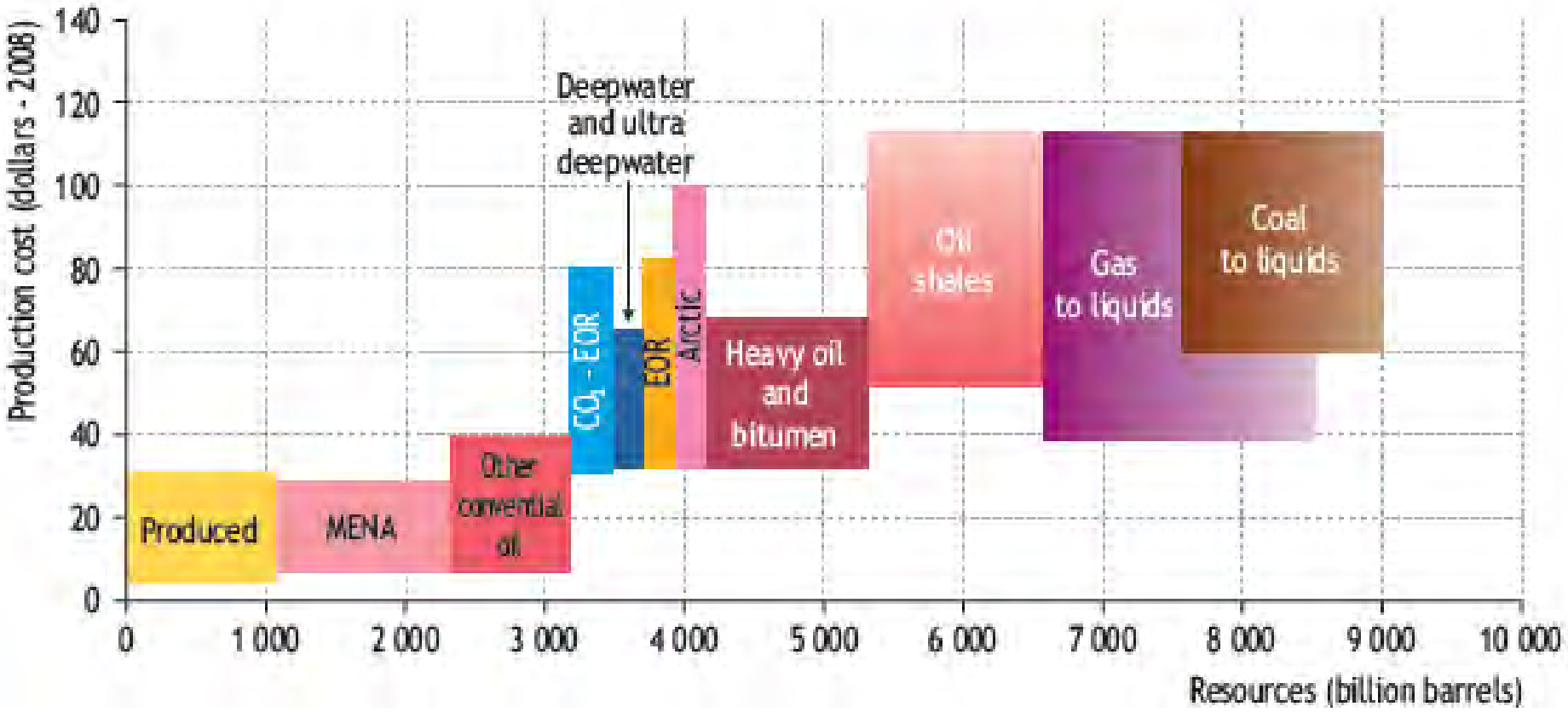


Discovery of Giant Oil Fields by Decade
Fredrik Robelius, Uppsala Universitet

New oil supply by type in the new policies scenario
IEA World Energy Outlook 2012, Fig. 3.15



Unconventional Resources

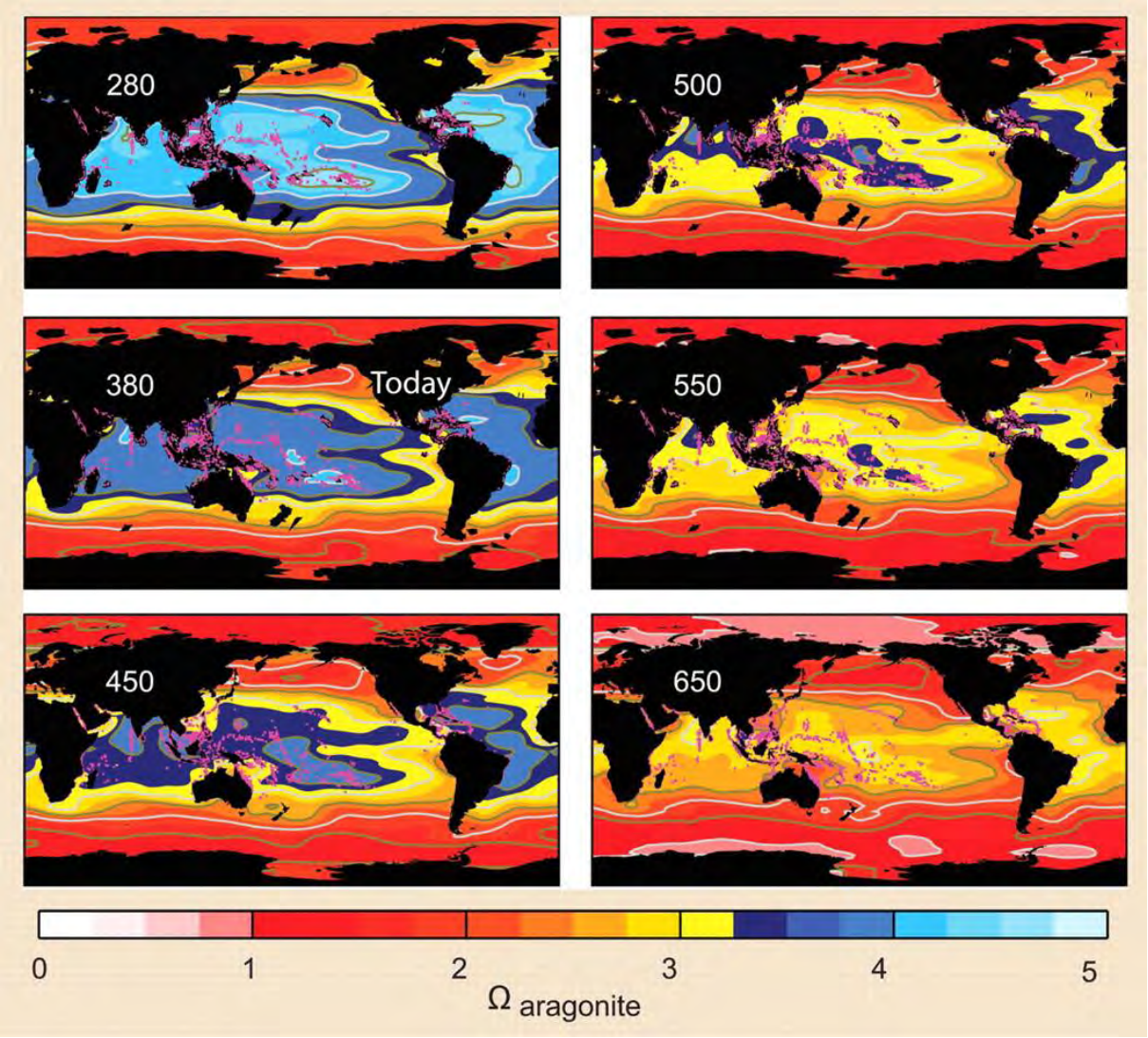


- **Constraints: Cost; Energy; Water; Atmosphere**

Source: IEA, World Energy Outlook 2008, part B, Figure 9.10

Potential Impacts of GHG Emissions

- **Temperature Increases**
  - **Ice Loss from Glaciers, Ocean Thermal Expansion, and Sea Level Rise**
  - **Ecological Zone Shifts … and Extinctions**
  - **Agricultural Zone Shifts … and Productivity**
- **Ocean Acidification**
- **Precipitation Changes and Water Availability**
  - **Agricultural Productivity**
  - **Wildfire Increases**



Source: Hoegh-Guldberg, et al, Science, V.318, pp.1737, 14 Dec. 2007

Inter-Academy Panel Statement On Ocean Acidification
1 June 2009

- **Signed by the National Academies of Science of 70 nations:**
  - Argentina, Australia, Bangladesh, Brazil, Canada, China, France, Denmark, Greece, India, Japan, Germany, Mexico, Pakistan, Spain, Taiwan, U.K., U.S…..

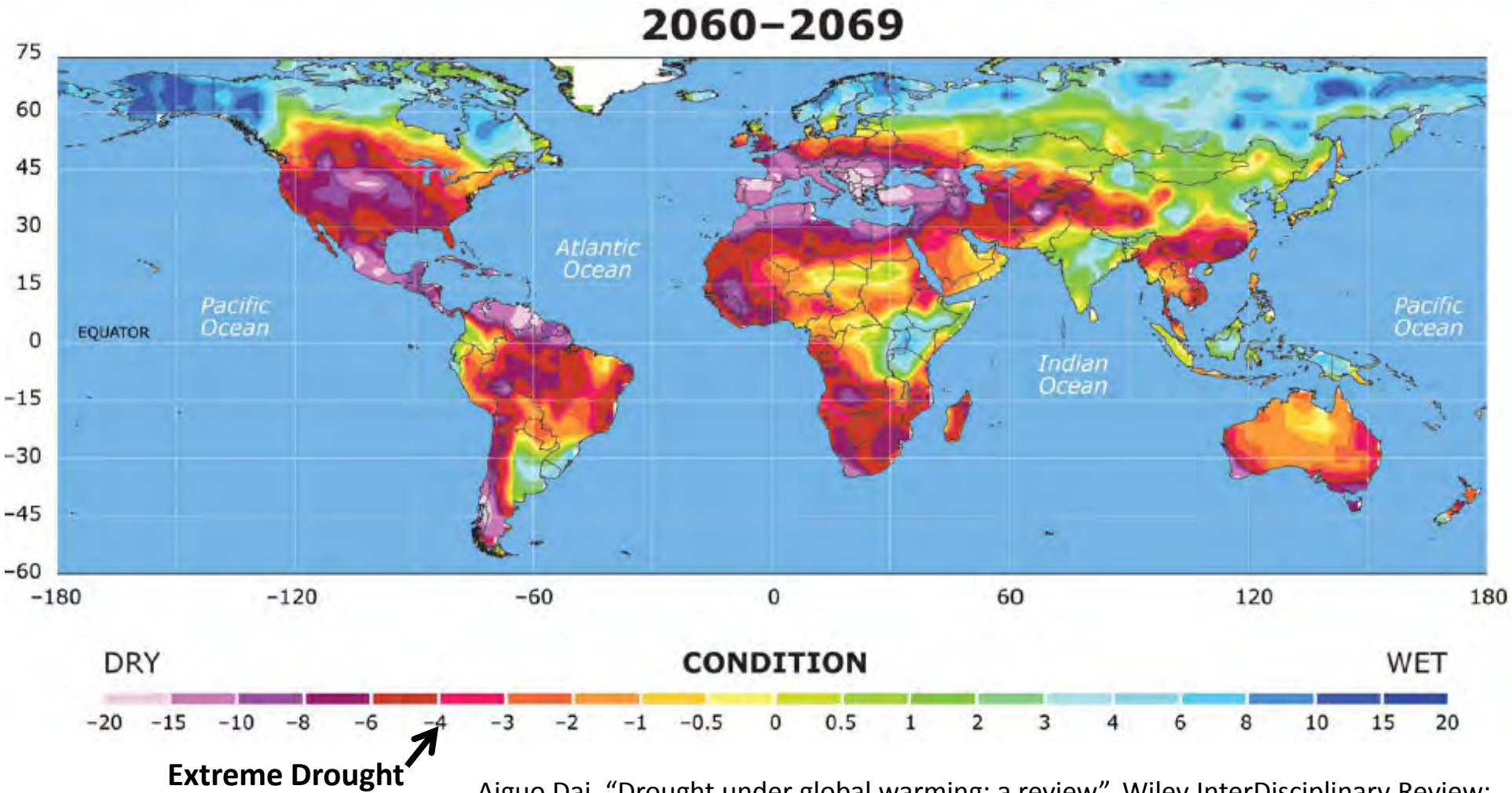
- **"The rapid increase in CO_2 emissions since the industrial revolution has increased the acidity of the world's oceans with potentially profound consequences for marine plants and animals, especially those that require calcium carbonate to grow and survive, and other species that rely on these for food."**
  - Change to date of pH decreasing by 0.1, a 30% increase in hydrogen ion activity.

- **"At current emission rates, models suggest that all coral reefs and polar ecosystems will be severely affected by 2050 or potentially even earlier."**
  - At 450 ppm, only 8% of existing tropical and subtropical coral reefs in water favorable to growth; at 550 ppm, coral reefs may be dissolving globally.

- **"Marine food supplies are likely to be reduced with significant implications for food production and security in regions dependent on fish protein, and human health and well-being."**
  - Many coral, shellfish, phytoplankton, zooplankton, & the food webs they support

- **"Ocean acidification is irreversible on timescales of at least tens of thousands of years."**

Drought?

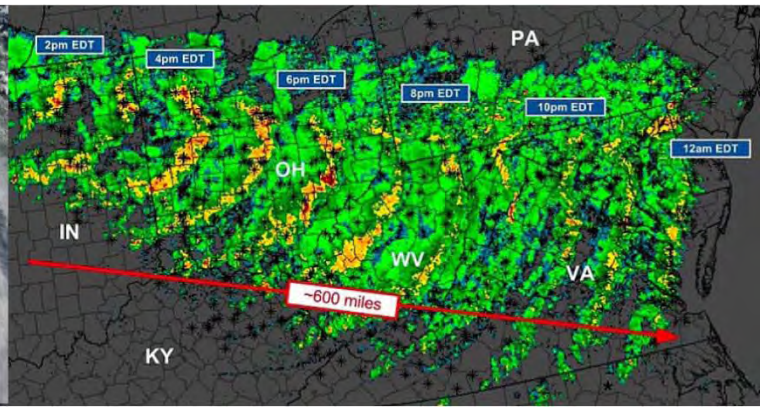


Aiguo Dai, "Drought under global warming: a review", Wiley InterDisciplinary Review: Climate Change, 2010; http://onlinelibrary.wiley.com/doi/10.1002/wcc.81/pdf
Aiguo Dai, "Increased drought under global warming in observations and models", Nature Climate Change V.3, Jan. 2013, pp.52-58.

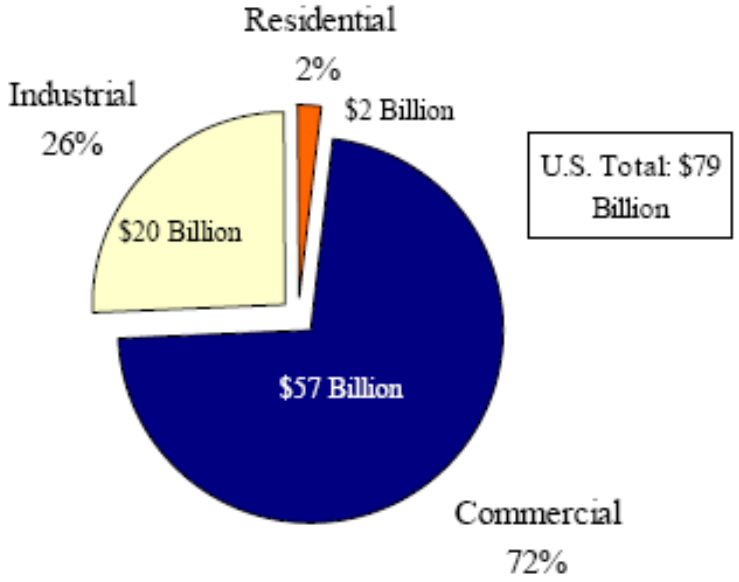
Power System Interruptions

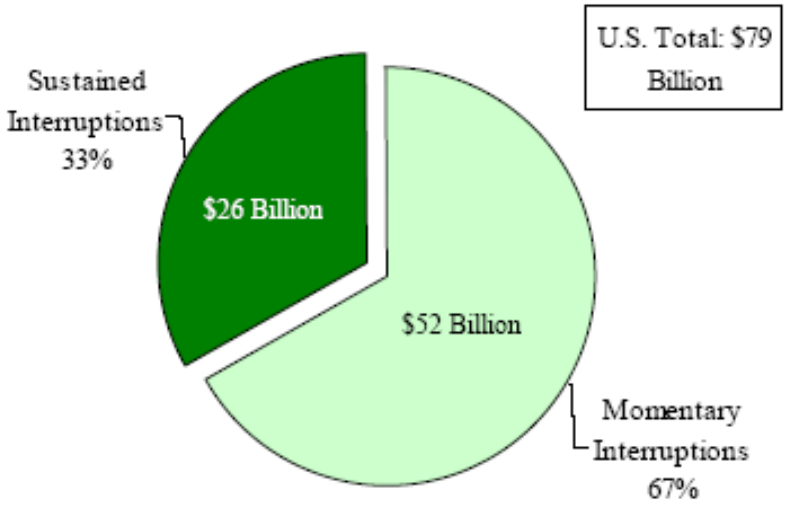
Northeast Blackout
New York City
August 2003

Hurricane Katrina
August 2005



Midwest & Mid-Atlantic
Derecho
June 2012





Kristina Hamachi LaCommare, and Joseph H. Eto, LBNL

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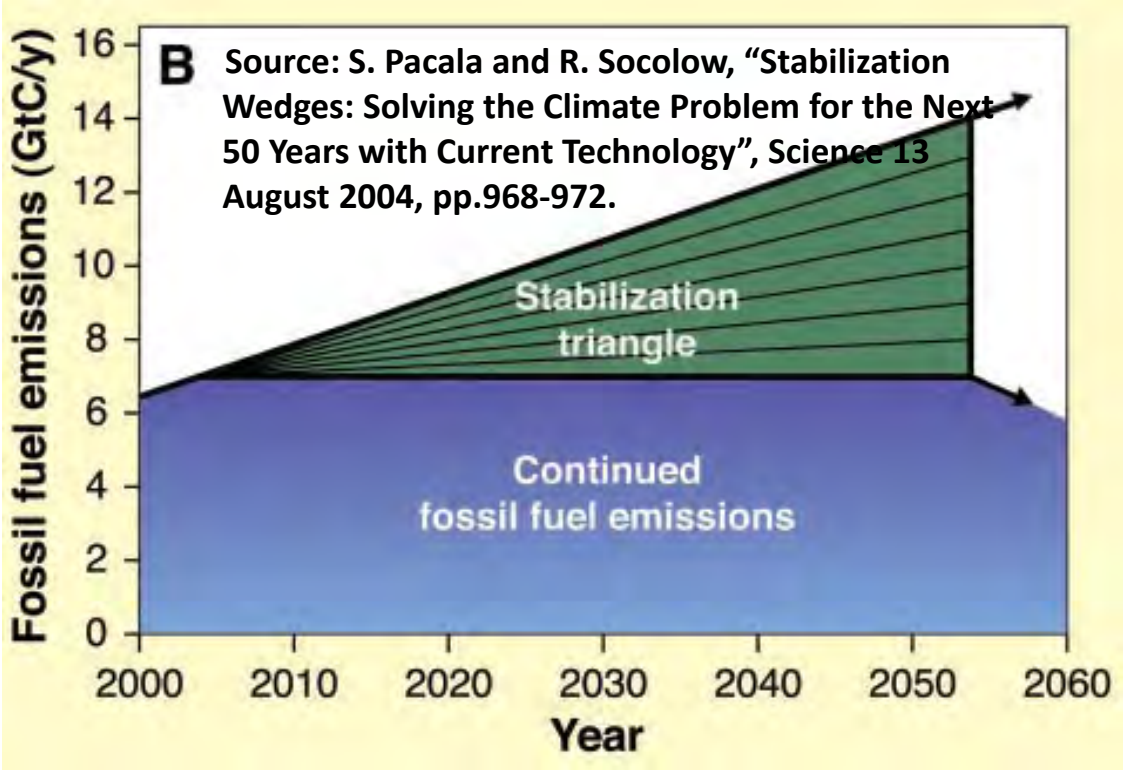
Scale of the Challenge

- **Install 1 million 2-MW wind turbines.**
- **Install 3000 GW-peak of Solar power.**
- **Increase fuel economy of 2 billion cars from 30 to 60 mpg.**
- **Cut carbon emissions from buildings by additional one-fourth by 2050.**
- **Introduce Carbon Capture and Storage at 800 GW of coal-fired power.**
- **Install 700 GW of nuclear power.**

- **See also:** Steven J. Davis, Long Cao, Ken Caldeira, Martin I. Hoffert, "Rethinking Wedges", Environ. Res. Lett, 8 (2013)



Time Constants

- Political consensus building ~ 3-30+ years
- Technical R&D ~10+
- Production model ~ 4+
- Financial ~ 2++
- Market penetration ~10++
- Capital stock turnover
  - Cars ~ 15
  - Appliances ~ 10-20
  - Industrial Equipment ~ 10-30/40+
  - Power plants ~ 40+
  - Buildings ~ 80
  - Urban form ~100's

- Lifetime of Greenhouse Gases ~10's-1000's
- Reversal of Land Use Change ~100's
- Reversal of Extinctions Never

Speed and Scale

Can EE & RE Meet These Challenges?

- **Extending Current Options**
  - Fossil/CCS
  - Nuclear
- **Efficiency**
  - Buildings
  - Industry
  - Transportation
  - Smart End-Use Equipment (dispatched w/ PV)
  - Plug-In Hybrids/Smart Charging Stations
- **Renewable Energy & Energy Storage**
  - Biomass
  - Geothermal
  - Hydropower
  - Ocean Energy
  - Solar Photovoltaics / Smart Grid / Battery Storage
  - Solar Thermal / Thermal Storage / Natural Gas
  - Wind / Compressed Air Energy Storage / Natural Gas
- **Transmission Infrastructure**
  - Smart Grid

HOW FAR?
HOW FAST?
HOW WELL?
AT WHAT COST?
BEST PATHWAYS?

BEST USE OF TAXPAYER FUNDS!

Public Accountability Drives Program Evaluation

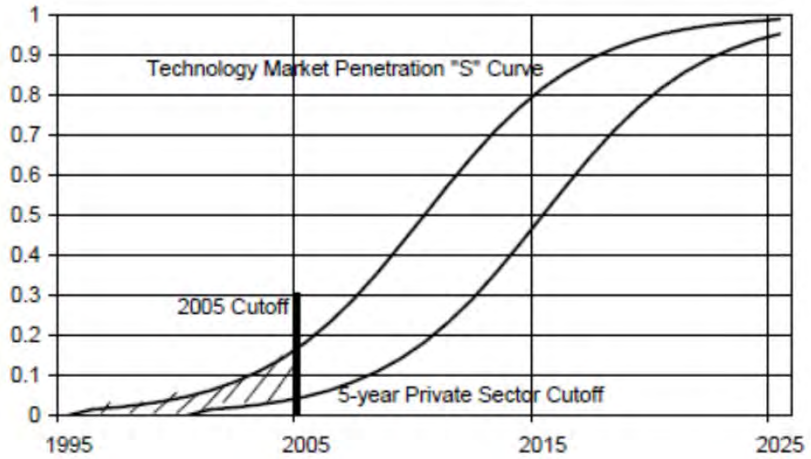
- OMB/OSTP:
  - OMB guidance on Increased Emphasis on Program Evaluation in Federal Agencies: *"…. evaluations can help the Administration and Congress determine how to spend taxpayer dollars effectively and efficiently….."*
  - OSTP/OMB calls for R&D agencies to conduct evaluations and strengthen capacity
  - OMB Performance Rating Assessment Tool (PART), 2003-2008; set expectations for periodic systematic evaluations to demonstrate results
- President:
  - ARRA unprecedented requirements for transparency & accountability, 2009
  - Executive Order 13450: Improving Government Program Performance, November 2007; agencies shall spend tax payers dollars efficiently & effectively
- Congress:
  - House Committee Reports HEWD, 2008/2009/etc., calls for reporting on ROI
    - *"The Committee directs the Department to quantify and track the progress and impact of the substantial investments the Committee has made in the Energy Efficiency and Renewable Energy portfolio."*
    - Assistant Secretary David Danielson, *Testimony before HEWD,* 2013-03-14
- And this is simply *Good Management Practice*

NRC Review:
Energy Research at DOE: Was It Worth It?
Energy Efficiency and Fossil Energy Research 1978-2000

- **Framework**
  - Economic; Environment; Security; Knowledge
  - Realized; Projected; Options

	Realized	Options	Knowledge
Economic			
Environmental			
Security			

- **Impacts Analysis**
  - Counterfactual with Five-Year Rule
  - Allow five-year forward projection



- **Findings**
  - $1.6 B of RD&D Investment reviewed
  - Electronic Ballasts: $ 15 B
  - Low-E Windows: $ 8 B
  - Refrigerator Compressors: $ 7 B
  - SubTotal $30 B (1999$)

EERE Progress

- **Merit Review**
  - Federal Register notice establishing qualification guidelines
  - Established Central Database of Reviewers
  - Workshop with Association of Public & Land-Grant Universities on Best Practices, 2010

- **In-Progress Peer Review**
  - Ten minimum requirements: Frequency; Scope; Evaluation Criteria (Quality, Productivity, Accomplishments, Relevance, Management); Documentation; etc.
  - Evaluation of Impact of In-Progress Peer Review: Hydrogen Program--$27M/$1.8M

- **Stage-Gate Review**
  - Strategic Fit; Feasibility; Market Need and Attractiveness; Financials

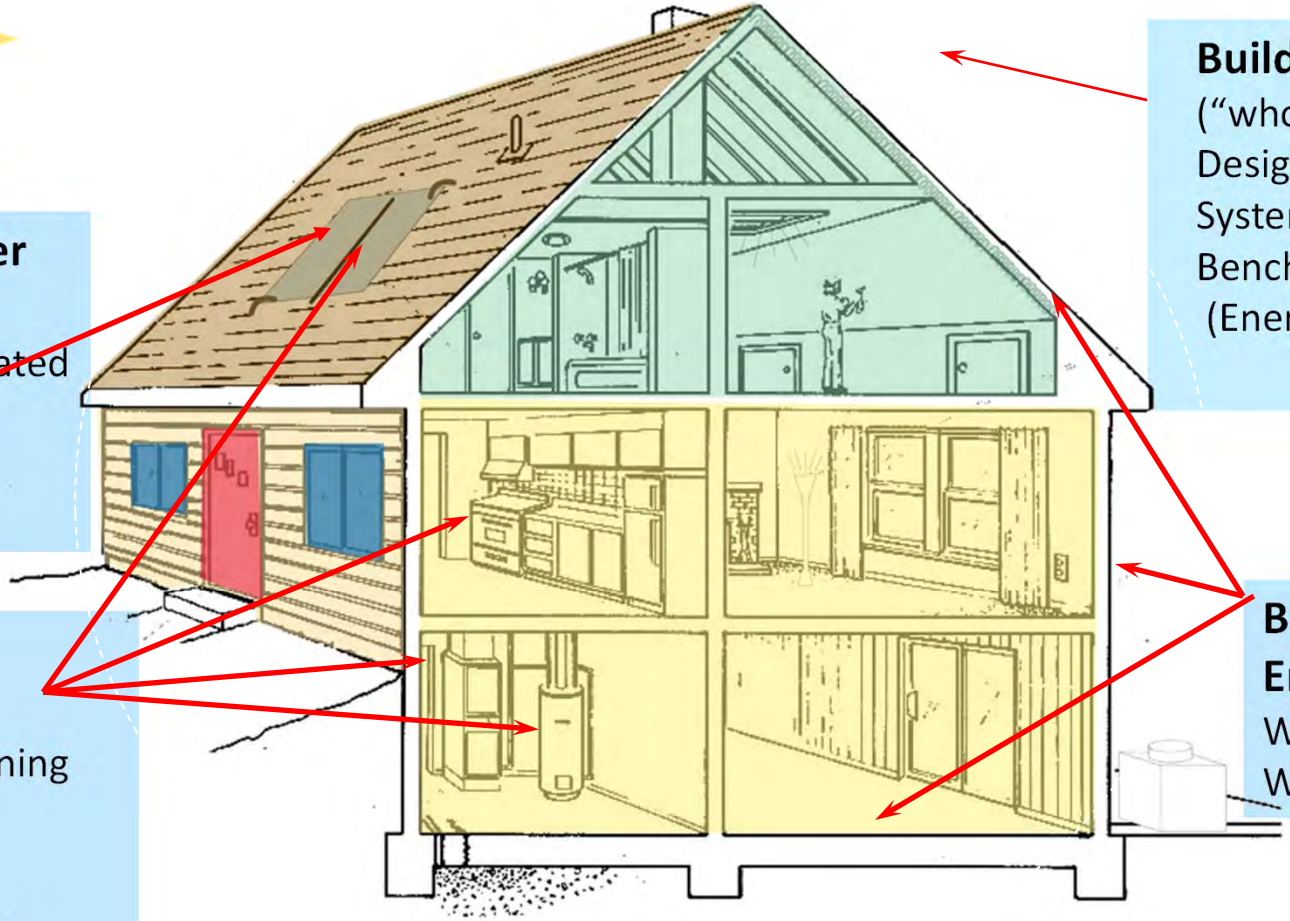
IMPACT	Realized	Projected	Options
Economic			
Environmental			
Security			
Knowledge			

- **Impact Evaluations:**
  - Completed more than 20 impact evaluation studies since 2008
    - Benefit-Cost Analysis; Historical tracing; Bibliometrics; Econometrics; Statistics; etc.
  - Completed 5 knowledge diffusion impact studies
  - More than 90% of DOE's retrospective impact evaluations conducted since 2008 have been done by EERE. Several EERE program evaluation resource guides have been made available to Federal Evaluators (Govt-wide) by GAO.
  - http://www1.eere.energy.gov/ba/pba/performance_evaluation.html
  - http://www1.eere.energy.gov/analysis/pe_plans_reports.html

Low-Energy Buildings

(Buildings use ~40% of all energy, ~70% of electricity)

On-Site Power Systems
Building Integrated Photovoltaics
Fuel Cells



Building Systems
("whole-systems")
Design tools
System Integration
Benchmarking
(EnergyStar, LEED)

Building Equipment
Space conditioning
Lights
Appliances
Smart Controls

Building Envelope
Windows,
Walls, Floors

Reduce total building energy use by 60–70 percent

Highly efficient, cost-effective solid-state lighting technologies, advanced windows and space heating and cooling technologies.

Source: BTP

Solar Decathlon

8-18 October 2009

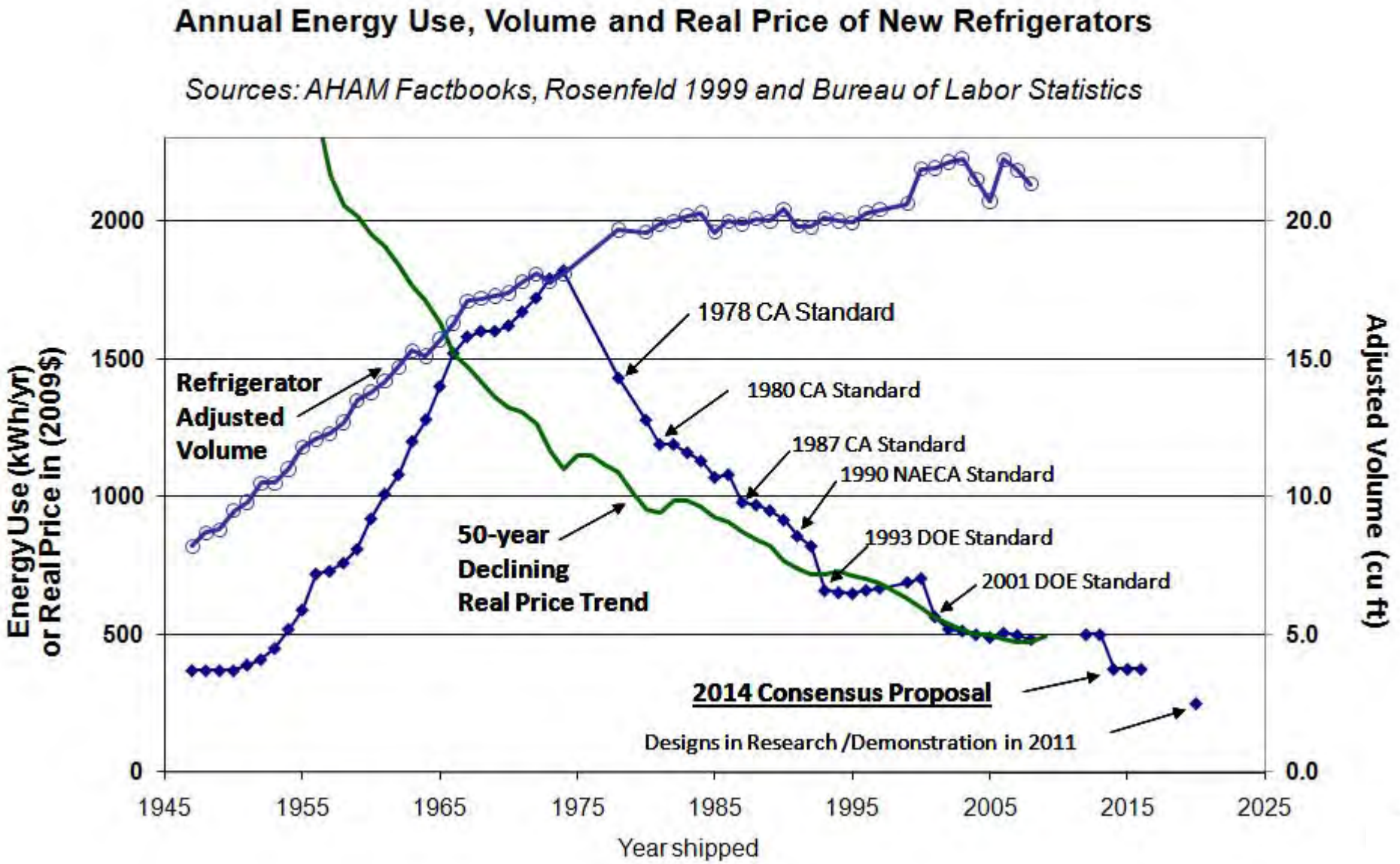
Architecture
Engineering
Market Viability
Communications
Comfort

Appliances
Hot Water
Lighting
Energy Balance
Net Metering

Cornell; Iowa State; Penn State; Rice; Team Alberta (U. Calgary, SAIT Polytechnic, Alberta College, Mount Royal College); Team Boston (Boston Architectural College, Tufts); Team California (Santa Clara U., California College of Arts); Team Missouri (Missouri S&T, U. Missouri); Team Ontario/BC (U. Waterloo, Ryerson, Simon Fraser); Technische Universitat Darmstadt; Universidad Politecnica de Madrid; Ohio State; U. Arizona; U. Puerto Rico; U. Illinois-Urbana; U. Kentucky; U. Louisiana-Lafayette; U. Minnesota; U. Wisconsin-Milwaukee; Virginia Tech.

Refrigerator Performance

Savings: ~1400 kWh/year * $0.10/kWh = $140/yr per household
***100 M households = $14 B/year**



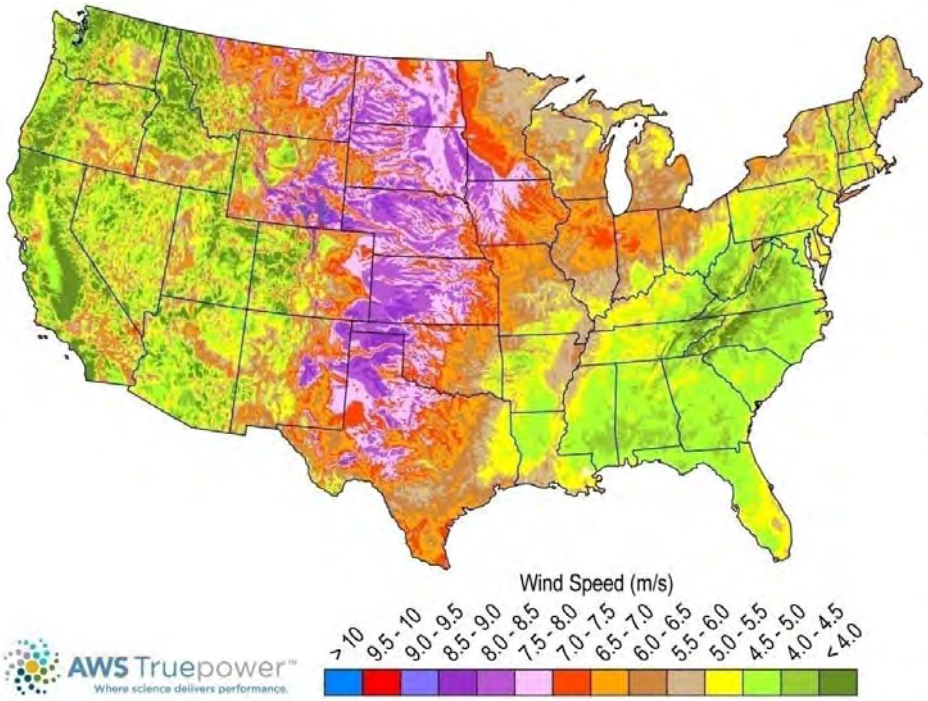
Vehicle Combustion Engine R&D B-C Study

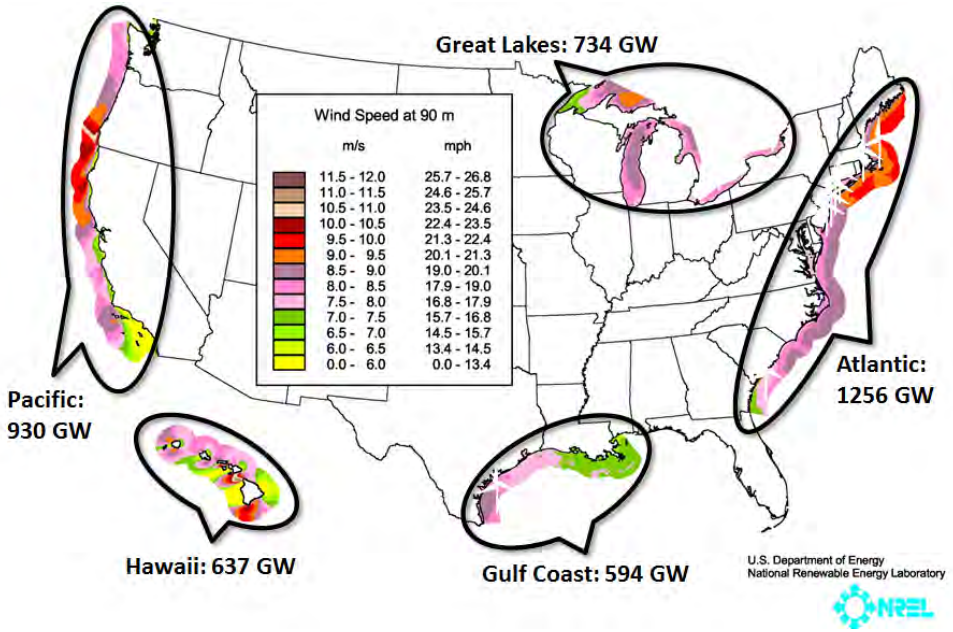
- **Vehicle R&D: Plug-In Hybrids**

- **R&D costs, 1986-2007: $931 million (2008$)**
- **Cluster of Technologies in Vehicle Combustion Sub-program on heavy-duty diesels:**
  - **- laser diagnostic and optical engine technologies; combustion modeling**
  - **- Not examined: emission control technologies; thermoelectrics; other**
- **Effect of EERE R&D in the 2 selected areas: fuel efficiency gain of 4.5%**
  - **Save 17.6 billion gallons of diesel fuel from 1995 through 2007, worth $34.5B (2008$)**
  - **Reduce emissions 177.3 MMTCO2, 0.063 tons NO_x; 3.0 tons PM; 0.096 tons So_x; saving $35.7 B**
  - **Security Benefits: Reduce imports equivalent of ~420 Million Barrels, 1% of imports 1995-2007**
  - **Knowledge Benefits: Foundation for 12+ important technologies in combustion; advances in ion mobility spectrometry**

Source: Ruegg & Jordan, 2010

Wind Resources





- **Highest quality wind resources are located in the Central states and offshore**
- **Combined onshore and offshore (fixed-bottom) resource is ~10,000 GW**

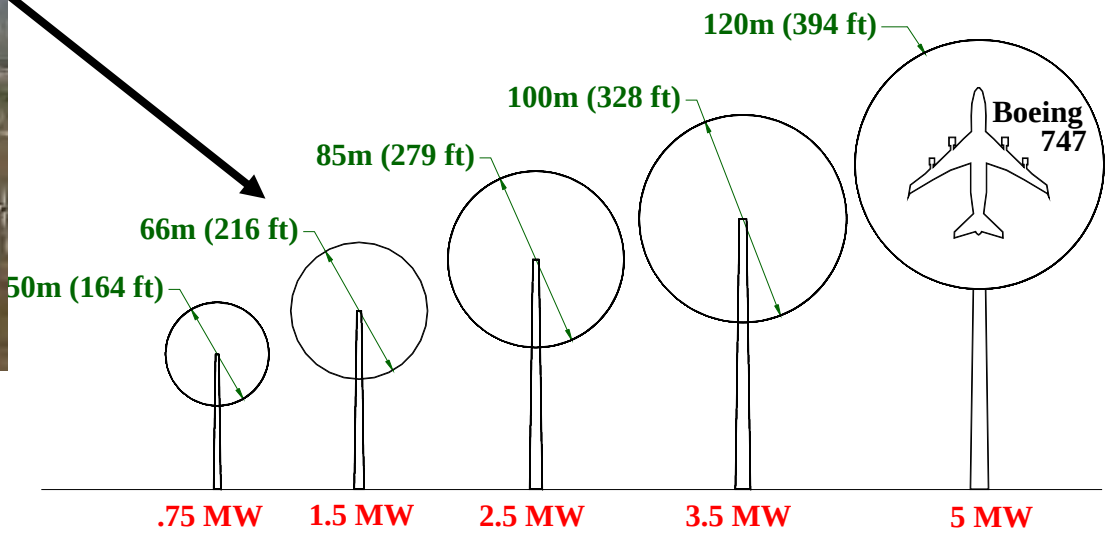
Wind Power

GE Wind 1.5 MW

The total economic benefits were $9.9 billion (2008$) on $1.2 B invested in:

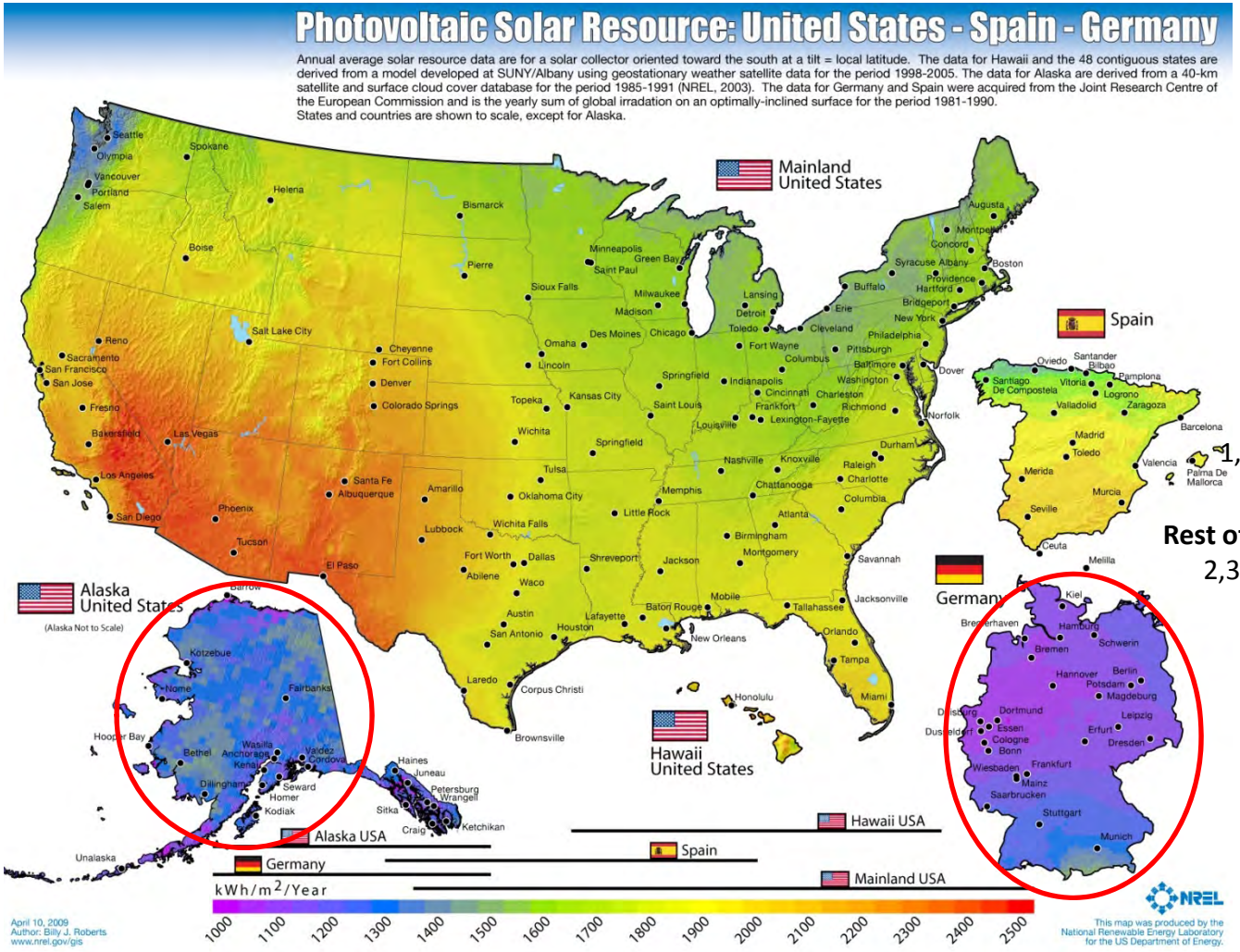
- Turbulence models;
- Wind tunnel experiments of turbine aerodynamics;
- Blade materials;
- Airfoil design codes;
- Demonstration and testing.

Typical Rotor Diameters

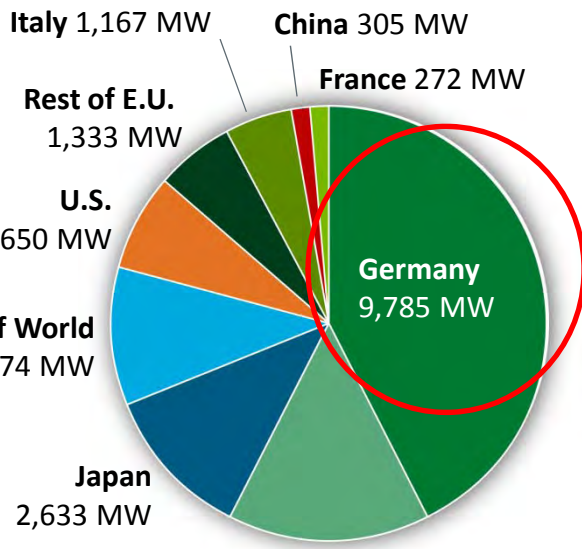


Source: EERE/WTP

Can Solar Energy Meet the Challenge?



Cumulative Installed PV
(through 2009)



Source: EERE/SETP, Goldstein

- **Solar technologies have enormous resource potential: ~80,000 GW for utility PV, ~700 GW for rooftop PV, and ~37,000 GW for CSP**

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Highlights from Solar

- **The economic benefits were $18.7 billion (2008$) on $3.7B examined of program investment in: Crystalline silicon PV module technologies, Thin Film PV module technologies, Manufacturing technologies, Technology infrastructure for measurement, characterization, and reliability.** **(A. O'Connor, R. Loomis, F. Braun, "Retrospective Benefit-Cost Evaluation of DOE Investment in Photovoltaic Energy Systems", August 2010, USDOE/EERE)**

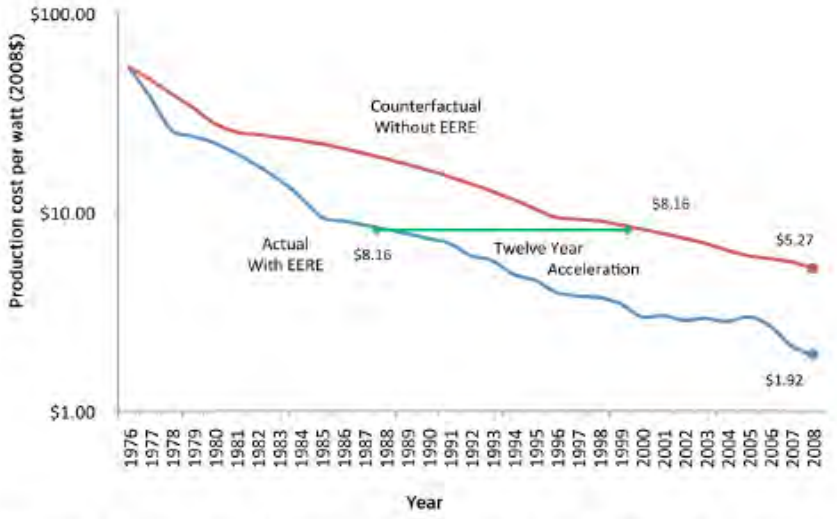
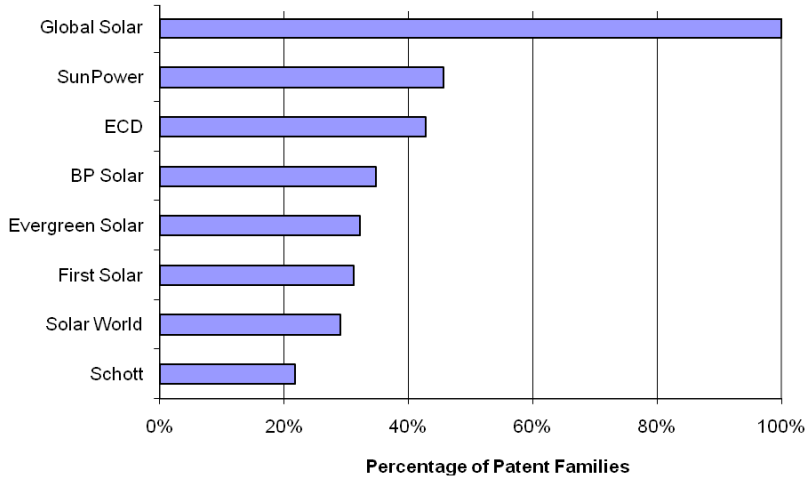


Figure 1: Actual and Counterfactual PV Module Production Cost

- **Patent Analysis: DOE supported research linked to 30% of the patent families for the top PV innovators from 1974-2008.** **(Ruegg, R., Thomas, P. (2011)** ***Linkages form DOE's Solar Photovoltaic R&D to Commercial Renewable Power from Solar Energy.*** **Washington, D.C.: USDOE/EERE**



- **Efficiency Records: Separate Solar Program estimates are that roughly 57% of the world record cell efficiencies from 1975-2011 were made by researchers supported by the DOE.**

- **Incubator $60M ➔ $1.6B VC investment**

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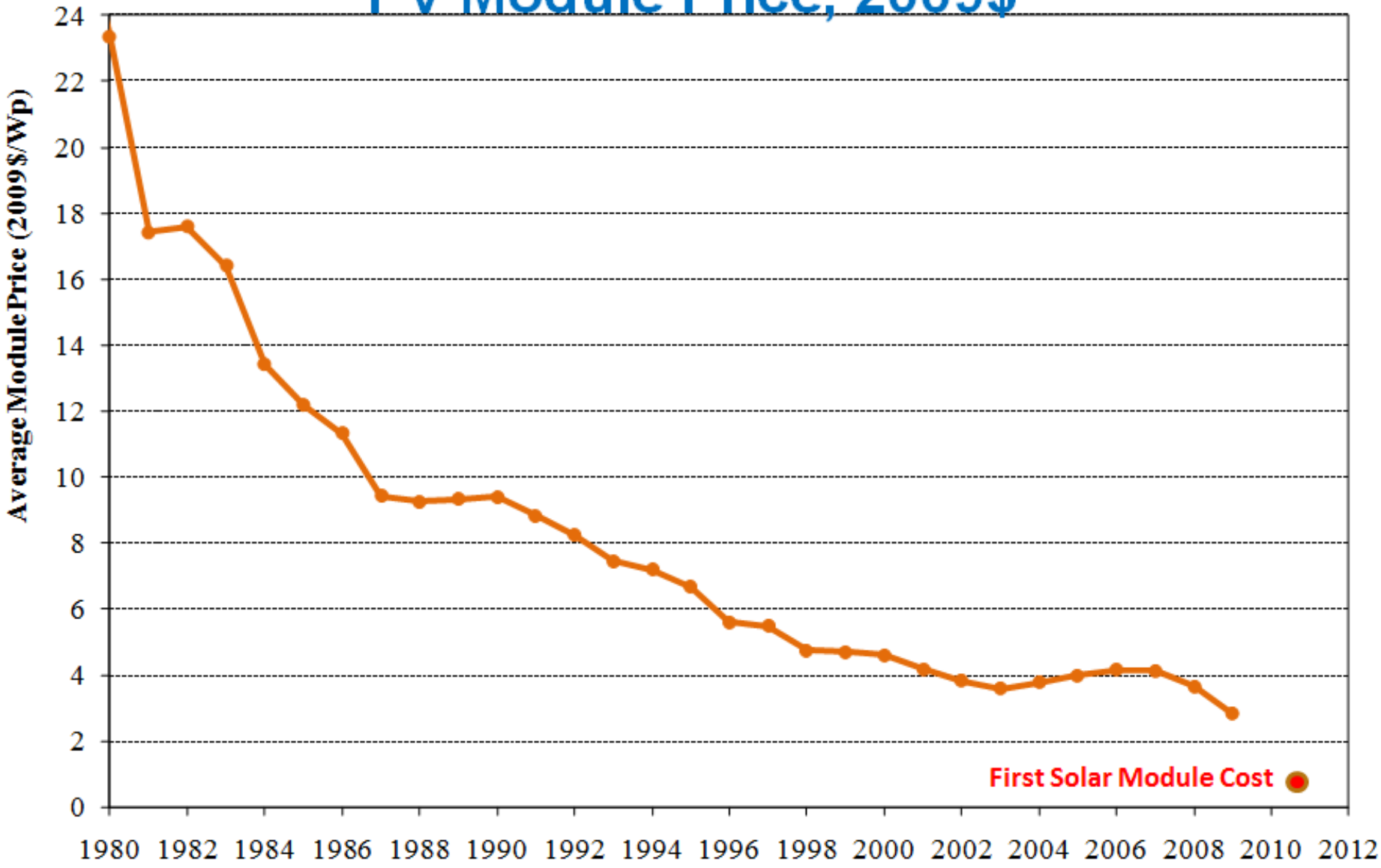
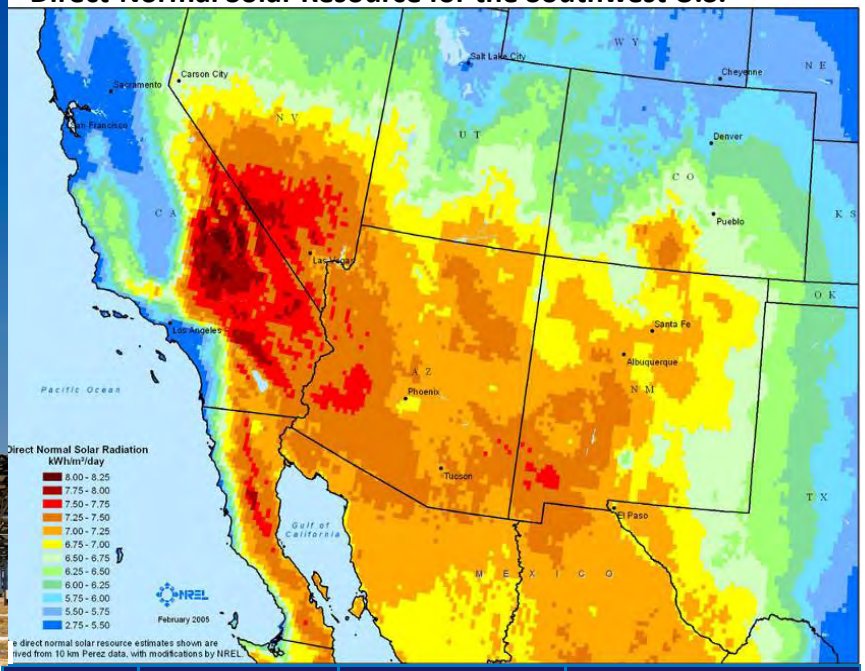
PV Module Price, 2009$



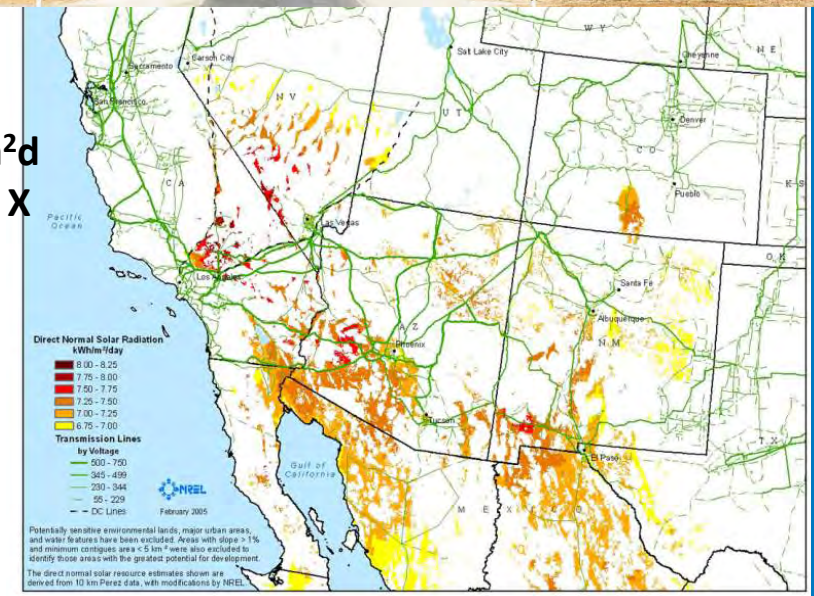
Source: Navigant & Robert Margolis, NREL

Concentrating Solar Thermal Power

Direct-Normal Solar Resource for the Southwest U.S.



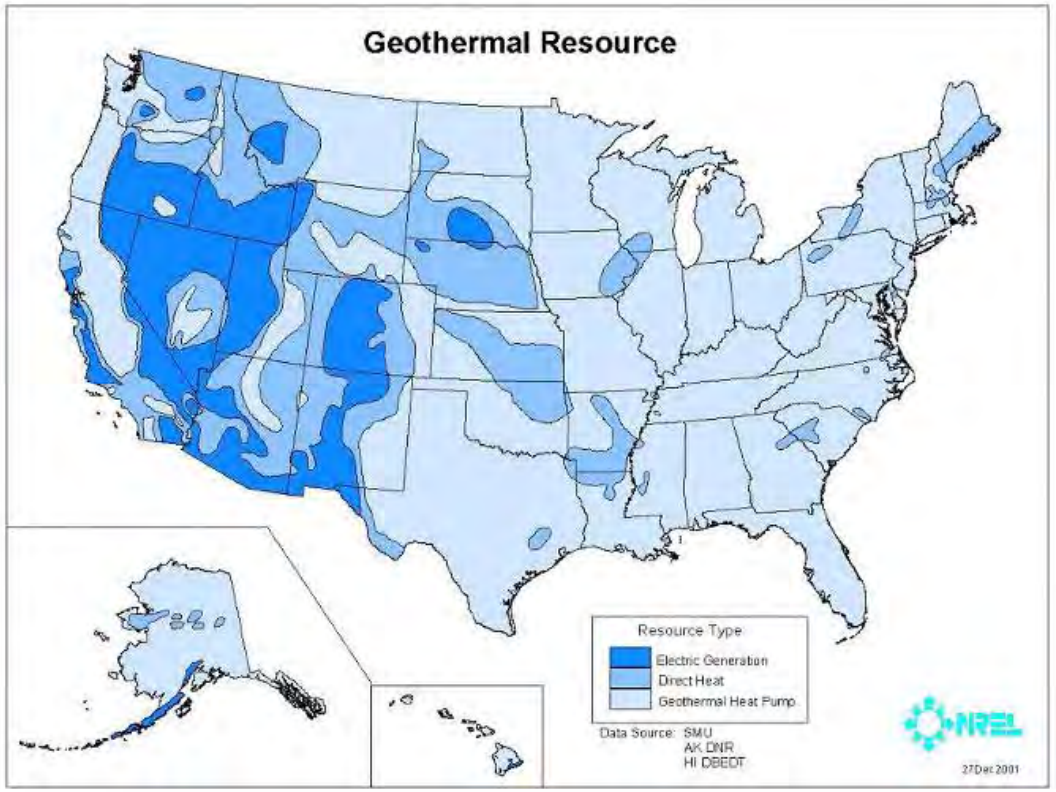
Filters:
Transmission >6.75kWh/m²d
Environment X
Land Use X
Slope < 1%



State	Land Area (mi²)	Solar Capacity (MW)	Solar Generation Capacity (GWh)
AZ	13,613	1,742,461	4,121,268
CA	6,278	803,647	1,900,786
CO	6,232	797,758	1,886,858
NV	11,090	1,419,480	3,357,355
NM	20,356	2,605,585	6,162,729
TX	6,374	815,880	1,929,719
UT	23,288	2,980,823	7,050,242
Total	**87,232**	**11,165,633**	**26,408,956**

Map and table courtesy of NREL

Geothermal Resources and Technologies



The net economic benefits were $35.8 billion (2008$), on the reviewed program investment of $1.4B in:

- Polycrystalline diamond compact (PDC) drill bit;
- Binary cycle power plant technology;
- TOUGH series of reservoir models;
- High-temperature geothermal well cements.

Geothermal Data: http://www.scientificamerican.com/article.cfm?id=new-geothermal-data-system

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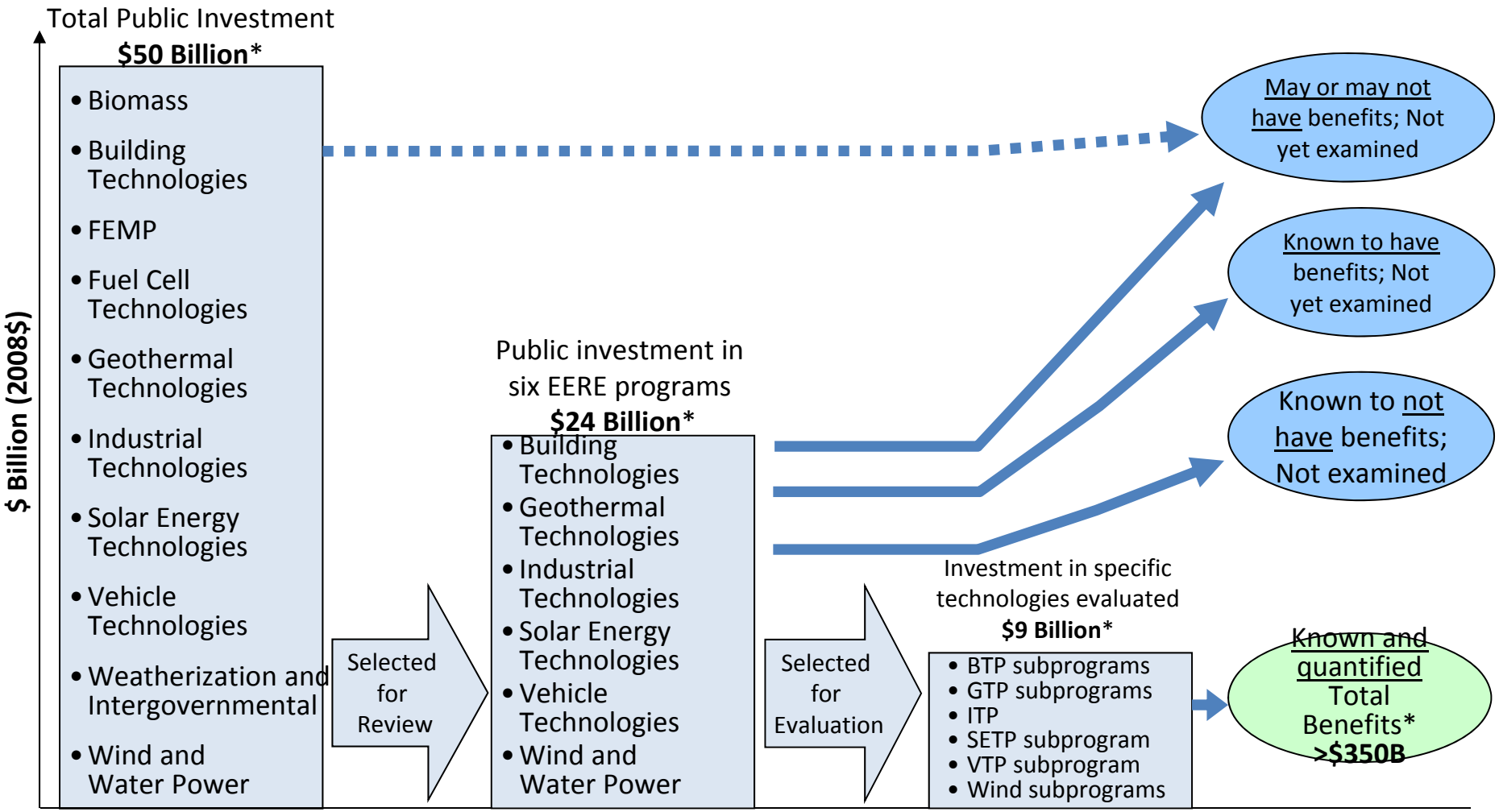
Economic returns analyzed to date



[a] *All dollars are expressed in 2008 inflation-adjusted dollars, not discounted.*
[b] *$326B net benefits = $350B total benefits - $24 investment in six programs.*
** Preliminary*

EERE Patent Analyses: Summary Metrics

Measure	Wind program	SETP solar PV	GTP	VTP combustion engine R&D	VTP energy storage R&D
Period Covered	Mid-1970s through 2008[a]				
% of other patents in field linked to EERE-attributed patents; and citation rate	25%	30%	21%	-- (Citation rate: 2.35)	18% (Citation rate: 2.17)
EERE rank & other organization rank	EERE #1 (United Technologies, #2)	EERE #1 (BP Solar & ECD, also #1)	EERE #2 (Chevron, #1)	EERE #2 (Nissan, #1)	EERE #2 (Matsushita, #1)
High impact DOE-attributed patents & citation index (CI)[b]	• Retractable rotor blades (CI=6.90) • Variable speed wind turbine (CI=6.58) • Doubly fed generator control system	• Fabricating nanostructures & nanowires (CI=27.04) • Nondestructive method for detecting defects (CI=6.48)	• Drilling using high pressure fluids (CI=6.08) • Kalina cycle (CI=5.14) • Drilling horizontal holes from a vertical bore	• HCCI engine (CI=8.51) • Fuel injection (CI=6.05) • Ion mobility spectrometer (CI=5.41)	• Ultracapacitor (CI=4.65) • Lithium ion (CI=4.55) • Carbon foams (CI=5.82)

[a] The beginning data series for the 5 studies are somewhat variable, though they each aim to examine the period from the mid-1970s through 2008.
[b] The Citation Index (CI) is a normalized measure derived by dividing the number of citations received by a patent by the mean number of citations received by peer patents from the same issue year and technology as indicated by its Patent Office Classification (POC).

Renewable Electricity Systems

Hydropower

BioPower

Photovoltaics

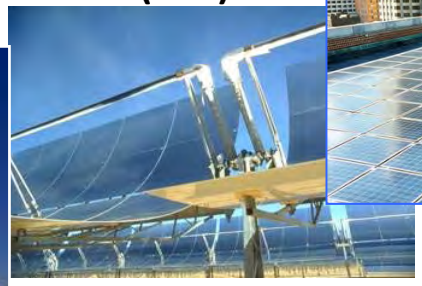
Geothermal

Wind

Distributed Generation
Demand Response
Distributed Storage
Smart Grid

Plug-in Hybrids

Concentrating Solar Power (CSP)



Photovoltaics

- Energy Intensity
- Site Specificity
- Variability & Uncertainty
- System Integration

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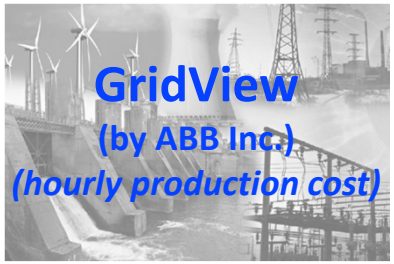
RE Futures Modeling Framework

Only currently commercial technologies were modeled, with incremental and evolutionary improvements.

rooftop PV penetration



2050 mix of generators

does it balance hourly?

ITI Projection
(by Black & Veatch)

ETI Projections
(by Tech Teams)

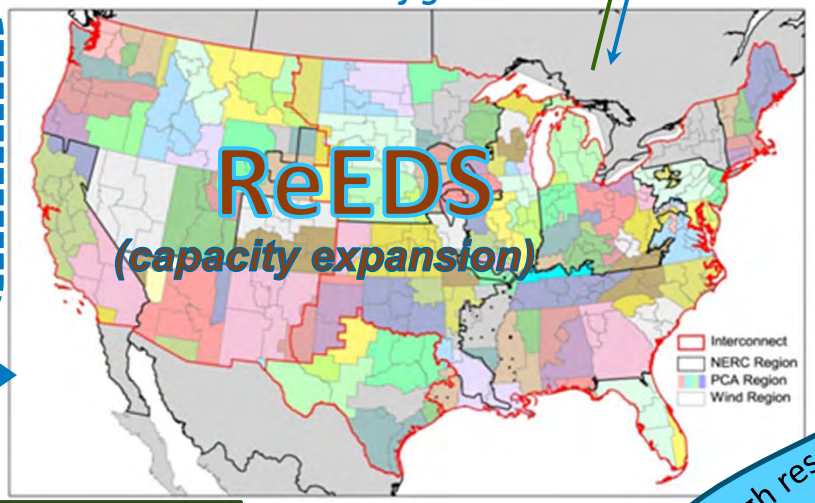
Flexible Resources

End-Use Electricity

System Operations

Transmission

Technology cost & performance
Resource availability
Demand projection
Demand-side technologies
Grid operations
Transmission costs



High resolution modeling using **134 nodes** & **hourly time steps**

Implications
GHG Emissions
Water Use
Land Use
Direct Costs

Capacity & Generation 2010-2050

Renewable Electricity Futures Study (2012): Hand, M.M.; Baldwin, S.; DeMeo, E.; Reilly, J.M.; Mai, T.; Arent, D.; Porro, G.; Meshek, M.; Sandor, D., editors. Lead authors include: Mai, T.; Sandor, D.; Wiser, R.; Brinkman, G.; Heath, G.; Augustine, C.; Bain, R.; Chapman, J.; Denholm, P.; Drury, E.; Hall, D.; Lantz, E.; Margolis, R.; Thresher, R.; Hostick, D.; Belzer, D.; Hadley, S.; Markel, T.; Marnay, C.; Milligan, M.; Ela, E.; Hein, J.; Schneider, T.; et al. - A U.S. DOE sponsored collaboration among more than 110 individuals from about 35 organizations.

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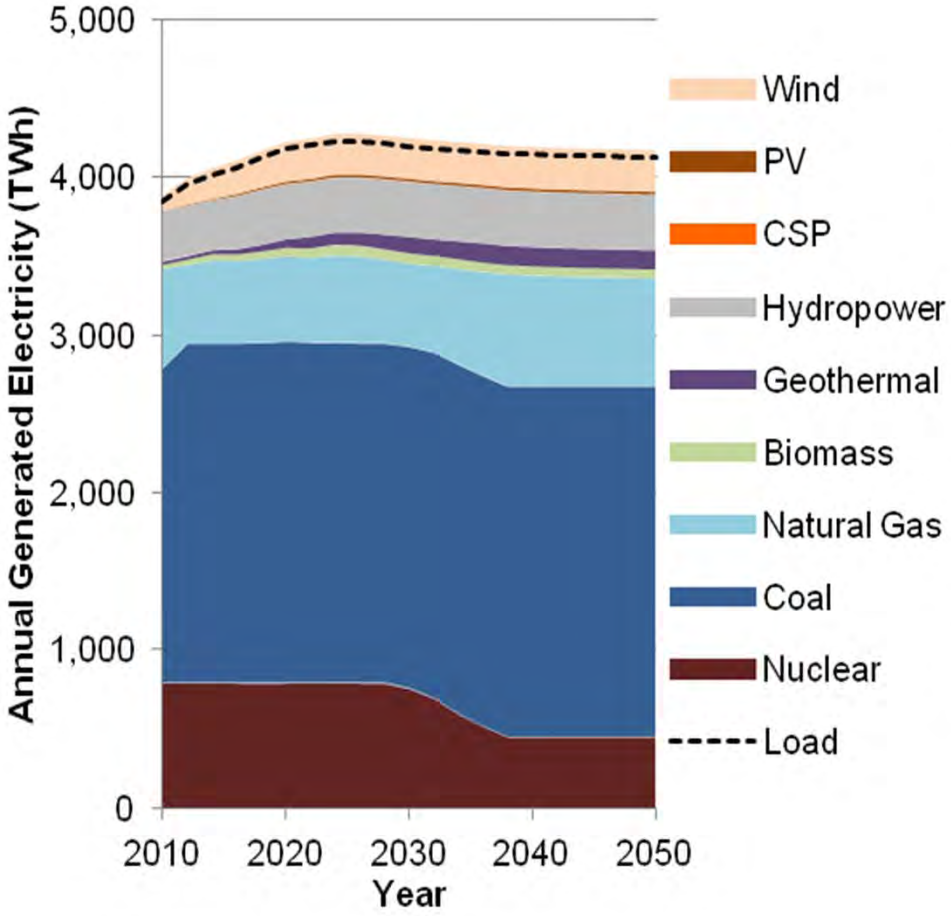
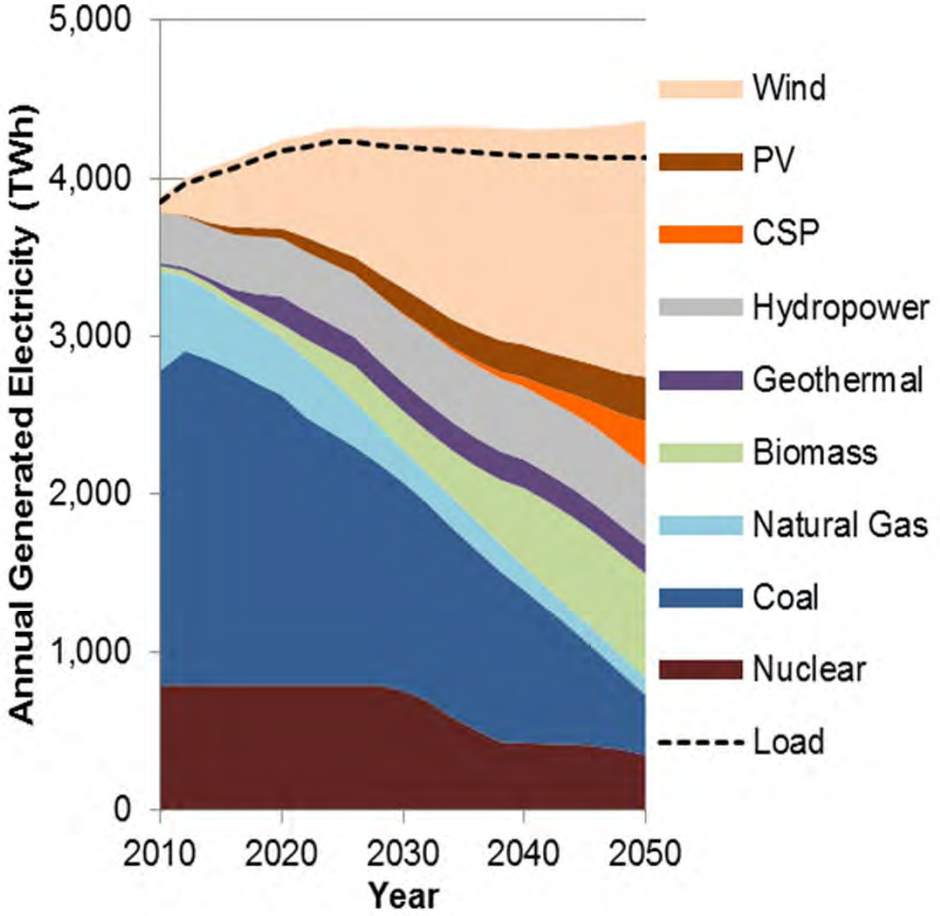
ReEDS Outputs

Baseline scenario



80% RE-ITI scenario



- **Renewable generation sources could supply 80% of U.S. Electricity in 2050**
- **Operational** challenges (curtailment, forecast, reserves) grow with deployment of VRE
- **Transmission** expansion can be significant with high RE targets
- **Storage** deployment grows with increasing RE targets

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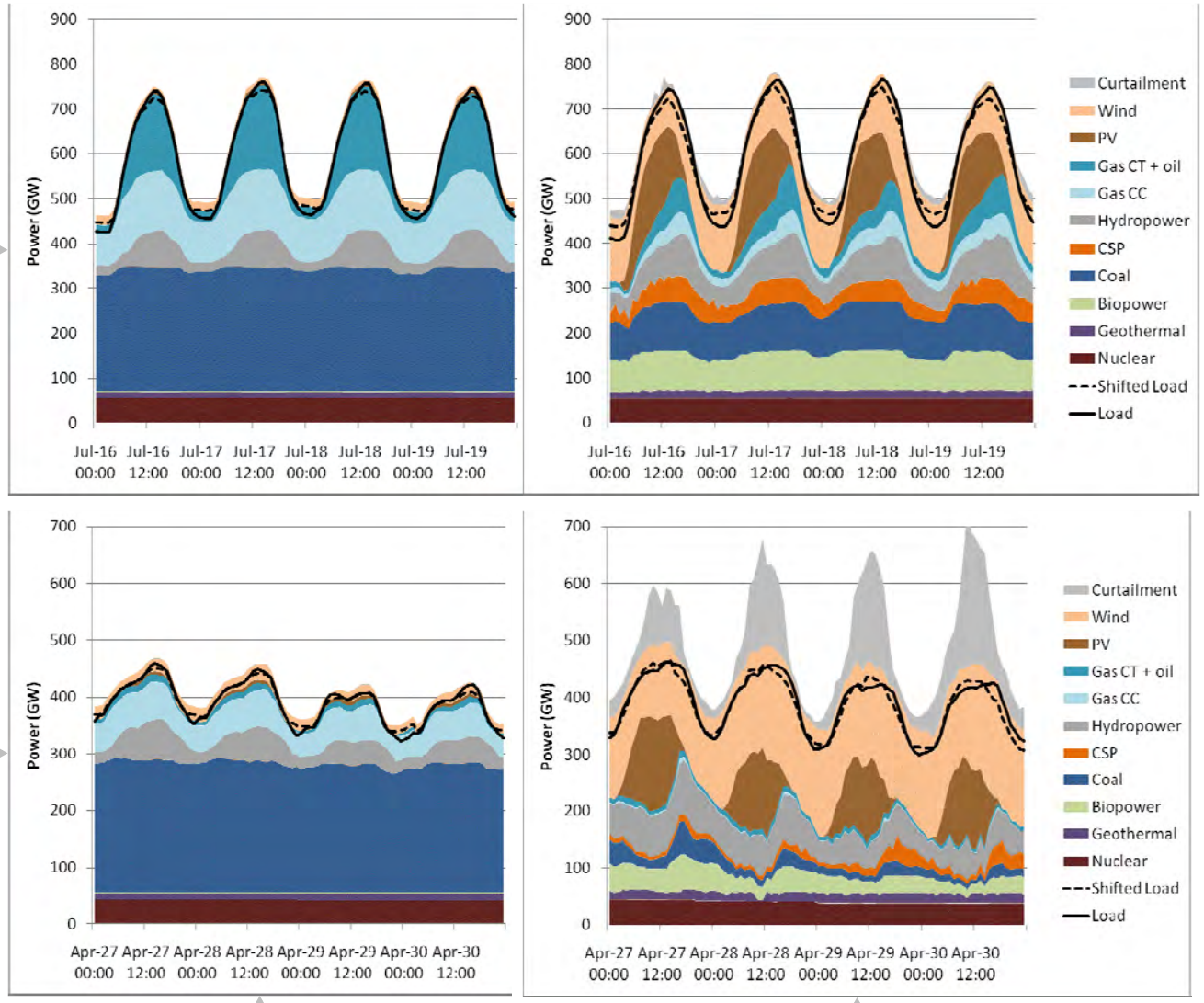
Electricity supply and demand can be balanced in every hour of the year in each region with 80% electricity from renewables*

Summer Peak

Spring Off-Peak

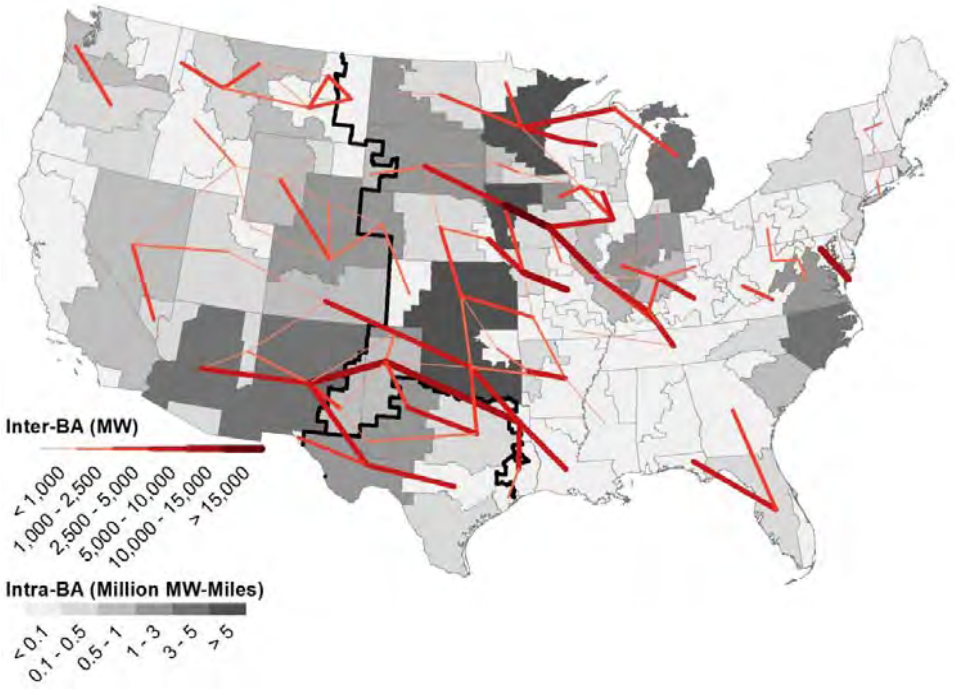


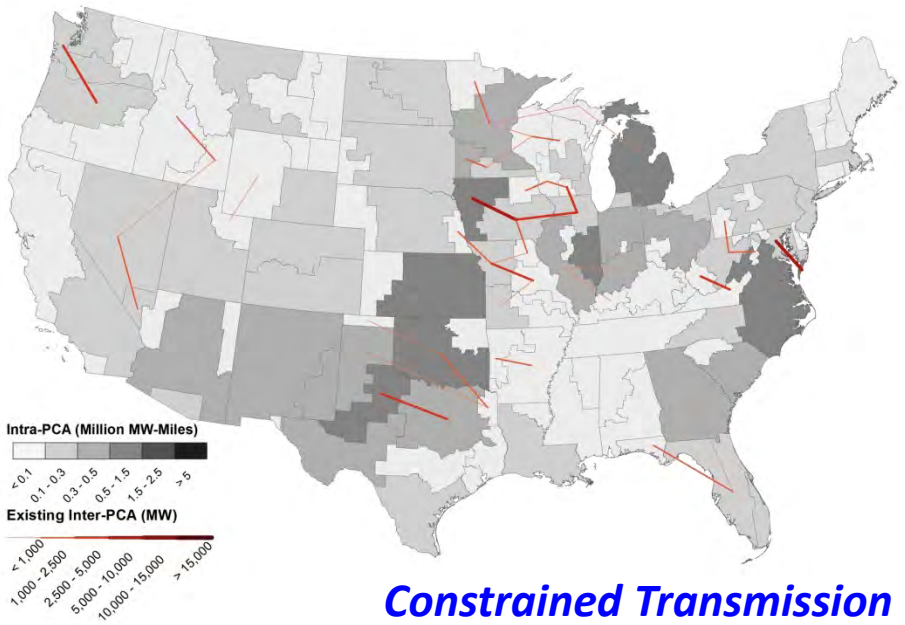
Baseline

80% RE-ITI Case

*Full reliability analysis not conducted in RE Futures

As RE deployment increases, additional transmission infrastructure is required

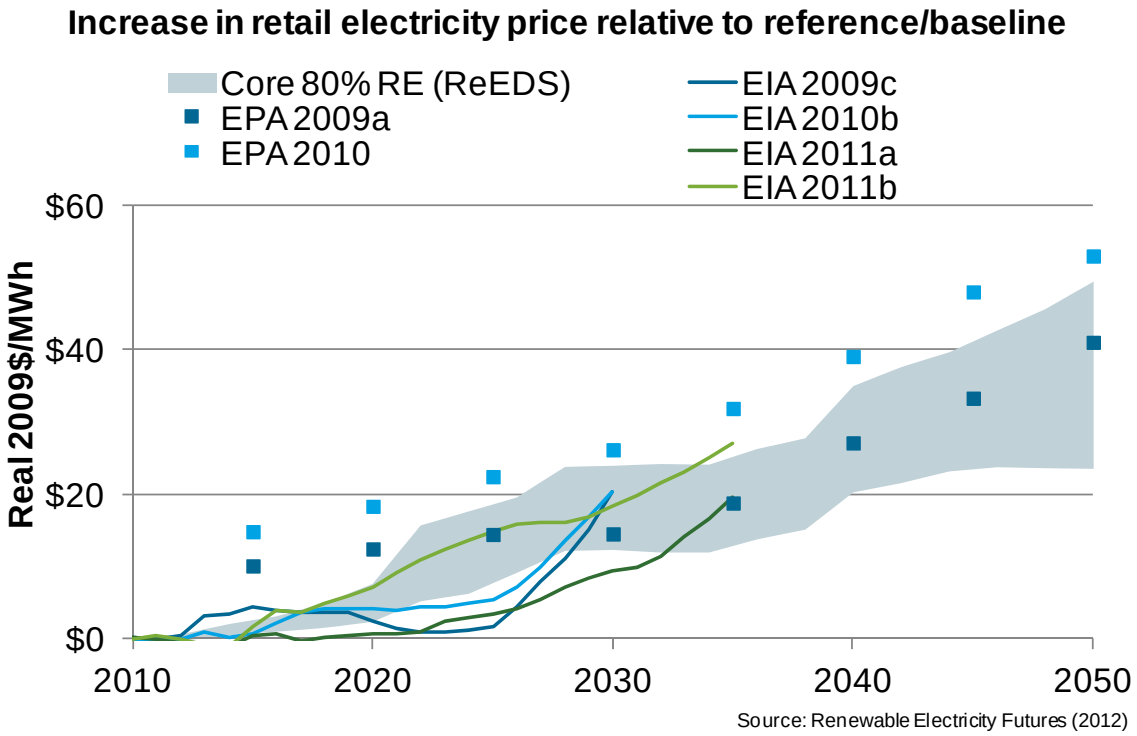


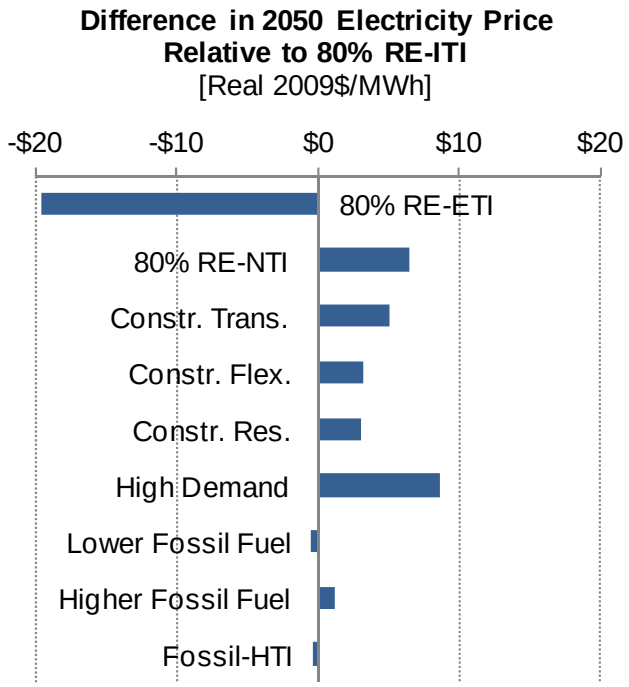


Constrained Transmission

- **In most 80%-by-2050 RE scenarios, 110-190 million MW-miles of new transmission lines are added.**
- **AC-DC-AC interties are expanded to allow greater power transfer between asynchronous interconnects.**
- **However, 80% RE is achievable even when transmission is severely constrained (30 million MW-miles)—which leads to a greater reliance on local resources (e.g. PV, offshore wind).**
- **Annual transmission and interconnection investments in the 80%-by-2050 RE scenarios range from B$5.7-8.4/year, which is within the range of recent total investor-owned utility transmission expenditures.**
- **High RE scenarios lead to greater transmission congestion, line usage, and transmission and distribution losses.**

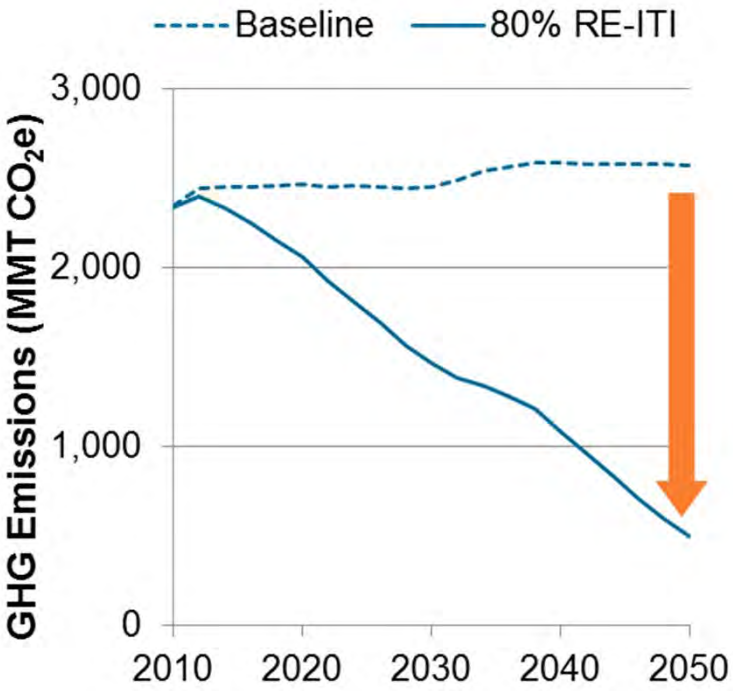
Incremental cost associated with high RE generation is comparable to published cost estimates of other clean energy scenarios

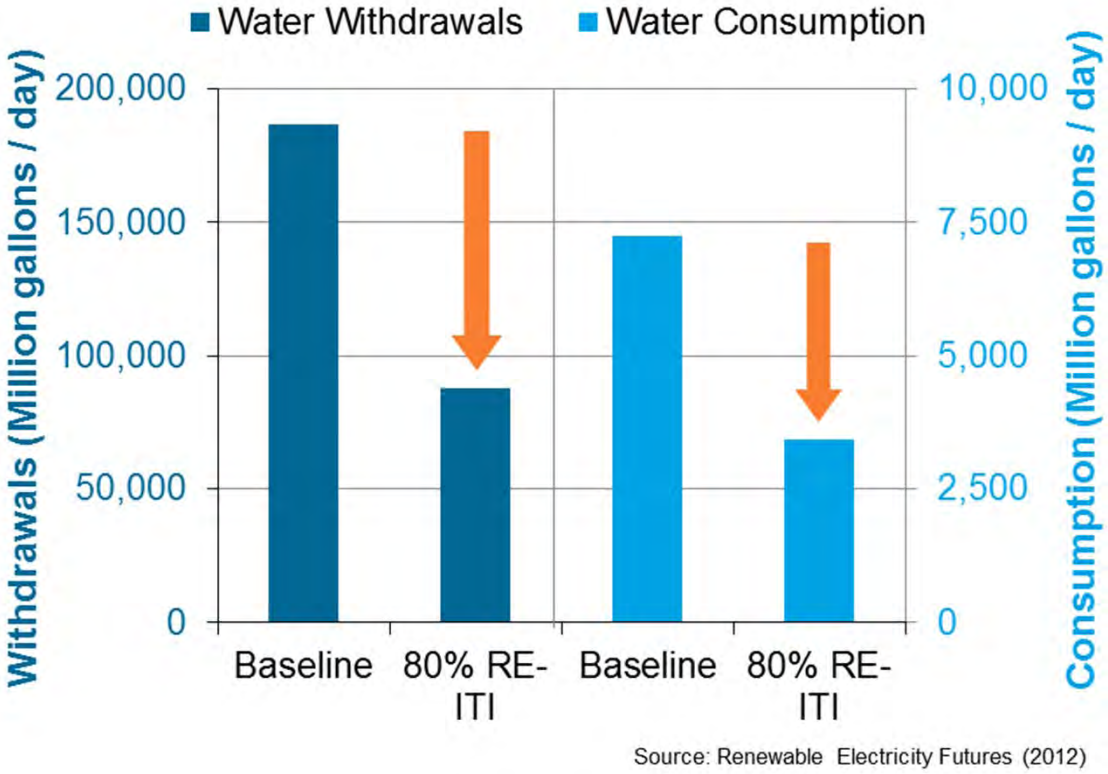




- **Incremental cost reflects replacement of existing generation plants with new generators and additional balancing requirements (combustion turbines, storage, and transmission) compared to baseline scenario (continued evolution of today's conventional generation system)**
- **Improvement in cost and performance of RE technologies is the most impactful level in reducing the incremental cost**
- **Cost is less sensitive to the assumed electric system constraints (transmission, flexibility, RE resource access)**

High RE Reduces Emissions and Water Use





Source: Renewable Electricity Futures (2012)

80% renewable electricity in 2050 could lead to:

- ~ 80% reduction in GHG emissions (combustion-only and full life-cycle)
- ~ 50% reduction in electric sector water use (withdrawals and consumption)

RE Land Use Implications

- **Area requirements:**
  - Gross estimate for RE Futures scenarios: < 3% of US land area
  - About half used for biopower
  - Majority of remainder for wind, but only about 5% is actually disturbed

Gross Land Use Comparisons (000 km^2)	
Biomass	44-88
All Other RE	52-81
All Other RE, disrupted	4-10
Transmission & Storage	3-19
Total Contiguous U.S.	7,700
Major Roads**	50
Golf Courses **	10

80% RE scenarios

** USDA 2010, 2012 ** Denholm & Margolis 2008*

- **Siting issues:**
  - Permitting processes vary with technology and location
  - Wildlife and habitat disturbance concerns
  - Public engagement for generation and transmission—landscape, noise

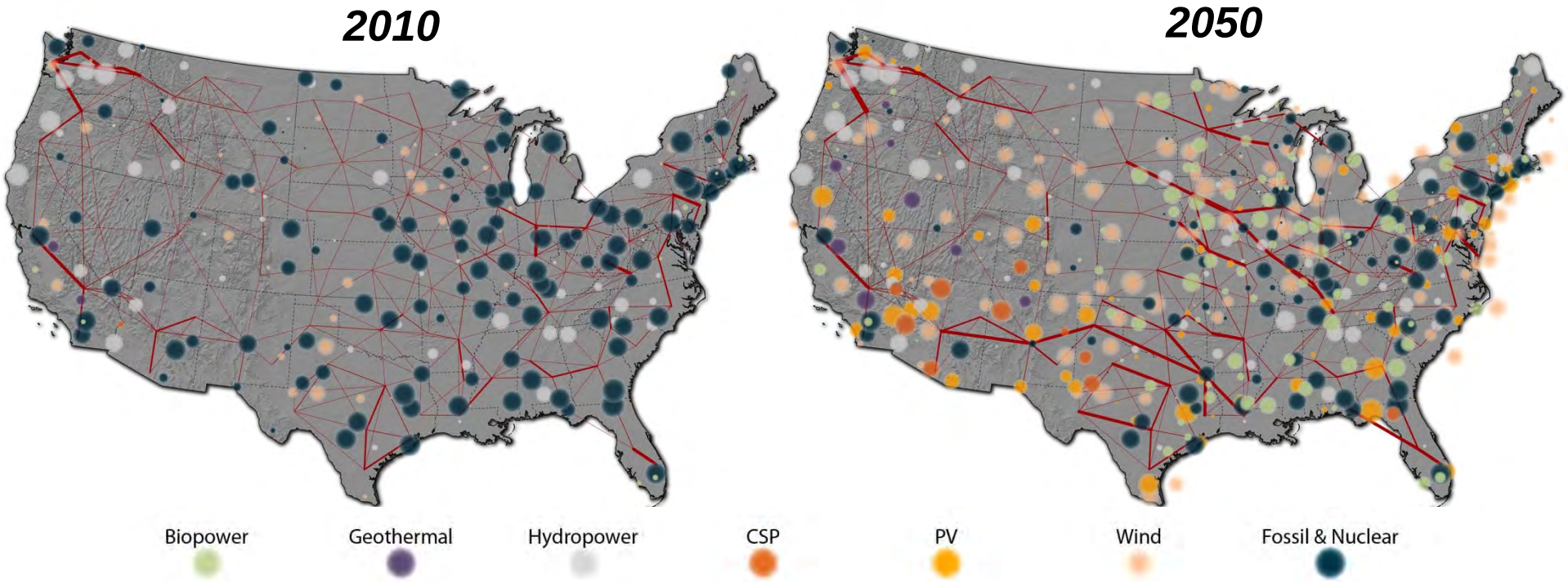
Clean Energy to Secure America's Future

"We have a choice. We can remain the world's leading importer of oil, or we can become the world's leading exporter of clean energy. We can hand over the jobs of the future to our competitors, or we can confront what they have already recognized as the great opportunity of our time: the nation that leads the world in creating new sources of clean energy will be the nation that leads the 21st century global economy. That's the nation I want America to be."

– **President Obama,**
Nellis Air Force Base,
Nevada, 5/27/09

A Transformation of the U.S. Electricity System

http://rpm.nrel.gov/refhighre/dispatch/dispatch.html



- **RE generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050—while meeting electricity demand on an hourly basis in every region of the country.**
- **The abundance and diversity of U.S. renewable energy resources can support multiple combinations of renewable technologies to achieve high levels of renewable electricity use, and result in deep reductions in electric sector greenhouse gas emissions and water use.**

For more information

http://www.eere.energy.gov

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