# Clean Energy: What It's All About!

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September 7, 2009

# Outline

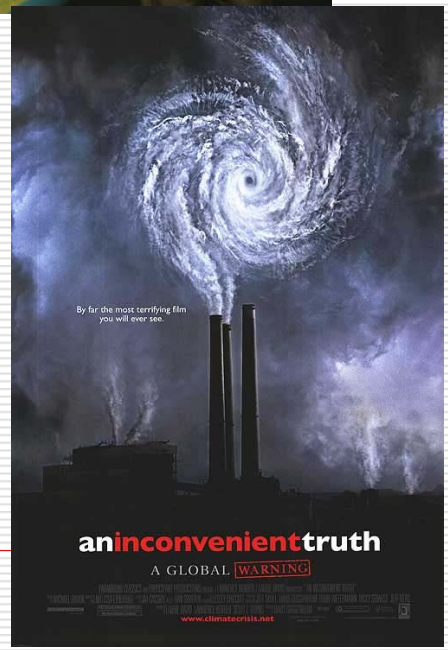
- Preface & Audience
- Clean Tech, Sustainable Energy defined
- US Energy Usage & Flow
- Global GHG Abatement
- World Energy Snapshot
- NE Electricity Market
- Smart Grid
- Renewables Snapshot
- Water & Other Resources
- Some Opportunity Areas

# Preface

- Vast topic involving technology, ecology, science, politics, economics, globalization
  - With many complex inter-dependencies
- Sweep thru Clean Energy expanse
  - Illustrate innovations with real life technology examples

# Audience

- Likely seen Al Gore movie
- Aware of GHG emissions, climate change, impact on the planet & its resources
- Curious about clean tech landscape
- Exploring options to make a difference



# Cleantech: More with Less

Ubiquitous Global Applications

**CLEANTECH** encompasses knowledge-based technology products/services that:

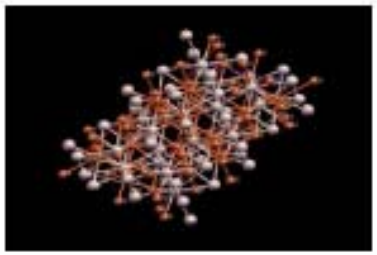
- Provide superior performance at lower costs
- Greatly reduce or eliminate negative ecological impact
- Improve the productive and responsible use of natural resources

ENERGY: Includes Energy Generation, Storage, Infrastructure and Efficiency

TRANSPORTATION: Includes vehicles design, fuels and logistics

WATER: Includes filtration, purification, water conservation and wastewater treatment

AIR & ENVIRONMENT: Includes remediation, emission control, trading and offsets



MATERIALS: Includes environmental friendly nanotech, biotech, chemical materials

MANUFACTURING/INDUSTRIAL: Includes monitoring/control appliance and smart production industries

AGRICULTURE: Includes land management, natural pesticides, natural fertilizers, irrigation

RECYCLING & WASTE: Includes various recycling services and waste treatment services.

www.cleantech.com

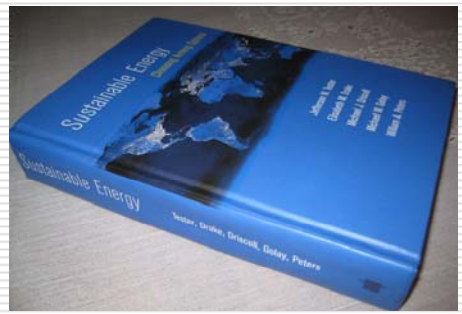
cleantech GROUP LLC

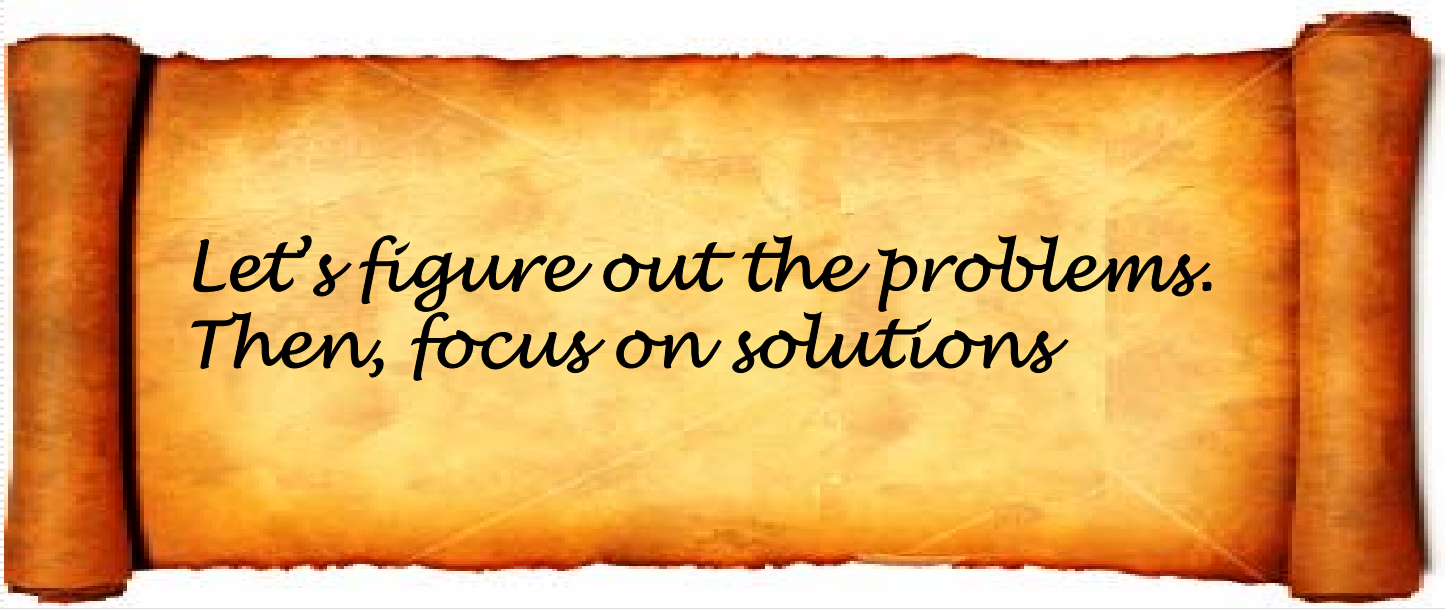
# Sustainable Energy

"A dynamic harmony between the equitable availability of energy-intensive goods & services to all people and the preservation of the earth for future generations"

"Sustainable Energy" – Choosing among options

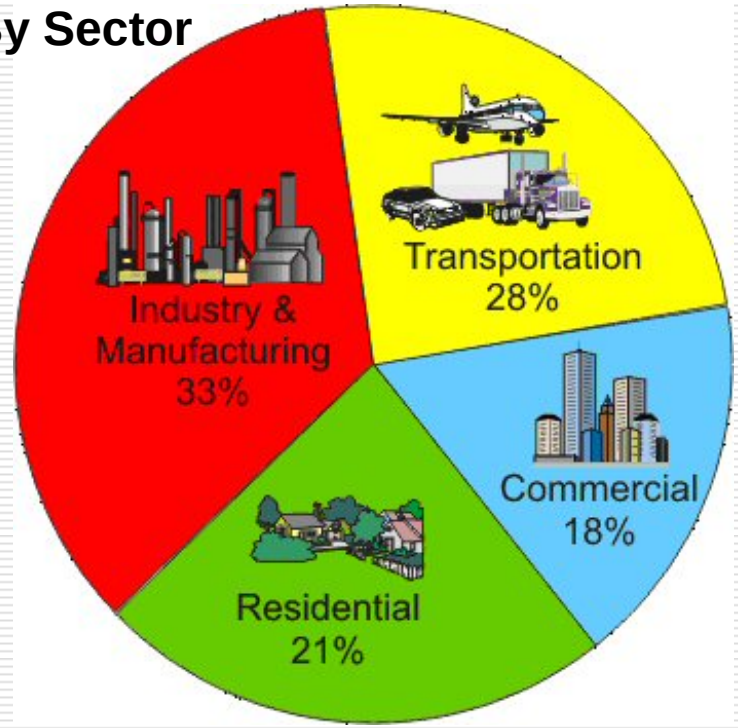
Prof. Jeff Tester et al, MIT Press



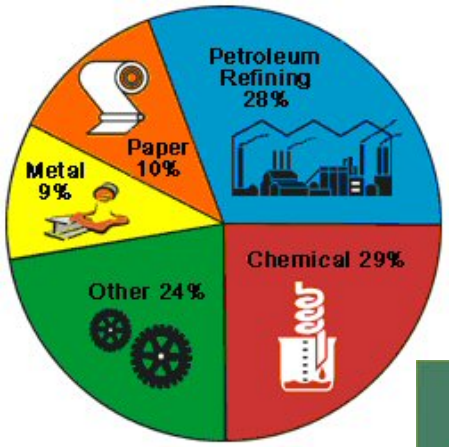

Let's figure out the problems.
Then, focus on solutions

# US Energy Usage

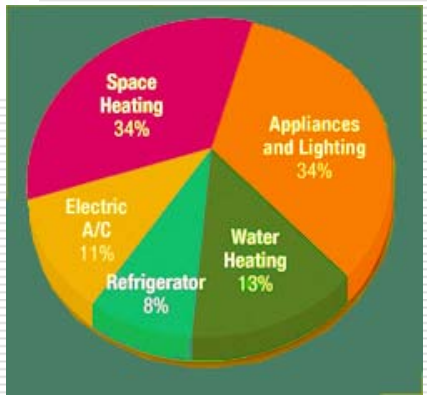
**By Sector**



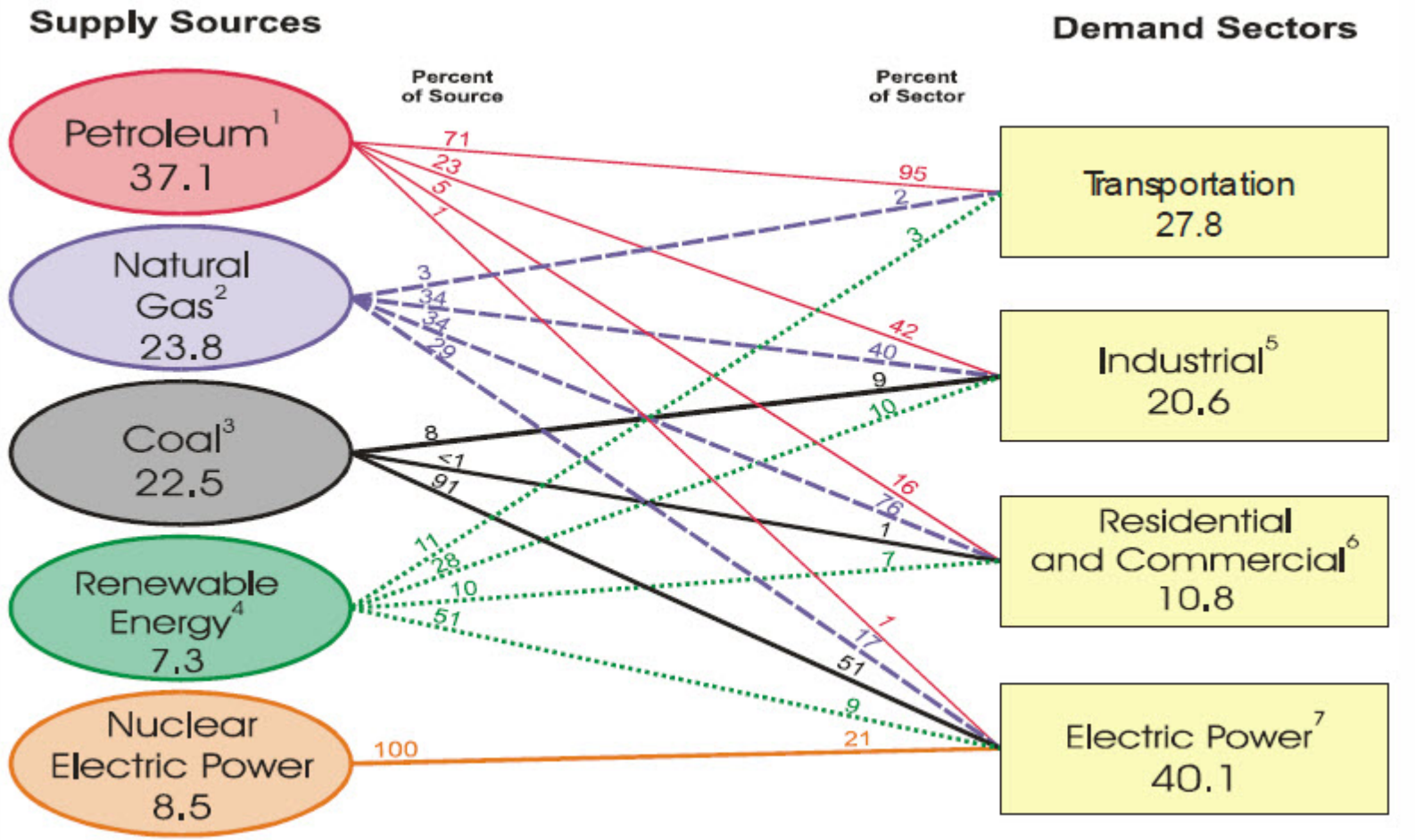

**Industrial**




**Residential**



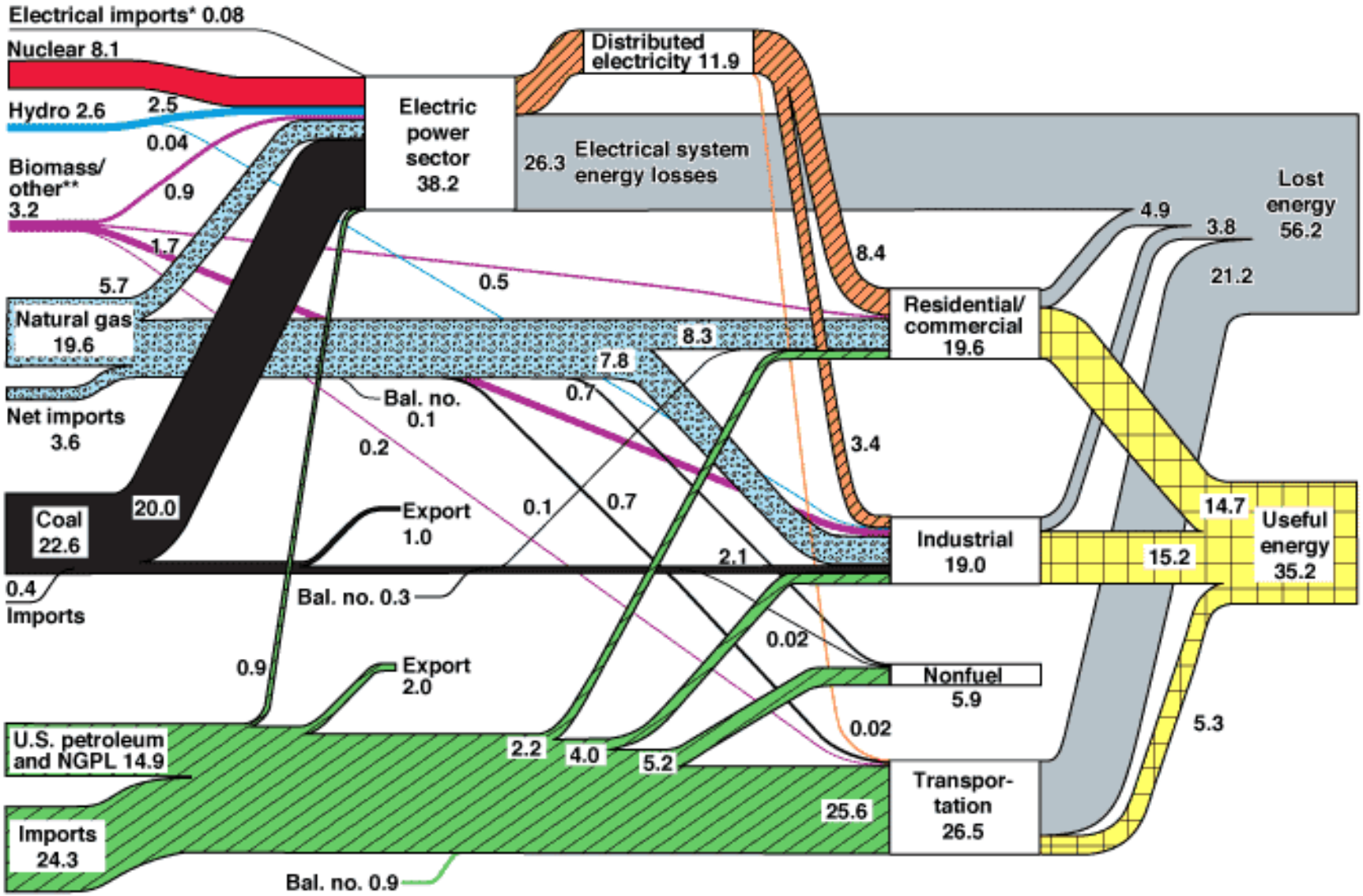
# US Primary Energy Consumption By Source & Sector 2008 (99.2 Quad BTU)




US Annual Energy Review. DOE/EIA

Point #1

# U.S. Energy Flow Trends – 2002
# Net Primary Resource Consumption ~97 Quads



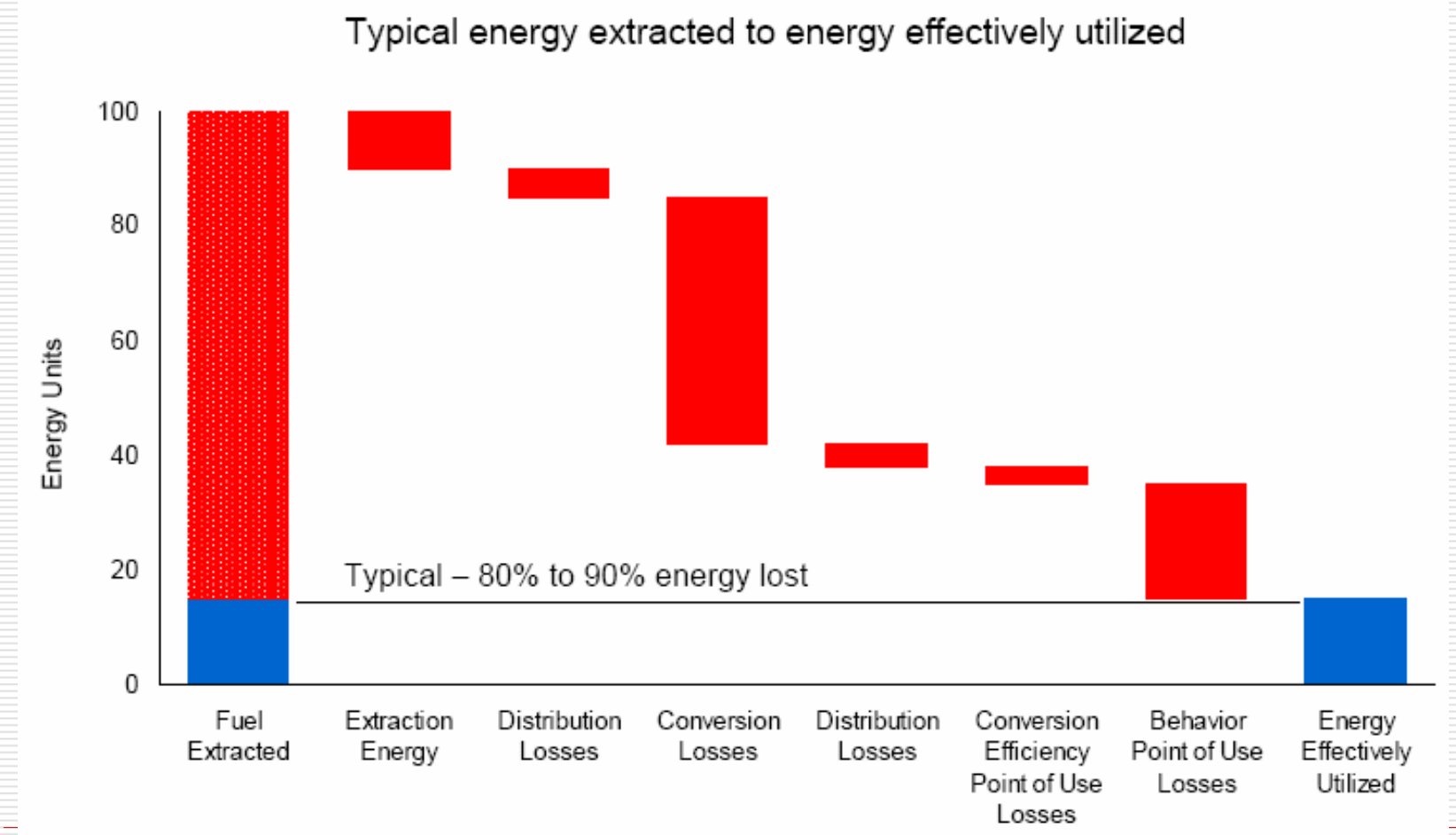

Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

June 2004
Lawrence Livermore National Laboratory
http://eed.llnl.gov/flow

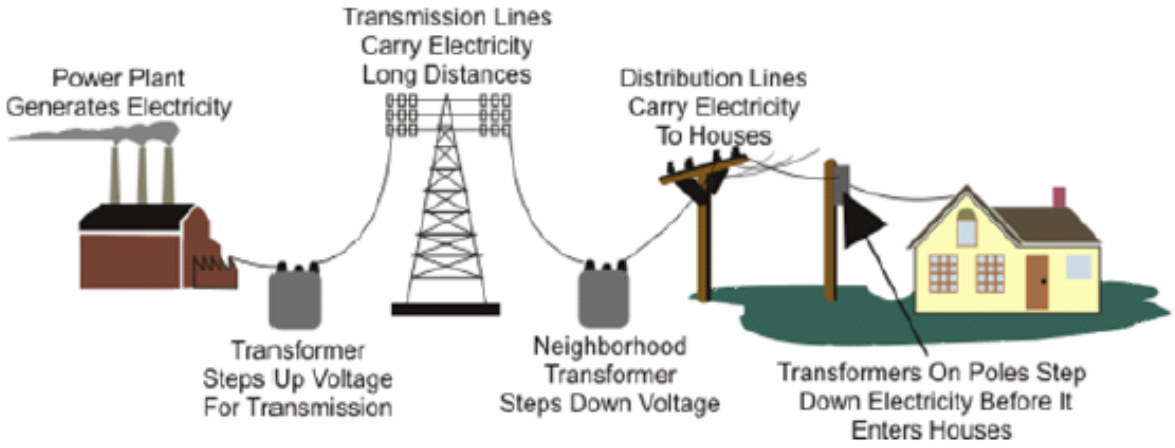
# The Epiphany

- All energy at left doesn't make it to right
- It isn't just about producing more energy
  - Renewable or conventional
- Are there efficiency opportunities in energy conversion & transmission?
- Also, there are two sides to energy equation
  - Supply & Demand
- How can usage efficiency reduce energy demand?

# Another Angle on Energy Loss



# Average Energy Conversion Efficiency of Primary Sources to Electricity is 33%




| Primary Energy Sources | Percent Used to Generate Electricity | Typical Conversion Efficiency | Primary Energy Units Consumed per 100 Units Delivered @ Point of Use * |
|---|---|---|---|
| Coal | 48.4 | 32 | 158.2 |
| Natural Gas | 19.4 | 43 | 47.1 |
| Nuclear | 21.6 | 35 | 64.4 |
| Hydro | 6.0 | 90 | 7.0 |
| Petroleum | 1.6 | 33 | 5.1 |
| Other | 3.1 | 20 | 16.2 |
| Total | 100.0 | | 297.9 |

* Includes 4.6% Transmission Loss

Point #2

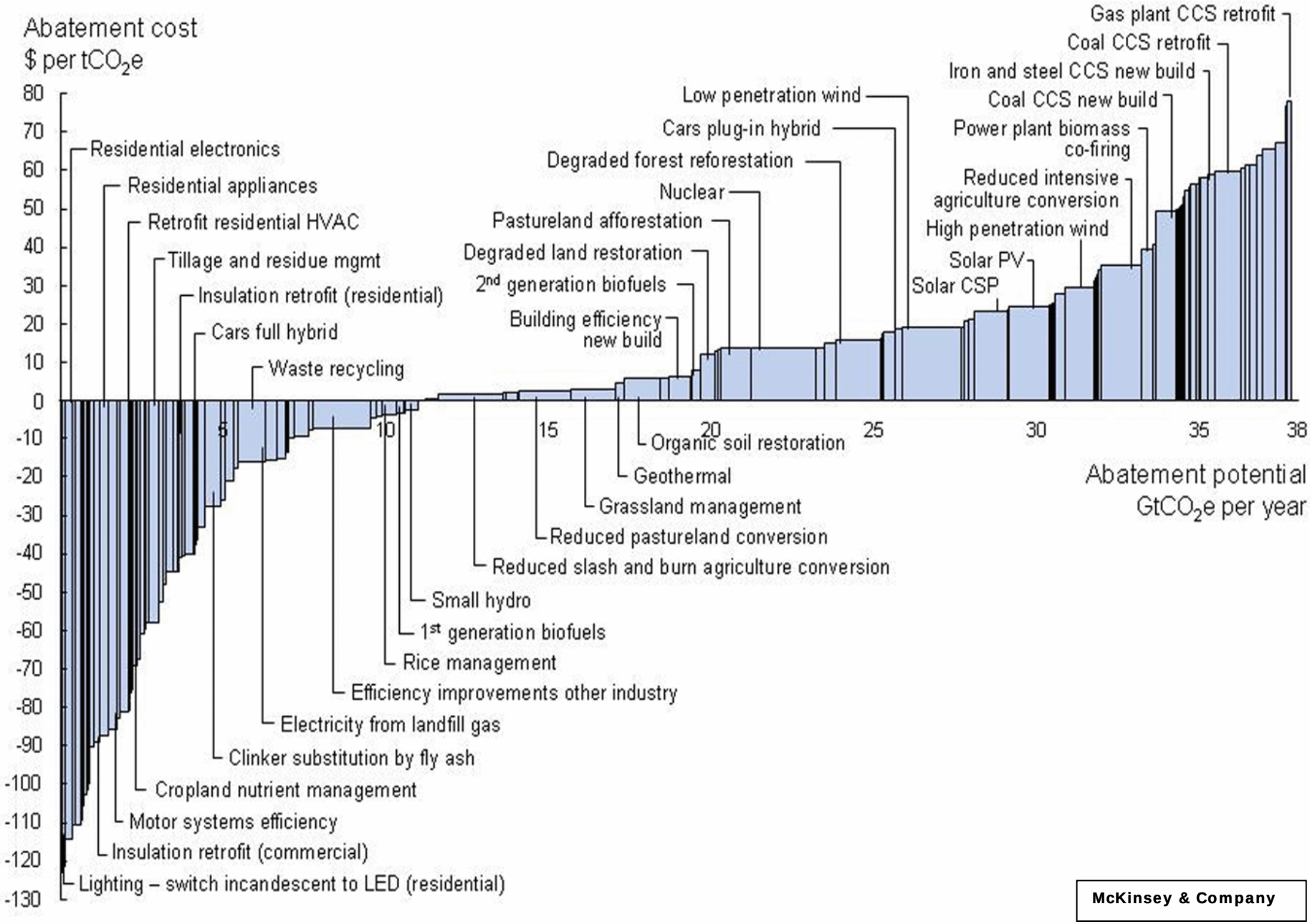
# US GHG Abatement Mapping Initiative

- Annual GHG projected to increase
  - From 7.2 GTons CO2e in 2005
  - To 9.7 GTons CO2e in 2030 (35% increase)

  Among others, based on pop. increase of 70 mil
- Assertion: US could reduce GHG emissions in 2030 by 3-4.5 GTons using tested approaches and high potential emerging technologies
  - With marginal cost < $50/Ton

McKinsey Report, Dec 2007

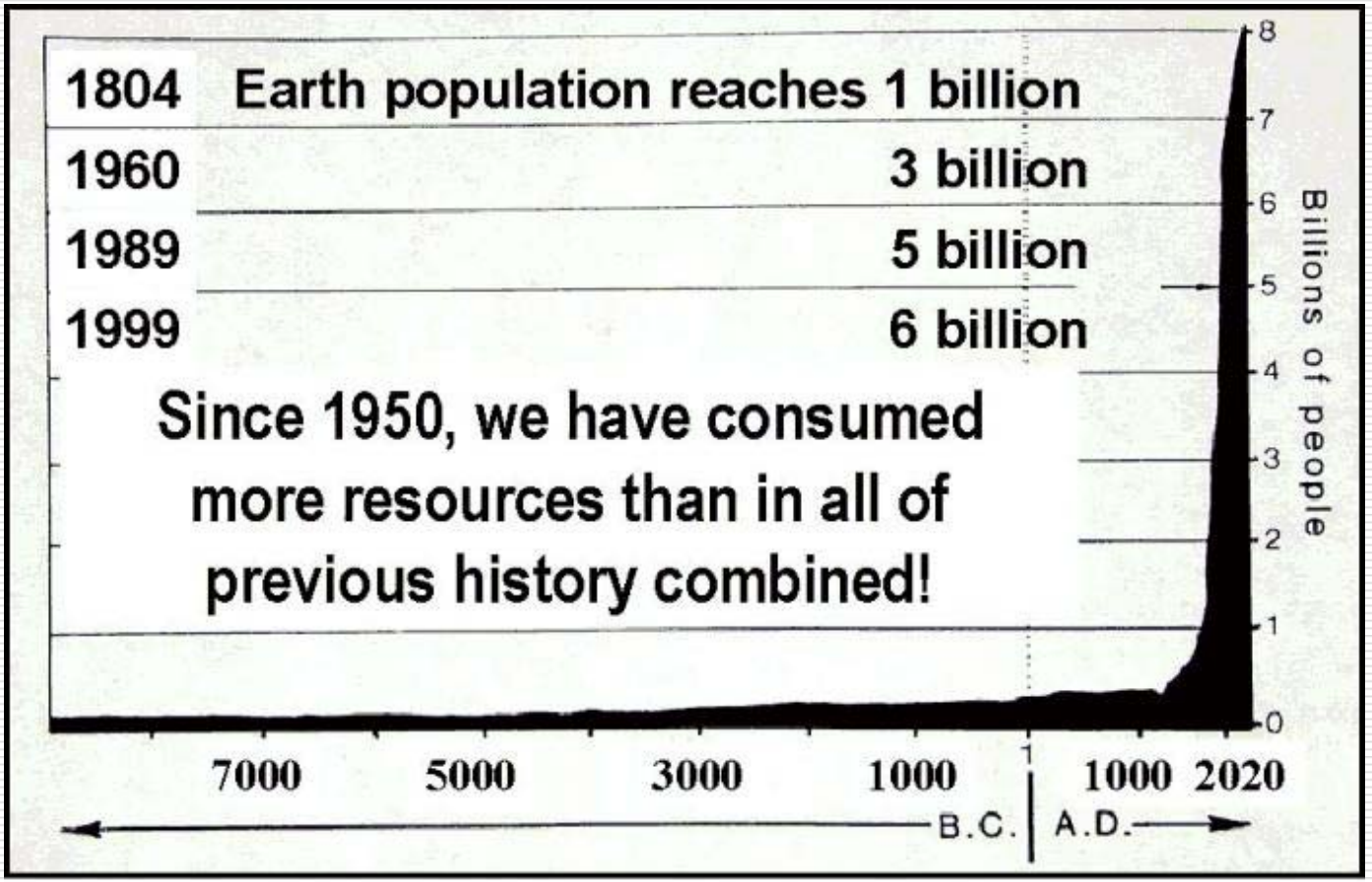
# Global GHG abatement cost curve beyond business-as-usual, 2030




McKinsey & Company

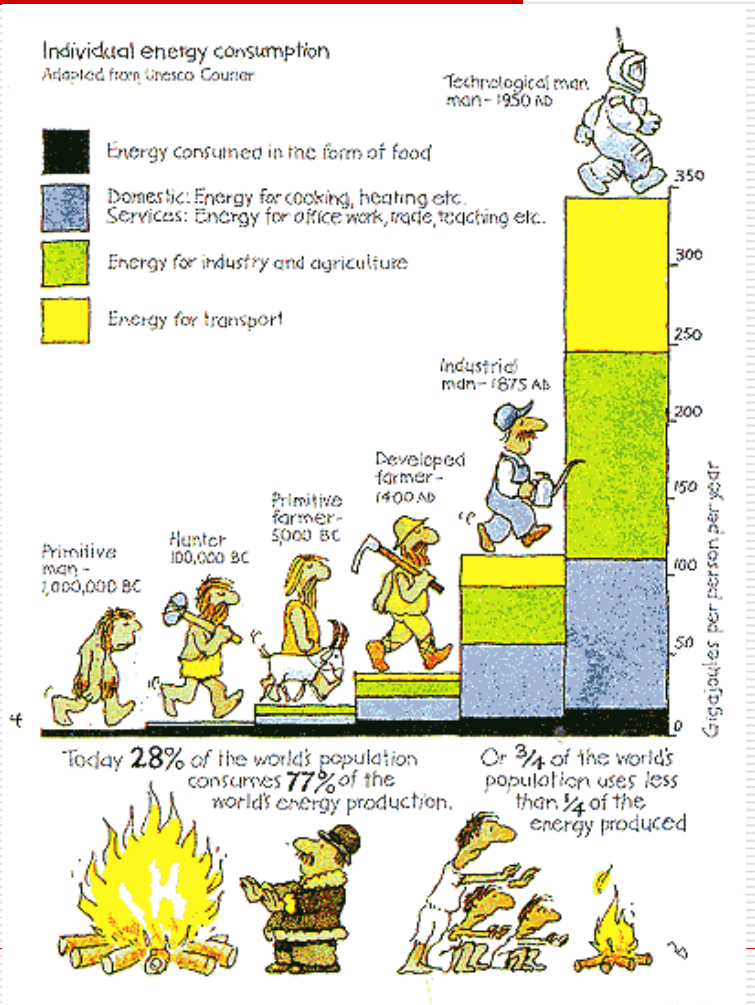
Point #3

# Population Growth Thru History




**Expected to hit 9 Billion by 2050**

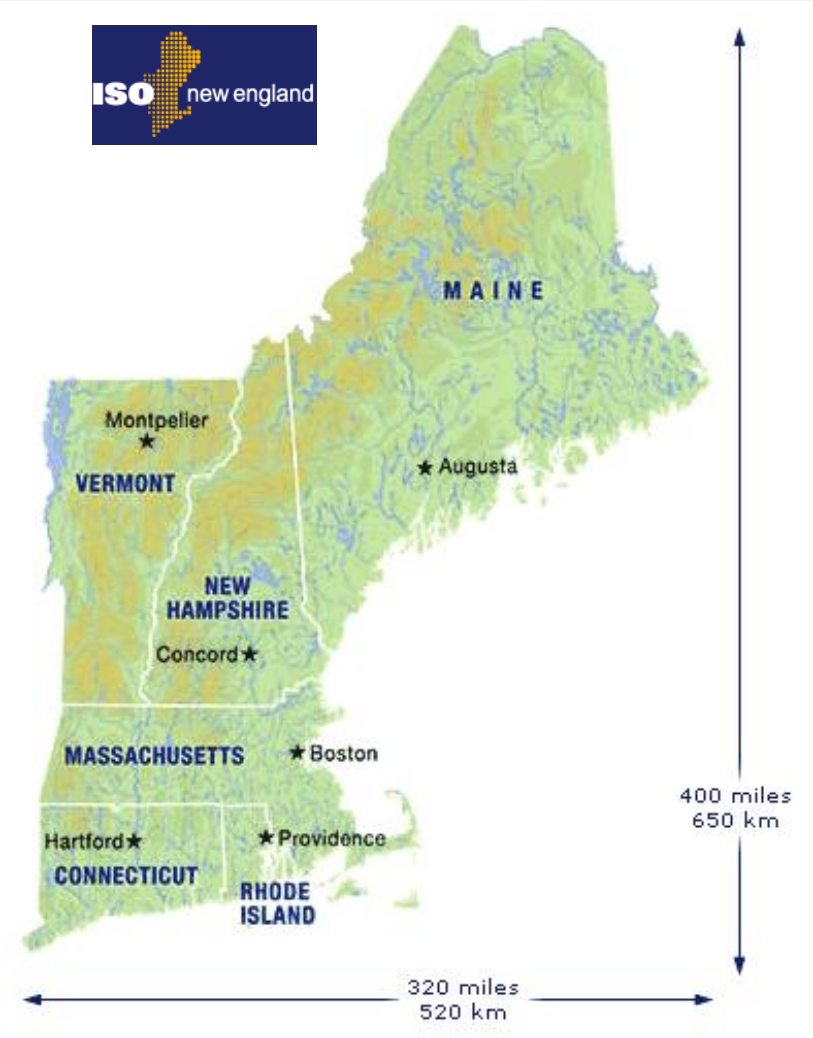
# Energy Consumption



# Electricity: The Unserved World

# Electricity Close to Home

# ISO New England




- Independent System Operator responsible for:
  - Ensuring reliable operation of the N.E. electric grid
  - Administration of region's wholesale electric markets
  - Administration of regional Open Access Transmission Tariff, including regional system planning
- ISO is a not-for-profit corp.
- ISO has no financial interest in in region's wholesale electricity market companies

# ISO NE Regional Profile

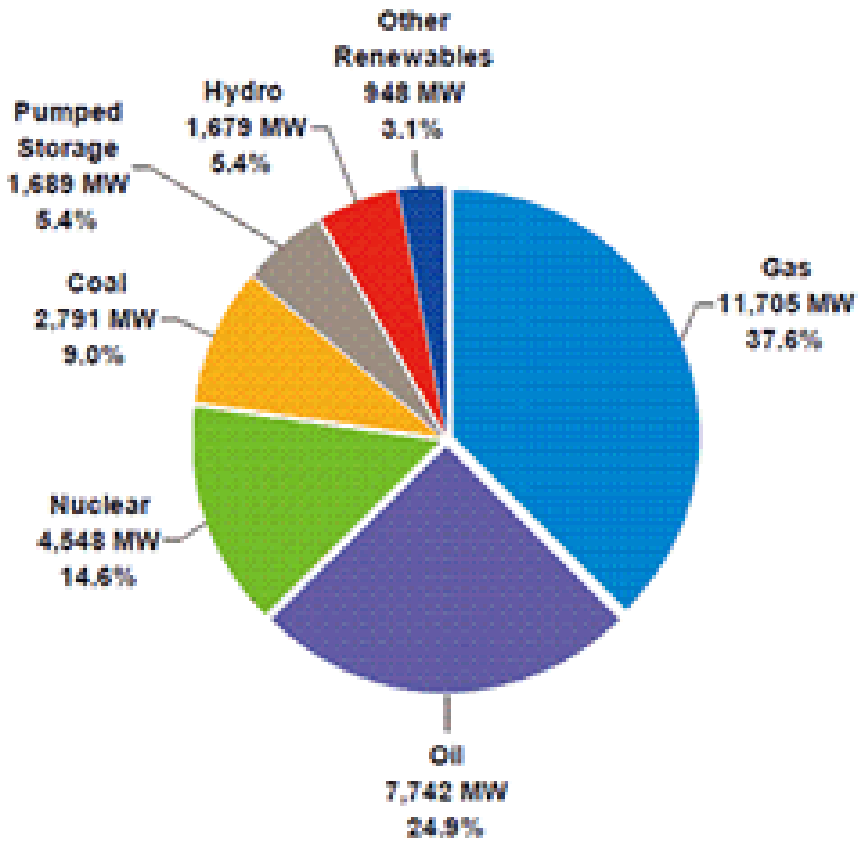
- **Population 14 million**
- **6.5M households & businesses**
- **300+ generators**
- **8000+ miles of HV transmission lines**
- **13 interconnections to electricity systems in NY & Canada**
- **400+ participants in the marketplace**
- **$12B annual energy market (2008)**
- **$4B transmission investment since 2002; $5B planned over next 10 years**
- **6 major 345-kV projects built in 4 states**

# ISO NE Sources

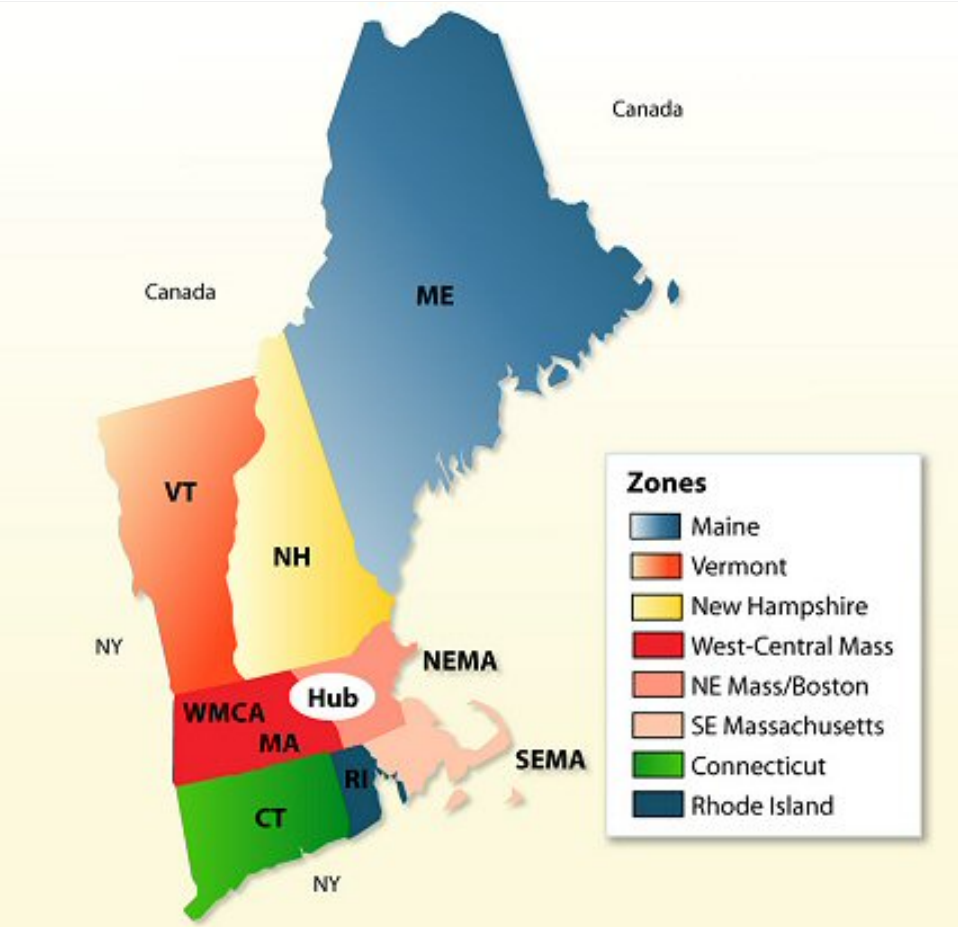
## New England Installed Generation Capacity by Primary Fuel Type

**Summer 2008**
**(MW and Percent)**

**Total = 31,102 MW**



# ISO NE Zones



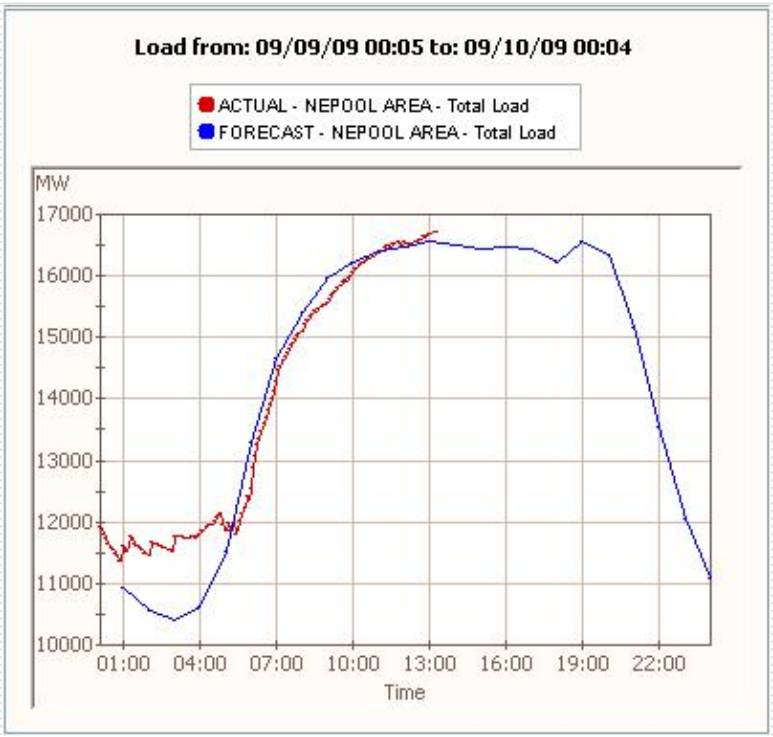

**ISO NE STATS**

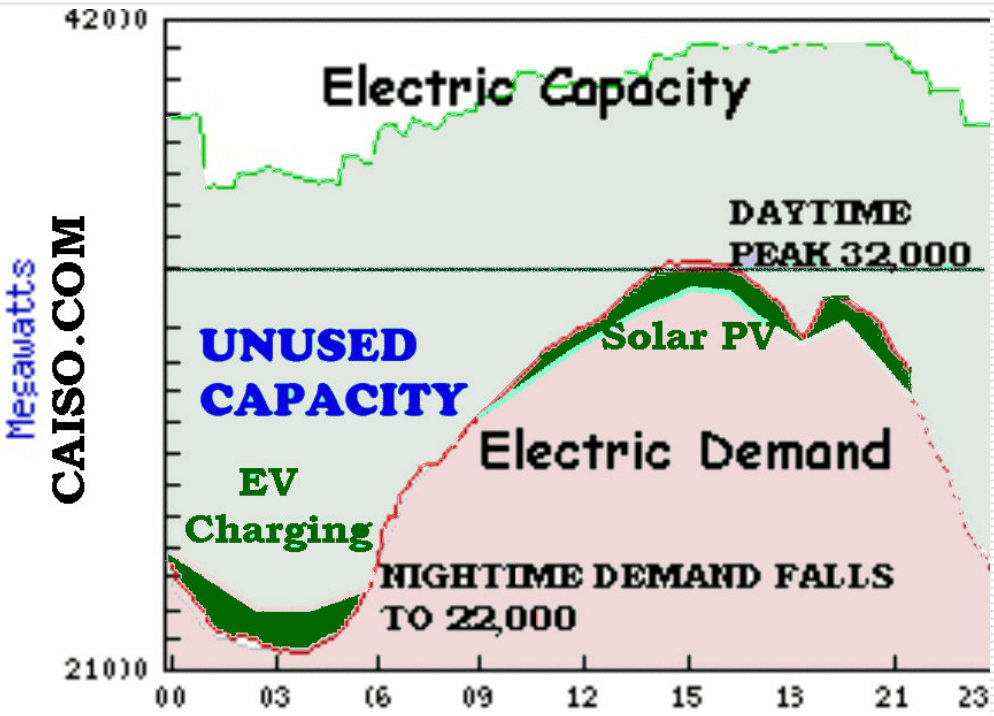
- **Baseload of 18,000 MW**
- **All-time peak demand of 28,130 MW set Aug 2, 06**
- **Winter peak demand of 22,818 M W set Jan 04**
- **31000+ MW total supply**
- **2000 MW demand-response (DR)**

**MASSACHUSETTS**

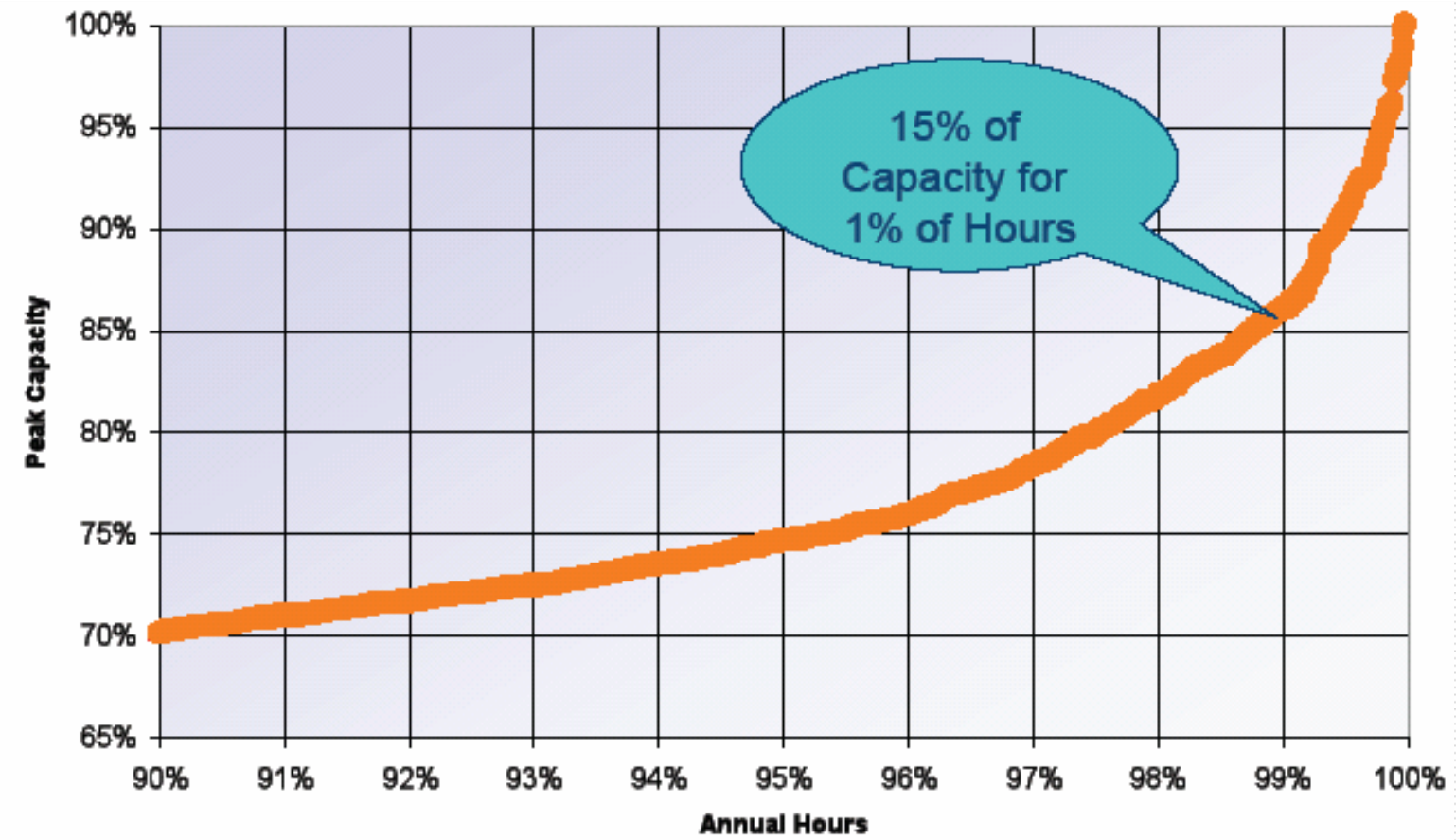
- **45% of region's pop.**
- **46% of electricity**
- **Projected growth 0.7%**
- **Peak summer demand projected growth 1.1%**

# Daily Electricity Demand Curve



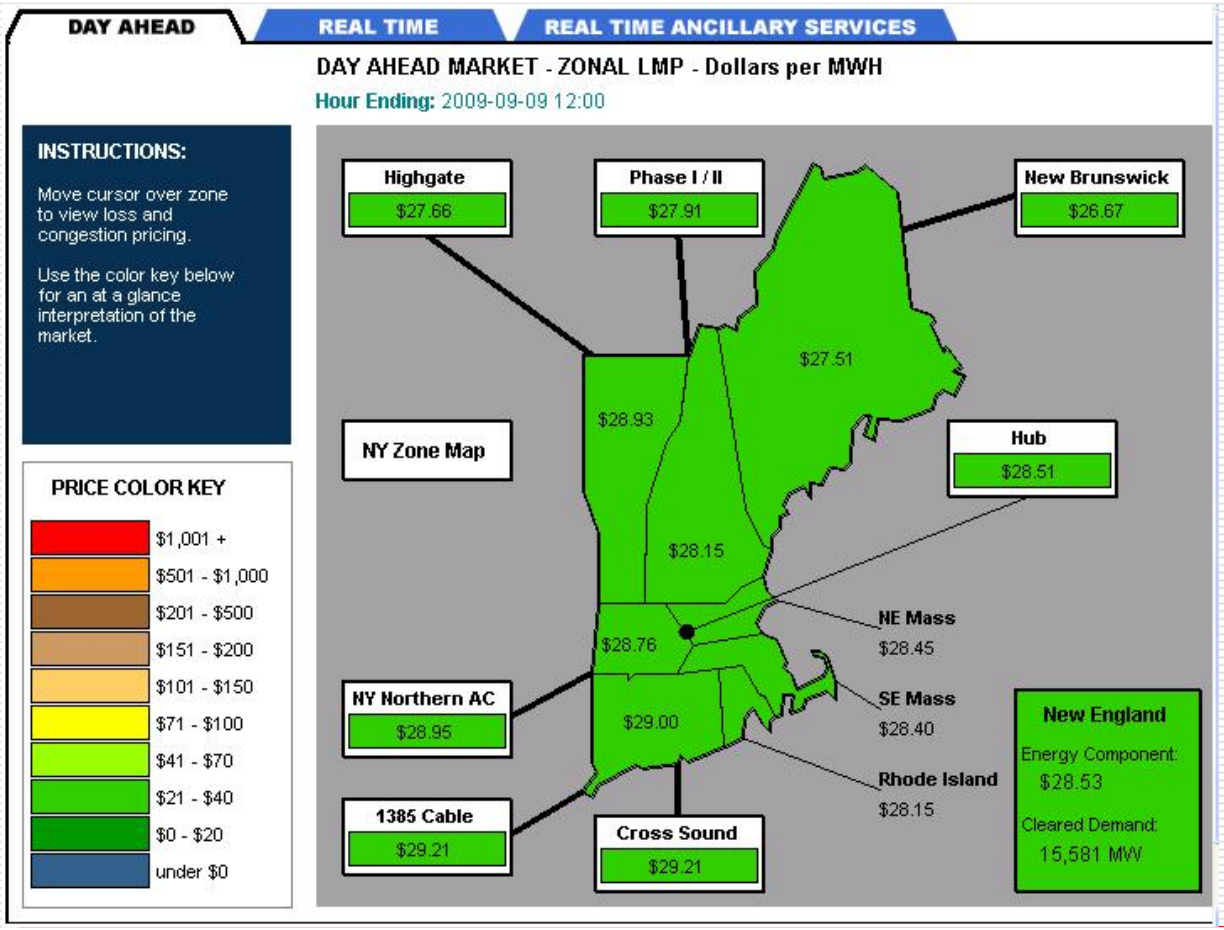



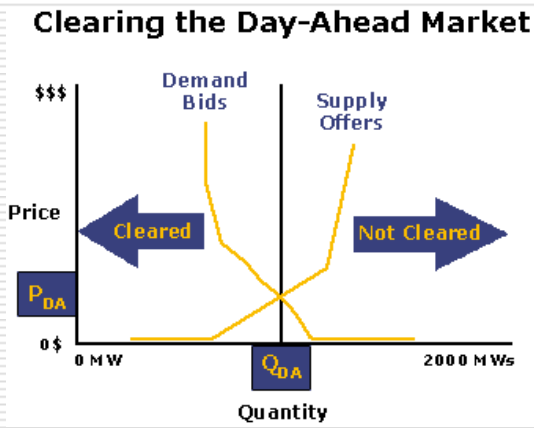
# Meeting Peak Demand



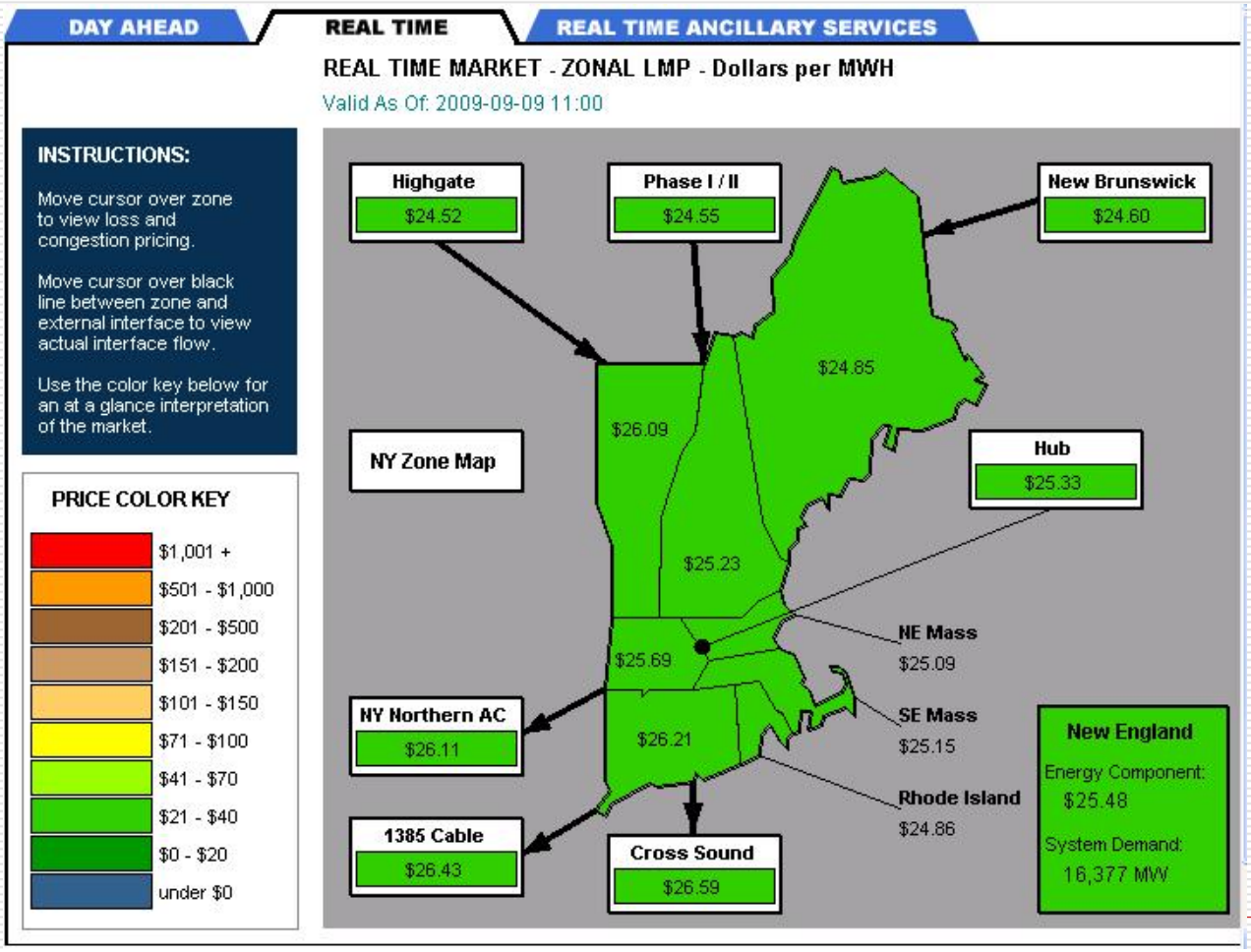

Source: ISO NE 2007 NEMA load zone

# ISO NE Day Ahead Market



# ISO NE Real-Time Market



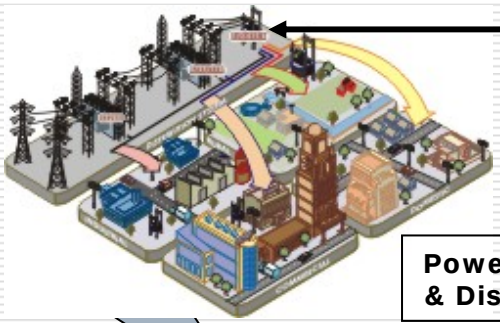
# Innovation: EnerNOC

- Boston-based energy services co - large C & I customers
  - Demand Response
  - Power Efficiency Mgt
  - Energy Procurement
  - Carbon Tracking & Trading
- 2Q2009: 2400 clients, 5450 sites, 3.15 GW managed
- IPO May 2007

| | 2006 | 2007 | 2008 |
|---|---|---|---|
| **Total Revenue** | **$26.1M** | **$60.8M** | **$106.1M** |
| **Energy Mgt. Revenue** | **$0.2M** | **$1.6M** | **$6.8M** |
| **Net Income** | **($5.8M)** | **($23.6M)** | **($36.7M)** |


EnerNOC, Inc. (NasdaqGM: ENOC)

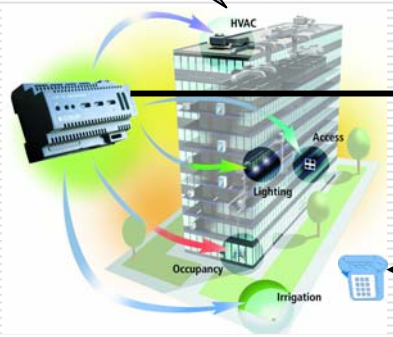
# Demand Response Eco System



Power Transmission & Distribution

Regional Grid Monitoring & Management

Grid Operator




Power Customer

Periodic Data Collection

Demand Requests


Energy Management Service Provider

# Demand Response Market

- 37 GW available DR Nationwide (FERC 2008)
  - 80% Large Commercial & Industrial (C & I)
  - 3% Small & Medium C & I
  - 17% Residential

| Disaggregated markets | Regulated markets |
|---|---|
| Generation separate from T & D<br>Energy curtailment treated the same as generation<br>Open capacity markets<br>- Forward capacity<br>- Day ahead<br>- Real-time<br>- Ancillary<br>CSPs aggregate capacity bids | Vertically integrated power companies<br>Utility or CSP or runs DR program<br>CSP contracts negotiated to aggregate customer MWs<br>Curtail x hours of y MWs per year on z minutes notice |

# Supply-Demand Challenge

**Biggest Issues**

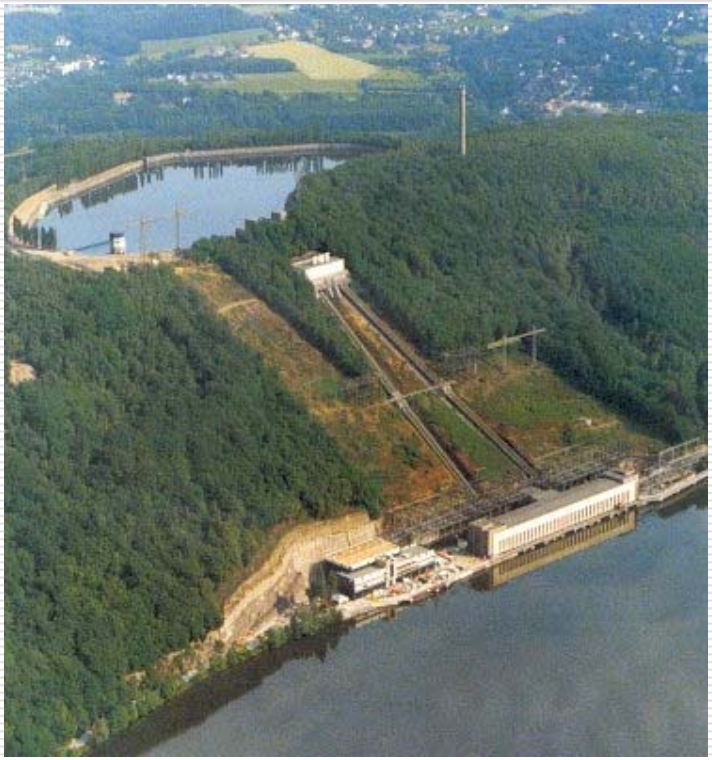
- **Electricity is a real-time resource**
- **Demand has peaks & ebbs**

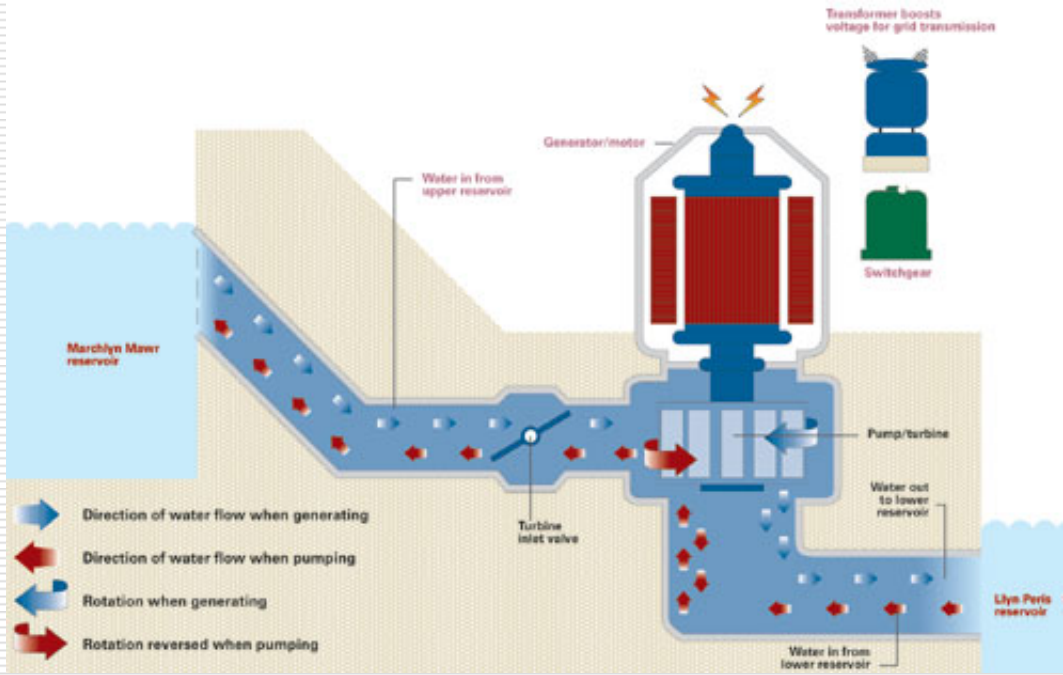
**Ideal Solution**

- **Store when there is over-supply**
- **Use when there is high demand**

**Q: How to implement grid-scale storage?**

# Storage – Pumped Hydro

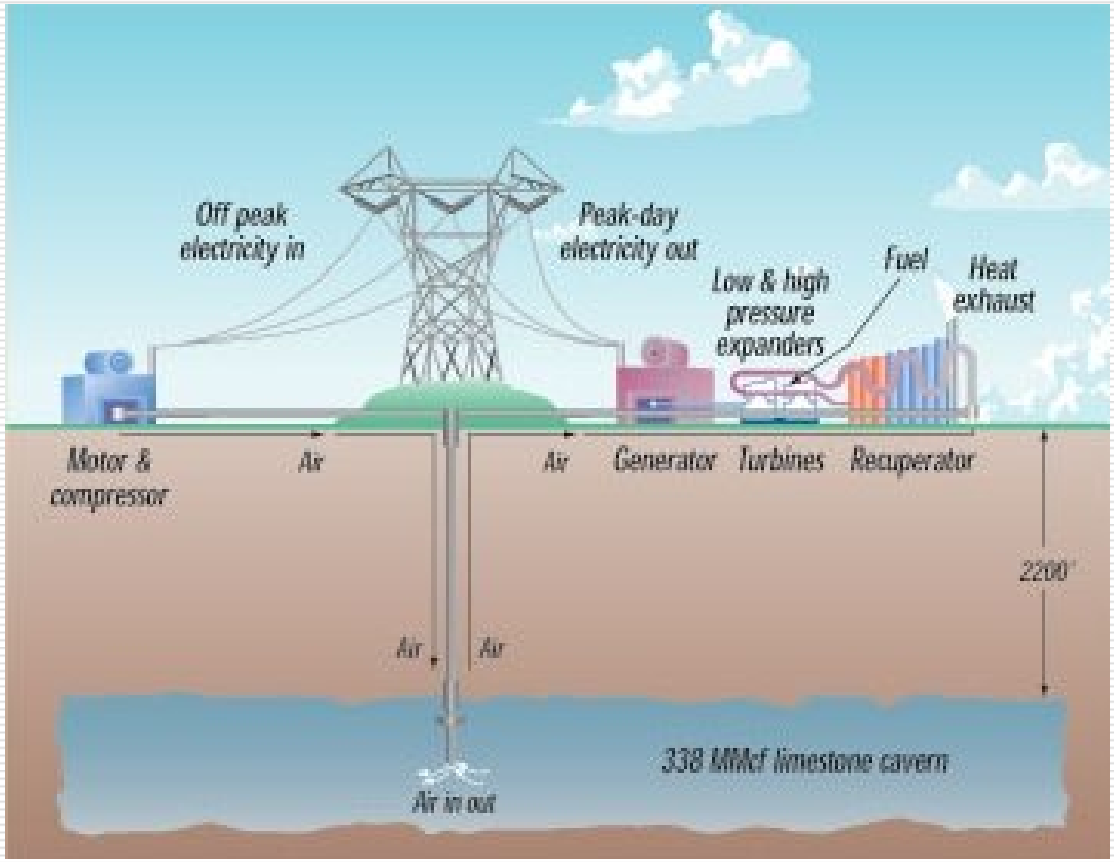





**Total US capacity (2000): 19.5 GW**

**All possible US resources for pumped hydro locations supposedly exhausted**

# Storage – Compressed Air




**General Compression, Attleboro MA working on long-term (week+) solution**

**PG&E, CA, seeking $25M from DOE's smart grid fund for a compressed air energy storage project**

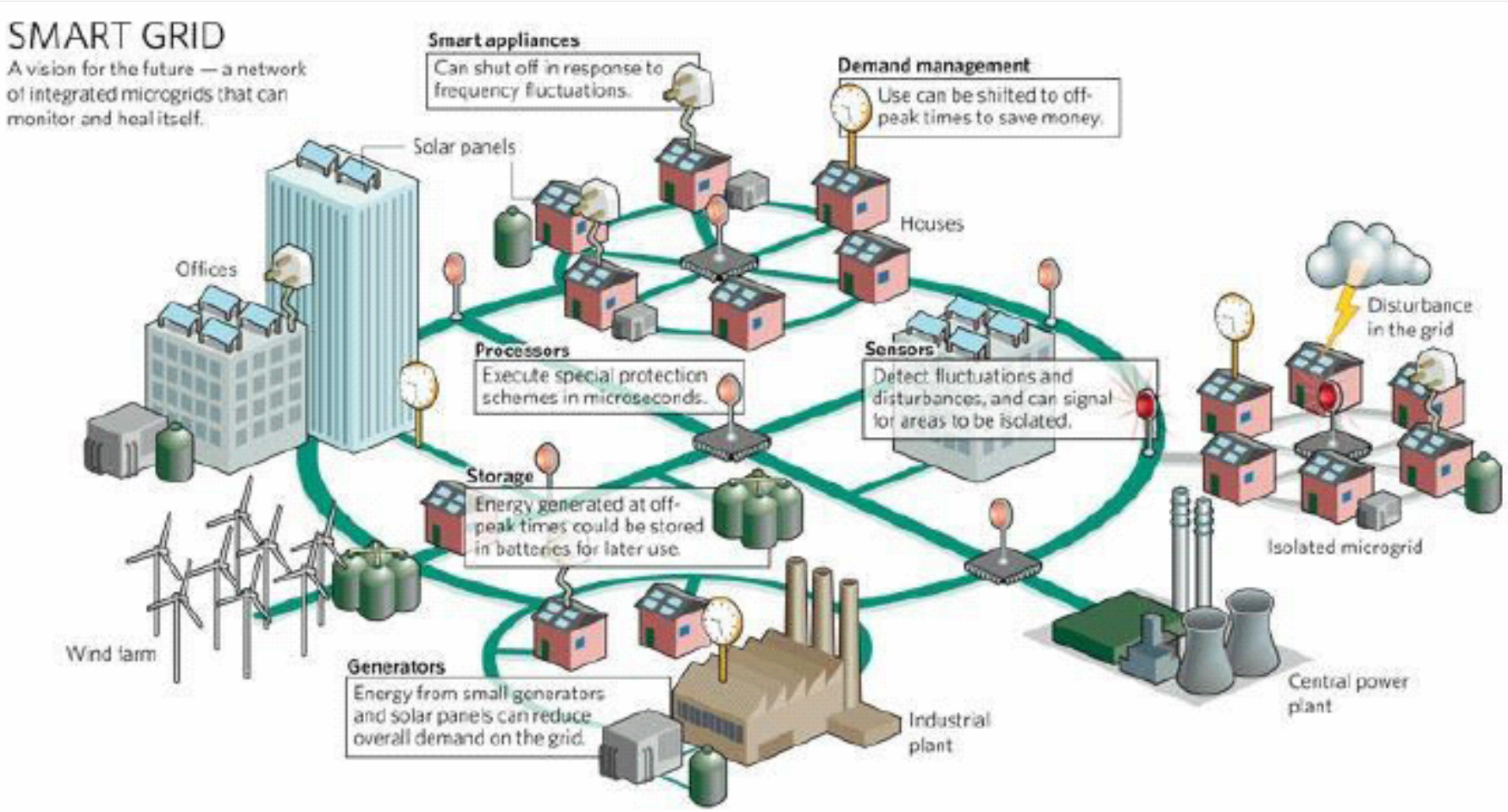
# Innovation: Beacon Power

- Carbon-fiber composite flywheel for short-term (15 min) energy storage
- Spins at 16000 RPM (surface speed Mach 2, or 1500 mph)
- Rotor works as motor or generator
- Participating in ISO NE market under Ancillary Services – Regulation Market to stabilize grid frequency
- Can respond within 5 seconds vs. 5-10 mins for fossil fuel plants
- Tyngsboro, MA public co.

# Innovation: A123 Systems

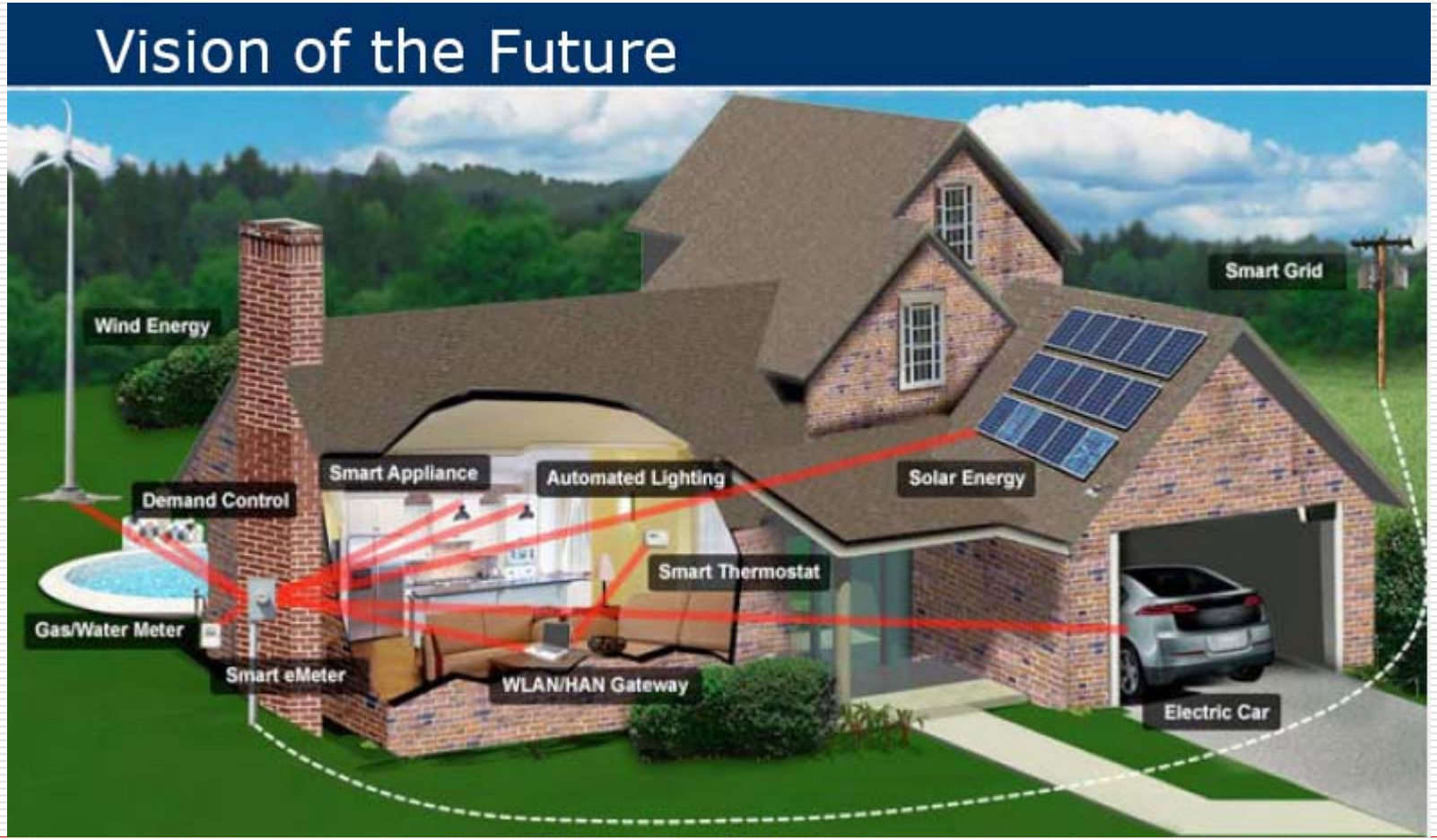
- Watertown, MA MIT spin-off, founded 2001
- Proprietary Nanophosphate™ tech built on new nanoscale materials for Li-Ion battery
- Target market: autos (HEV, PHEV, EV)
- Recent $249M ARRA grant for new US mfg for auto batteries – likely plant in MI
- So. Cal. Edison seeking $25M US grant to store wind power in largest-ever grid storage battery: small A123 batteries assembled in a 8000 s.f. bldg (Aug 26, 09)

# Smart Grid




National Renewable Energy Laboratory

# Smart Home




Bangor Hydro

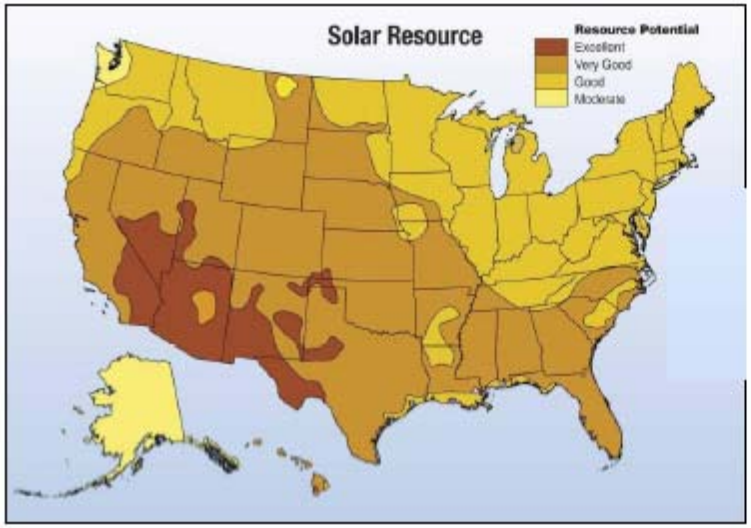
# Computers & Electricity

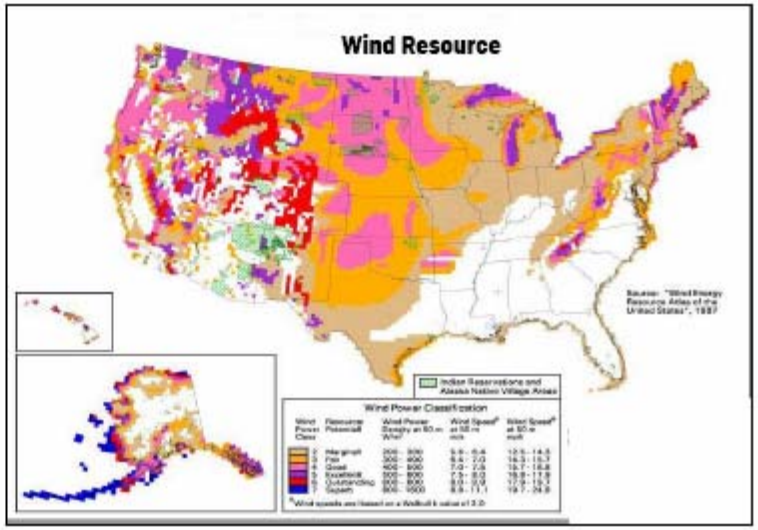
- US data centers use ~3% electric power
- 10k PCs left on overnight cause
  - $165k/yr in electric bills
  - 1380 Tons CO2 = driving a car for 2 months
- Desktops left on overnight in US waste approx. $1.7 B with 15 MTons CO2 emitted

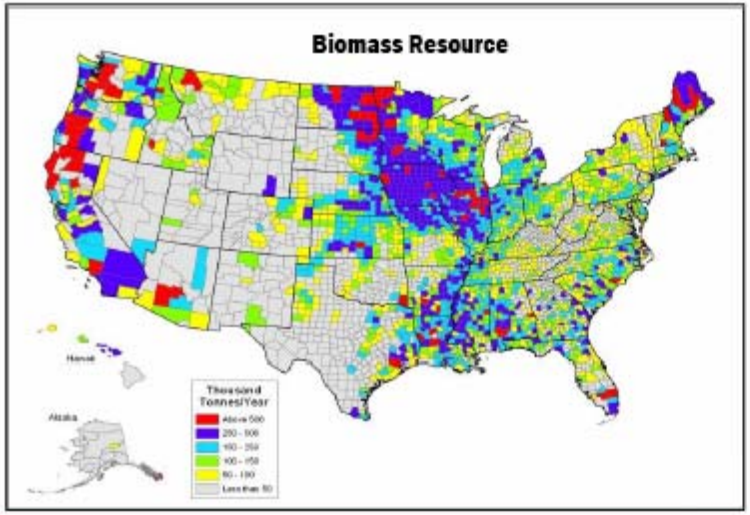
  http://online.wsj.com/article/SB10001424052970204908604574336280116296164.html
- HW & SW solutions in place & forthcoming
- Virtualization & cloud computing being pitched as “green” solutions

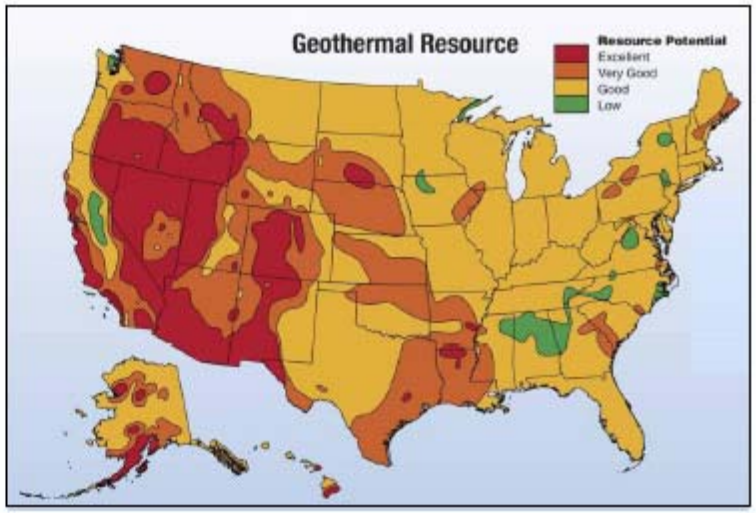
# Renewables Snapshot

# U.S. Renewable Energy Resources

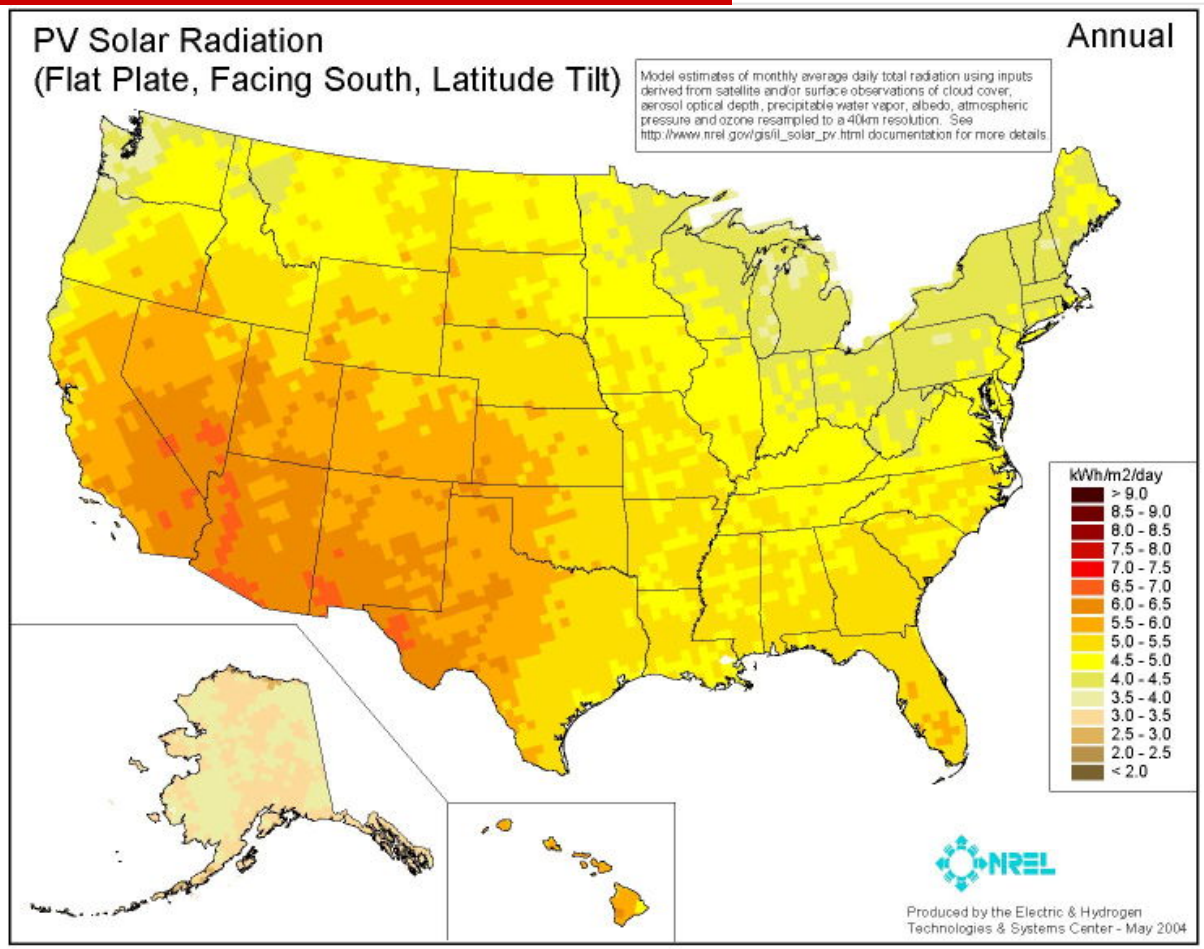


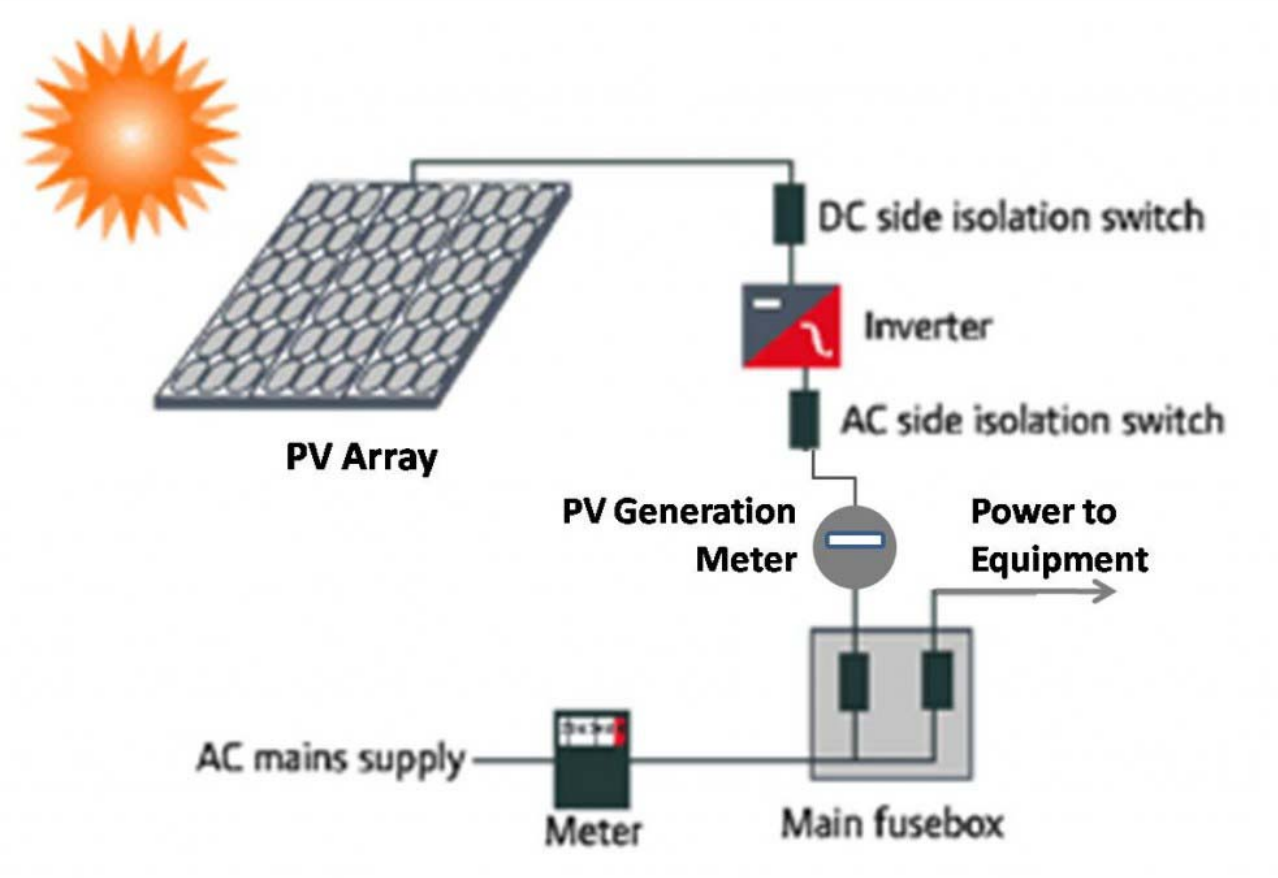



# US Solar Resource



# Solar PV – How It Works

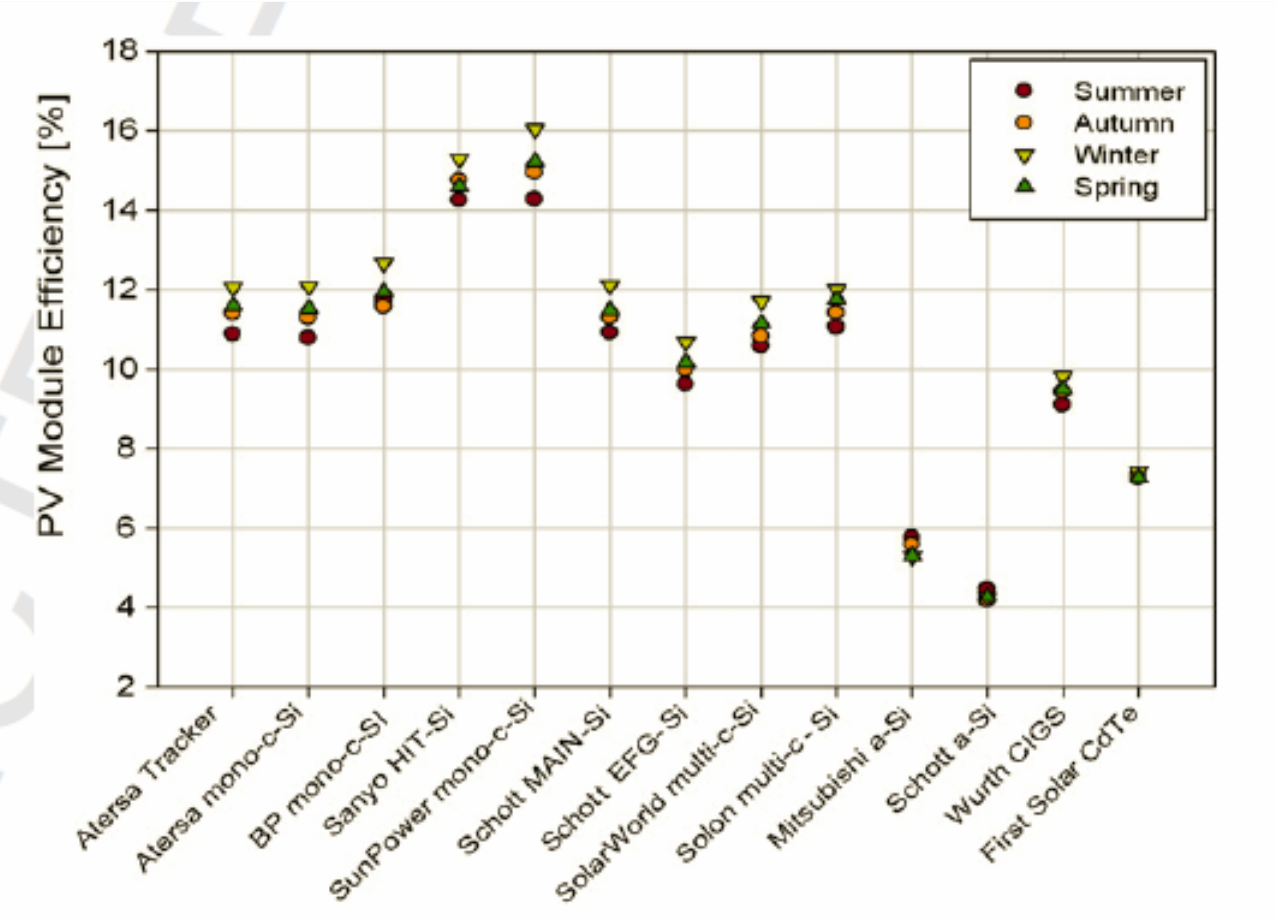


# Solar PV

- Available in many forms
- Crystalline theoretical max efficiency ~25%
  - In production today ~14-18%
- Thin film efficiency is ~6-11%
- Mfr's trying to lower costs through various techniques and improved conversion efficiency
- III-V semiconductor research promises 40-50% efficiency; some claim as high as 70% (??)
  - Multi-junction synthesized with 3rd & 5th periodic table group elements; e.g. GaAs, GaP, GaN, GaAlAs

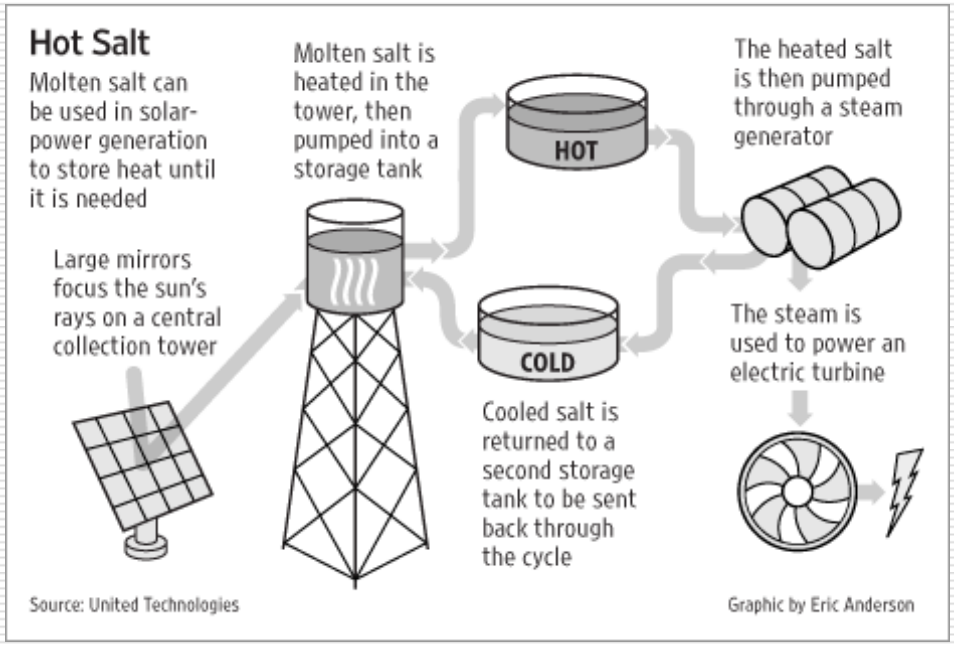
http://www.altenergystocks.com/archives/solar/

# PV Module Efficiencies




http://www.altenergystocks.com/archives/solar/

# Concentrated Solar Power - CSP



# Solar PV & CSP – US Status

- 1,000 MW PV installed capacity
  - Cost 18-23¢/kWh
- 419 MW CSP installed capacity
  - Cost 12¢/kWh
- PV potential
  - 11-18¢/kWh by 2010
  - 5-10 ¢/kWh by 2015
- CSP potential
  - 8.5 ¢/kWh by 2010
  - 6 ¢/kWh by 2015

US DOE, IEA

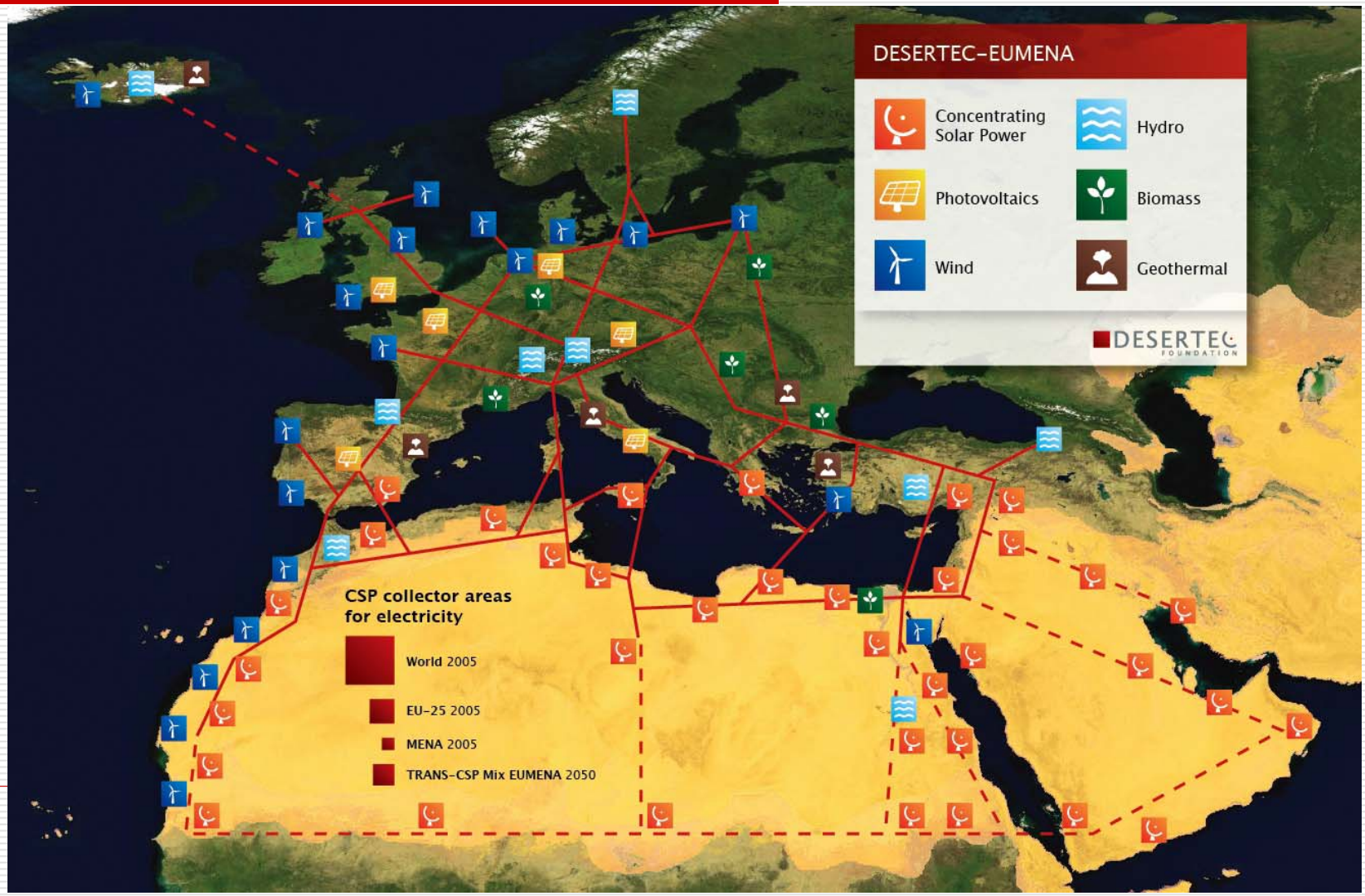
# Solar Future

- PV innovations continuing
- PV prices expected to drop to “grid parity” over the next 3-7 years – depending on who you believe
  - Competitive Gas/Oil prices the wildcard
- Hybrid systems may make a push
  - Get the most out of the solar energy in terms of electricity, heat and light

# Reaching For The Sun: DeserTec

- Sustainable energy for EU
- Energy, water and jobs for MENA
- €400B to progressively build solar thermal plants in MENA
  - €350B for power plants over 16900 $km^2$
  - €50B for transmission lines
  - Goal
    - Up and running by 2019
    - Complete in 2050
  - Provide 15% to 25% of Europe's electricity

# DeserTec Concept



# DeserTec Technologies

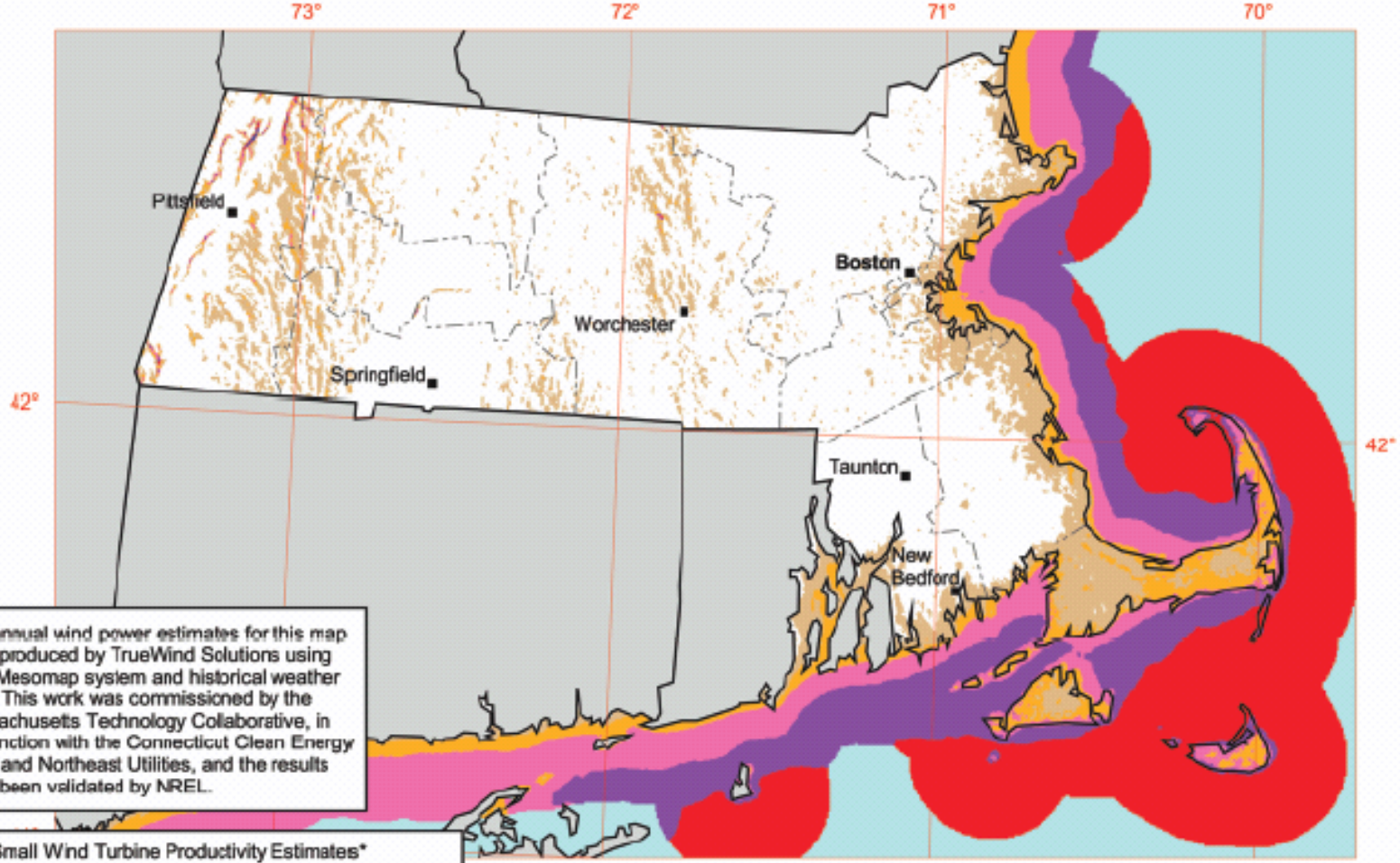
# Wind

- **Very cost effective when wind available**
- **Today's Status in U.S.**
  - 25,300 MW installed capacity
  - Cost 6-9¢/kWh at good wind sites*
- **DOE Cost Goals**
  - 3.6¢/kWh, onshore at low wind sites by 2012
  - 7¢/kWh, offshore in shallow water by 2014
- **Long Term Potential**
  - 20% of the nation's electricity supply

US DOE, AWEA

# Massachusetts

## Yearly Electricity Production Estimated per m$^2$ of Rotor Swept Area for a Small Wind Turbine




The annual wind power estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. This work was commissioned by the Massachusetts Technology Collaborative, in conjunction with the Connecticut Clean Energy Fund and Northeast Utilities, and the results have been validated by NREL.

### Small Wind Turbine Productivity Estimates*

| Wind Power Class | Productivity per m$^2$ of swept area** (kWh/year) | Wind Power Density at 33 ft (10 m) (W/m$^2$) | Wind Speed at 33 ft (10 m) (mph) | Wind Speed at 33 ft (10 m) (m/s) |
|---|---|---|---|---|
| 1 | < 350 | <100 | < 9.8 | < 4.4 |
| 2 | 350 - 500 | 100 - 150 | 9.8 - 11.5 | 4.4 - 5.1 |
| 3 | 500 - 610 | 150 - 200 | 11.5 - 12.5 | 5.1 - 5.6 |
| 4 | 610 - 690 | 200 - 250 | 12.5 - 13.4 | 5.6 - 6.0 |
| 5 | 690 - 770 | 250 - 300 | 13.4 - 14.3 | 6.0 - 6.4 |
| 6 | 770 - 860 | 300 - 400 | 14.3 - 15.7 | 6.4 - 7.0 |

* Estimates are based on different models and sizes of wind turbines assuming a tower height of 80 ft (24 m).

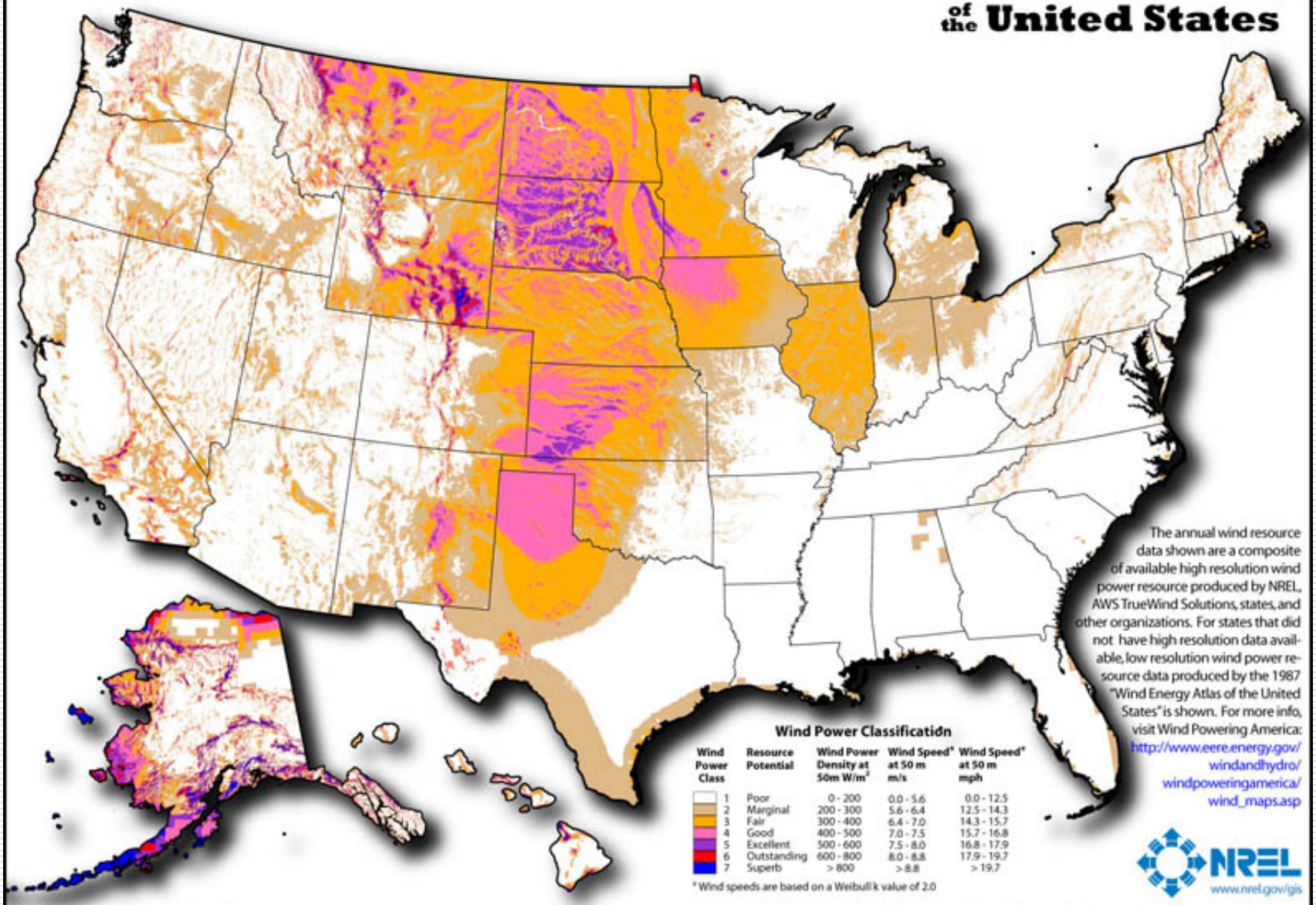
** For systems of different sizes, multiply the estimated productivity by the total swept area of the turbine.

U.S. Department of Energy
National Renewable Energy Laboratory

NREL

04-JUN-2003 21.2

# Wind Resource (50m)
## of the United States



The annual wind resource data shown are a composite of available high resolution wind power resource produced by NREL, AWS TrueWind Solutions, states, and other organizations. For states that did not have high resolution data available, low resolution wind power resource data produced by the 1987 "Wind Energy Atlas of the United States" is shown. For more info, visit Wind Powering America: http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp

**Wind Power Classification**

| Wind Power Class | Resource Potential | Wind Power Density at 50m W/m² | Wind Speed* at 50 m m/s | Wind Speed* at 50 m mph |
|---|---|---|---|---|
| 1 | Poor | 0 - 200 | 0.0 - 5.6 | 0.0 - 12.5 |
| 2 | Marginal | 200 - 300 | 5.6 - 6.4 | 12.5 - 14.3 |
| 3 | Fair | 300 - 400 | 6.4 - 7.0 | 14.3 - 15.7 |
| 4 | Good | 400 - 500 | 7.0 - 7.5 | 15.7 - 16.8 |
| 5 | Excellent | 500 - 600 | 7.5 - 8.0 | 16.8 - 17.9 |
| 6 | Outstanding | 600 - 800 | 8.0 - 8.8 | 17.9 - 19.7 |
| 7 | Superb | > 800 | > 8.8 | > 19.7 |

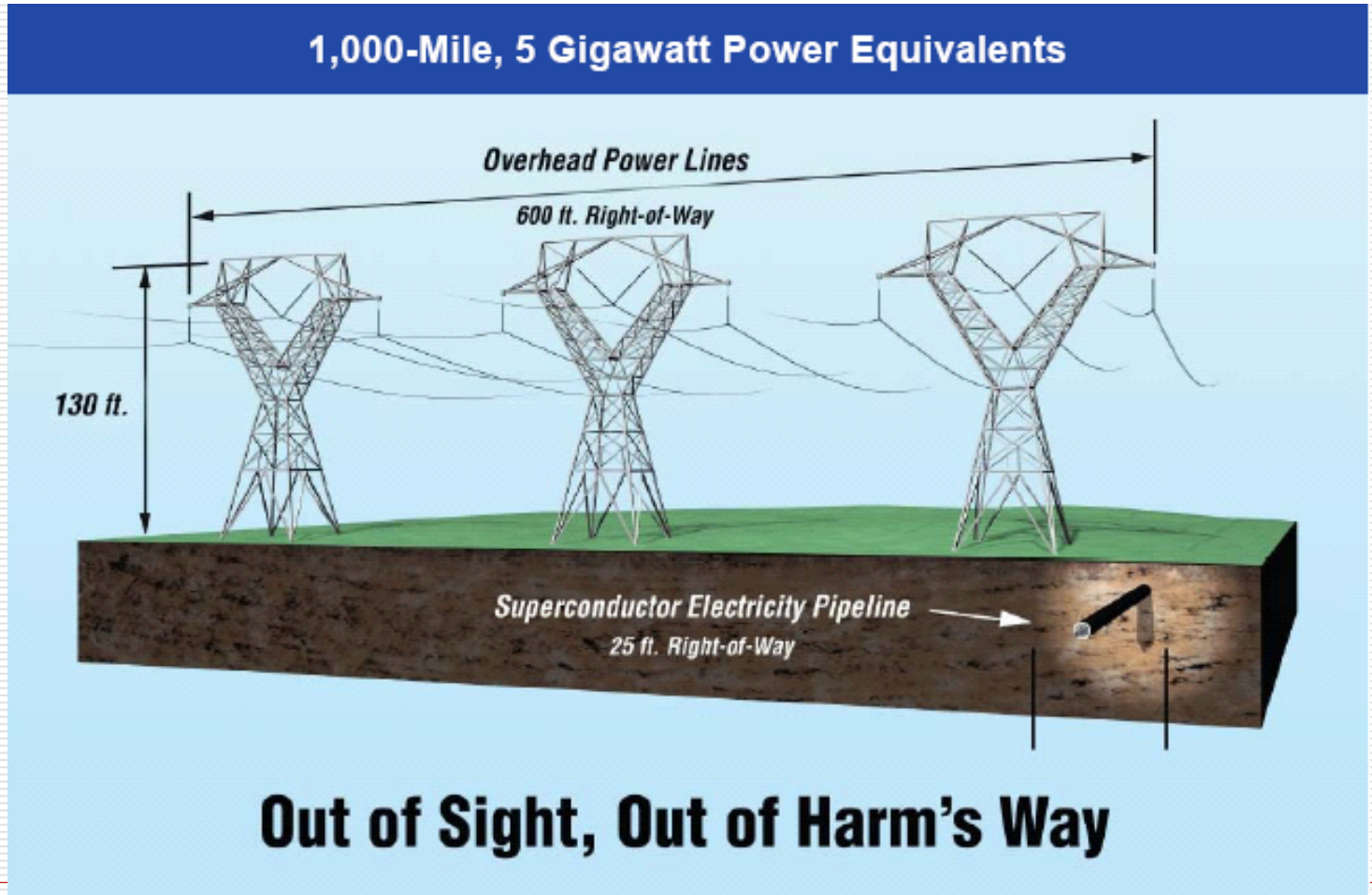
* Wind speeds are based on a Weibull k value of 2.0

NREL
www.nrel.gov/gis

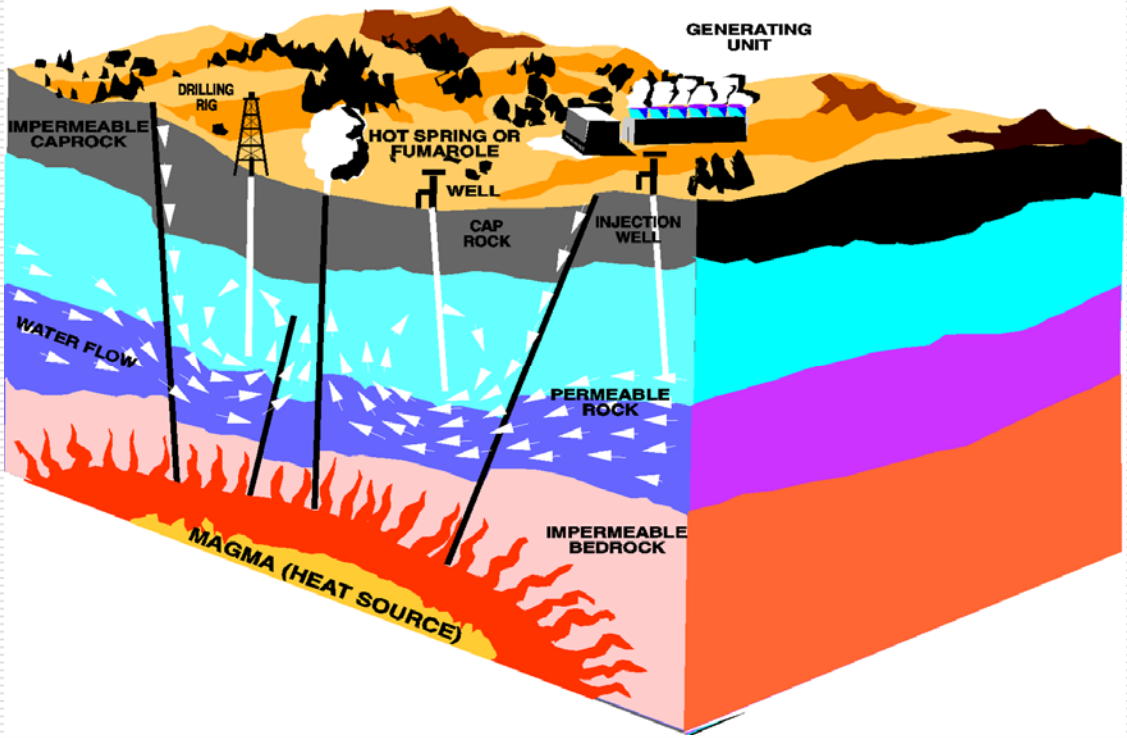
Author : Billy Roberts - December 12, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

# Innovation: American Superconductor



# Geothermal




- **Utility-scale requires very deep drilling**
- **US biggest global producer with ~6000 MWe**
- **Iceland has 440 MWe**
- **Residential plants can be very effective, but high capital cost**

# Geothermal

## Today's Status in U.S.

- 2,800 MWe installed, 500 MWe new contracts, 3000 MWe under development
- Cost 5-8¢/kWh with no PTC
- Capacity factor typically > 90%, base load power

## DOE Cost Goals:

- <5¢/kWh, for typical hydrothermal sites
- 5¢/kWh, for enhanced geothermal systems with mature technology

## Long Term Potential:

- Recent MIT Analysis shows potential for 100,000 MW installed Enhanced Geothermal Power systems by 2050, cost-competitive with coal-powered generation

## NREL Research Thrusts:

- Analysis to define the technology path to commercialization of Enhanced Geothermal Systems
- Low temperature conversion cycles
- Better performing, lower cost components
- Innovative materials

# Biofuels

## Current Biofuels Status in U.S.

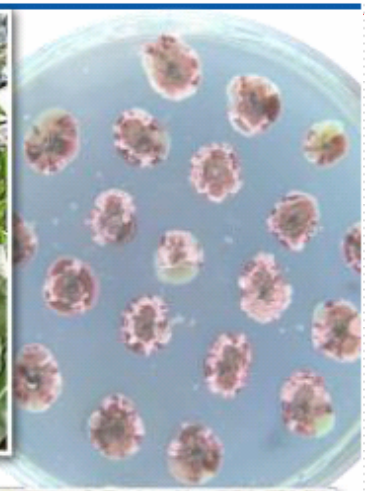
- Biodiesel – 171 companies; 2.2 billion gallons/yr capacity1
- Corn ethanol
  - 174 commercial plants2
  - 10.8 billion gal/yr. capacity2
  - Additional 2.4 billion gal/yr planned or under construction
- Cellulosic ethanol (current technology)
  - Projected commercial cost ~$3.50/gge

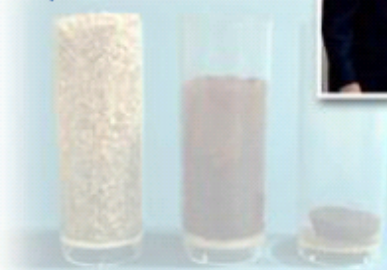
## Key DOE Goals

- 2012 goal: cellulosic ethanol $1.33/ETOH gallon or ~$1.99/gge
- 2022 goal: 36B gal Renewable Fuel; 21B gal "Advanced Renewable Fuel"– 2007 Energy Independence and Security Act
- 2030 goal: 60 billion gal ethanol (30% of 2004 gasoline)

## NREL Research Thrusts

- The biorefinery and cellulosic ethanol
- Solutions to under-utilized waste residues
- Energy crops
- New biofuels






Updated February 2009
Sources: 1- National Biodiesel Board
2 - Renewable Fuels Association, all other information based on DOE and USDA sources

# A Word On Water & Other Resources

- Water supply quickly becoming major issue in many parts of the world
- Water-related energy/yr in California
  - 19% of state's electricity
  - 30% of natural gas
  - 88 B gallons of diesel

**California Energy Commission, Nov 2005**

# Innovation: AEB

- Advanced Electron Beam: www.aeb.com
- Wilmington, MA
- Working on in-line sterilization of PET bottles using new gen electron beam wand
- Saves electricity, water and/or materials

# Innovation: Aspen Aerogels

- Nanomaterial insulation, with 97% volume as trapped air
- Cryogel for Low temps
- Pyrogel for High temps
- 2-5 times thinner than competitive products
- Environmentally friendly
- Northboro, MA

# Some Opportunity Areas

- Energy storage
  - For instance, lower cost, highly efficient battery storage for PHEV or EV
- Harnessing waste heat
- Energy efficiency, demand reduction
- Industrial waste water treatment & harvesting
- Lower cost/Watt PV
- Low cost, efficient geothermal drilling

*Thank You*

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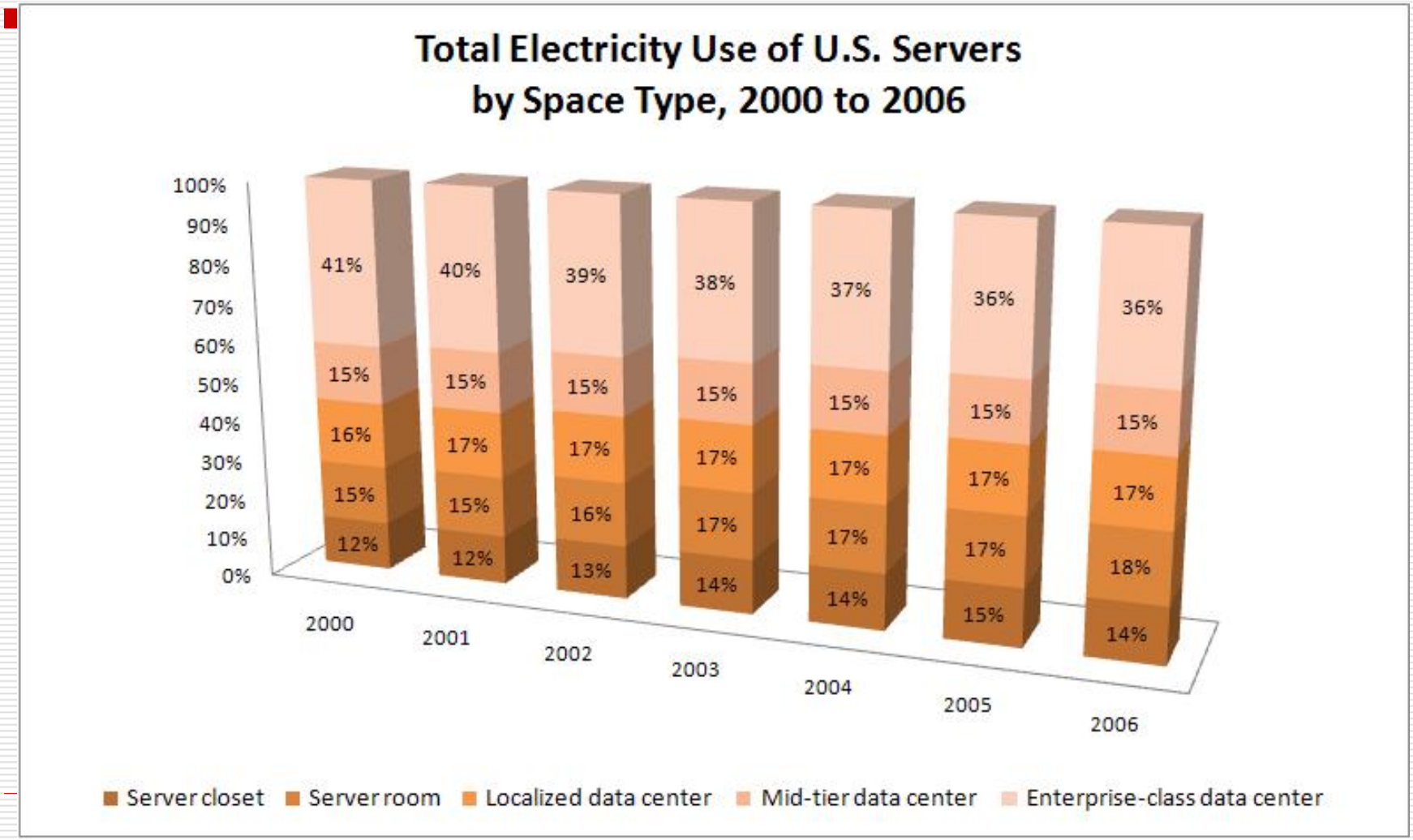
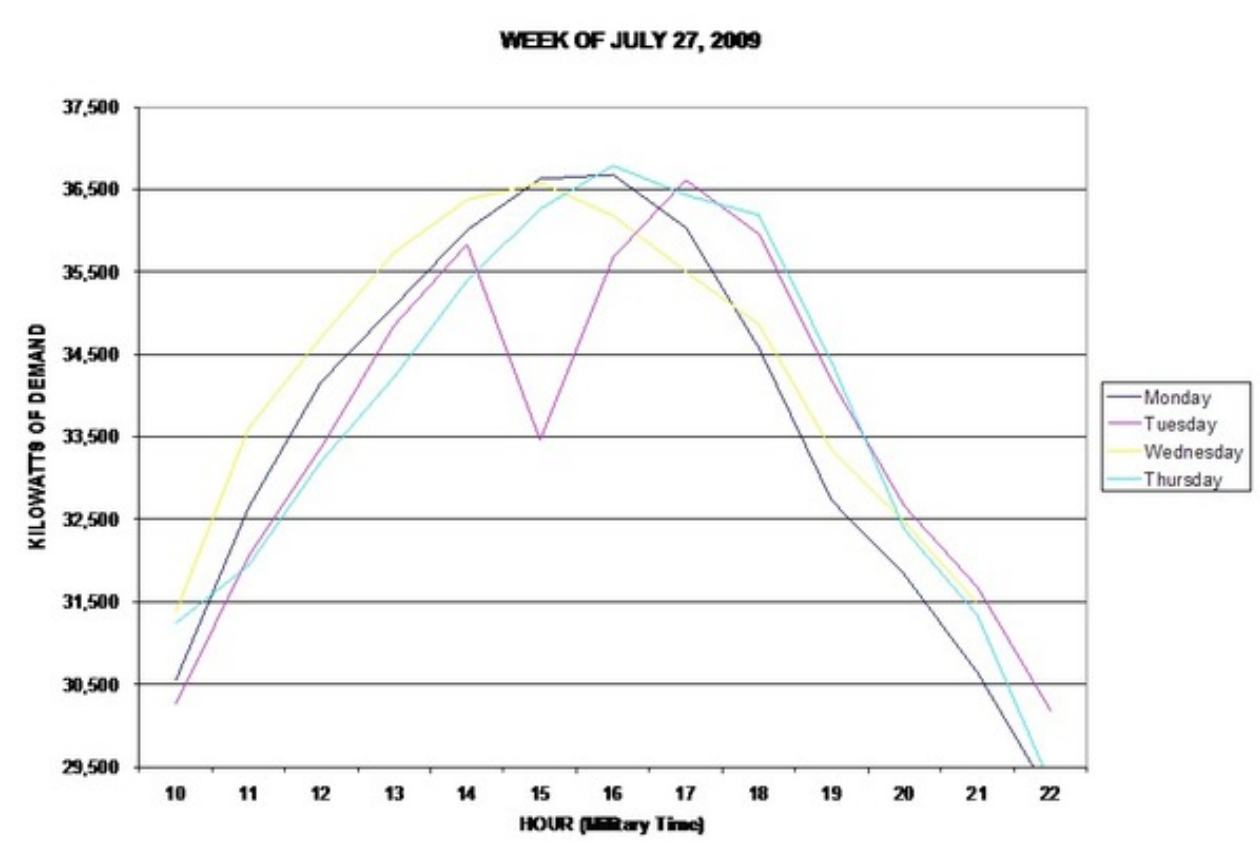
# Resources: Chris Jordan

- I attended the first Greener Gadgets conf in NYC in Feb 2008
- Worth watching video of Chris Jordan's address:
  - Blip TV
  - YouTube
- Chris has other material on YouTube as well

# Servers & Electricity



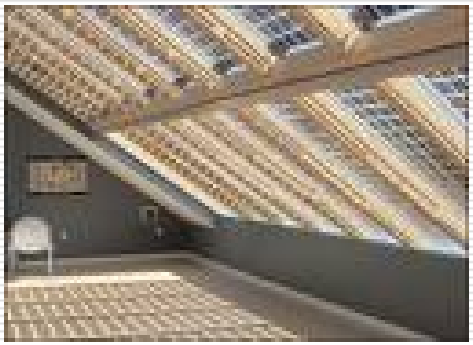
# Daily Electricity Demand Curve

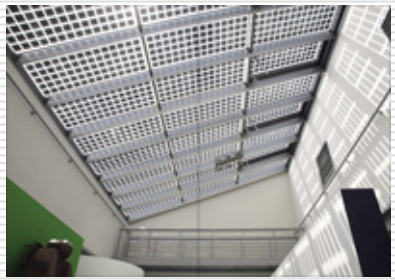



**Concord, MA MLP**

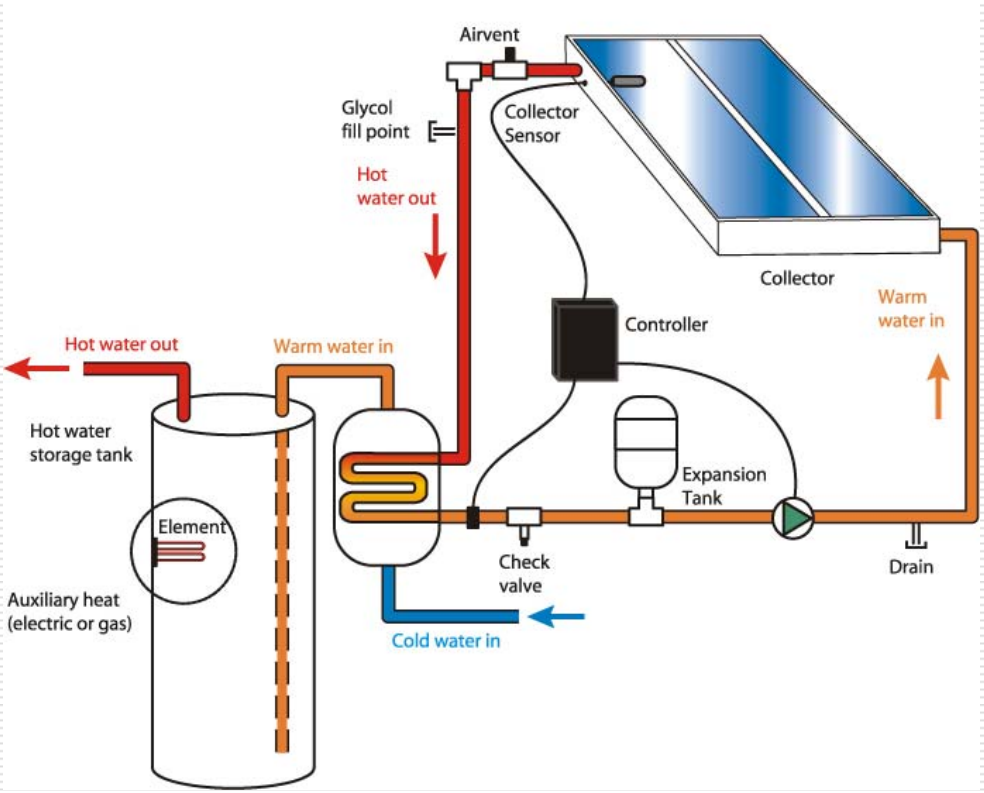
- **Not part of ISO NE**

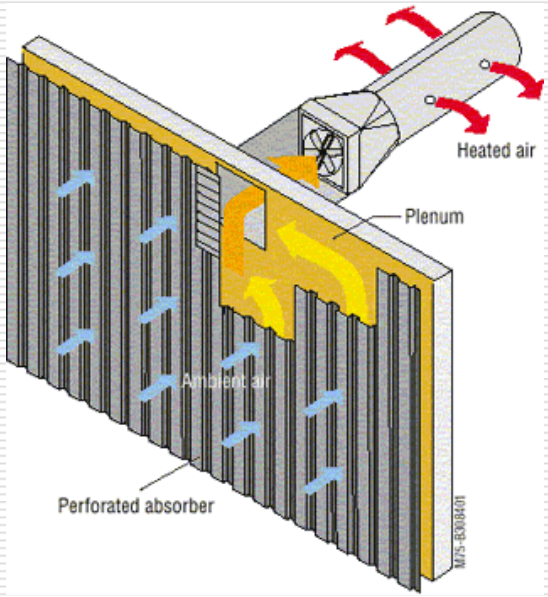
# BIPV (Building Integrated)





# Solar Thermal – Air or Water



# Solar Hybrid – Many Variations

# Solar Hybrid Lighting