Renewable Electricity Futures: Challenges and Opportunities

Solar Program Review
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Challenges

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

Can EE & RE meet these Challenges?

- **Buildings and Industrial Efficiency**
- **Transportation Efficiency and Renewable Fuels**
- **Renewable Electricity**

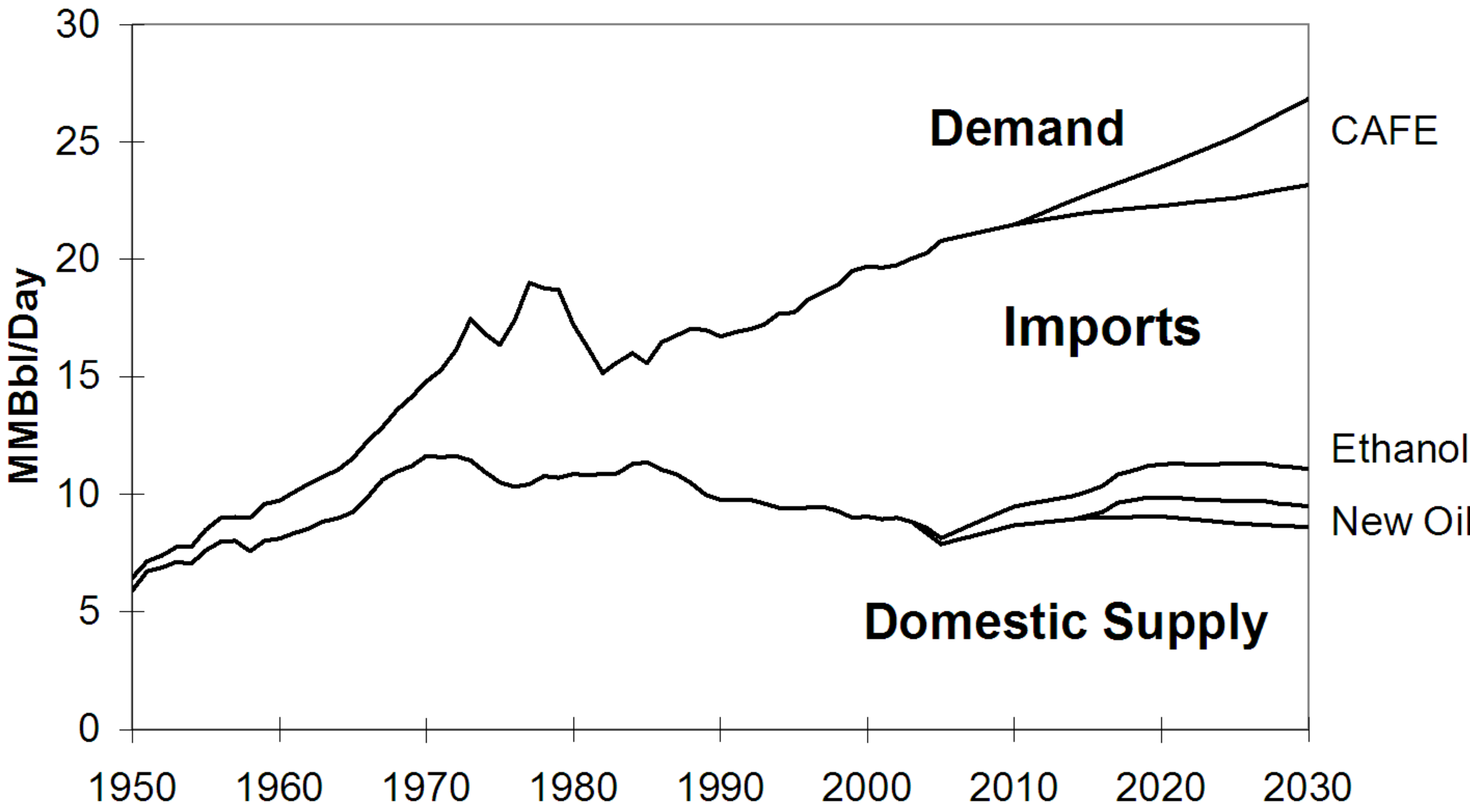
Speed and Scale

The Oil Problem

Nations that **HAVE** oil (% of Global Reserves)		Nations that **NEED** oil (% of Global Consumption)	
Saudi Arabia	26%	**U.S.**	**24. %**
Iraq	11	China	8.6
Kuwait	10	Japan	5.9
Iran	9	Russia	3.4
UAE	8	India	3.1
Venezuela	6	Germany	2.9
Russia	5	Canada	2.8
Mexico	3	Brazil	2.6
Libya	3	S. Korea	2.6
China	3	Mexico	2.4
Nigeria	2	France	2.3
U.S.	**2**	Italy	2.0
		Total	85 MM Bbl/day

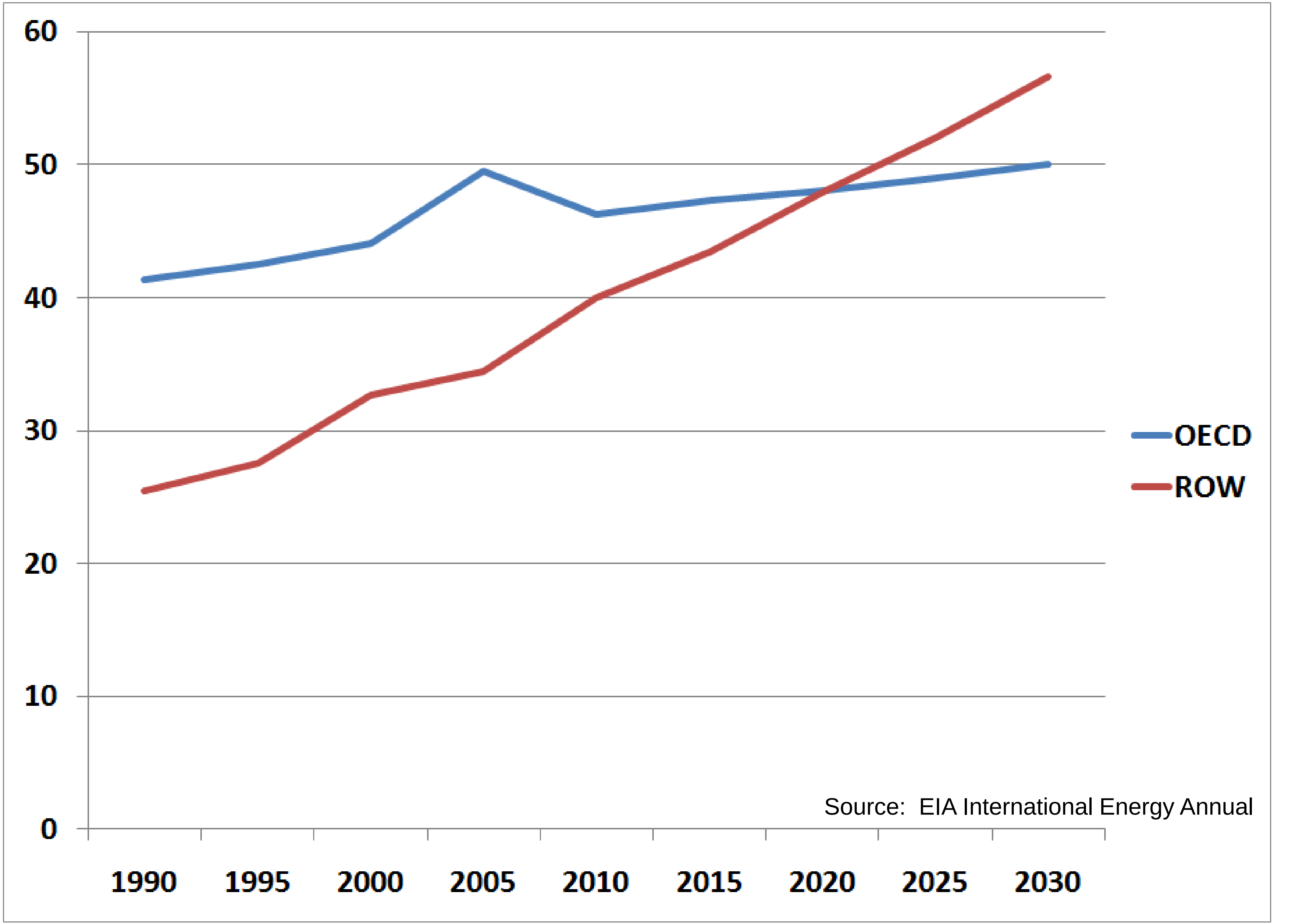
Source: EIA International Energy Annual

Oil Futures?



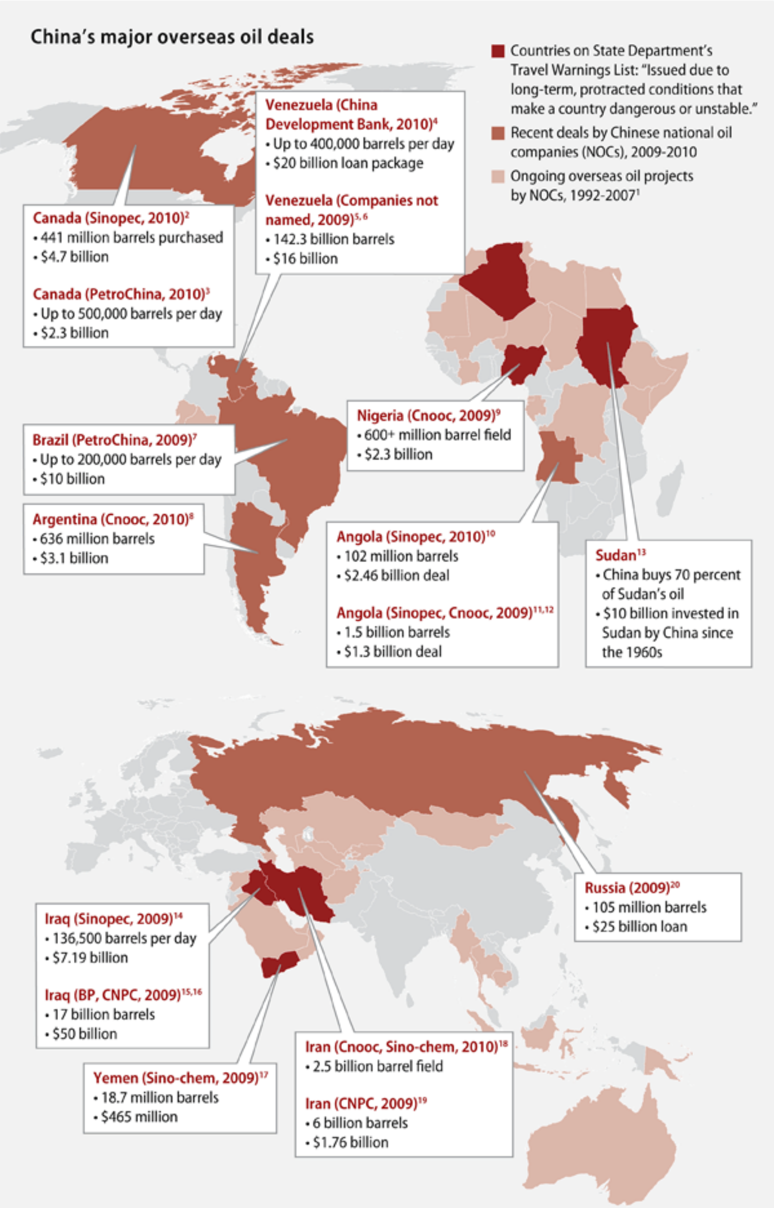
Estimated: pre-2007 & EISA

Global Liquid Fuel Demand (MB/d)



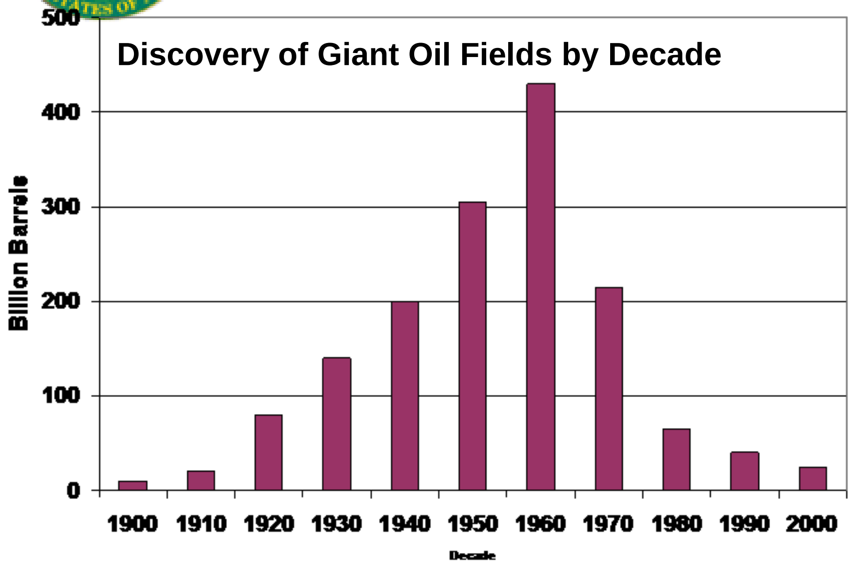
Impacts of Oil Dependence

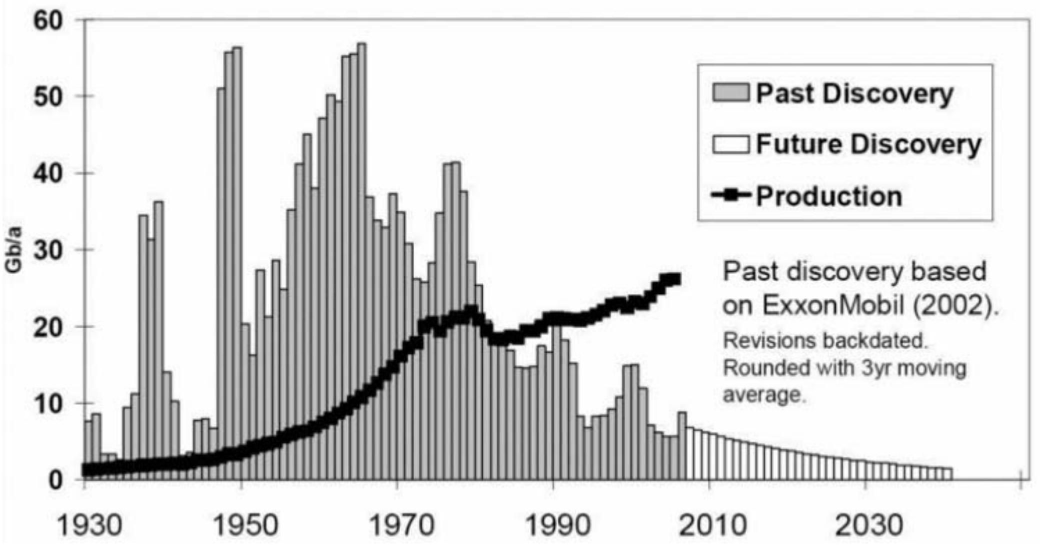
- **Trade Deficit: Oil ~57% of $677B trade deficit, 2008**
- **Foreign Policy Impacts**
  - Strategic competition for access to oil
  - Oil money supports undesirable regimes
  - Oil money finds its way to terrorist organizations
- **Vulnerabilities**
  - to system failures: tanker spills; pipeline corrosion; well blowouts; …
  - to natural disasters: Katrina; …
  - to political upheaval: Nigeria; …
  - to terrorist acts: Yemen; Saudi Arabia; …
- **Economic Development**
  - Developing country growth stunted by high oil prices; increases instability



Source: Center for American Progress, April 27, 2010

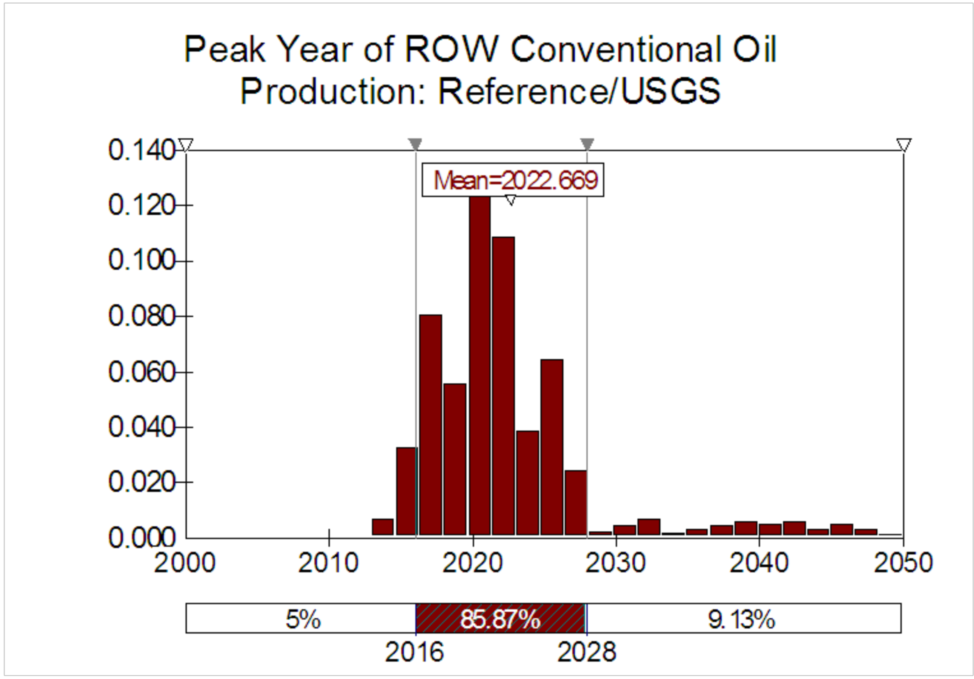
Conventional Oil





International Energy Agency, 2008

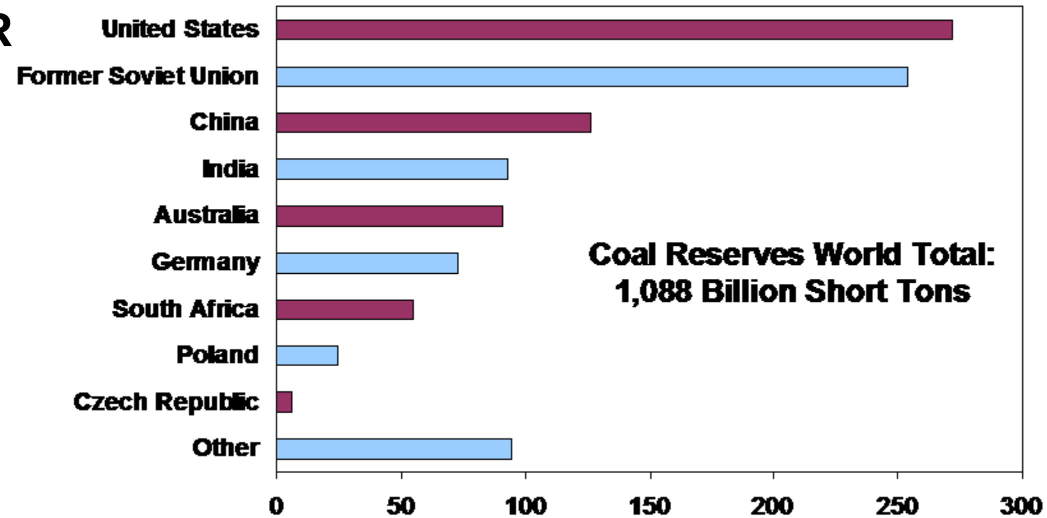
- Across 798 of world's largest oil fields, average production decline of 6.7%/year.
- Of 798 fields, 580 had passed peak.
- To meet growth & replace exhausted resources, will have to add 64 MB/d by 2030, or 6X Saudi Arabia.



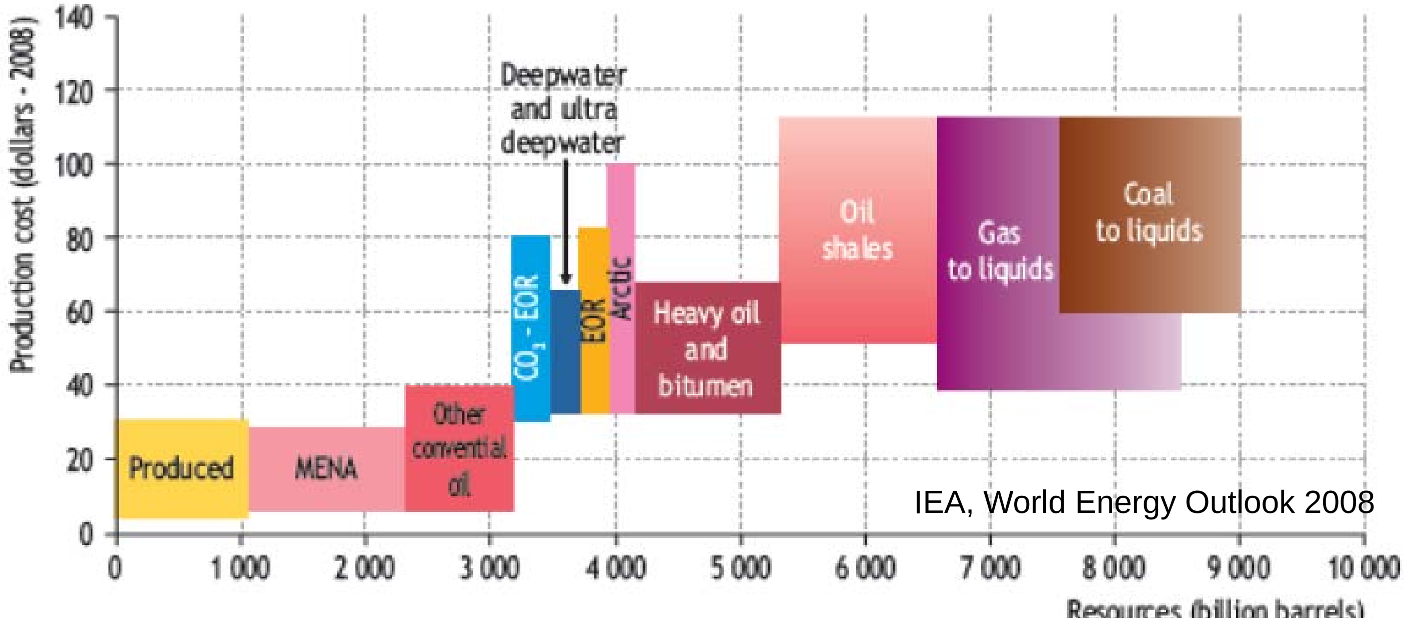
- Sources: (Figure 1) Fredrik Robelius, Uppsala Universitet; (Figure 2) Association for the Study of Peak Oil; (Figure 3) David Greene, ORNL.

Oil Sources

- **Resources**
  - **Oil: Infill wells, Flooding, EOR**
  - **Oil Shale: U.S.—Over 1.2 trillion Bbls-equiv. in highest-grade deposits**
  - **Tar Sands: Canadian Athabasca Tar Sands—1.7 T Bbls-equivalent; Venezuelan Orinoco Tar Sands (Heavy Oil)—1.8 T Bbls-equiv.**
  - **Coal: Coal Liquefaction—(4 Bbls/ton)**



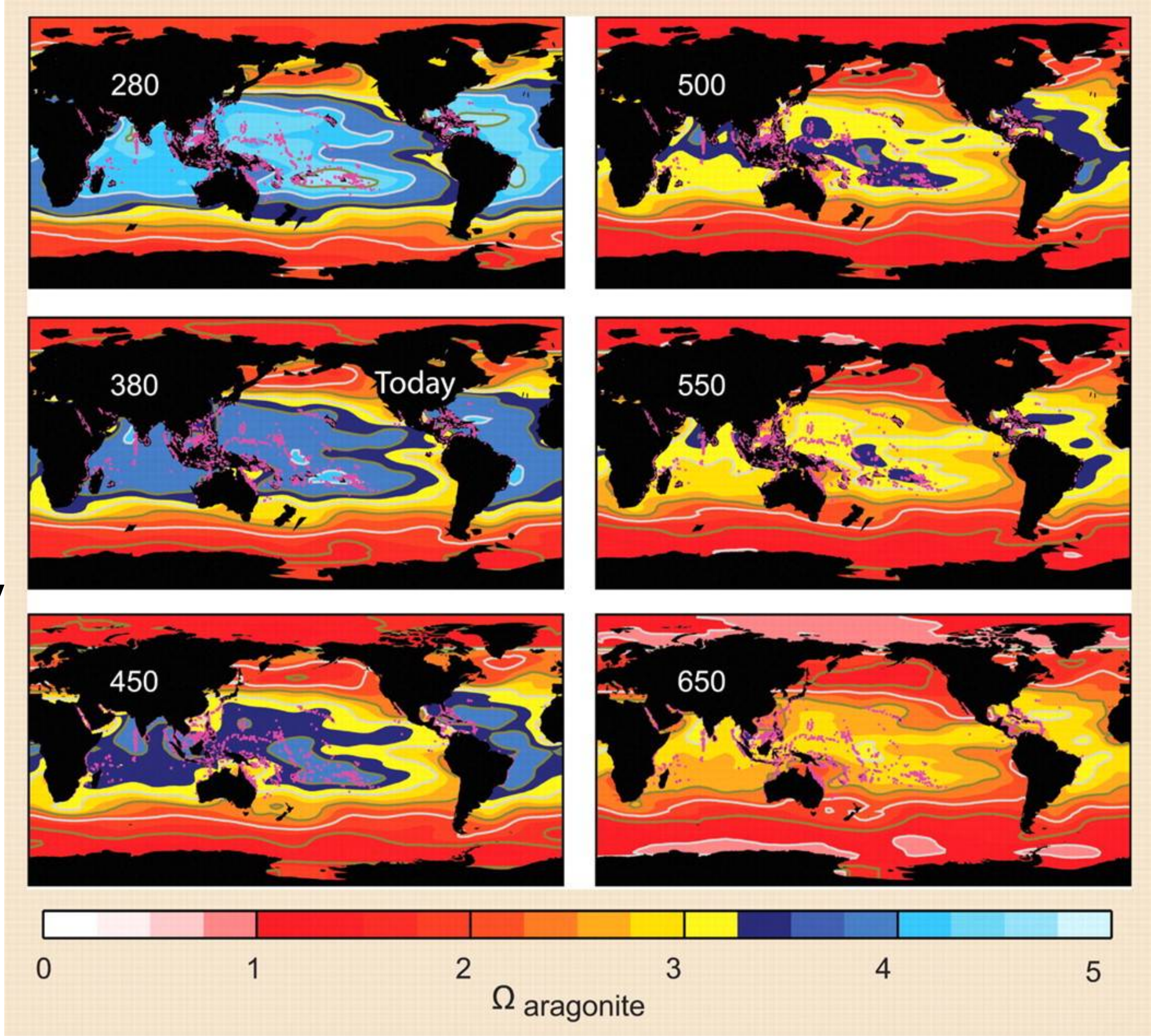
- **Constraints**
  - **Cost; Energy**
  - **Water**
  - **Atmosphere**



IEA, World Energy Outlook 2008

Potential Impacts of GHG Emissions

- **Temperature Increases**
- **Precipitation Changes**
- **Glacier & Sea-Ice Loss**
- **Water Availability**
- **Wildfire Increases**
- **Ecological Zone Shifts**
- **Extinctions**
- **Agricultural Zone Shifts**
- **Agricultural Productivity**
- **Ocean Acidification**
- **Ocean Oxygen Levels**
- **Sea Level Rise**
- **Human Health Impacts**
- **Feedback Effects**



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

U.S.: 5.9 GT CO_2/yr energy-related
World: 28.3 GT CO_2/yr

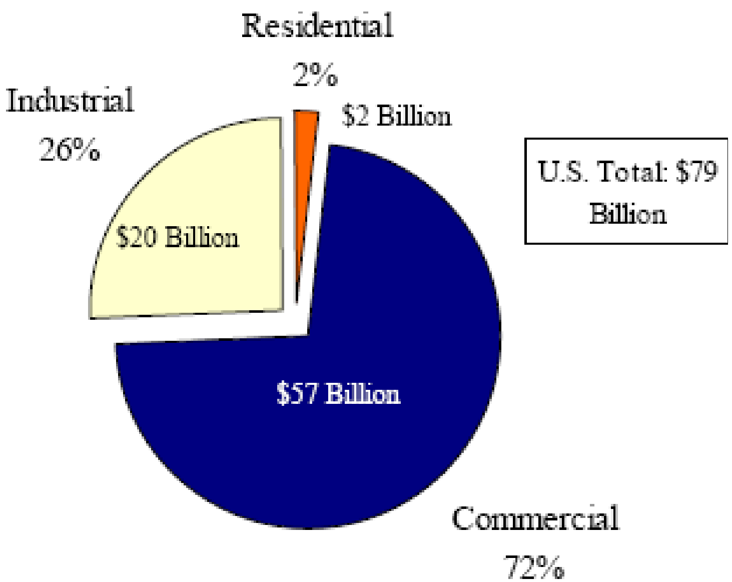
InterAcademy Panel Statement On Ocean Acidification, 1 June 2009

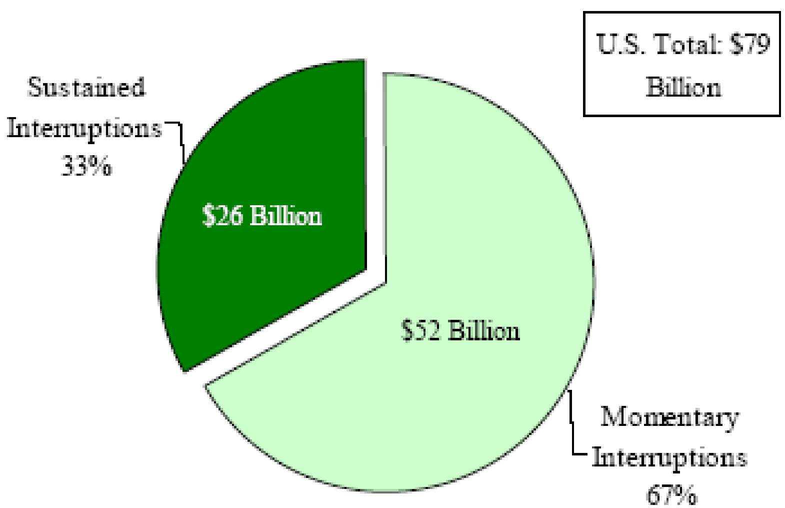
- **Signed by the National Academies of Science of 70 nations:**
  - Argentina, Australia, Bangladesh, Brazil, Canada, China, France, Denmark, Greece, India, Japan, Germany, Mexico, Pakistan, Spain, Taiwan, U.K., U.S…..
- **"The rapid increase in CO2 emissions since the industrial revolution has increased 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.**

Costs of Power Interruptions

New York City during the August 2003 blackout

Chip East / Reuters file

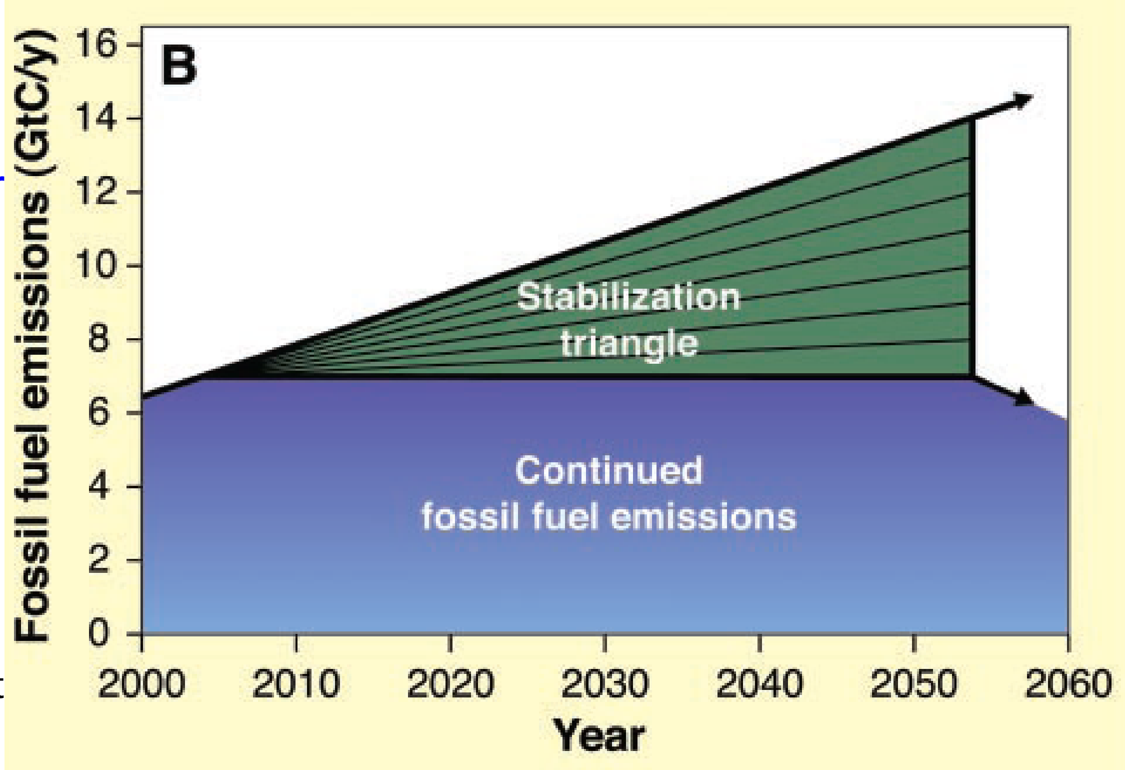




Kristina Hamachi LaCommare, and Joseph H. Eto, LBNL

Scale of the Challenge

- Increase fuel economy of 2 billion cars from 30 to 60 mpg.
- Cut carbon emissions from buildings by one-fourth by 2050—on top of projected improvements.
- With today's coal power output doubled, operate it at 60% instead of 40% efficiency (compared with 32% today).
- Introduce Carbon Capture and Storage at 800 GW of coal-fired power.
- Install 1 million 2-MW wind turbines.
- Install 3000 GW-peak of Solar power.
- Apply conservation tillage to all cropland (10X today).
- Install 700 GW of nuclear power.



Source: S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technology", Science 13 August 2004, pp.968-972.

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

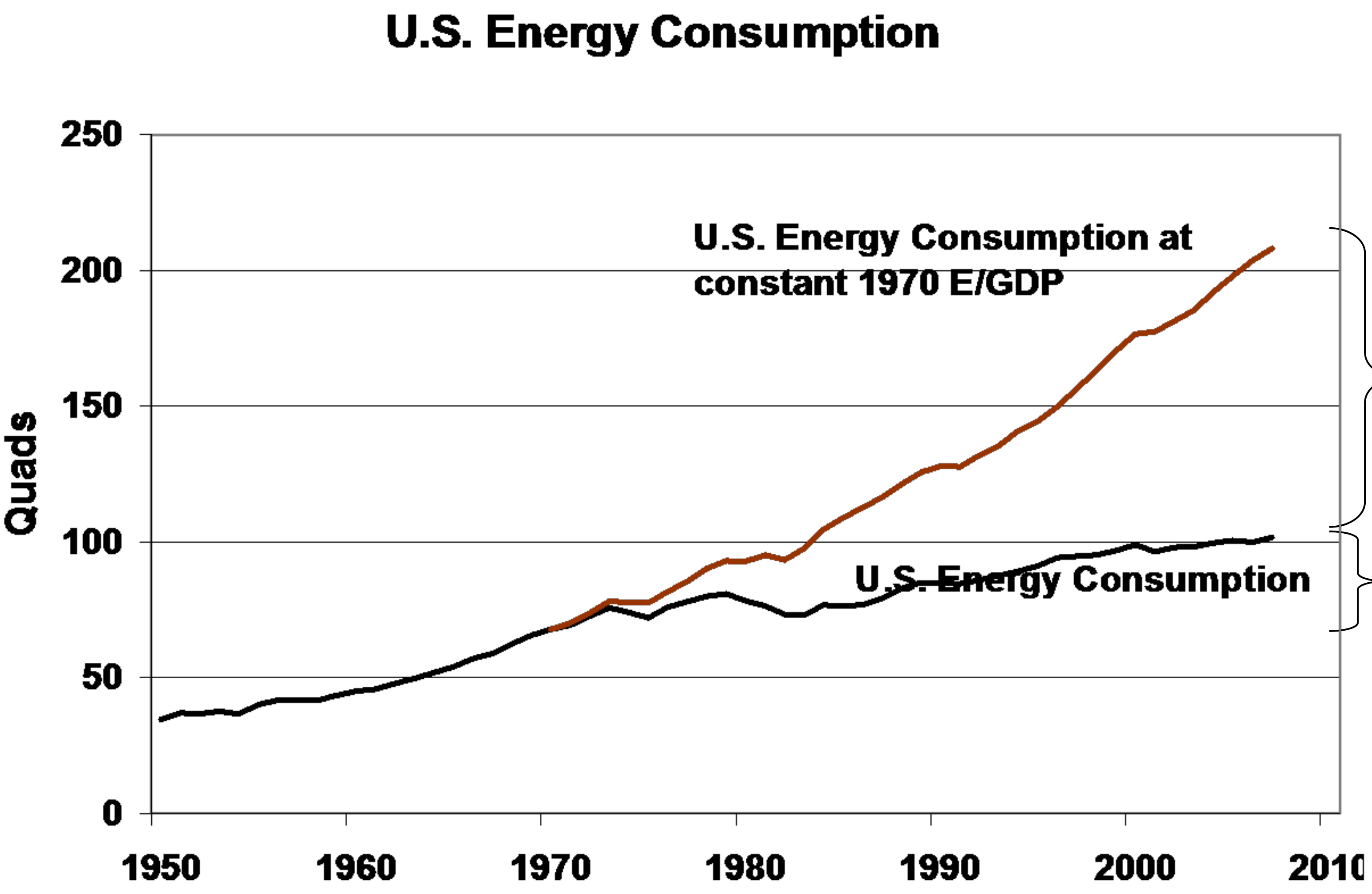
- Time available for significant action Must Act Now!

How Can We Meet These Challenges?

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

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

Energy Efficiency: 1970-2007

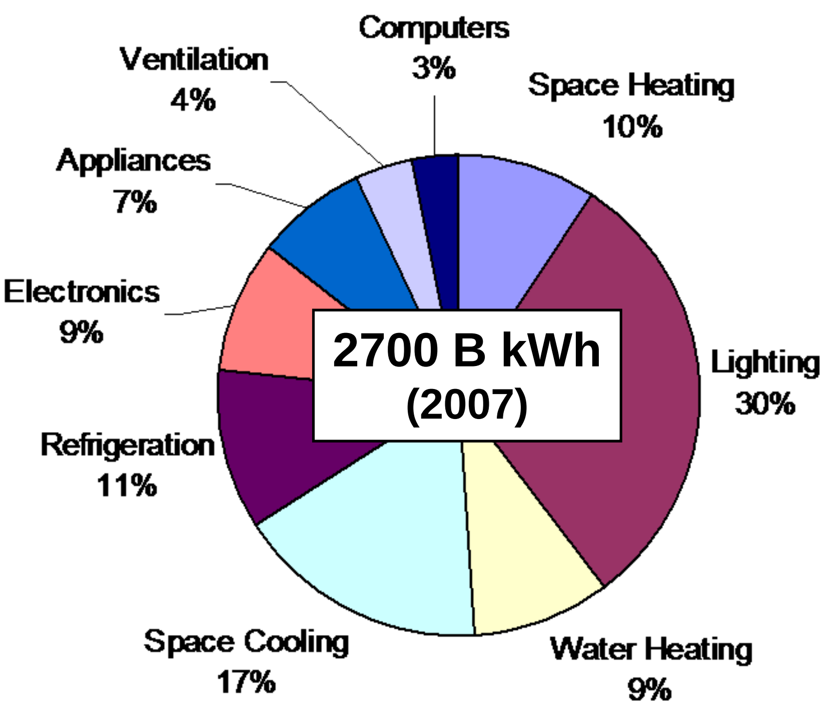


Efficiency;
Structural
Change:
Total 106.8

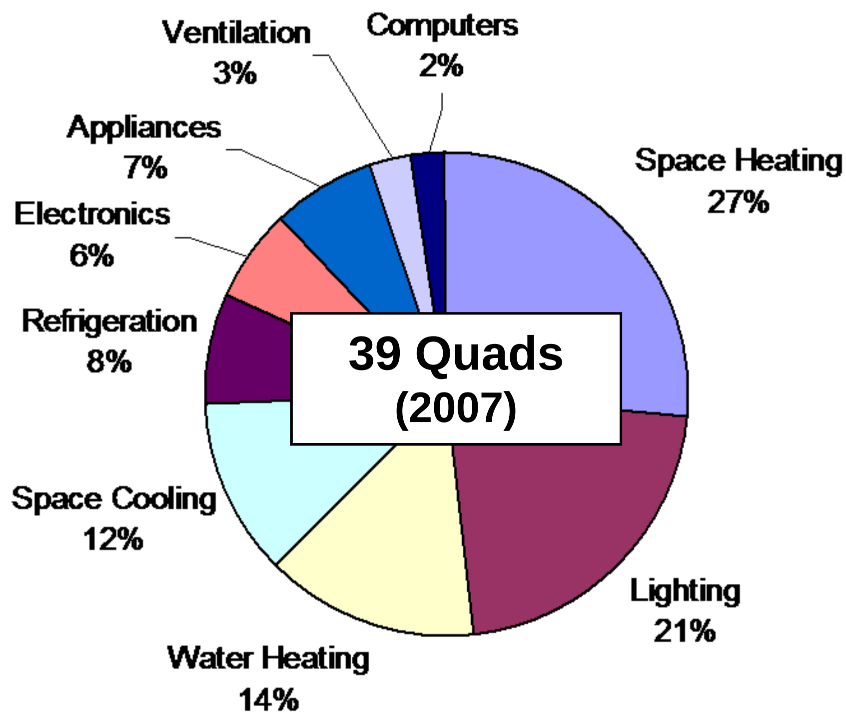
New Supply
Gas 1.8Q
RE 2.8
Nucl 8.2
Oil 10.3
Coal 10.5
Total 33.8

Buildings Energy Use

Site Electricity Consumption

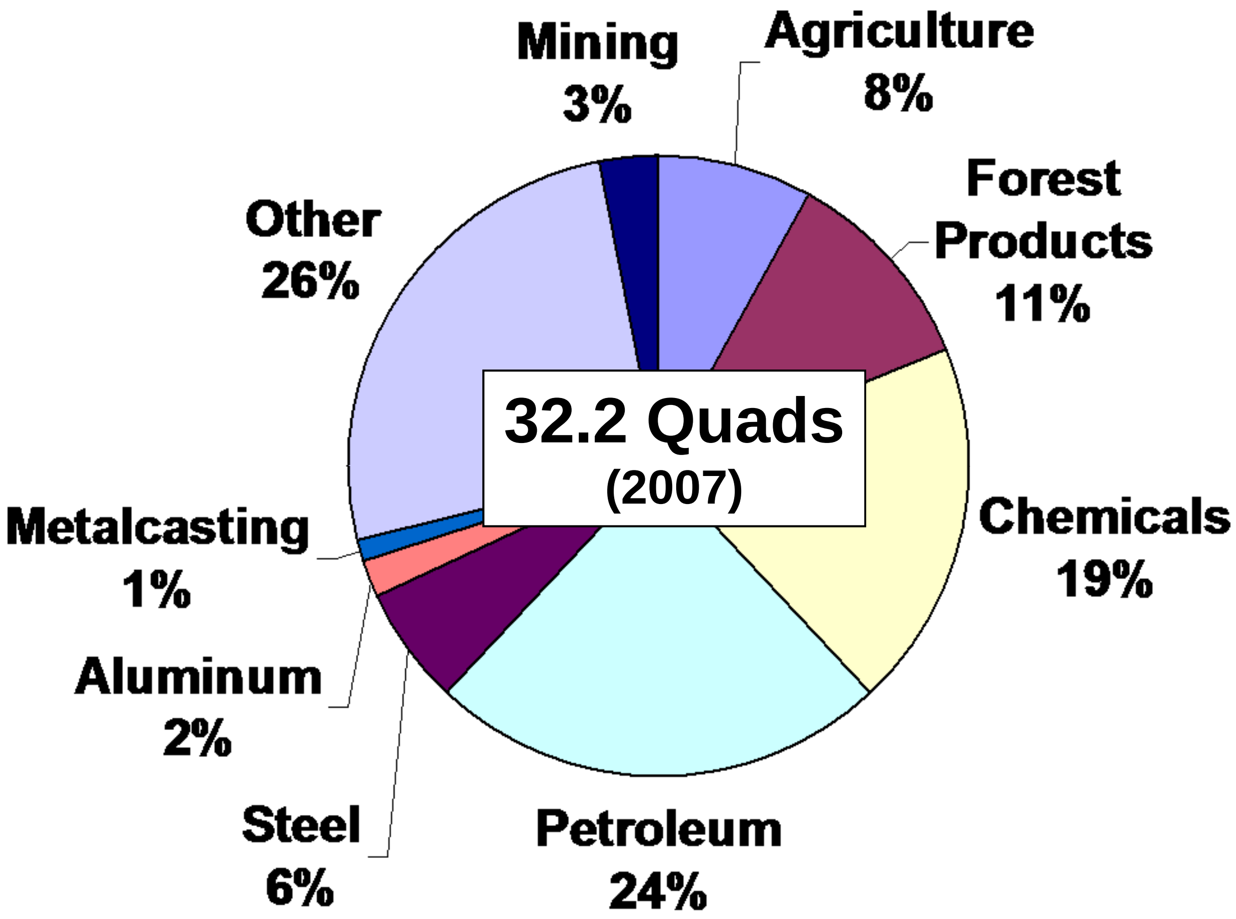


Total Primary Energy (all fuels)

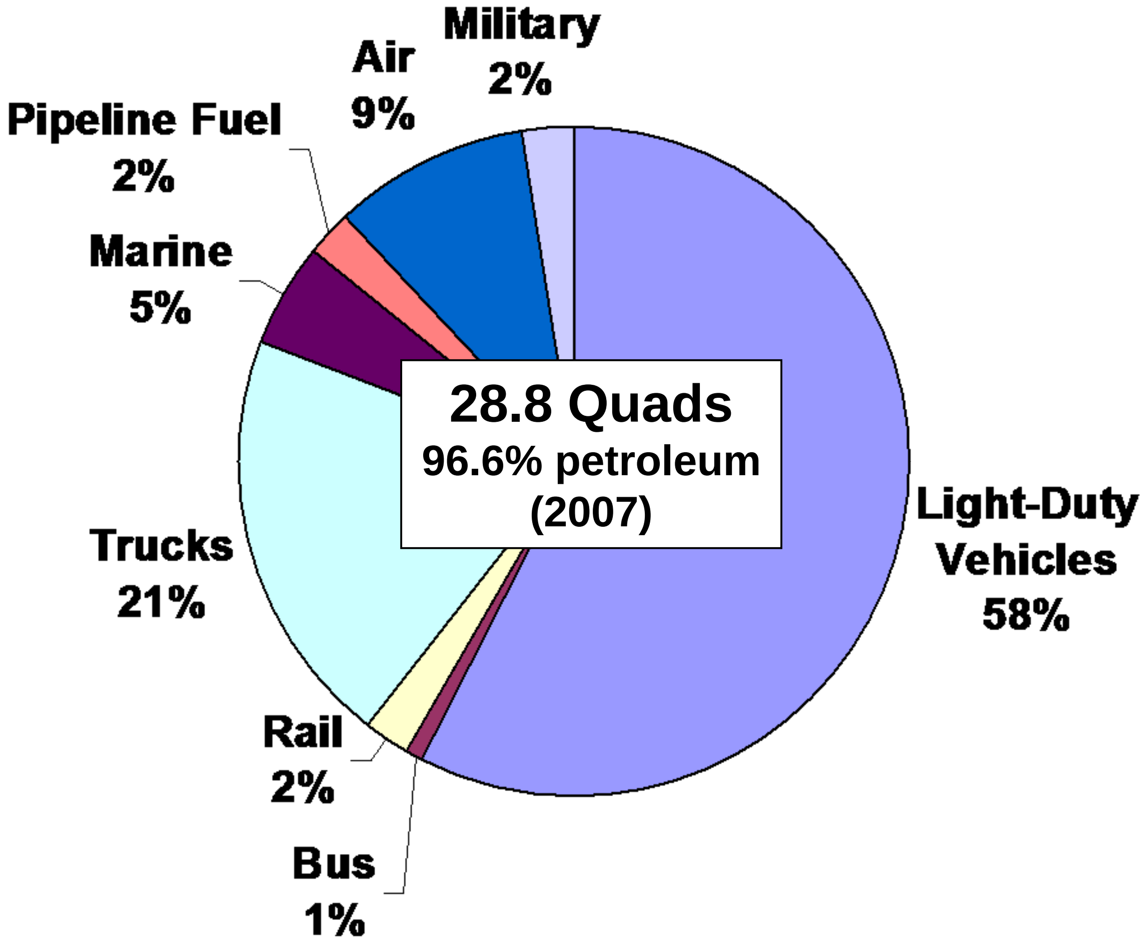


Source: Building Technology Program Core Databook, August 2003. http://buildingsdatabook.eren.doe.gov/frame.asp?p=tableview.asp&TableID=509&t=xls

Industrial Energy Use

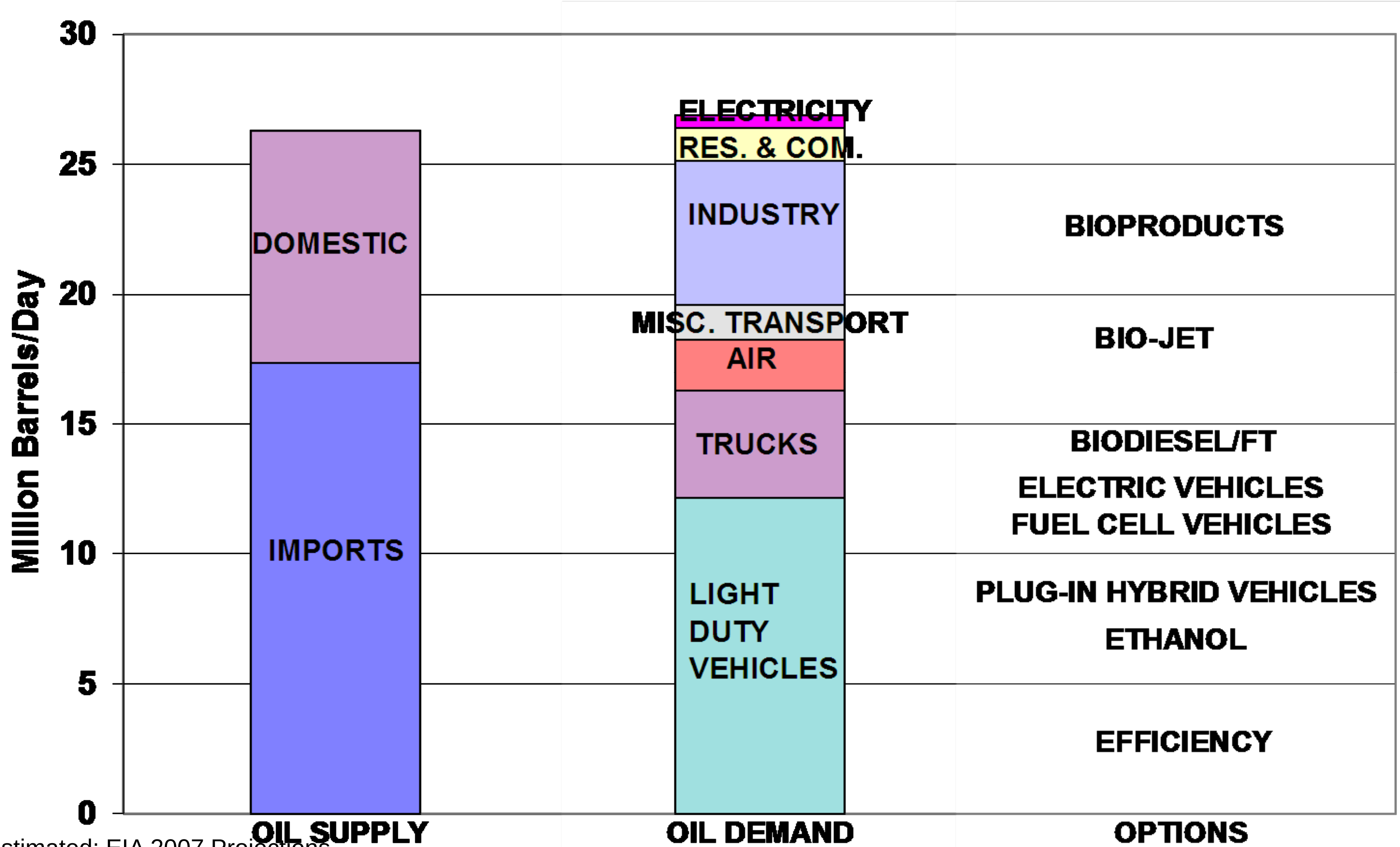


Transport Energy Use



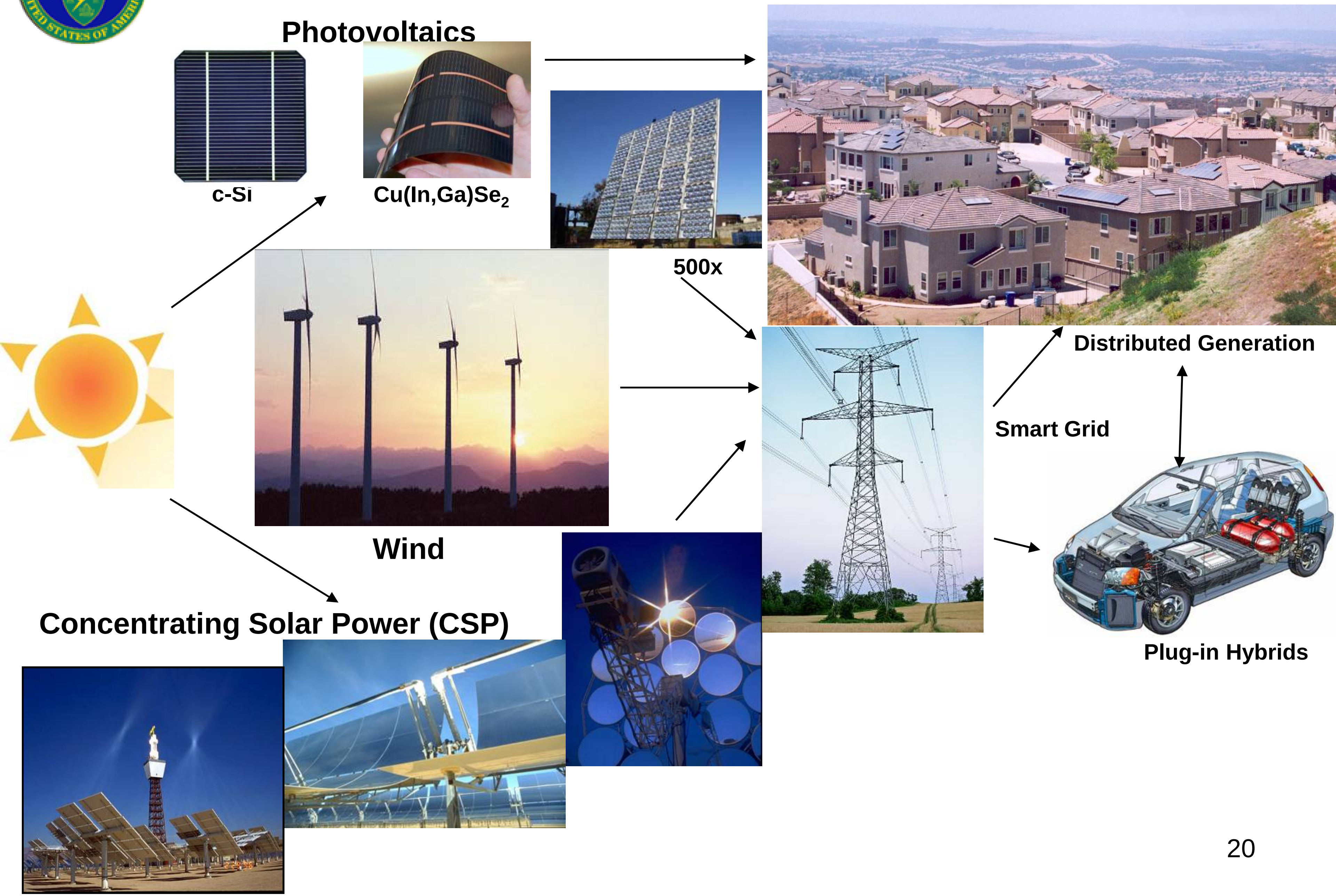
Can We Meet the Oil Challenge?

Oil Supply, Demand, Options in 2030



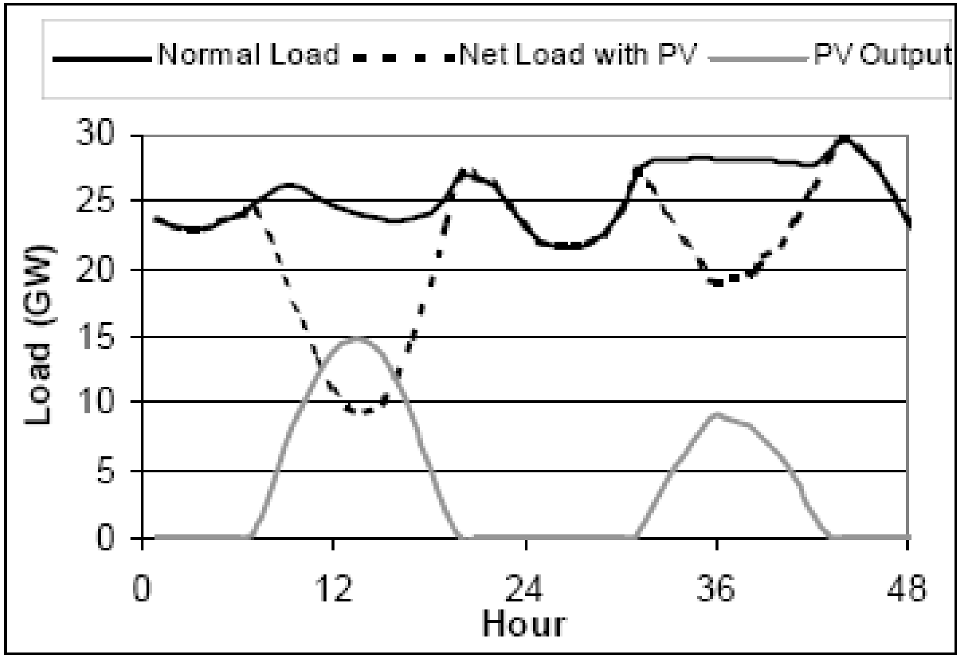
Estimated: EIA 2007 Projections

Renewable Electricity Systems



Grid Integration

- **Barriers:** Variable output; Low capacity factor; Located on weak circuits; Lack of utility experience; Economics of transmission work against wind/solar.



ISSUES

-Geographic Diversity **-Storage**
-Resource Forecasting **-Load Shifting**
-Ramp Times **-2-Way Power Flow**
-Islanding **-Stability**
-System Interactions **-Dynamic Models**
-Communications, Control, Data Management

- **Assess** potential effects of large-scale Wind/Solar deployment on grid operations and reliability:
  - Behavior of solar/wind systems and impacts on existing grid
  - Effects on central generation maintenance and operation costs, including peaking power plants
- **Engage** with utilities to mitigate barriers to technology adoption
  - Prevent grid impacts from becoming basis for market barriers, e.g. caps on net metering and denied interconnections to "preserve" grid
  - Provide utilities with needed simulations, controls, and field demos
- **Develop** technologies for integration:
  - Smart Grid/Dispatch.

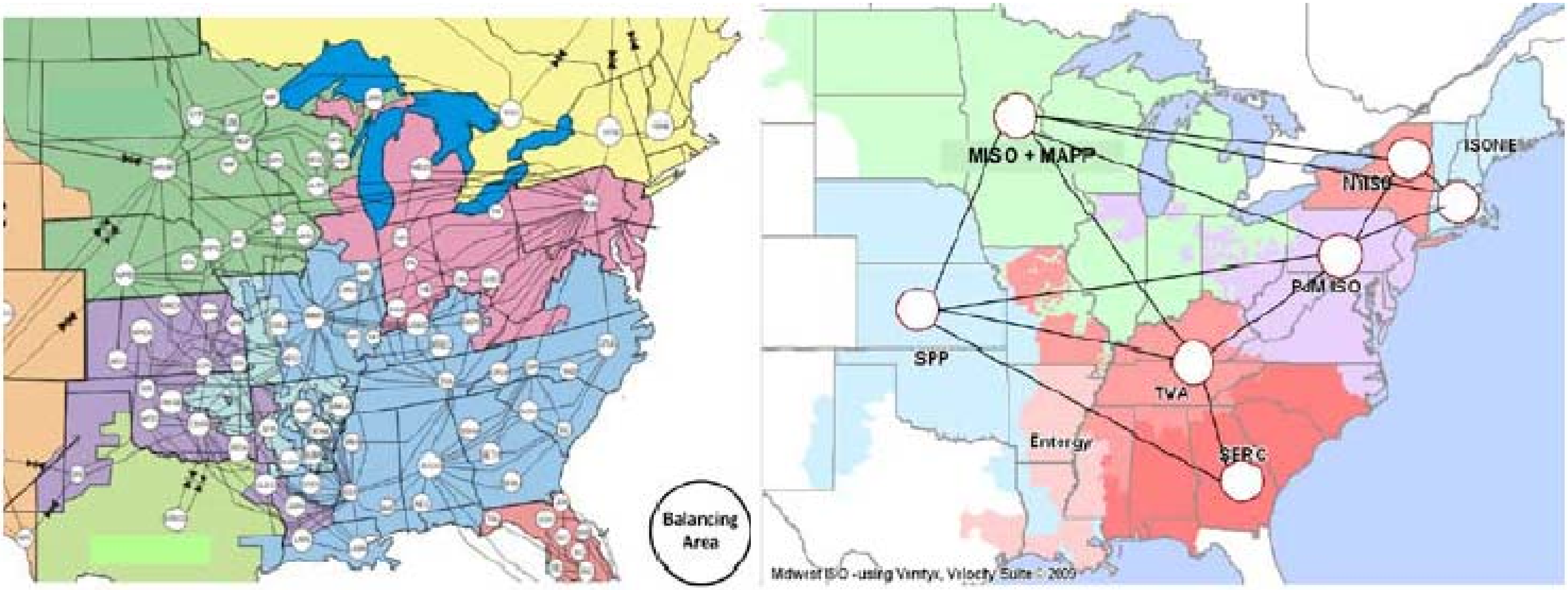
20% Wind: Costs & Benefits

Incremental direct cost to society (Siting: Land Use of 2-5% of 15 M acres) (Siting: Wildlife & Habitat, Visual Impacts)	**$43 billion** 50 cents/month/ household
Reduction in emissions of greenhouse gases and avoided carbon regulation costs (Avoid Acids, Ash, Heavy Metals (Hg), Particulates, etc)	825 million tons of CO_2 **$50 to $145 billion**
Reduction in water consumption	8% through 2030 17% in 2030
Jobs supported and other economic benefits	500,000 total with 150,000 direct jobs $2 billion in local annual revenues
Reduction in nationwide natural gas use and likely savings for all gas consumers	11% **$86-214 billion**

Sources: DOE, 2008 and Hand et al., 2008

Note: All dollar values are in NPV

Eastern Wind Integration & Transmission Study
Consolidation of Balancing Authorities

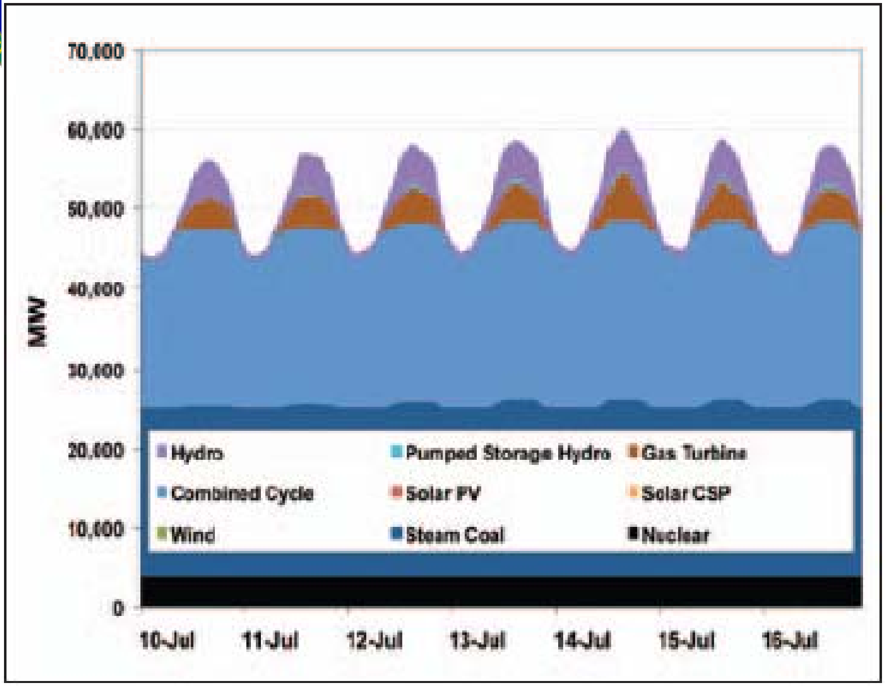


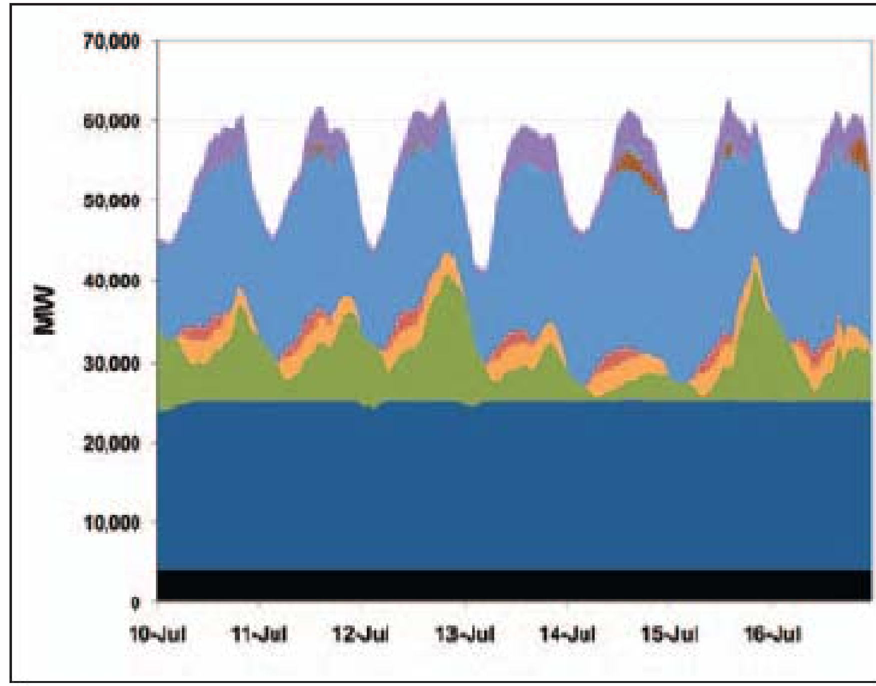
As of August 1, 2007 | Assumption for 2024

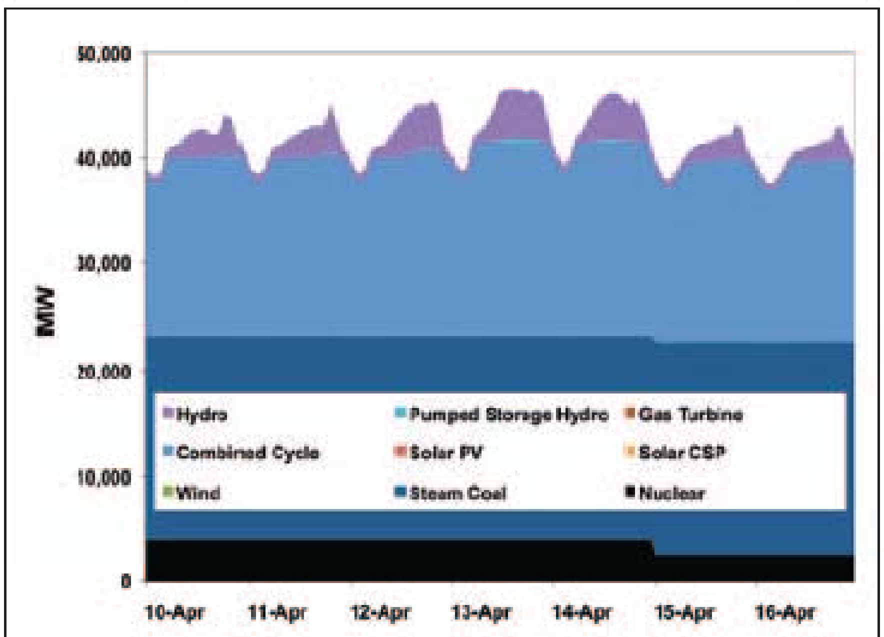
- Long distance high capacity transmission can assist smaller balancing areas with wind integration and contributes to system robustness.
- Substantial benefits of geographic diversity and pooling of load and generating resources

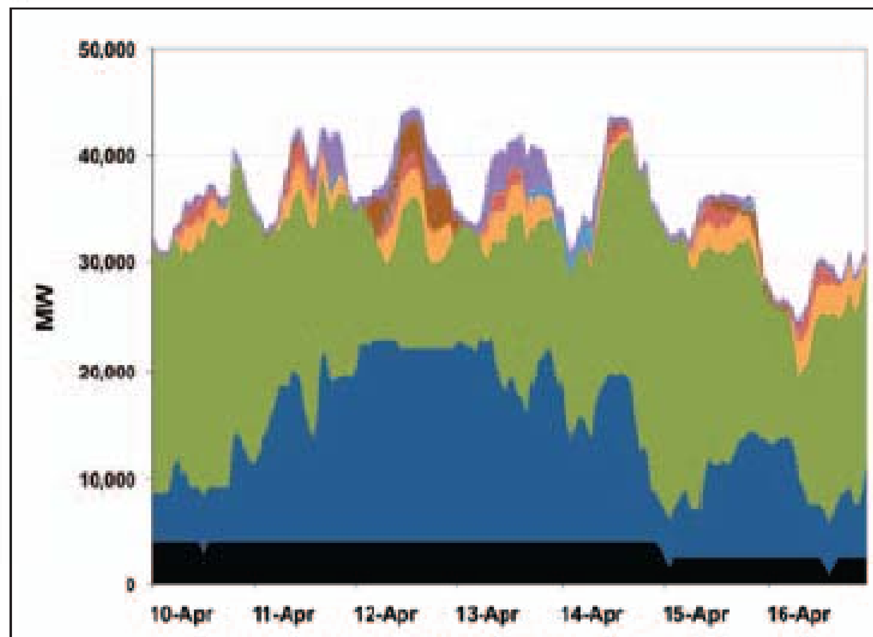
Source: EWITS Study; Dave Corbus, NREL

Western Wind & Solar Integration Study



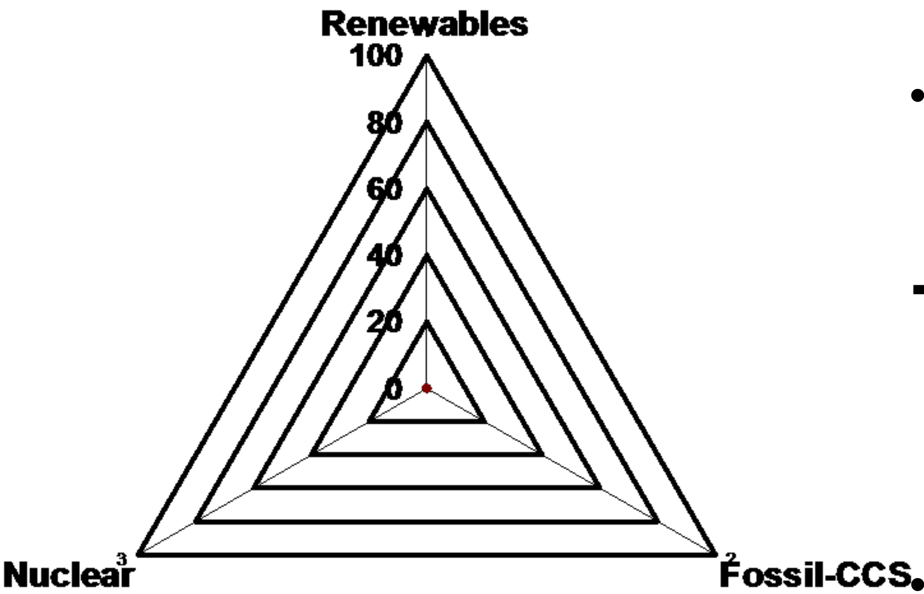






RE Futures: Project Goals

Electric Sector Carbon Mitigation Options



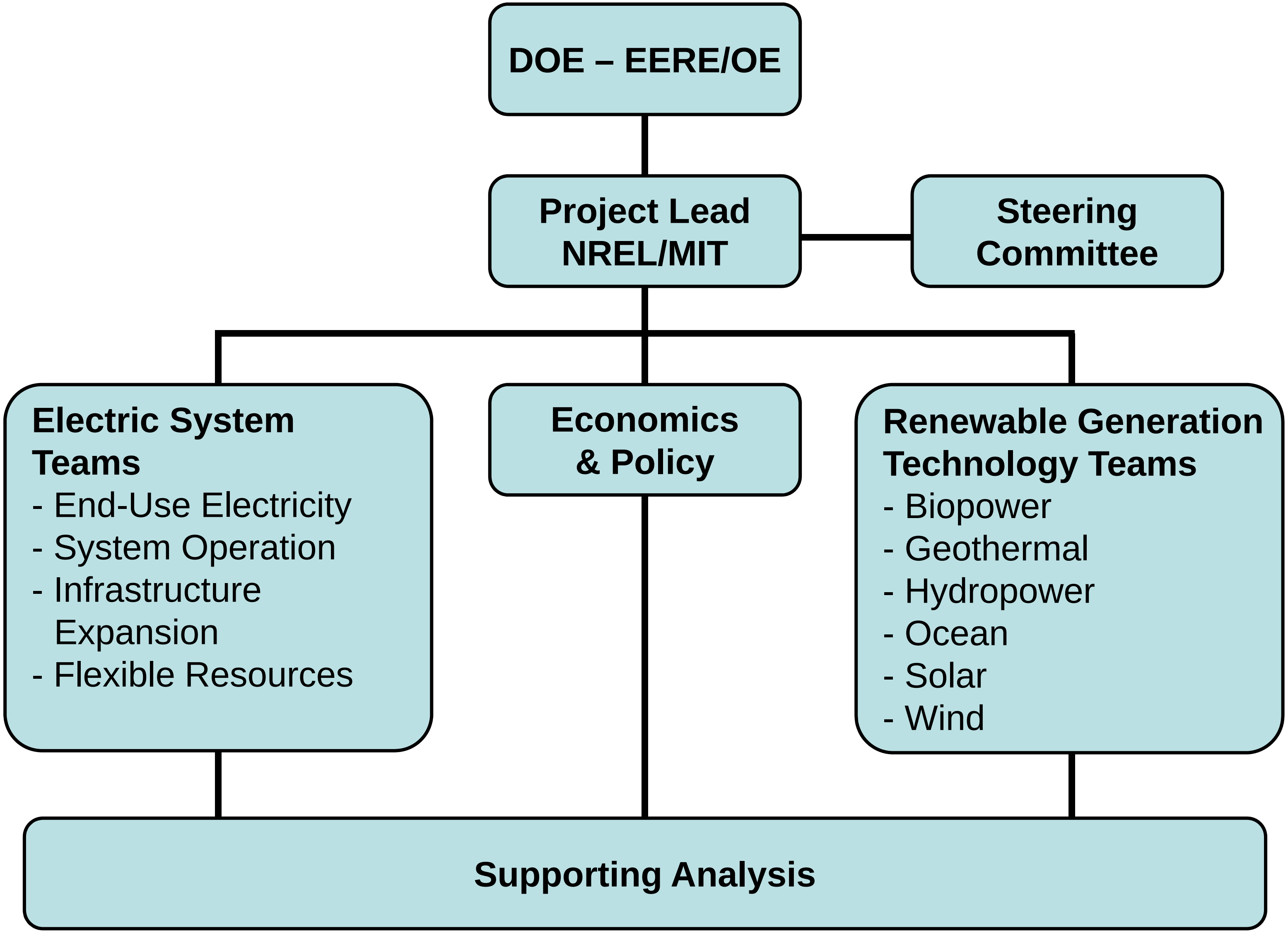
Renewables are one carbon mitigation pathway – ultimately all technologies have important role.

- Explore technical, economic, and social feasibility associated with high RE generation – up to *80% Renewable Electricity generation* in 2050 in the continental US.
- Not a comprehensive carbon policy analysis, and not a value judgment as to whether this future *should* be sought
- Analysis must recognize that a wide range of high renewable electricity futures are possible; the "best" pathway may not be known in advance -- uncertainties abound!

➔ Implication: Analyze an analytically tractable but broad array of scenarios to help characterize and bound the challenges and implications for meeting aggressive RE targets

- Describe implications of large-scale renewable technology deployment, including:
  - Resource potential and geographic distribution
  - RE technology development pathways
  - Economic costs and secondary impacts as well as benefits
  - Electric system operation and expansion challenges.

RE Futures Project Structure

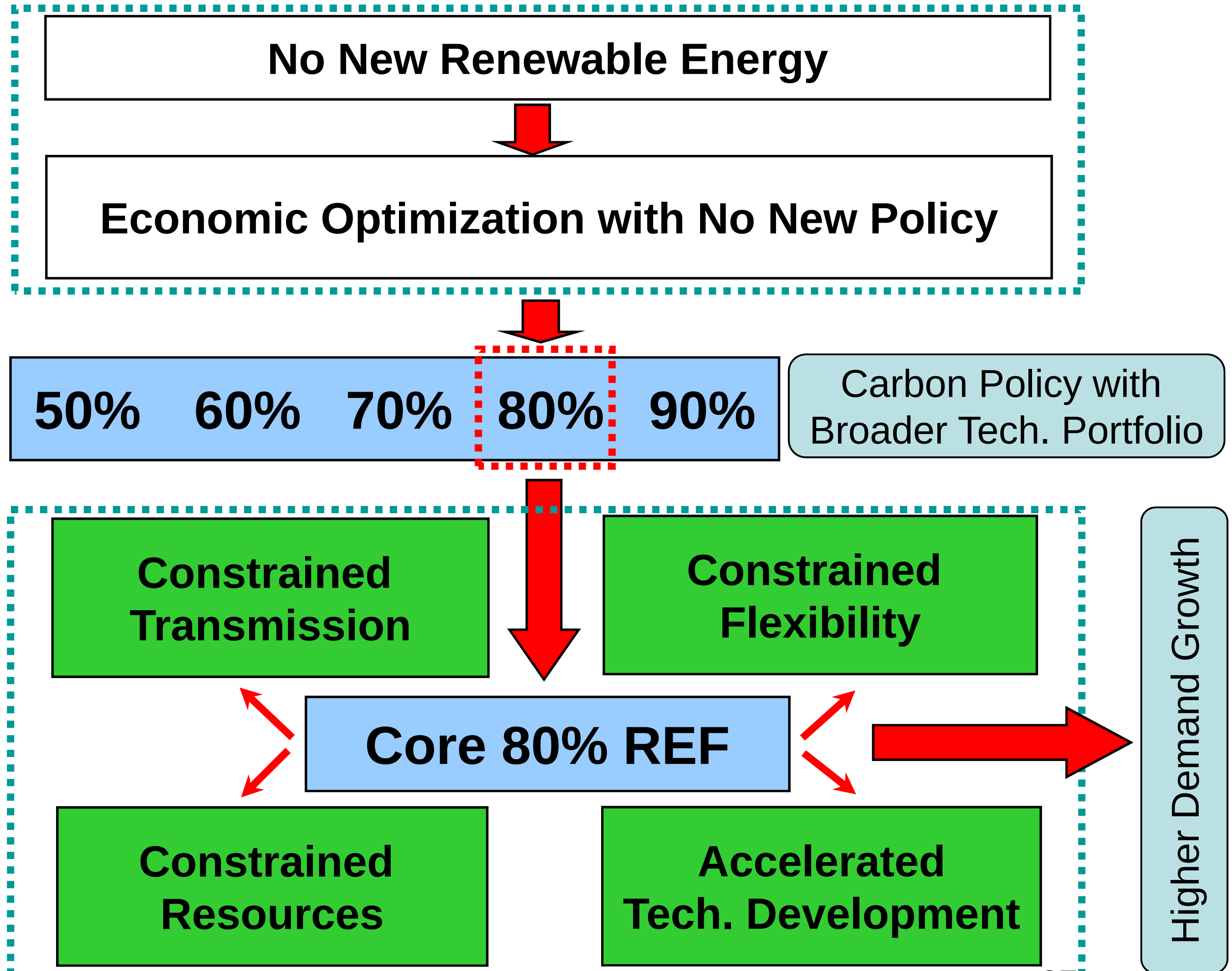


Scenarios

Reference Cases

Exploratory
PERCENT RE CASES

Policy-Relevant REF CASES



Current Implementation of Scenarios

CT – Constrained Transmission: evaluate how limits to building new transmission might impact location, mix, and cost of RE resources used to meet an 80% RE future

- Existing transmission corridors only
- 2X transmission costs (incl. AC-DC-AC intertie cost)
- 2X DG PV penetration

CF – Constrained Flexibility: understand how institutional constraints to managing variability of wind and solar resources might impact resource mix and costs of achieving an 80% RE future

- Balance (reserves & curtailment) at the RTO-level
- No increase in availability of Interruptible Load beyond 2010
- No dynamic PEV charging
- Halve CAES supply curve
- Reduced daily coal cycling (minimum coal plant load set to 70%)

CR – Constrained Resources: posits that environmental/other concerns may reduce developable potential for many RE technologies; evaluates how such constraints might impact composition and cost of RE supply

- Halve supply curve for all RE technologies (except PV)
- Halve biomass feedstock supply curve

AD – Accelerated Technology Development: explore implications of enhanced advancements in RE techs, with reduction in cost of RE supply

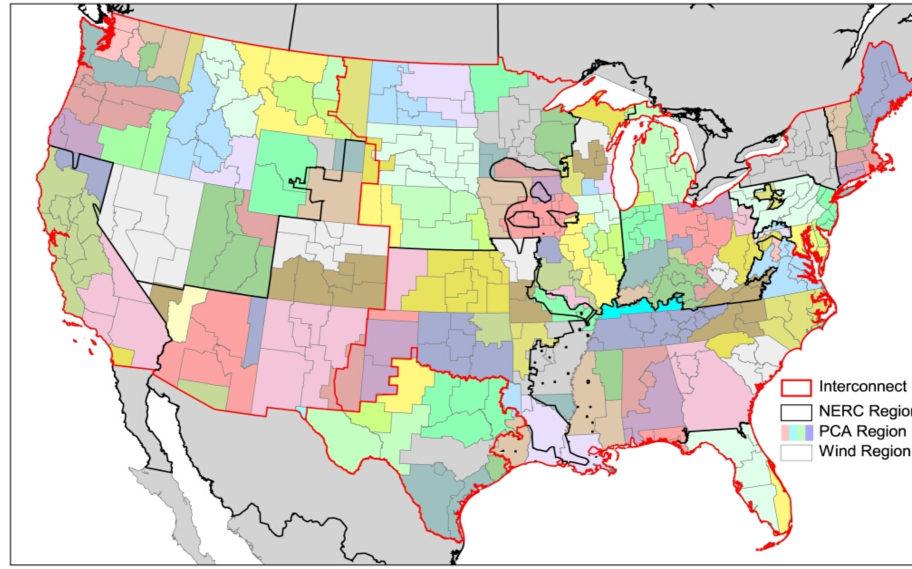
- Use B&V low cost / improved performance projections for all RE technologies

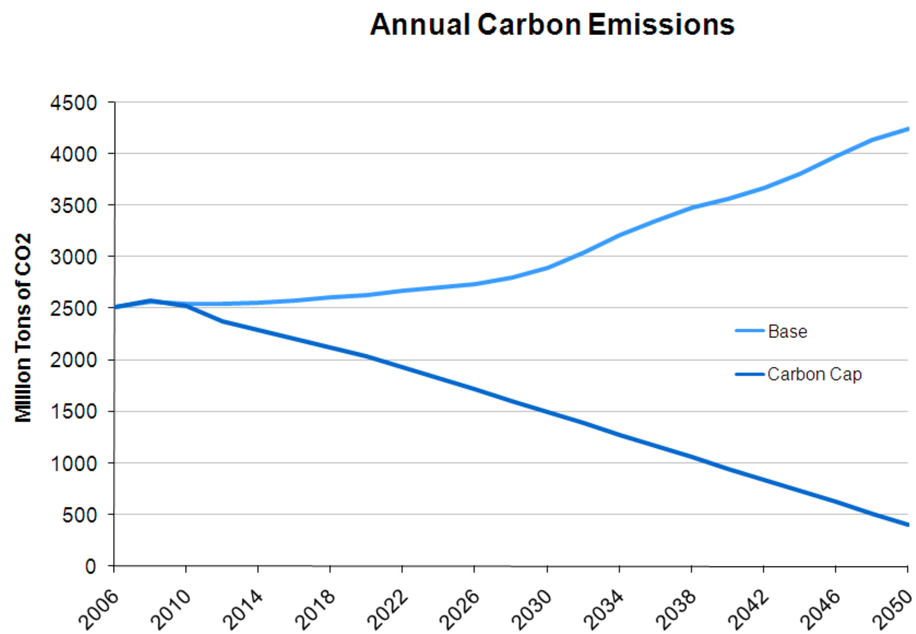
HD – High Demand: explores technical/economic viability of 80% RE Future if demand increases according to traditional expectations

- Use higher demand growth close to AEO reference case

ReEDS Model

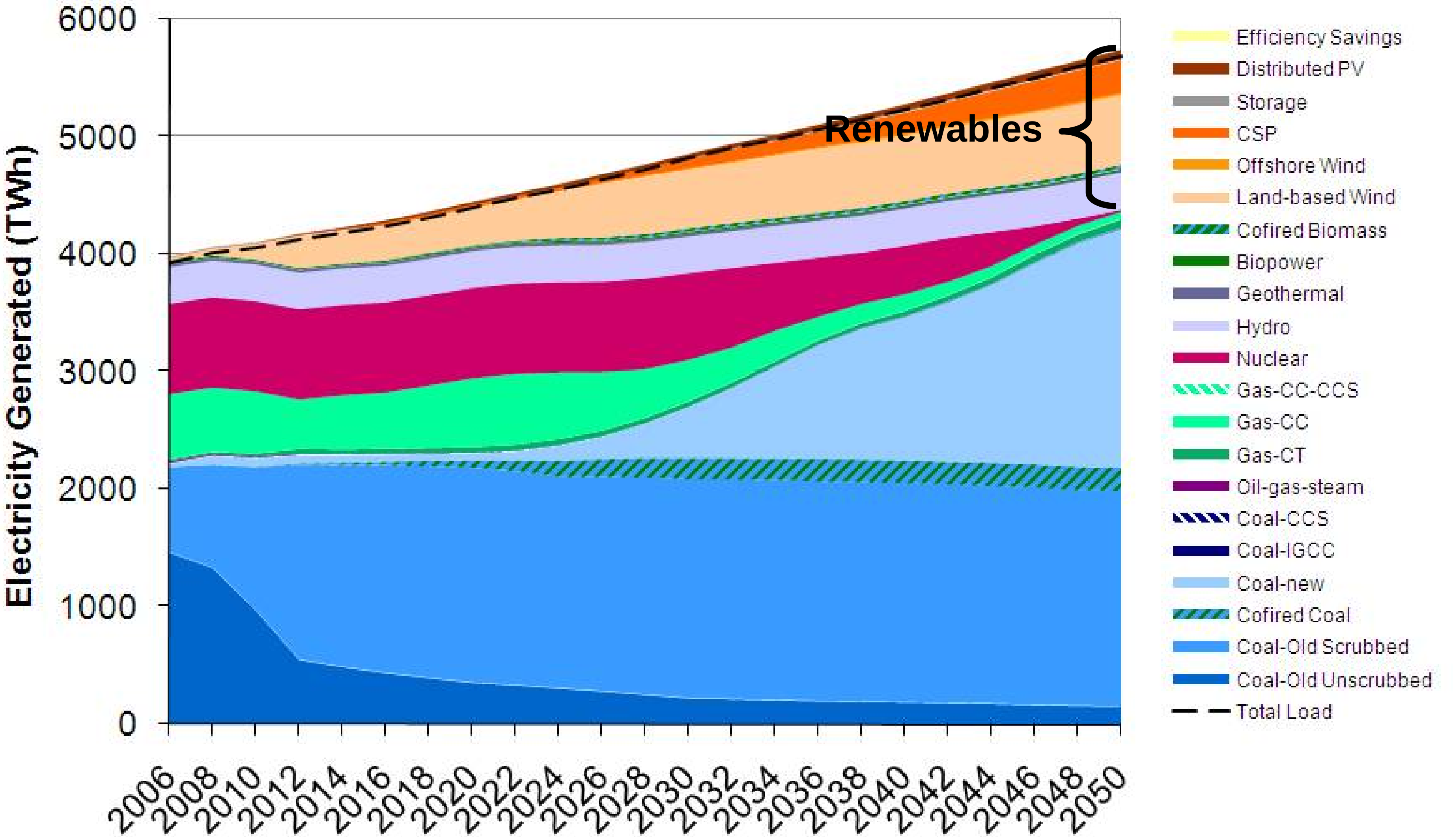
- **356 regions in Continental U.S.**
- **Linear program cost minimization**: 23 two-year periods from 2006-2050.
- **All major power technologies**–hydro, gas CT, gas CC, 4 coal (w/wo CCS), gas/oil steam, nuclear, wind, CSP, biopower (wo *CCS*), geothermal, 3 storage technologies.
- **17 time slices in each year**: 4 daily x 4 seasons (+one super-peak).
- **Input future electric demands and fuel prices by region.**
- Simple elasticities provide *demand* and fossil fuel price response.
- **6 levels of regions** – RE supply, power control areas, RTOs, states, NERC areas, Interconnection areas.
- **Existing/new transmission lines.**
- **State-level incentives.**
- **Stochastic treatment of resources.**
- **Does not yet directly include PV or distributed benefits;** PV a placeholder
- **Policy: 80% emissions reduction from 2005 by 2050.**





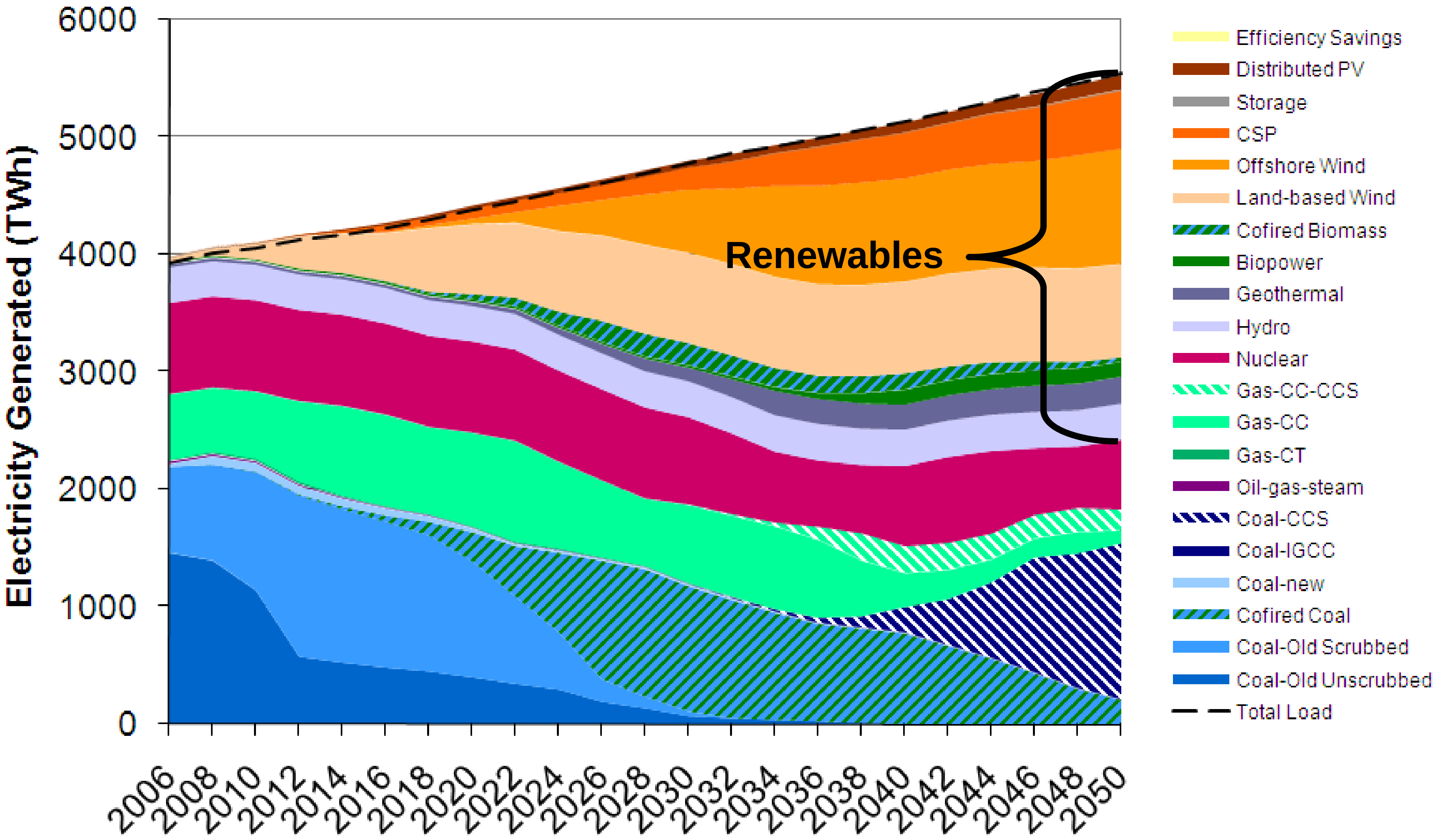
Source: Walter Short, NREL

Base Case Generation



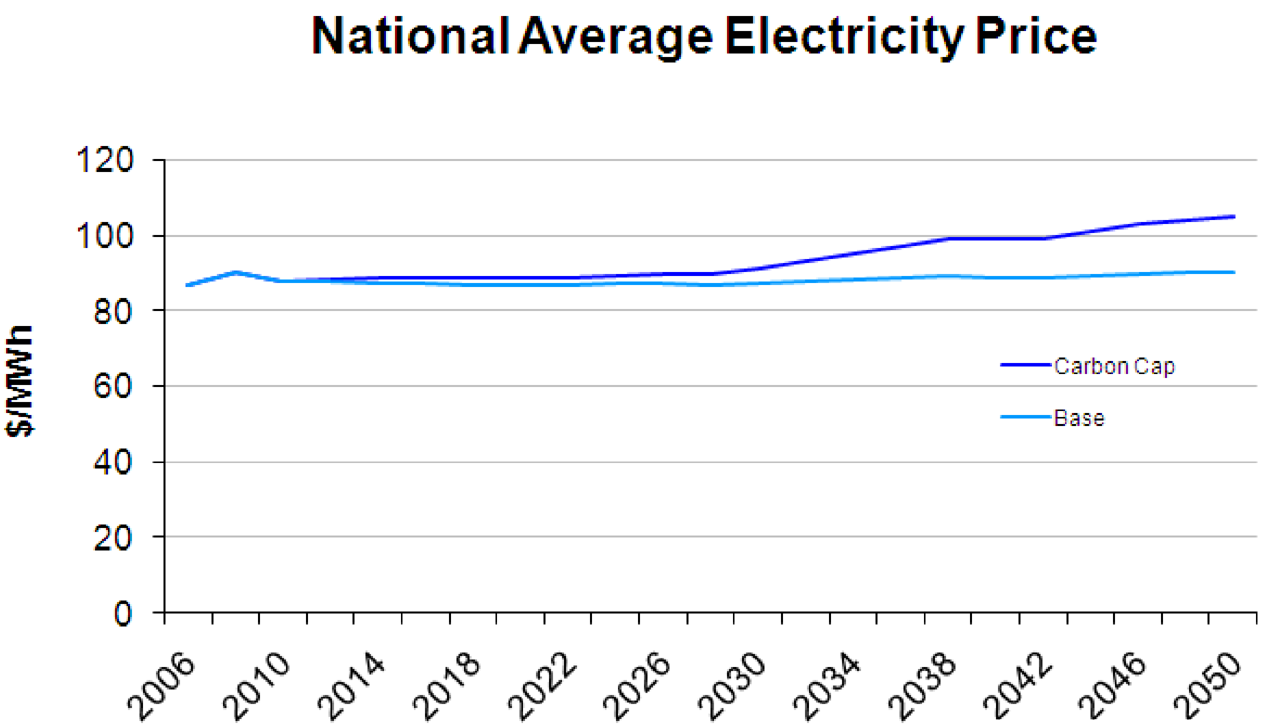
Source: Walter Short, NREL

Carbon Cap: Generation

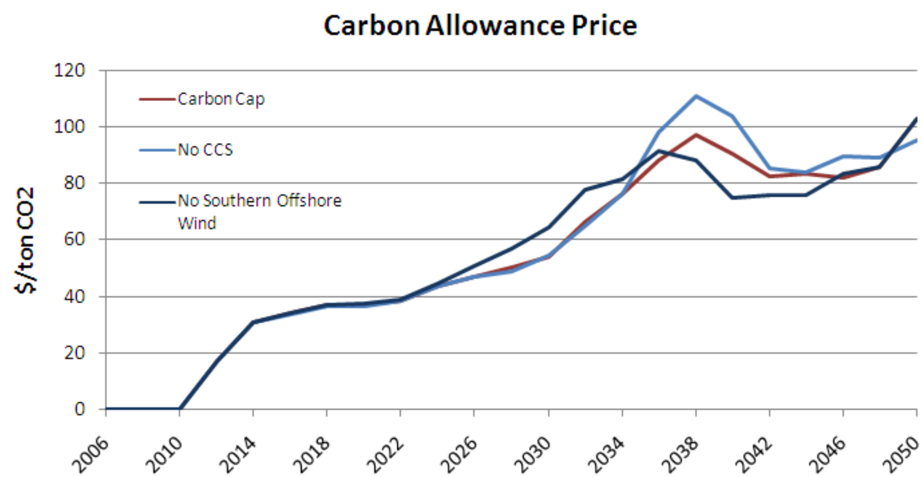


Source: Walter Short, NREL

Carbon Cap: Electricity Prices



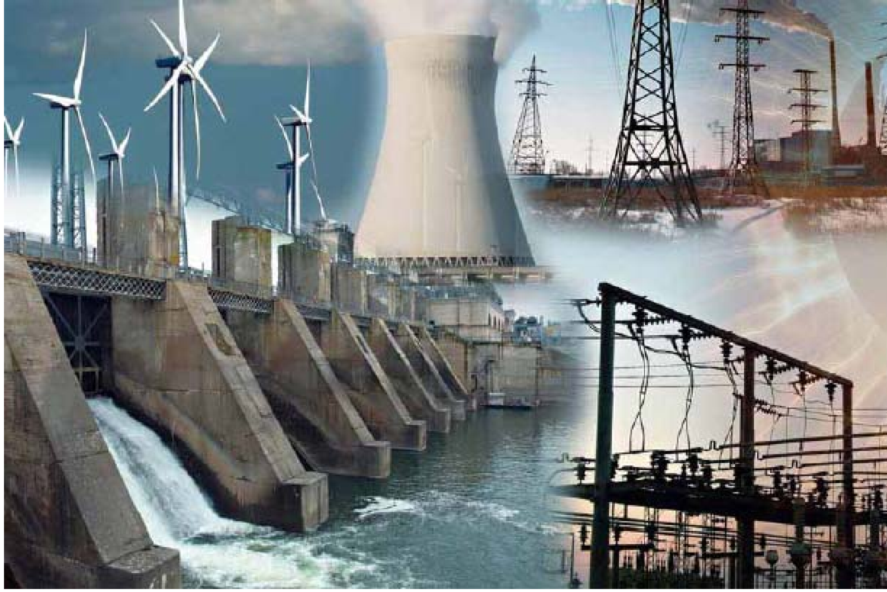
➔ Price targets for PV systems, not including distributed benefits.



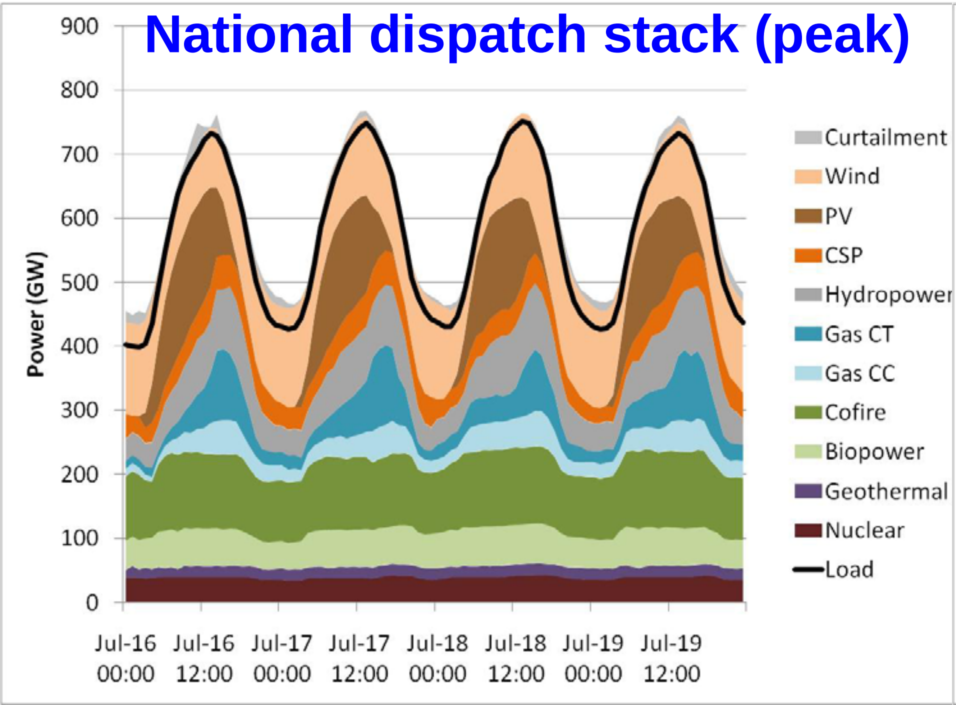
Source: Walter Short, NREL

GridView

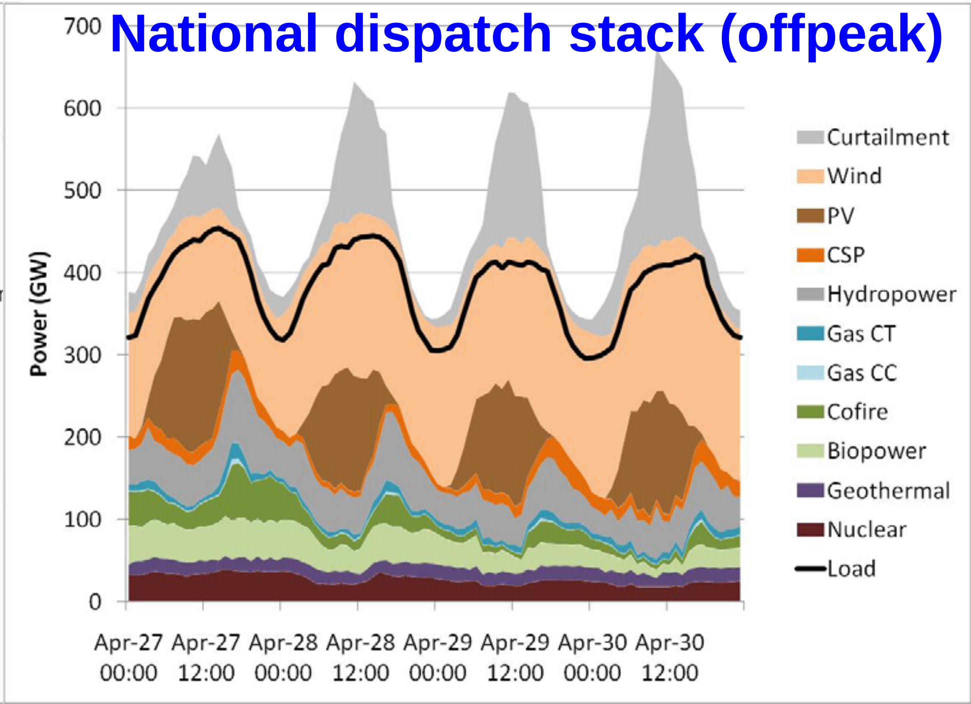
- Commercial Production cost model by ABB
- Used by ISOs, utilities, others for planning…
- 11,000 Generators; 85,000 Transmission lines; 34,000 Buses w load; 65,000 nodes; 136 transmission zones
- Simulates 8760 hours/year: power flow, dispatch, transmission congestion, unserved load; etc.



National dispatch stack (peak)

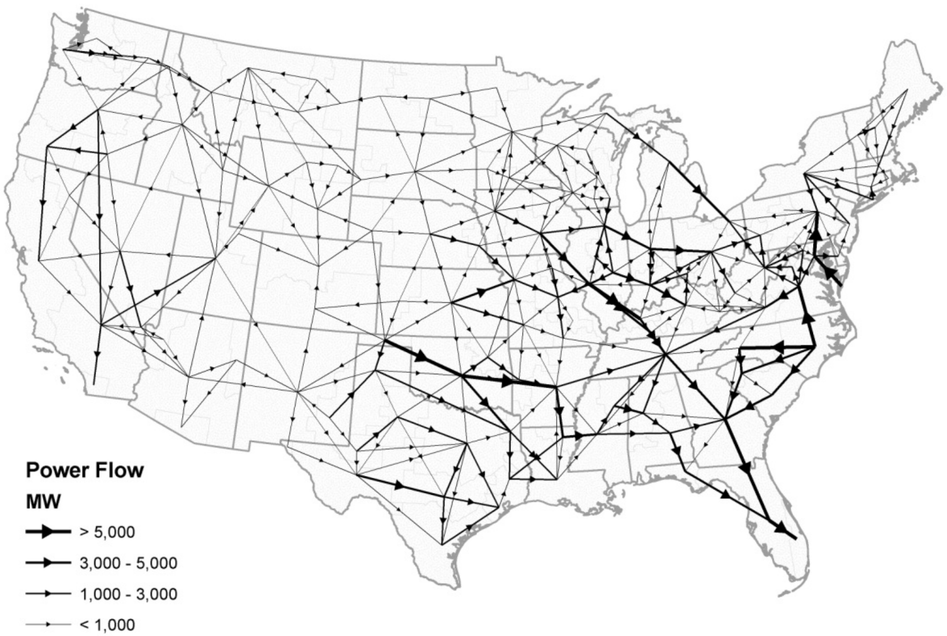


National dispatch stack (offpeak)

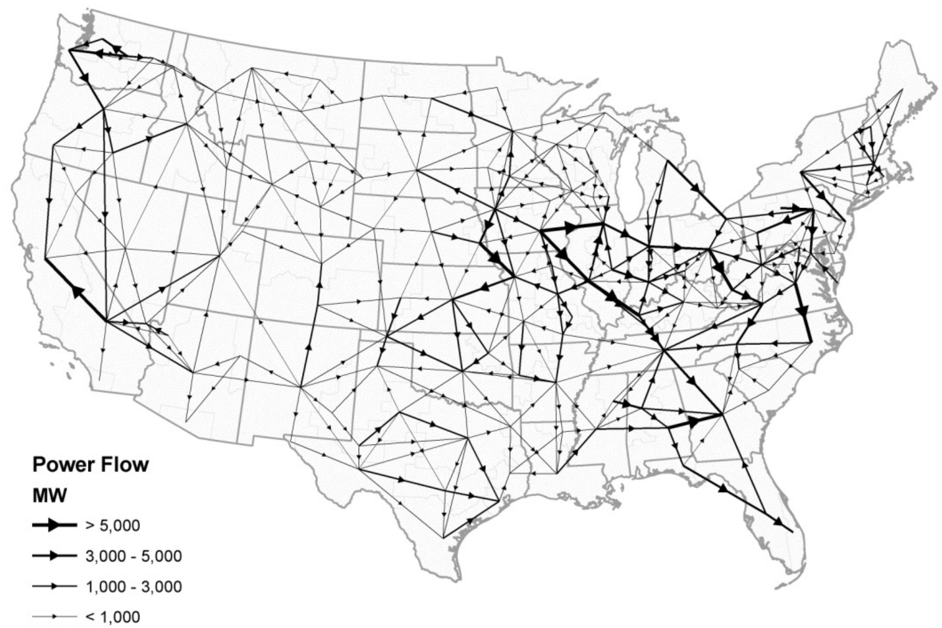


GridView hourly power flows

Peak hour (July 17, 15:00 PST)

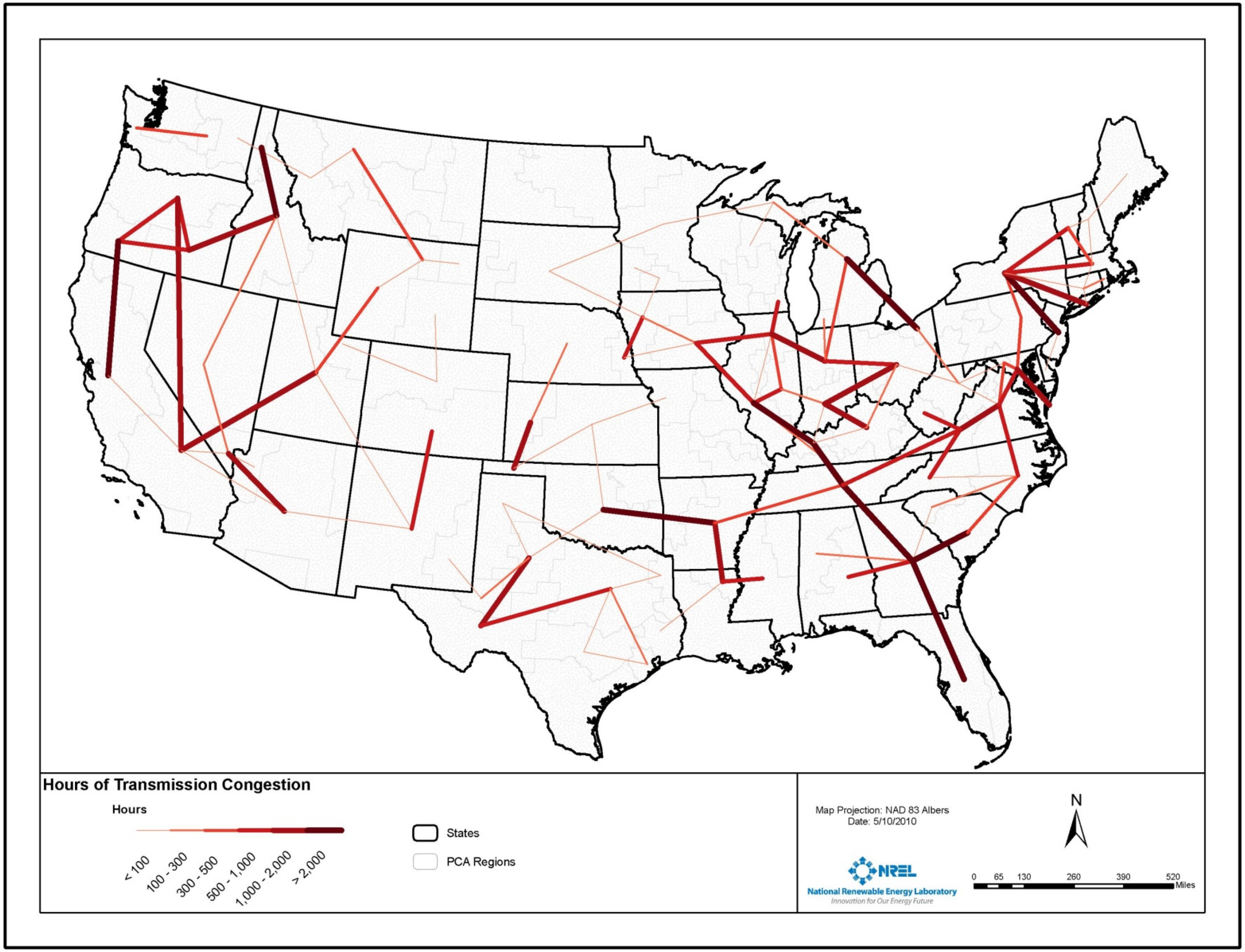


Off-peak hour (April 30, 1:00 PST)



Source: Greg Brinkman, NREL

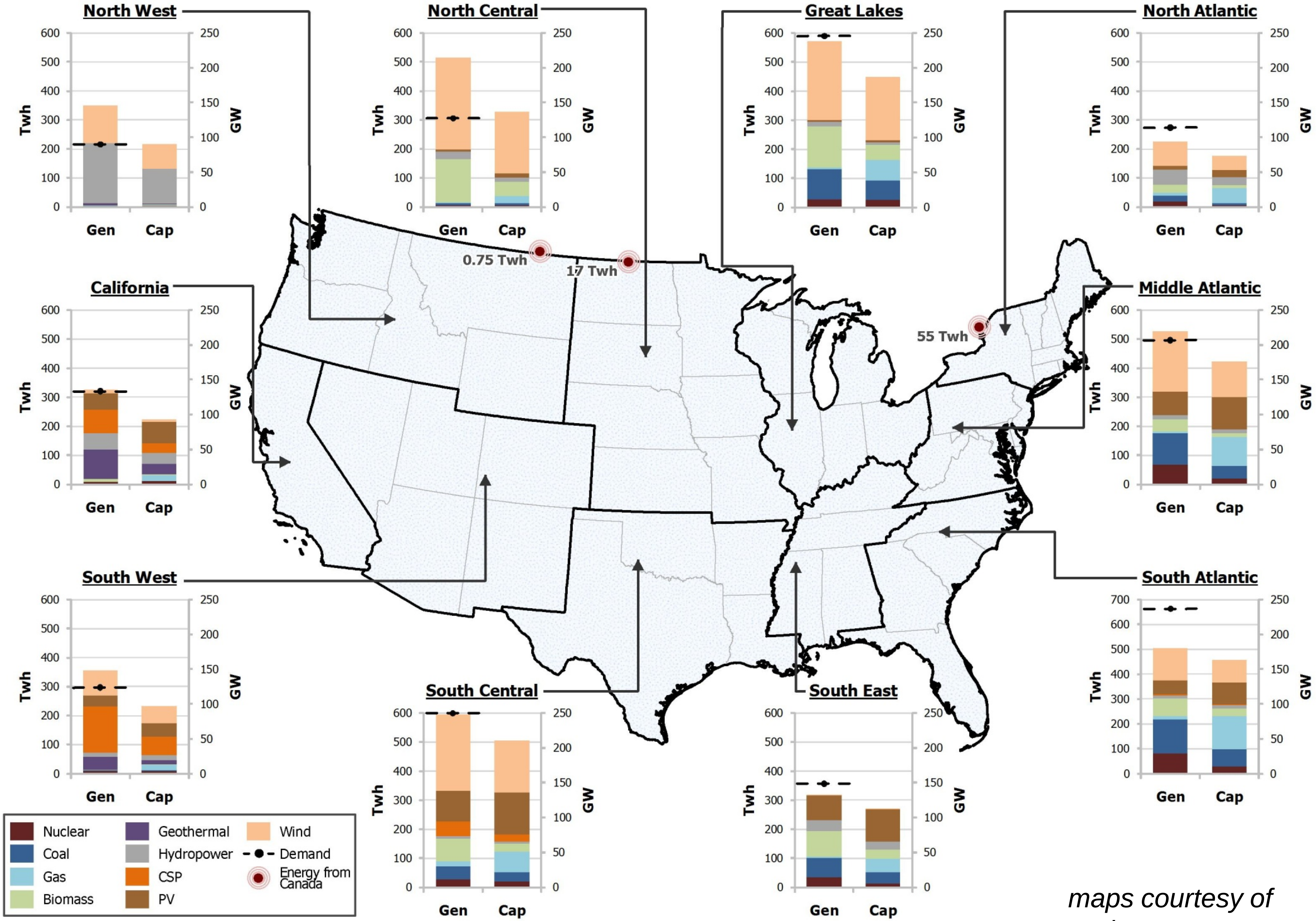
Hours of congestion



Source: Greg Brinkman, NREL

2050 Regional Generation and Capacity

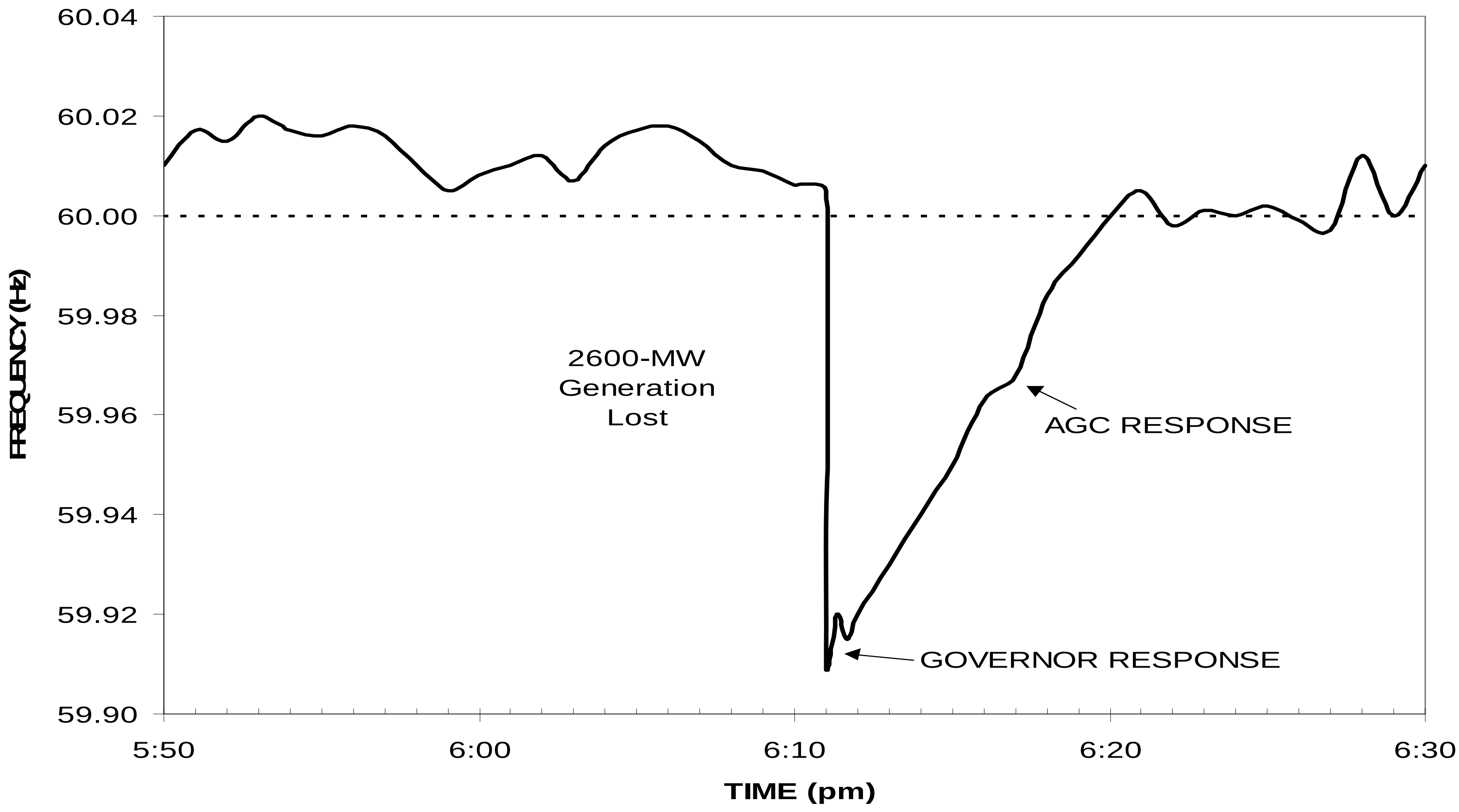
Renewable Electricity Futures 80%-by-2050 Core Scenario



maps courtesy of Anthony Lopez, NREL

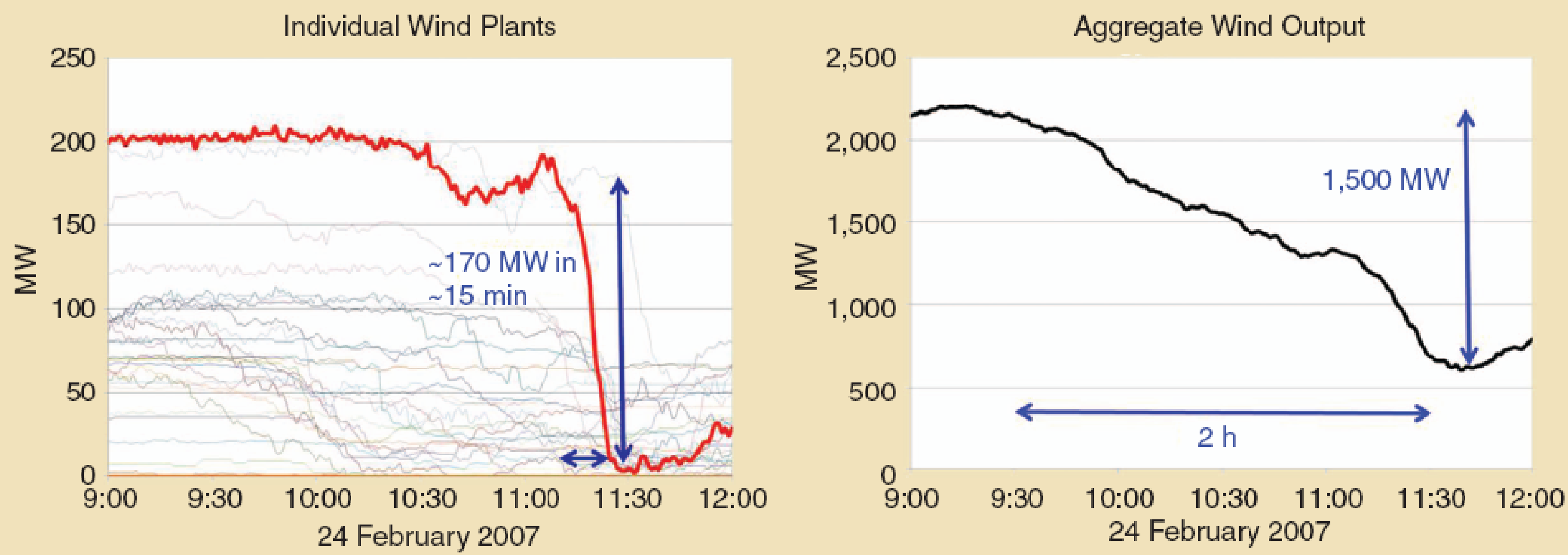
System Loss and Frequency Excursion

Energy Must Be Re-Balanced Quickly by Adding Generation or Shedding Load



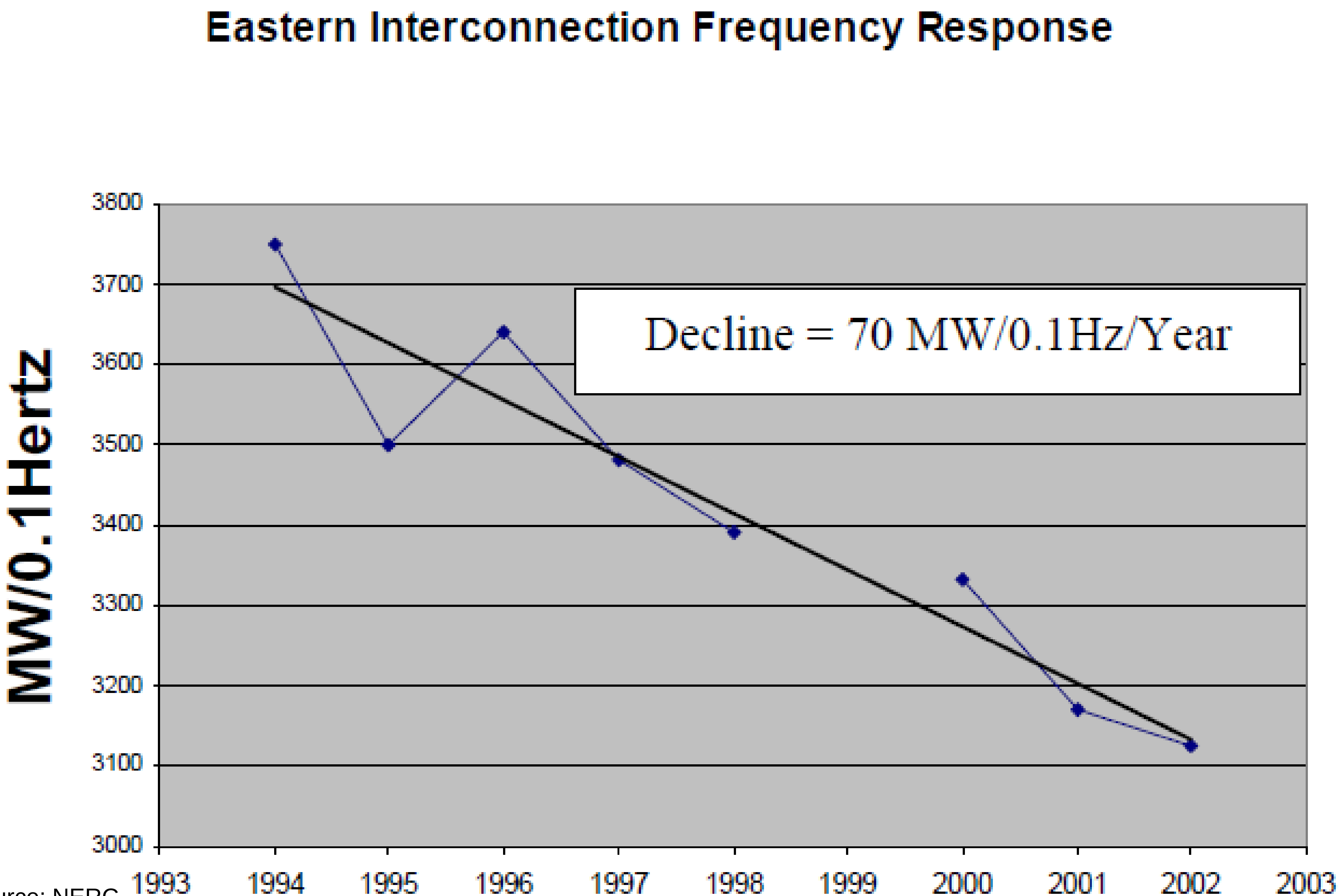
Source: Provided by NREL

Distributed Systems



Source: Milligan, et al., IEEE Power & Energy, Nov./Dec 2009, pp.92

Frequency Response



Source: NERC

Clean Energy to Secure America's Future

"For everywhere we look, there is work to be done. The state of our economy calls for action: bold and swift. And we will act not only to create new jobs but to lay a new foundation for growth... We will restore science to its rightful place... We will harness the sun and the winds and the soil to fuel our cars and run our factories. All this we can do. All this we will do."

President Obama 1/20/09

"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

For more information

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