# What Will It Take to Be Energy Independent?

**Advanced Energy Conference**

**New York, NY**

**November 9th, 2010**


**Thomas King, Director**

**Energy Efficiency & Electricity Technologies Program**


U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

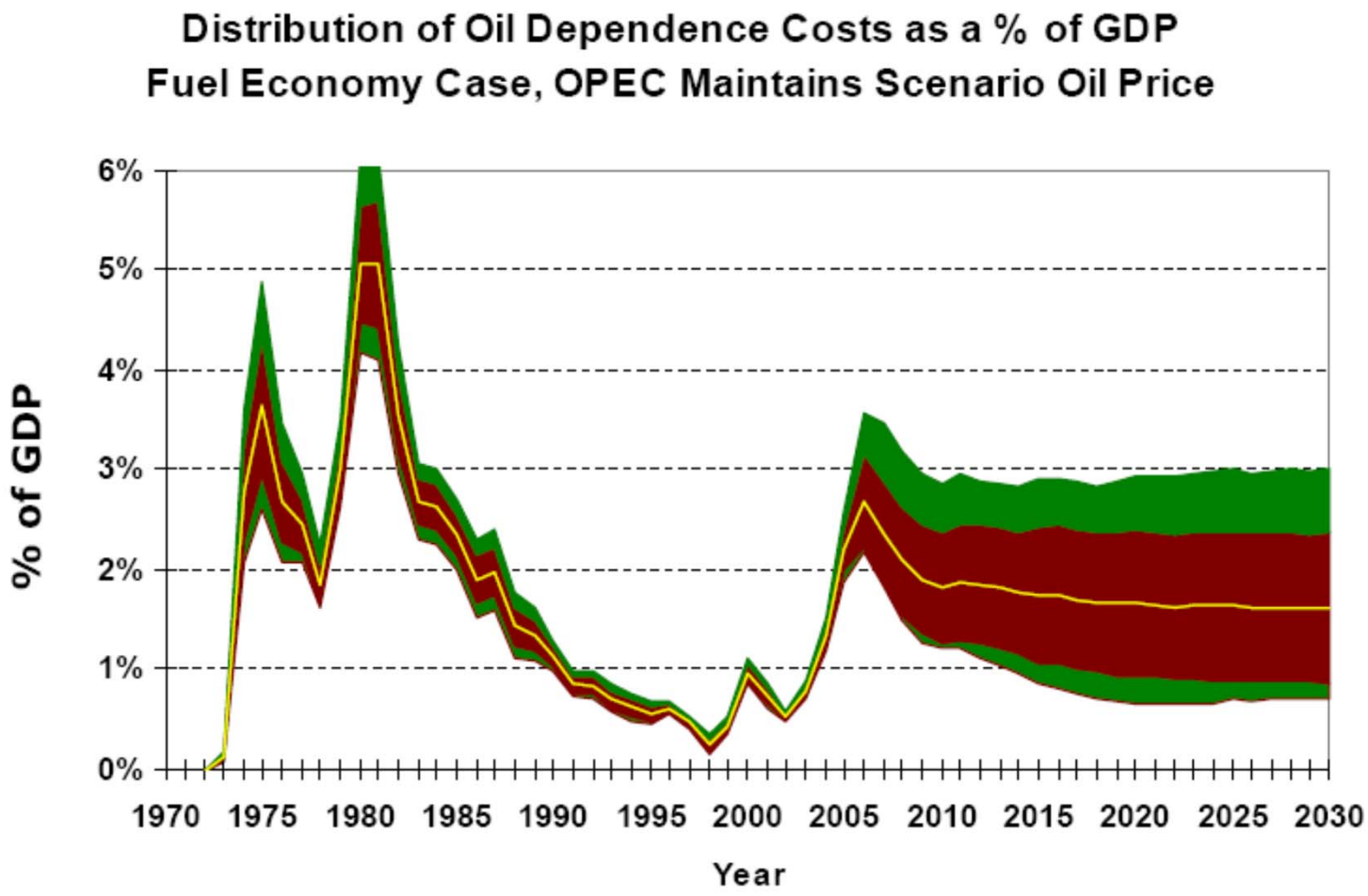
# Energy

- **The number one challenge facing humanity**
  - **Energy security**
  - **Climate impacts**
- **A principal driver for economic competitiveness and quality of life**

# What does it mean to be energy independent?

**"Not subject to control of others"**

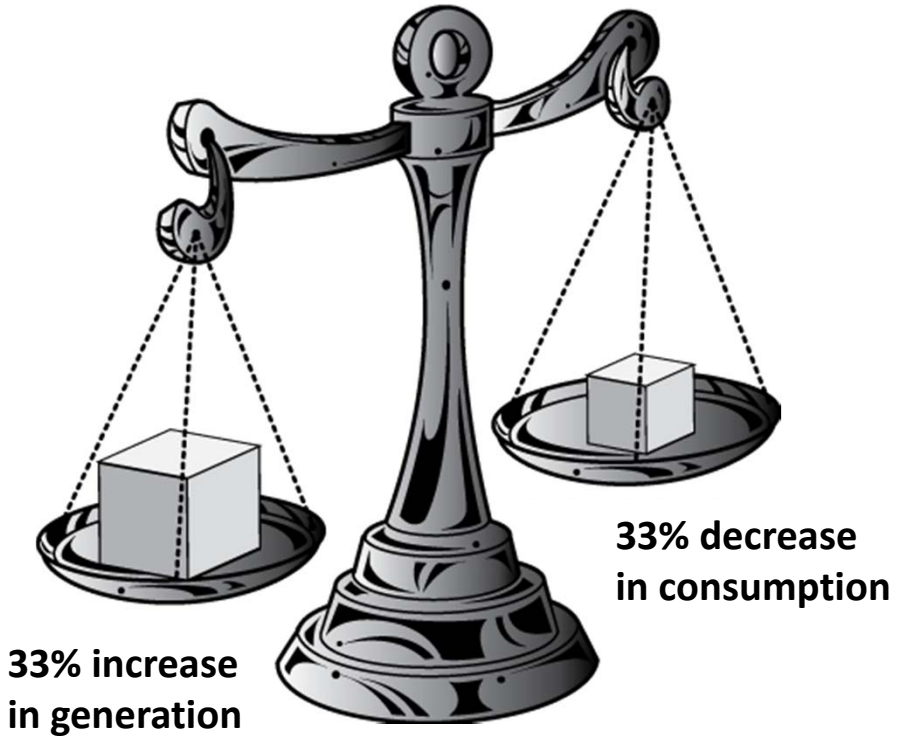
**- Websterian**




***D. Greene and P. Leiby, Oak Ridge National Lab***

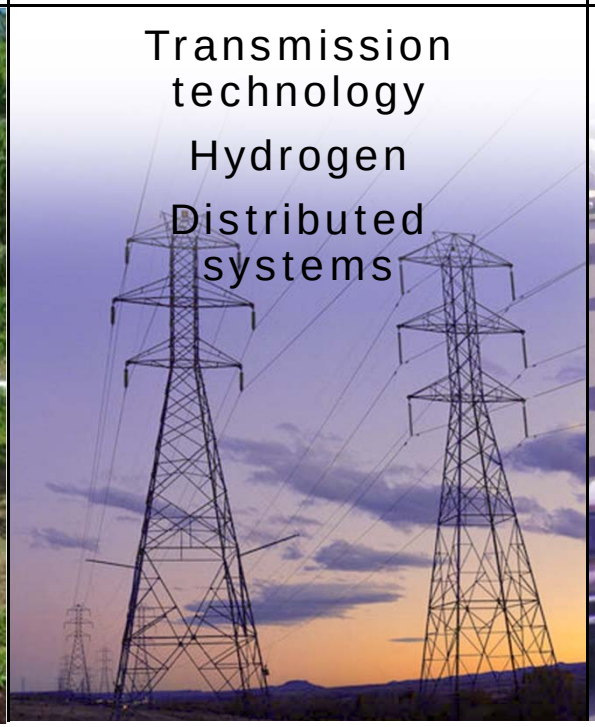
# The nation needs to reduce consumption while increasing domestic resources

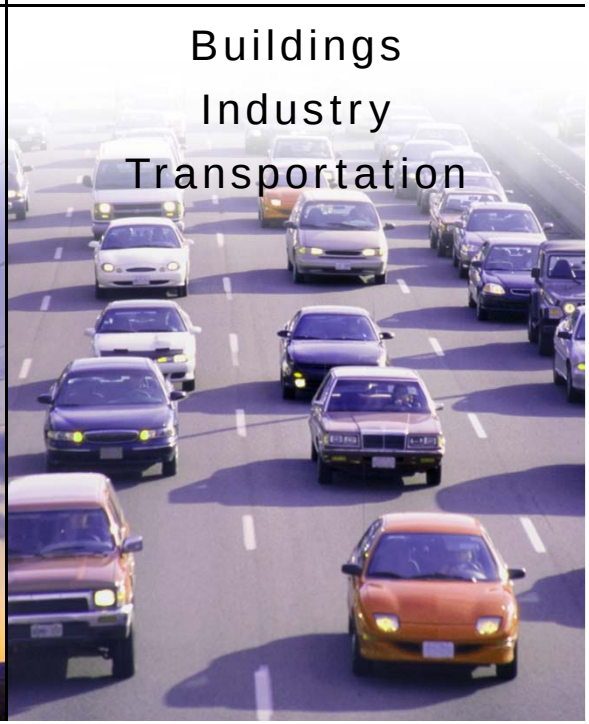
- **Factoring both energy security and environmental impacts:**
  - **There is no silver bullet**
- **Increase generation and domestic resources by 33%**
  - **Biofuels**
  - **Clean coal & low carbon technologies**
- **Decrease end-use consumption by 33%**
  - **Buildings**
  - **Vehicles**
  - **Industry**



# Innovation is key to address energy challenges across entire system

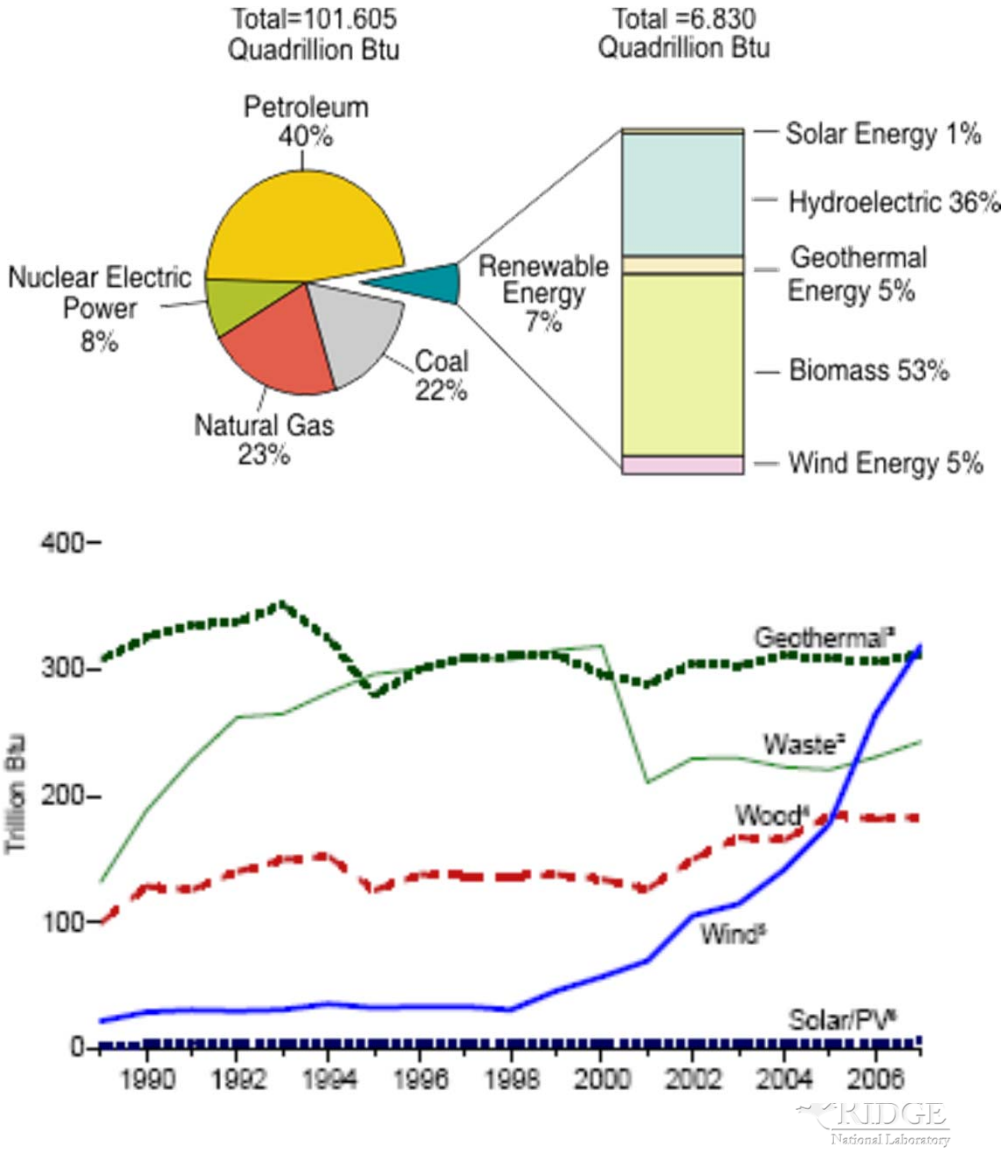
| Generation | Distribution | Consumption |
|---|---|---|
| Fossil<br>Nuclear<br>Renewables<br>Fusion | Transmission technology<br>Hydrogen<br>Distributed systems | Buildings<br>Industry<br>Transportation |



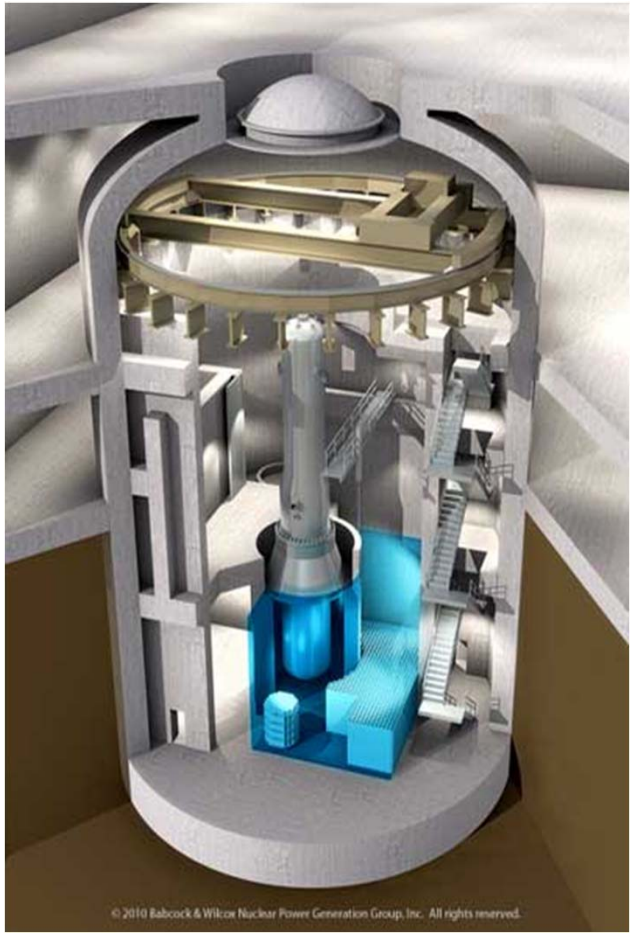


# Our generation portfolio is diverse with about 20% low carbon technologies

- **Electricity Generation:**
  - **Coal (33%), Natural Gas (28%), Diesel (14%), Nuclear (11%), Renewables (11%)**
- **Renewable energy sources:**
  - **Hydro (8.3%), wind (1.75%), geothermal (.25%), solar(.06%) biomass (.24%)**
- **Wind energy has been fastest growing renewable resource**
- **Solar photovoltaics not making an impact, today**



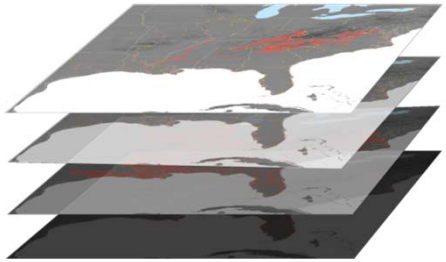
# Nuclear Power could be a key generation option to meet national energy goals – 300 GW required



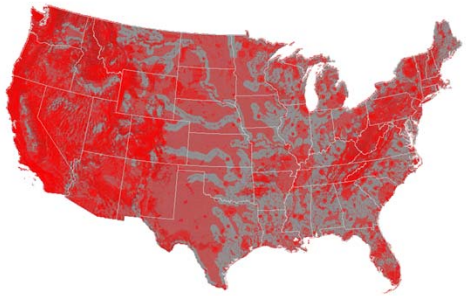

Courtesy Babcock and Wilcox

## ORNL Employing Geographical Information Systems To Identify Sites for both Large and Small Reactors

- ***Apply 10 Plant Perimeter Envelopes***
- ***Using 22 GIS Datasets***
- ***Scanning 1.8 B ac using grid size of 2.5 ac***



- ***Applies both exclusionary and avoidance criteria***
- ***More intense red, area excluded by multiple PPE***



- ***Analysis approach focuses on comparison of suitability criteria***
- ***Potentially support quantitative analyses comparing finite number of sites***

# The administration's New Energy for America plan focuses on renewables

- **Ensure 10 percent of our electricity comes from renewable sources by 2012, and 25 percent by 2025**
- **Implement an economy-wide cap-and-trade program to reduce greenhouse gas emissions 80 percent by 2050**

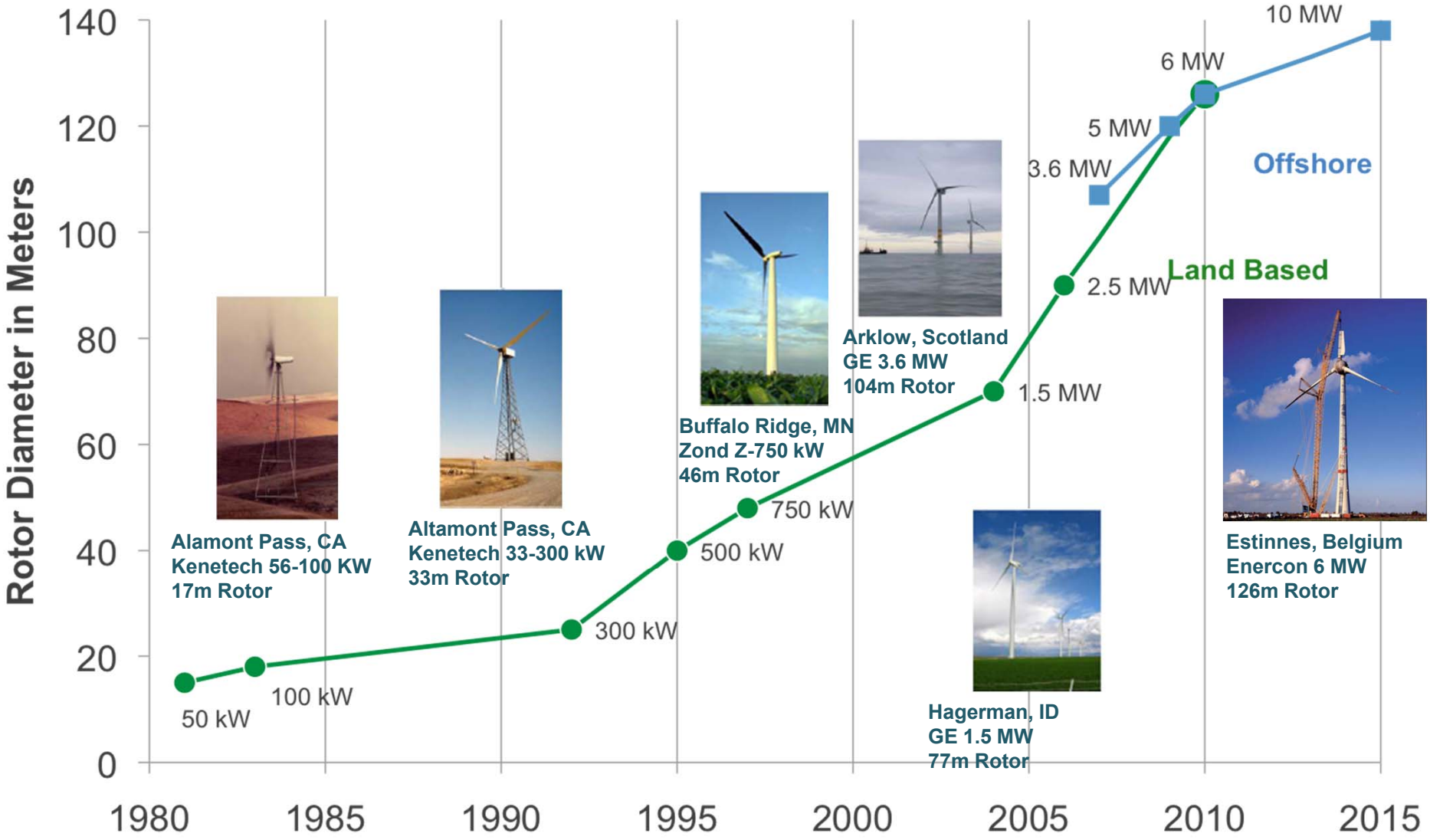

**"Double renewable deployment in three years"** **February 2009**

# There are many challenges for renewable energy technologies, but innovation will advance these systems

## Challenges for renewables:

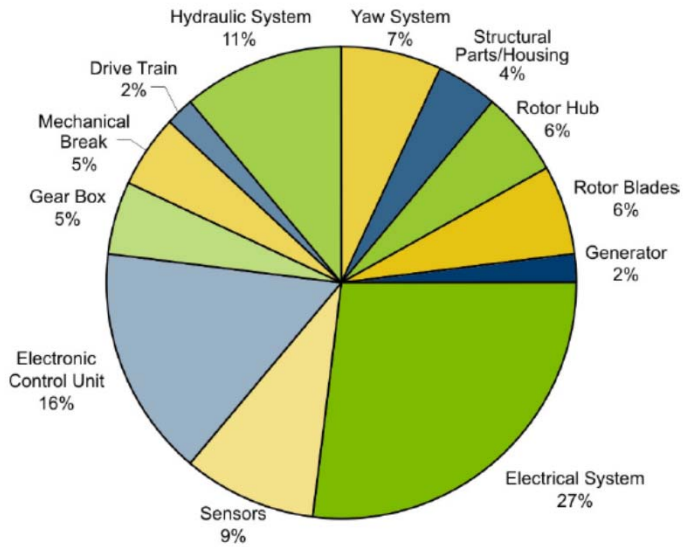
- Cost
- Intermittency & variability
- Performance & Reliability
- Grid Connection & Siting
- Education and Outreach
- Workforce Training

# Advancement in wind technologies have been significant



# Technology challenges continue to be addressed

Figure 2-17. Types of repairs on wind turbines from 2.5 kW to 1.5 MW




*Identified Technology Improvement Goals:*

- **Blades** – advanced materials, higher strength-to-weight, bend-twist coupling
- **Active controls** – pitch, generator torque, sensors to mitigate structural loads
- **Towers** – mitigating tower/load resonance
- **Drivetrain** – gearbox reliability
- **Power conversion** – higher-temp, higher-frequency, lower cost, better power quality
- **Grid response** technology for wind farms

➢Off shore wind has many advantages including alignment with load, wind potential.

➢weathering from wind and water, UV radiation, erosion and bending impact life of systems
➢coatings protect the fiberglass and epoxy of wind power blades. Coatings for carbon fiber blades also needed.
➢wind turbines are subjected to enormous stresses
➢weight reduction –superconducting generators, material selection

# Photovoltaic Near-Term Goals (Department of Energy)

Solar America Initiative

Grid Parity for Solar Energy by 2015

| Material System | Efficiency Goal (module) | Manufacturing Cost |
|---|---|---|
| Crystalline Si | 13-16% | $0.5 / W |
| Amorphous Si | 10-13% | $0.45 - $0.7 / W |
| CdTe Thin Film | 13% | $0.7 /W |
| CIGS Thin Film | 10-15% | ~$1 / W |

Longer Term: Cheap, Flexible PV, >30% Efficient

# National Grand Challenge: Develop Organic Photovoltaic Solar Cells

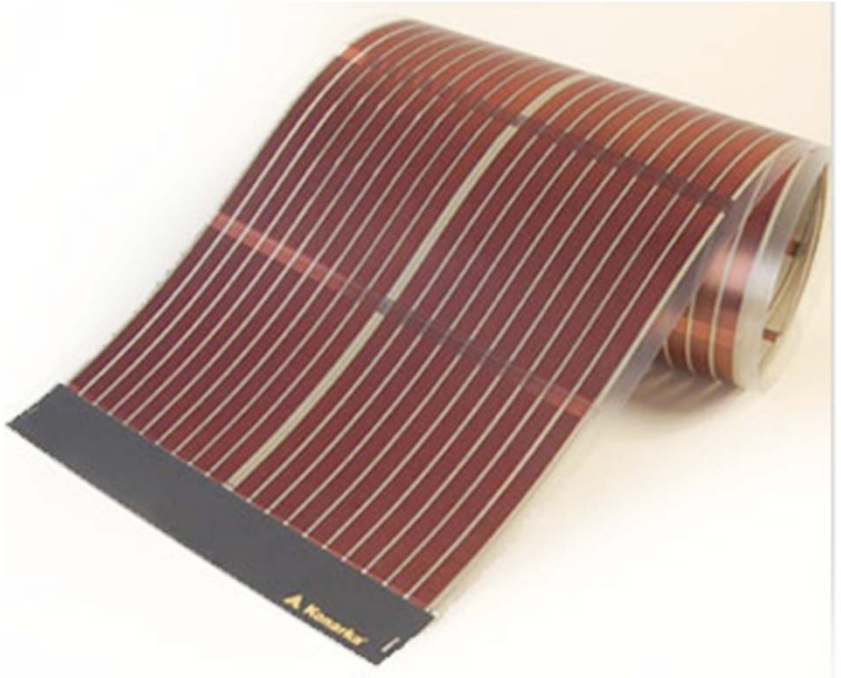
Efficiency = ~6% (1-2%) OPV
Efficiency = ~10% (~8%) DSSC

<u>Advantages</u>

- Highly Versatile (Flexible)
- Potentially Very Low Cost
- Simplified Fabrication
- Abundant Materials (C-based)

<u>Challenges</u>

- Lifetime Performance Degradation
- Low Mobility / Exciton Diffusion
- Exciton Device Physics New
- Integration of Organic with Inorganic
- Low IR Absorption of Dyes



<u>Current Research</u>

- Long-Term Reliability and Degradation Studies
- Fundamental Understanding (Excitons, Charge Transport, etc)
- Interfacial Adhesion and Electrical Conductance
- New Donor and Acceptor Materials
- Increased Carrier Mobility – Reduce Recombination

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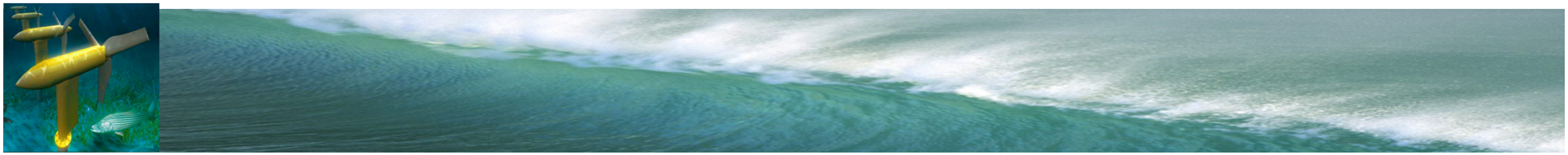
# Water Power (Marine and Hydrokinetic)

- **Extracting power from natural Ocean and River Currents, Tidal, Wave, and Thermal energy**
- **Assess the potential of extractable energy from water resources**
- **Facilitate development and deployment of renewable, environmentally-friendly, and cost-effective energy systems from domestic rivers, estuaries and coastal waters**
- **R&D needed for economic and environmental improvements to existing hydroelectric facilities and dams**



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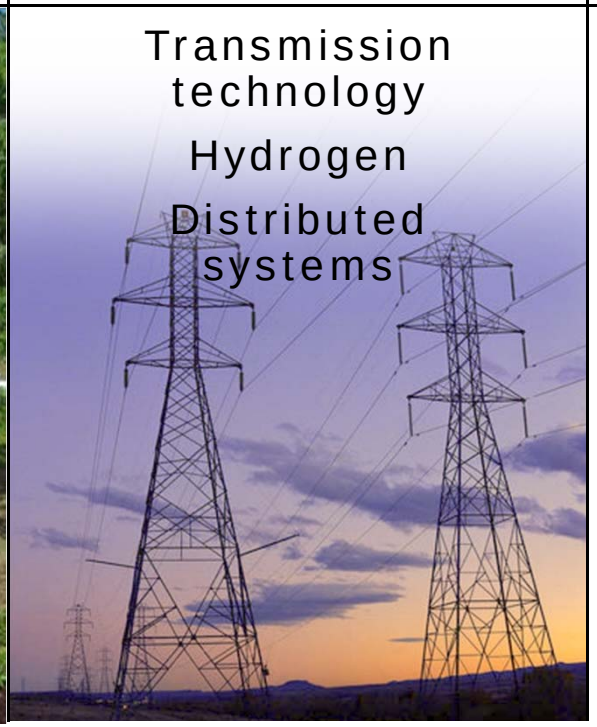
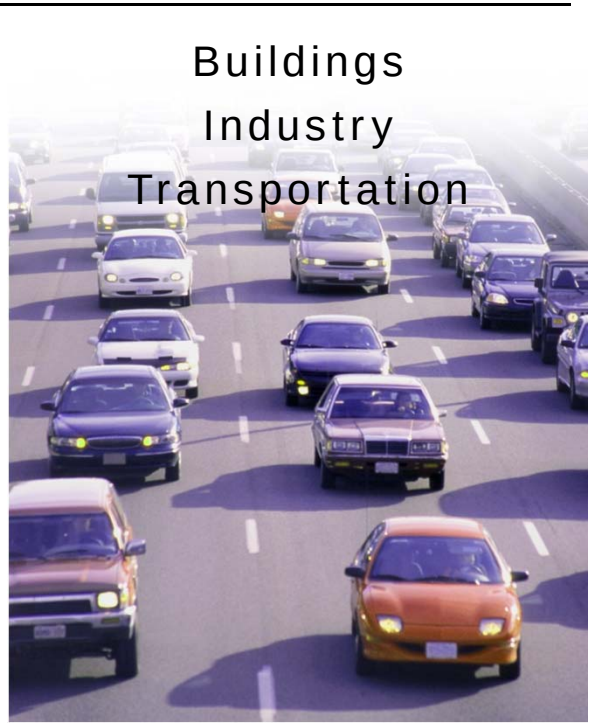
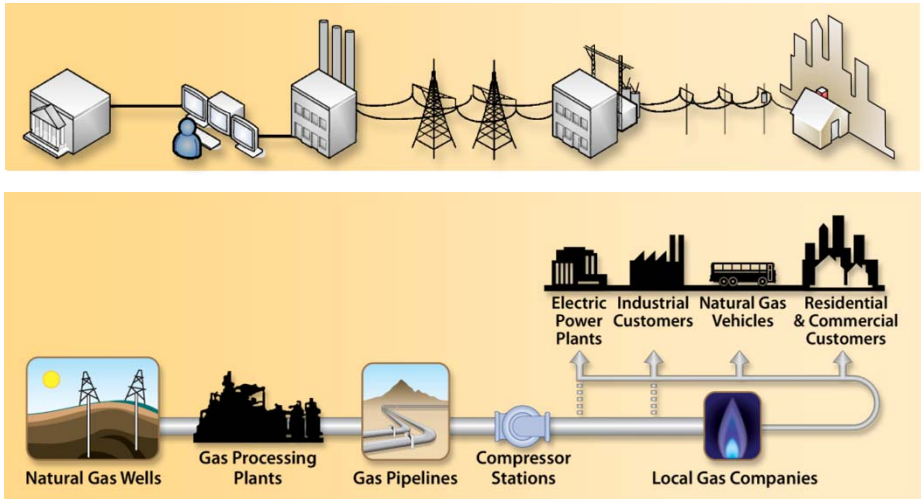


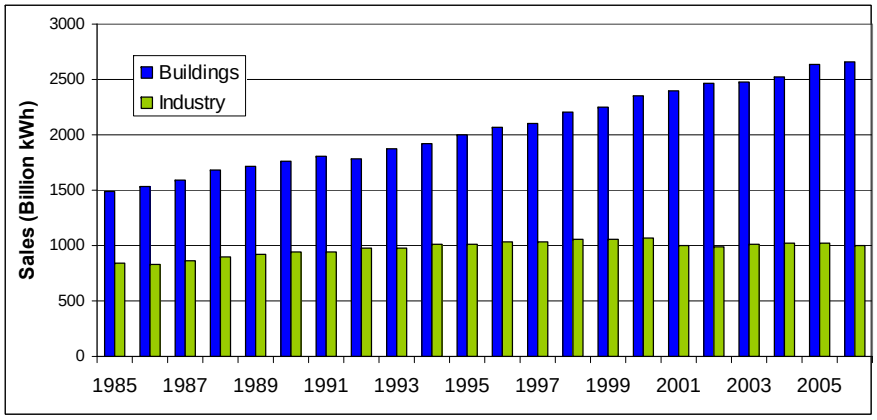


# Building energy use continues to grow

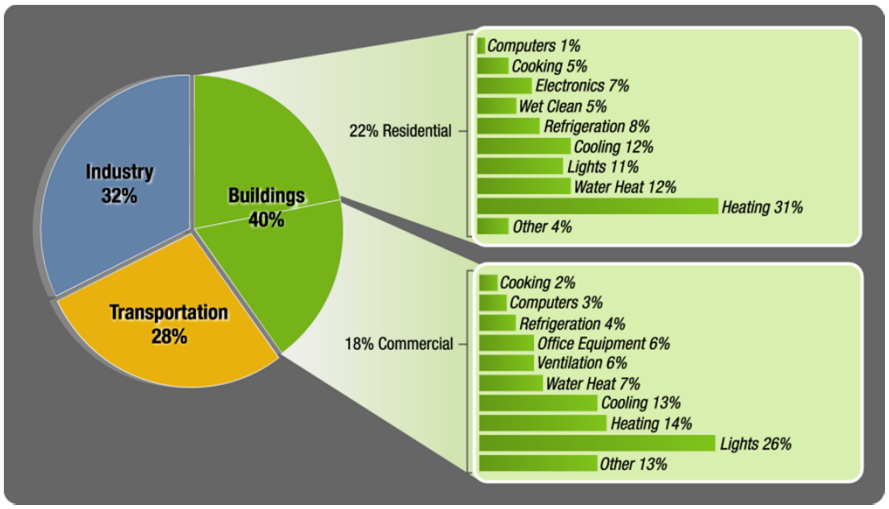



**Buildings Consume 72% of U.S. Electricity and 55% of U.S. Natural Gas**

**Buildings Drive Electricity Supply Investment**

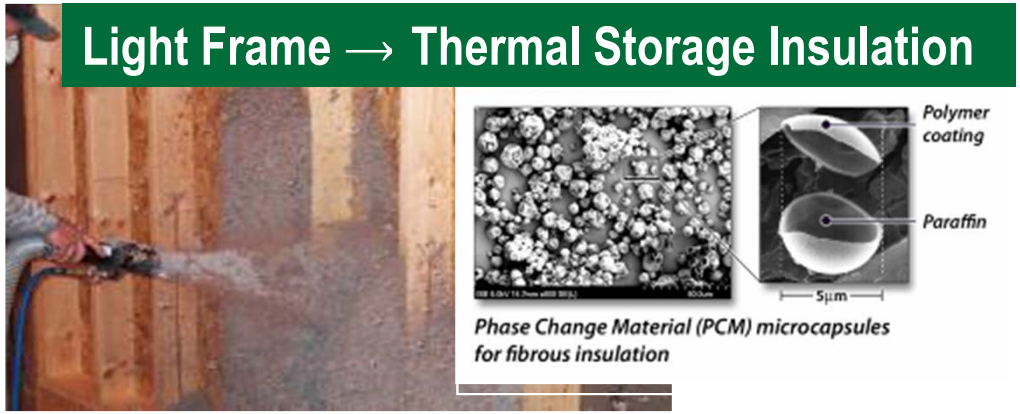



Source: EIA Annual Energy Review, Table 8.9, June 2007




**40% of U.S. Primary Energy Consumption**

# Recent building envelope technologies are reducing loads on buildings



# Efficient Appliances: Heat Pump Water Heaters are 50% More Efficient

- **Same hot water amenity while consuming less than half the energy of a conventional electric storage water heater**
- **Can provide dehumidification and cooling as a byproduct**
- **GE's new GeoSpring™ was introduced in November 2009**
- **Rheem and A.O. Smith have since introduced products**
- **DOE regulation will require all electric storage water heaters 55 gal and up to be HPWHs starting January 2016**
- **http://www.geappliances.com/**

**Accelerated Durability Testing**

# Highly efficient, integrated homes being developed

ZEBRAlliance™

*An Alliance Maximizing Cost-Effective Energy Efficiency in Buildings*



**www.ZEBRAlliance.org**

# Energy-efficient, low-emission vehicle technologies are being developed that will reduce oil consumption

**Low-cost, high-efficiency motors and inverters/ converters for electric hybrid vehicles**

**Lighter-weight structural materials and propulsion materials**

**Advanced combustion regimes with reduced emissions without fuel efficiency penalty**

Develop energy-efficient, low-emissions transportation technologies that enable America to use less petroleum

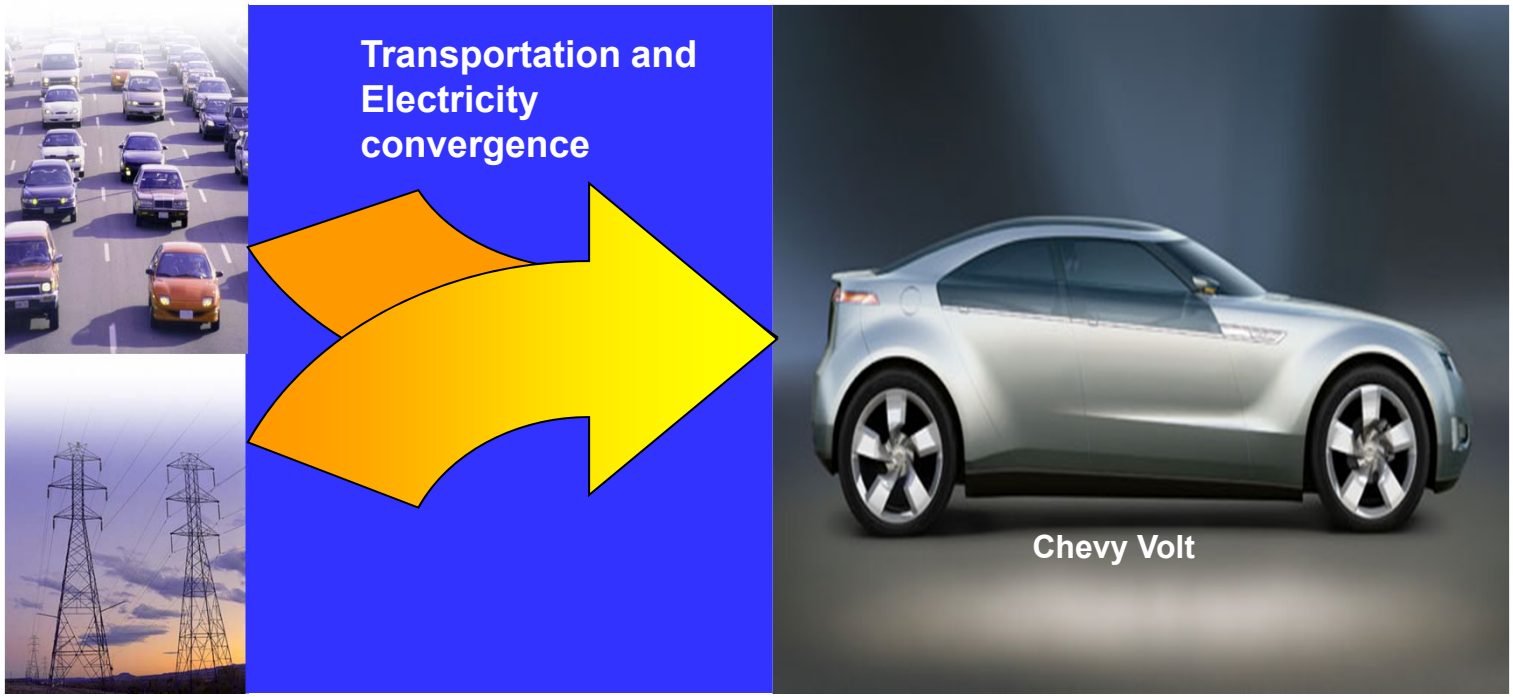
Carbon fiber is a leading candidate for mass reduction.

- 10% Mass Savings = 6-7% Fuel Savings
- Mass reduction allows earlier introduction of alternative propulsion systems.

Enable deployment of low-cost technology in high-volume applications

- Low-cost raw materials
- Low-cost fiber manufacturing processes
- High-rate, robust composites manufacturing processes

# Innovation is leading us towards a more-electric, more efficient transportation system…



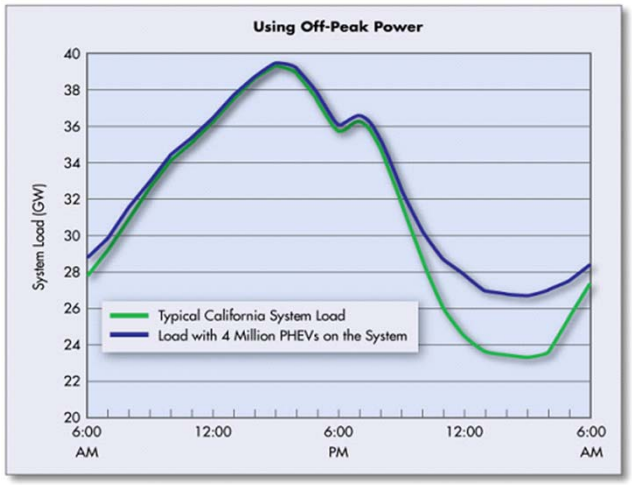

## …but there's a growing need for the utility and auto industry to collaborate

# Electrification of vehicles can reduce oil dependency

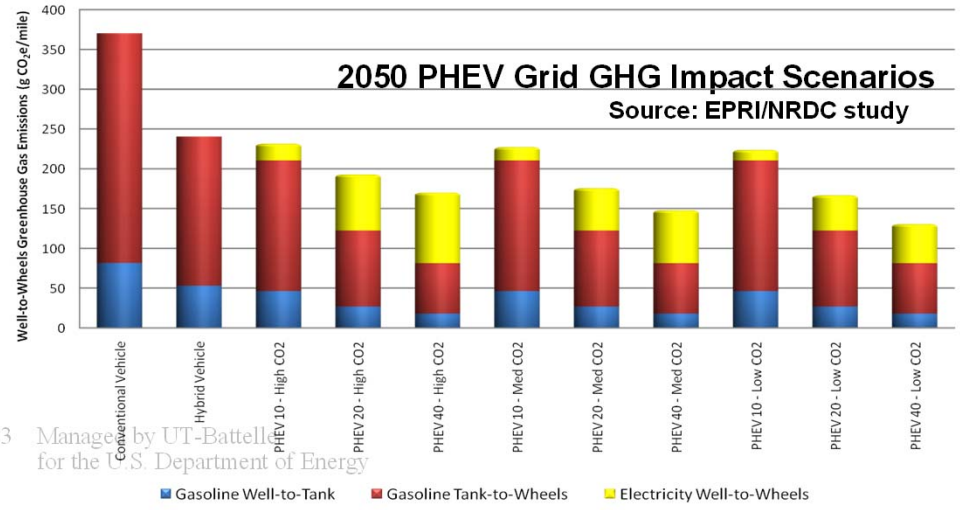
Courtesy of Southern California Edison

**1** **Electricity is 25-50% the cost of A gallon of gasoline equivalent (gge)**


**US grid has significant excess capacity (off-peak)** **2**

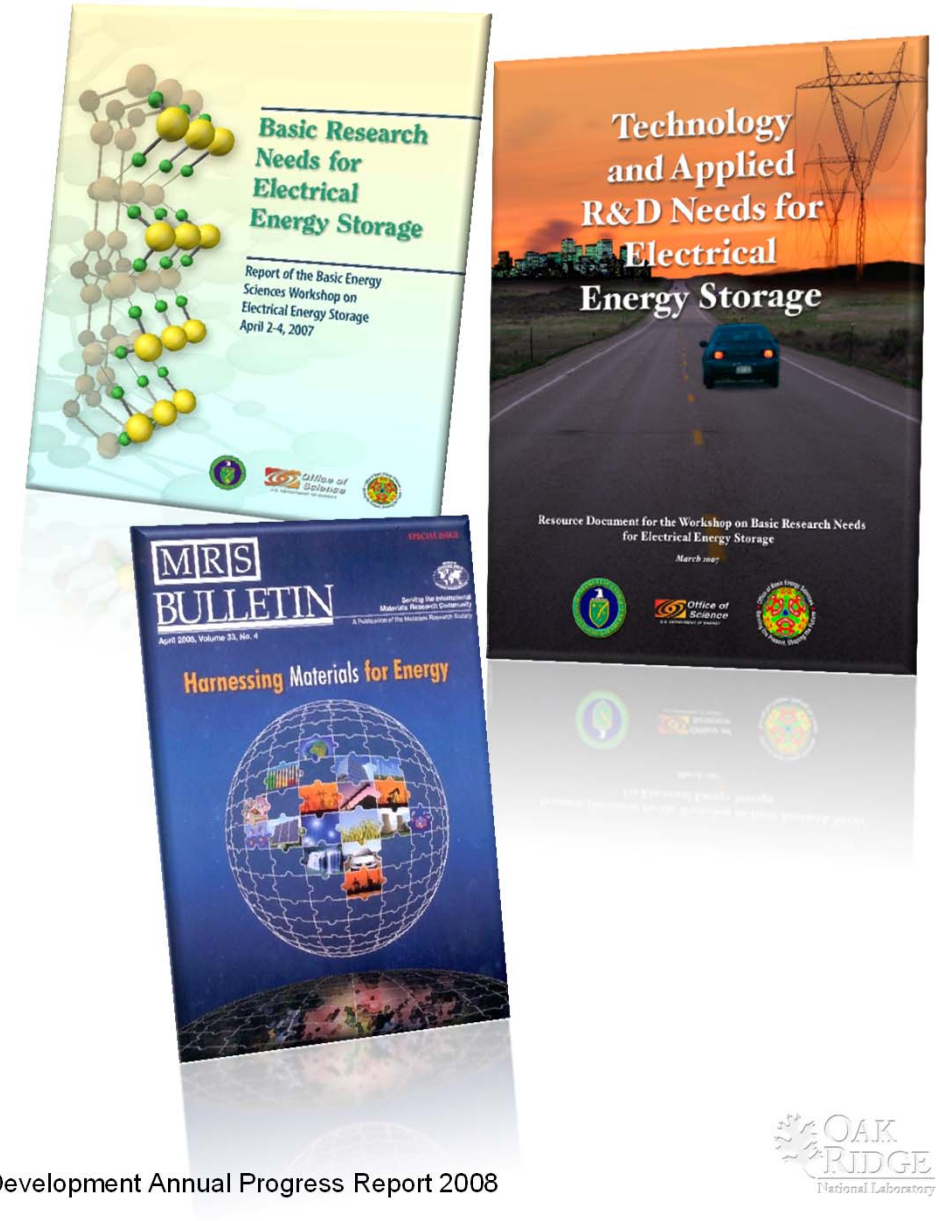



**3** **Vehicle GHG and emissions reduced**



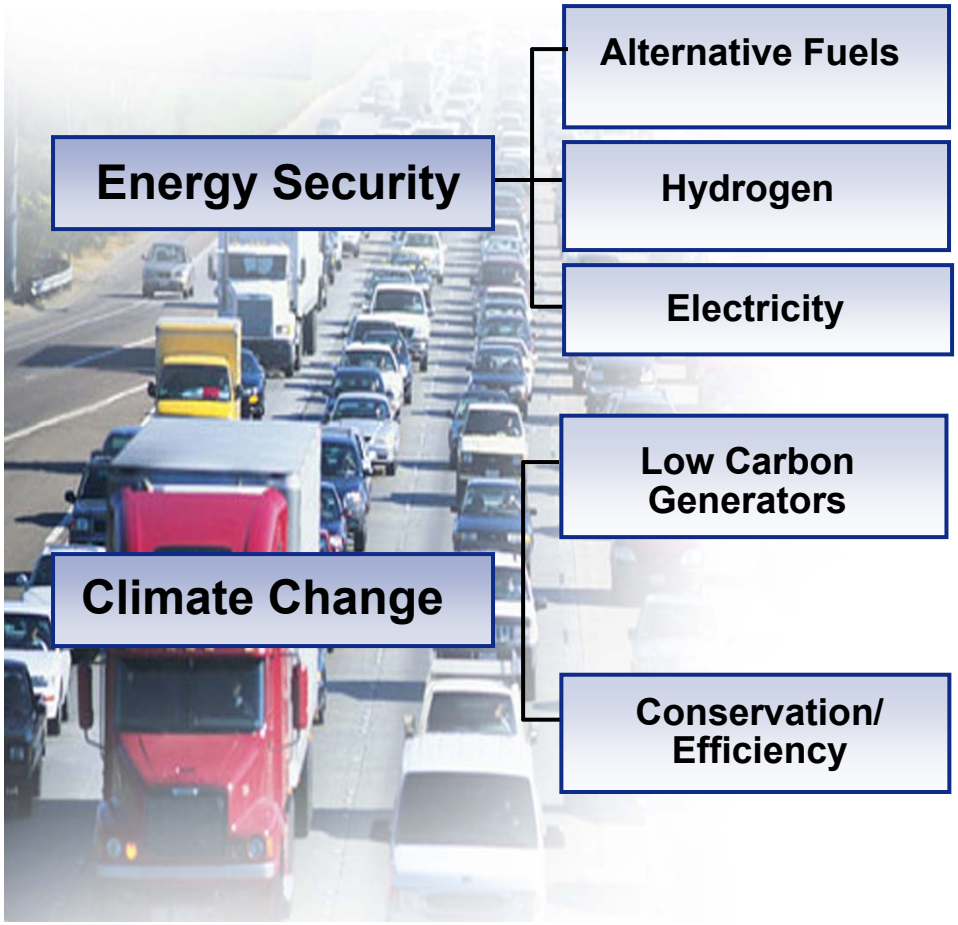

# Battery breakthroughs are needed

- **Cost**
  - raw materials
  - materials processing
  - cell and module packaging
  - manufacturing
- **Performance**
  - discharge pulse power limitations at low temperatures
  - capacity and power fading
  - power and energy densities
- **Abuse Tolerance / Safety**
  - short circuits
  - overcharge, over-discharge
  - fire or high temperatures
  - thermal runaway
- **Life**
  - calendar life



# The electric grid will help enable the country to achieve its energy goals

| Energy Challenge | Energy Pathway |
|---|---|
| Energy Security | Alternative Fuels |
| | Hydrogen |
| | Electricity |
| Climate Change | Low Carbon Generators |
| | Conservation/ Efficiency |

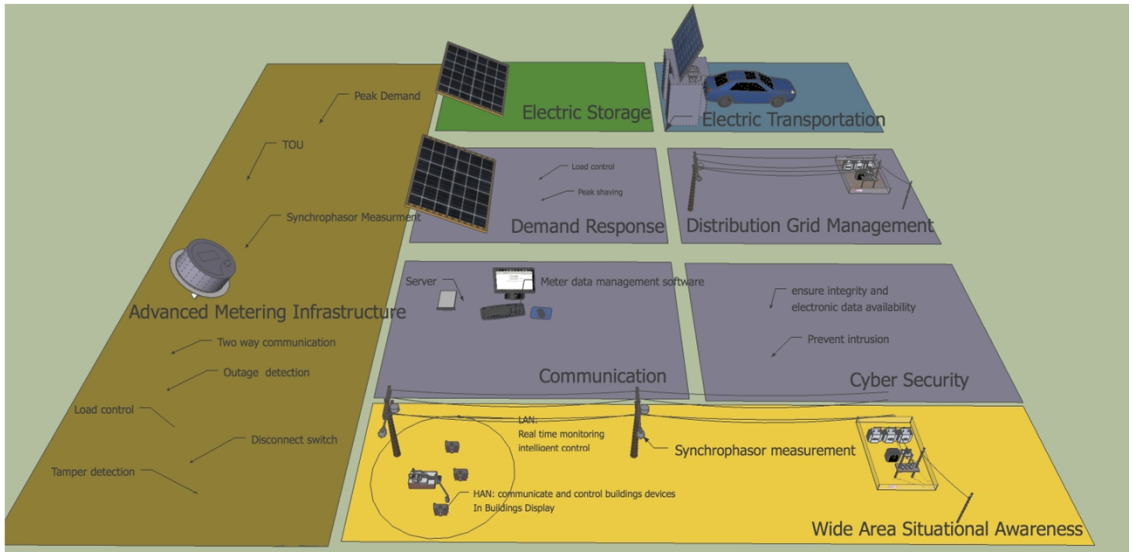


*Both pathways will place additional burden on an already stressed electric grid*

"Electricity, not oil, is the heart of the U.S. energy economy."
Peter Huber, The Million-Volt Answer to Oil

# Smart grid is a catch-all definition, but comes down to seeing and controlling

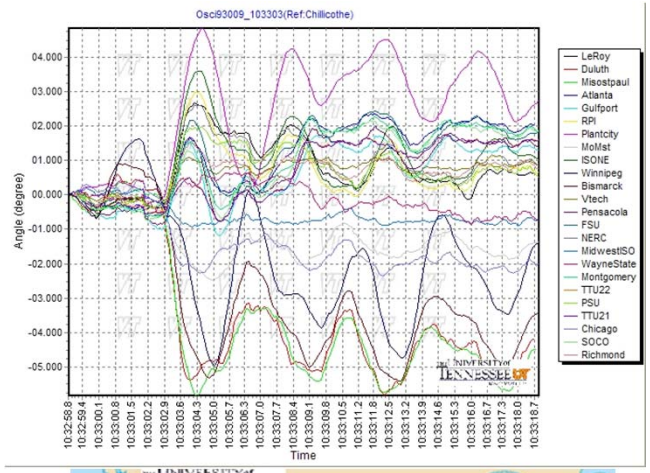
- **Smart Grid definition varies on stakeholder**
- **Two key elements**
  - **Wide area visibility**
  - **Controllability**
- **Telecommunications & Grid Security are foundational elements to the smart grid**

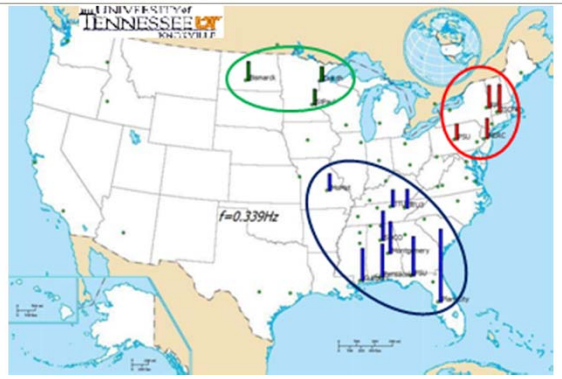


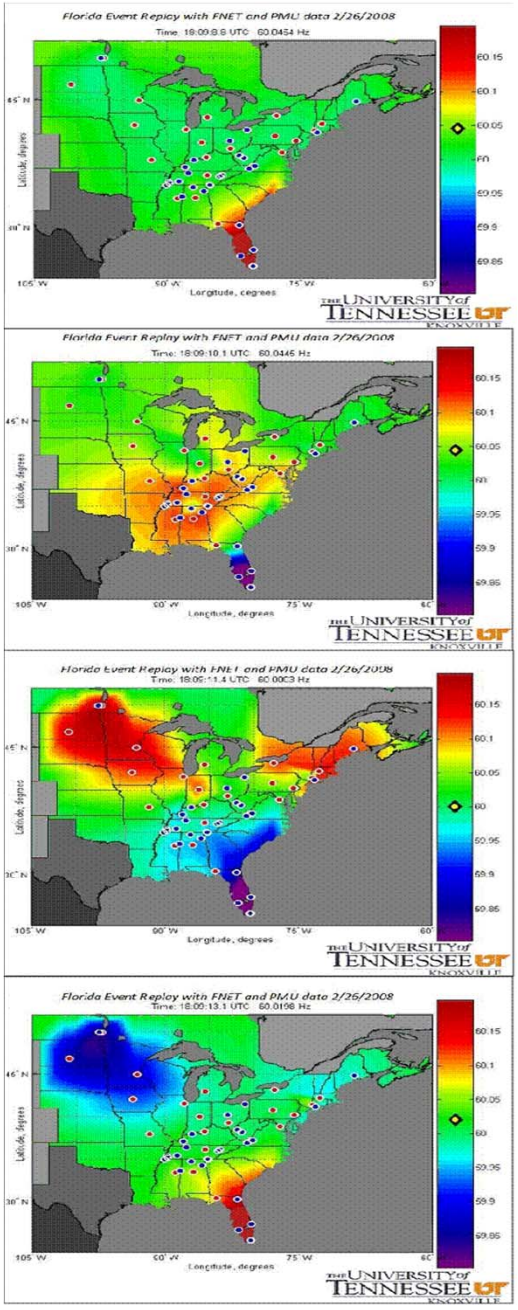

Use of digital technology to improve reliability, security, and efficiency of the electric system with applications for dynamic optimization of system operations, maintenance, and planning

# GridEye: Real-time Monitoring of Grid Health

- **Frequency monitors to collect real-time data**
- **Low cost monitors compared to phasor measurement units**
- **Real-time display of frequency swings**
- **Provide input for dynamic modeling**

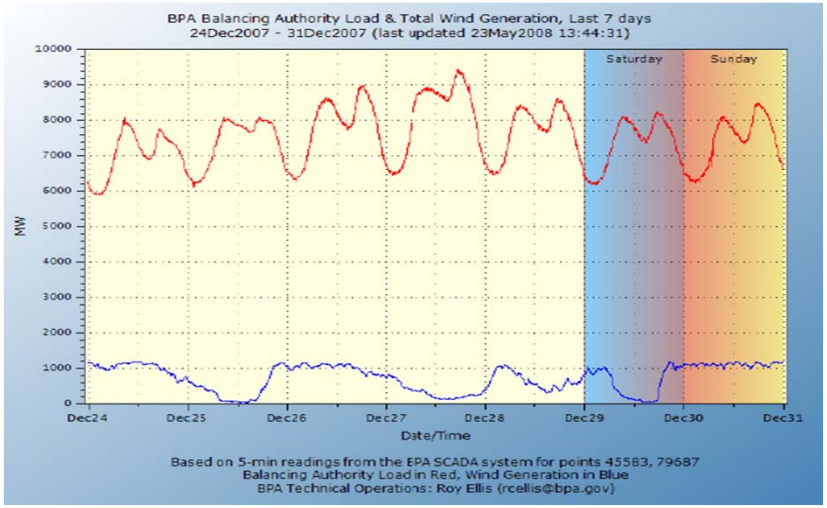


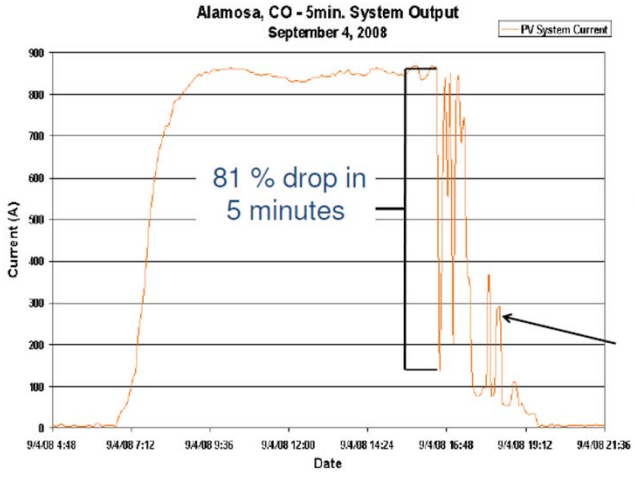



# A systems approach will help with the integration of variable generation

- **A "smarter grid" can help address variable generation: systems approach**
- **Loads can help respond to system disturbances, sometimes faster than generators**
- **Responsive load is just beginning to provide regulation – the minute to minute energy balancing of the system.**
- **Communication system needed**
- **Energy storage and power electronics will be key technologies for the future**


*Secretary Chu, GridWeek 2009*




Output from an 8MW solar PV panel in Colorado on 9/4/08

**High variability due to clouds**

# Regulation from Industrial Loads are being demonstrated today

## Problem Statement

- Generation reserves held back to compensate for minute-to-minute load fluctuations
- Energy & economic inefficiencies are significant (0.4 quads & $4Billion)
- Arc furnace loads will place additional burden on the TVA region
- Additionally the nation is losing aluminum manufacturing capability
    - Energy is ~30% costs of Al production
    - 43% of capacity shut down in 2001, in part, due to high energy prices

**Benefits to Al Industry**

- Plants, such as Alcoa's Massena facility, could earn $14M/yr if 10% of load is used for regulation

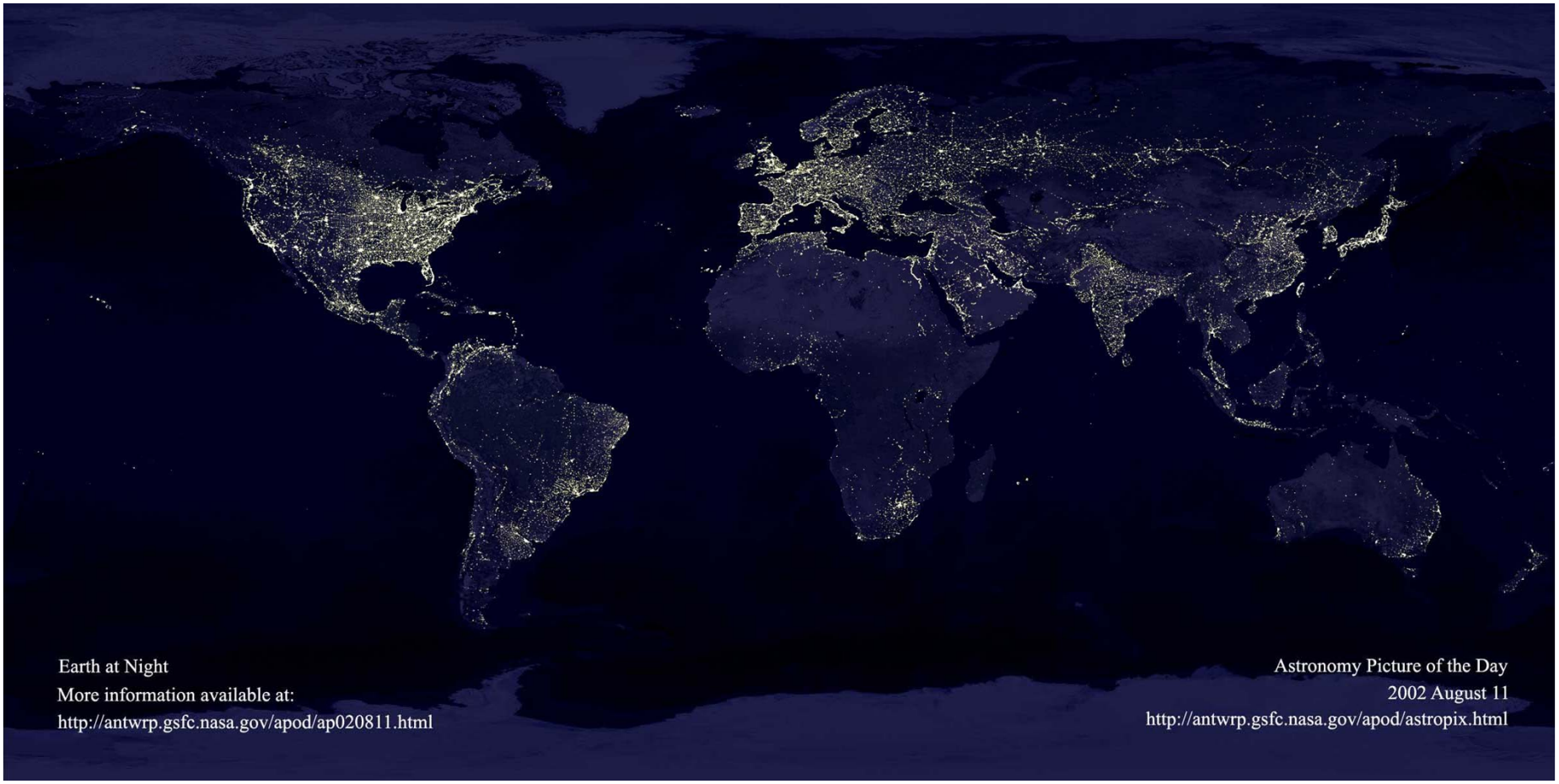
## Problem Solution

- Large loads have the ability to help balance generation and loads (regulation)
- Electrolytic processes, such as aluminum, provide over 14,000 MW of regulation
- Regulation is the most expensive ancillary service by 5-8x spinning reserve
- This could benefit aluminum industry and grid security in near term:
    - Maintain smelting operations & jobs in the U.S.

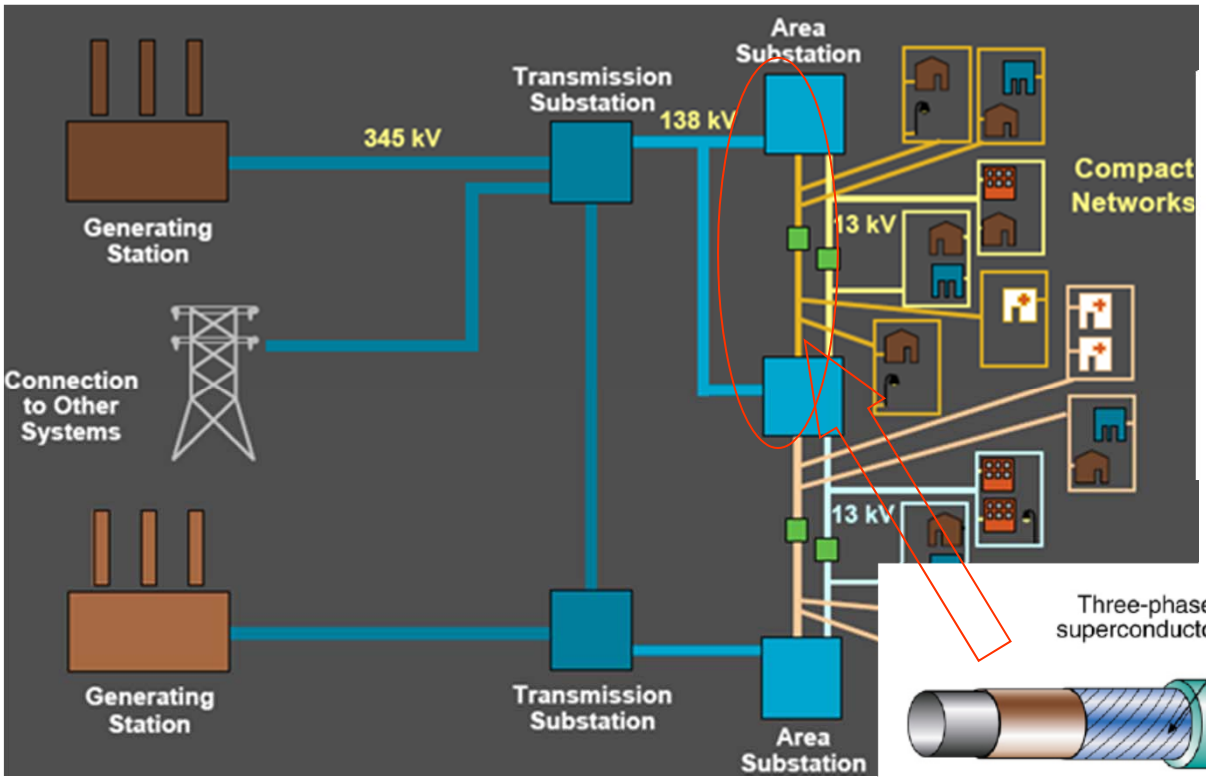
# Power Electronics will play a key role in the future grid

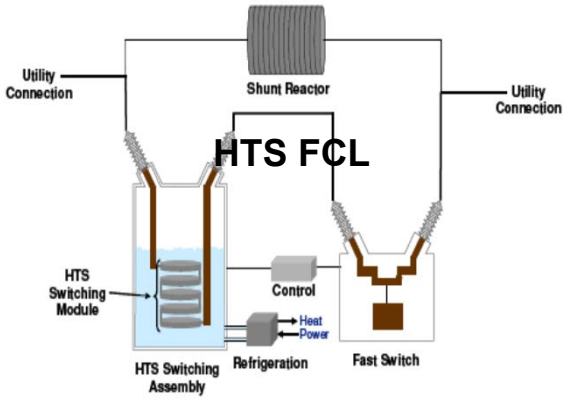
- **Power electronics provide the interface of generation to the grid**
- **Provides power conversion needed to integrate new technologies**
- **Use the inverter to regulate local voltage**
- **The inverter can supply or absorb reactive power rapidly using ORNL algorithms**
- **The inverter would be slightly oversized and the software modified to perform voltage control**

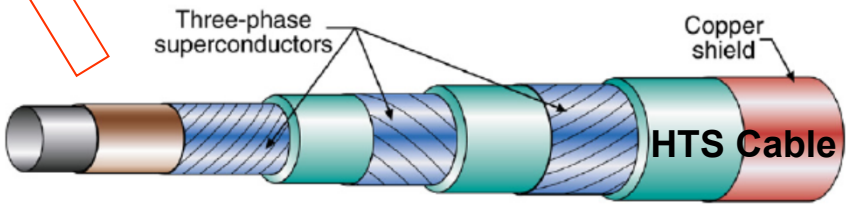
# Innovation can help keep the lights on



# A resilient electric grid can be achieved




- HTS Cable links substations which allows sharing of excess capacity in emergencies
  - w/o HTS, not enough real estate in urban areas – copper is just too big
- HTS FCL allows the two substations to be continuously connected under normal and contingency conditions and to limit current flow between substations during fault conditions
  - w/o FCL, linking the substations could generate dangerous short circuit “fault currents”
  - w/o HTS FCL, there would be excessive resistive and inductive losses on the line



Homeland Security

OAK RIDGE National Laboratory

# Summary

- **Future holds many challenges**
  - **Energy independence requires multi-faceted solution**
- **Innovation is paramount to meeting the energy needs**
  - **Renewable Energy**
  - **Electrification of transportation system**
  - **Energy storage**
  - **Zero-energy buildings**
- **The Electric Grid is a key enabling system to meet the energy goals**
- **Sustained effort is needed to stay ahead**

# Thank you!

**Tom King**

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*www.ornl.gov/sci/eere*

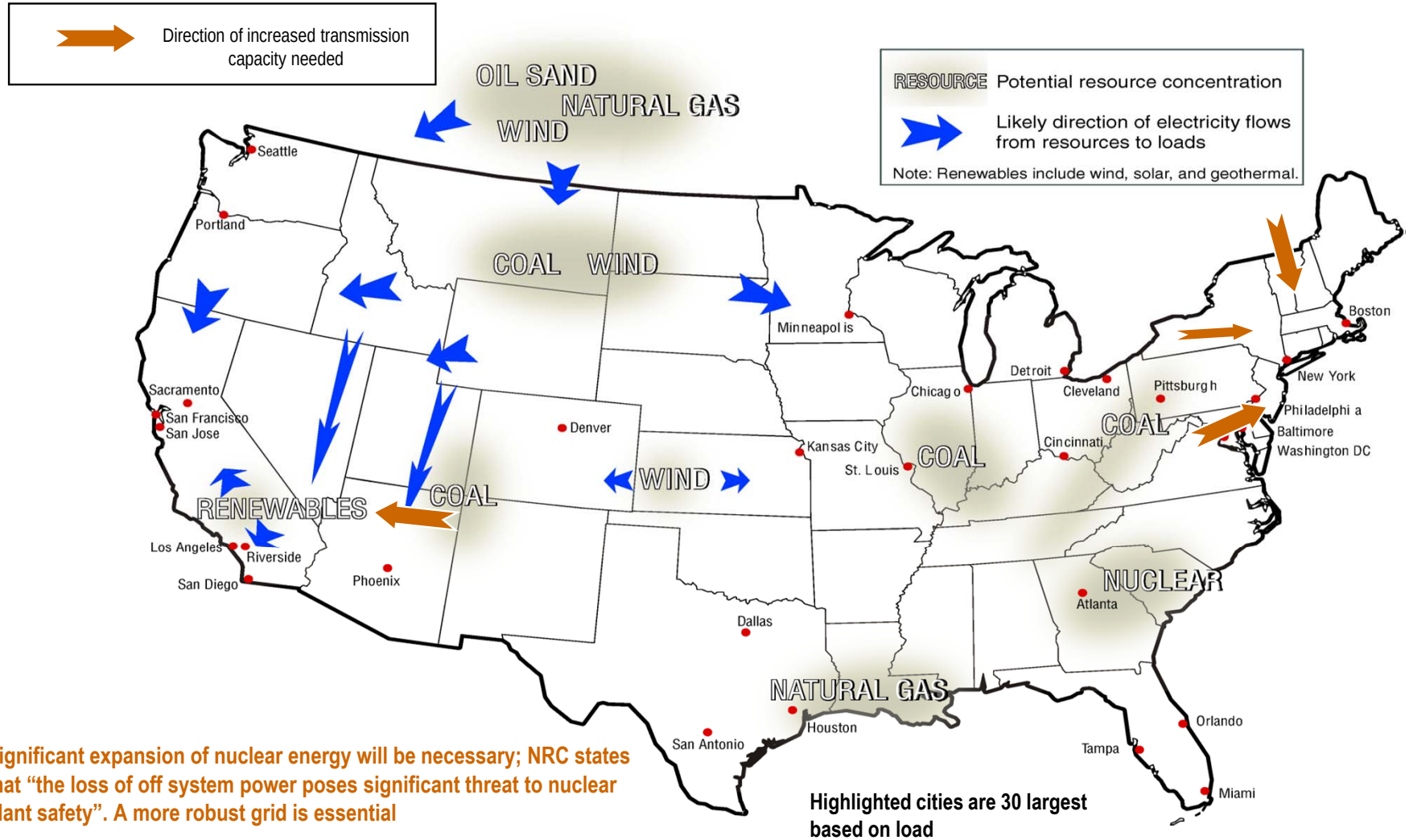
# Variability of renewables can be problematic on the grid

- **Wind farms 20-40%**
- **Photovoltaic solar in Massachusetts 12-15%**
- **Photovoltaic solar in Arizona 19%**
- **Hydroelectricity, worldwide average 44%, range of 20% - 75% depending on water availability**

| Generators | Capacity Factor |
|---|---|
| Nuclear | 91% |
| Coal | 72% |
| Natural Gas/CC | 41% |
| Renewables | 37% |
| Other | 10% |
| Petroleum | 9% |

**Source:** U.S. Energy Information Administration, Form EIA-860, “Annual Electric Generator Report;” Form EIA-923, "Power Plant Operations Report.”

# Strategic resources are not always aligned with location of loads – more lines needed



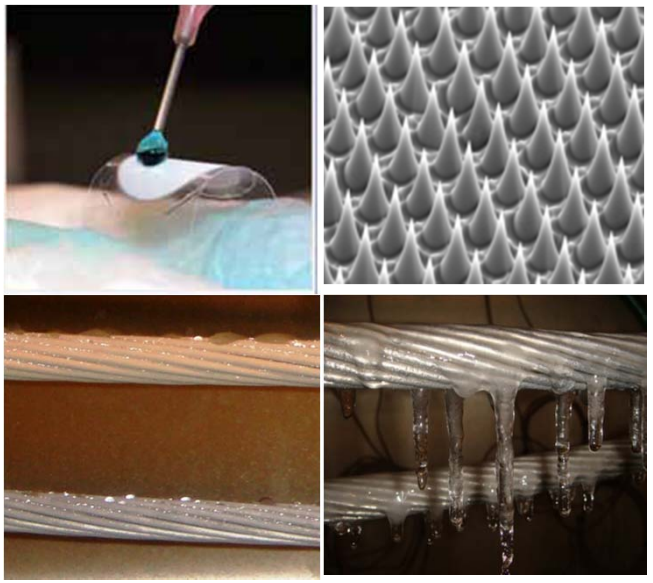

**Significant expansion of nuclear energy will be necessary; NRC states that "the loss of off system power poses significant threat to nuclear plant safety". A more robust grid is essential**

**Highlighted cities are 30 largest based on load**

# Innovative materials can improve reliability to the Electric Delivery System

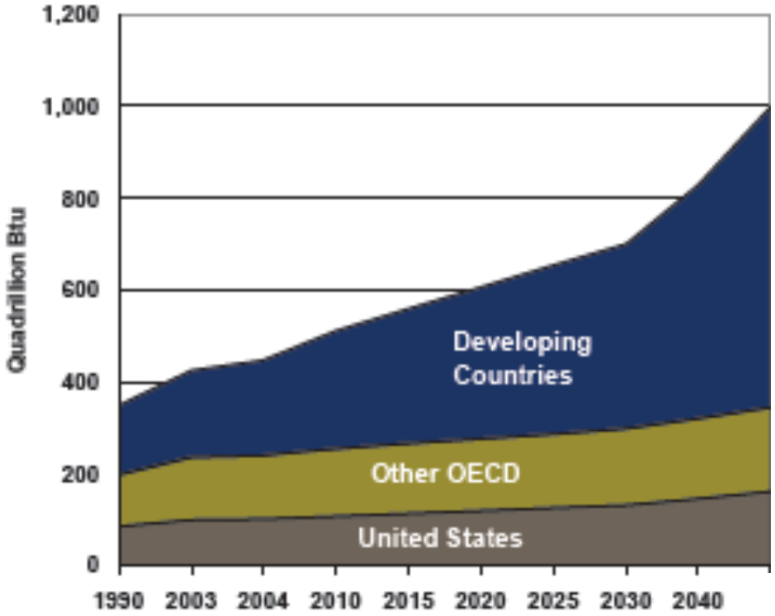
- **Moisture and salt fogging can reduce reliability of electric grid components**
- **ORNL can produce macroscopic objects having nanoscale features that impart superhydrophobicity.**
- **There are a number of everyday and advanced uses for these ultra-waterproof materials.**
- **Electric grid applications include coatings on equipment to prevent icing, coatings for transformer insulation.**

**Superhydrophobic Materials**

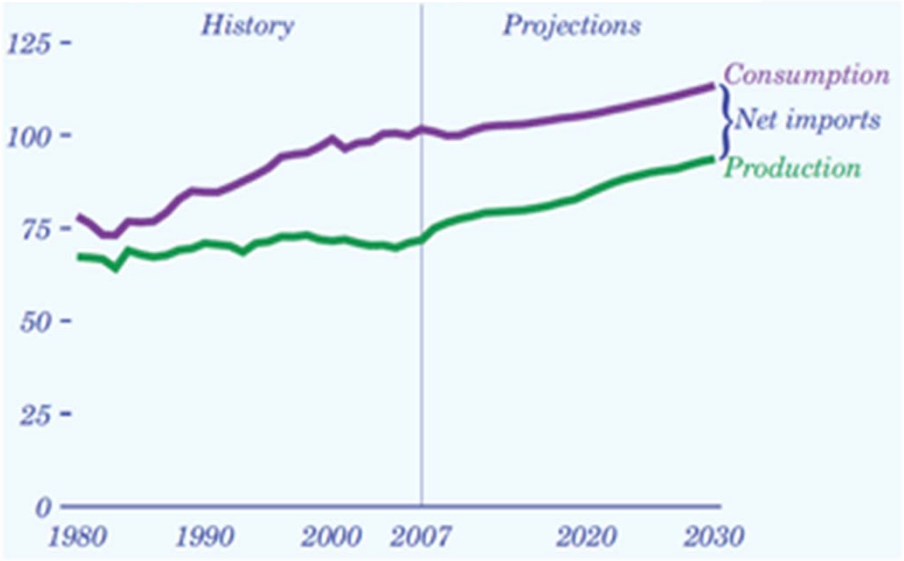


# Total energy production and use increasing nationally and internationally

**Internat'l Consumption**




**U.S. Demand and Use**
**(Quads)**



# Carbon Fiber Technology: From Lab Discovery to Commercialization

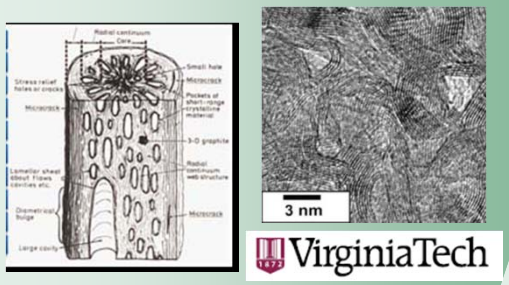
## Basic Science
Biomaterials and Petrochemicals

## Applied R&D
(EERE Vehicle Technologies and Industrial Technologies Programs)

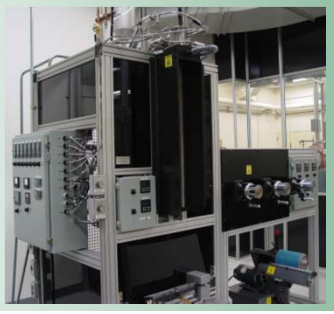
## Manufacturing & Commercialization

**Precursor Materials and Fiber Formation**

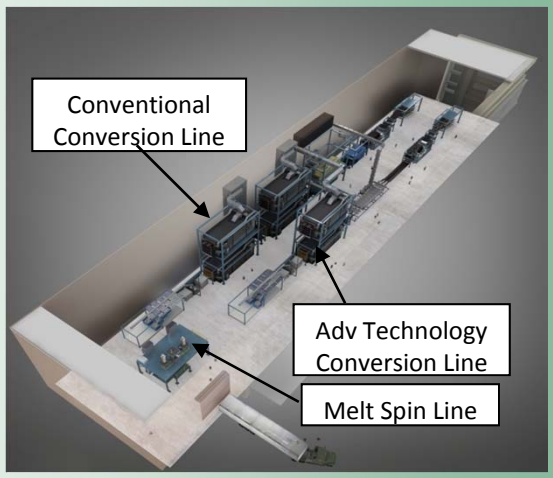
**Precursor Chemistry and Microstructure**




**Melt spinning increases throughput with less energy and no solvent**

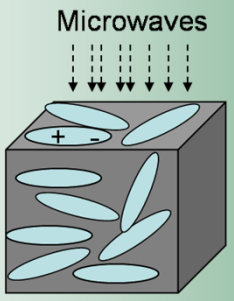


**25 ton/yr carbon fiber semi-production facility in 2012**




**Fiber Processing**

**Process Science**




**Microwaves create internal heating through material dipole vibrations**

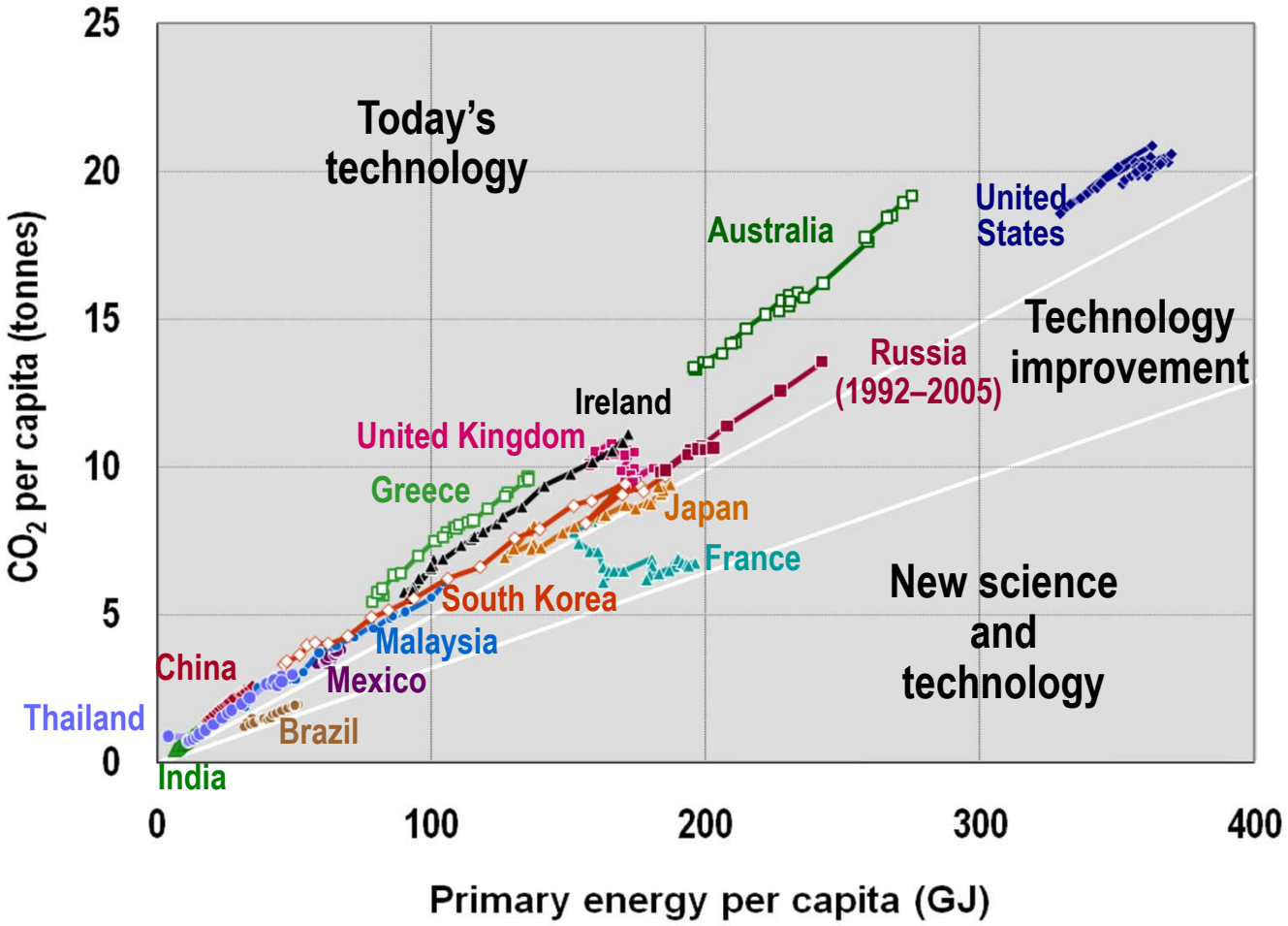
**Microwave/plasma-based conversion processes reduce residence time and energy demand**

SENTECH, *Inc.*

- **Large IP portfolio available for licensing**
- **Developing key partnerships in multiple industries**

FISIPE

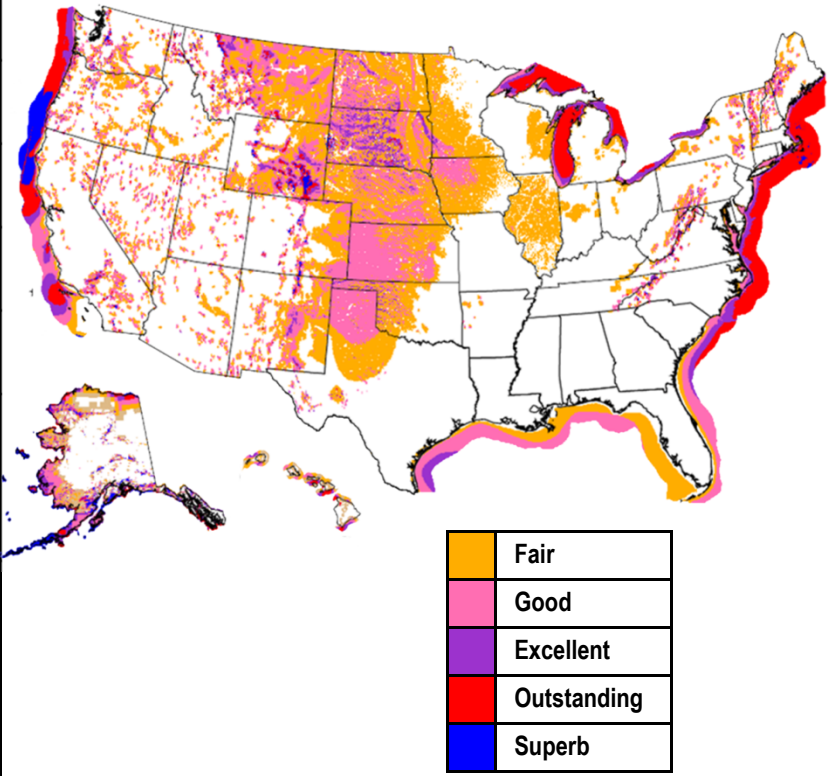
# Emissions and energy (1980–2005)



# How do we compare internationally?

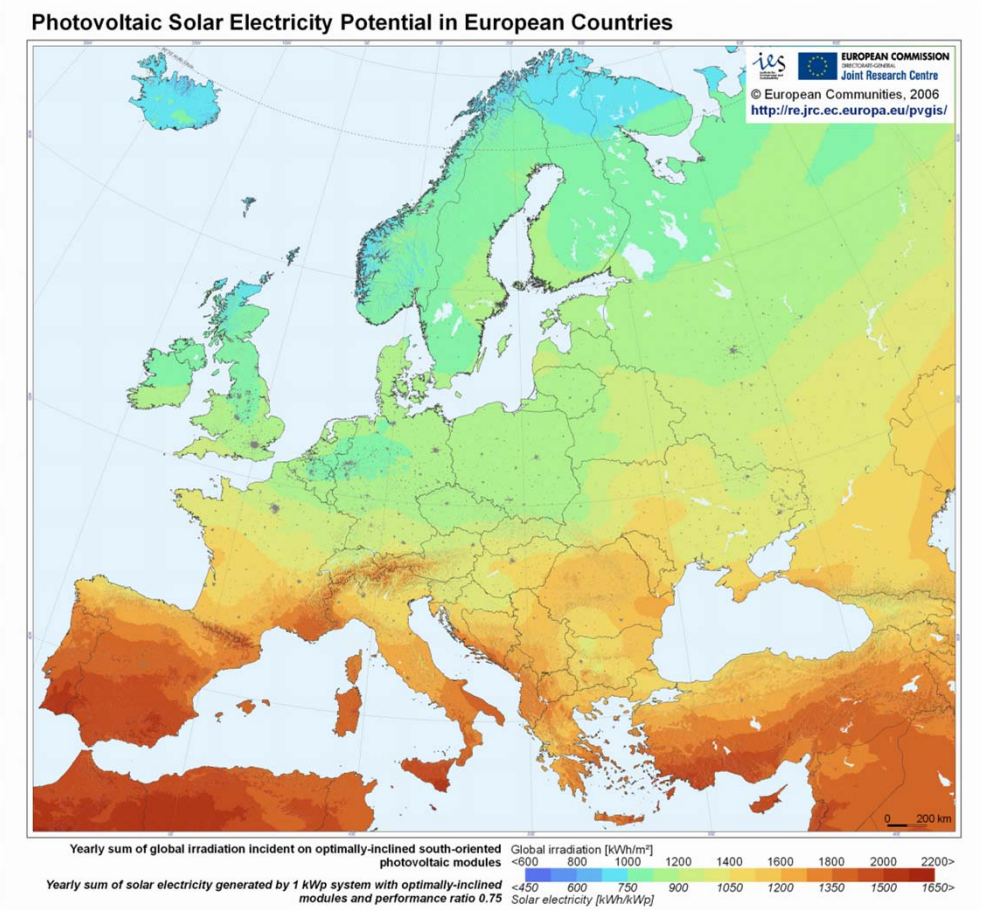
| | Country | 2006 | 2007 | 2008 |
|---|---|---|---|---|
| 1 | United States | 11,603 | 16,818 | 25,170 |
| 2 | Germany | 20,622 | 22,247 | 23,903 |
| 3 | Spain | 11,615 | 15,145 | 16,740 |
| 4 | China | 2,604 | 6,050 | 12,210 |
| 5 | India | 6,270 | 8,000 | 9,587 |
| 6 | Italy | 2,123 | 2,726 | 3,736 |
| 7 | France | 1,567 | 2,454 | 3,404 |
| 8 | United Kingdom | 1,963 | 2,389 | 3,288 |
| 9 | Denmark | 3,140 | 3,129 | 3,160 |
| **World Total** | | **74,223** | **93,849** | **121,188** |

**Wind Generation**



# How do we compare internationally?

| | Country | MW 2006 | MW 2005 |
|---|---|---|---|
| 1 | Germany | 3,063 | 1,910 |
| 2 | Spain | 118.1 | 57.6 |
| 3 | Italy | 57.9 | 46.3 |
| 4 | Netherlands | 51.2 | 50.8 |
| 5 | France | 32.7 | 26.3 |
| 6 | Austria | 29.0 | 24.0 |
| 7 | Luxemborg | 23.6 | 23.6 |
| 8 | UK | 13.6 | 10.9 |
| Total Europe | | 3,420 | 2,170 |




***PVGIS © European Communities, 2001-2008***

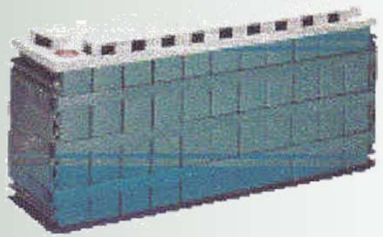
***U.S. has 700 MW of installed solar***

*Source : EurObserv'ER 2007*

# Widely used rechargeable batteries

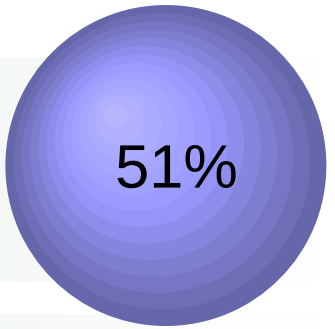
- **Lead acid (30-40 Wh/kg, 70-92% eff., 2V)**
  - Over 100 years old, and still the most widely used rechargeable battery in the world.

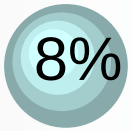
- **Nickel metal hydride (30-80 Wh/kg, 66% eff., 1.2 V)**
  - A high power battery chemistry similar to nickel cadmium, introduced in the 1980s. It is environmentally friendly, contains no toxic cadmium, and is replacing NiCd in many applications.

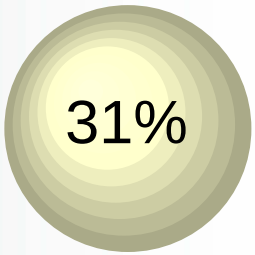


- **Lithium ion (160 Wh/kg, 99.9% eff., 3.6-3.7V)**
  - The newest and fastest growing rechargeable battery technology
  - Theoretical capacity: 150-275mAh/g

**Market share**



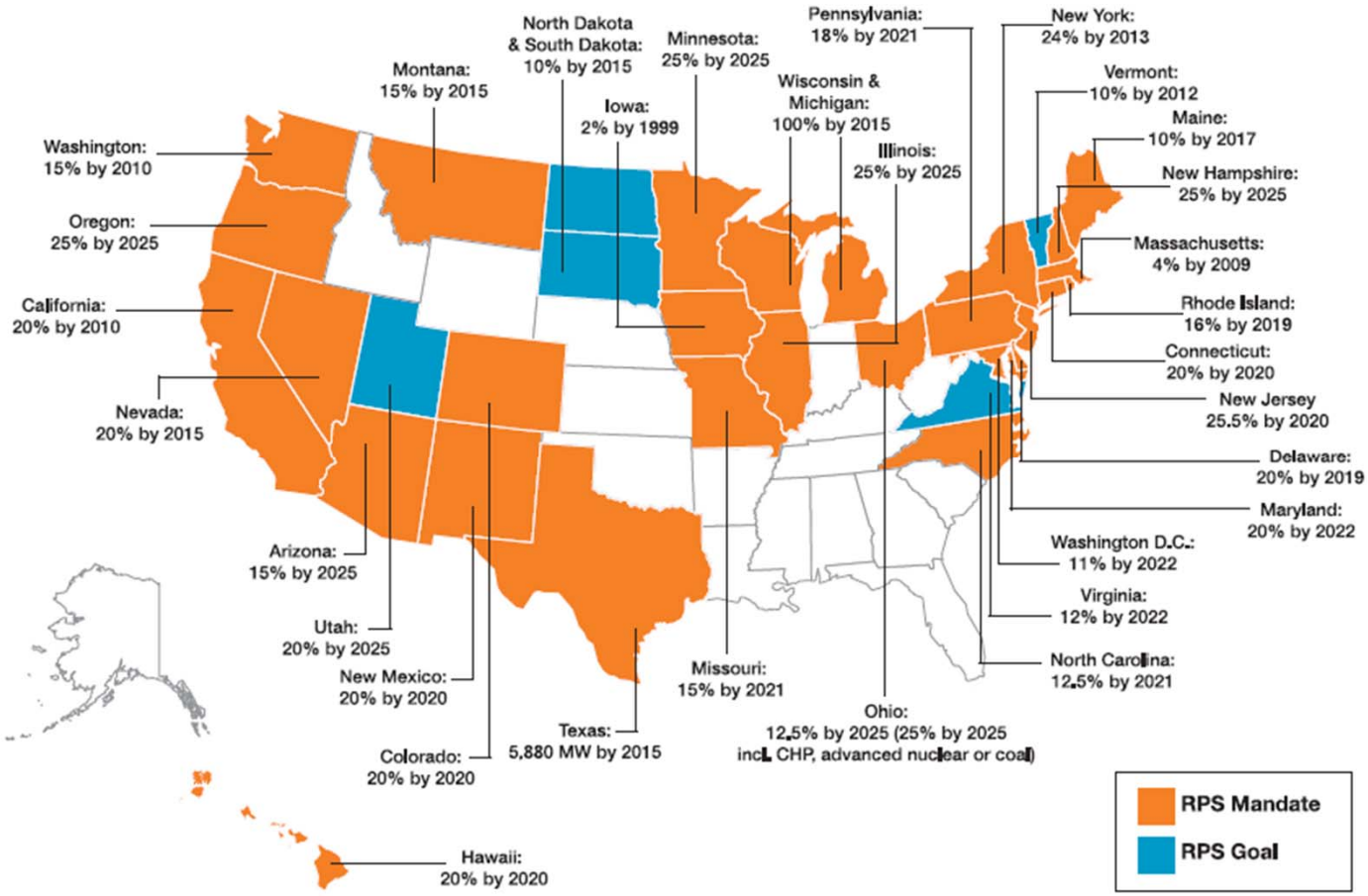




Others




Sentech, Wikipedia

# Renewable Portfolio Standards will drive higher penetration of renewables




*Source: Energy Insights 2009 NA Utilities Industry Update and Capgemini*

# Renewable Generation is Variable, But, this Challenge Can be Overcome

- **We can improve day ahead and hour to hour planning by developing a method for probabilistic analysis of renewable generation aggregations.**
- **Supply forecasts can be done statistically as a function of weather and time over areas as large as a balancing area.**


- **Today, 5- minute energy markets are responsive to system variability.**
- **Responsive load is just beginning to provide regulation – the minute to minute energy balancing of the system.**
- **Storage is also being used to supply regulation.**

# Other green innovation in buildings

- **Soy- based Insulation**
- **More efficient: greater R-value in less space; 50% energy savings**
- **Emits no VOCs or CFCs. Contains no formaldehyde.**


- **Open cell: less expensive; R – 3.6 per inch**
- **Closed cell: densely packed foam; provides added strength to building R-6.8 per inch**

# WHAT MAKES A **WINDOW** ENERGY EFFICIENT?

CHANGE FOR THE BETTER WITH ENERGY STAR

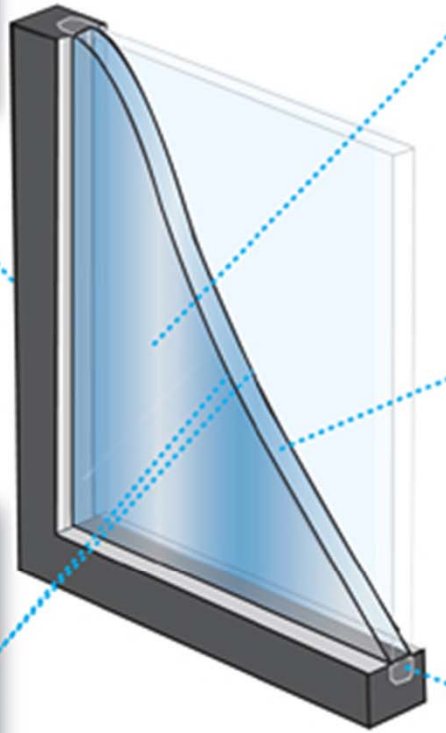
Today, manufacturers use an array of advanced technologies to make ENERGY STAR-qualified windows.

## IMPROVED FRAME MATERIALS

Wood composites, vinyl, and fiberglass frames reduce heat transfer and help insulate better.

## LOW-E GLASS

Special coatings reflect infrared light, keeping heat inside in winter and outside in summer. They also reflect damaging ultraviolet light, which helps protect interior furnishings from fading.



## GAS FILLS

Some energy-efficient windows have argon, krypton, or other gases between the panes. These odorless, colorless, non-toxic gases insulate better than regular air.

## MULTIPLE PANES

Two panes of glass, with an air or gas-filled space in the middle, insulate much better than a single pane of glass. Some ENERGY STAR-qualified windows include three or more panes for even greater energy efficiency, increased impact resistance, and sound insulation.

## WARM EDGE SPACERS

A spacer keeps a window's glass panes the correct distance apart. Today's warm edge spacers—made of steel, foam, fiberglass, or vinyl—reduce heat flow and prevent condensation.

# There are several challenges to deploying wave power devices

- **High total cost of electricity**
- **Efficiently converting wave motion into electricity**
- **Constructing devices that can survive harsh environments**
- **Impacts on the marine environment**
  - **Noise pollution**
  - **Beach sand nourishment**
  - **Navigation hazards**
- **State and federal regulatory hurdles and limited R&D funding.**
- **Industry vision and R&D priorities have not been clearly defined; Very early stage of development, with few full-scale demonstrations**

# Solar Cell Material Pathways