Energy Efficiency & Renewable Energy: Challenges and Opportunities

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Rethink, Reimagine and Recreate the Energy EcoSystem
IEEE GreenTech 2013
Denver, CO
April 4, 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**

Speed and Scale

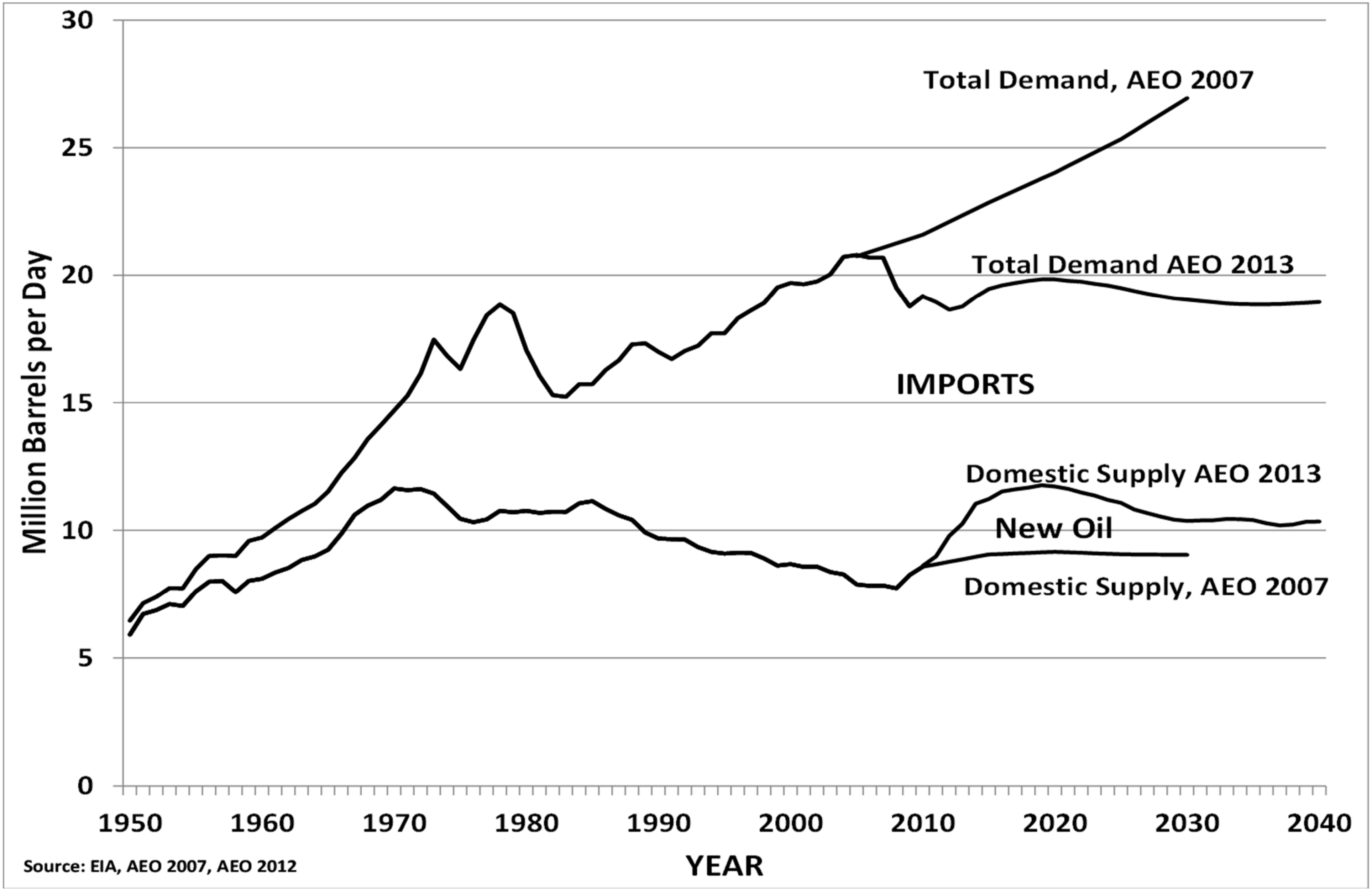
The Oil Problem

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**

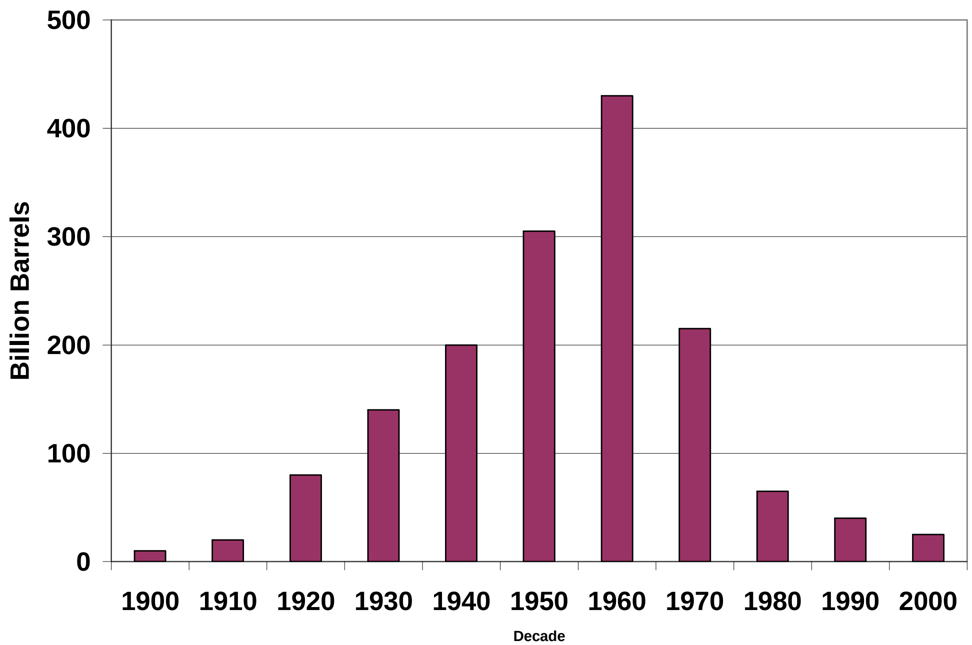
Source: EIA International Energy Annual; *Conventional Oil

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

Oil Supply and Demand?

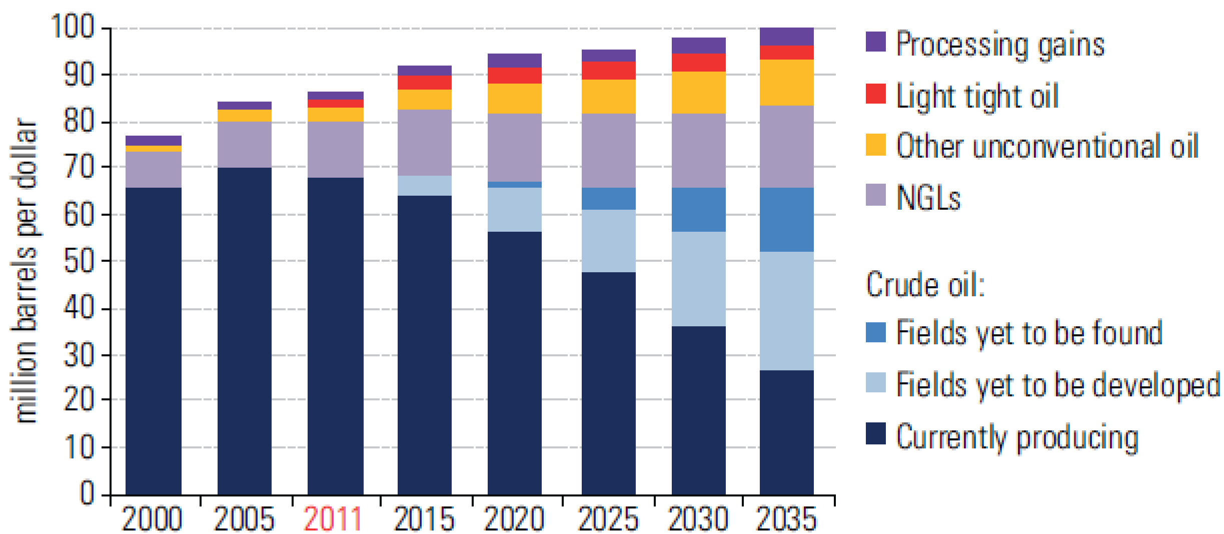


Resources and Supply Projections

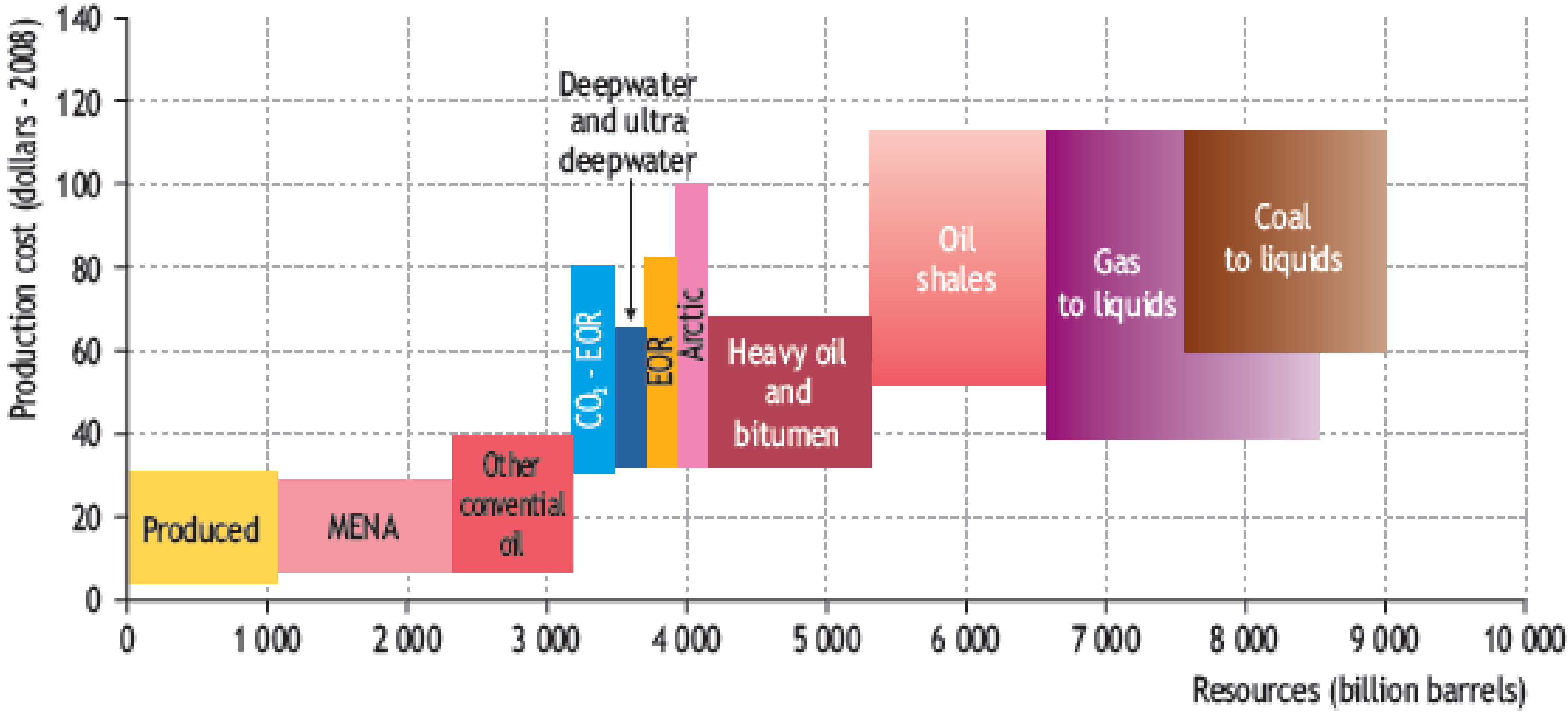


Discovery of Giant Oil Fields by Decade
Fredrik Robelius, Uppsala Universitet

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

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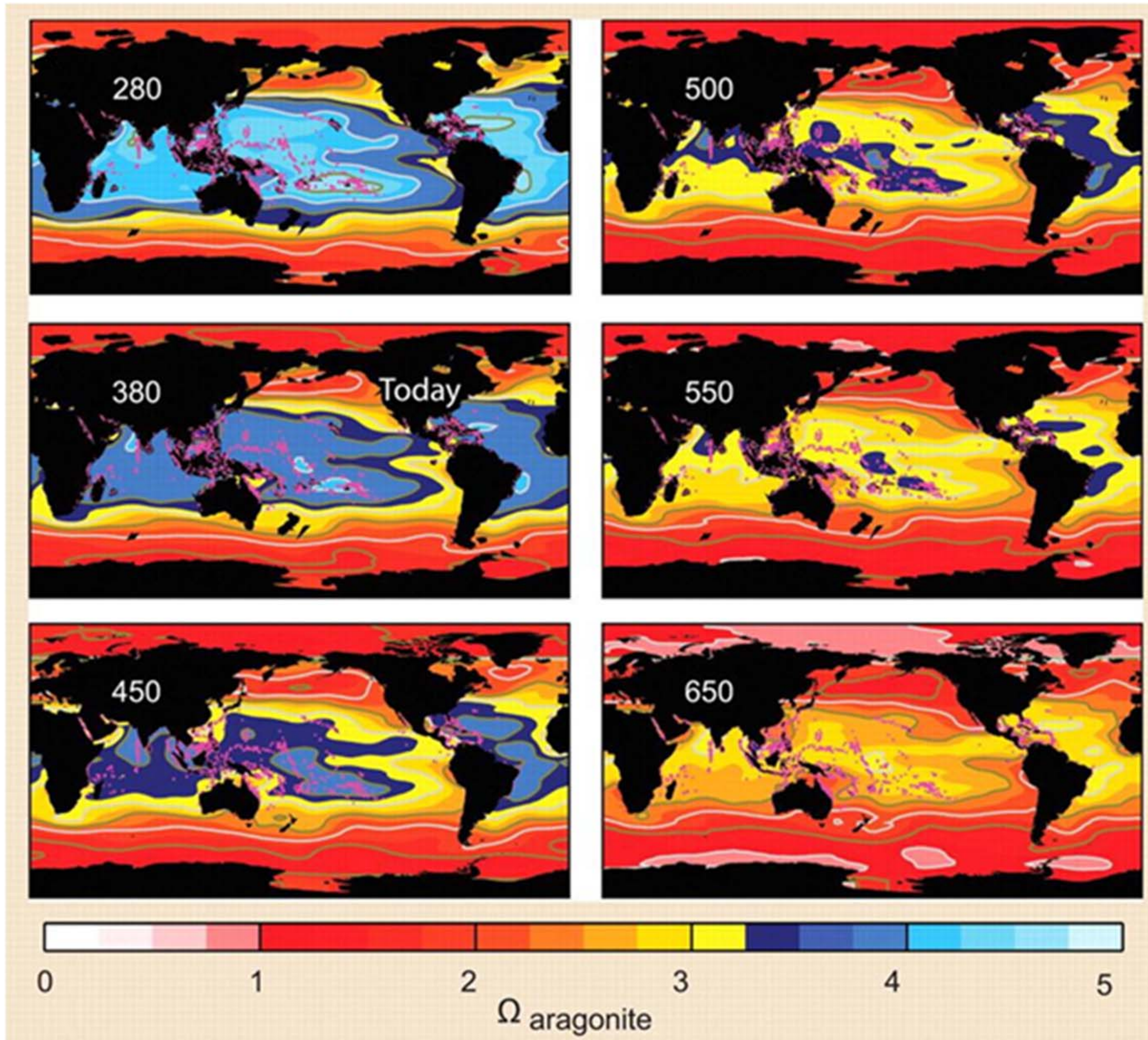
Potential Impacts of GHG Emissions

- **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.....

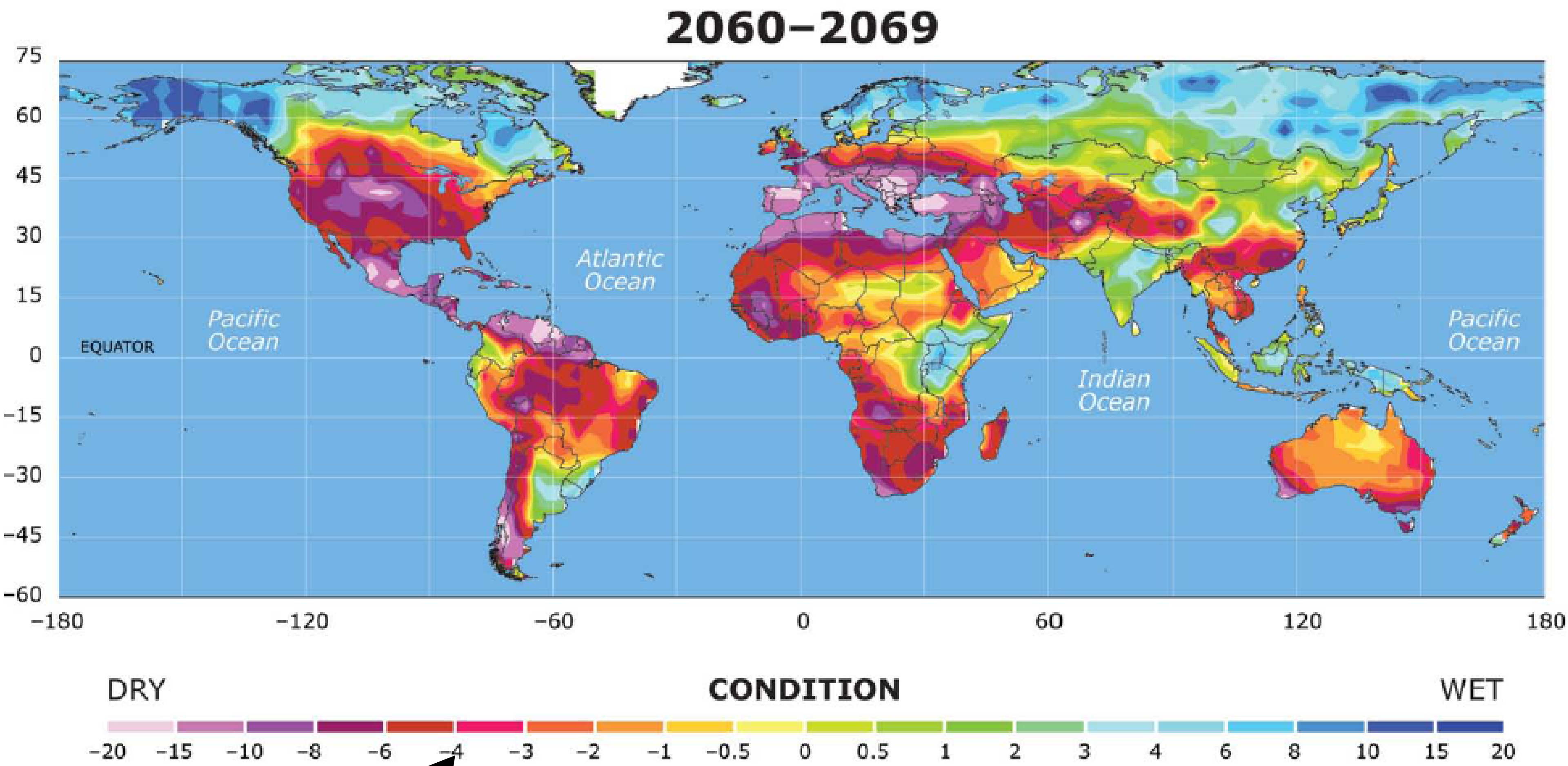
- **"The rapid increase in CO_2 emissions since the industrial revolution has increased the acidity of the world's oceans with potentially profound consequences for marine plants and animals, especially those that require calcium carbonate to grow and survive, and other species that rely on these for 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?



Extreme Drought

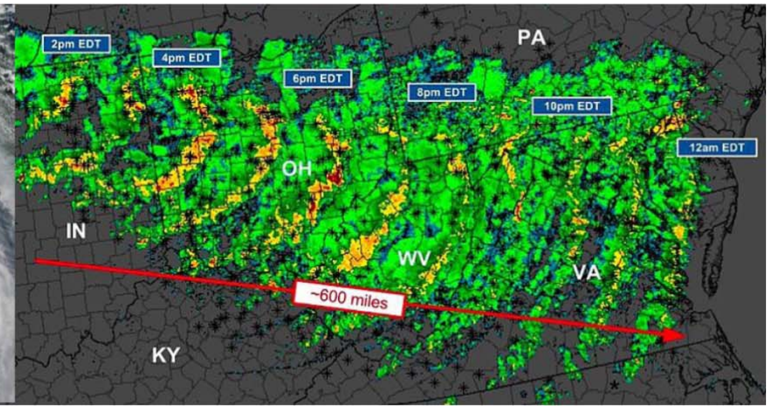
Aiguo Dai, "Drought under global warming: a review", Wiley InterDisciplinary Review: Climate Change, 2010; http://onlinelibrary.wiley.com/doi/10.1002/wcc.81/pdf
Aiguo Dai, "Increased drought under global warming in observations and models", Nature Climate Change V.3, Jan. 2013, pp.52-58.

Storms and Power System Interruptions

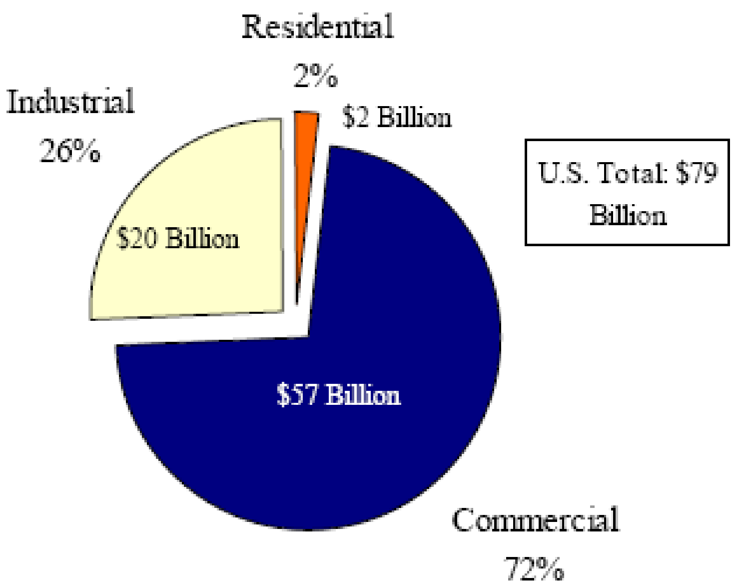
Chip East / Reuters file

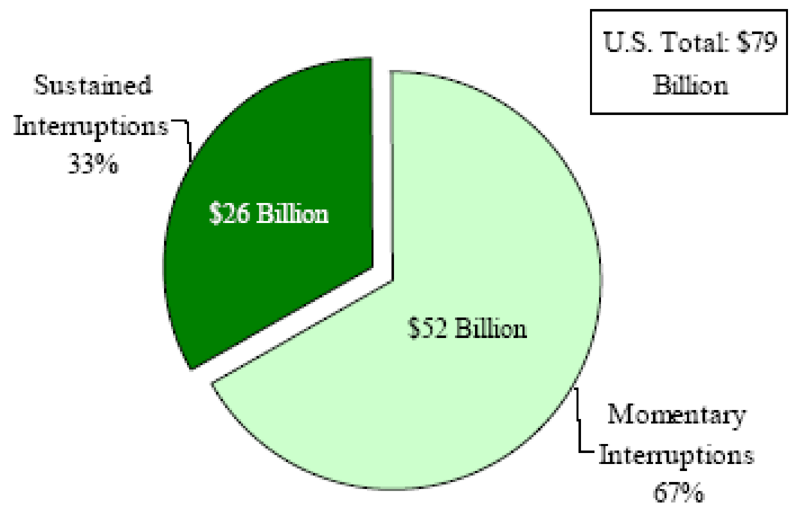
Northeast Blackout
New York City
August 2003

Hurricane Katrina
August 2005



Midwest & Mid-Atlantic
Derecho
June 2012





Kristina Hamachi LaCommare, and Joseph H. Eto, LBNL

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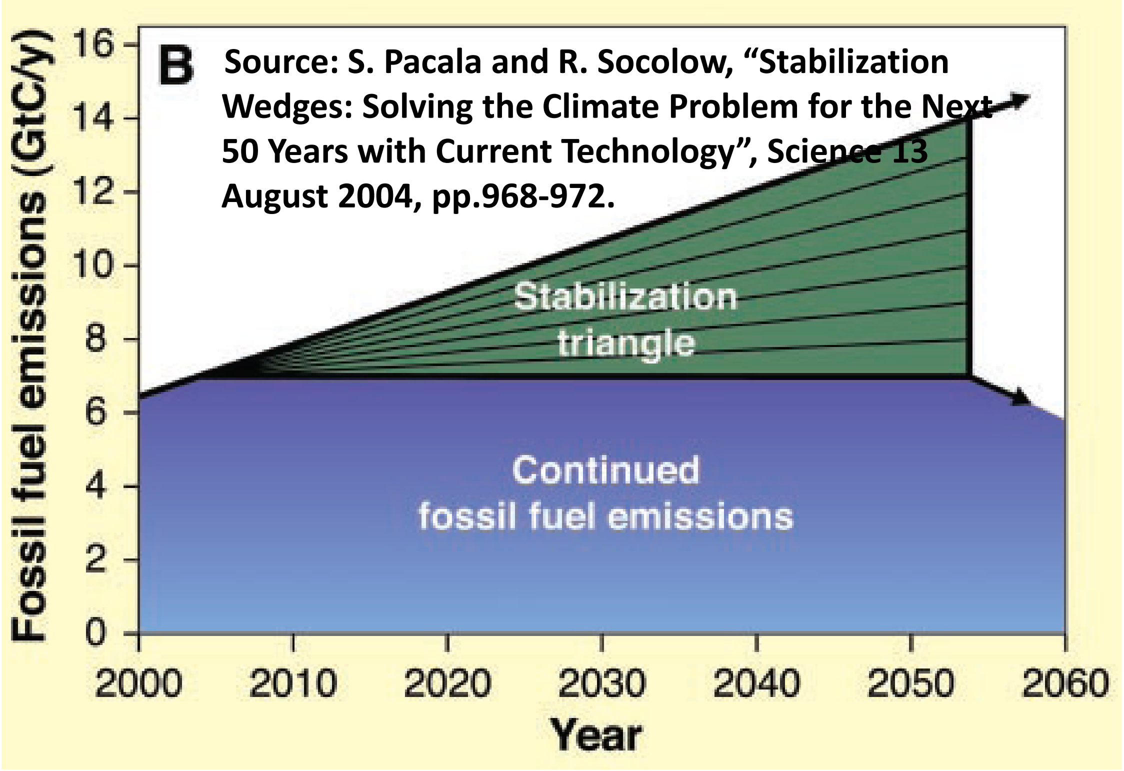
Scale of the Challenge

- 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

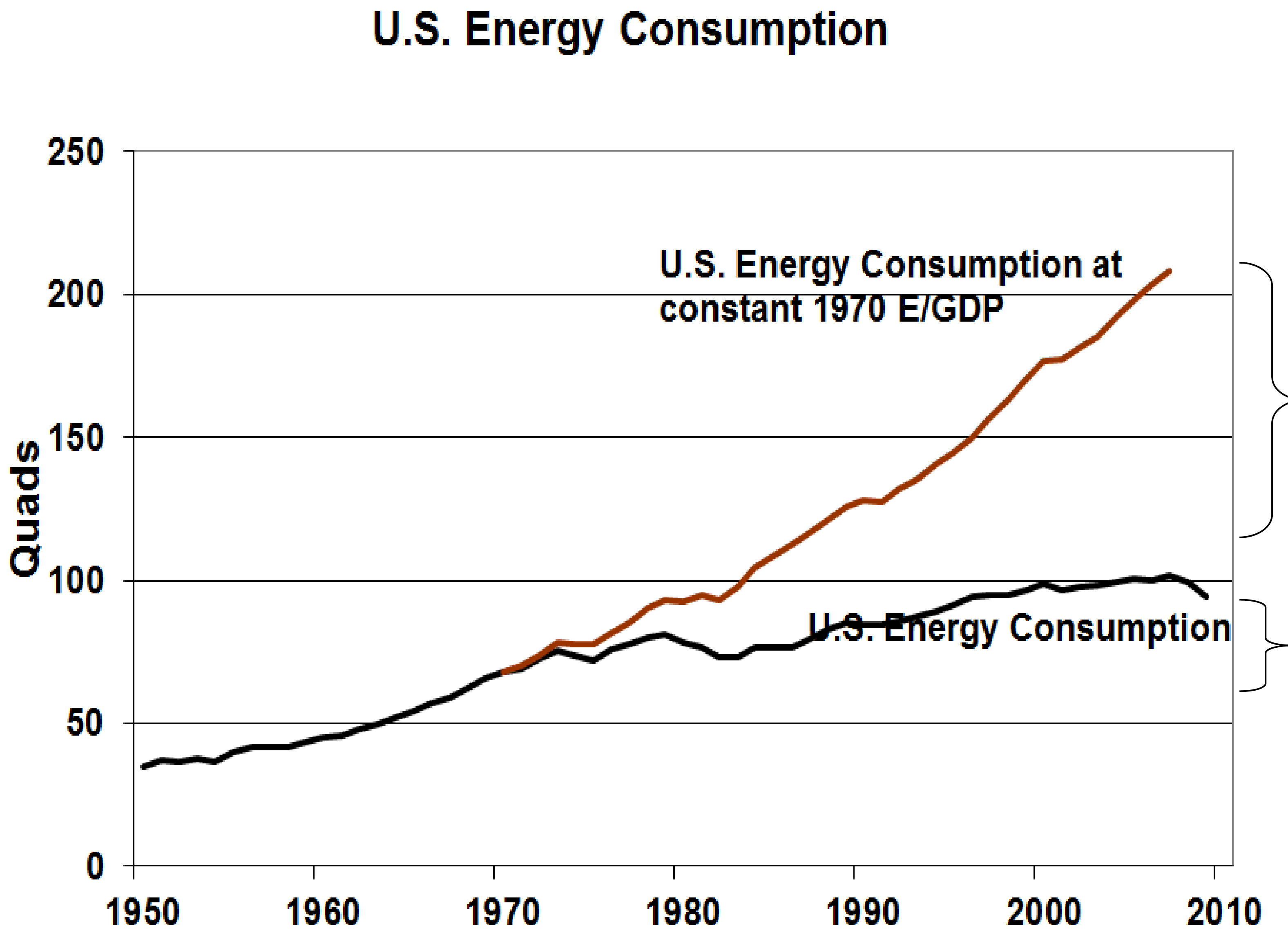
Speed and Scale

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?

Energy Efficiency: 1970-2010

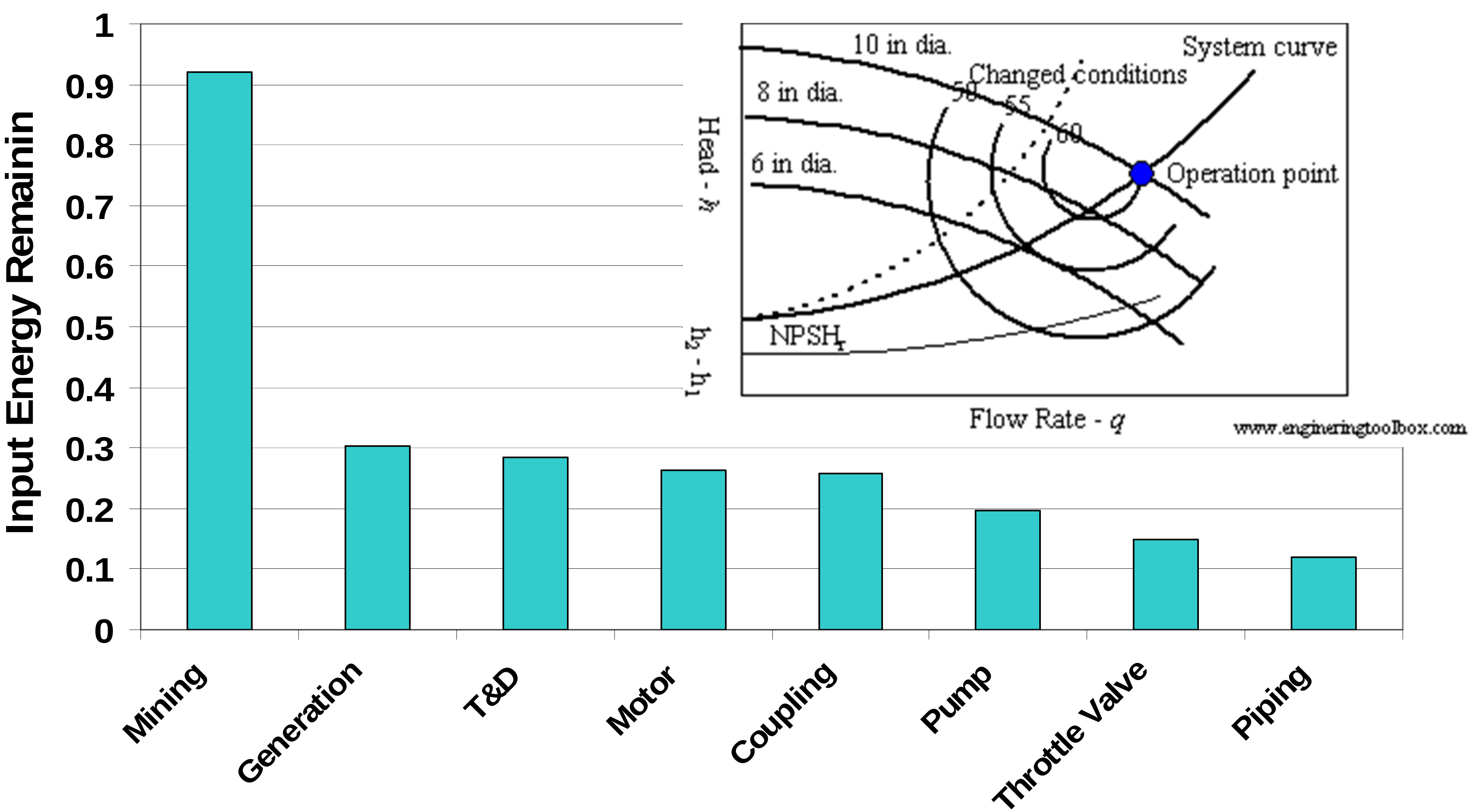


Efficiency; Structural Change: Total ~100+

New Supply
Gas 1.8Q
RE 2.8
Nucl 8.2
Oil 10.3
Coal 10.5
Total ~34

End-use Efficiency Upstream Leverage

Motor Drive System Efficiency



Reducing energy loss in end-use systems has large leverage upstream!

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Solar Decathlon

8-18 October 2009

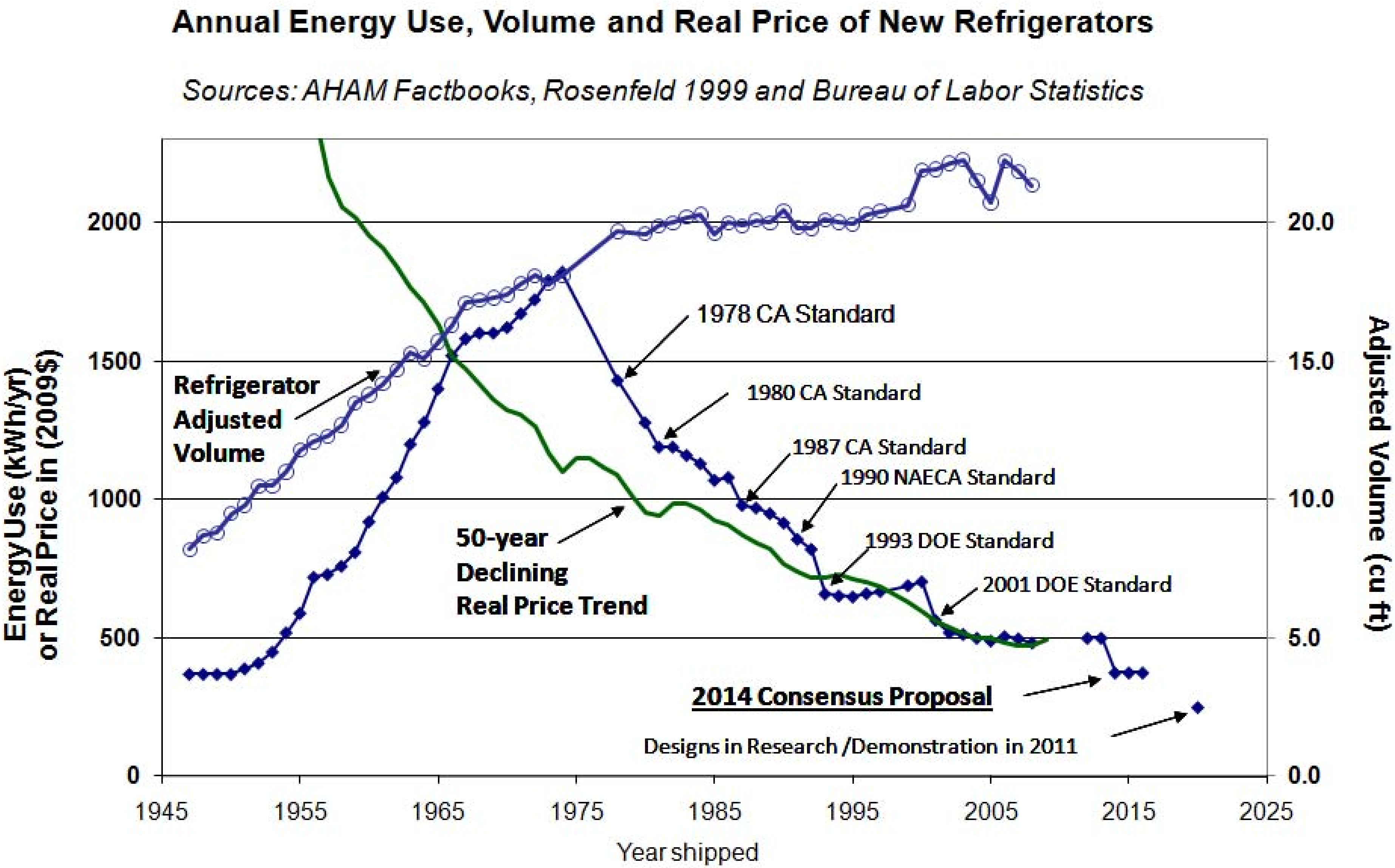
Architecture
Engineering
Market Viability
Communications
Comfort

Appliances
Hot Water
Lighting
Energy Balance
Net Metering

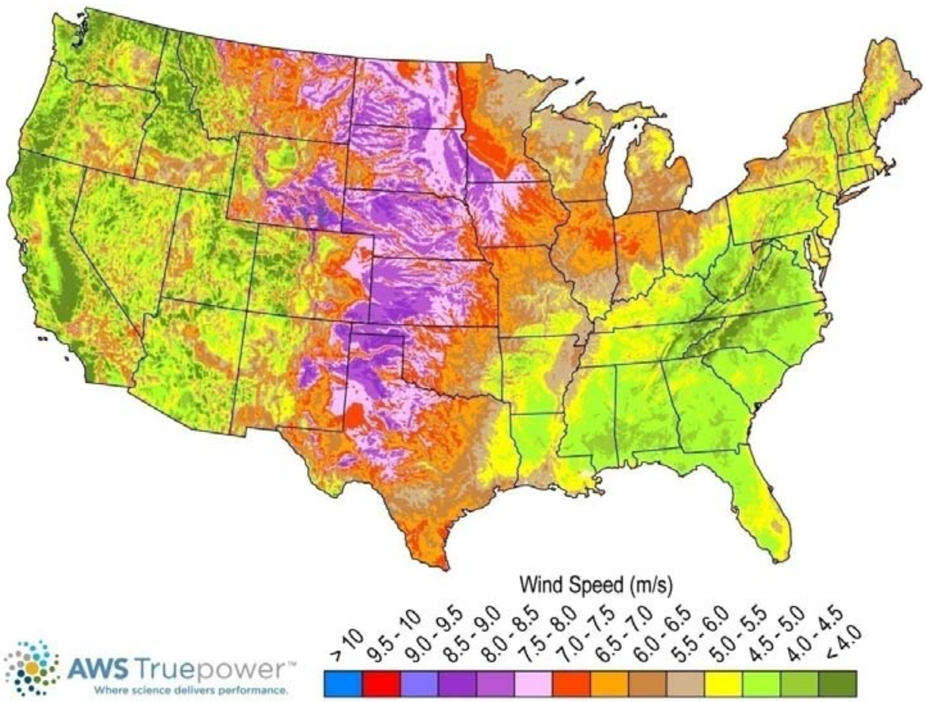
Cornell; Iowa State; Penn State; Rice; Team Alberta (U. Calgary, SAIT Polytechnic, Alberta College, Mount Royal College); Team Boston (Boston Architectural College, Tufts); Team California (Santa Clara U., California College of Arts); Team Missouri (Missouri S&T, U. Missouri); Team Ontario/BC (U. Waterloo, 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.

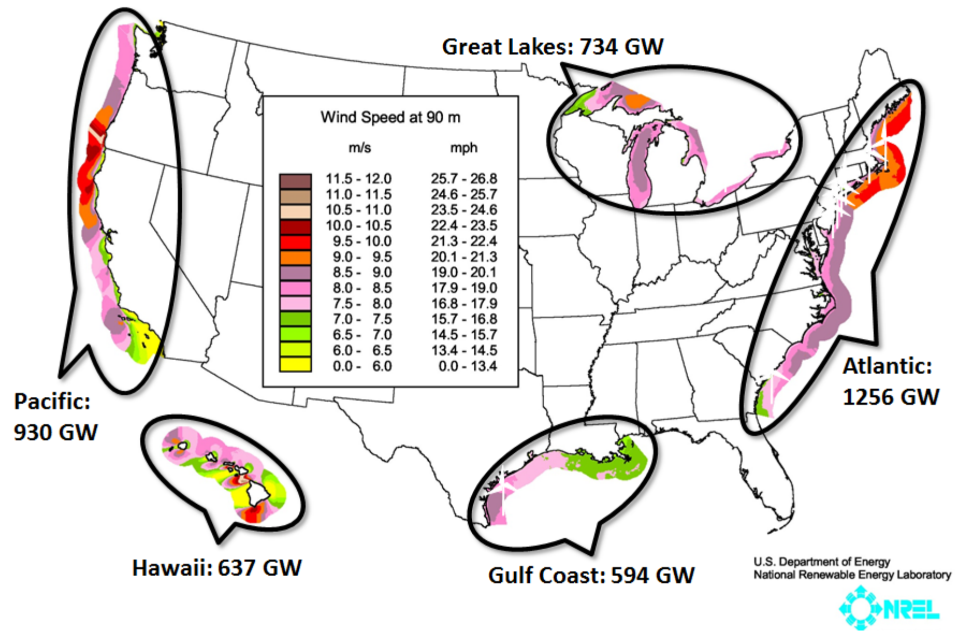
Refrigerator Performance

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



Wind Resources





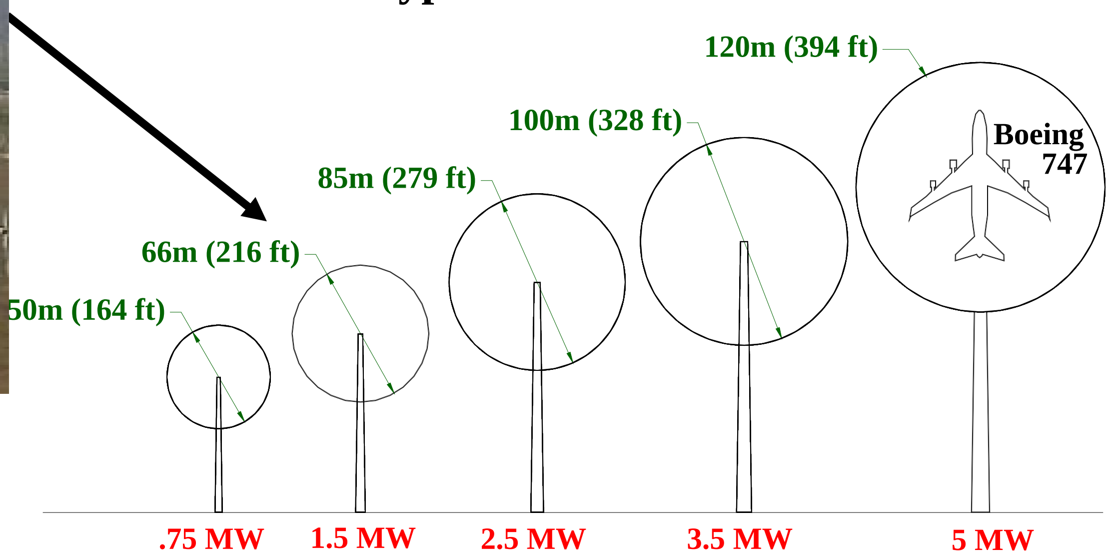
- **Highest quality wind resources are located in the Central states and offshore**
- **Fixed-bottom offshore wind resources also considered in RE Futures modeling**
- **Floating-platform offshore wind not considered in RE Futures modeling (focus on currently commercial technologies only)**
- **Combined onshore and offshore (fixed-bottom) resource is ~10,000 GW**

Wind Power

- **“20% Wind Energy by 2030”, 2008**
  - http://www1.eere.energy.gov/wind/wind_energy_report.html
- **“Eastern Wind Integration and Transmission Study”, 2010**
  - http://www.nrel.gov/electricity/transmission/eastern_renewable.html
- **“Western Wind and Solar Integration Study”, 2010**
  - http://www.nrel.gov/electricity/transmission/western_wind.html
- **Hawaii Renewable Integration and Transmission Study**
  - http://www.nrel.gov/electricity/transmission/oahu_wind.html

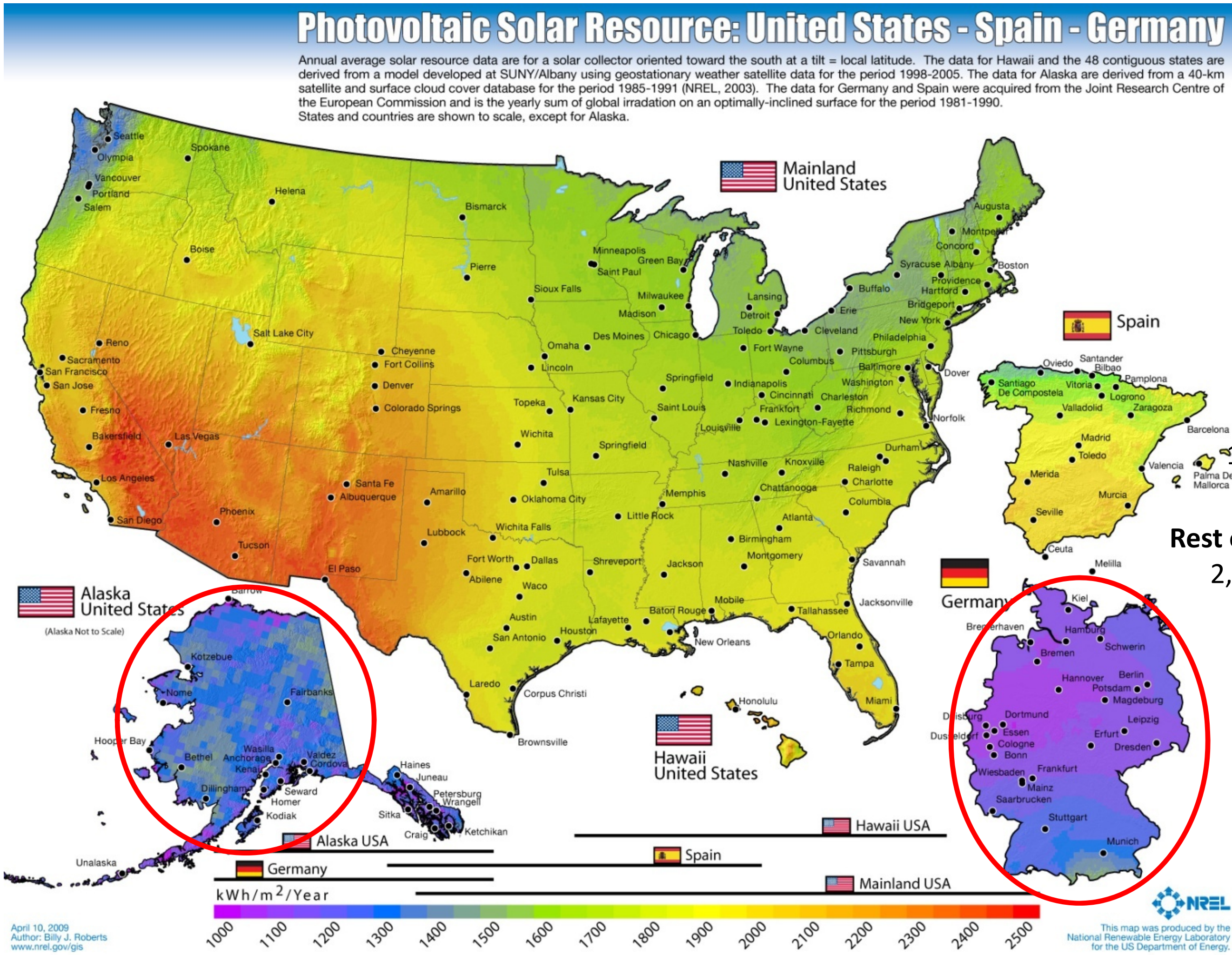
GE Wind 1.5 MW

Typical Rotor Diameters

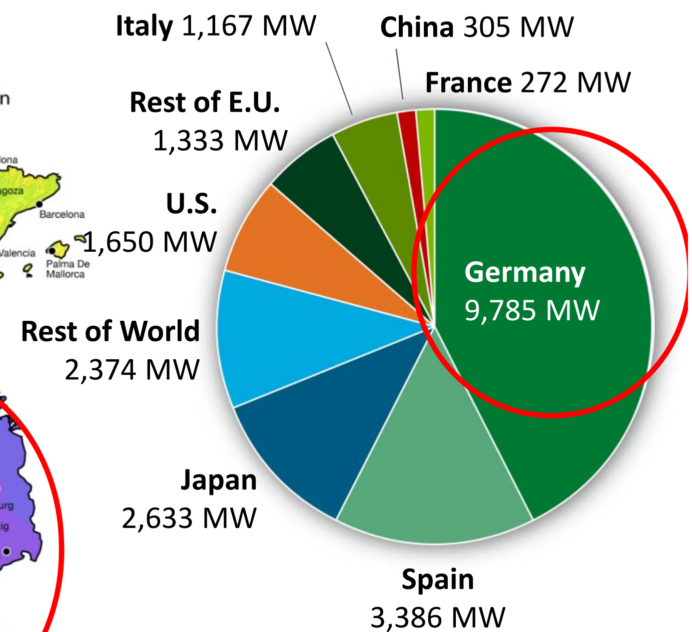


Source: EERE/WTP

Can Solar Energy Meet the Challenge?

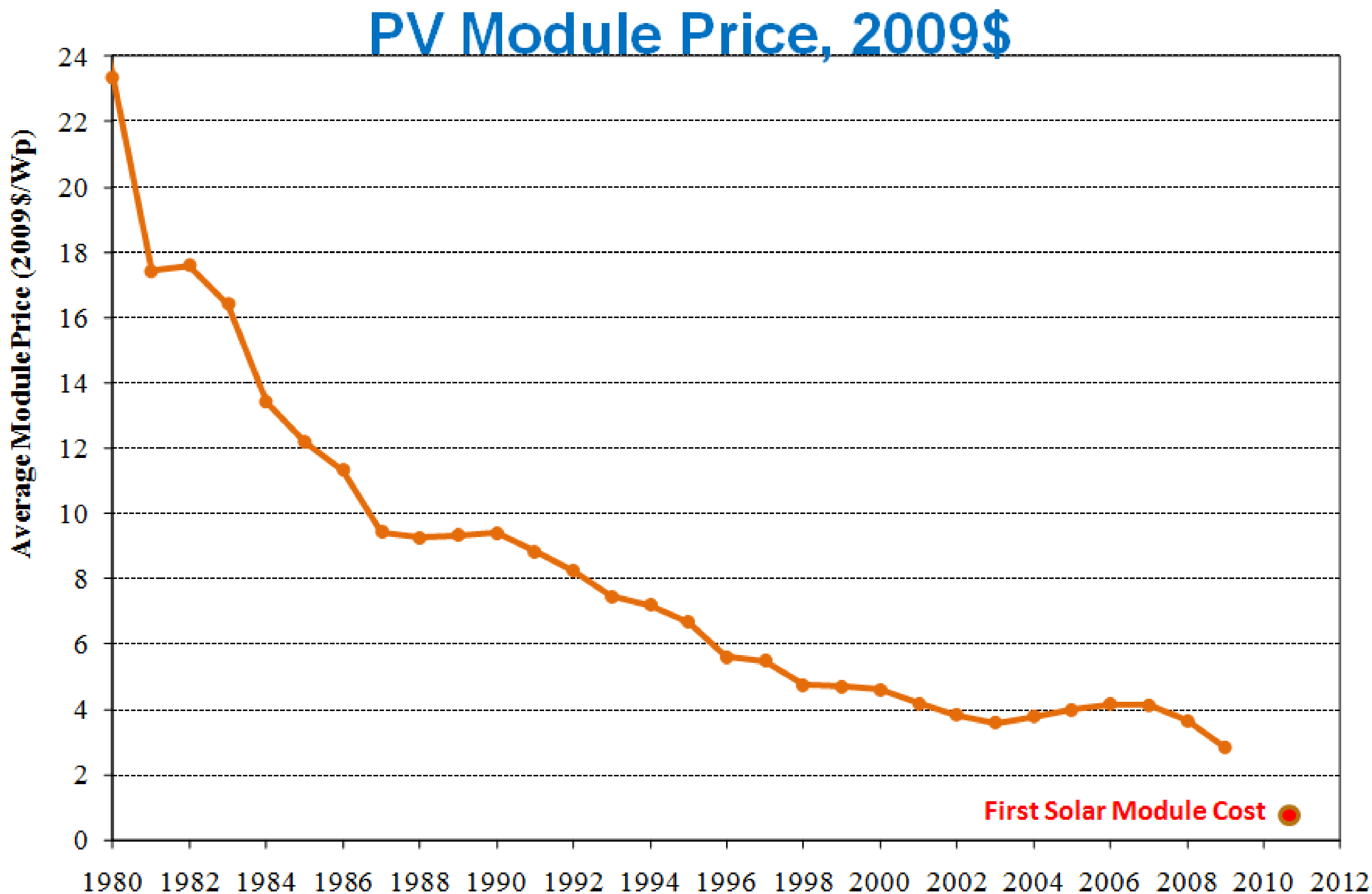


Cumulative Installed PV
(through 2009)



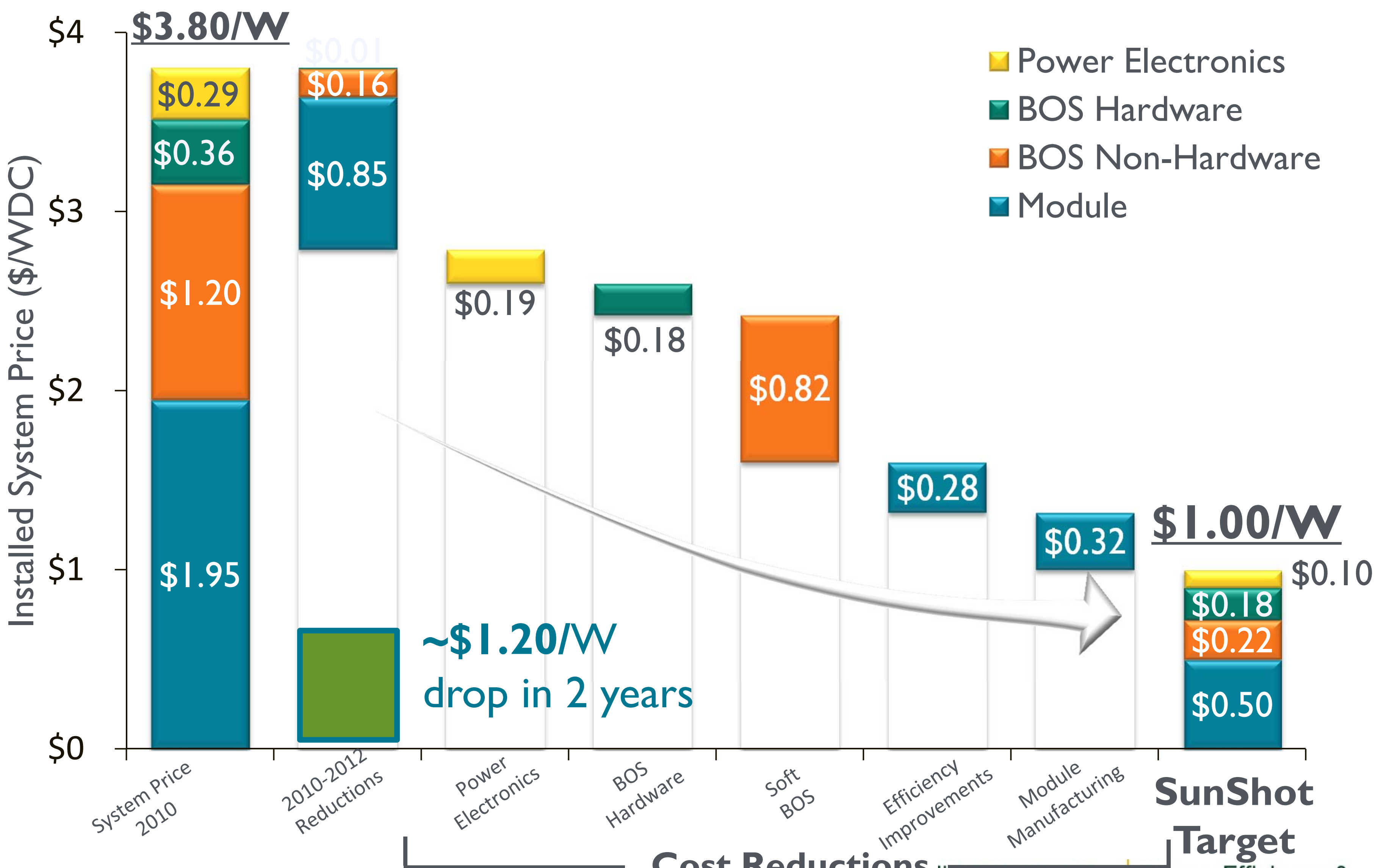
Source: EERE/SETP, Goldstein

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



Source: Navigant & Robert Margolis, NREL

SunShot: Direct Cost Competitive Solar by 2020



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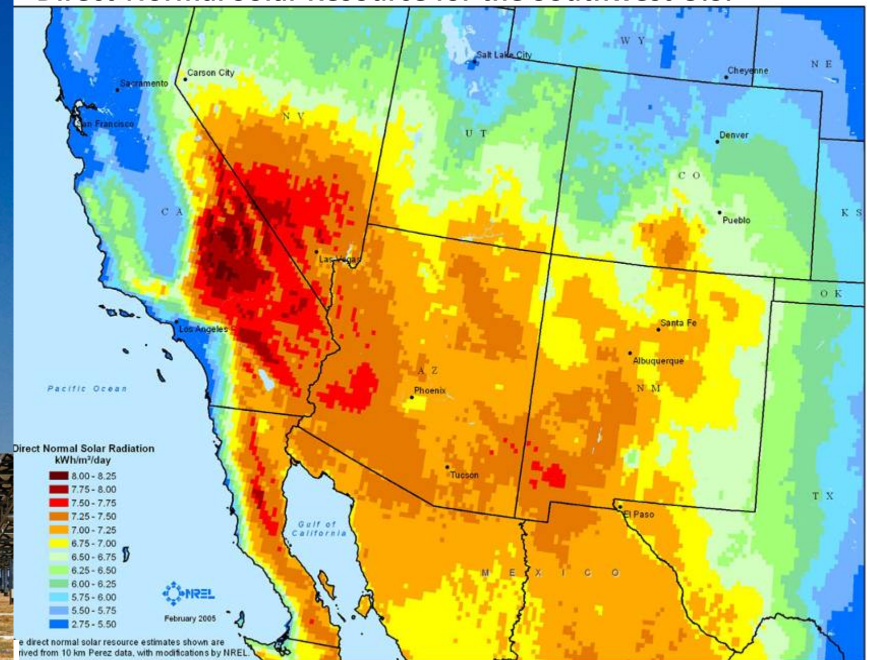
Concentrating Solar Thermal Power

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



Filters:

Transmission

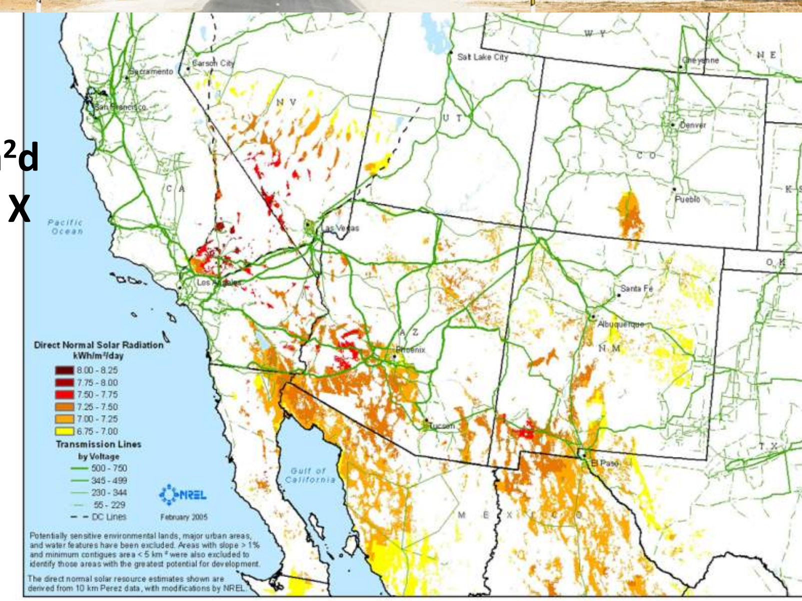
>6.75kWh/m²d

Environment X

Land Use X

Slope < 1%

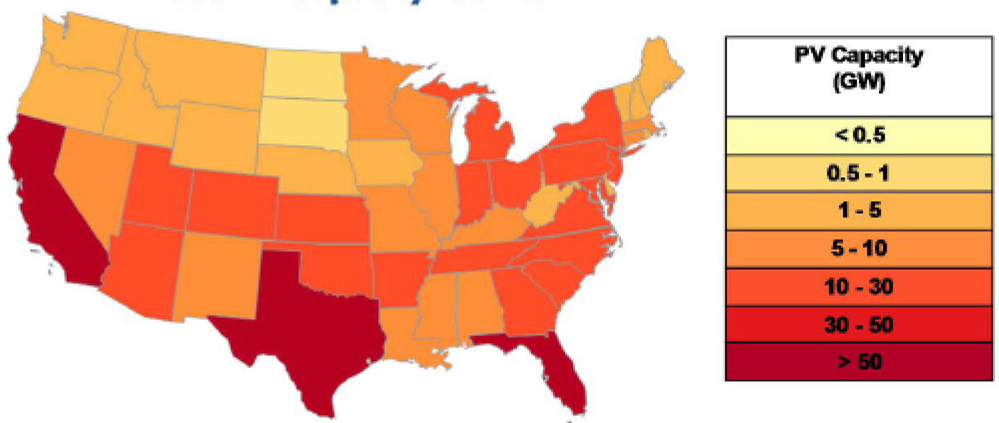
Map and table courtesy of NREL



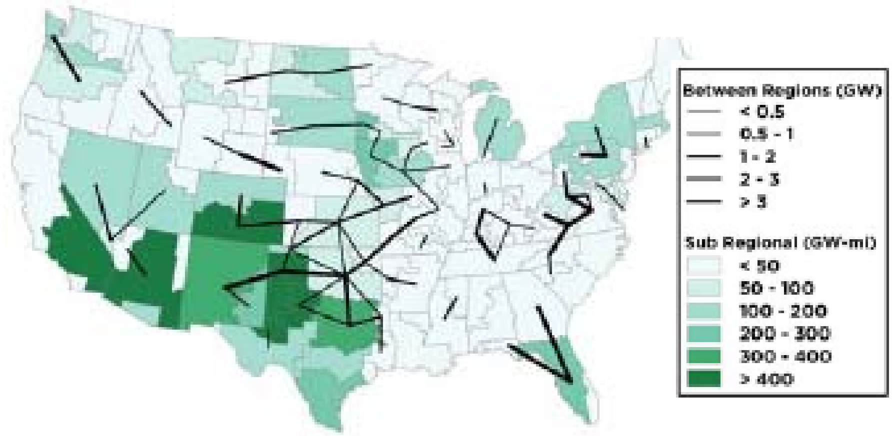
State	Land Area (mi²)	Solar Capacity (MW)	Solar Generation Capacity (GWh)
AZ	13,613	1,742,461	4,121,268
CA	6,278	803,647	1,900,786
CO	6,232	797,758	1,886,858
NV	11,090	1,419,480	3,357,355
NM	20,356	2,605,585	6,162,729
TX	6,374	815,880	1,929,719
UT	23,288	2,980,823	7,050,242
Total	**87,232**	**11,165,633**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

SunShot Vision Study

2050 PV Capacity: 632 GW

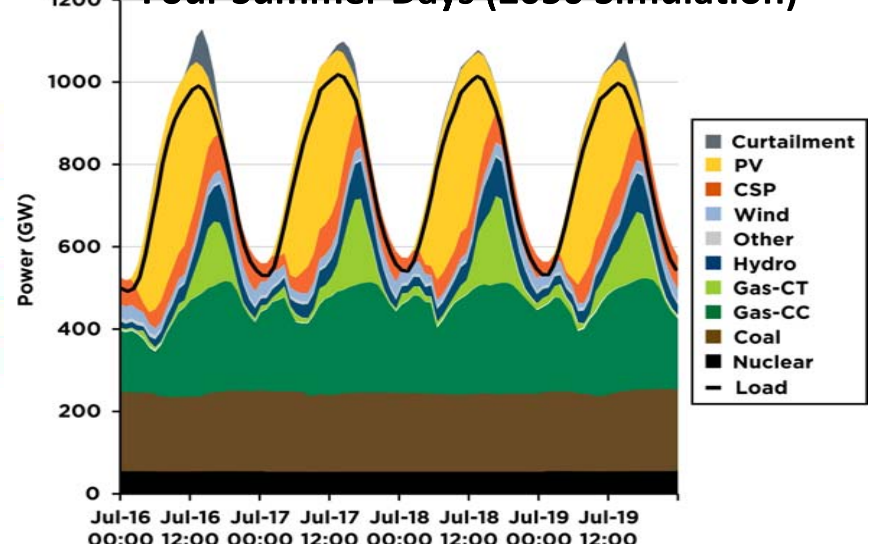


2050 Transmission Expansion



2050 CSP Capacity: 83 GW

Hourly Dispatch
Four Summer Days (2050 Simulation)



http://www1.eere.energy.gov/solar/sunshot/vision_study.html

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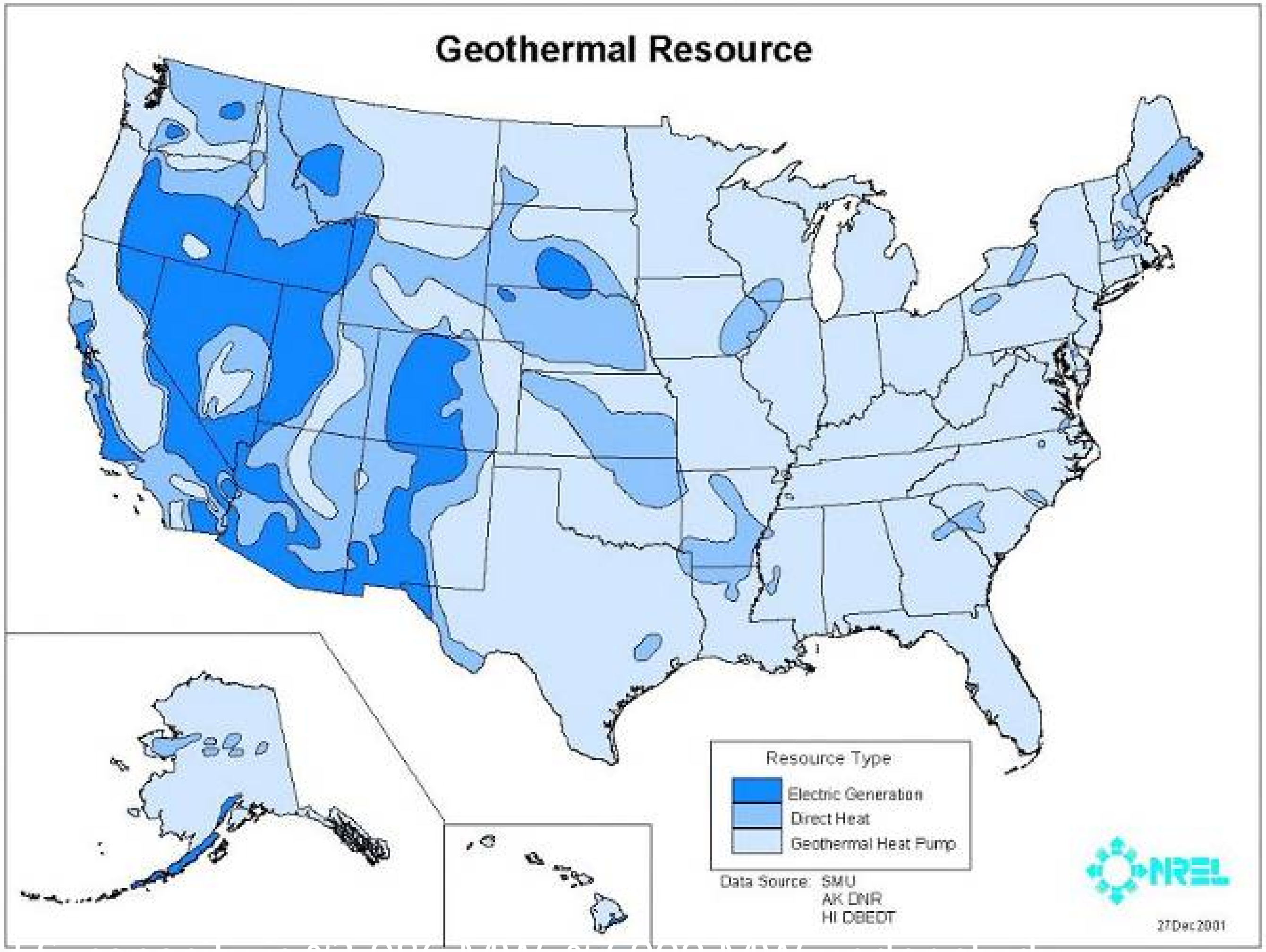
Geothermal Resources and Technologies



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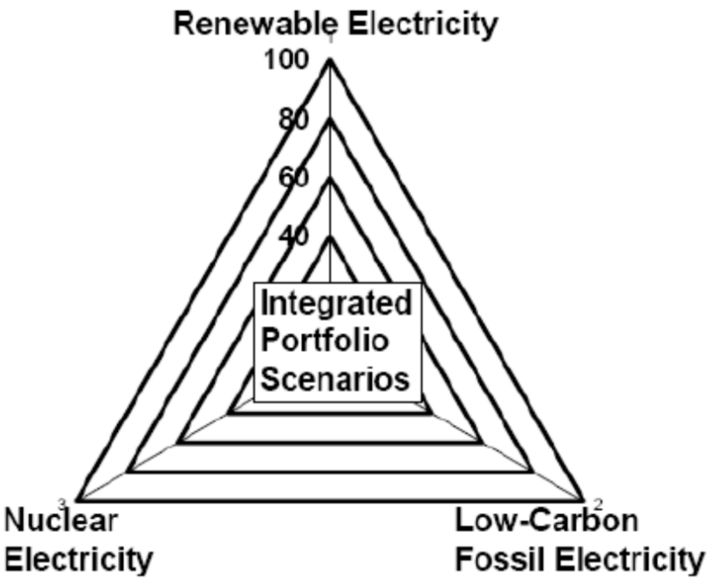
Context

- **Three primary pathways for providing clean electricity:**
  - o Renewable energy;
  - o Nuclear energy;
  - o Fossil energy with carbon capture, utilization, and storage (CCUS).

  All will likely contribute to clean electricity needs for the foreseeable future.



- **Energy efficiency improvements in end-use sectors are a critical contributor to all these pathways**

- **This multi-pathway approach is consistent with the Administration's all-of-the-above energy strategy.**
  - o In the electricity sector, this strategy is further defined by the Administration's goal of achieving 80% of electricity generation from clean electricity sources by 2035— renewables, nuclear, efficient natural gas, clean coal.

Renewable Electricity Systems

Hydropower

BioPower

Photovoltaics

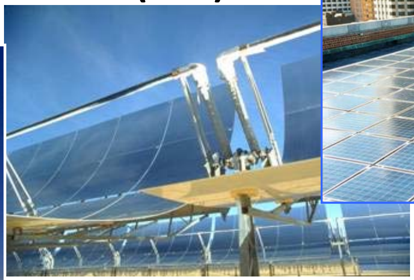
Geothermal

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 Analysis and Report

- **RE Futures is an analysis of the U.S. electric sector focused on 2050 that explores**
  - Whether the U.S. power system can supply electricity to meet customer demand with high levels of renewable electricity, including variable wind and solar generation
  - Grid integration using models with unprecedented geographic and time resolution for the contiguous U.S.
  - Synergies, constraints, and operational issues associated with a transformation of the U.S. electric sector

RE Futures is a U.S. DOE-sponsored collaboration with more than 110 contributors from about 35 organizations, including national laboratories, industry, universities, and NGOs.

- **Volume 1: Exploration of High-Penetration Renewable Electricity Futures**
- **Volume 2: Renewable Electricity Generation and Storage Technologies**
- **Volume 3: End-Use Electricity Demand**
- **Volume 4: Bulk Electric Power Systems: Operations and Transmission Planning**

Published June 2012. **www.nrel.gov/RE_Futures**

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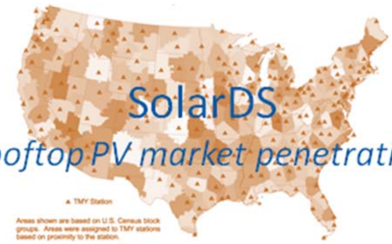
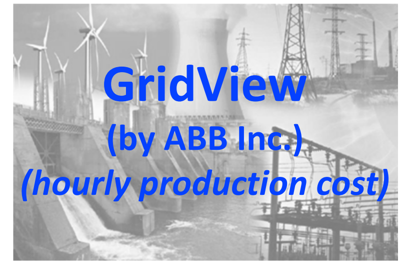
Boundaries

RE Futures does….	RE Futures does not…
Identify commercially available RE generation technology combinations that meet up to 80% or more of projected 2050 electricity demand in every hour of the year	Consider policies, new operating procedures, evolved business models, market rules, or regulatory frameworks that could facilitate high levels of RE generation
Identify electric sector characteristics associated with high levels of RE generation	Fully evaluate power system reliability
Explore a variety of high renewable electricity generation scenarios	Forecast or predict the evolution of the electric sector
Estimate associated US electric sector carbon emissions reductions	Assess optimal pathways to achieve a low-carbon electricity system
Explore a select number of economic, environmental and social impacts	Conduct comprehensive cost-benefit analysis
Illustrate a RE-specific pathway to a clean electricity future to inform the development of integrated portfolio scenarios that include consideration of all technology pathways and their implications	Provide a definitive assessment of high RE generation, but does identify areas for deeper investigation

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)

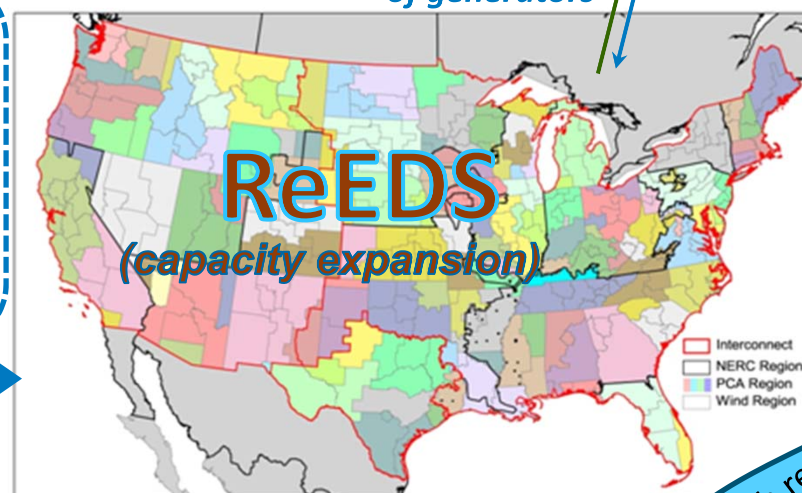
Flexible Resources

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

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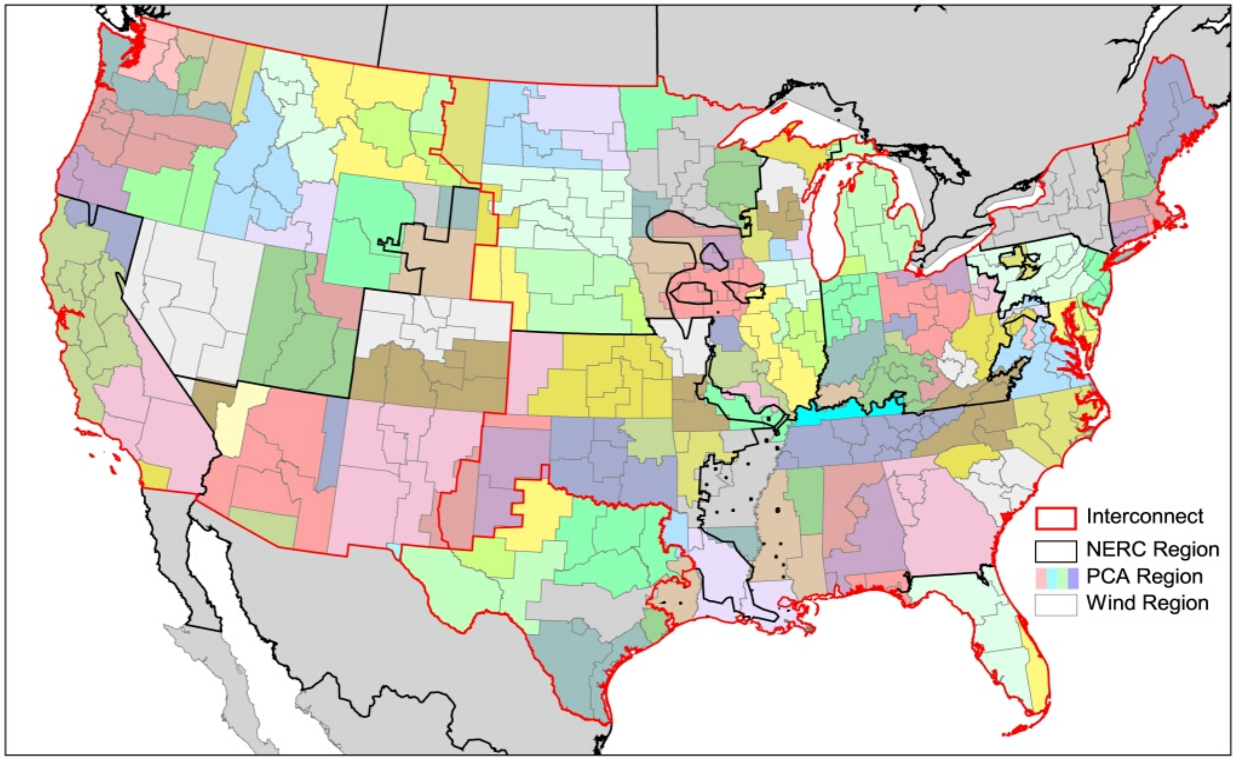
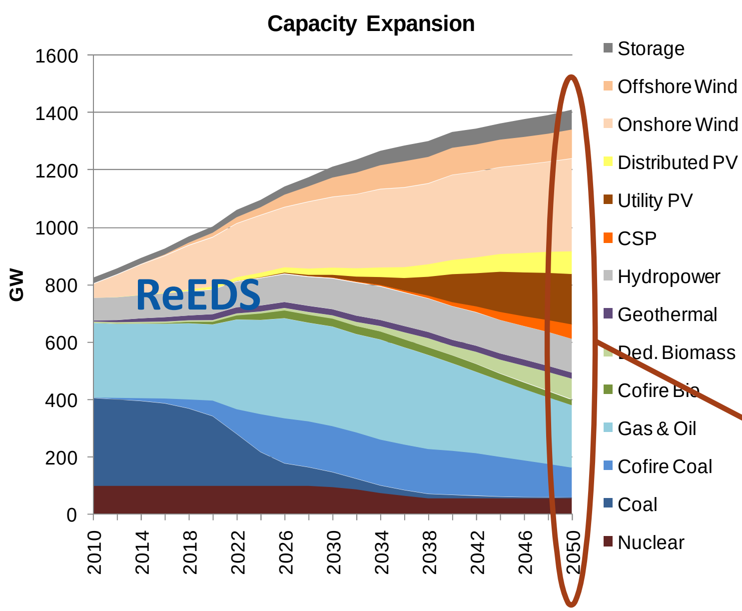
Regional Energy Deployment Systems Model (ReEDS)

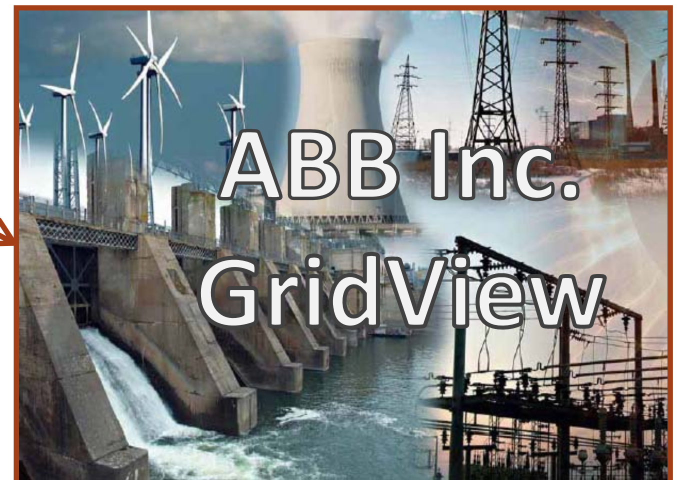
- **Capacity expansion & dispatch** for the continental U.S. electricity sector, including transmission and all major generator types
- **Minimize total system cost** in each 2-year investment period until 2050. All constraints (e.g. balance load, planning & operating reserves, etc.) must be satisfied. Linear program without inter-temporal optimization (nonlinear calcs between periods)
- **Multi-regional**: 356 regions in continental US; 134 power control areas; RTOs; States; NERC areas; Interconnection areas.
- **Temporal Resolution**: 17 time slices in each year: 4 daily x 4 seasons, 1 super-peak



Operating the Electricity System



- Commercial production cost model
- Hourly chronological model, 8760 hours
- Realistic plant flexibility parameters
- Directly simulates plant outages and forecast error events, unserved load
- Transmission: DC power flow



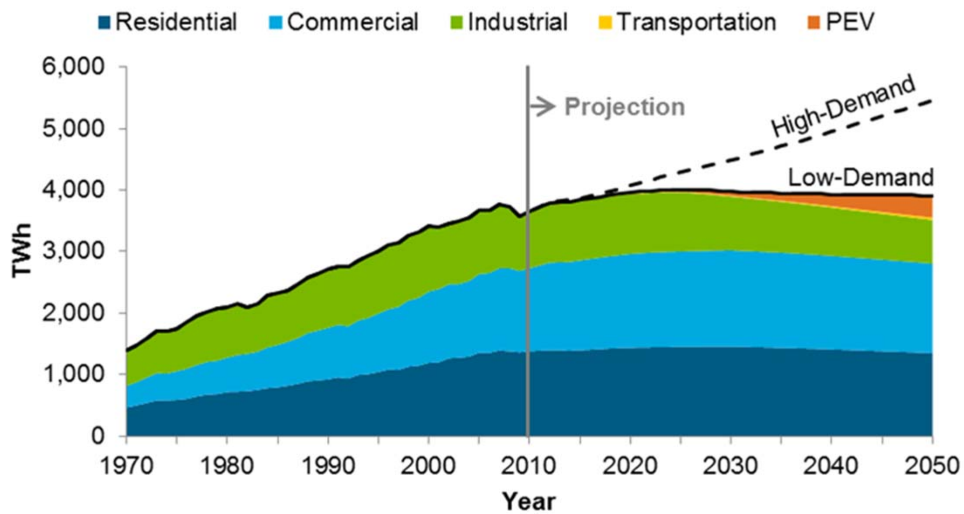
- Used by ISOs, utilities, others for planning—transmission/generation expansion; total production cost, prices, congestion, etc.
- 11,000 Generators; 85,000 Transmission lines; 34,000 Buses with load; 65,000 nodes; 136 transmission zones
- Commits/Dispatches generating units based on electricity demand, operating characteristics of generators, transmission grid parameters.

Does the system operate (hourly)?

Scenarios and Assumptions

- **Renewable Technology Improvements: NTI, ITI, ETI**
- **Exploratory Scenarios: 30%, 40%, 50%, 60%, 70%, 80%, 90%**
- **System Constraints: Transmission, Flexibility, Resources**
- **Sensitivities: Demand—High/Low, Fossil Fuel Costs—High/Low, Fossil Technology**

- **Energy Efficiency**: Most scenarios assumed significant energy efficiency measures in the residential, commercial, industrial sectors.
- **Transportation**: Most scenarios assumed a shift toward plug-in hybrid or electric vehicles, partially offsetting the electricity efficiency advances that were considered.



- **Grid Flexibility**: Most scenarios assumed improved electric system operations to enhance flexibility in both electricity generation and end-use demand, helping to enable more efficient integration of variable-output renewable electricity generation.
- **Transmission**: Most scenarios expanded transmission infrastructure and access to support renewable energy deployment. Distribution-level upgrades were not considered.
- **Siting and Permitting**: Most scenarios assumed project siting/permitting that allows RE development and transmission expansion with standard land-use exclusions.

Scenarios and Sensitivity Cases

Case	Conditions
RE-ITI	• Costs at Incremental Technology Improvement; only commercial technologies considered
RE-ETI	• Costs at Evolutionary Technology Improvement; only commercial technologies considered
RE-NTI	• Costs at 2010 levels and frozen through 2050—no technology improvement
Constrained Transmission	• Costs of transmission lines increased 3X • Only allow new transmission lines along existing corridors between BAs • Disallow new intertie capacity • Double transmission loss factors • Limit transmission of variable RE to 1,000 miles (all other scenarios assume 2,000-mile limit) • Double the deployment of rooftop PV
Constrained Flexibility	• Halve the capacity value of wind and PV • Double the reserves for wind and solar forecast errors • Set required minimum load of coal & biomass plants to 70% (all other scenarios assume 40%) • Cap availability of interruptible load to 2010 levels in all years
Constrained Resources	• Halve available resource base for all RE technologies (except utility-scale and distributed PV) • For biopower, this meant halving the available biomass feedstock
High-Demand 80% RE	• "Business-as-usual" higher growth in electricity demand • 50% greater deployment of rooftop PV
FE-Cost/Tech	• Fossil fuel costs 30% higher/lower than base; Fossil Technology advances faster than base

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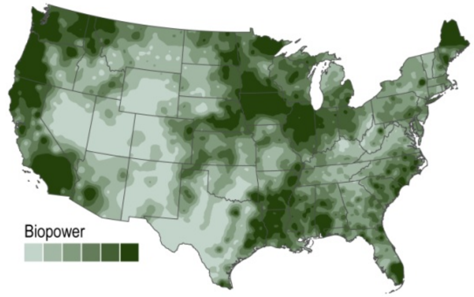
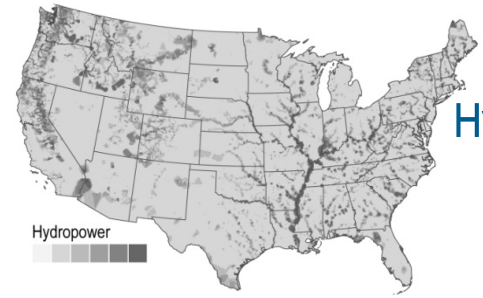
Renewable Resources and Technologies

Biopower ~100 GW
- Stand-alone
- Cofired with coal

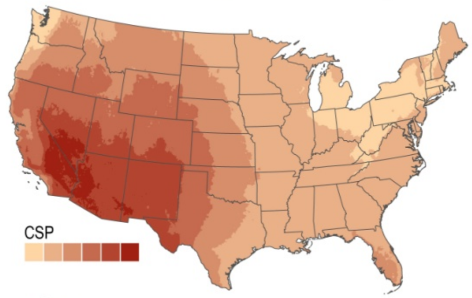


Hydropower ~200 GW
- Run-of-river

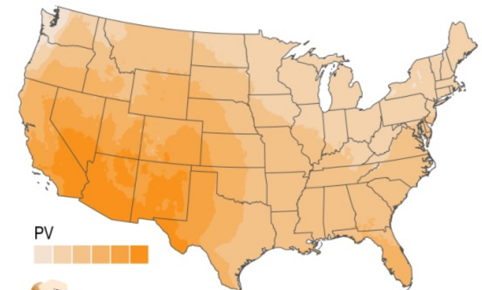


CSP ~37,000 GW
- Trough
- Tower

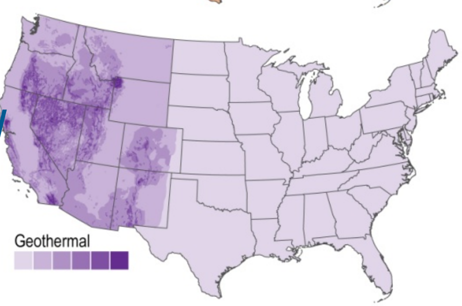
(Trough and Tower: With thermal storage)



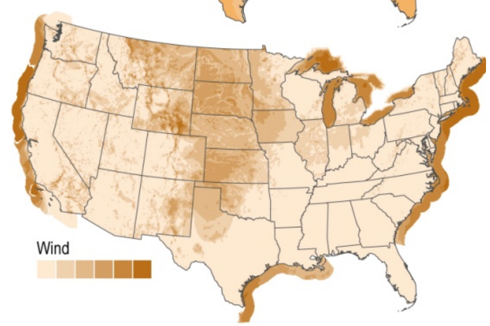
PV ~80,000 GW (rooftop ~700 GW)
- Residential
- Commercial
- Utility-scale



Geothermal ~36 GW
- Hydrothermal



Wind ~10,000 GW
- Onshore
- Offshore fixed-bottom

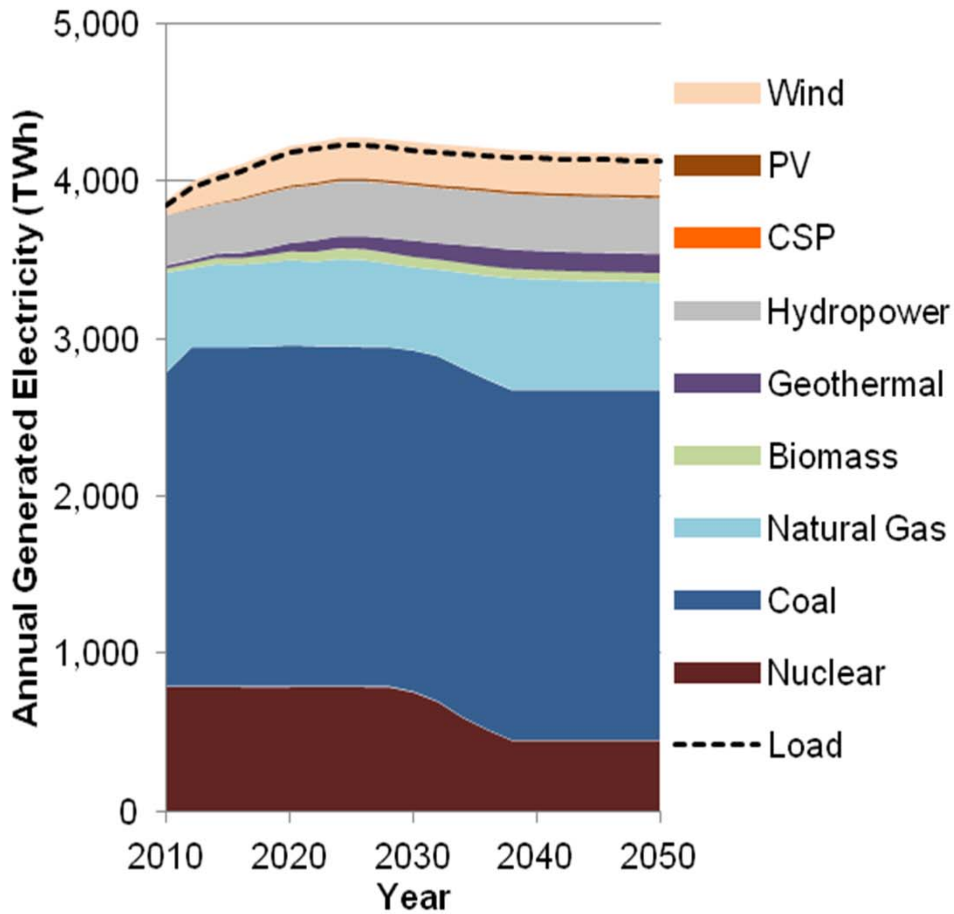


Resource
Dark = Higher
Light = Lower

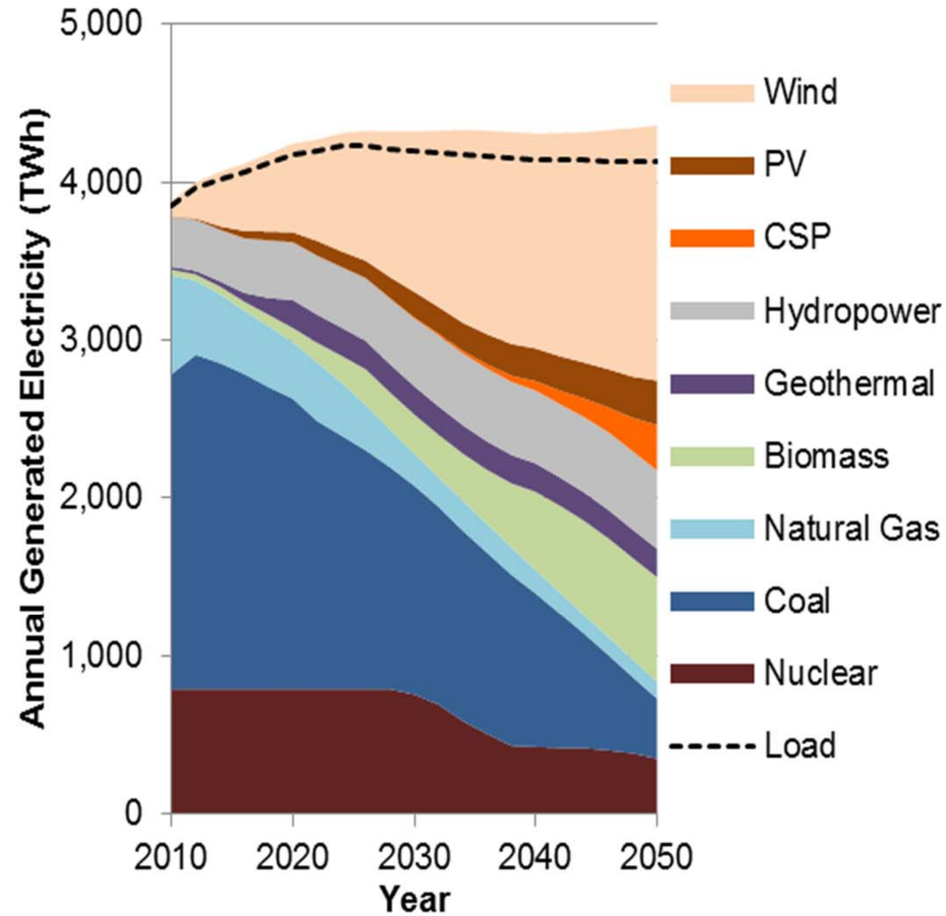
- **Only currently commercial technologies were modeled (no EGS, ocean, floating wind) with incremental and evolutionary improvements.**
- **RE characteristics, including location (exclusions), technical resource potential, and grid output (dispatchability), were considered**
- **Technical resource potential shown, not economic potential**

ReEDS Outputs

Baseline scenario



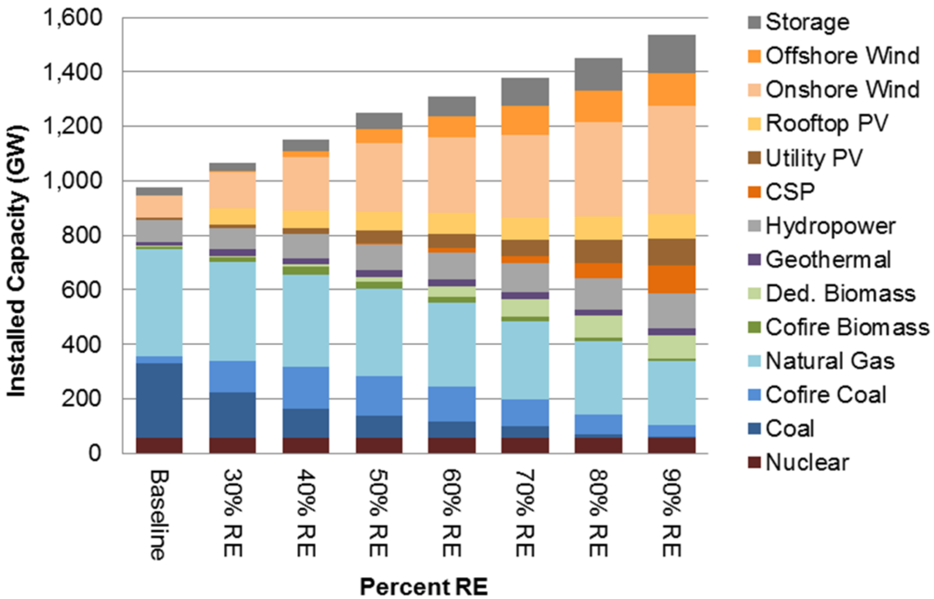
80% RE-ITI scenario

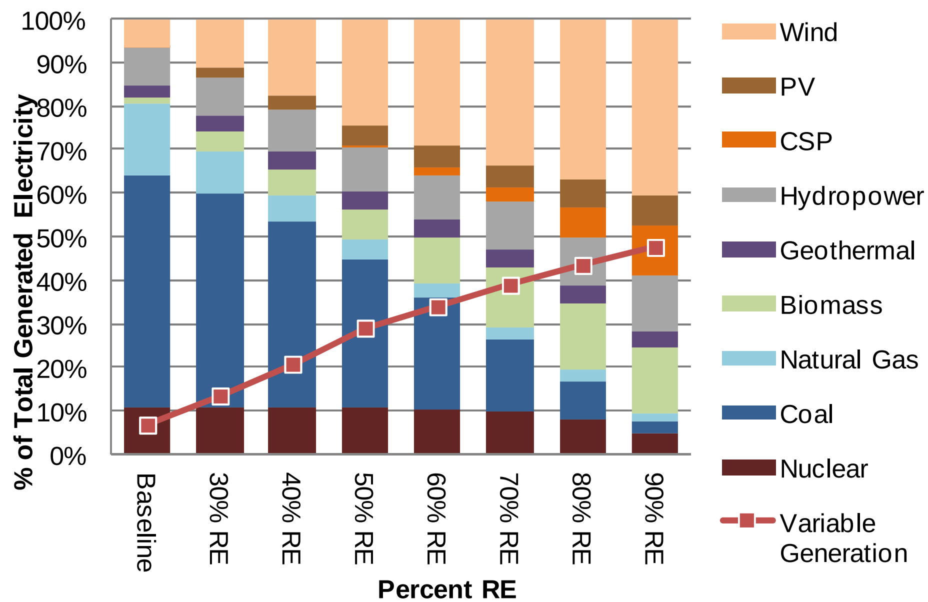


- **Renewable generation sources could supply 80% of U.S. Electricity in 2050**
- **Operational** challenges (curtailment, forecast, reserves) grow with deployment of VRE
- **Transmission** expansion can be significant with high RE targets
- **Storage** deployment grows with increasing RE targets

Renewable generation resources could adequately supply 80% of total U.S. electricity generation in 2050 while balancing supply and demand

RE-ITI scenarios





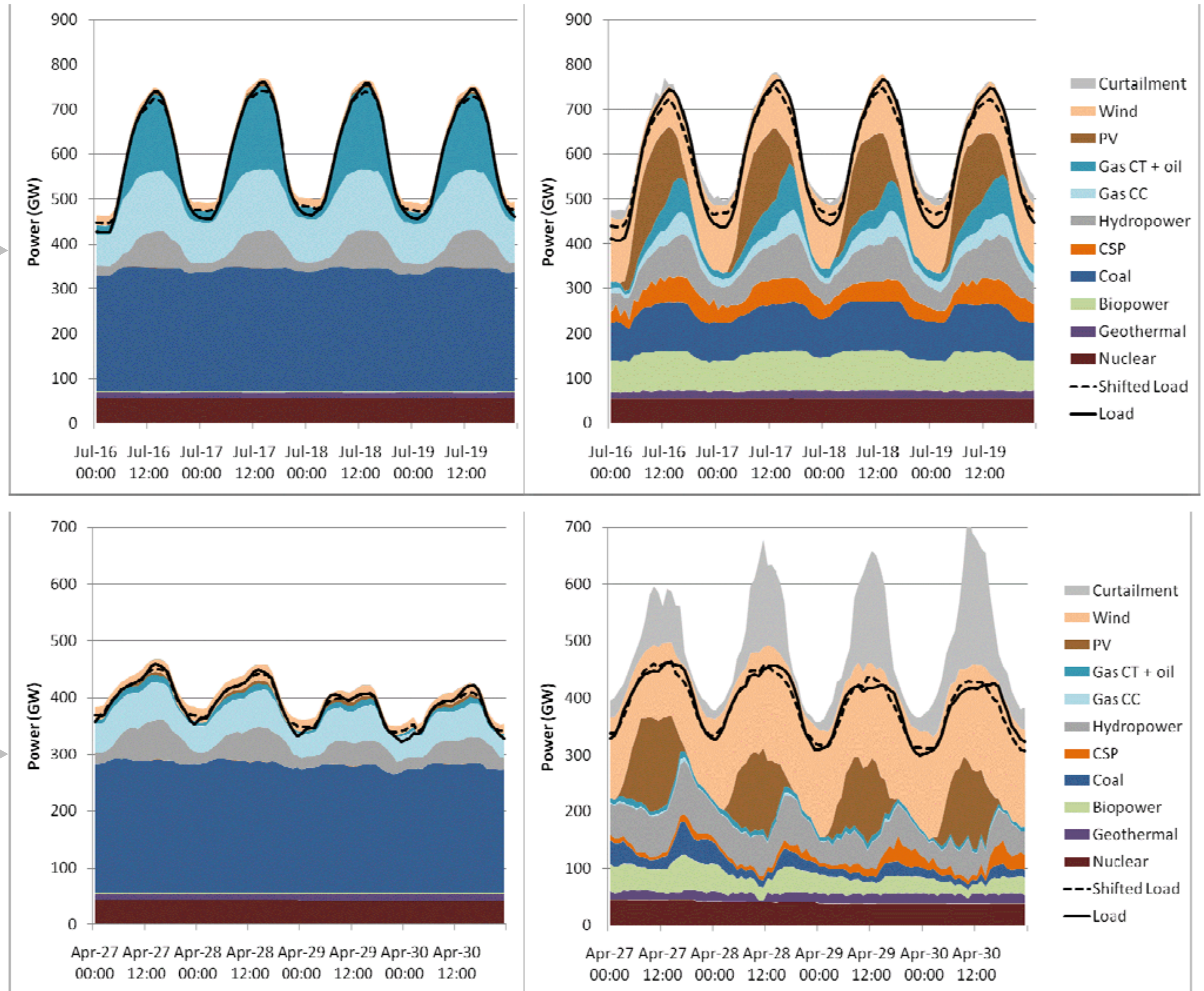
- **Deployment** significant for all major renewables
- **Operational** challenges (curtailment, forecast, reserves) grow with deployment of VRE
- **Transmission** expansion significant with high RE targets (though reduced because of the low demand assumption and reduced conventional generation)
- **Storage** deployment grows with increasing RE targets
- **Costs** rise non-linearly with RE deployment (but not exponentially)

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

Full reliability analysis not conducted in RE Futures

Summer Peak

Spring Off-Peak



Baseline

80% RE-ITI Case

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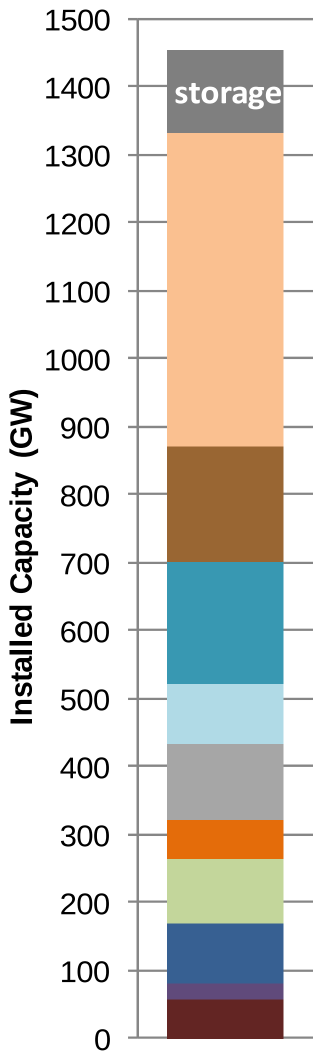
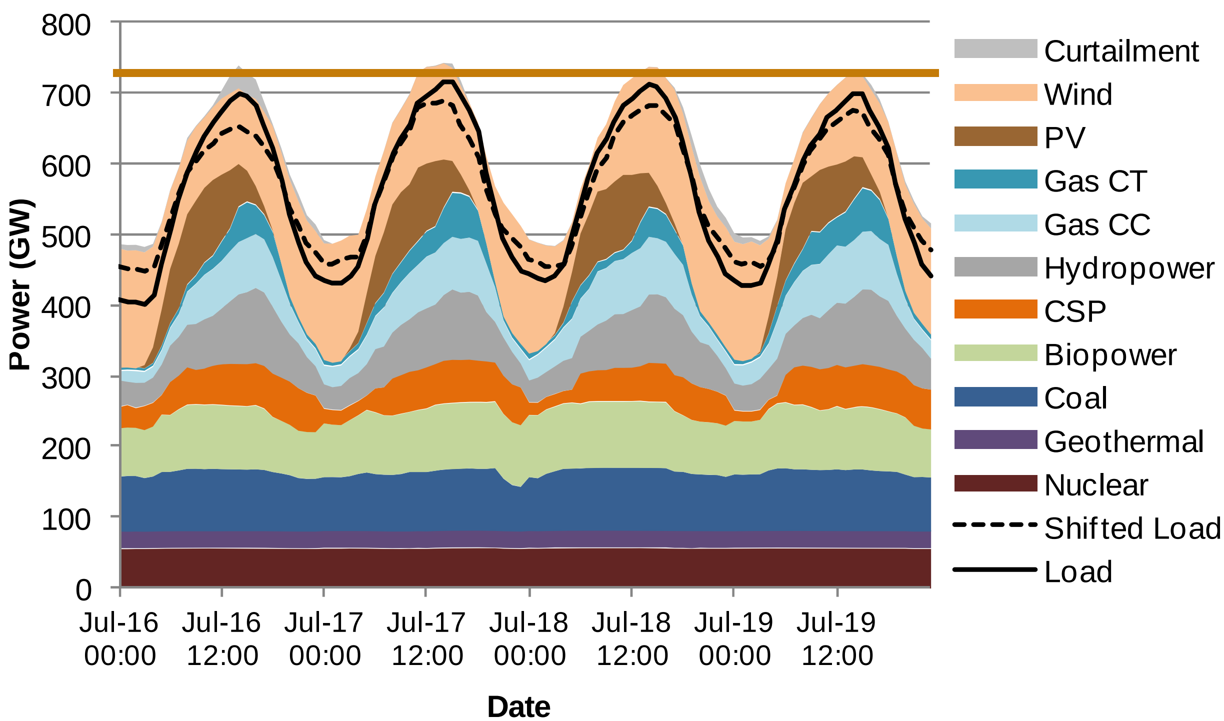
Installed capacity is sufficient to meet summer afternoon peak demand from diverse reserves

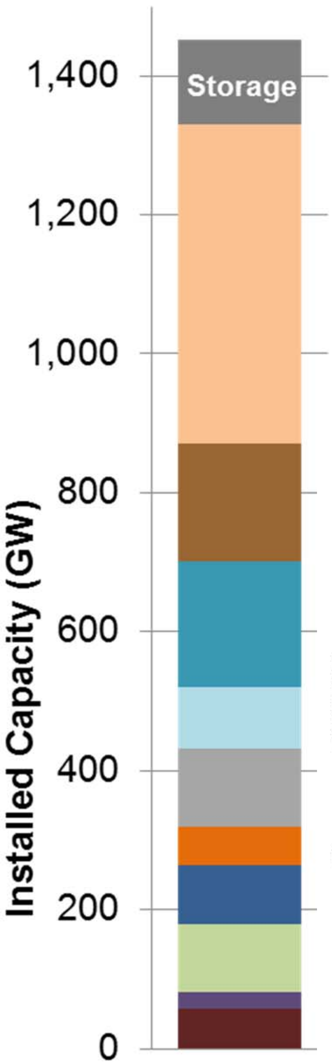


Firm capacity from:

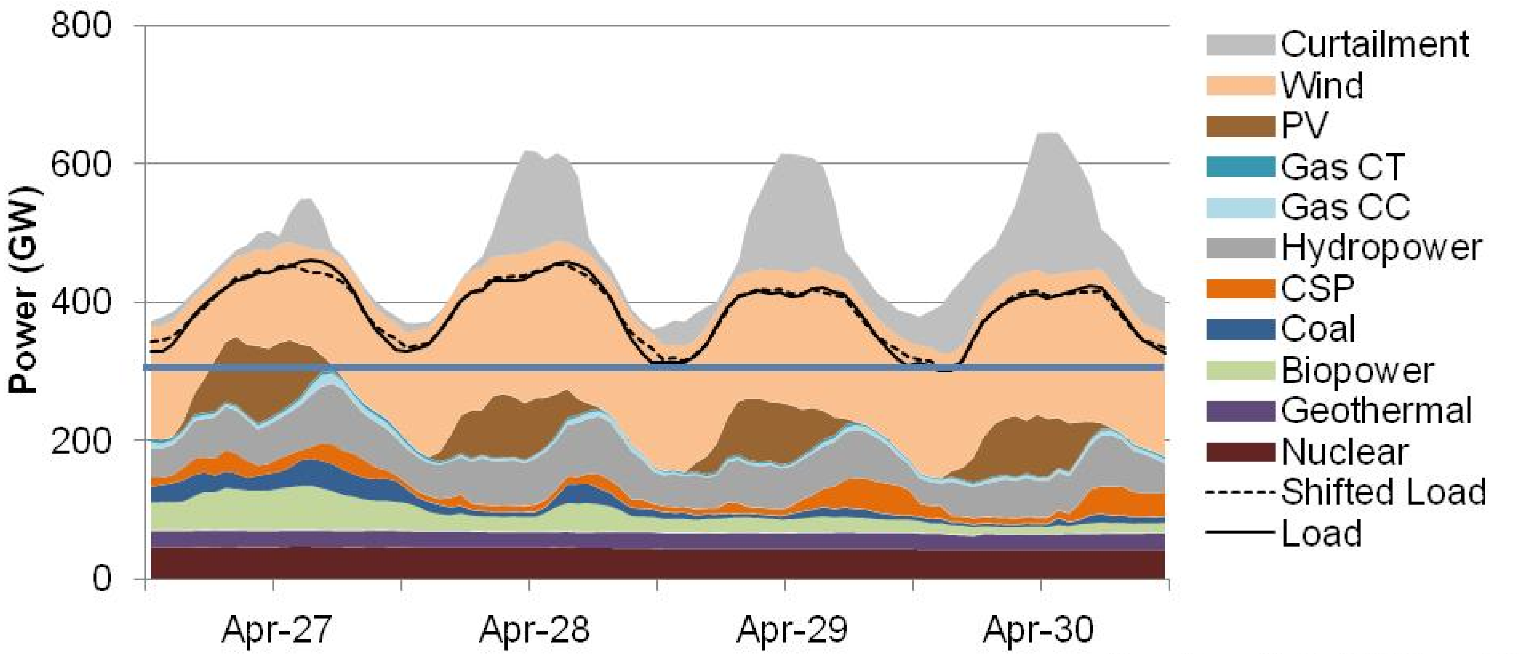
- Biopower
- Geothermal
- Hydropower
- CSP with storage
- Gas
- Coal
- Nuclear
- Utility-scale storage



Flexible Electricity System Manages Variability

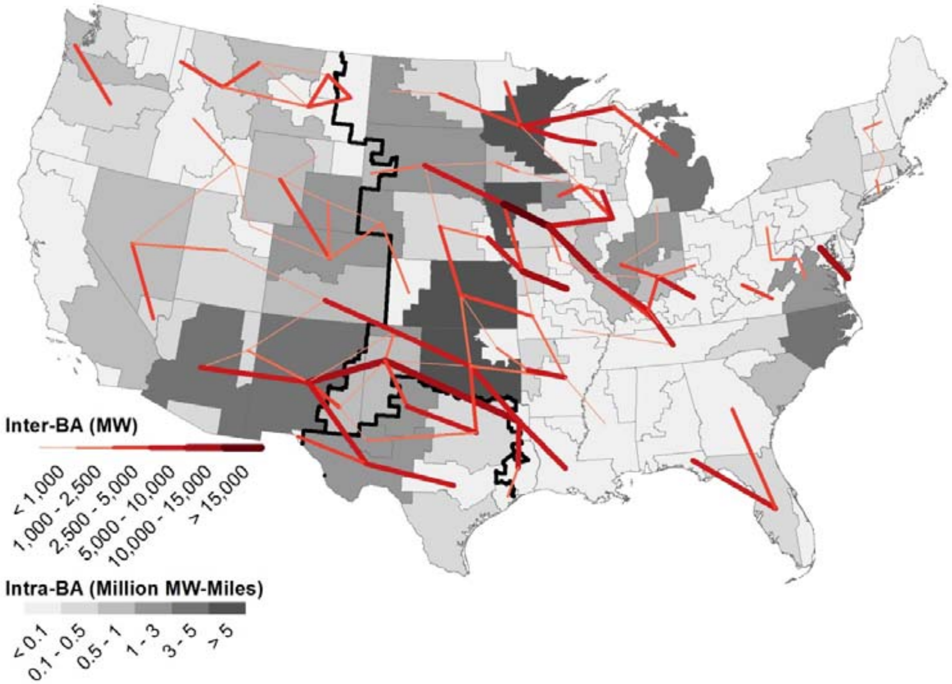


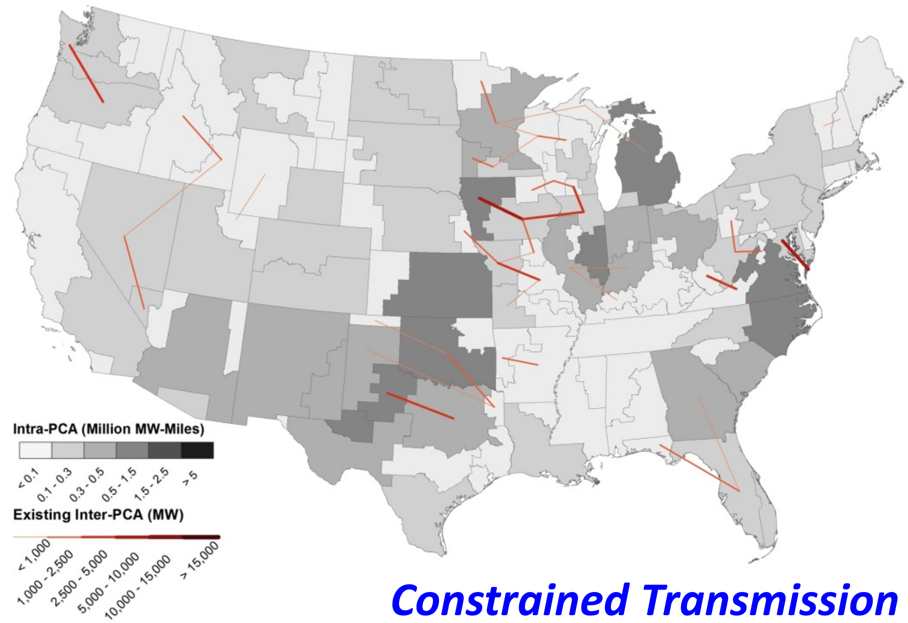
- **Operational challenges for high renewable scenarios are most acute during low-demand periods (e.g., spring).**
- **There is greater thermal power plant ramping and cycling, as well as increased curtailment of excess renewable generation (8-10% of wind, solar, and hydropower curtailed in 2050).**
- **Storage and demand-side options (e.g. PHEV charging) can help shift loads to mitigate these challenges,** *e.g., 100-150 GW of storage & 28-48 GW of interruptible load deployed in 2050 for (low demand) 80%-by-2050 RE scenarios.*



Source: Renewable Electricity Futures (2012)

As RE deployment increases, additional transmission infrastructure is required

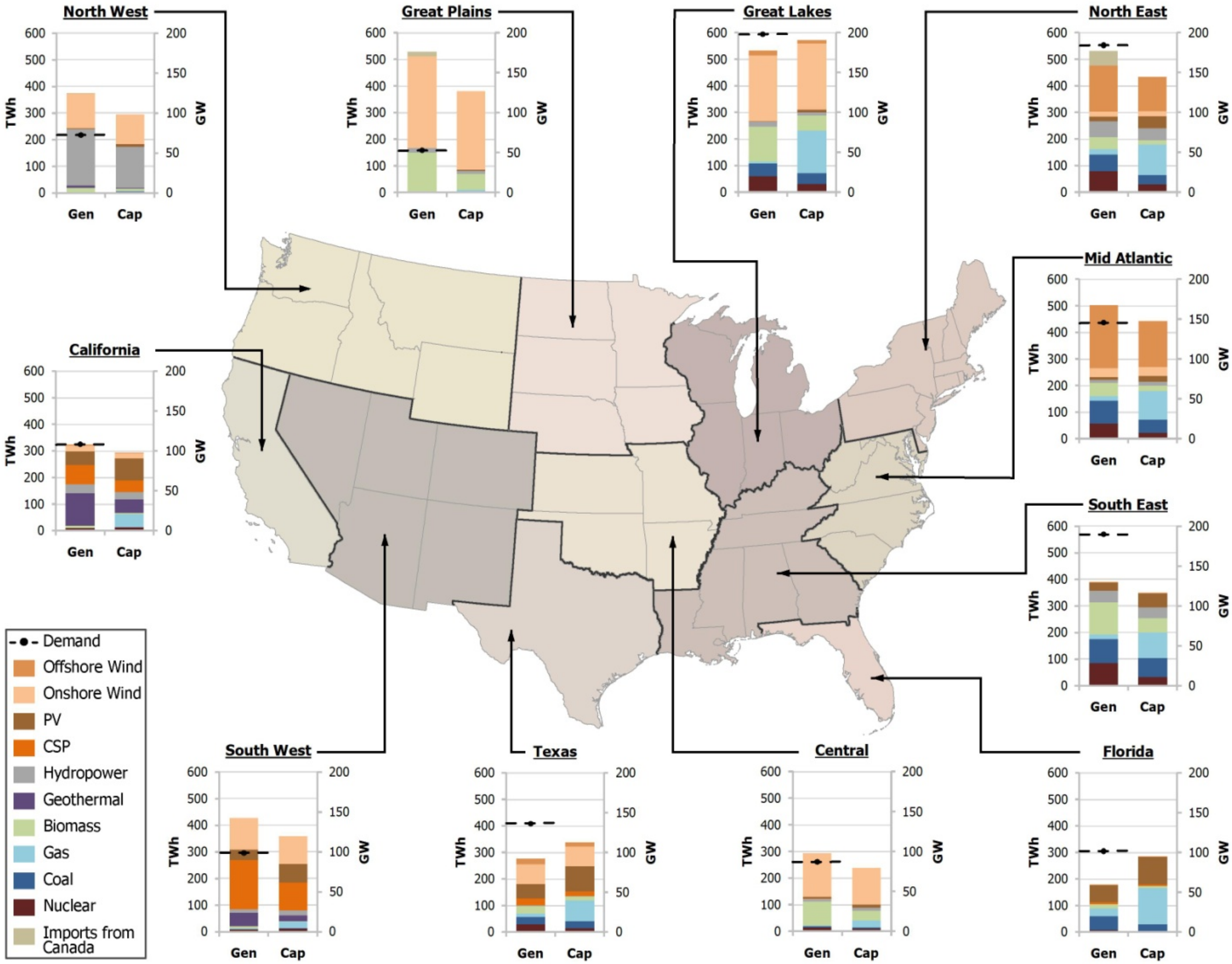




Constrained Transmission

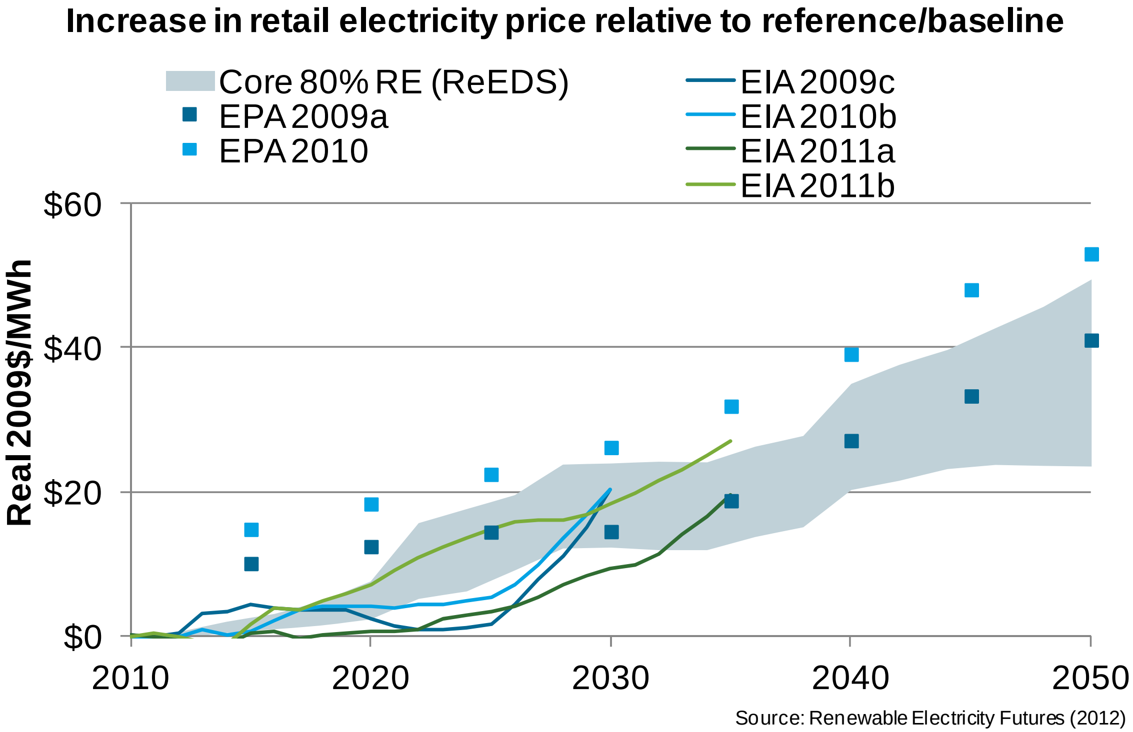
- **In most 80%-by-2050 RE scenarios, 110-190 million MW-miles of new transmission lines are added.**
- **AC-DC-AC interties are expanded to allow greater power transfer between asynchronous interconnects.**
- **However, 80% RE is achievable even when transmission is severely constrained (30 million 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.**

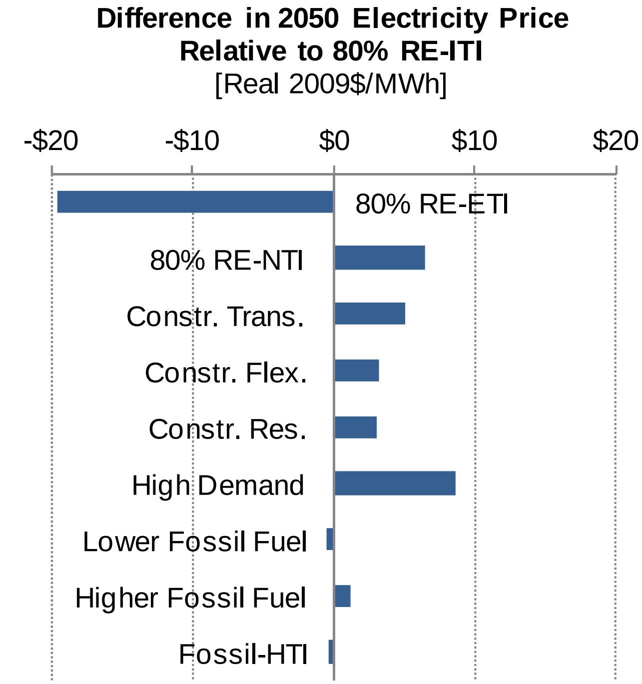
All regions of the country could contribute substantial renewable electricity supply in 2050



80% RE-ITI scenario

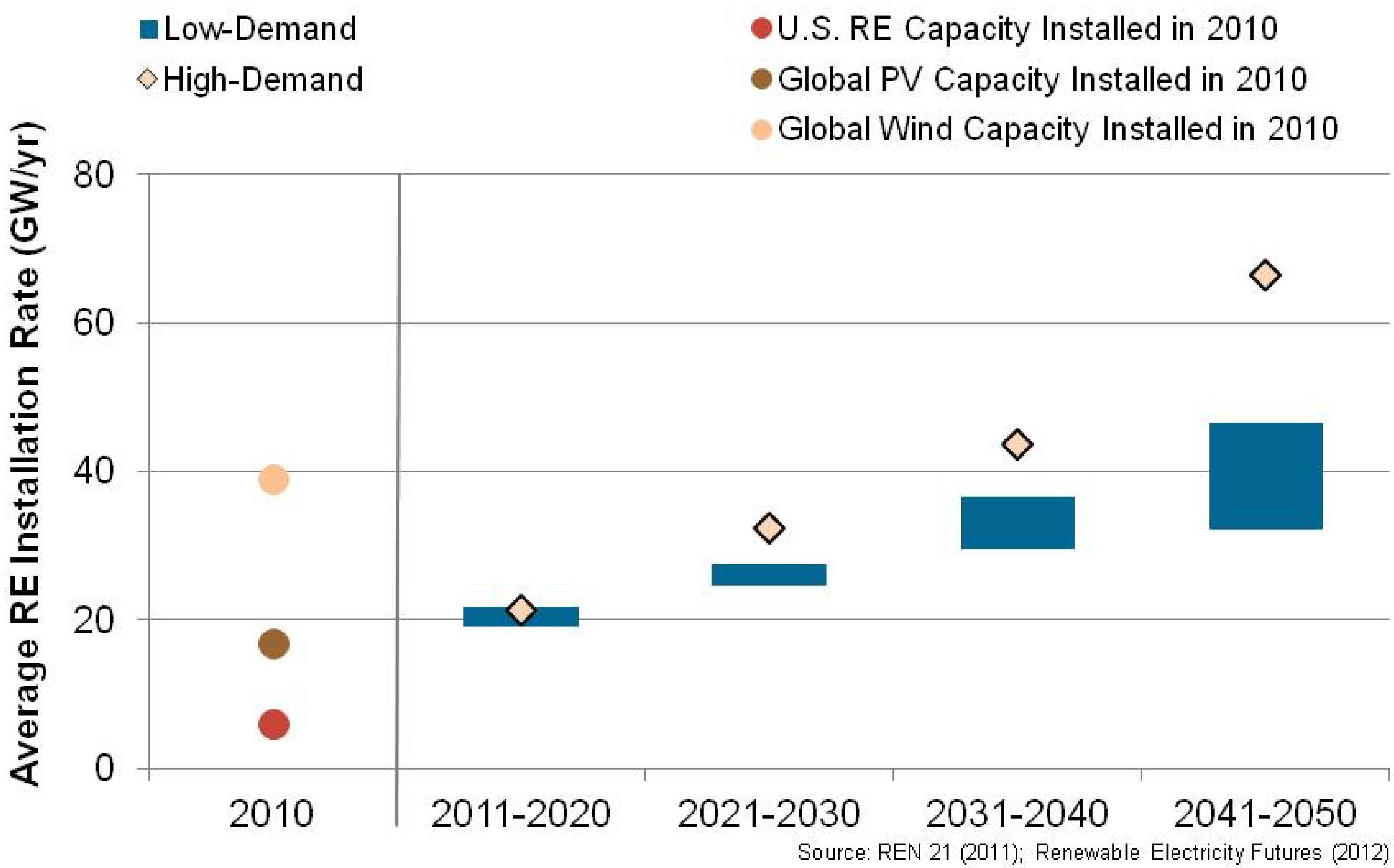
Incremental cost associated with high RE generation is comparable to published cost estimates of other clean energy scenarios





- **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)**

RE Industry Growth



No insurmountable long-term constraints to RE technology manufacturing capacity, materials supply, or labor availability were identified.

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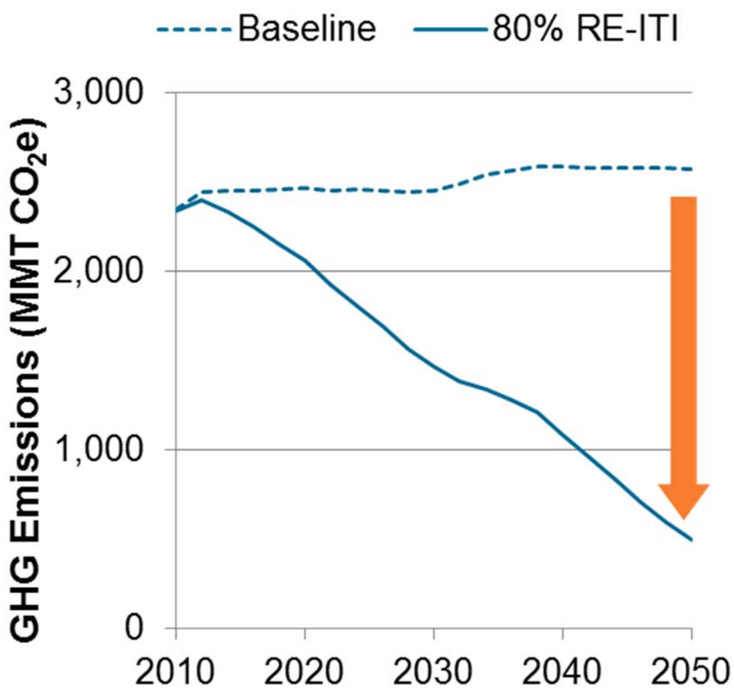
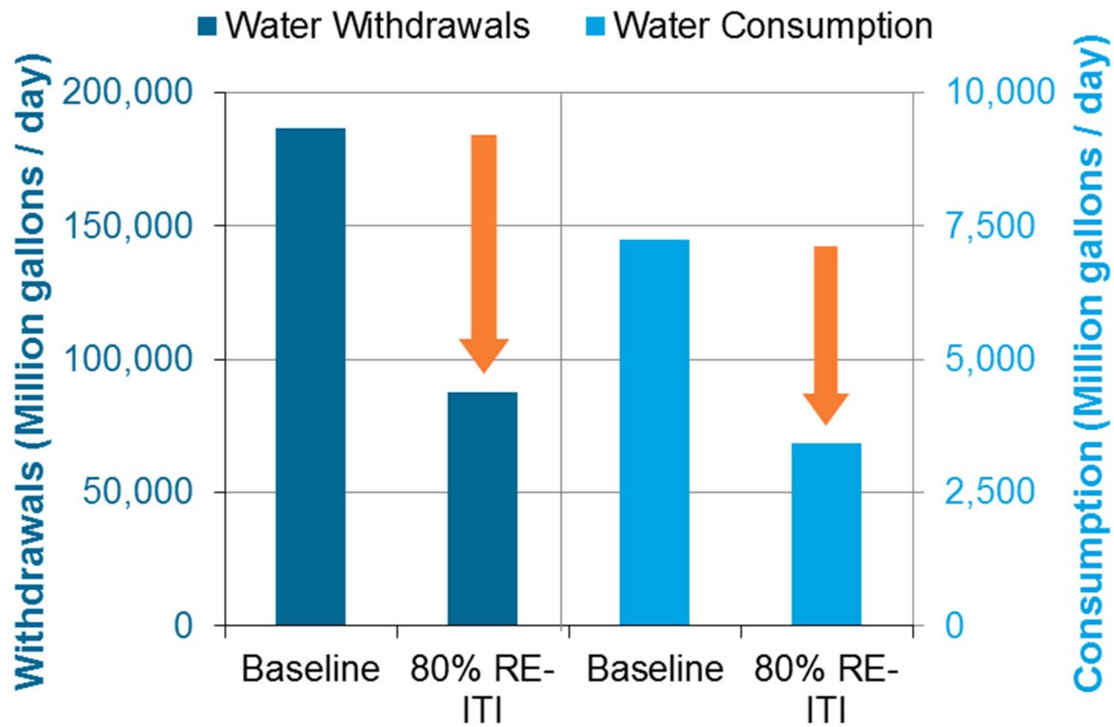
High RE Reduces Emissions and Water Use





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)

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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

80% RE scenarios (Biomass through Transmission & Storage)

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

** 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

Summary of Key Analysis Results

- **Renewable electricity 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.**

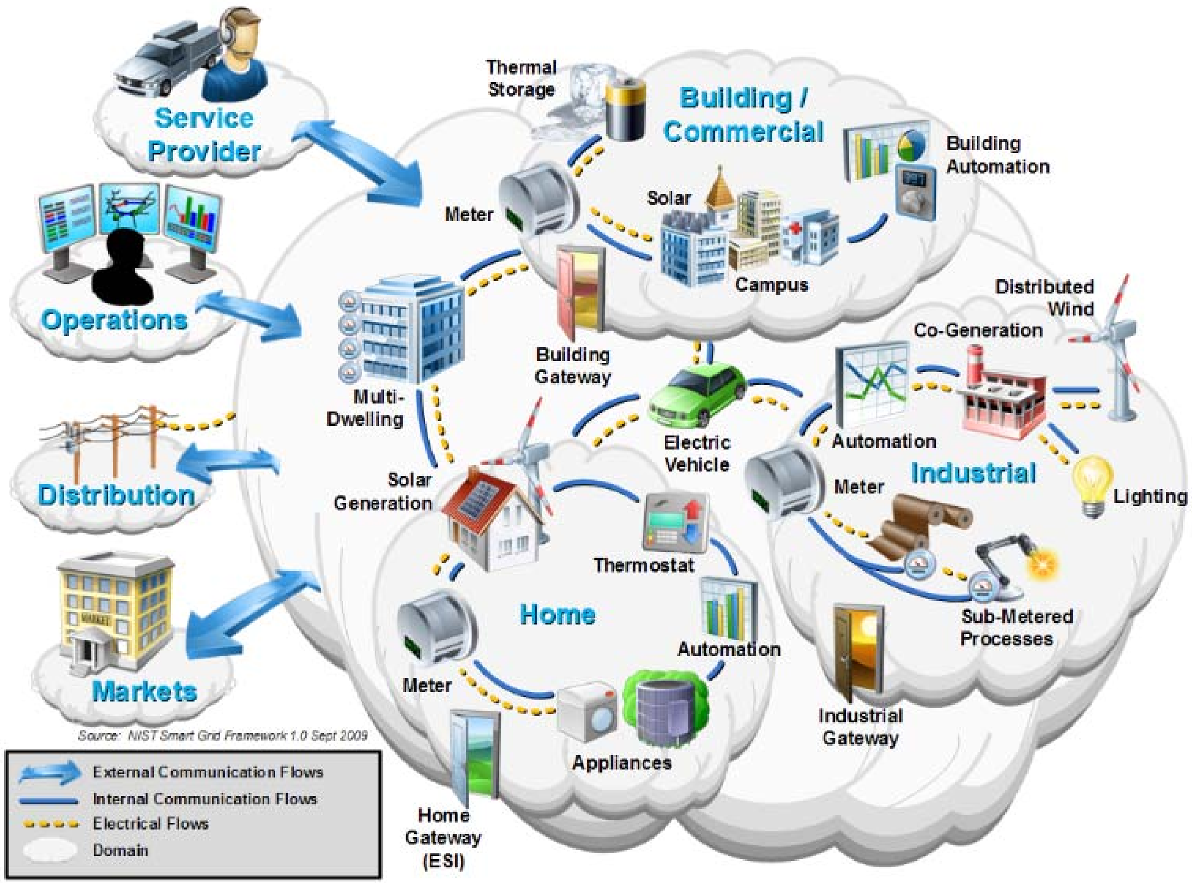
- **Increased electric system flexibility is needed to enable electricity supply-demand balance with high levels of renewable generation, and can come from a portfolio of supply- and demand-side options, including flexible conventional generation, grid storage, new transmission, more responsive loads, and changes in power system operations.**

- **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.**

- **The direct incremental cost associated with high renewable generation is comparable to published cost estimates of other clean energy scenarios. Improvement in the cost and performance of renewable technologies is the most impactful lever for reducing this incremental cost.**

- **Future Work Needed: Comprehensive cost-benefit analysis; Power system reliability; Institutional challenges; Accelerating technology advancements**

Distribution System Integration



- Modeling, Simulation & Optimization
- Advanced Components, Controls & Interoperability
- Communications & Database Architecture
- Protocols, Codes & Standards
- Business Case, Demonstrations, Risk & Valuation
- http://apps1.eere.energy.gov/grid_integration_workshop/distribution.cfm
- http://apps1.eere.energy.gov/grid_integration_workshop/transmission.cfm

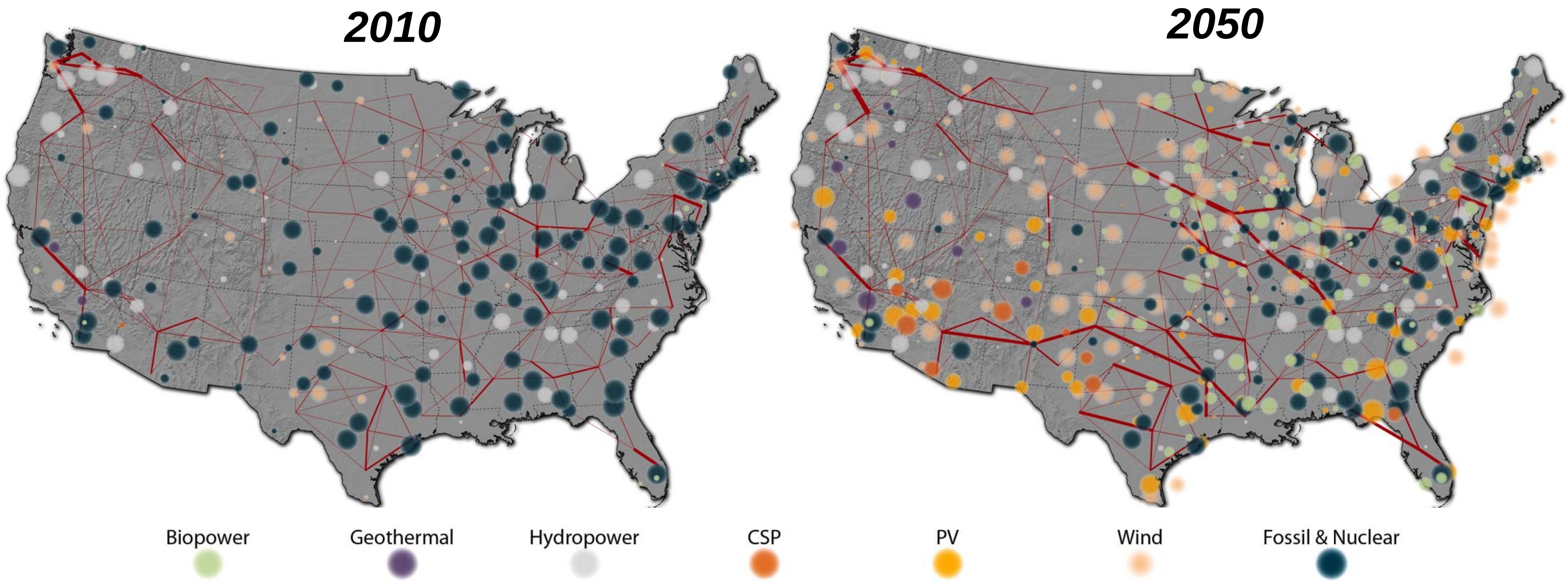
Clean Energy to Secure America's Future

"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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