Energy Efficiency & Renewable Energy: Challenges and Opportunities

Clean Energy SuperCluster Expo
Colorado State University
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Sam Baldwin
Chief Science Officer
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

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?

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

Speed and Scale

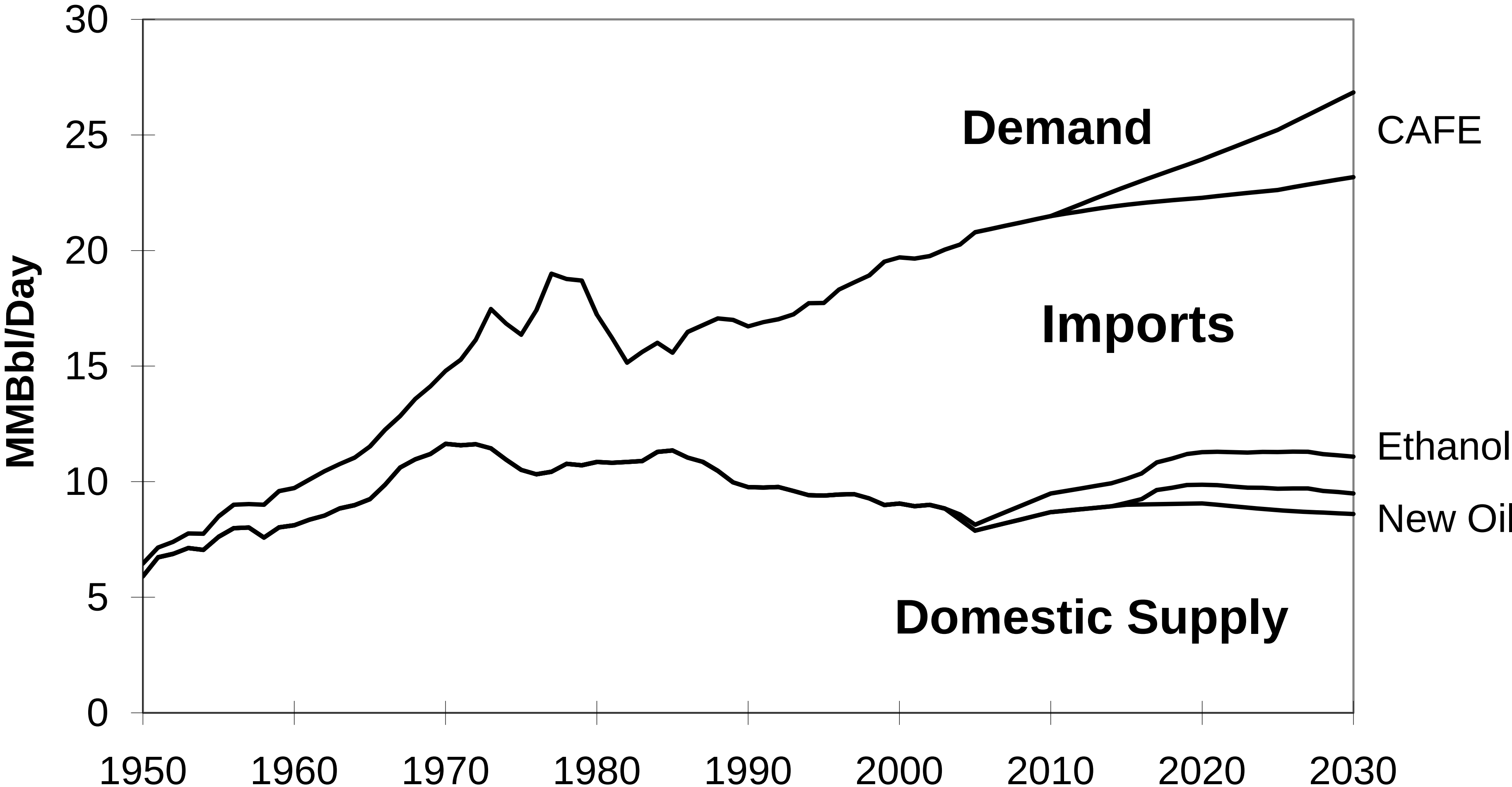
The Oil Problem

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**

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

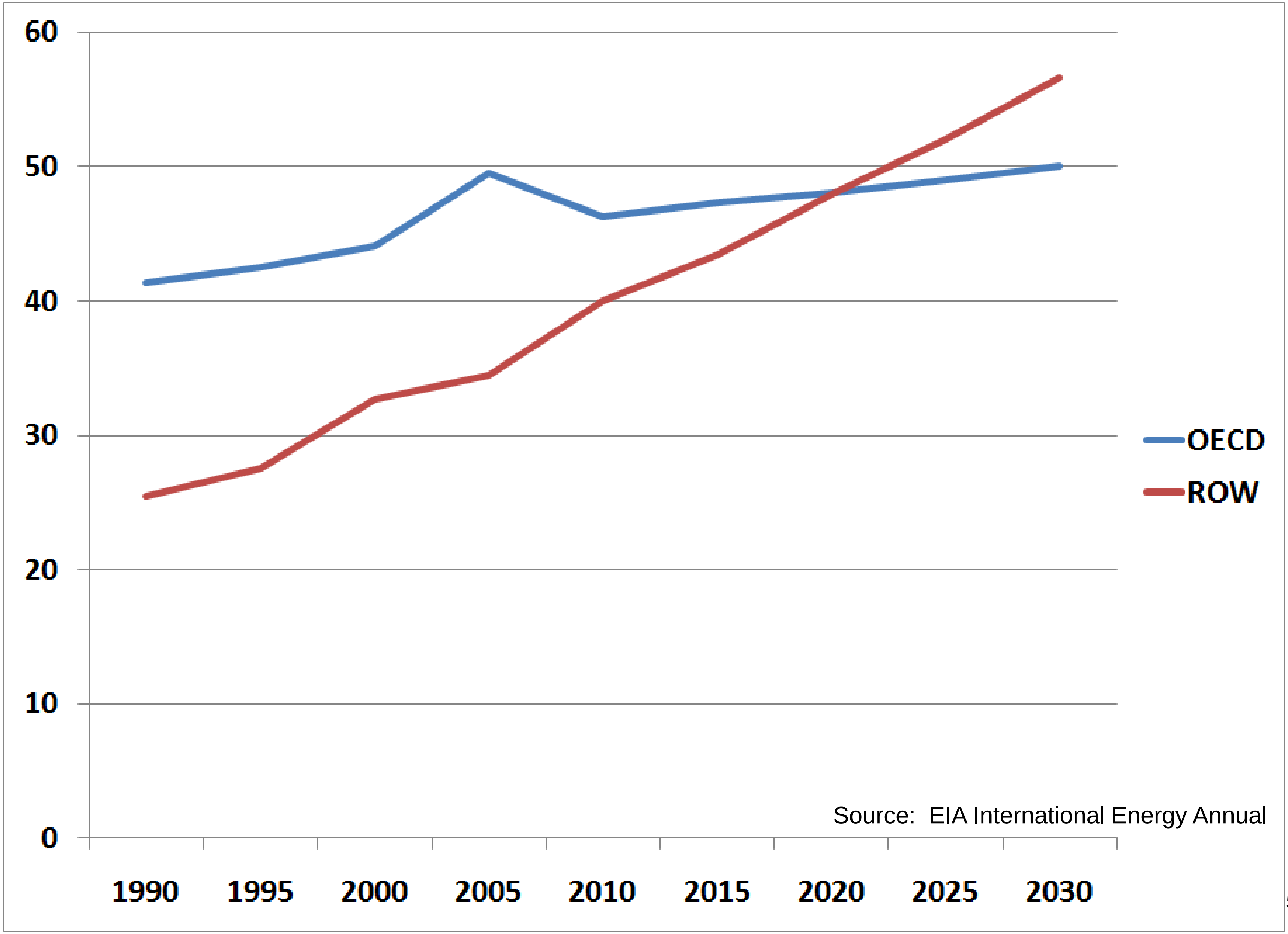
Source: EIA International Energy Annual

Oil Futures?



Source: Adapted from EIA Annual Energy Outlook

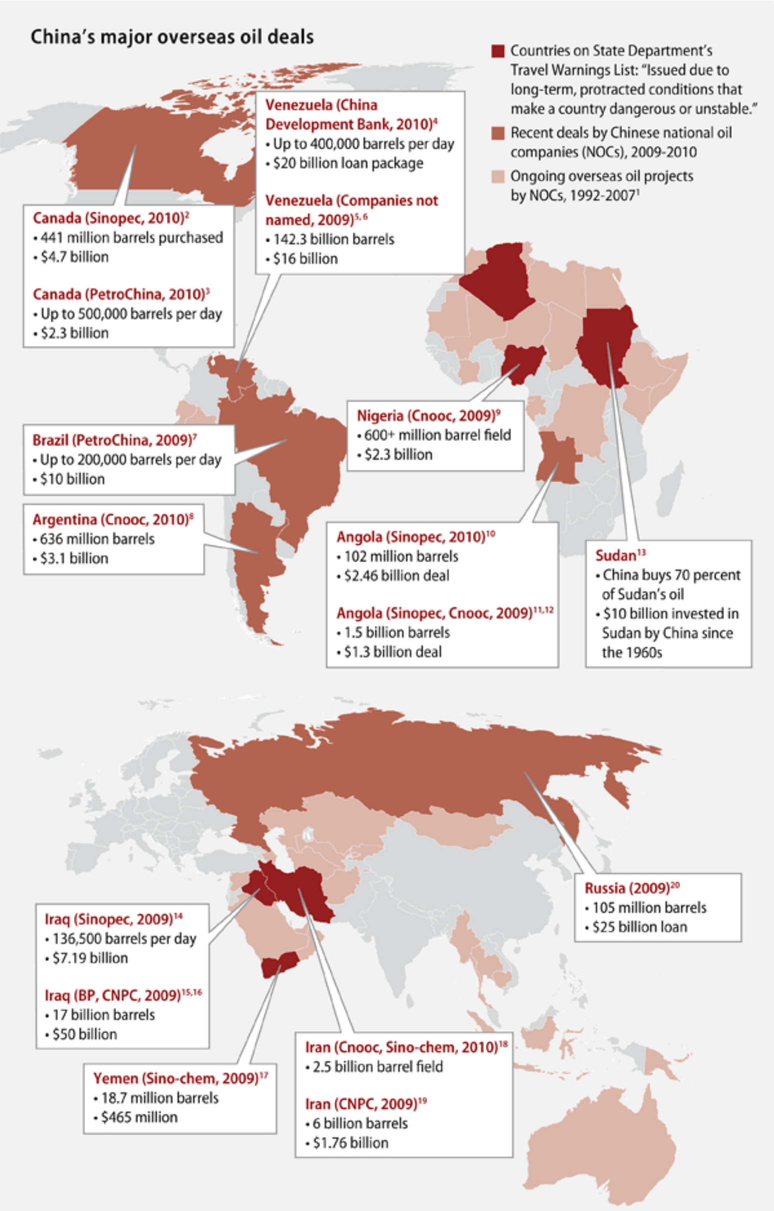
Global Liquid Fuel Demand (MB/d)



Source: EIA International Energy Annual

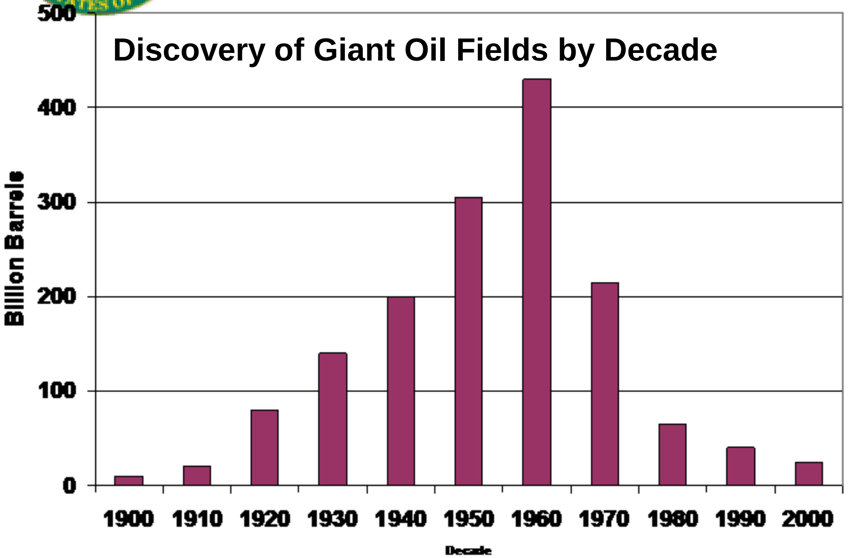
Impacts of Oil Dependence

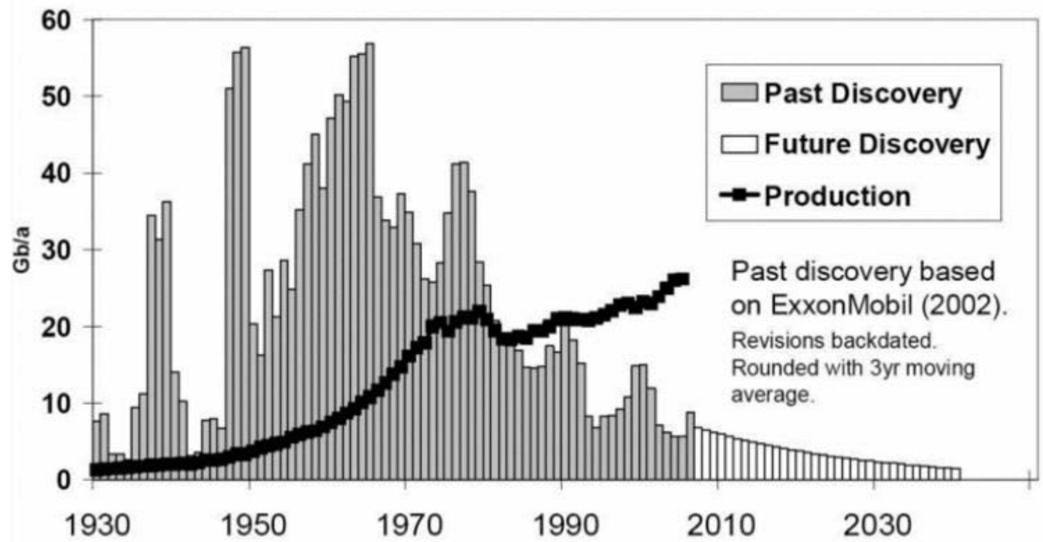
- **Trade Deficit: Oil ~57% of $677B trade deficit, 2008**
- **Foreign Policy Impacts**
  - Strategic competition for access to oil
  - Oil money supports undesirable regimes
  - Oil money finds its way to terrorist organizations
- **Vulnerabilities**
  - to system failures: tanker spills; pipeline corrosion; 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

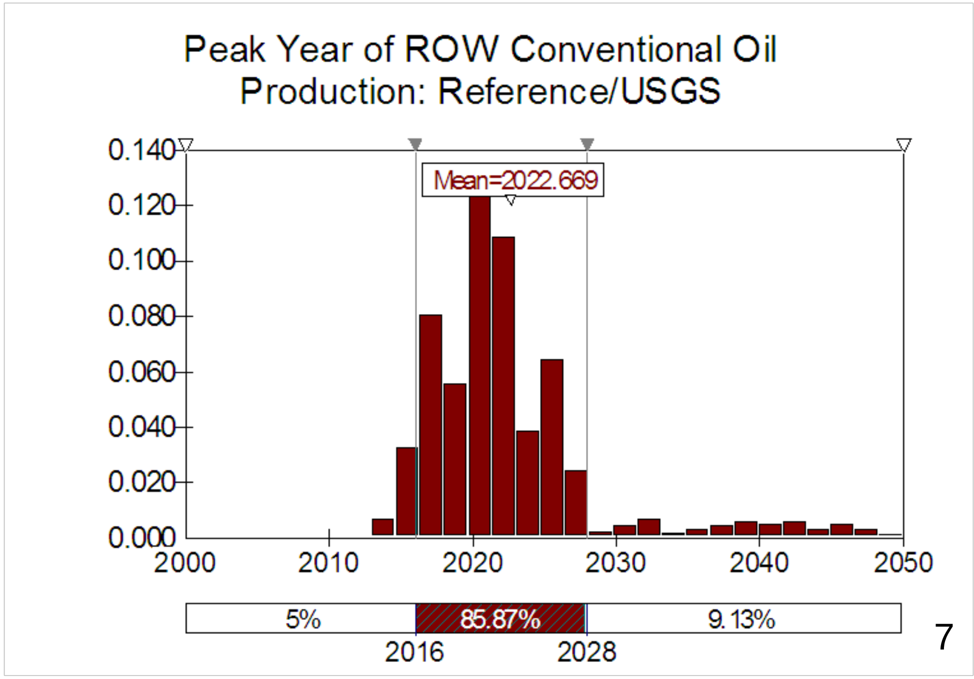
Conventional Oil





International Energy Agency, 2008

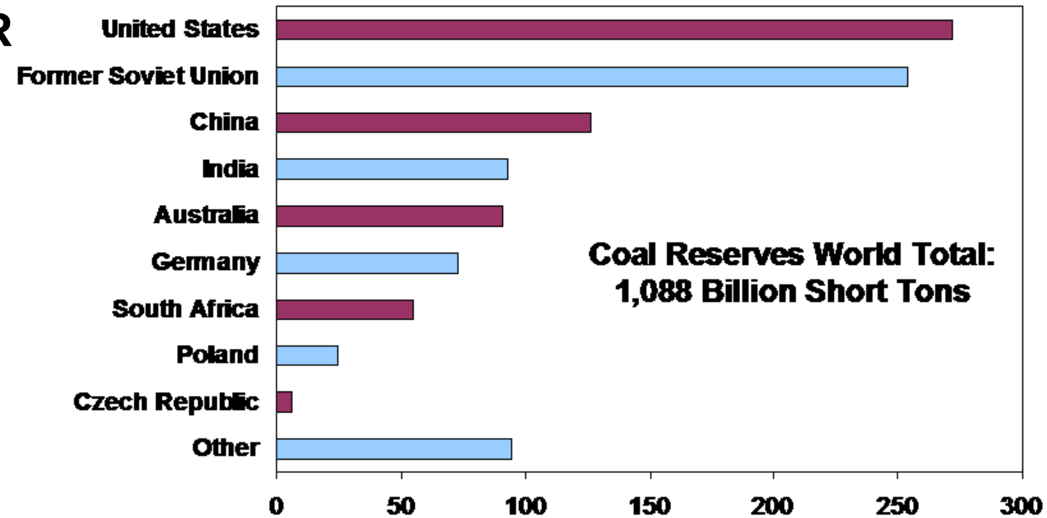
- Across 798 of world's largest oil fields, average production decline of 6.7%/year.
- Of 798 fields, 580 had passed peak.
- To meet growth & replace exhausted resources, will have to add 64 MB/d by 2030, or 6X Saudi Arabia.



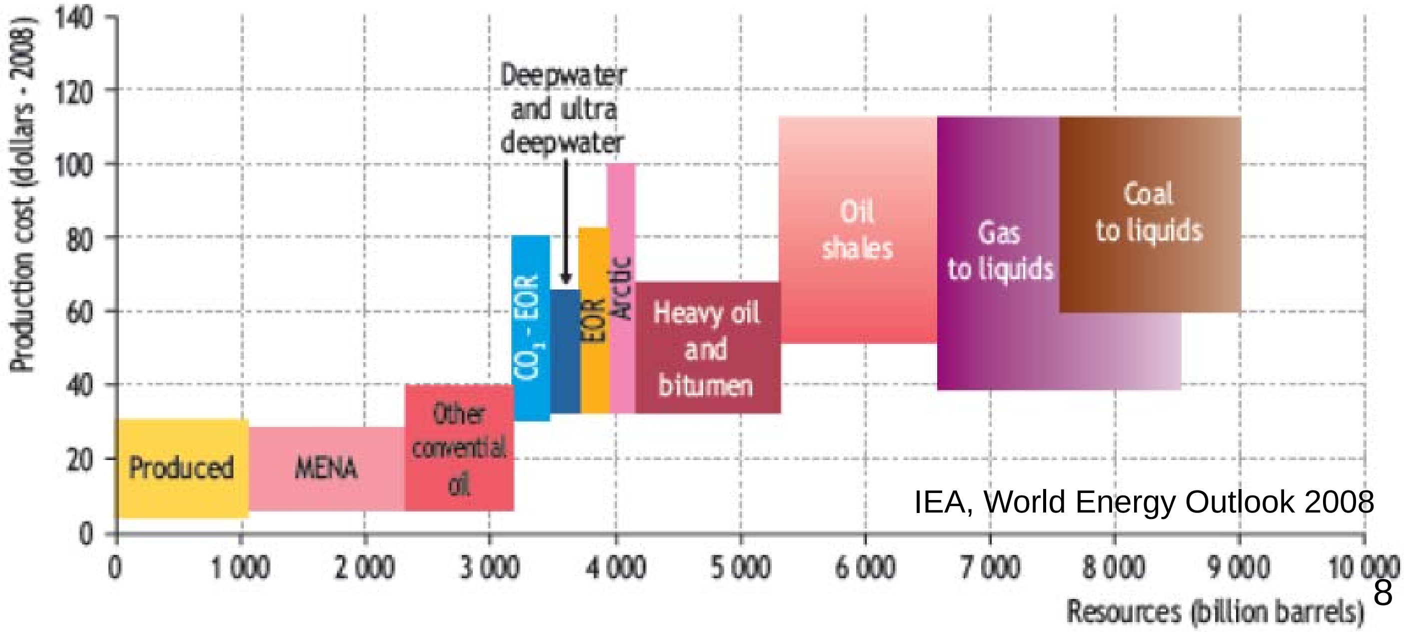
- Sources: (Figure 1) Fredrik Robelius, Uppsala Universitet; (Figure 2) Association for the Study of Peak Oil; (Figure 3) David Greene, ORNL.

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



Potential Impacts of GHG Emissions

- Temperature Increases

- Precipitation Changes
- Glacier & Sea-Ice Loss
- Water Availability

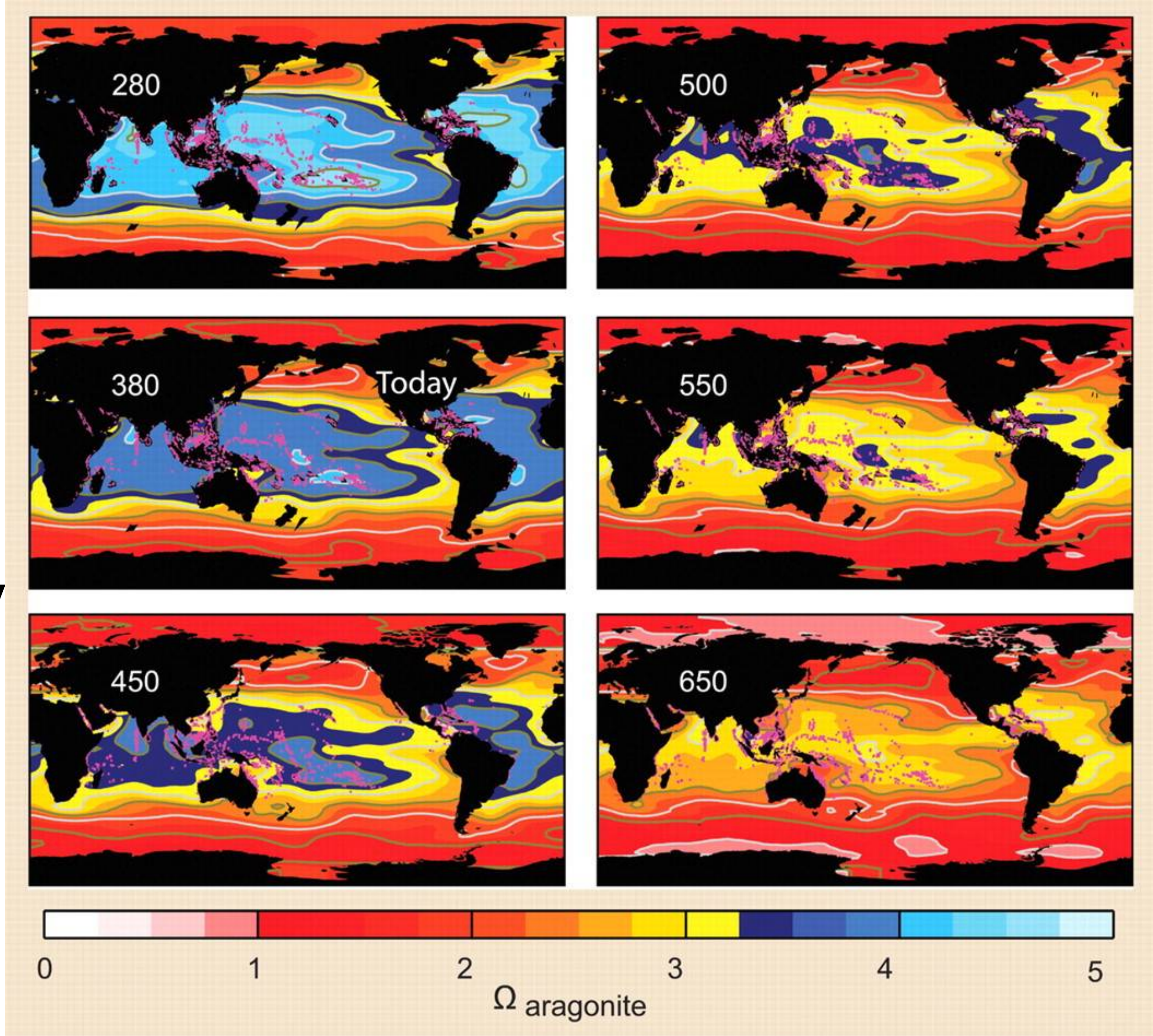
- Wildfire Increases
- Ecological Zone Shifts
- Extinctions

- Agricultural Zone Shifts
- Agricultural Productivity

- Ocean Acidification
- Ocean Oxygen Levels
- Sea Level Rise

- Human Health Impacts

- Feedback Effects

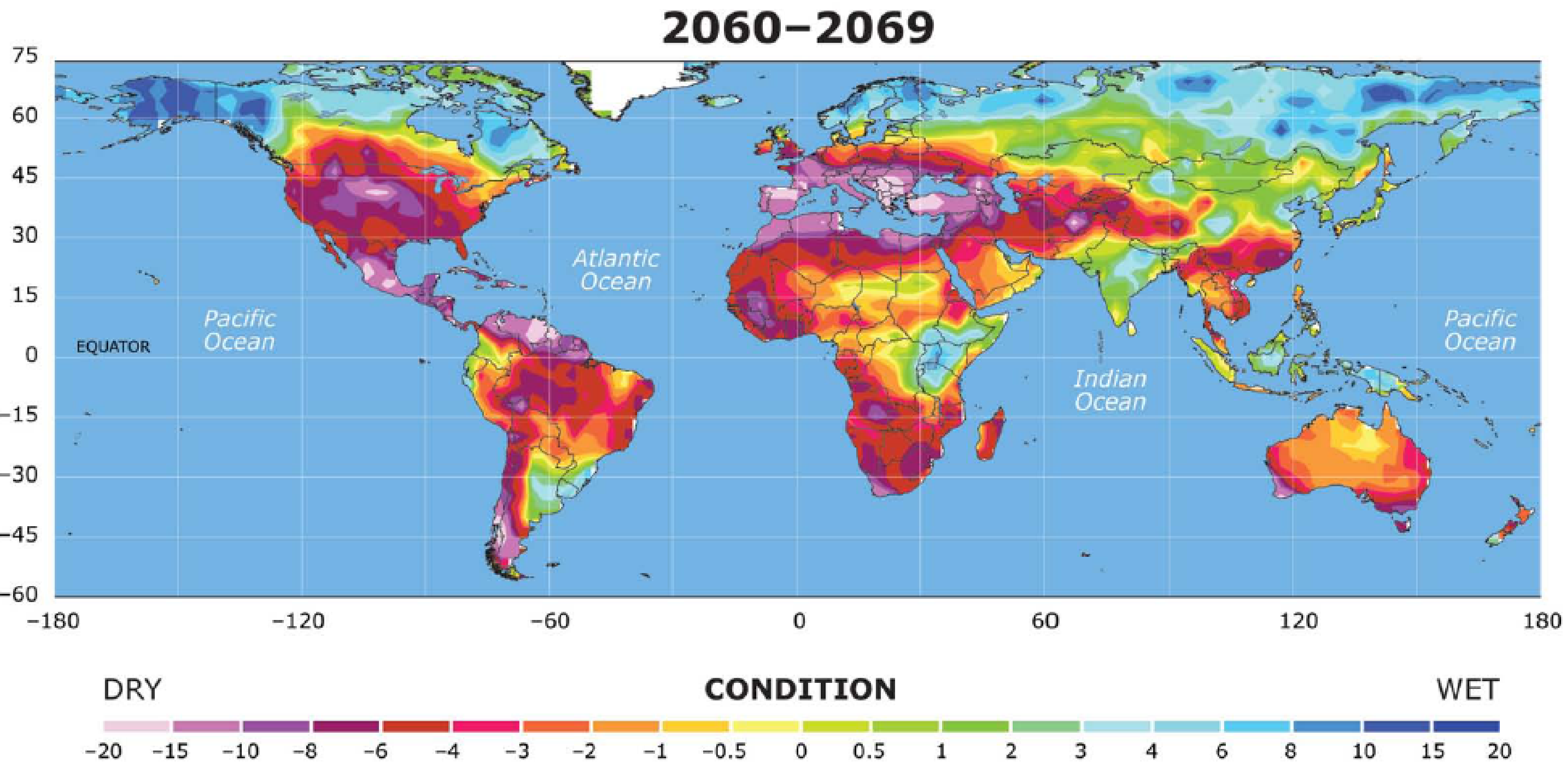


Hoegh-Guldberg, et al, Science, V.318, pp.1737, 14 Dec. 2007

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

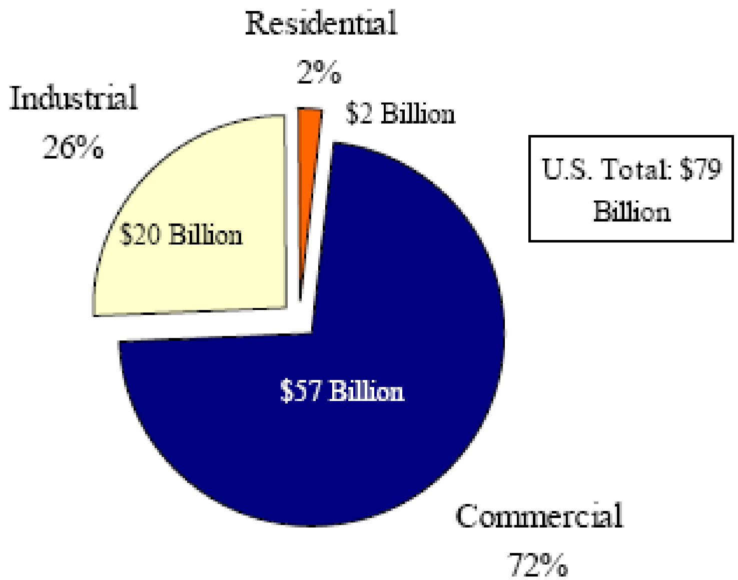
- **Signed by the National Academies of Science of 70 nations:**
  - Argentina, Australia, Bangladesh, Brazil, Canada, China, France, Denmark, Greece, India, Japan, Germany, Mexico, Pakistan, Spain, Taiwan, U.K., U.S…..
- **“The rapid increase in CO2 emissions since the industrial revolution has increased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

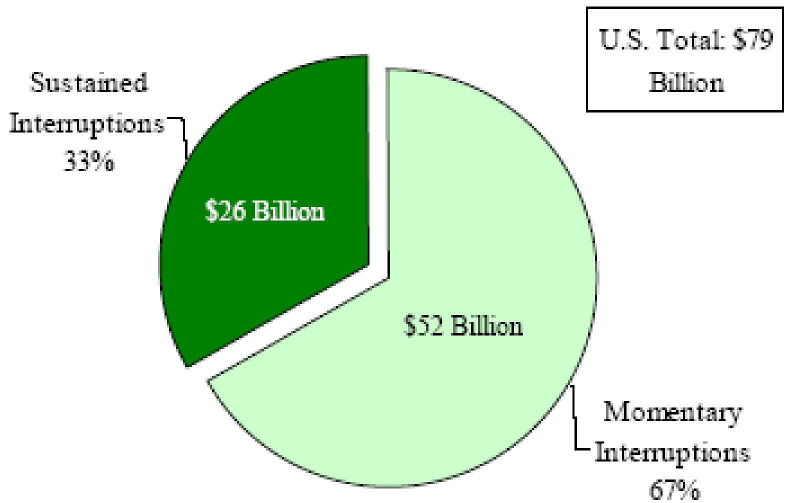


Extreme Drought ↑

Aiguo Dai, "Drought under global warming: a review", Wiley InterDisciplinary Review: Climate Change, 2010; Online Oct 19, 2010; http://onlinelibrary.wiley.com/doi/10.1002/wcc.81/pdf

Costs of Power Interruptions





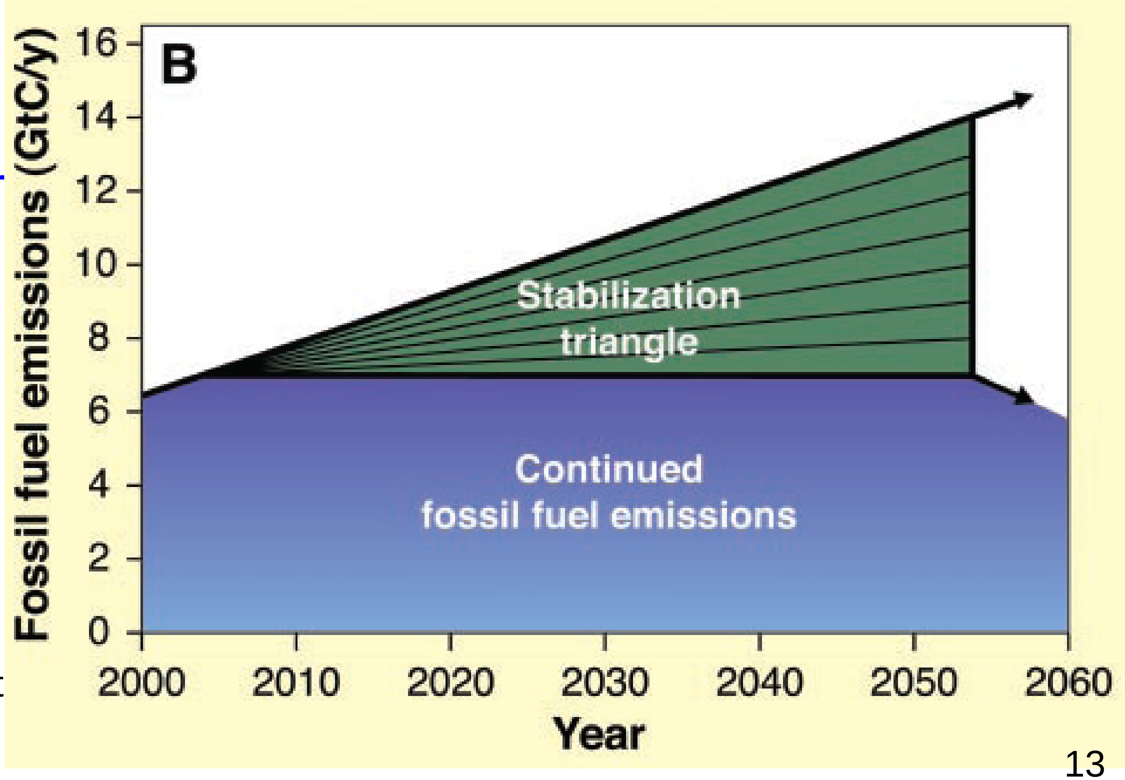
Kristina Hamachi LaCommare, and Joseph H. Eto, LBNL

New York City during the August 2003 blackout

Chip East / Reuters file

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.

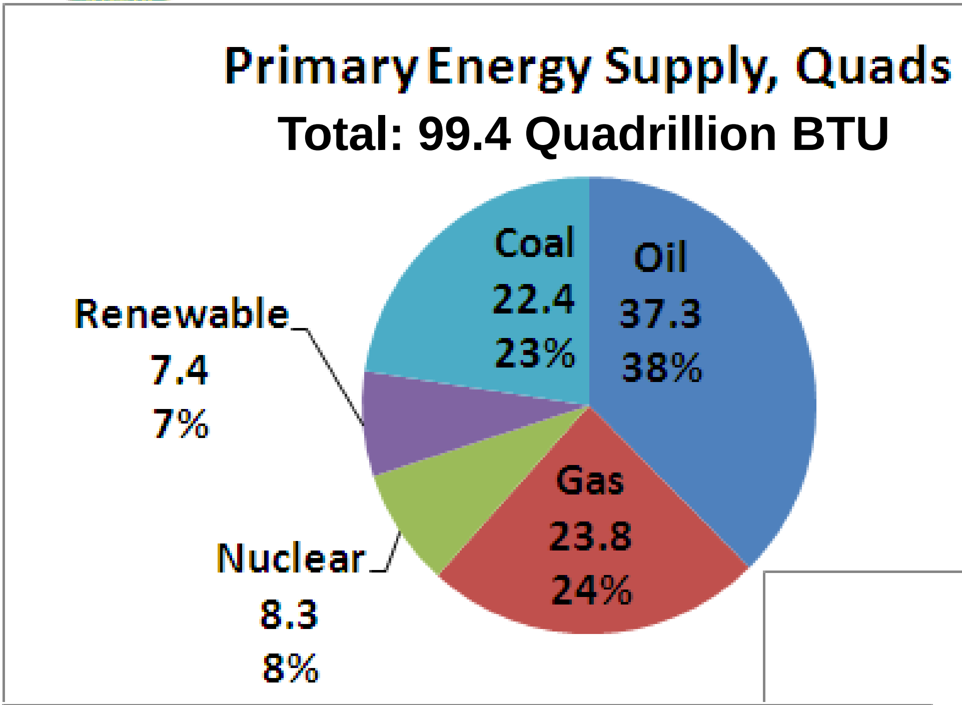
Time Constants

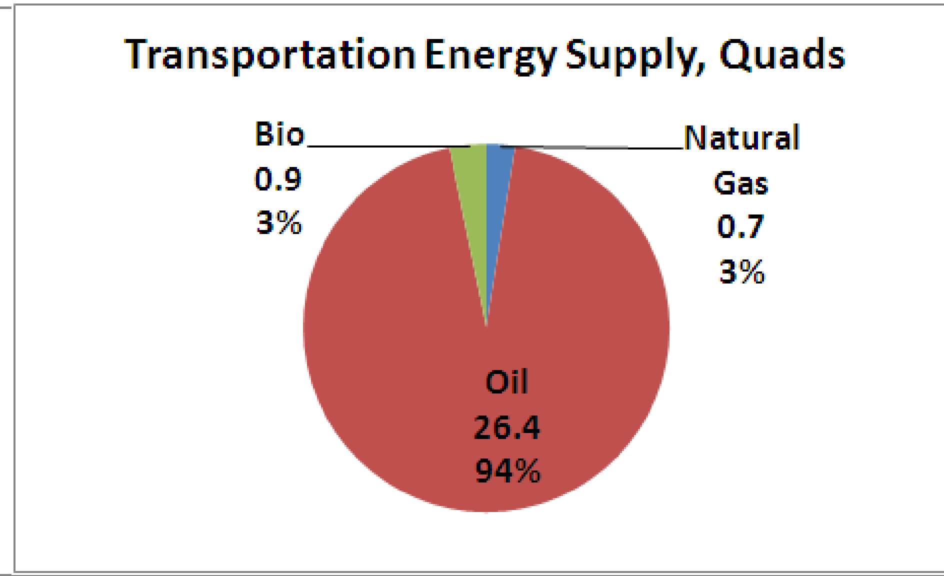
- Political consensus building ~ 3-30+ years
- Technical R&D ~10+
- Production model ~ 4+
- Financial ~ 2++
- Market penetration ~10++
- Capital stock turnover
  - Cars ~ 15
  - Appliances ~ 10-20
  - Industrial Equipment ~ 10-30/40+
  - Power plants ~ 40+
  - Buildings ~ 80
  - Urban form ~100's

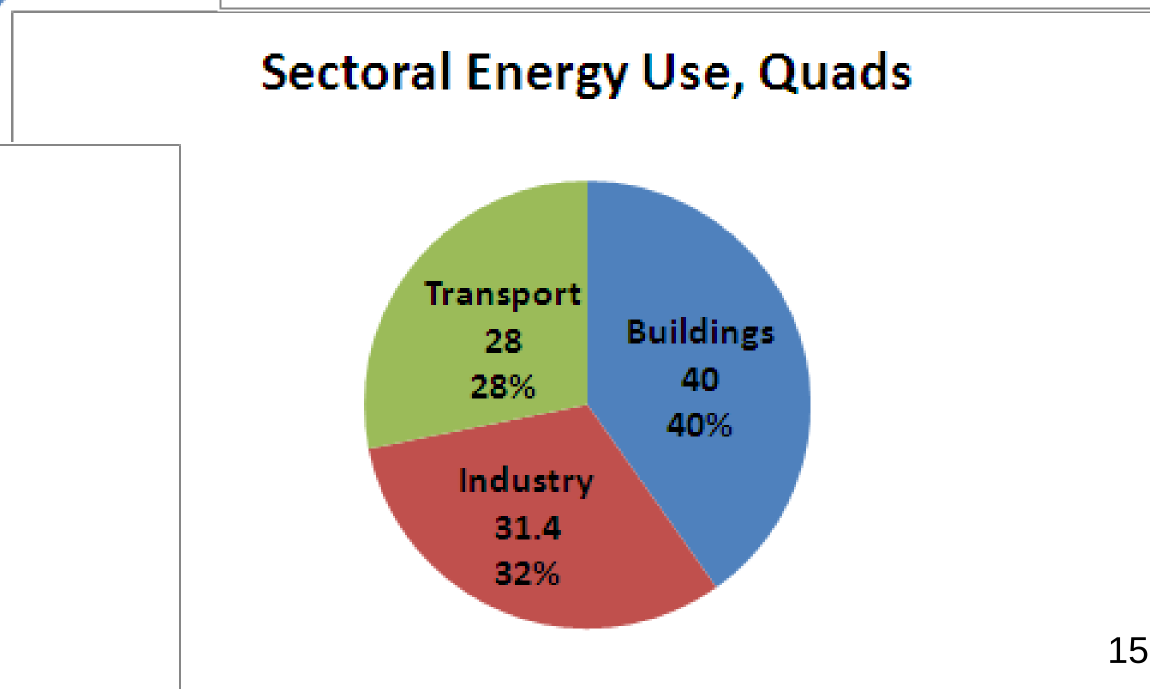
- Lifetime of Greenhouse Gases ~10's-1000's
- Reversal of Land Use Change ~100's
- Reversal of Extinctions Never

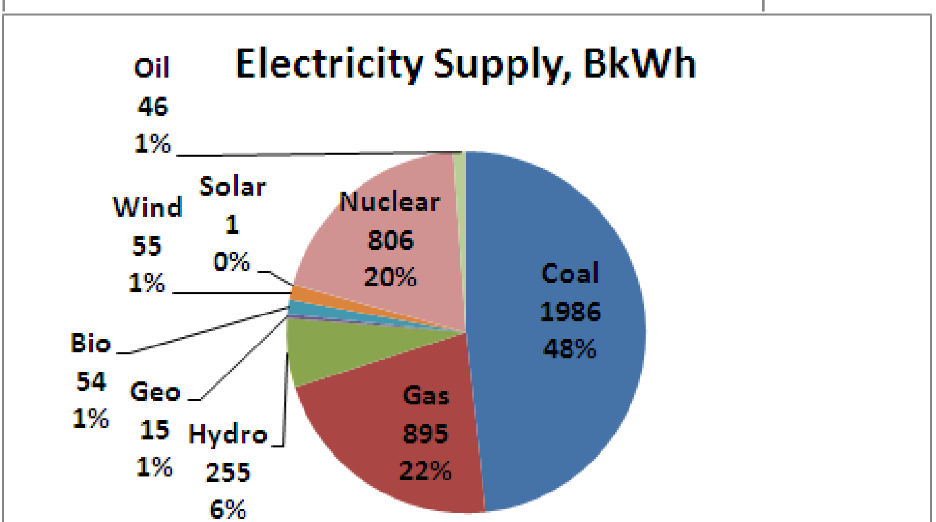
Speed and Scale

Energy Consumption Patterns, 2008









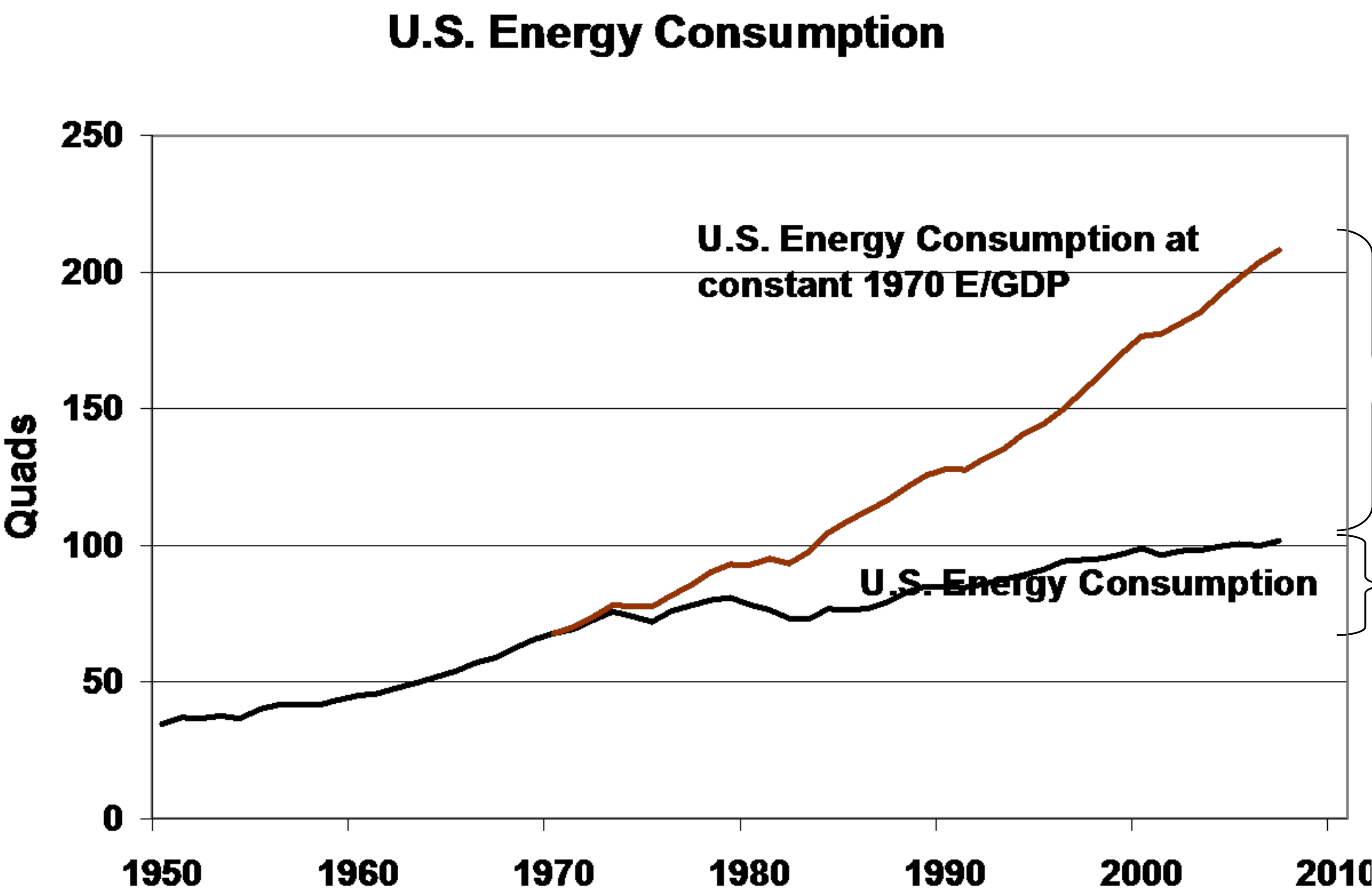
Source: EIA Annual Energy Review

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: 1970-2007

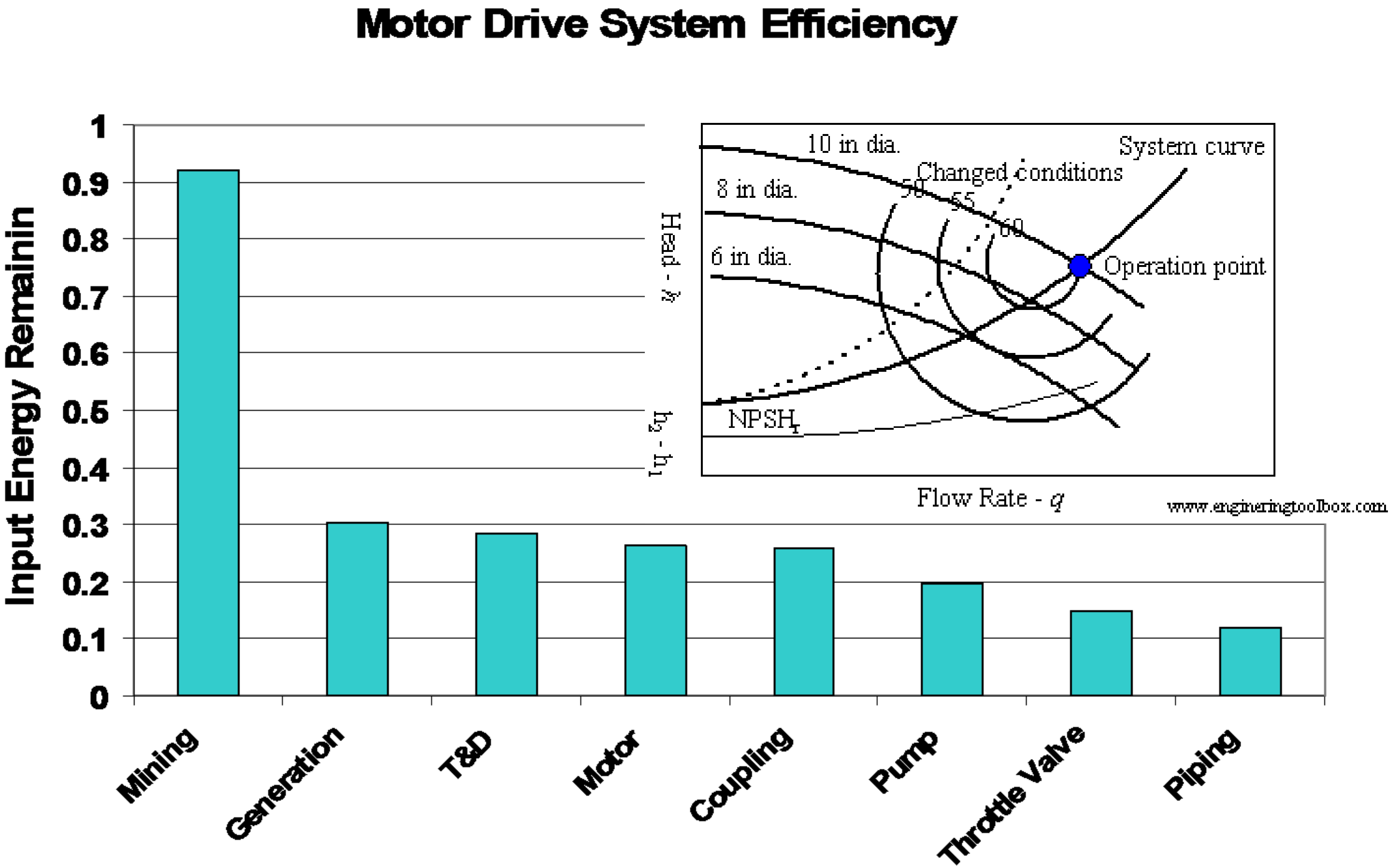


Efficiency; Structural Change: Total 106.8

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

Source: Adapted from EIA Annual Energy Review

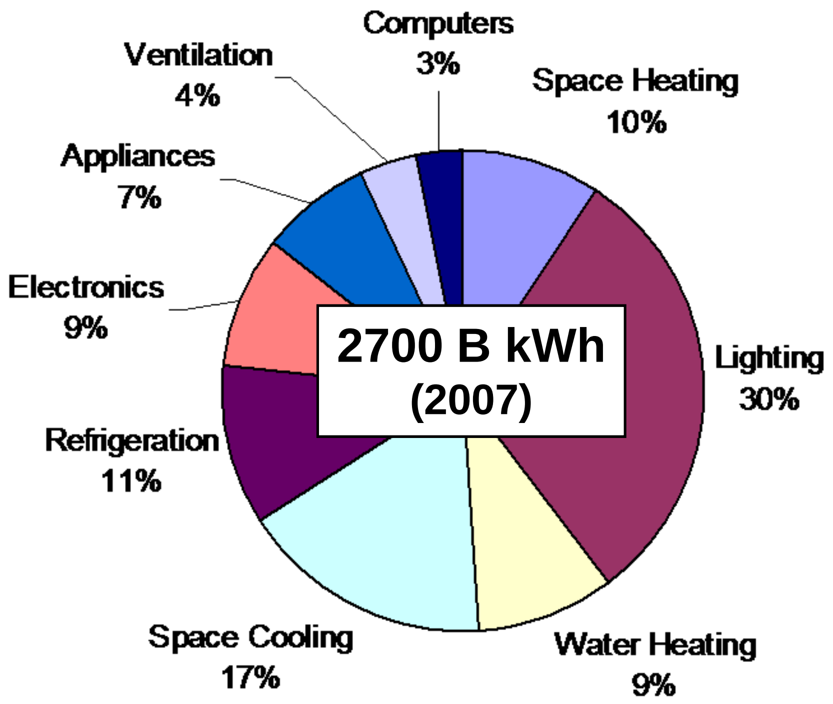
End-use Efficiency Upstream Leverage



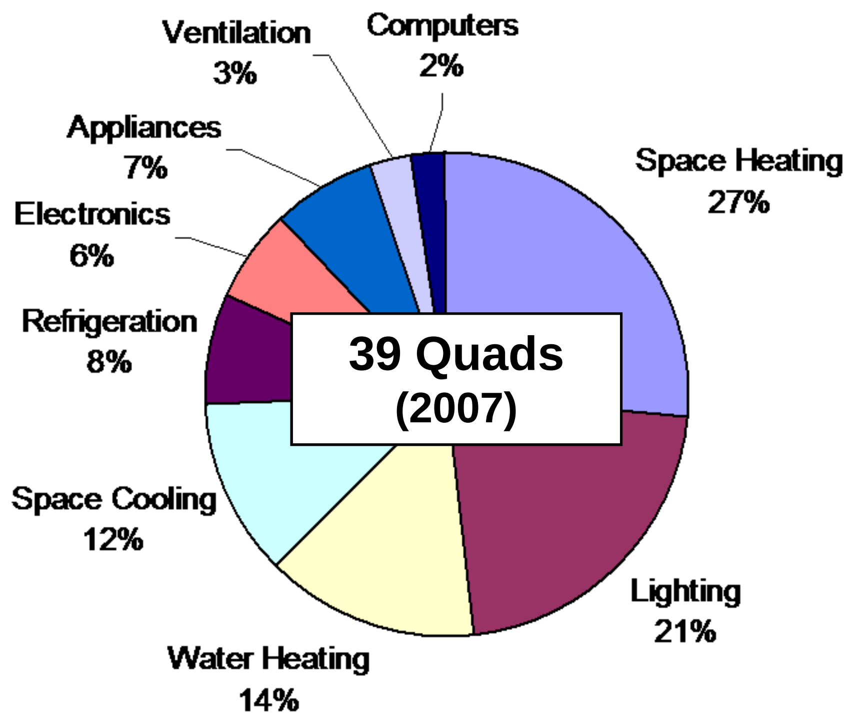
Reducing energy loss in end-use systems has large leverage upstream!

Buildings Energy Use

Site Electricity Consumption



Total Primary Energy (all fuels)

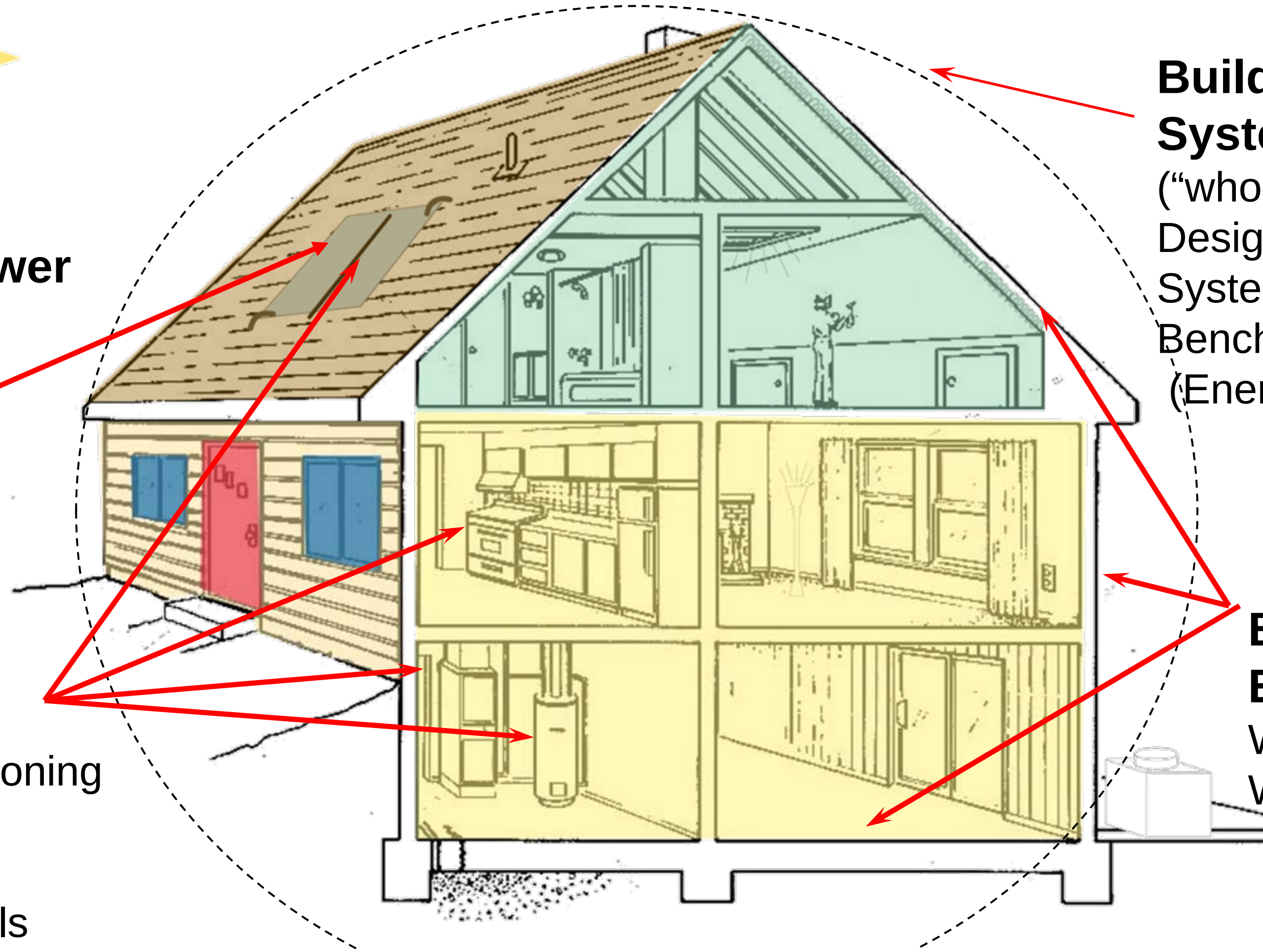


Source: Building Technology Program Core Databook, August 2003. http://buildingsdatabook.eren.doe.gov/frame.asp?p=tableview.asp&TableID=509&t=xls

Low-Energy Buildings

On-Site Power Systems
Building
Integrated
Photovoltaics
Fuel Cells

Building Equipment
Space conditioning
Lights
Appliances
Smart Controls



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

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

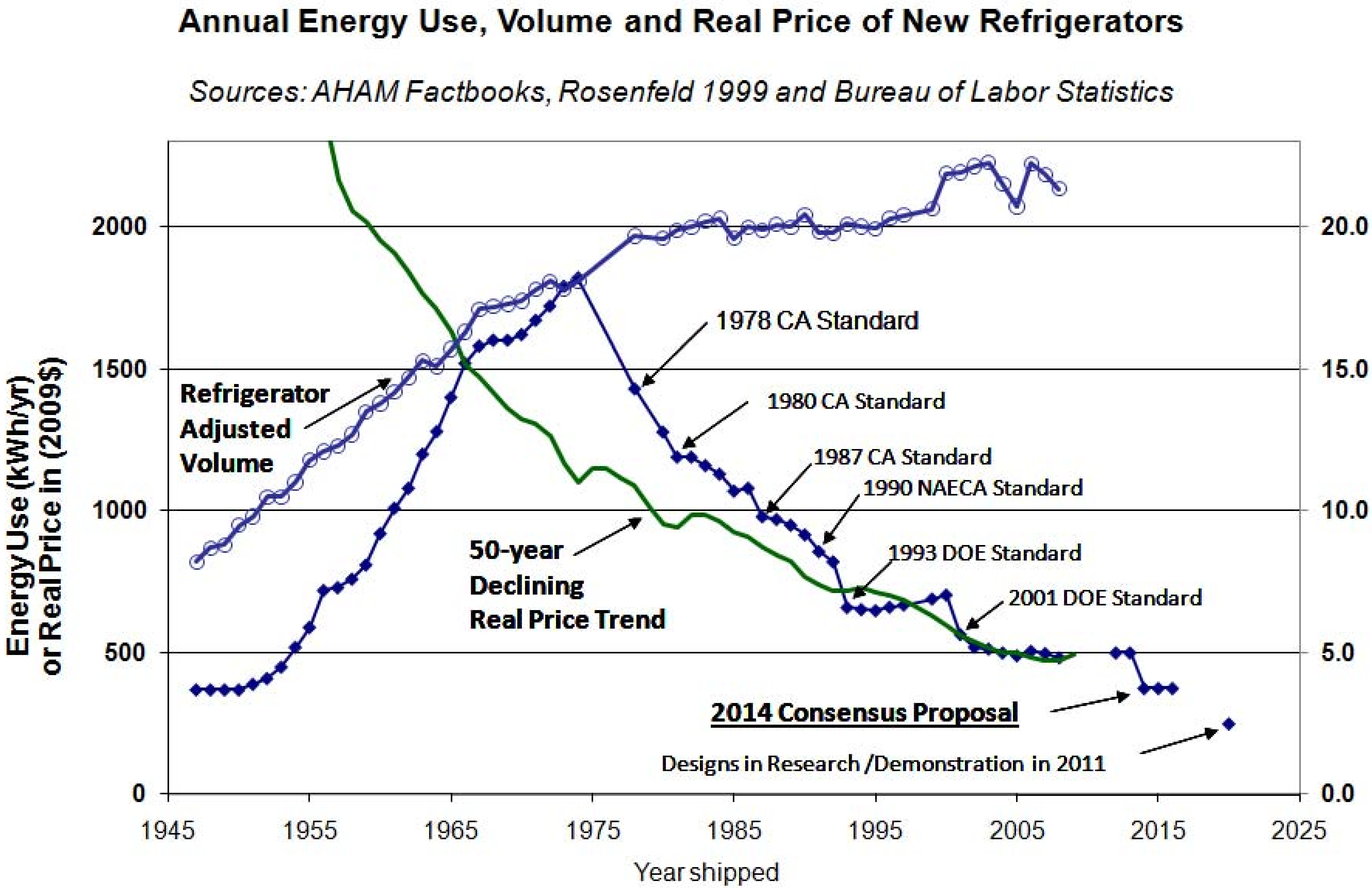
Architecture
Engineering
Market Viability
Communications
Comfort

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**



Buildings R&D Issues

- **HVAC Technologies**: Building A/C & Refrigeration (7.5Q—utility peak load); Industrial A/C & process cooling (~1.6Q); transportation A/C (1.0—vehicle load); Eliminate use of HFC refrigerants
  - Thermoelectrics; Magnetocalorics; Electrocalorics; Thermionics; New Vapor Compression Cycles; Absorption Cycles; Dehumidification materials; Heat Exchangers; Phase-Change Materials for Thermal Load Shifting
- **Building Design Tools, Construction, Intelligent Operation:**
  - Building-Integrated Sensor Networks/Controls; System Integration; Passive Design; Cradle-to-Cradle Materials Design/Use
- **Building Shells:**
  - Insulants; Phase-change materials for thermal storage; Advanced Membranes
  - Windows: Electrochromics; High Insulation
  - Spectrally-selective paints and roof coatings
- **Lighting**:
  - LED lighting—materials, device structures, phosphors, encapsulants.
  - Conventional lighting—non-Hg fluorescent lamps; multi-photon phosphors, etc.
- **Water Heating**: Building water heating (3.6Q); industrial water heating:
  - Building-Integrated solar water heaters: low-cost, long-life, freeze-tolerant, operate at line pressure.
  - Low-cost, high reliability electric- or gas-powered heat pump water heaters.
- **Others**: Low-wattage standby devices; low-cost adjustable speed motor drives with integrated sensors/controllers

Buildings Technology Barriers

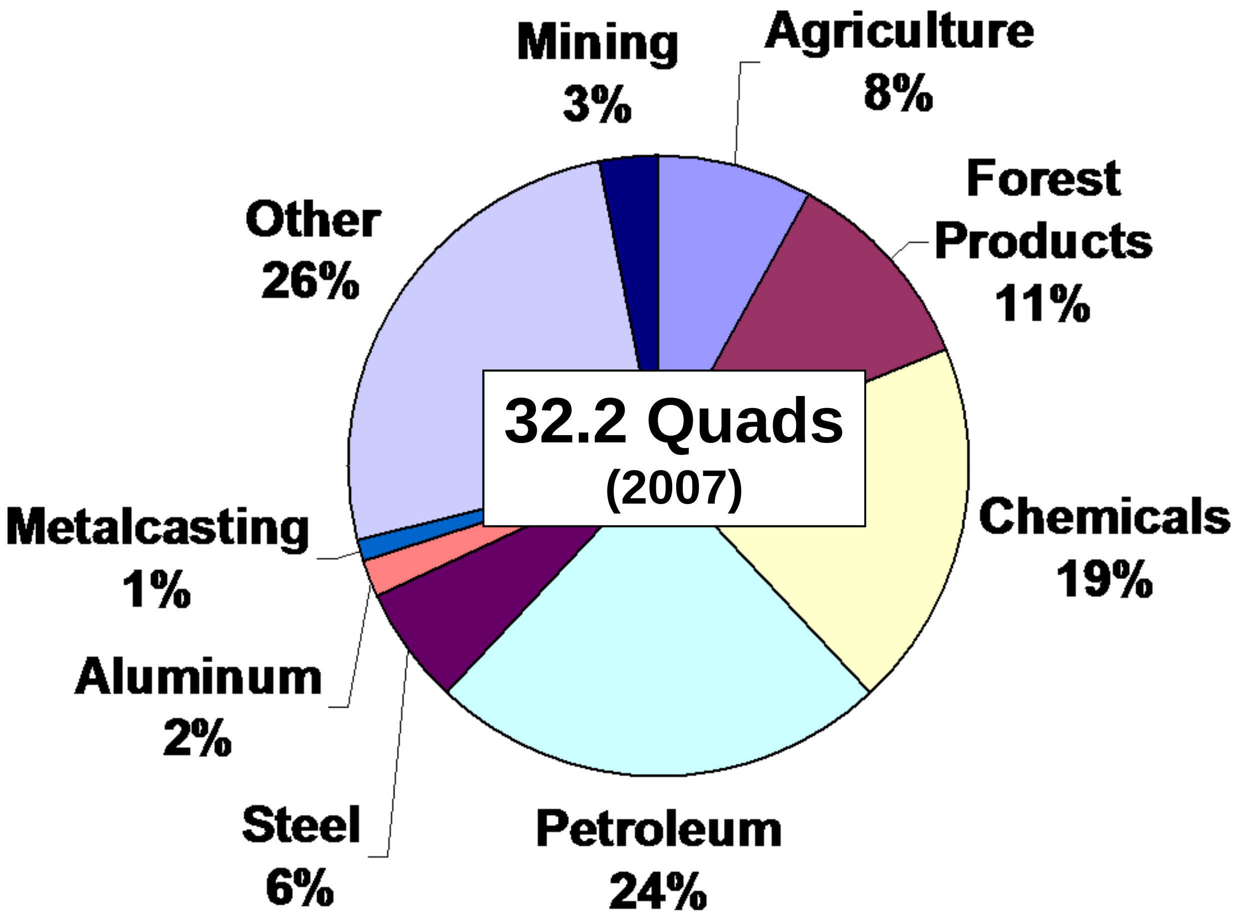
- **Owner/Consumer Perspective:**
  - **Split incentives**: owner may not pay utilities—paid instead by the tenants—so that owner has little or no incentive to invest in high efficiency equipment.
  - **Capital Cost**: consumers more sensitive to first cost than operating cost.
  - **Externalities**: environmental impacts or national security (oil) impacts are generally not fully captured, if at all, in the price/rent of the building.
  - **Lack of information**: The energy performance of a building may not be known, or reliable information difficult to get, limiting the ability of the purchaser or user to make an informed investment decision. There are a variety of other shortcomings in information, such as the difficulty of getting reliable information about the opportunities for improved efficiency.
  - **Bundled attributes**. Efficiency just one consideration among many attributes.
  - **Uncertainties** about the new technology may delay consumer adoption.
- **Corporate Perspective:**
  - **Appropriability of R&D**. Difficult to capture full value of R&D, limiting investment
  - **Externalities** often not included in energy price, limiting R&D value/investment.
  - **Market Fragmentation** limits ability of new efficiency technologies to penetrate or for industry to gather critical mass for R&D or market development.
  - **Compartmentalization** of architects, developers, construction firms, others, fail to provide appropriate incentives for energy efficiency, limits technology adoption
  - **Economies of scale/learning** may be difficult to develop for new technology
- **Appliance standards & building codes assist rapid deployment at low risk. Beyond standards…. finance,**

Impacts: Buildings

• Advanced Compressors for Refrigerator-Freezers:	$ 7B	1978-2000	NRC
• Electronic Ballasts for Fluorescent Lamps	$15B	1977-2000	NRC
• Low-Emissivity Glass Coatings	$ 8B	1976-2000	NRC
SubTotal	~$30B	1980-2000	
Total Program Investment	~$ 1.6B	1978-2000	

Source: NRC, Energy Research at DOE; and EERE

Industrial Energy Use



Source: EIA Annual Energy Review

Industry Strategy

Develop game-changing next-generation materials; develop cost-competitive, energy-efficient, low-carbon based materials/products

- Technological advances in material sciences and engineering to obtain order-of-magnitude improvements (e.g., 10x lifetime extension).
- Invention of new, cost-competitive materials and products for a low-carbon economy (e.g., nanomaterials, new cements, carbon fibers and composites, smart materials integrated in energy systems, substitutes for rare earth elements).

Develop novel processes for production of energy-intensive materials (e.g., chemicals, steels) with substantially reduced energy and carbon footprints

- New manufacturing processes to increase productivity/agility as U.S. adapts to dynamic global markets.
- Step change advances through novel technology development, such as smart manufacturing, next generation catalysts, advanced forming and fabrication technology; innovative bioprocessing techniques, low-temperature or non-thermal processing; high-performance separations, including membrane technology and hybrid reaction-separation processes; nano-scale manufacturing and processing; and single or minimal-stage material conversion pathways.

Advance innovative manufacturing for emerging clean technologies and products

•Assist in achieving major cost reductions in manufacturing energy efficiency devices (lighting, windows, batteries) and renewable energy (wind blades, power conversion, PV arrays).

•Turn energy innovations into economic opportunities.

Source: ITP

Mesabi Nugget Cokeless Ironmaking

Technology

- Produces high-quality iron directly from iron ore using 30% less energy and no (carbon-intensive) coke. This innovative technology completes the reduction, melting, and slag removal processes in 10 minutes vs. hours required in the traditional blast furnace.

DOE Role

- Invested $6 million to evaluate viability at pilot scale.
- Development partners included Mesabi Nugget LLC, Steel Dynamics, and Kobe Steel.

Status

- February 2010: First shipment of Mesabi iron nuggets for testing at Steel Dynamics' flat-roll mill in Minnesota.

January 2010, the Mesabi Nugget plant one month before going fully operational

Impacts

Market: DOE funding paved way for private investment of $265 million for commercial plant capable of producing 500,000 tons of nuggets annually in Hoyt Lakes, a small town in Minnesota. Total U.S. pig iron market >35 million tons/yr. Technology creates new markets for the taconite ore, providing economic stimulus and new jobs in an area hit hard by a weak economy.

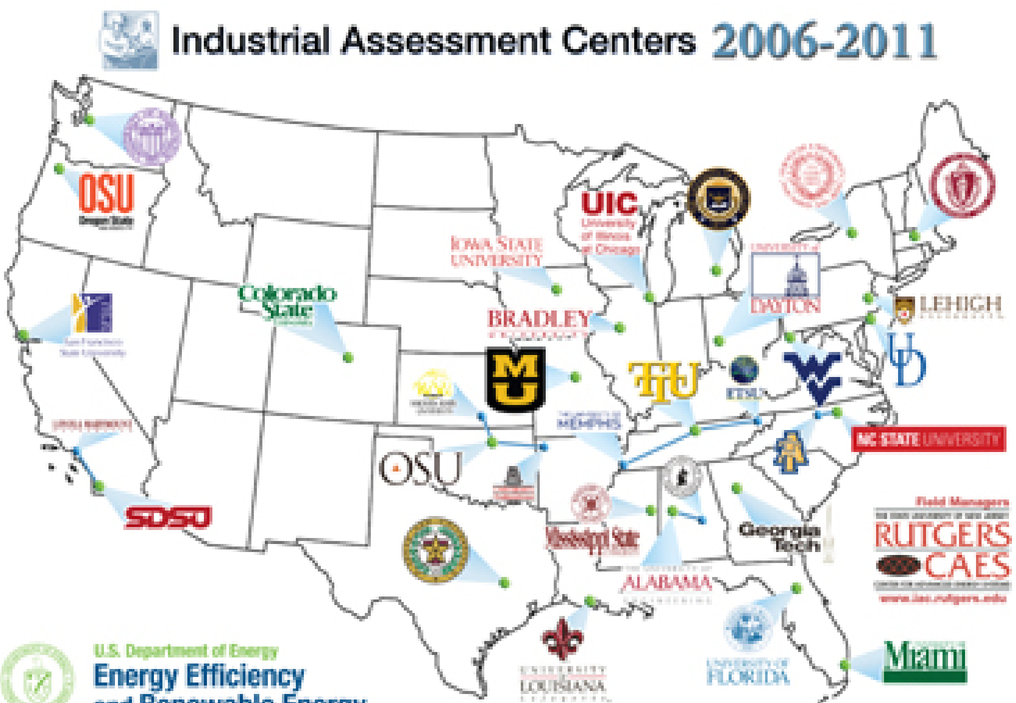
Energy: Saves 4.7 million Btu/ton of iron produced (2.5 trillion Btu/year) with this first commercial plant. Reduces CO_2 emissions relative to the traditional coke/blast furnace route by >40%.

Jobs: Created 700 construction jobs to launch commercial plant in February 2010 and will require 65 permanent jobs for plant operation.

Source: ITP

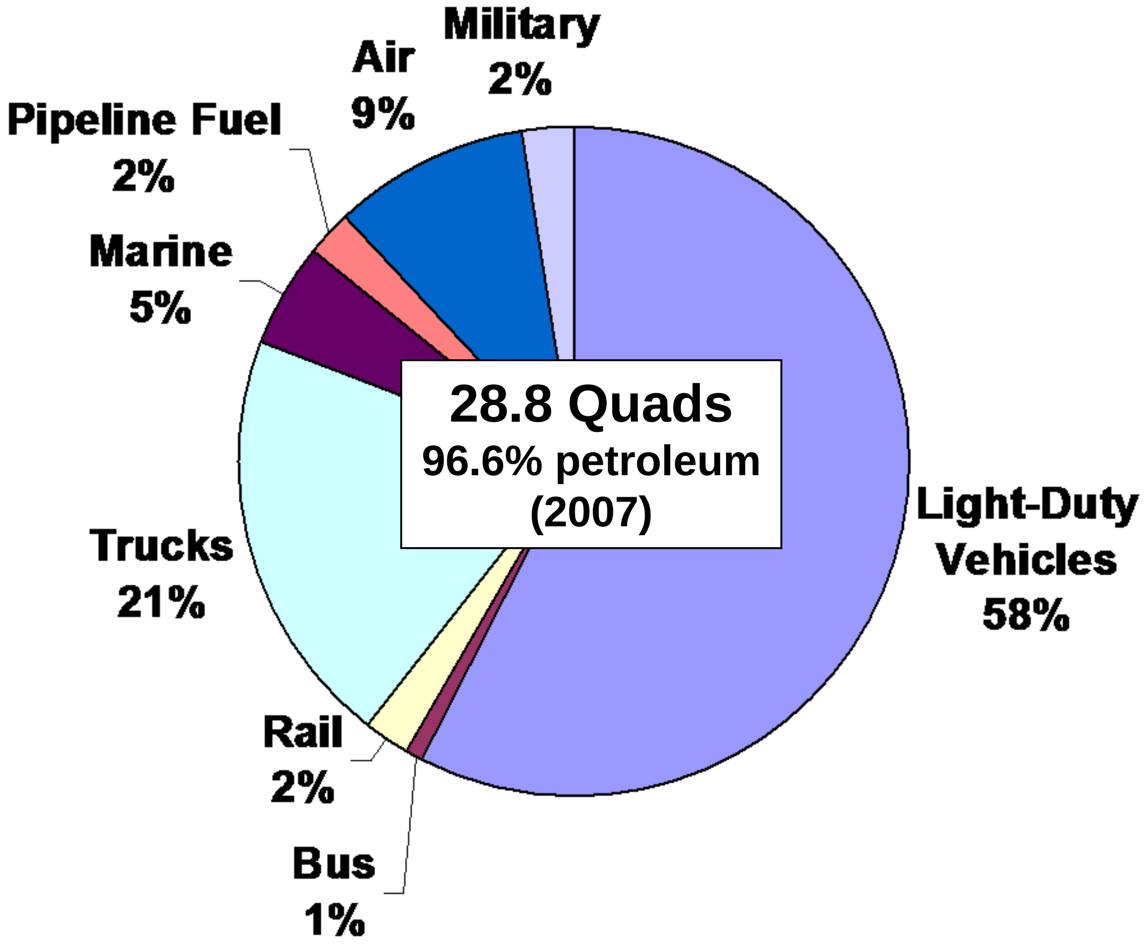
Industrial Assessment Centers

- DOE's 26 university-based Industrial Assessment Centers (IACs) train engineering students for careers in industrial energy efficiency
- IACs serve 300+ plants per year (under 1 TBtu/yr) and typically identify savings of 8%-10% or $115,000/plant
- Database of 13,500 assessment results: http://iac.rutgers.edu/database



U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

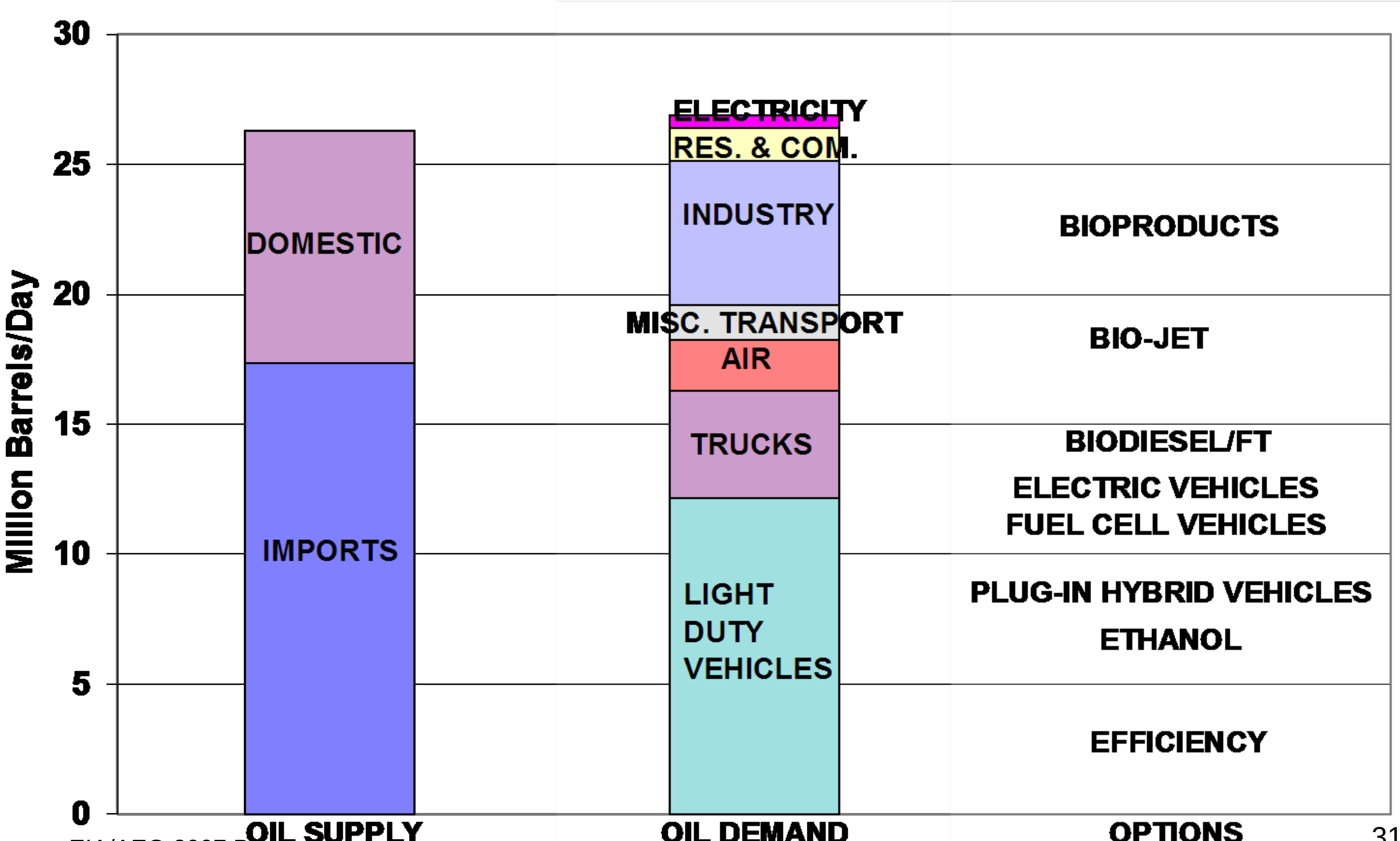
Transport Energy Use



Source: EIA Annual Energy Review

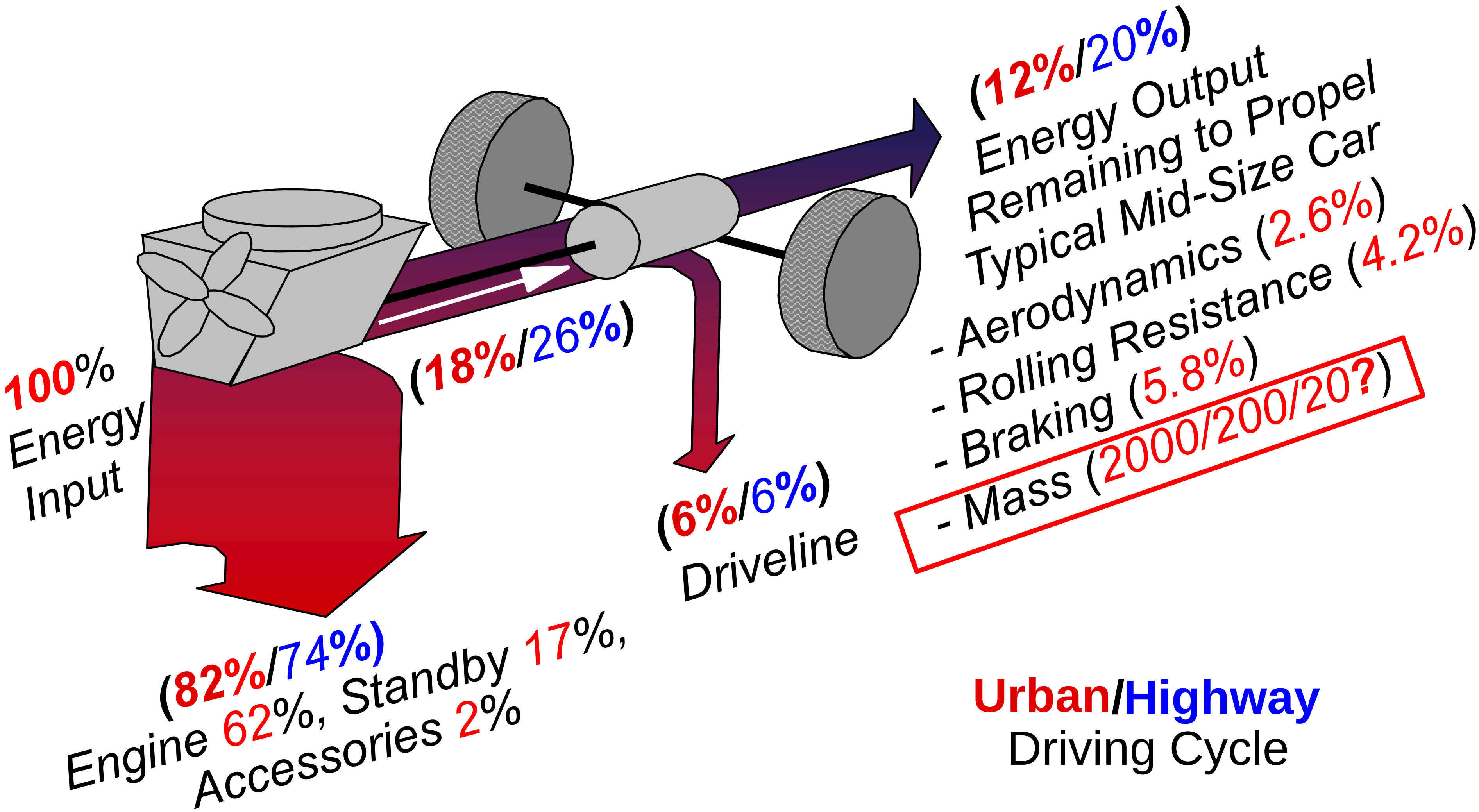
Can We Meet the Oil Challenge?

Oil Supply, Demand, Options in 2030



Source: EIA/AEO 2007 Projections

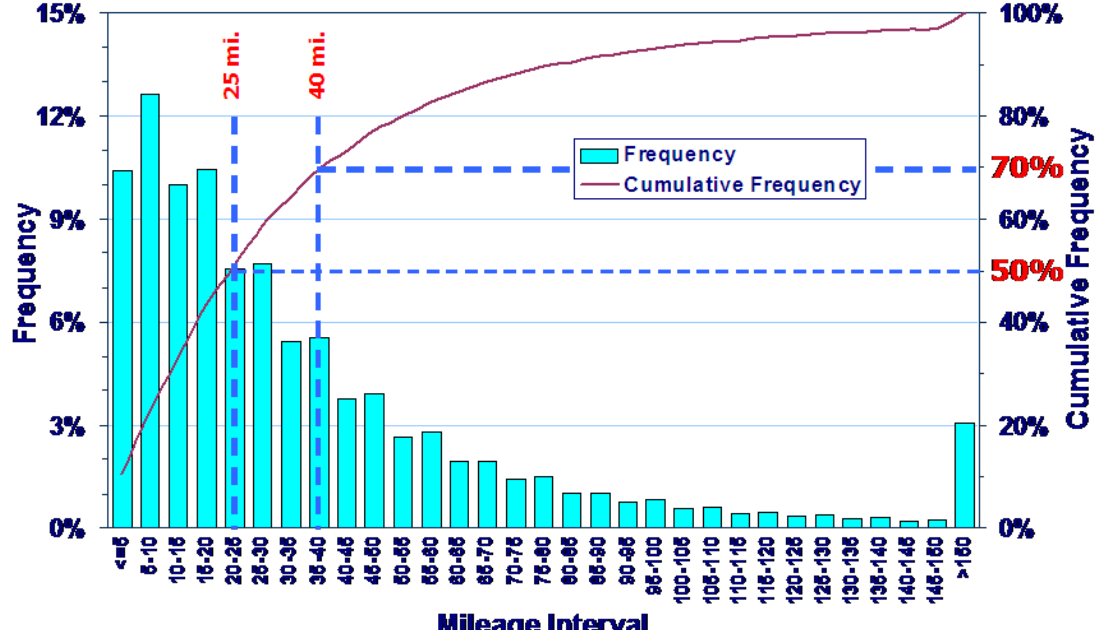
Energy Use in Light-Duty Vehicles



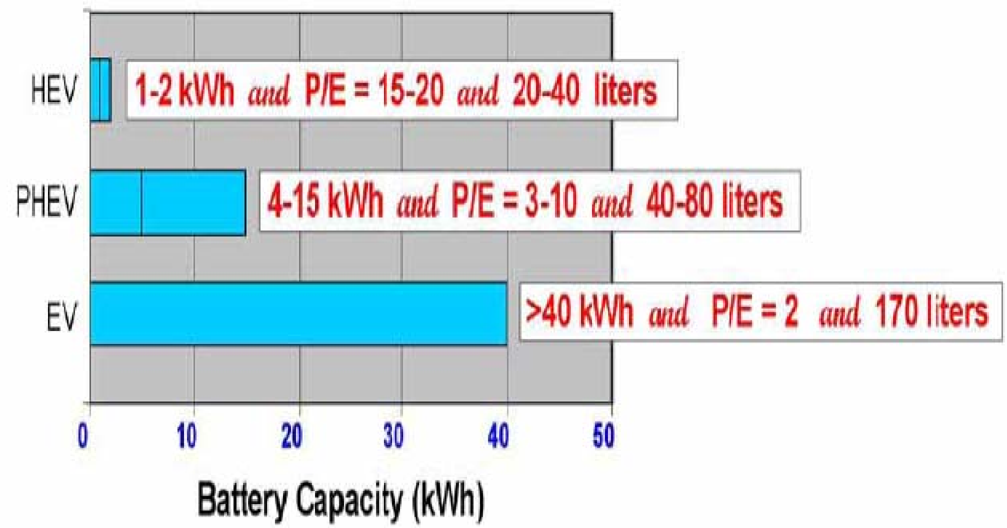
Plug-In Hybrids

- Battery Storage, Power Electronics, System Int.
- A123 -- Nano-Structured Iron-Phosphate Cathode.
- **Wind 200 GW→450 GW**

50% Travel ≤25 mi./day; 70% ≤40 mi./day



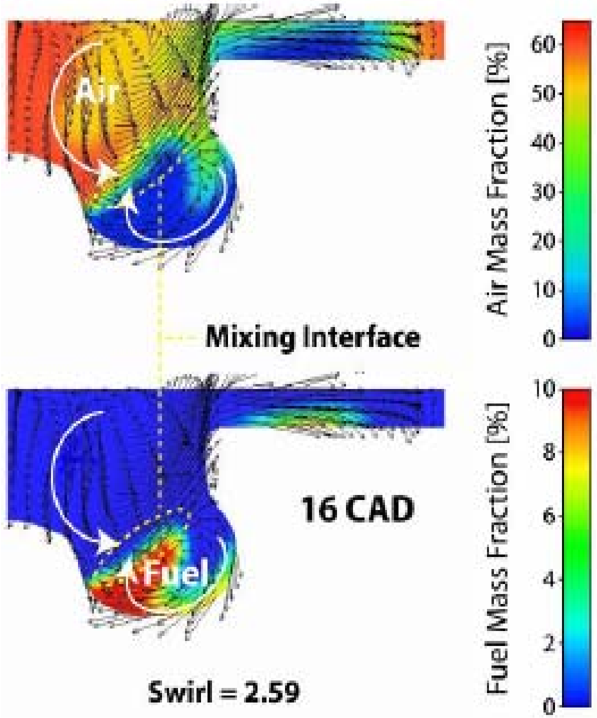
Source: 2001 National Household Travel Survey



Vehicle R&D Issues

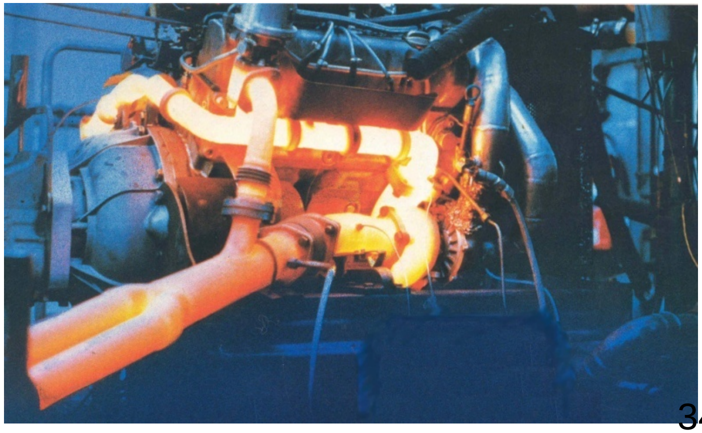
- **Battery Storage: HEV/PHEV**
  - High Power/High Energy
  - Abuse Tolerance; Stability
- **Thermoelectrics:**
  - Waste heat recovery
  - Air conditioning

- **Advanced Motors:**
  - NdFeB temperature sensitivity
- **Lightweight Frames and Components:**
  - Material deformation in crashes
    - Composites; lightweight alloys.
- **Aerodynamic Drag:**
  - Low speed flow; turbulence
- **Power Electronics:**
  - Reliability; Temperature sensitivity
- **High Performance Engines:**
  - Combustion modeling
  - Soot formation and evolution
  - Lean NOx catalyst modeling
  - Low speed multiphase flows; turbulence



Simulation of Fuel-Air Mixing and Combustion. R.D. Weitz, U Wisconsin, in “Basic Research Needs for Clean and Efficient Combustion of 21st Century Transportation Fuels.”

Hot exhaust system suitable for thermoelectrics.



Ultimate Biorefinery Goal: From any Feedstock to any Product

Feedstock production, collection, handling & preparation

Hydrolysis Acids, enzymes	Sugars and Lignin
Gasification High heat, low oxygen	Synthesis Gas
Digestion Bacteria	Bio-gas
Pyrolysis Catalysis, heat, pressure	Bio-Oil
Extraction Mechanical, chemical	Carbon-Rich Chains
Separation Mechanical, chemical	Plant Products

USES

Fuels:
- Ethanol
- Renewable Diesel
- Hydrogen

Power:
- Electricity
- Heat

Chemicals
- Plastics
- Solvents
- Chemical Intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty acids
- Acetic Acid
- Carbon black
- Paints
- Dyes, Pigments, and Inks
- Detergents
- Etc.

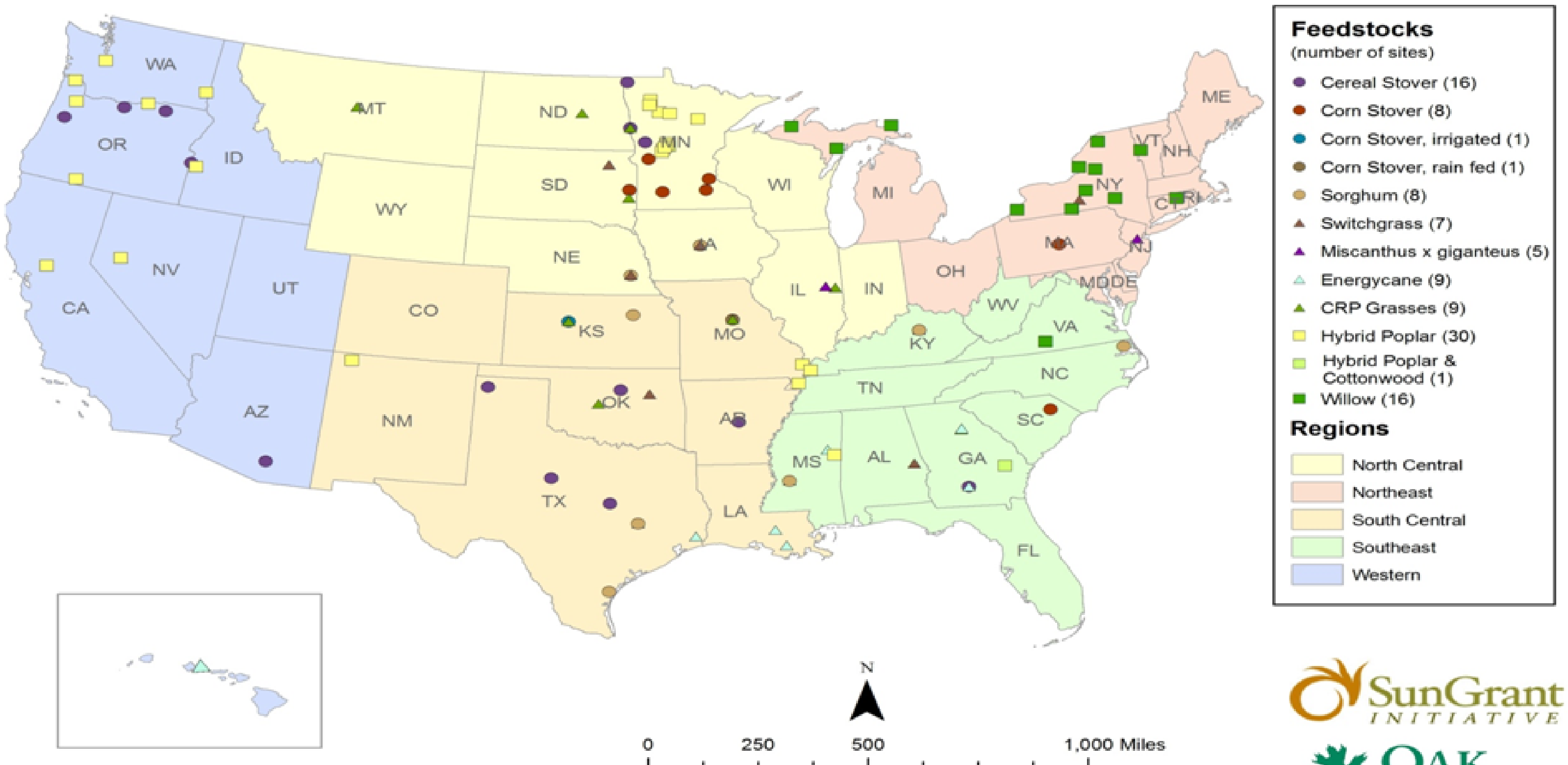
Food and Feed

Source: EERE/BP

Sustainable Feedstock Production

Regional Biomass Energy Feedstock Partnerships, part of the Sun Grant Initiative, are conducting in-field studies to:

- Determine best location for dedicated energy crops
- Validate decision support system to ensure soil health while utilizing agricultural waste for bioenergy



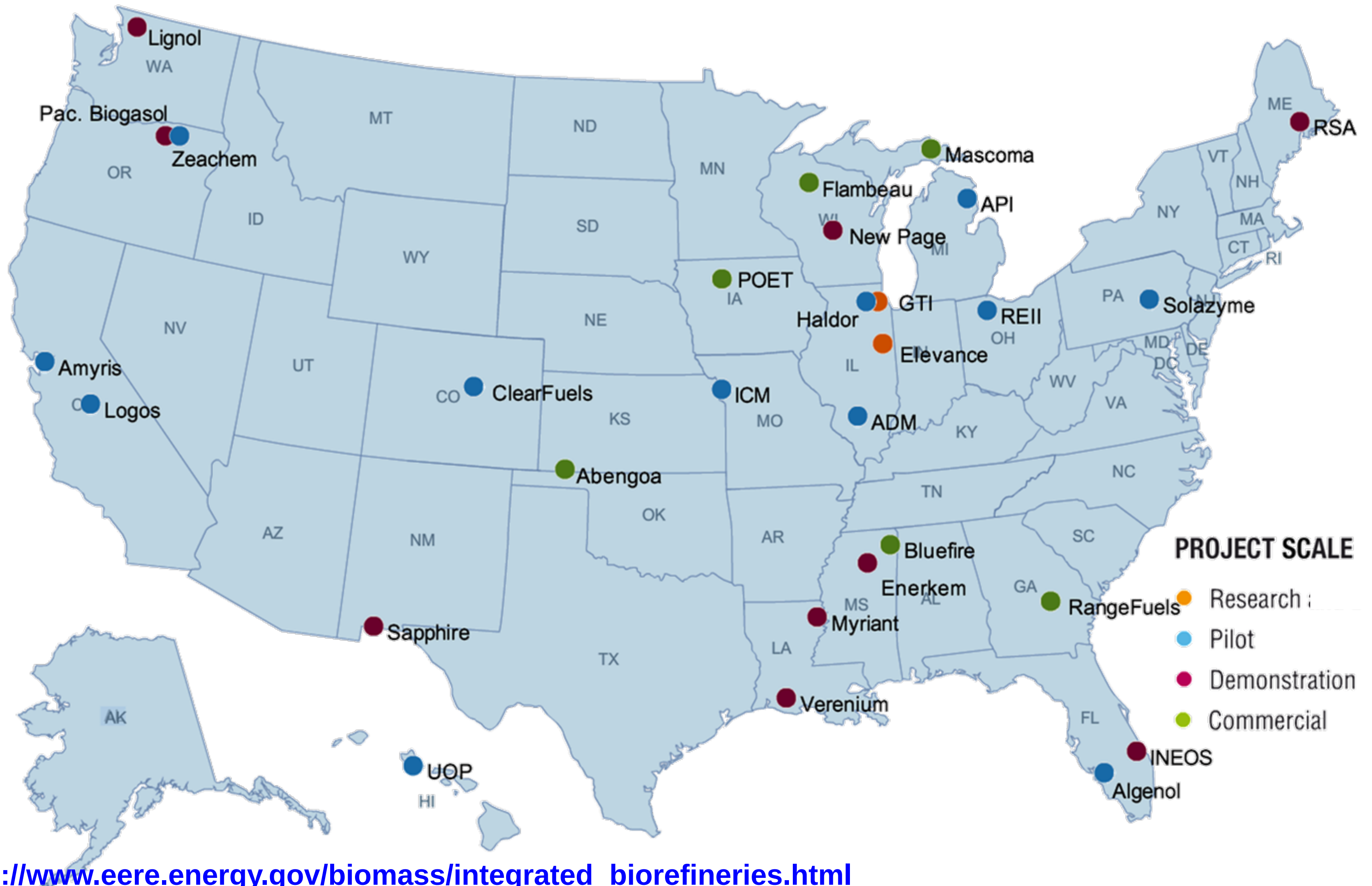
Disclaimer: This map is intended for visual representation only. Many field trials occur within the same research location and may not be indicated on the map. Users of this information should contact the Department of Energy Golden Field Office for additional data information.

Current as of October 25, 2010

SunGrant INITIATIVE

OAK RIDGE National Laboratory

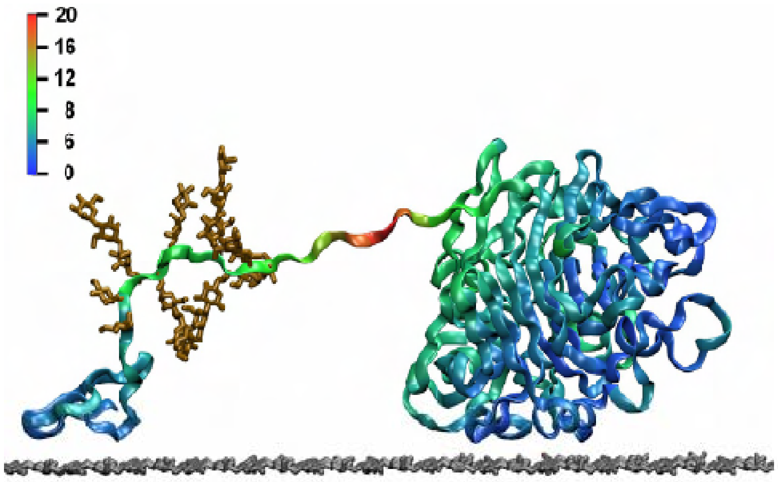
Integrated Biorefineries



http://www.eere.energy.gov/biomass/integrated_biorefineries.html

BioEnergy R&D Issues

- **Feedstock production and collection**
  - Functional genomics; respiration; metabolism; nutrient use; water use; cellular control mechanisms; physiology; disease response;
  - Plant growth, response to stress/marginal lands; higher productivity at lower input (water, fertilizer)
  - Production of specified components
- **Biochemical platform**
  - Biocatalysis: enzyme function/regulation; enzyme engineering for reaction rates/specificity
- **Thermochemical platform**
  - Combustion; Gasification; hot gas cleanup
  - CFD modeling of physical and chemical processes in a gasification/pyrolysis reactor
  - Product-selective thermal cracking. Modeling catalyst-syngas conversion to mixed alcohols, FTs—predicting selectivity, reaction rates, controlling deactivation due to sulfur (e.g. role of Ru to improve S tolerance of Ni). NOx chemistry
- **Bioproducts**
  - New and novel monomers and polymers;
  - Biomass composites; adhesion/surface science
- **Logistics; Drop-in Fuels**



Cellulase Enzyme interacting with Cellulose. Source, Linghao Zhong, et al., “Interactions of the Complete Cellobiohydrolase I from *Trichodera reesei* with Microcrystalline Cellulose I”

Hydrogen Fuel Cell Technologies
Key Challenges

Technology Barriers*

Fuel Cell Cost & Durability

Targets*:

Stationary Systems: **$1,000-1,500 per kW, 60,000-80,000 hr durability**

Vehicles: **$30 per kW, 5,000-hr durability**

No fundamental breakthroughs required

Hydrogen Cost

Target*: $2 – 4 /gge, (dispensed and untaxed)

Renewable platforms; centralized production

Hydrogen Storage Capacity

Target: > 300-mile range for vehicles—without compromising interior space or performance

Technology Validation:

Technologies must be demonstrated under real-world conditions.

Economic & Institutional Barriers

Safety, Codes & Standards Development

Domestic Manufacturing & Supplier Base

Hydrogen Supply & Delivery Infrastructure

Public Awareness & Acceptance

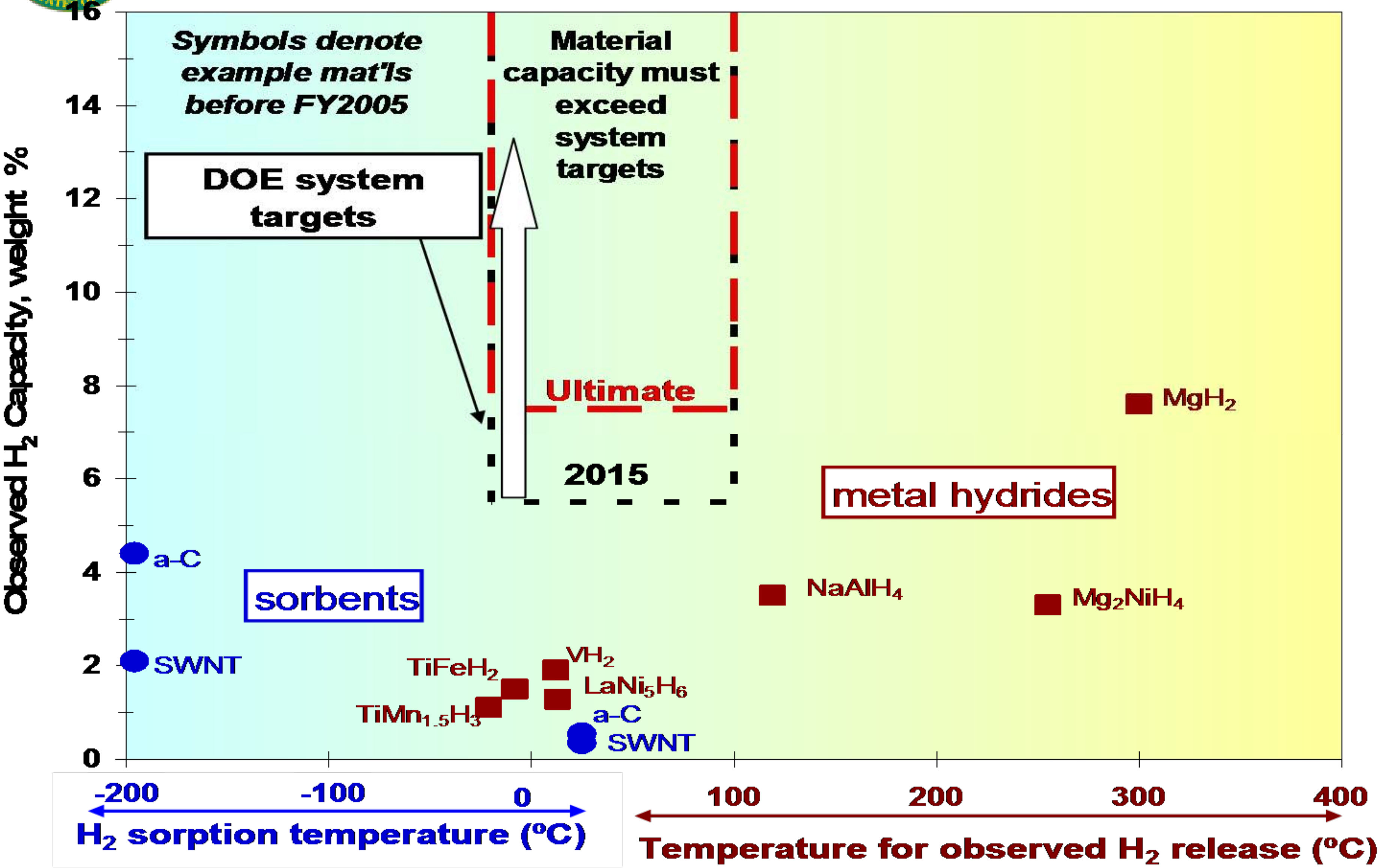
Market Transformation

Assisting the growth of early markets will help to overcome many barriers, including achieving significant cost reductions through economies of scale.

*** Targets and Metrics are being updated in 2011 .**

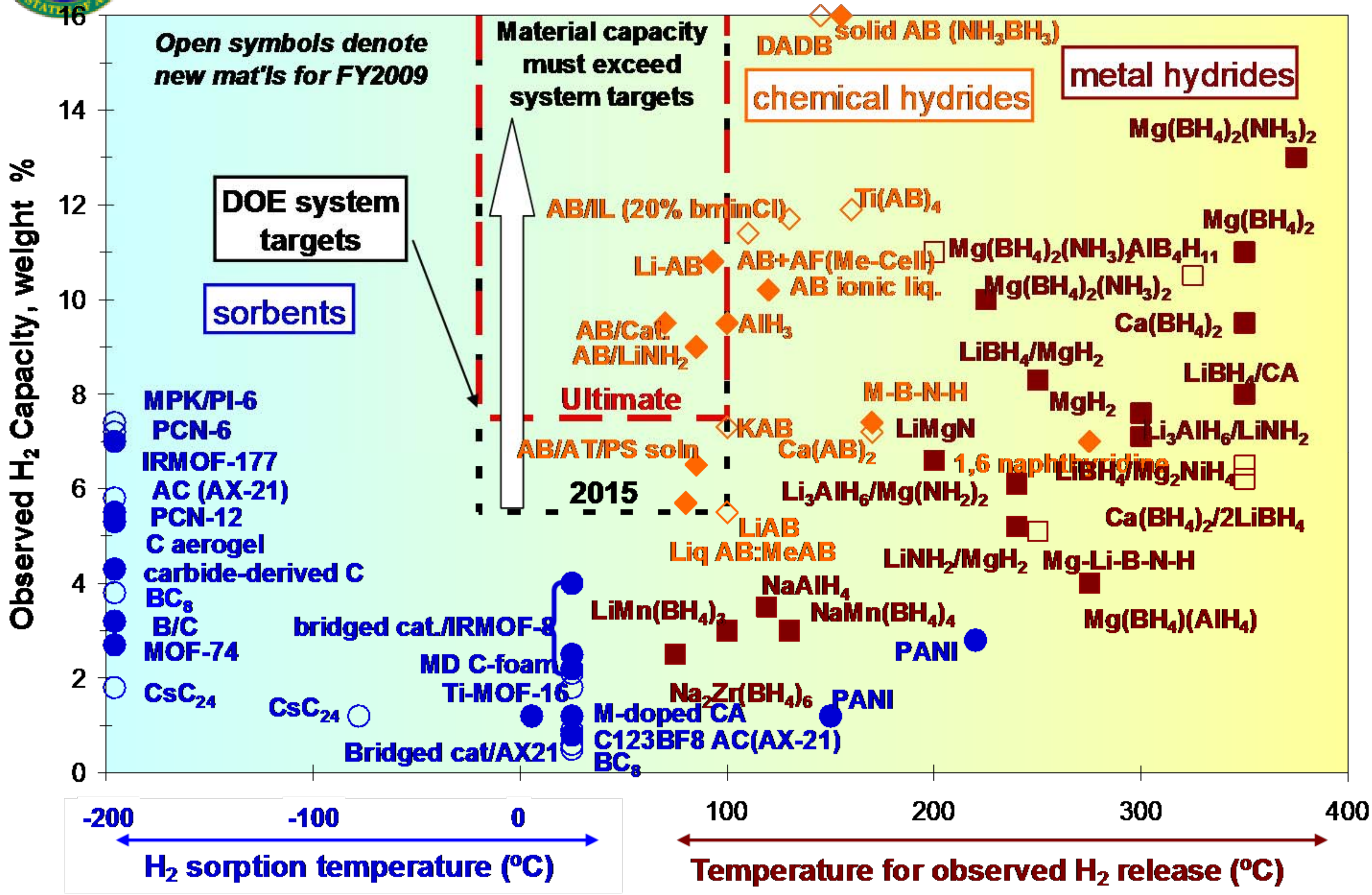
Source: EERE HFC Program

H_2 Storage Materials Research — *Pre-2005*



Source: EERE HFC Program

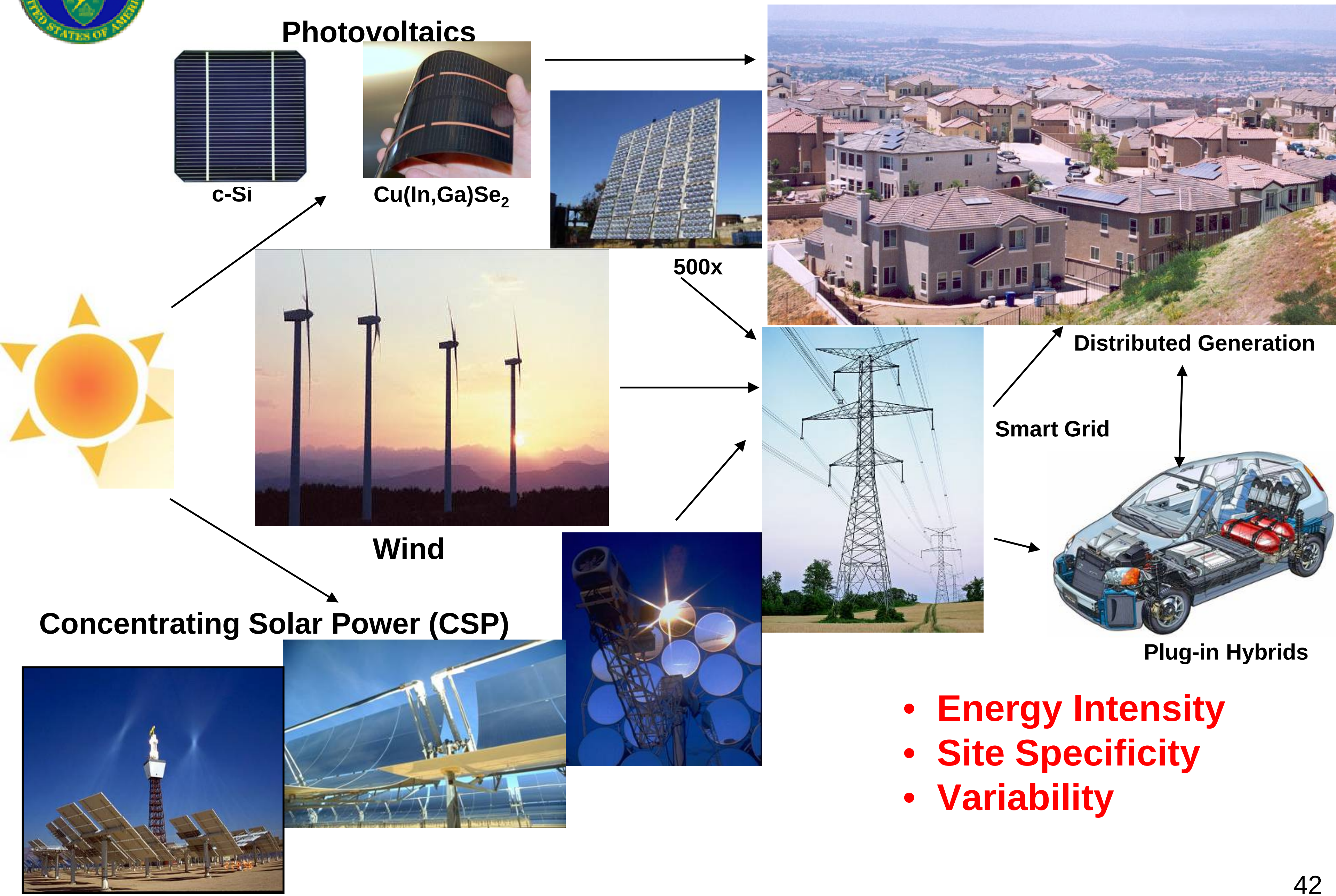
H_2 Storage Materials Research — *Post-2005*



DOE: G. Thomas (2007), G. Sandrock (2008), B. Bowman (2009)

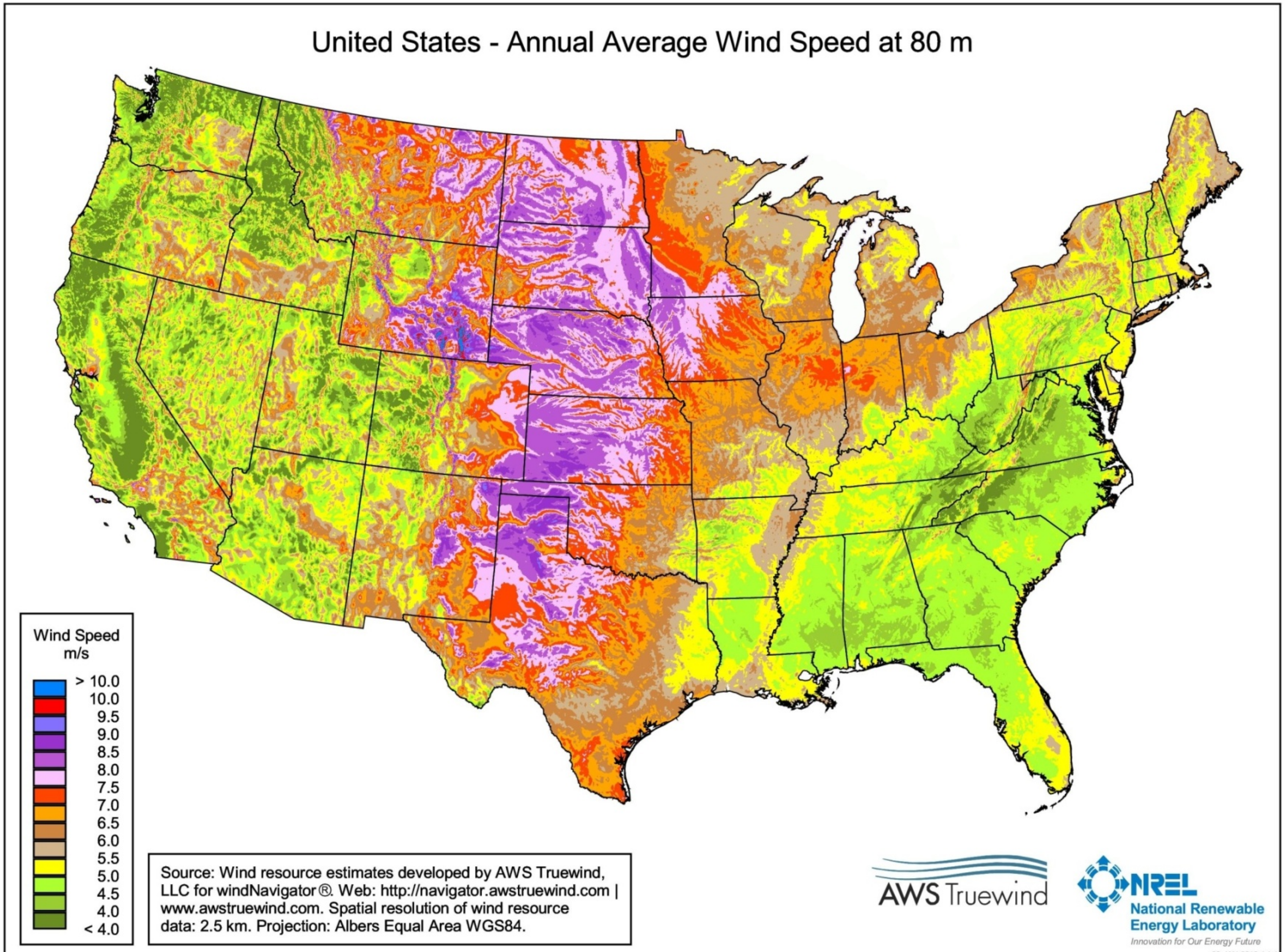
Source: EERE HFC Program

Renewable Electricity Systems

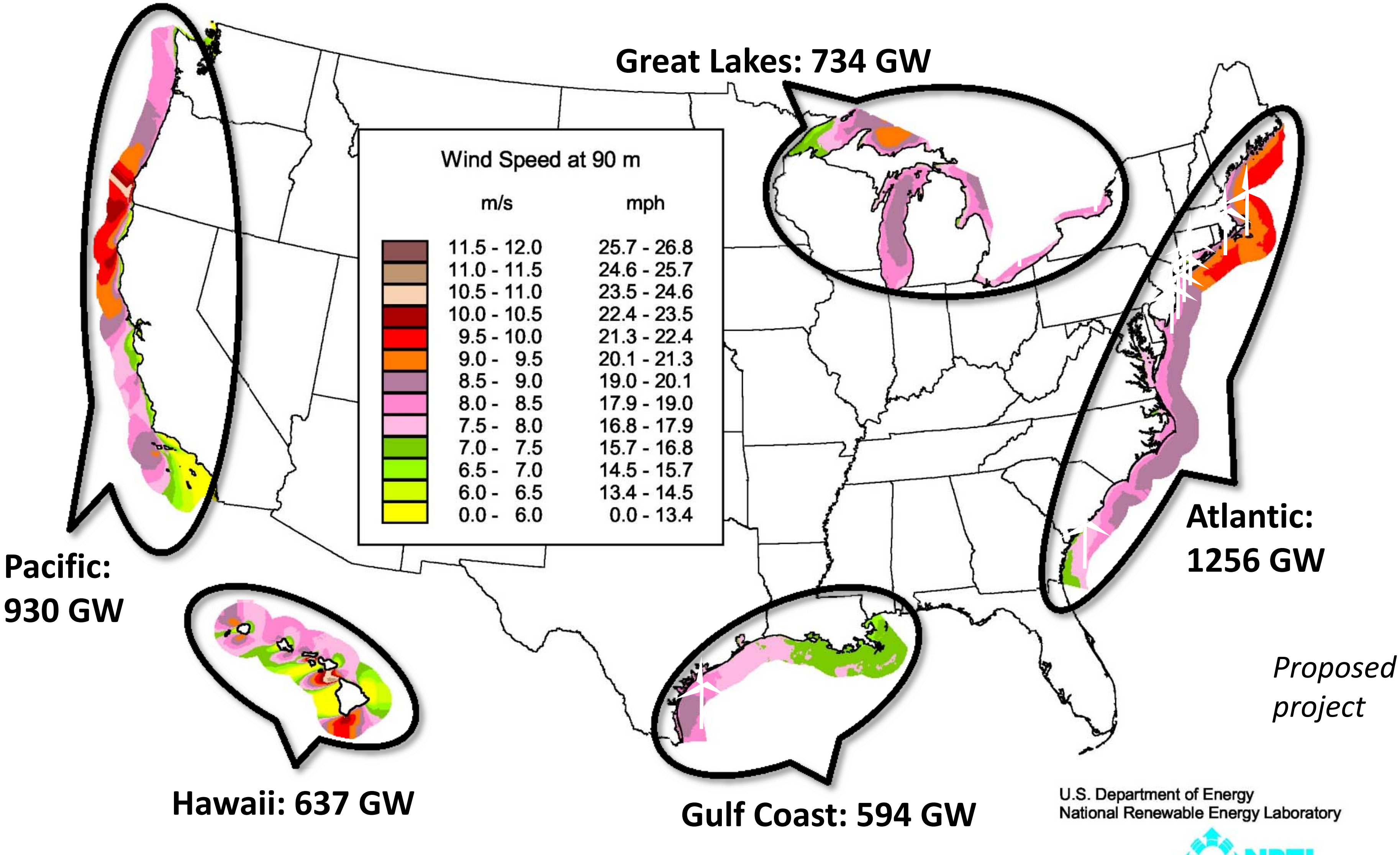


- Energy Intensity
- Site Specificity
- Variability

Can Wind Energy Meet the Challenge?

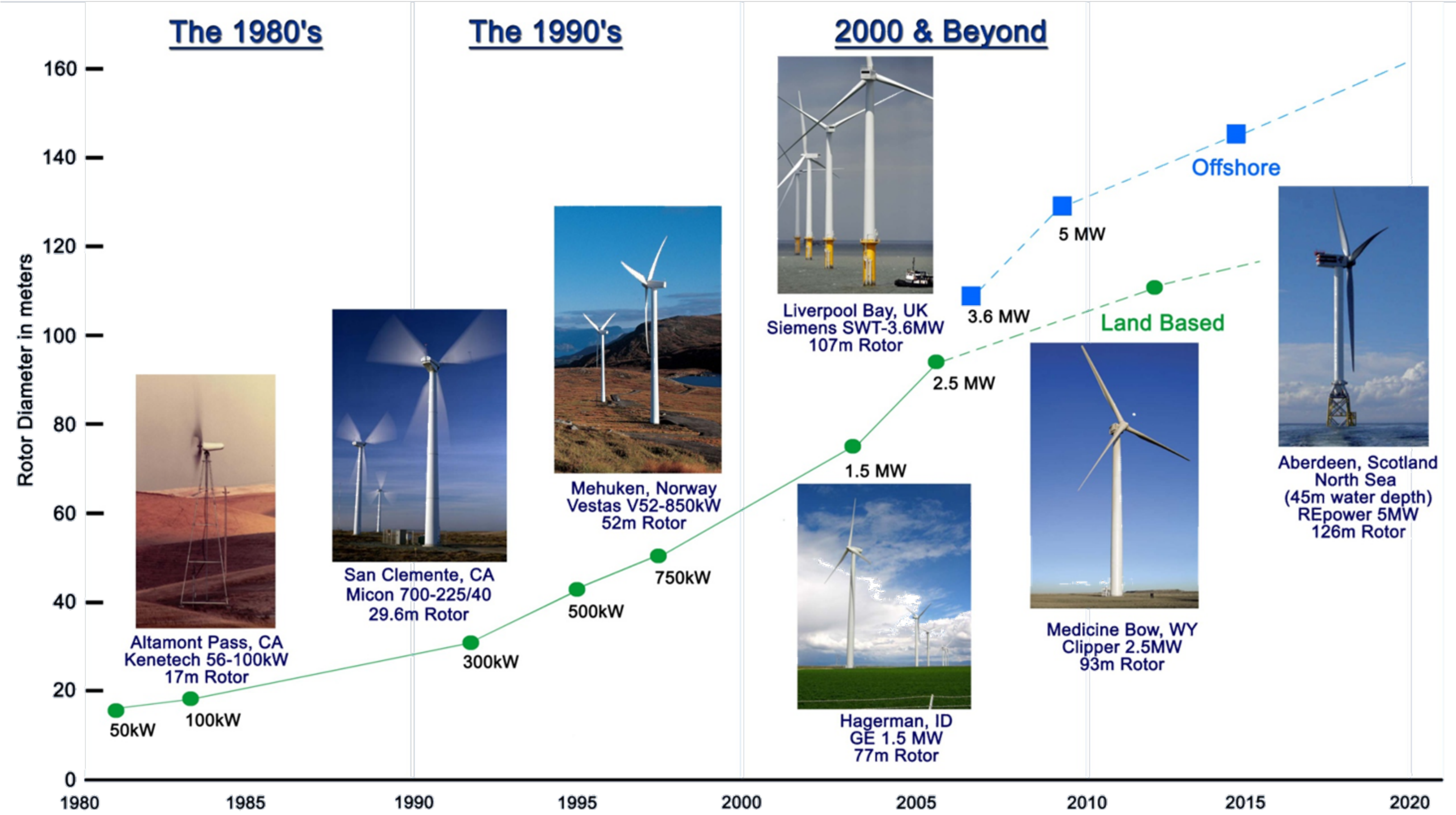


U.S. Offshore Wind Potential: >4000 GW



Total gross resource potential does not consider exclusion zones or siting concerns

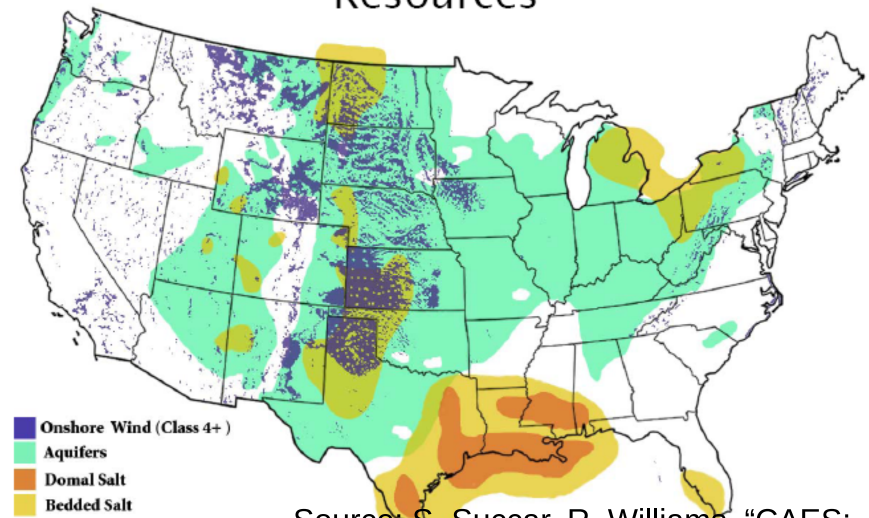
Evolution of Commercial Wind Technology



Source: EERE/WTP; NREL

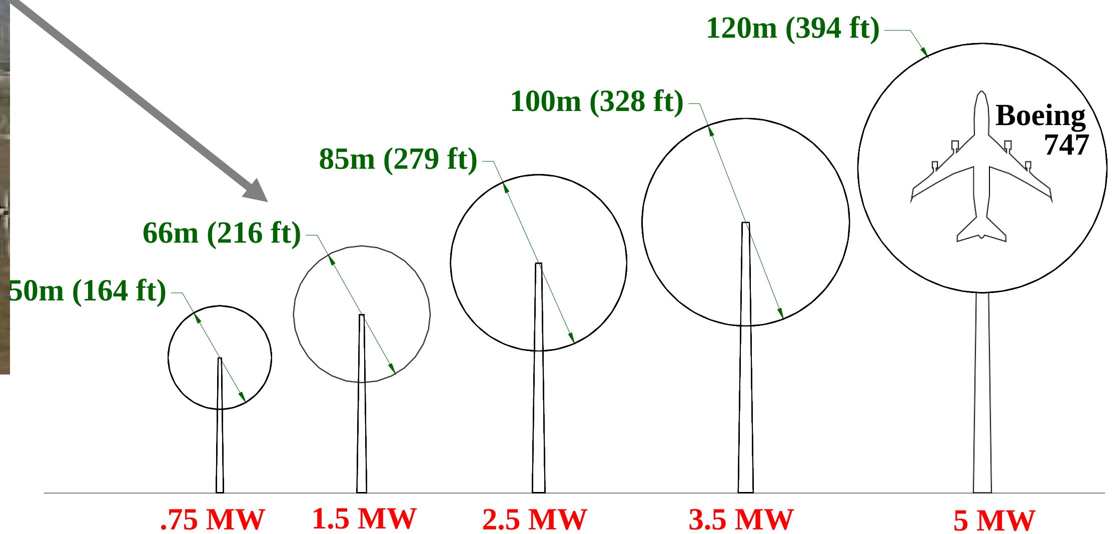
Wind Energy and Storage

Geology Suitable for CAES & Class 4+ Wind Resources



Source: S. Succar, R. Williams, "CAES: Theory, Resources, Applications…" 4/08

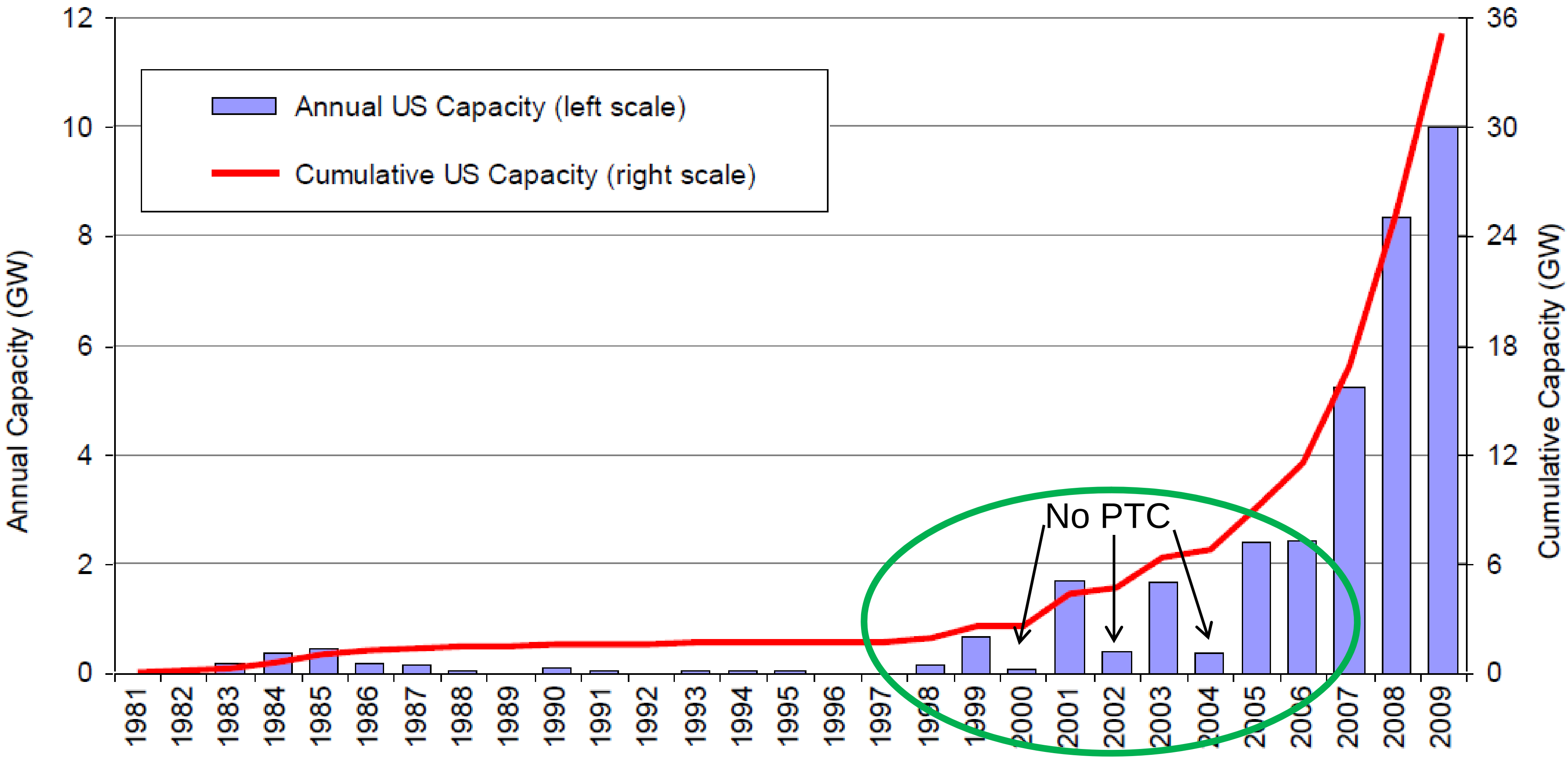
Typical Rotor Diameters



GE Wind 1.5 MW

Source: EERE/WTP

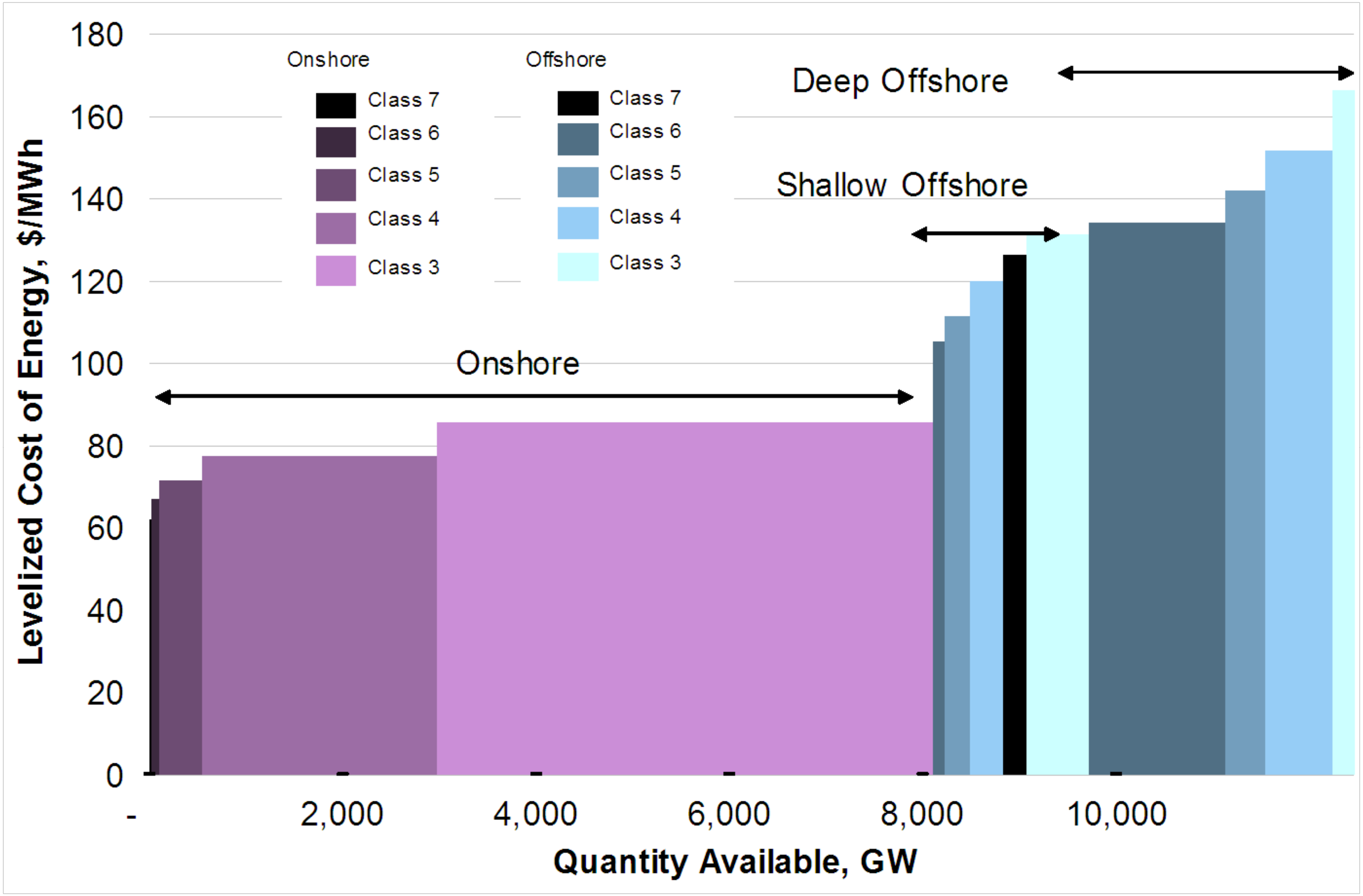
Wind Capacity



- 10 GW of wind capacity installed in 2009; ~$21B of project activity
- Cumulative total of 35 GW

Source: Wiser et al, LBNL

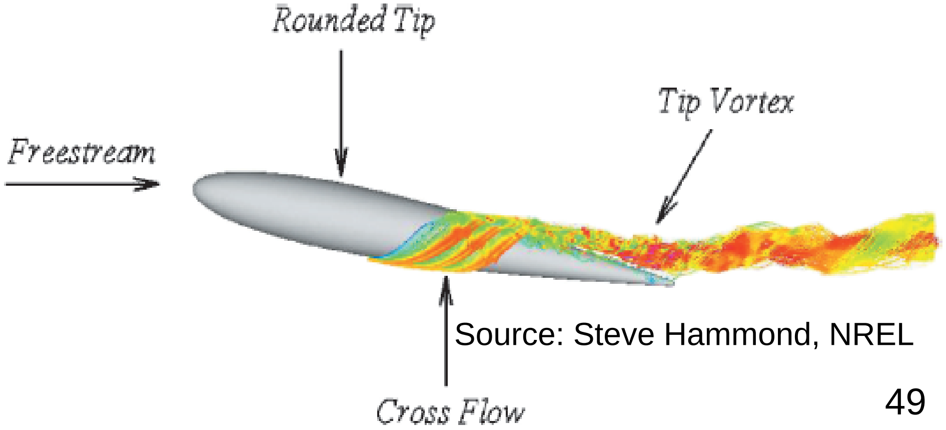
Resource Potential Exceeds Electricity Demand



2010 Costs w/o PTC, w/o Transmission or Integration costs

Wind Energy R&D Issues

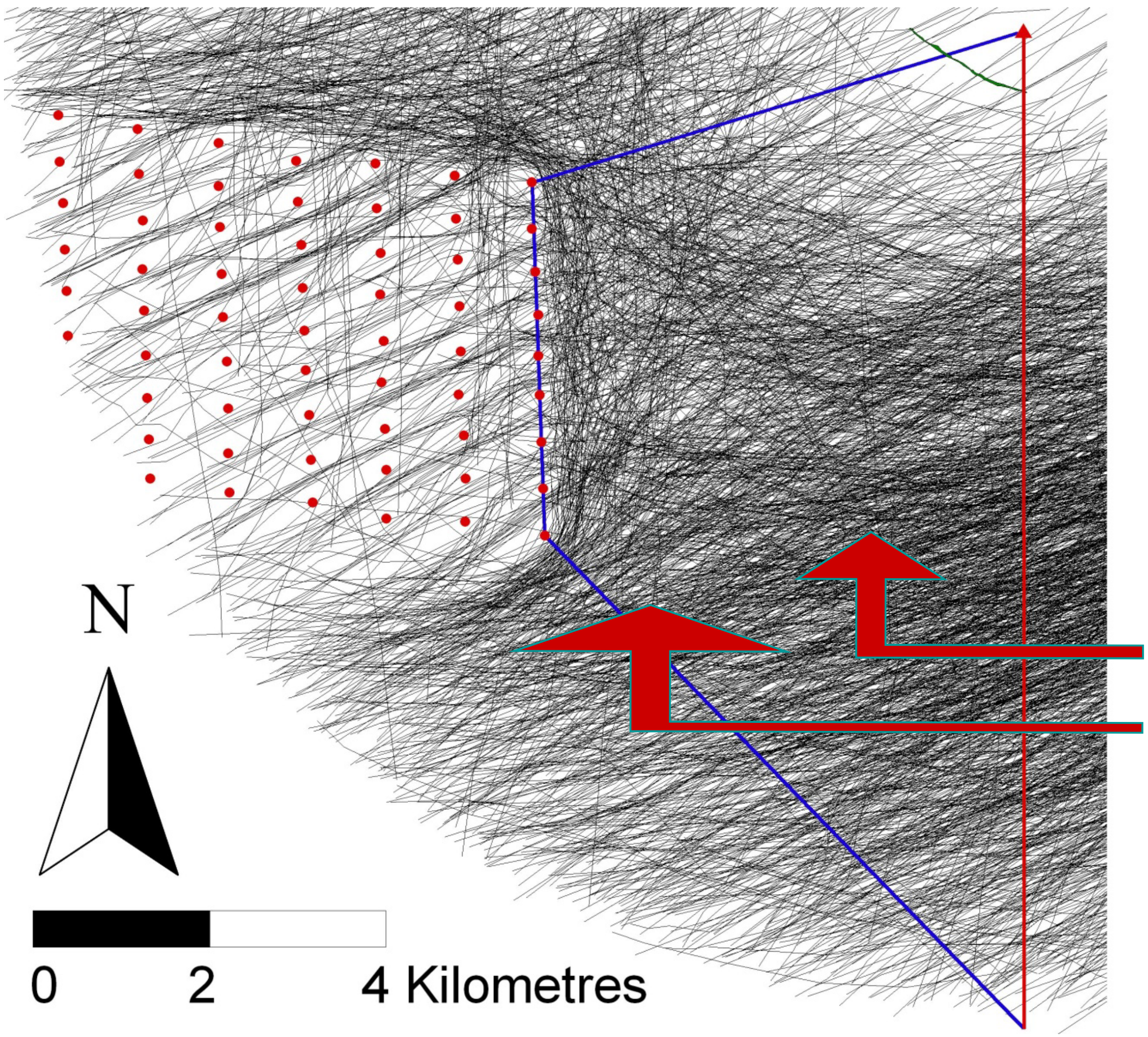
- **Reliability:** Testing and validation of blades, hubs, gear boxes, etc.
- **Wind Energy Systems:**
  - Stiff, heavy machines that resist cyclic and extreme loads—Versus—Lightweight, flexible machines that bend and absorb or shed loads.
  - Need 30 year life in fatigue driven environment with minimal maintenance/no major component replacement.
  - Improve models of turbulence and flow separation; Improve analysis of aeroacoustics, aeroelastics, structural dynamics, etc.
- **Wind Turbine Design Methods:**
  - Replace full-scale testing with computational models to prove blade and turbine design.
- **Wind Farm Design:**
  - Model turbine interactions with each other and with complex terrain to improve farm layout.
- **Composite Materials:**
  - Model material strength, fatigue (progressive loss of strength and stiffness), and failure (fiber failure, bond failure, wall collapse, buckling, etc.)
- **Grid Integration:**
  - Understand impact of system on the utility grid—to better accommodate intermittent wind.
- **Atmospheric Modeling:**
  - Improve modeling for wind forecasting; turbine interactions.
- **Optimize Turbines for Off-Shore:**
  - Wave loading; marine environment



Source: Steve Hammond, NREL

Avoidance Behavior is Significant

Radar Tracks of Migrating Birds through Nysted Offshore Windfarm for Operation in 2003

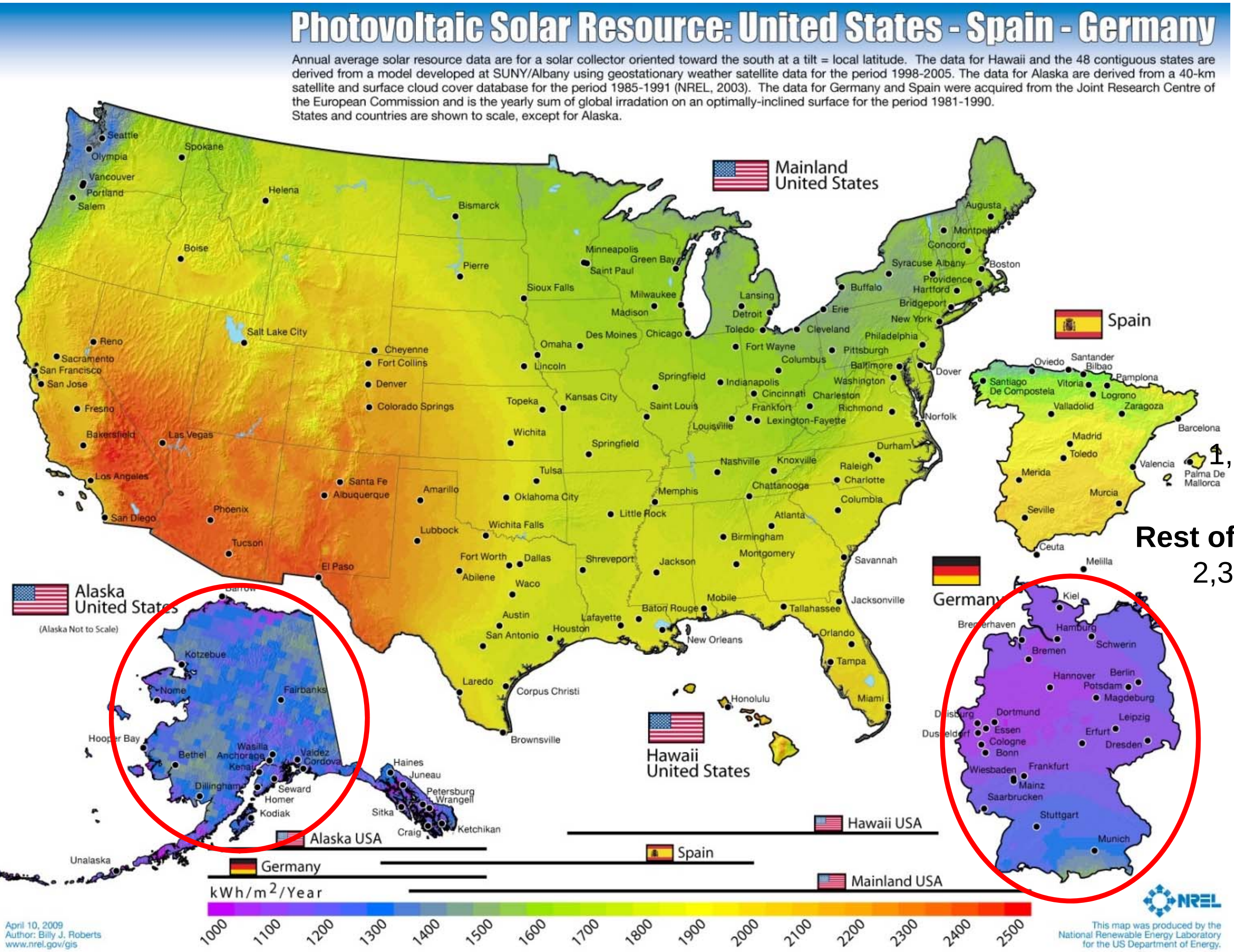


Response distance:

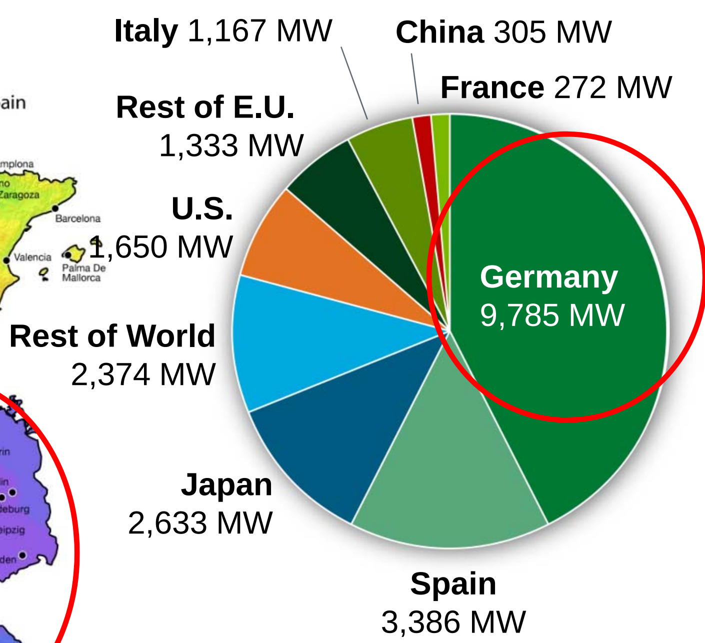
day = c. 3000m

night = c. 1000m

Can Solar Energy Meet the Challenge?



Cumulative Installed PV
(through 2009)

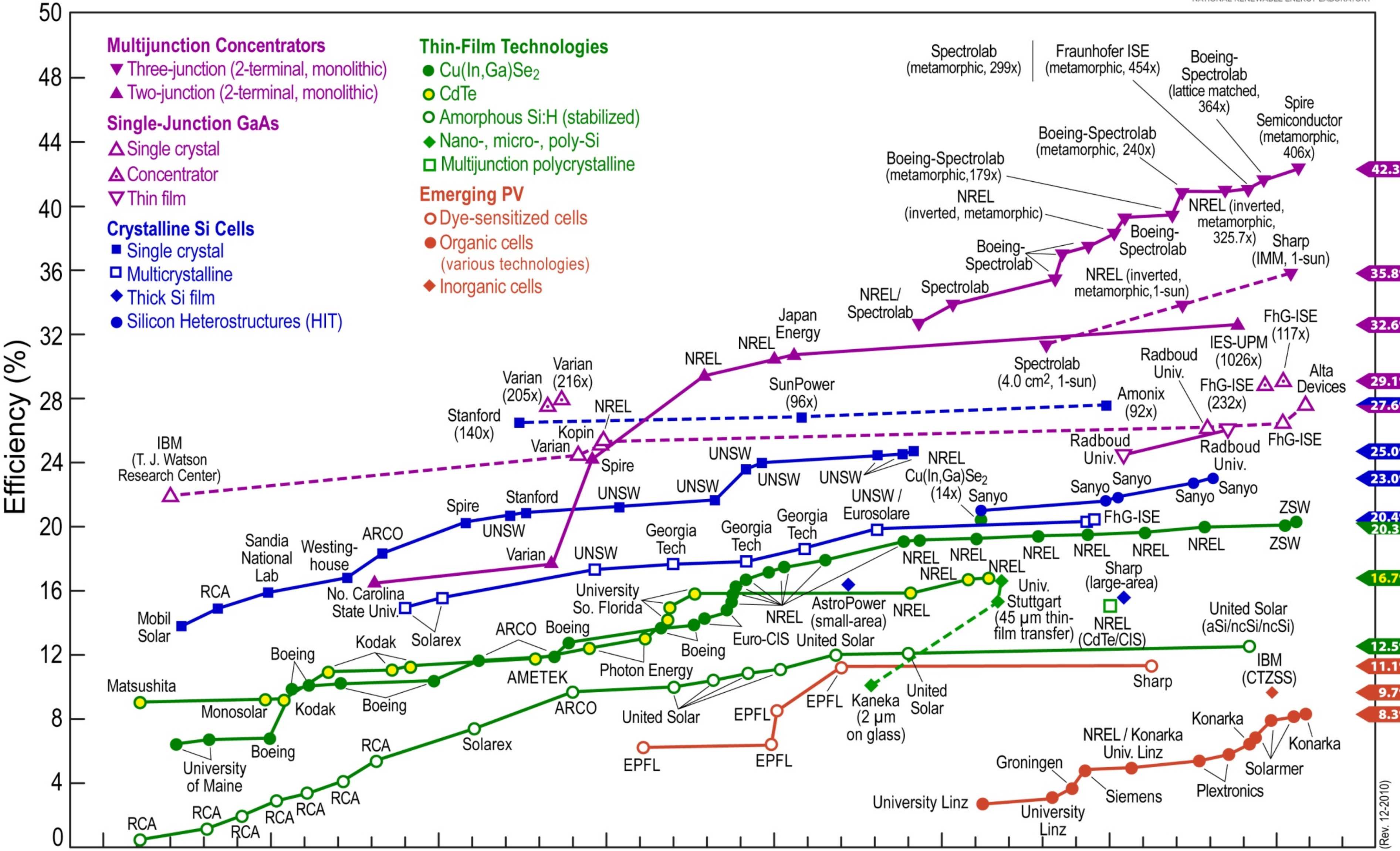


Source: EERE/SETP, Goldstein

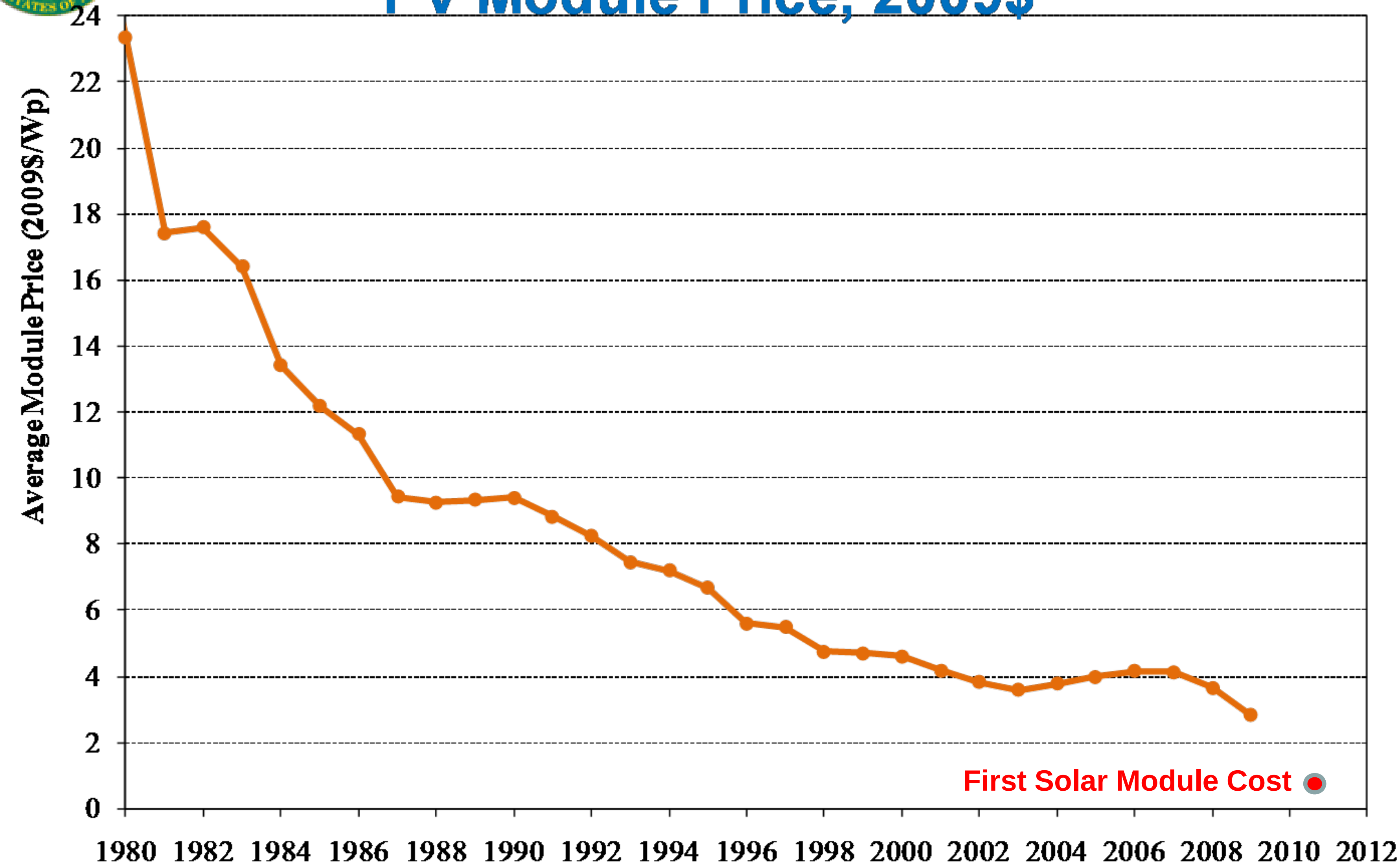
Can PV Meet the Challenge?

Source: EERE/STP

Best Research-Cell Efficiencies



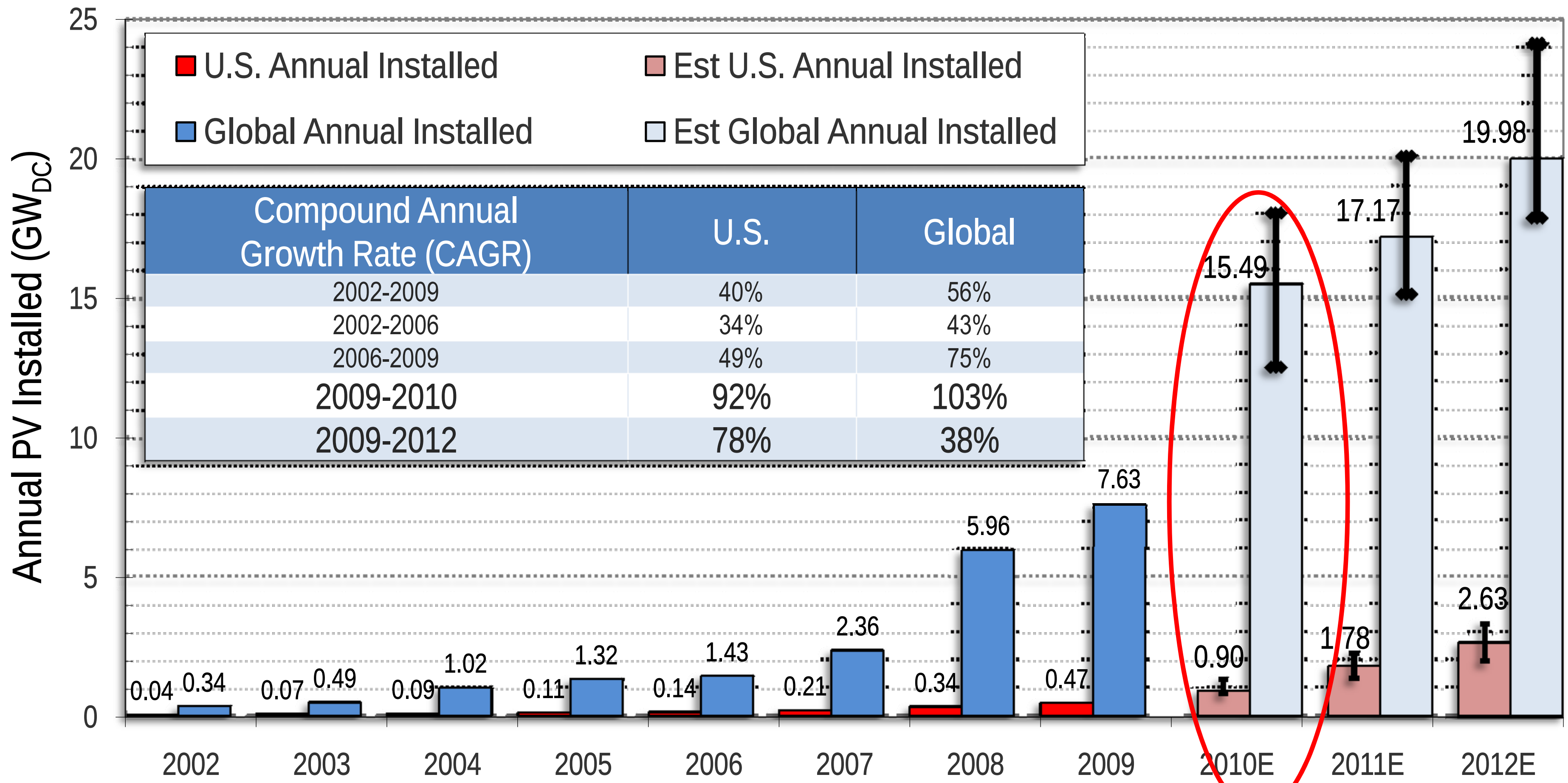
PV Module Price, 2009$



Source: Navigant & Robert Margolis, NREL

U.S. & Global Annual PV Installations

- 103% rise in global and 92% rise in U.S. installations expected for 2009-2010, however the U.S. is expected to lead the global growth rate during 2009-2012

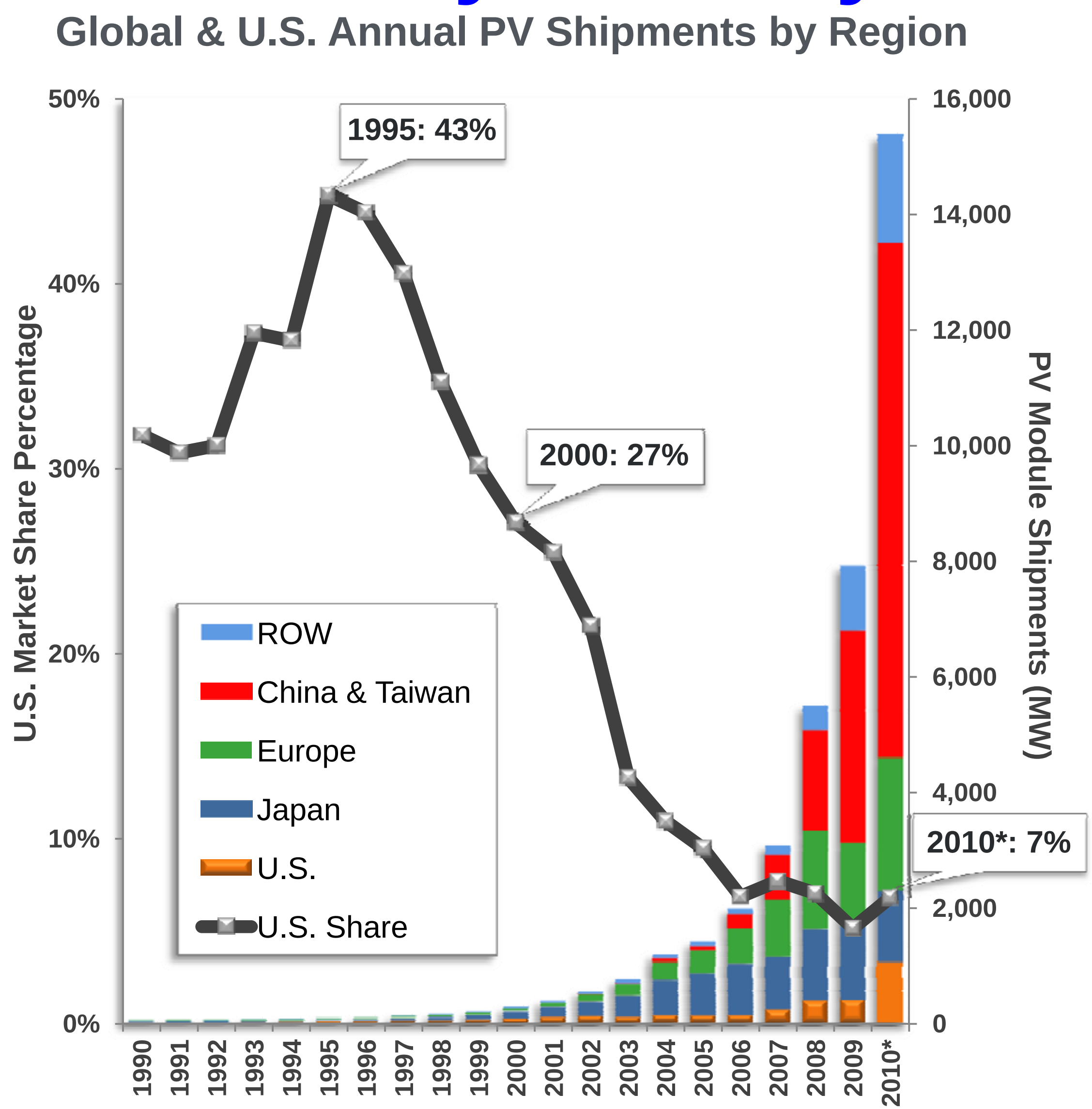


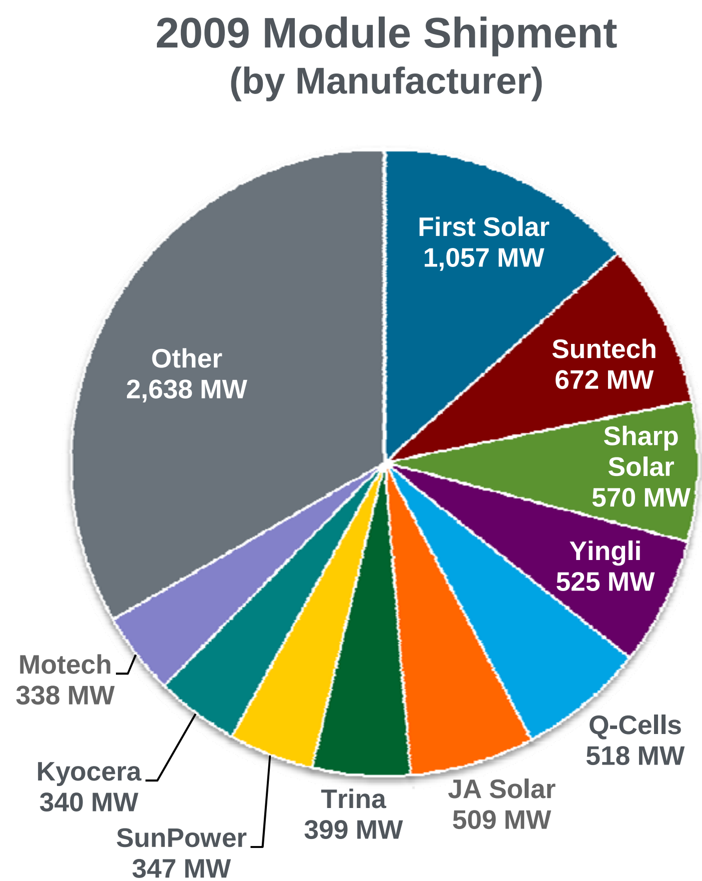
Compound Annual Growth Rate (CAGR)	U.S.	Global
2002-2009	40%	56%
2002-2006	34%	43%
2006-2009	49%	75%
2009-2010	92%	103%
2009-2012	78%	38%

•Sources: 2002-2008: NREL, "2008 Solar Technologies Market Report" (1/20/10), 2009 U.S.: SEIA, "2009, Year In Review" (4/15/10), 2009 Global: Bloomberg NEF (10/5/10), 2010E-2012E: Barclays (9/23/10), Bloomberg NEF (7/30/10 & 10/5/10), Goldman Sachs (10/1/10), Jefferies & Co. (10/27/10), Lazard Capital Markets (10/21/10), Stifel Nicolaus (10/12/10), UBS (10/29/10), Wells Fargo Securities (5/4/10 & 9/21/10)

Source: EERE/SETP, Goldstein

Global Module Share by Country and Firm





Notes & Sources:

2010 are preliminary data.

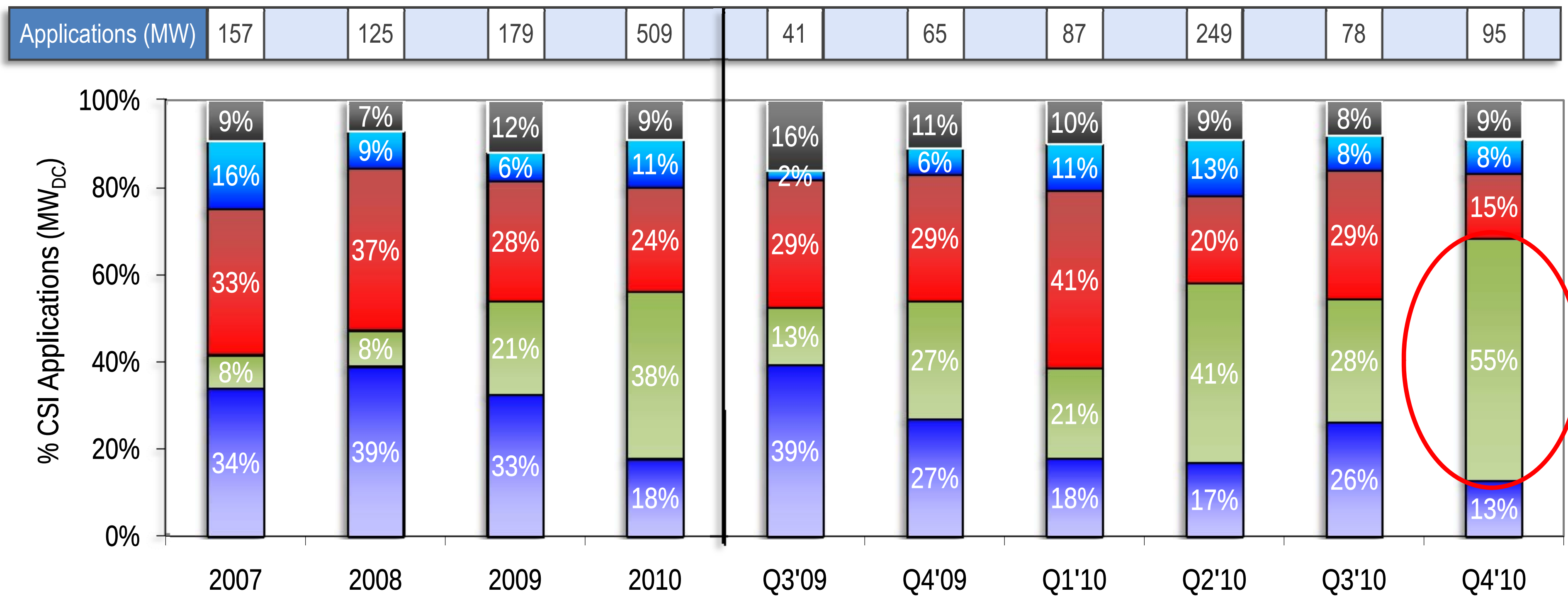
Global & Annual PV Shipments by Region: 1990-92 : PV News (2/1993), 1993-2000: PV News (3/2001), 2001-2004: PV News (3/2006), 2005-2010*: Navigant Consulting (2/2011).

2009 Module Shipment: Navigant Consulting (4/2010).

Source: EERE/SETP, Goldstein

Market Share by Country

- Chinese market share rising since 2007; accelerated last year to 55% in Q4’10
- Q4’10: Suntech: 19%, Yingli: 16%, Trina: 15%, SunPower: 10%, Sharp: 9%, SolarWorld: 5%, Other: 26%
- Q1’07-Q4’10: SunPower: 15%, Sharp: 13%, Suntech: 10%, Yingli: 9%, SolarWorld: 7%, Kyocera: 7%, Other: 39%



•Country is HQ of manufacturer

Other | Germany | Japan | China | USA

•Sources: Bloomberg NEF (4/16/10, 7/27/10, 10/14/10, & 2/21/11) (1/16/11)

•Notes: Based upon CSI data as of 3/12/11 (data posted online on 3/9/11), discussions with Bloomberg NEF (2/10/10), and LBNL

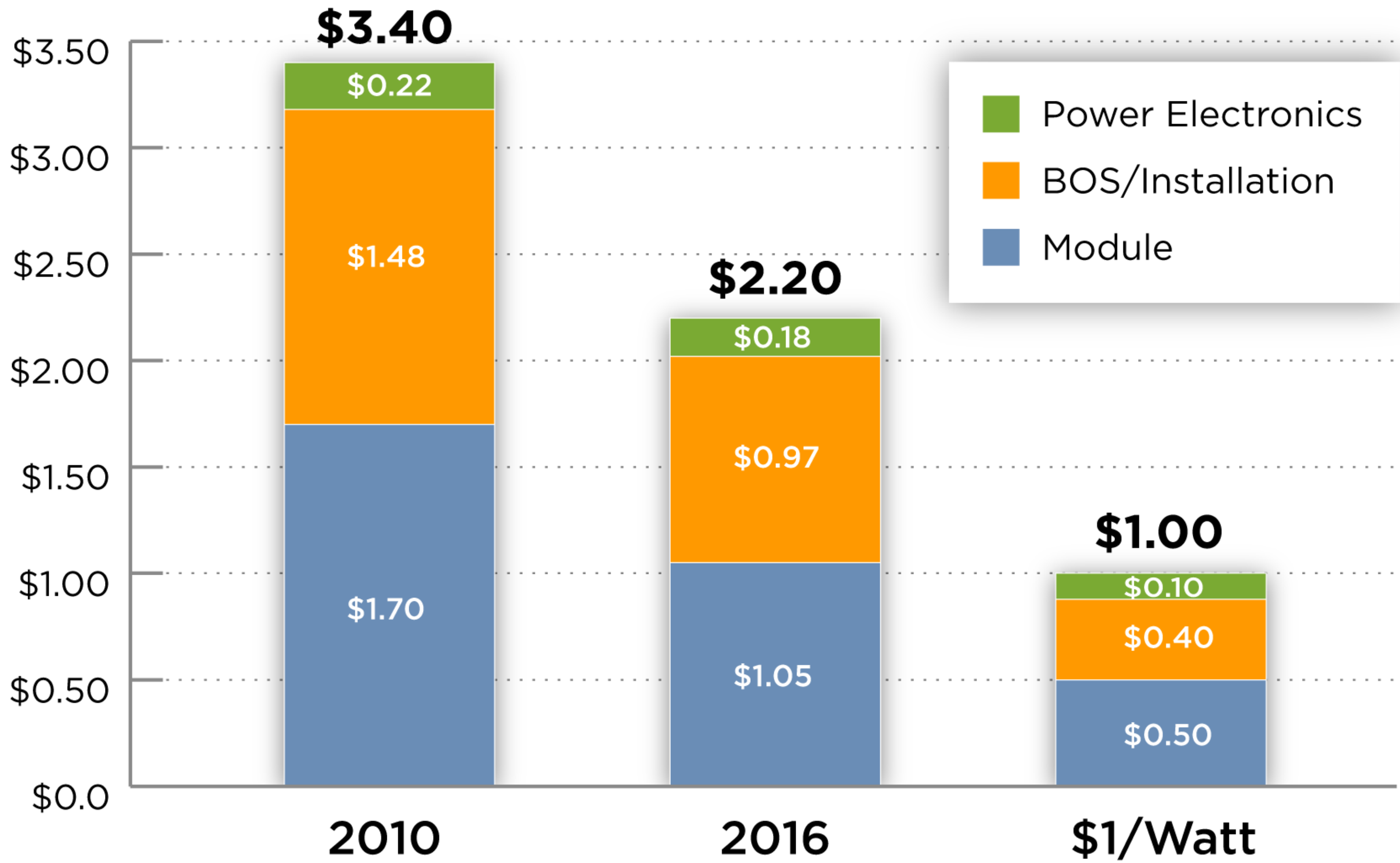
•Please see Appendix for data analysis assumptions and notes.

•Numbers may not sum to 100% due to independent rounding.

Source: EERE/SETP, Goldstein

SunShot:
Advances required in all PV system components

Utility System with SunShot $1/W Goal



Estimates do not include the cost of land, Hardware costs include power electronics and mounting, Soft Costs includes permitting,

Materials

- **Commodity Materials**
  - Steel, Cement, Glass, Copper
  - Silicon
- **Specialty Materials**
  - CIGS, CdTe, others.
  - Lithium; Cobalt; Ruthenium; Tb

Material	World Production	Material at 20 GW/y	% Current Production
Indium	250 MT/y	400 MT/y	160%
Selenium	2,200 MT/y	800 MT/y	36%
Gallium	150 MT/y	70 MT/y	47%
Tellurium	450 MT/y (2000 MT/y unused)	930 MT/y	38% (of total)
Cadmium	26,000 MT/y	800 MT/y	3%

- **X 5+ Globally**

- **National Controls?**

- **Responses**
  - New sources of supply
  - More efficient use
  - Substitution
  - Recycling

Table adapted from NREL

Concentrating Solar Thermal Power

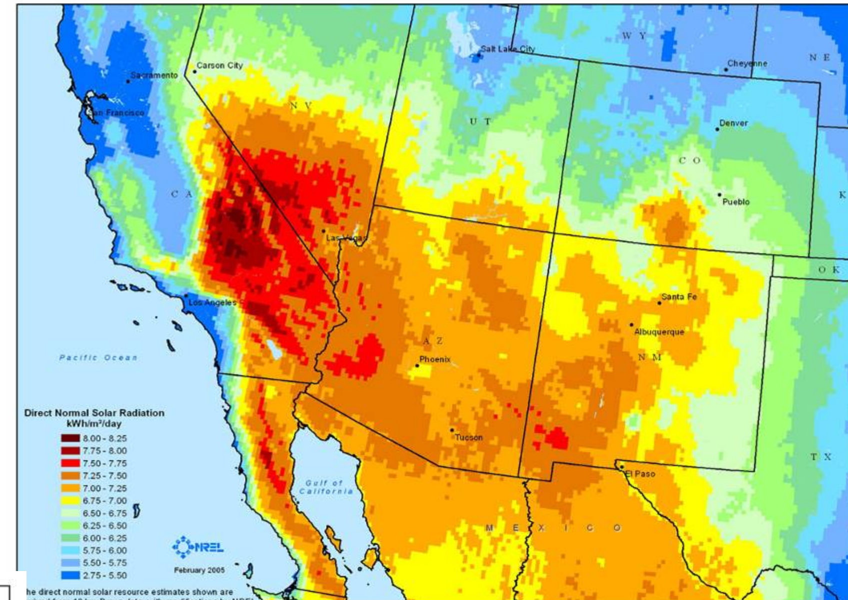
Source: EERE/STP

Can CSP Meet the Challenge?

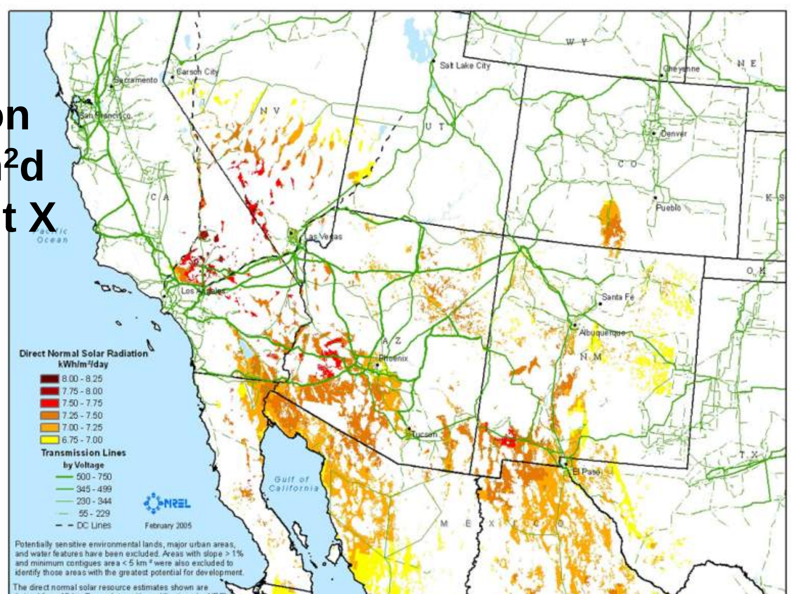
Systems in place
- 354 MW Trough, 1984-1990, ~14¢/kWh
- 1 MW Trough, Arizona, 2006
- 64 MW Trough, Nevada, 2007
- 5 MW Kimberlina Linear Fresnel, CA 2008
- Much more in planning, construction…

Cost Reduction Potential
- CSP costs ~8 cents/kWh w RD&D.
  - Scale-up ~37%
  - Volume Production ~21%
  - Technology Development ~42%

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**

CSP Systems

50 MW AndaSol Parabolic Trough Plants w/ 7-hr Storage, Andalucía

CSP Projects

– Abu Dhabi	100 MW
– Algeria	150
– China	1000
– Egypt	20
– Israel	240
– Mexico	30
– Morocco	470
– South Africa	150
– Spain	1300
– U.S.	4500
– TOTAL	7960

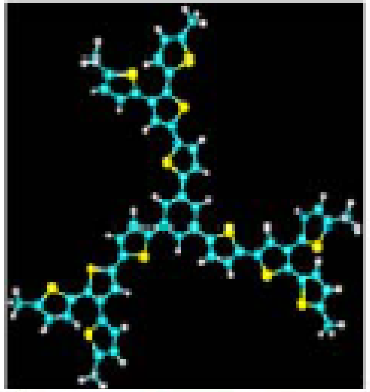
DeserTec?

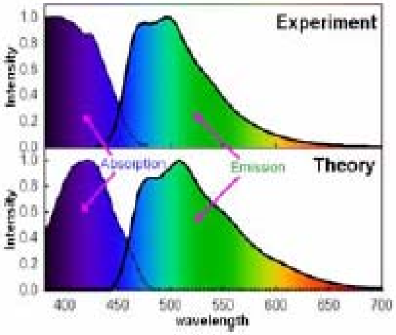
Abengoa PS10, PS 20; Spain

Photos Courtesy of Mark Mehos, NREL

Solar Energy R&D Opportunities

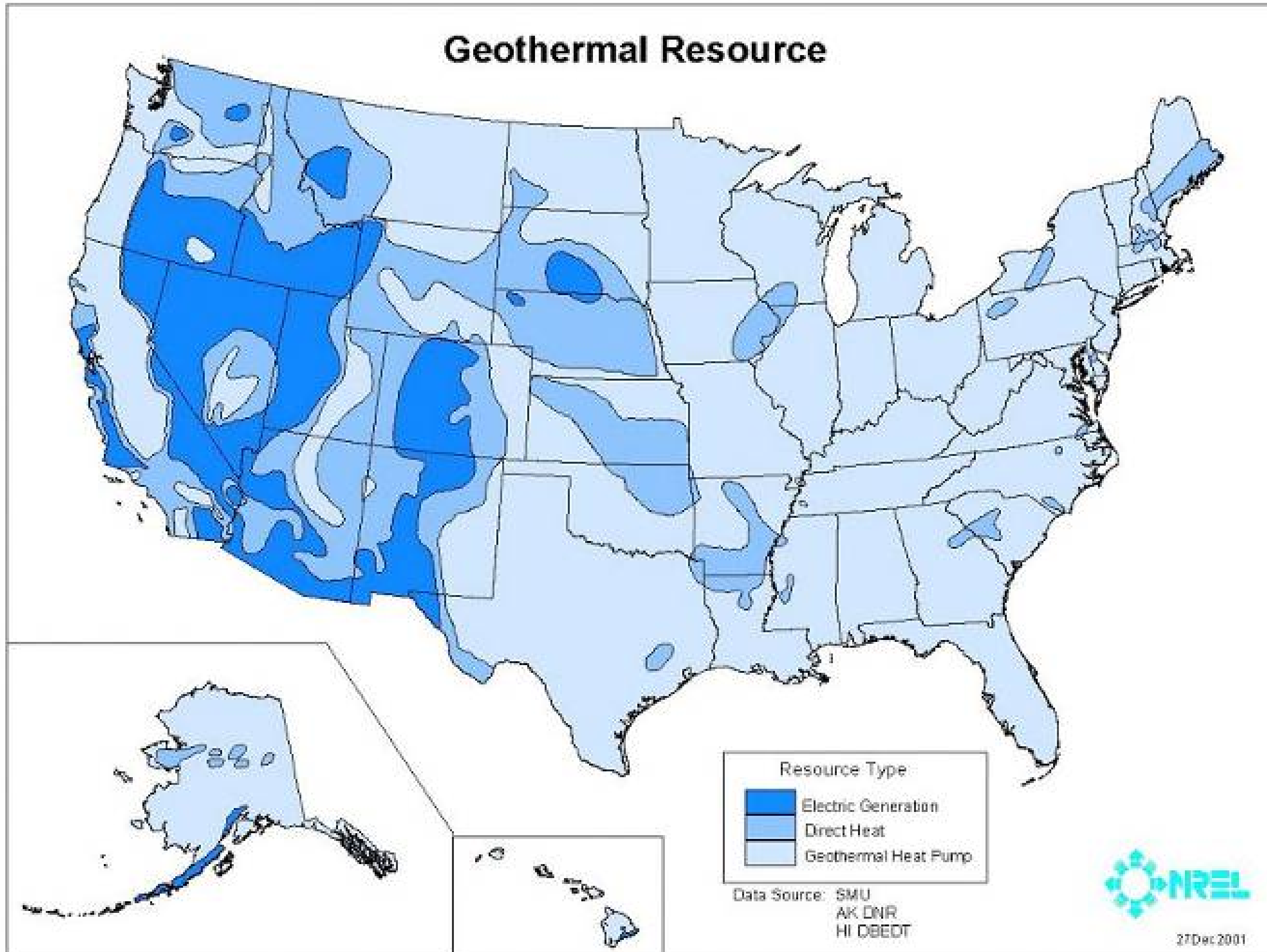
- **Photovoltaics**:
  - Improve materials/devices, esp. CdTe, CIGS, multi-junction thin films, reduce thickness of active layers, increase production rates
  - Develop new/improved Transparent Conducting Oxides
  - Improve module and interconnect designs and performance
  - Improve packaging: encapsulants cure time/hermiticity/UV-resistance/etc
  - 3rd Generation intermediate-band cells, Quantum Dot cells, etc.
  - Improve inverter performance/reliability/cost/surge prot.; plug & play; etc.
  - Improve BOS; Improve concentrator secondary optics for T>70 C, x100s
- **Concentrating Solar Power**:
  - Stable, high temperature heat transfer and thermal storage materials to 600C (1200 C), with low vapor pressure, low freezing points, low cost
  - Stable, high temperature, high performance selective surfaces
  - High performance reflectors; self-cleaning coatings; improved optics/aim
  - High temperature tower systems for combined cycles with storage.
- **Fuels:**
  - High-temperature thermochemical cycles for CSP production—353 found & scored; 12 under further study; Develop falling particle receiver and heat transfer system for up to 1000 C cycles. Develop reactor/receiver designs and materials for up to 1800 C cycles.
  - Improved catalysts
  - Photoelectrochemical: good band-edge matching, durable in solution
  - Photobiological—unleashing hydrogenase pathway;
  - Electrolysis, including thermally boosted solid-oxide electrochemical cells
- **Cross-cutting Areas**:
  - Power electronics—wide-band gap materials; Reliable capacitors
  - Energy Storage





Source: *Muhammet E. Köse, et al.* "Theoretical Studies on Conjugated Phenyl-Cored Thiophene Dendrimers for Photovoltaic Applications", NREL

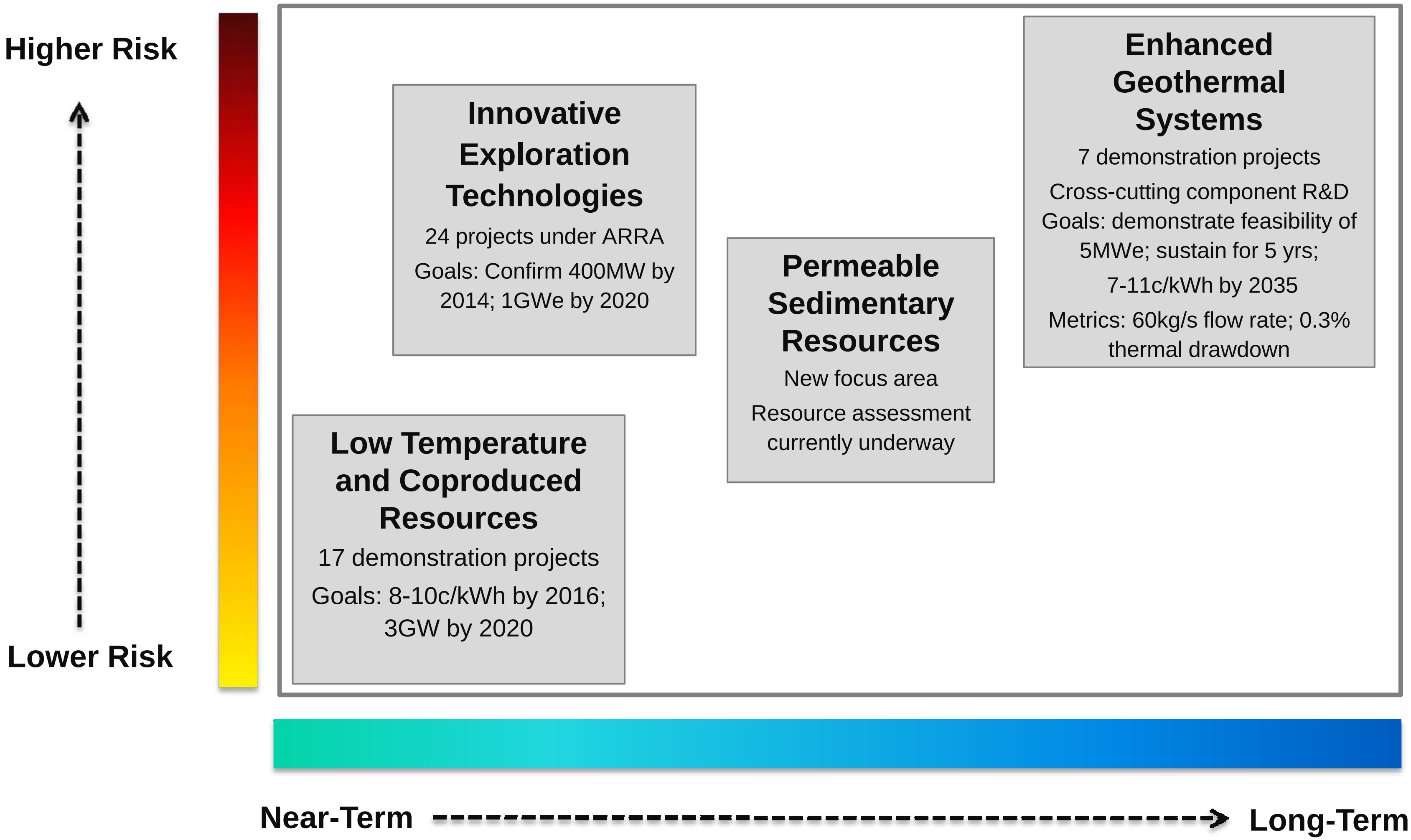
Geothermal Technologies



- U.S. capacity is ~3,086 MW; ~7,000 MW under study

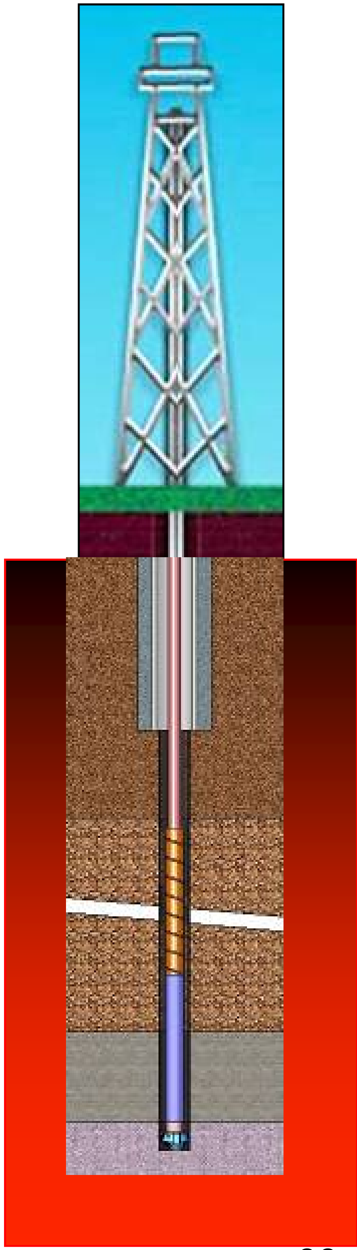
Geothermal Program Strategy

The Program supports a diverse portfolio that spans near- to long-term resources and low to high risk technology development, while seeking to enable widespread access to geothermal energy.



Source: EERE/GTP

Geothermal R&D Issues



- **Exploration:**
  - Remote sensing
- **Reservoir Development:**
  - Well stimulation techniques; proppants; Enhanced Geo Systems
- **Drilling and Field Development**:
  - Bits--advanced materials, controls, mechanisms; (PDC Bits)
  - High-temp systems; diagnostics while drilling; telemetry
  - Lost circulation or short circuit control materials/techniques
  - Liners; casings; cements
- **Conversion**:
  - Mixed working fluids in binary plants;
  - Variable Phase Turbines;
  - Enhanced Heat Rejection
- **Oil & Gas**:
  - Coproduction of geothermal energy using binary systems
- **Sequestration**: CO_2 as a working (supercritical) fluid for EGS
  - Reduced power consumption in flow circulation; Reduced viscosity/higher flow rates than water, but lower heat capacity
  - CO_2 uptake/mineralization/sequestration at elevated temp.
- **PCD Drill Bits: $16B Success** (3%Discount; 2008$)

Water Technology Types & Barriers

Program Focuses on the Following Technologies:

5 wave technology types

- Attenuator, Point Absorber, Oscillating Water Column, Oscillating Wave Surge Converter, Overtopping

3 hydrokinetic technology types

- Horizontal Axis Turbine, Vertical Axis Turbine, Oscillating Hydrofoil

3 types of ocean thermal energy conversion (OTEC)

- Closed-cycle, Open-cycle, Hybrid

R&D Necessary to Reduce Implementation Barriers:

Technologies are in very early stage of development, with few full-scale demonstrations

- Lack of cost and performance data
- No standardized basis for technology assessments and comparisons
- Prototype deployment is costly and time-consuming

Lack of water resource assessment data for rivers, ocean and tidal currents, and wave states/regimes

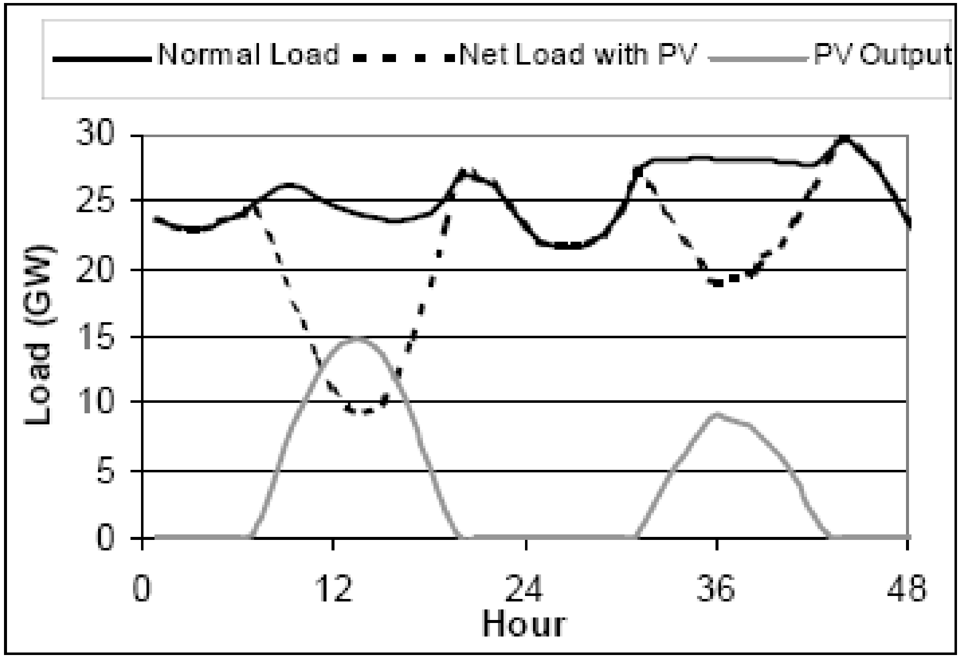
Uncertain environmental impacts

- More data necessary on the environmental, navigational, and competing use impacts

Source: EERE/WWTP

Grid Integration

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

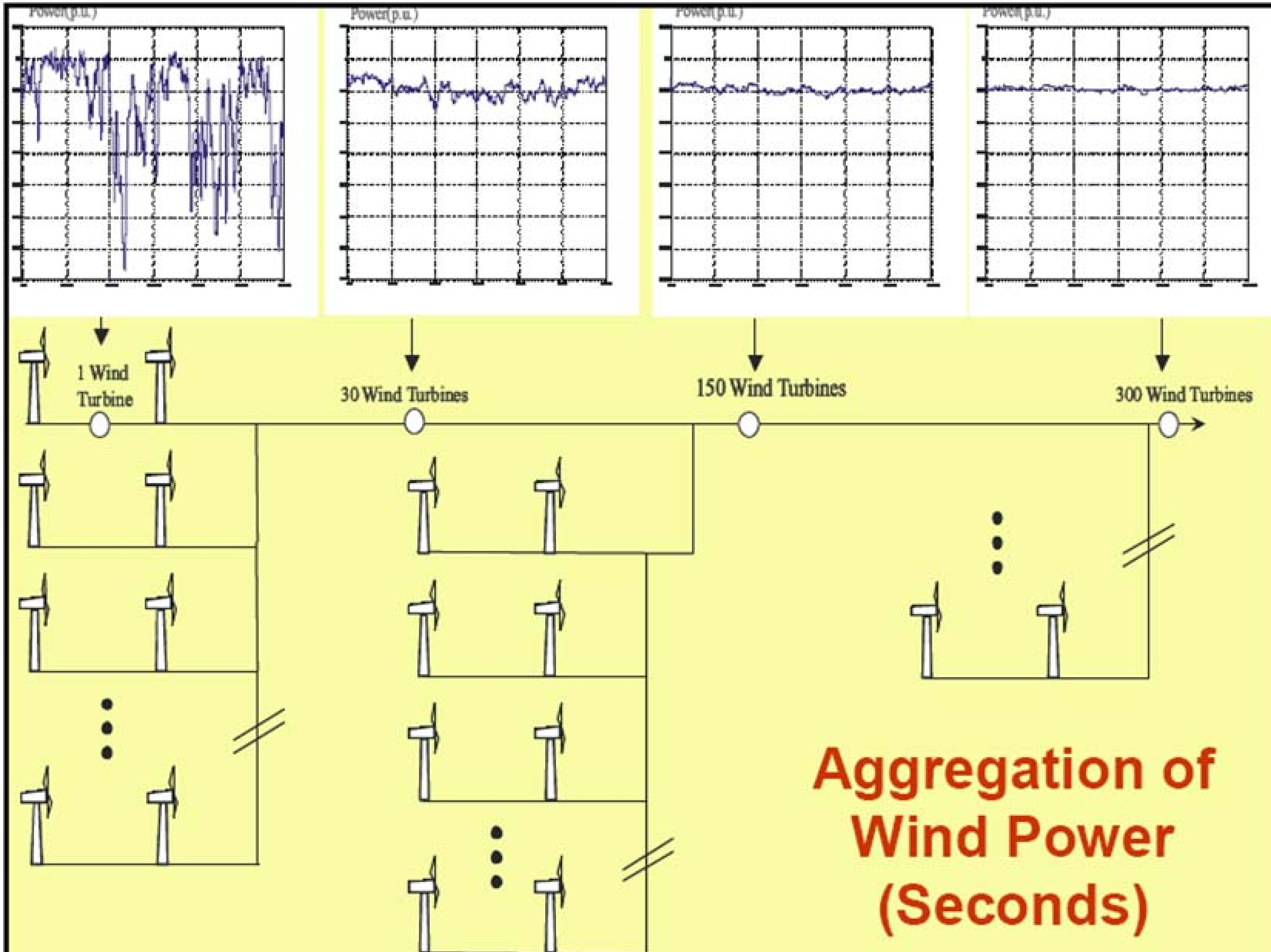


ISSUES

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

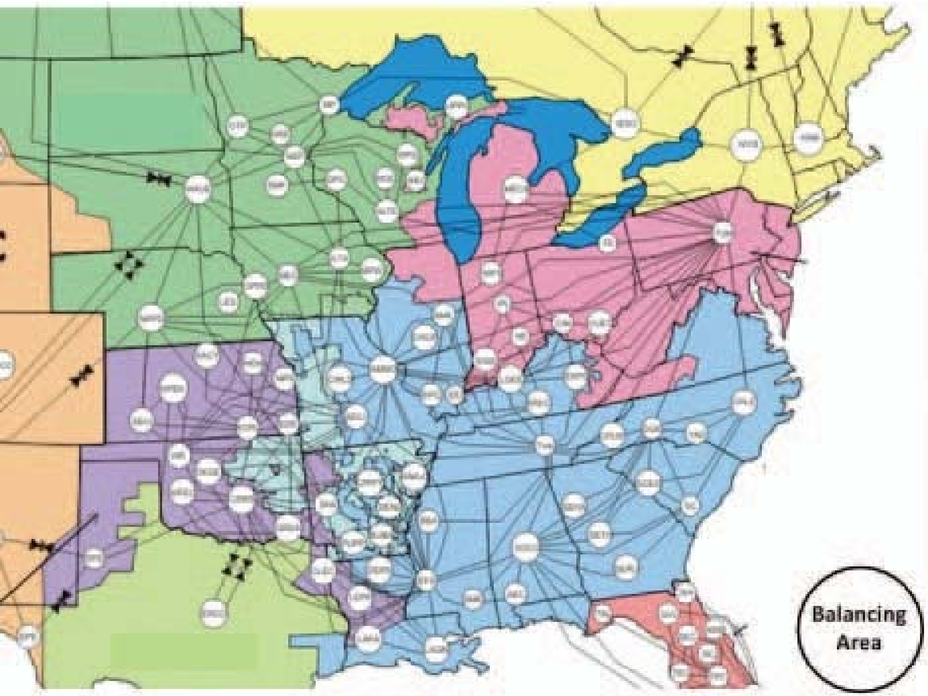
- **Assess potential effects** of large-scale Wind/Solar deployment on grid operations and reliability:
  - Behavior of solar/wind systems and impacts on existing grid
  - Effects on central generation maintenance and operation costs, including peaking power plants
- **Engage with utilities** to mitigate 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.

The Power of Aggregation & Geographic Diversity

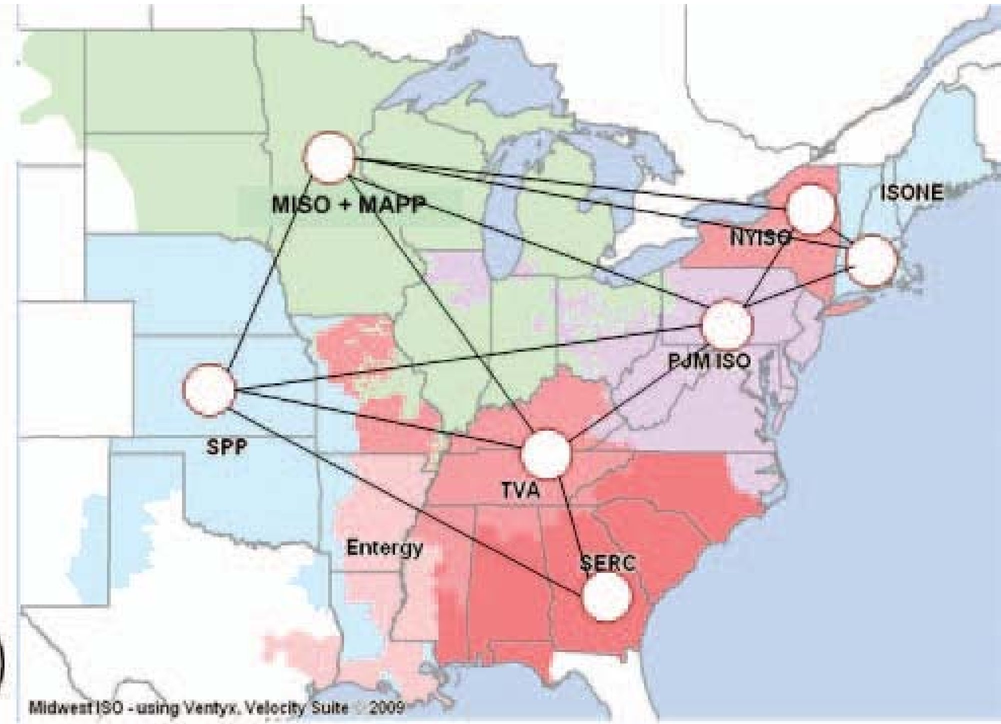


Source: EWITS Study; Dave Corbus, NREL

Balancing Authorities: Consolidation?



As of August 1, 2007



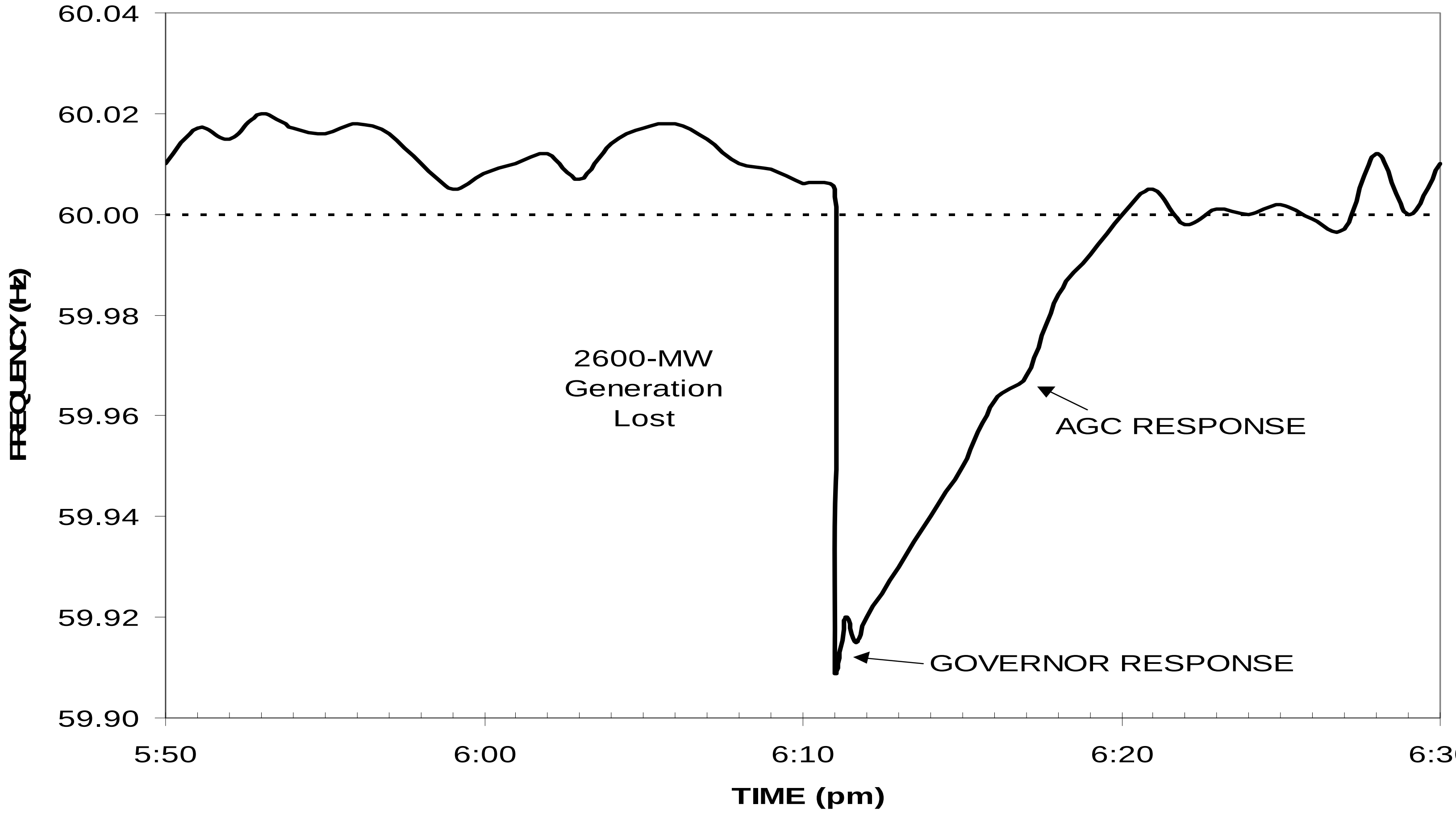
Assumption for 2024

- 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

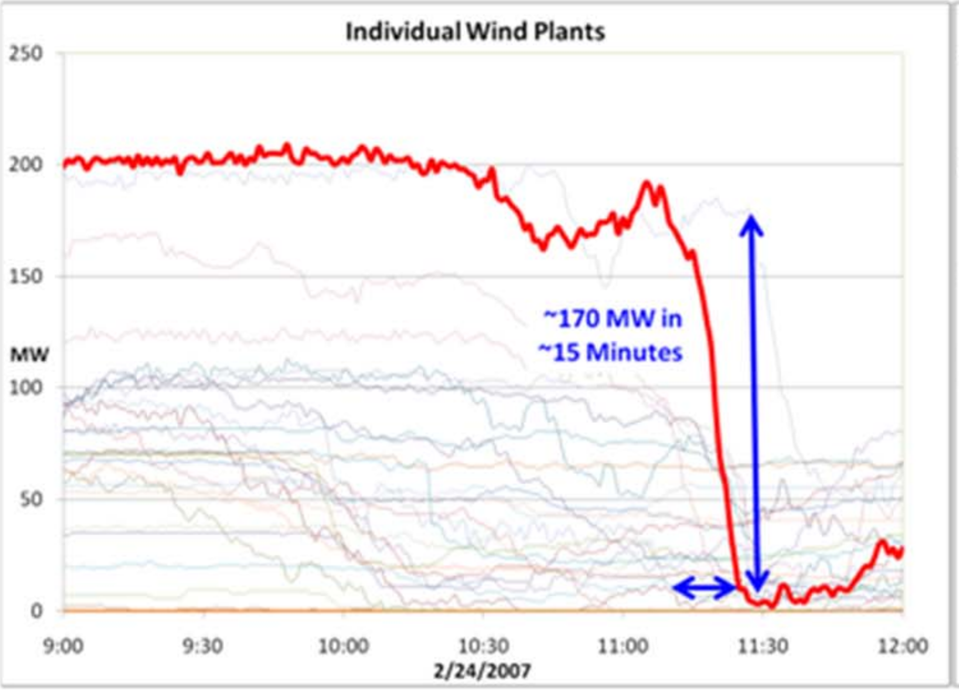
System Loss and Frequency Excursion

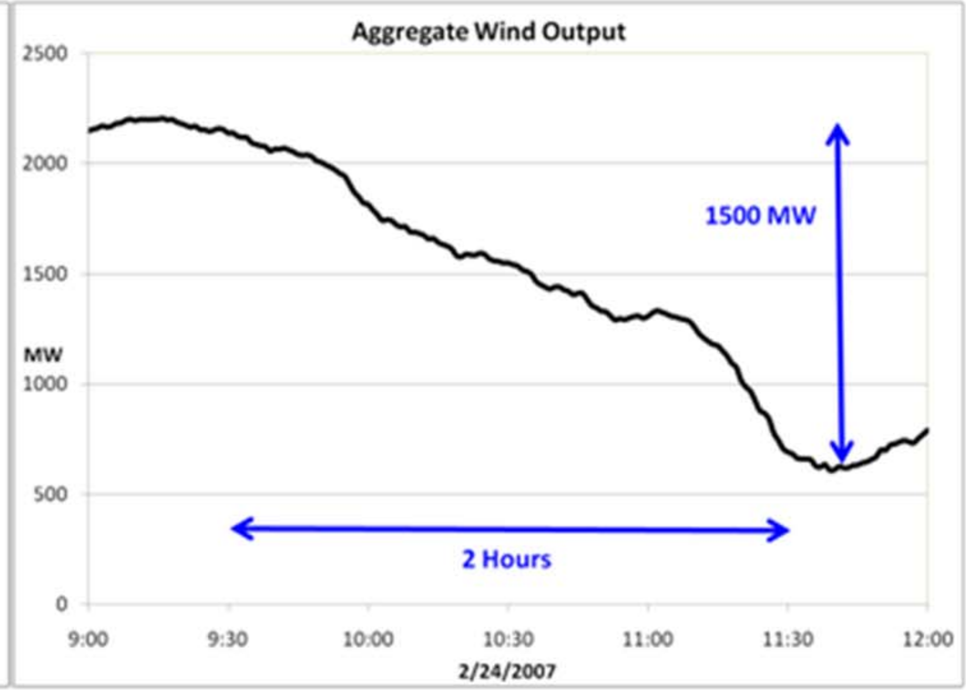
Energy Must Be Re-Balanced Quickly by Adding Generation or Shedding Load



Source: Provided by NREL

Distributed Systems



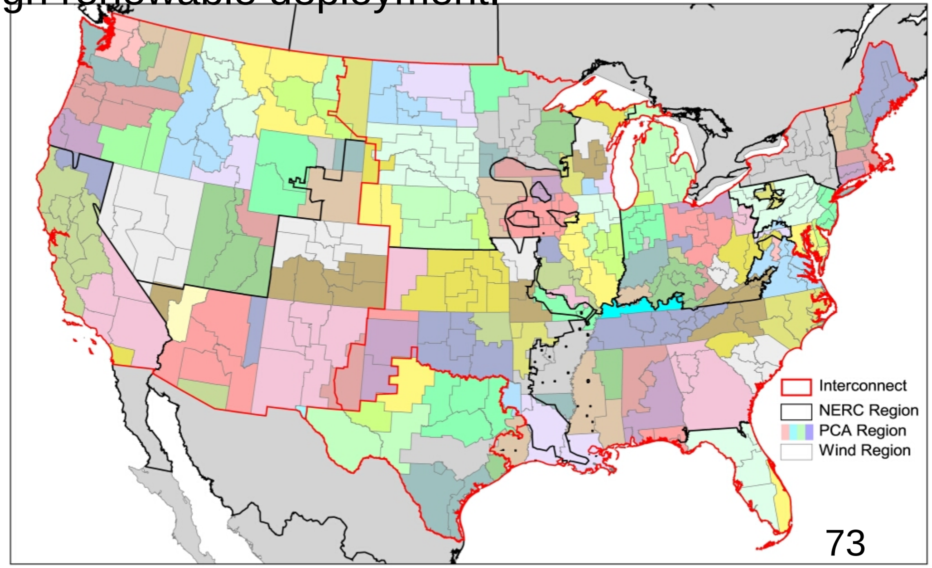


Source: Milligan, et al., IEEE Power & Energy, Nov./Dec 2009, pp.92

Regional Energy Deployment Systems Model

- **Capacity expansion & dispatch** for the continental U.S. electricity sector, including transmission and all major generator types:
  - hydro, gas CT/CC, coal (w/wo CCS), gas/oil steam, nuclear, wind, CSP, biopower (wo *CCS*), geothermal, storage, central station PV.
- **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
- **Linked with GridView** hourly unit commitment/economic dispatch model
  - Examines amount of "unserved load", curtailment, congestion, etc.
  - Identify potential operational issues with high renewable deployment.

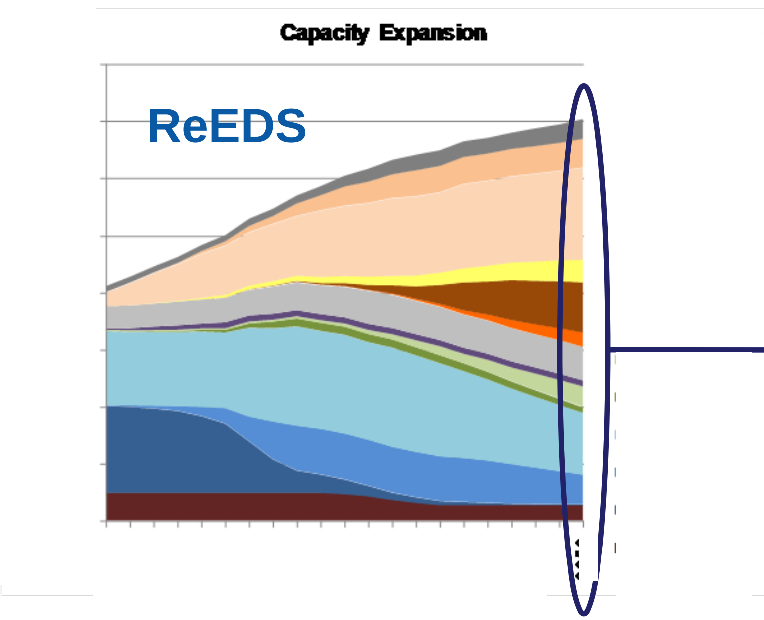
- Input future electric demands and fuel prices by region.
- Simple elasticities provide *demand* and fossil fuel price response.
- Expands transmission capacity as needed.
- Does not yet directly include distributed PV; imports SolarDS

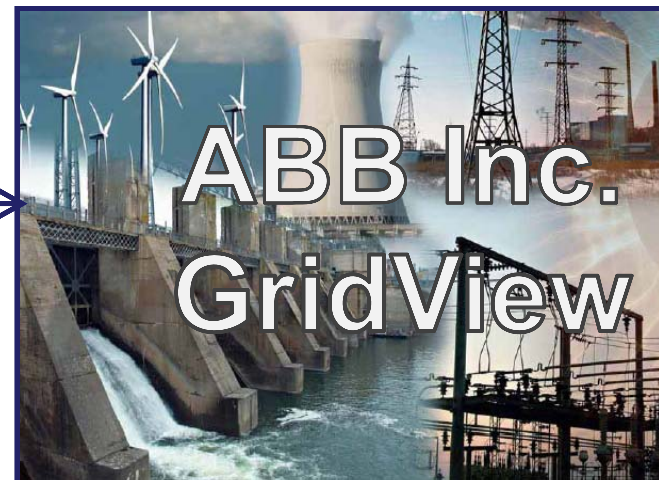


Source: NREL, Walter Short

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





Does the system operate (hourly)?

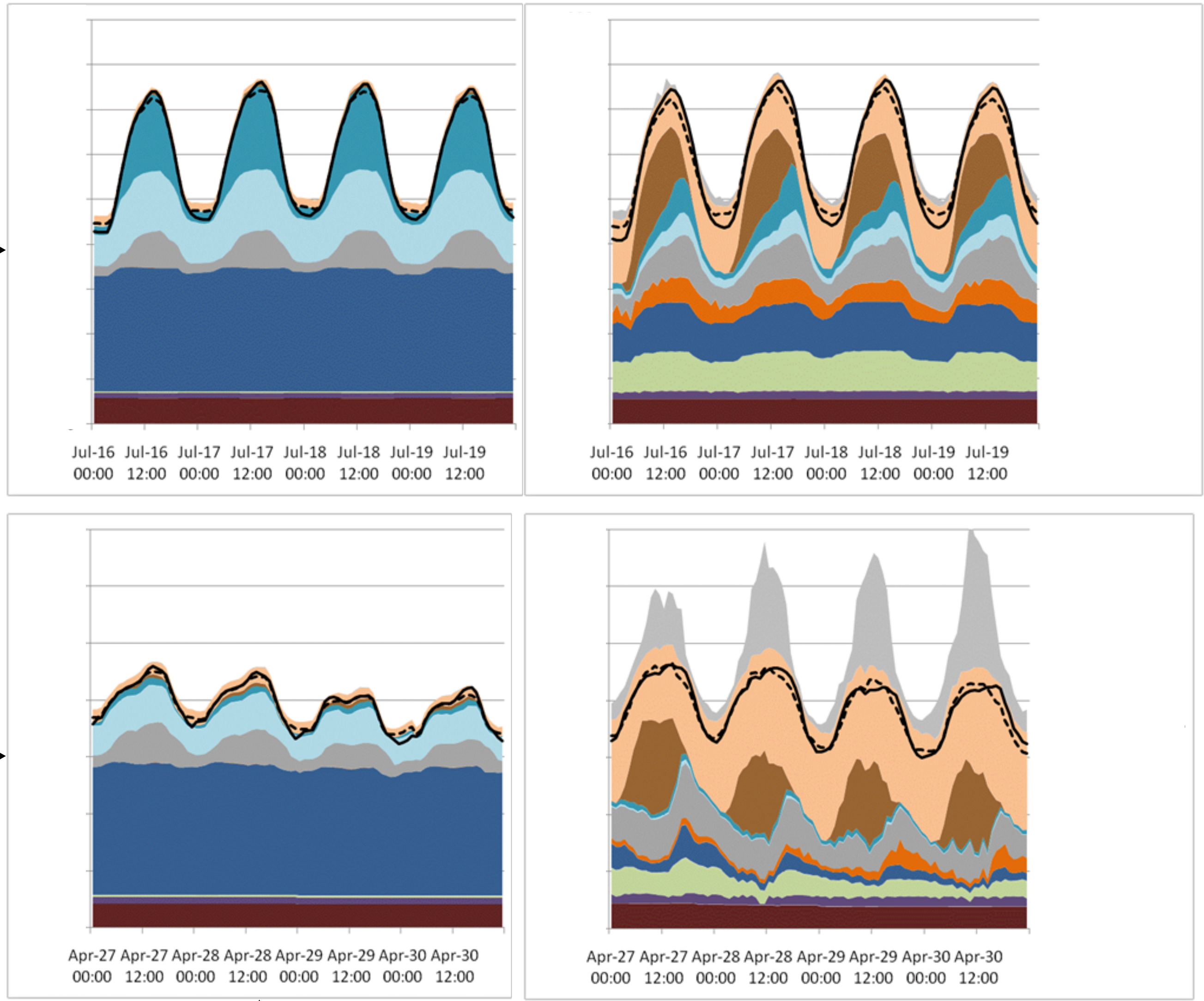
- Used by ISOs, utilities, others for planning—transmission/generation expansion; total production cost, prices, congestion, etc.
- 11,000 Generators; 85,000 Transmission lines; 34,000 Buses with load; 65,000 nodes; 136 transmission zones
- Commits/Dispatches generating units based on electricity demand,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

Source: NREL, Brinkman

Representative GridView Outputs

Summer Peak →

Spring Off-Peak →

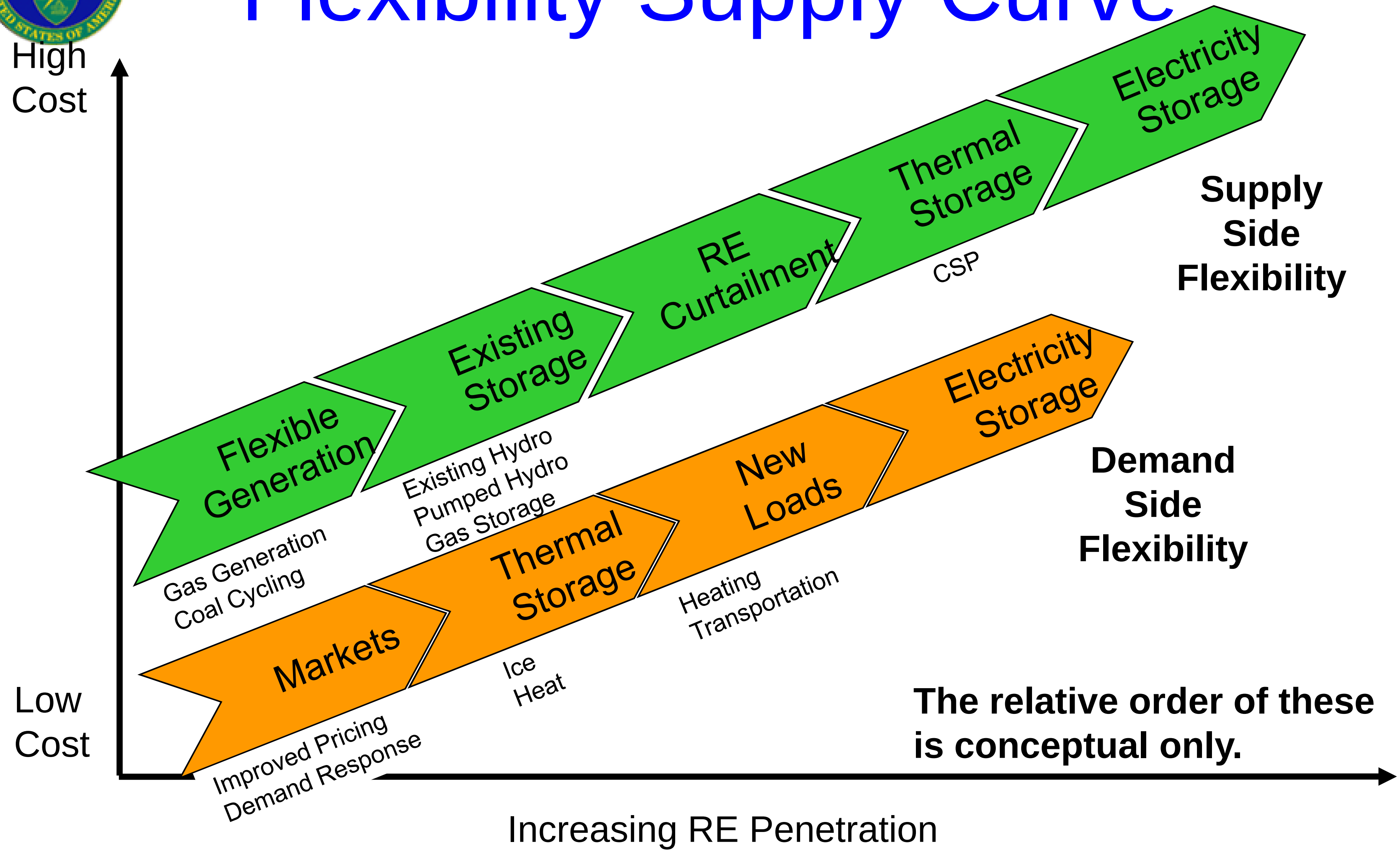


↑ **Baseline**

↑ **RE Case**

Source: NREL, Brinkman

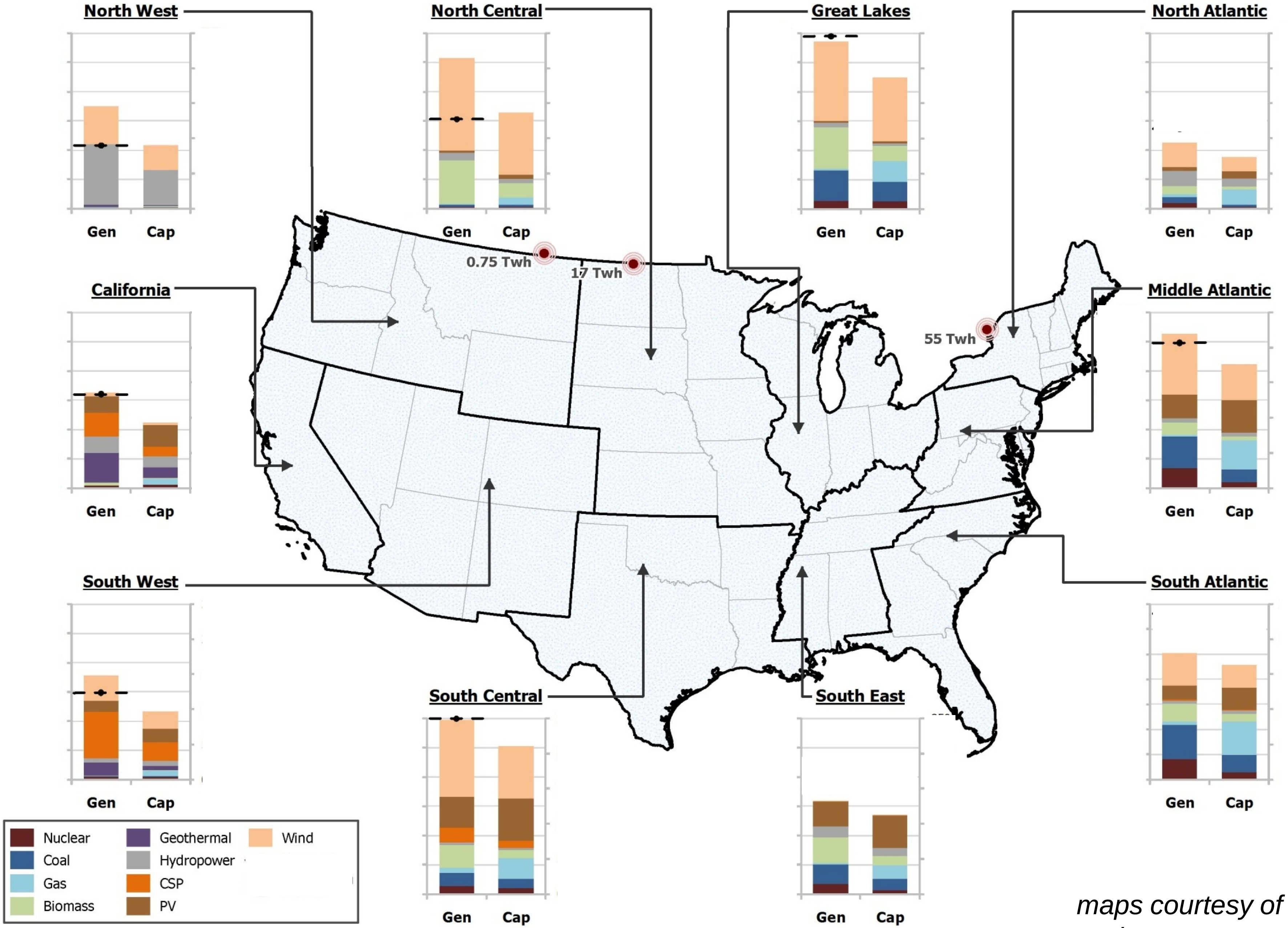
Flexibility Supply Curve



The relative order of these is conceptual only.

Source: NREL, Hand

2050 Regional Generation and Capacity



maps courtesy of Anthony Lopez, NREL

Observations

- Studies:
  - 20% Wind;
  - Eastern Wind Integration Study;
  - Western Wind and Solar Integration Study
  - Underway: Renewable Electricity Futures

- Intermediate levels of RE are feasible under ten-minute simulation Exploring high levels of RE under hourly simulation

- Continued R&D can increase the diversity of supply; reduce economic costs.

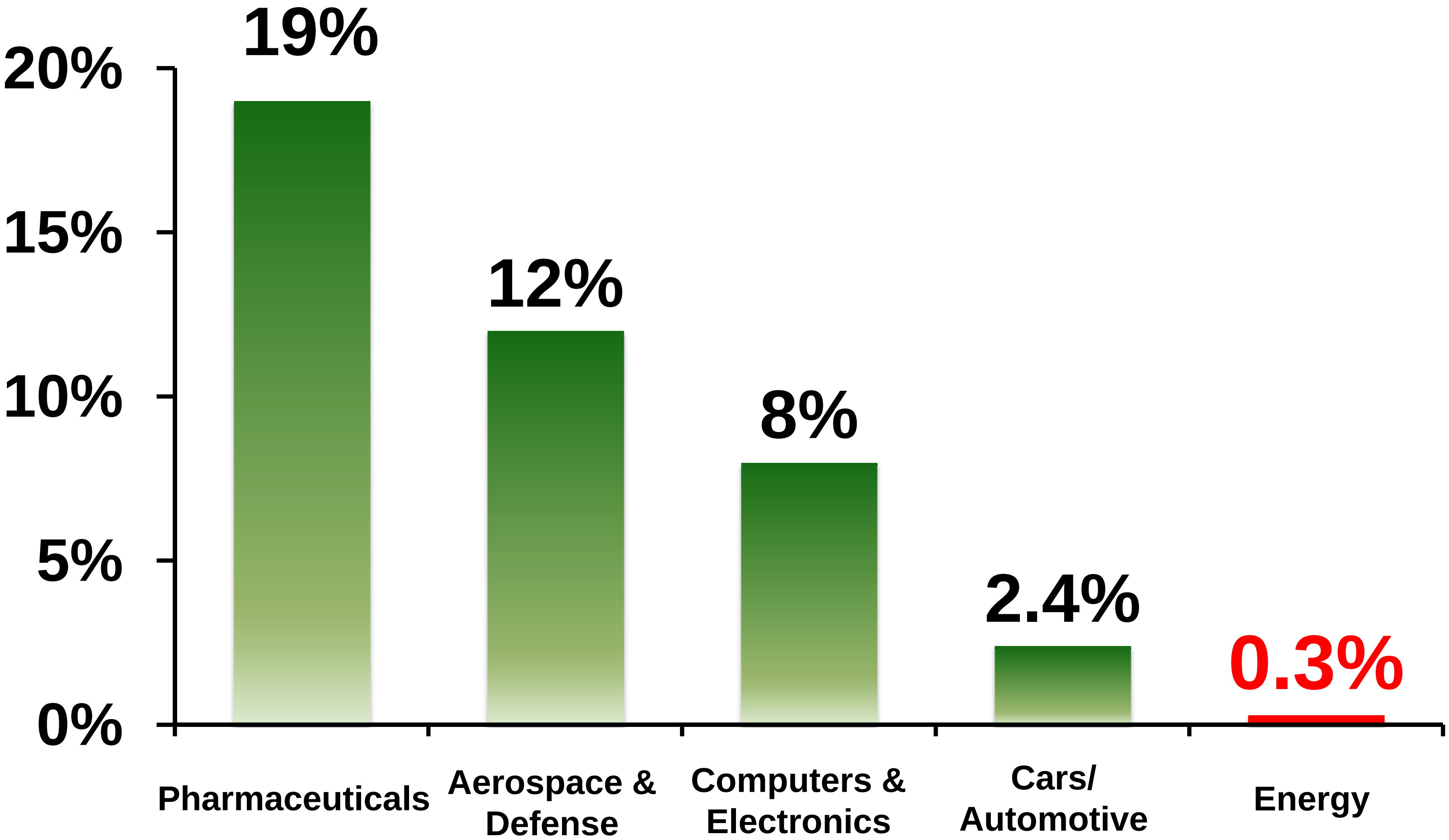
- High levels of variable RE generation challenges electric power system operations. These challenges appear manageable, but will require substantial technical & institutional changes to grid operations/planning practices. The required operational changes would be largely feasible only if substantial new transmission infrastructure is added.

- RE can reduce GHGs, water use, and fuel price risks; provides public health benefits. RE also presents challenges with respect to environmental and social impacts.

- Medium-to-high RE will require major changes in the generation and use of electricity; the technical and institutional aspects of power system operations; the planning, siting, permitting and financing of transmission; and society's understanding of the impacts of energy choices.

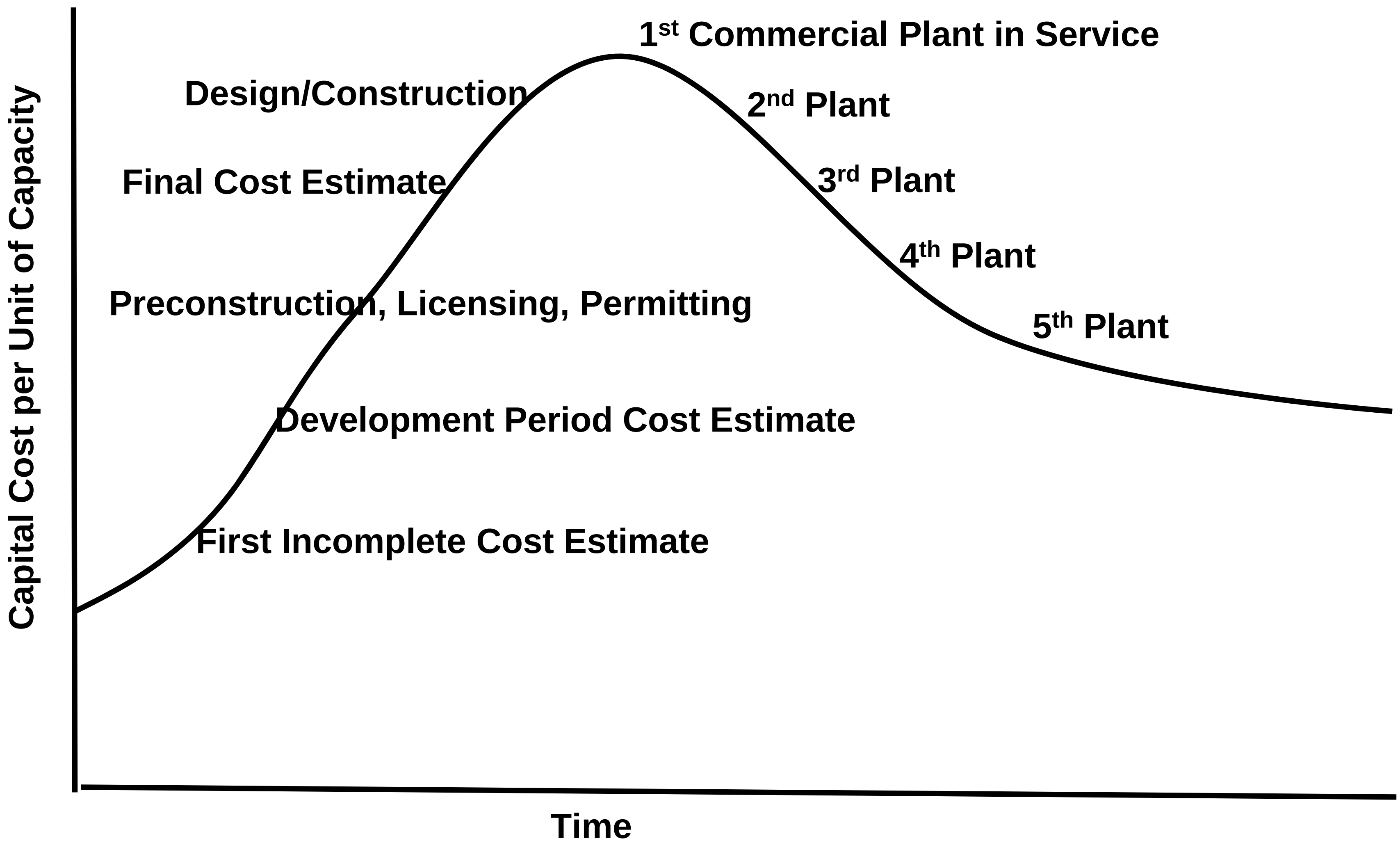
- Further Technology and Integration research, and real world validation is needed.

Percent Sales Invested in R&D



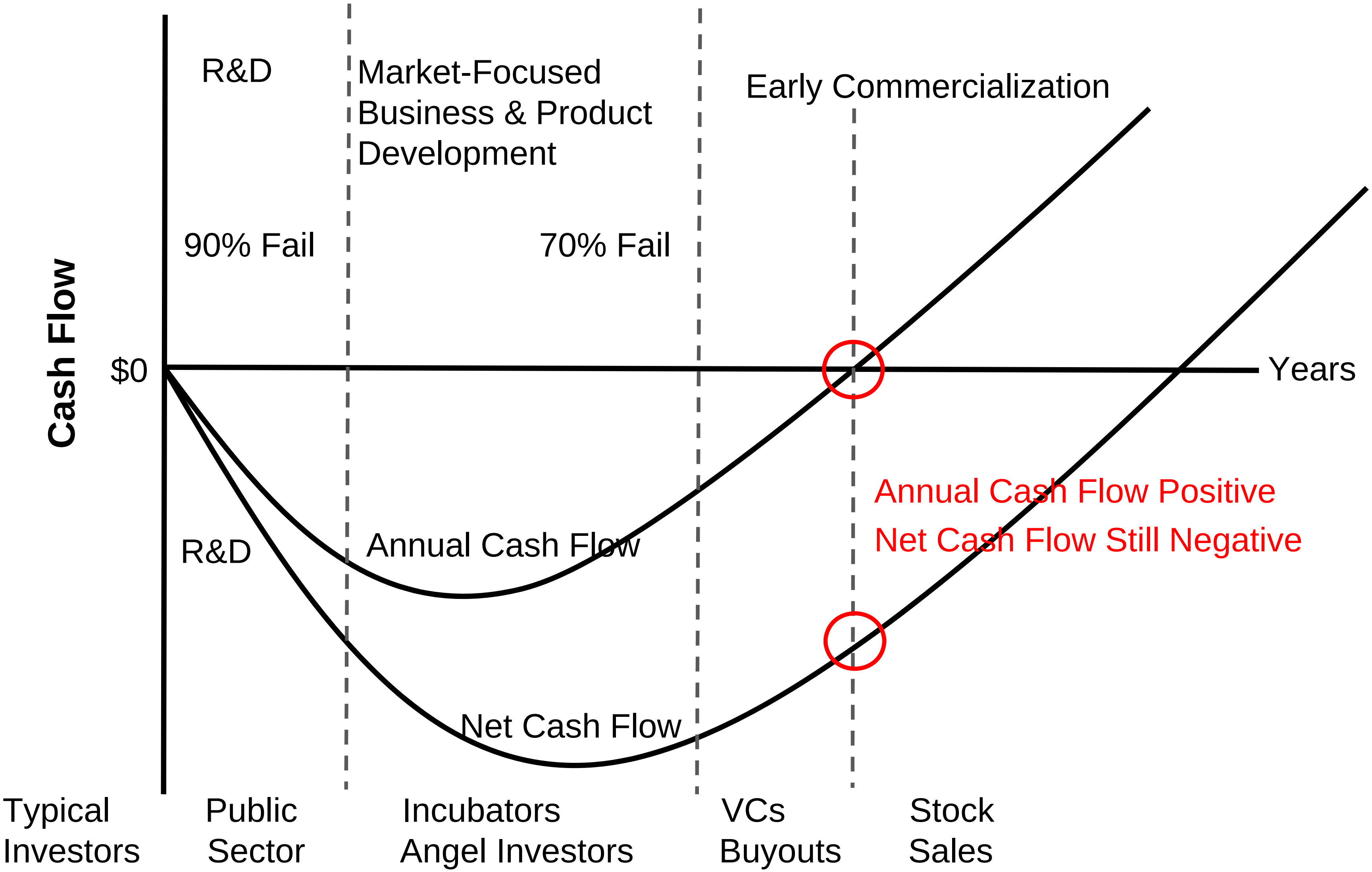
Source: American Energy Innovation Council, *Business Plan for America's Energy Future,* 2010

First of a Kind Plant



Source: Adapted from EPRI and PCAST 1997.

Valley of Death



Source: PCAST 97

Clean Energy Technology Innovation

	Research & Development	Demonstration / Proof of Concept	Deployment/ Pilot Facility	Diffusion/ Commercial-ization	Commercial Maturity
Barriers	**High Risk** **Long Time Horizons** **Appropriability r&d** **CommodityProduct** **No Externality Price**	**High Risk** **Long Time Horizons** **Appropriability** **Commodity Product** **No Externality Price** **High Capital Costs**	**Tech/Project Risk** **Time Horizon** **Commodity Product** **No Externality Price** **Higher Capital Cost** **Cost Uncertainty**	**Market Risk** **Transaction Costs** **CommodityProduct** **No Externality Price** **Lack Retail Finance** **Lack of Information**	**Time for Buydown** **MarketPenetration** **Transaction Costs** **Access to Finance**
Public / Non-Profit Funding Source	• DOE-funded R&D • State programs • University funds	•DOE-funded R&D • State programs • University funds • SBIR • Entrepreneur Supprt	•DOE demo programs (e.g., smart grid) • Technology Portal	• DOE Loan Programs	•Investment Tax Credits • Production Tax Credits
Private Funding Source	Angel / Series A venture capital	Series B venture capital	Series C & later	Limited VC or corporate equity for a few companies	• Corporate investor / public markets • Project finance

Recovery Act Tax Provisions on Clean Energy

Grants for Qualifying Energy Projects in Lieu of Tax Credits (1603)

- At a minimum, projects must have entered service during 2009 and 2010, or begun construction during 2009 or 2010 and been completed before the credit termination date
- Extension (through 2012 for wind, through 2013 for biomass, geothermal, small irrigation, landfill gas, trash combustion, and hydropower facilities)
- As of early-September, 2010 $5.2 billion in grants in lieu of the ITC or PTC have been awarded (administered by the U.S. Treasury with consultation and technical input by DOE)

Investment Tax Credit

- Extended 8 years for solar in 2008 legislation
- ITC credit in lieu of PTC credit – allows PTC to be converted into 30% ITC

48C Advanced Energy Manufacturing Tax Credit

- Grow U.S. domestic manufacturing of renewable & efficiency technologies
- $2.3 billion 30% tax credits of capital costs of manufacturing facilities

1703/1705 Loan Guarantees

- $26 billion in conditional commitments in Loan Guarantees across all DOE technologies with largest concentration in Nuclear and Solar

DOE 1703/1705 Loan Examples

Program	Technology	Loan Guarantee Amount	Jobs (permanant/ construction)	Date of agreement	Locations	Status
1703						
Red River Environmental Products, LLC	Energy Efficiency	$245 million	70/500	Dec 2009	Littleton, CO	Conditional Commitment
SAGE Electrochromics, Inc.	Energy Efficiency	$72 million	160/210	Mar 2010	Faribault, MN	Conditional Commitment
1705						
Abengoa Solar, Inc.	Solar Generation	$1.446 billion	60/1,600	July, 2010	Lakewood, CO	Closed
Abound Solar	Solar Manufacturing	$400 million	1,200/400	Dec 2010	Loveland, CO	Closed
AES Corporation	Battery Storage	$17 million	5/30	Aug 2010	Arlington, VA	Closed
Agua Caliente	Solar Generation	$967 million	10/400	Jan 2011	Tempe, AZ	Conditional Commitment
Beacon Power Corporation	Energy Storage	$43 million	40/20	Aug 2010	Tyngsboro, MA	Closed
BrightSource Energy, Inc.	Solar Generation	$1.6 billion	86/1,000	Apr 2011	Oakland, CA	Closed
Caithness Shepherds Flat	Wind Generation	$1.3 billion	35/400	Oct 2010	New York, NY	Closed

http://lpo.energy.gov/

$26 Billion

EERE R&D Activities

($Millions)

	FY06Ap	FY08Ap	FY09Ap	FY10Ap/CR	FY12Rq
• Efficiency					
– Buildings	$ 68.3	$ 107.4	$ 140.0	$ 200	$470
– Industry	$ 55.8	$ 63.2	$ 90.0	$ 96	$320
– Vehicles	$ 178.4	$ 208.4	$ 273.2	$ 311	$588
– Hydrogen	$ 153.5	$ 206.2	$ 168.9	$ 174	$100
• Renewables					
– Biomass	$ 89.7	$ 195.6	$ 217.0	$ 220	$340
– Wind/Water	$ 38.8	$ 49/9.6	$ 55/40	$80/50	$127/38
– Solar	$ 81.8	$ 166.3	$ 175.0	$ 225	$457
– Geothermal	$ 22.8	$ 19.3	$ 44.0	$ 44	$101
Total R&D	$ 689	$1025	$1203	$1400	$2541
Total EERE	$1162	$1704	$2178	$2242	$3200

0.1%

-$438

Energy Access

- **~3B people** in rural areas of developing countries with little energy access
- **Biomass Stoves**
  - Emissions kill ~1.6M/year, as well as cause cataracts, burns, low birth weight
  - Black Carbon and other emissions significantly contribute to climate change
  - Use of biomass can contribute to deforestation, reduce soil fertility
  - Collection of biomass can require several hours/day for a household
- **Response**: Clean, Efficient, Affordable, Widely-Used Biomass Stoves
  - Global Alliance for Clean Cookstoves; AID/DOE/EPA/HHS-NIH-CDC/DoState
  - Key R&D Pathways:
    - **Combustion and Heat Transfer:** emissions formation/control; air flow
    - **Controls, Sensors, Fan Drives:** Real-time data/monitoring/control
    - **Materials:** Special/local materials; Metals; Ceramics; Lifetime/Cost
- **Develop energy efficient and renewable energy powered economy**
  - Develop applications that generate income; catalyze economic development
    - Agriculture: Planting, Development, Harvesting, Preservation, Transport
    - Industry: Agricultural equipment production and repair; small industry
    - Energy: Produce energy for rural use and surplus energy for use in urban areas

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

http://www.eere.energy.gov

Sam.Baldwin@ee.doe.gov