SAND2010-7390C

Renewable Energy Overview

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Energy and Infrastructure Future
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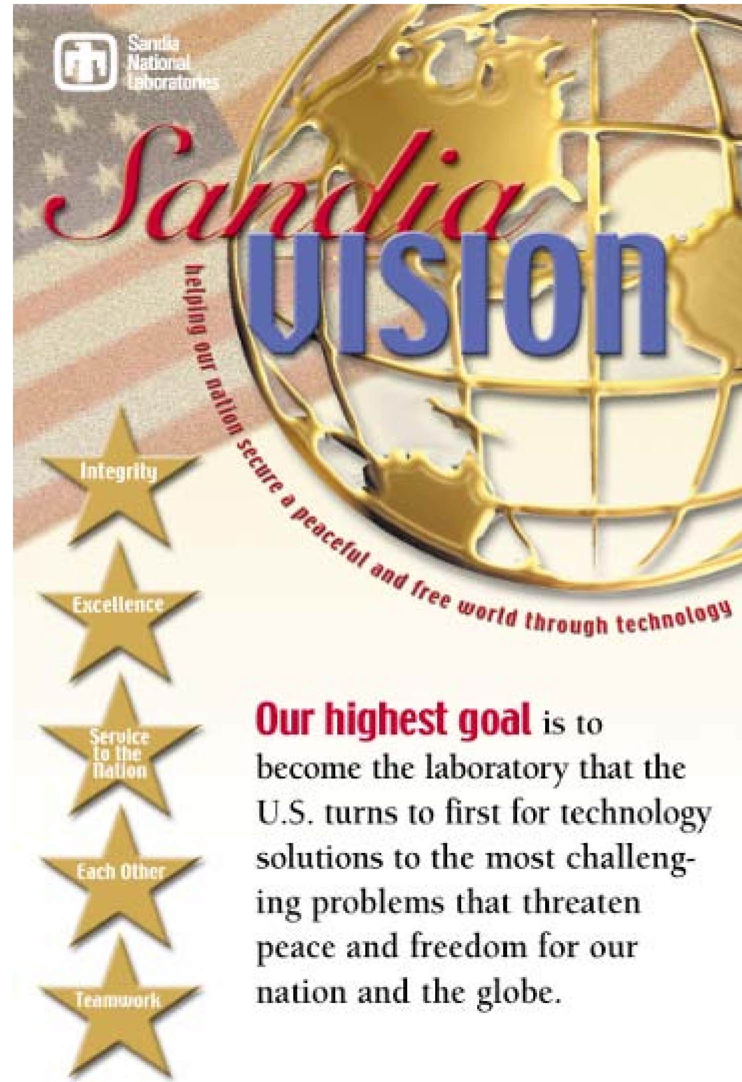
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

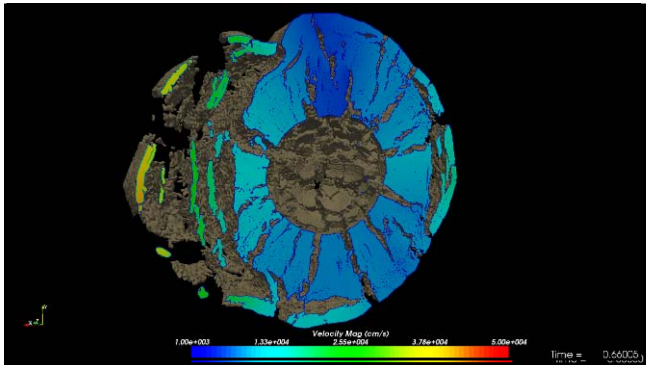
Introduction

Our Business: National Security

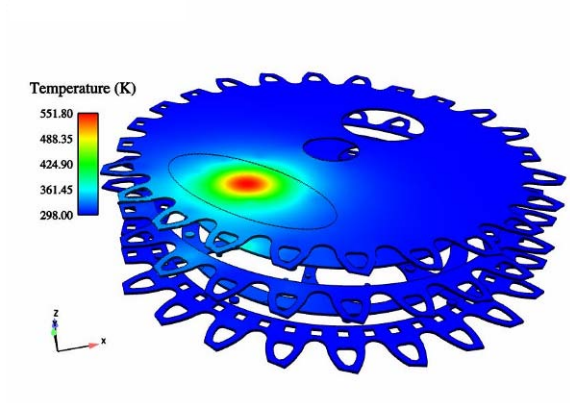
- **Broad mission in developing science and technology applications to meet our rapidly changing, complex national security challenges**
- **Safety, security and reliability of our nation's nuclear weapon stockpile**



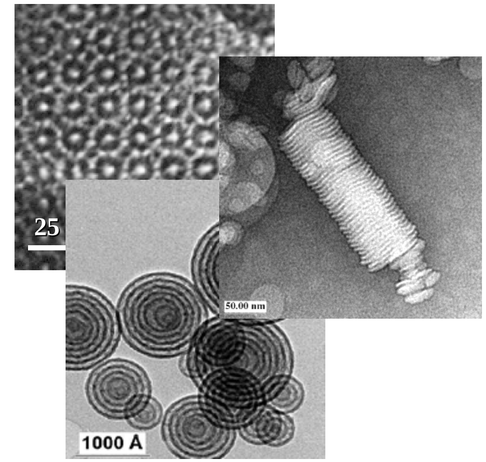
Our Mission Focus Relies on Strong Science and Engineering



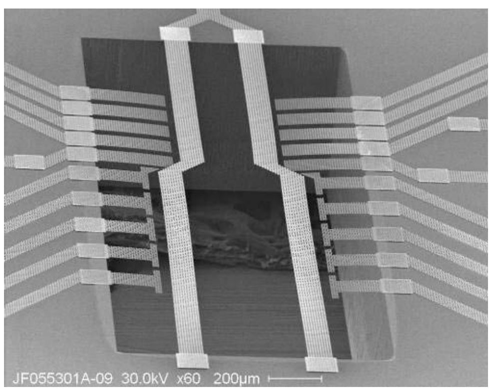
Computational and Information sciences



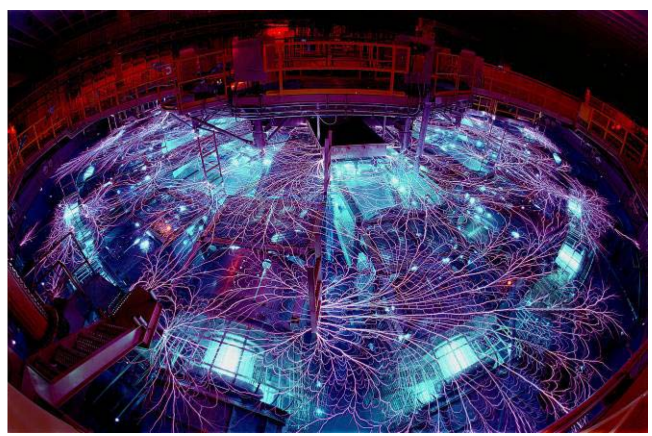
Engineering Sciences



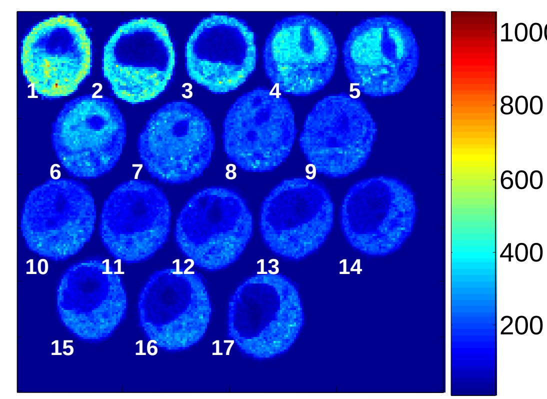
Materials Science and Technology



Microelectronics and Photonics



Pulsed Power



Bioscience

NNSA National Nuclear Security Administration

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Distributed Facilities

Albuquerque,
New Mexico

Tonopah Test Range,
Nevada

Kauai Test Facility,
Hawaii

Livermore, California

Yucca Mountain,
Nevada

WIPP, New Mexico

Pantex, Texas

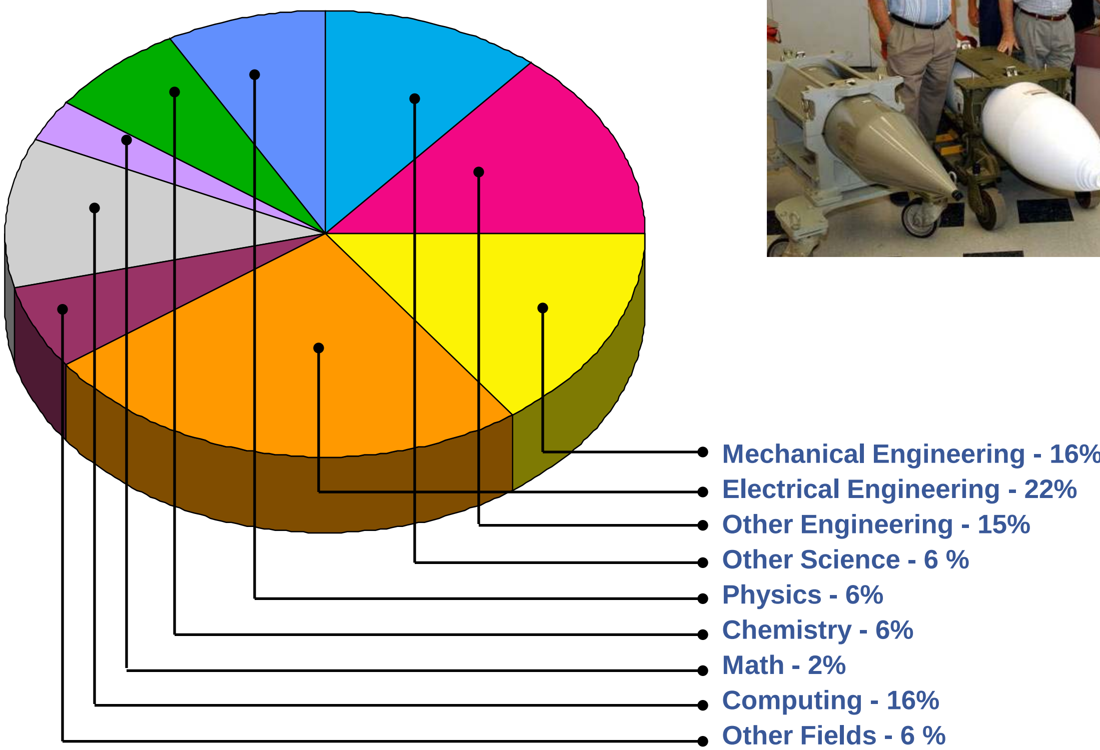
Unparalleled Large-Scale Facilities and Test Capabilities

- User facilities
- Designated national capabilities
- Z-Machine and radiation effects
- Real-life physical test ranges

Sandia National Laboratories

Highly Skilled Workforce

- More than 8,600 full-time employees
- More than 1,500 PhDs and 2,700 MS/MAs
- 2,200 on-site contractors
- $2.7 billion FY08 total budget



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Center for Integrated Nanotechnologies

Sandia National Laboratories • Los Alamos National Laboratory

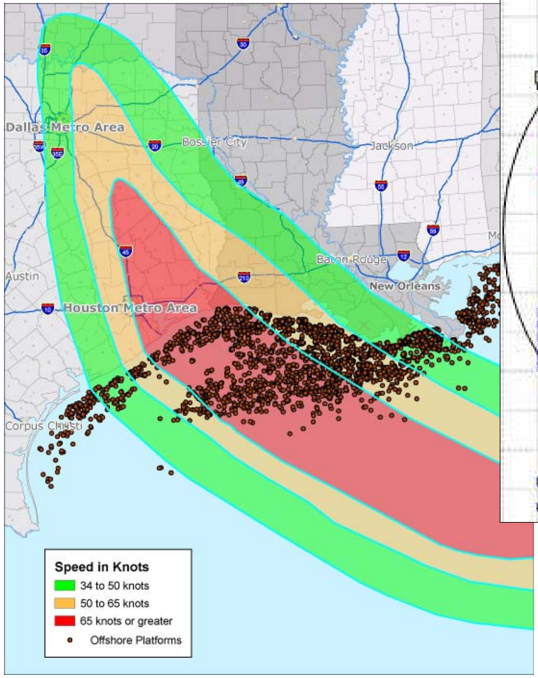
- DOE National User Facility
- Science focus on barriers to integrating nanoscience into the world around us.
- New dedicated facilities & leverage existing DOE investment
- User program for open access to tools and expertise.
- Jump Start user projects

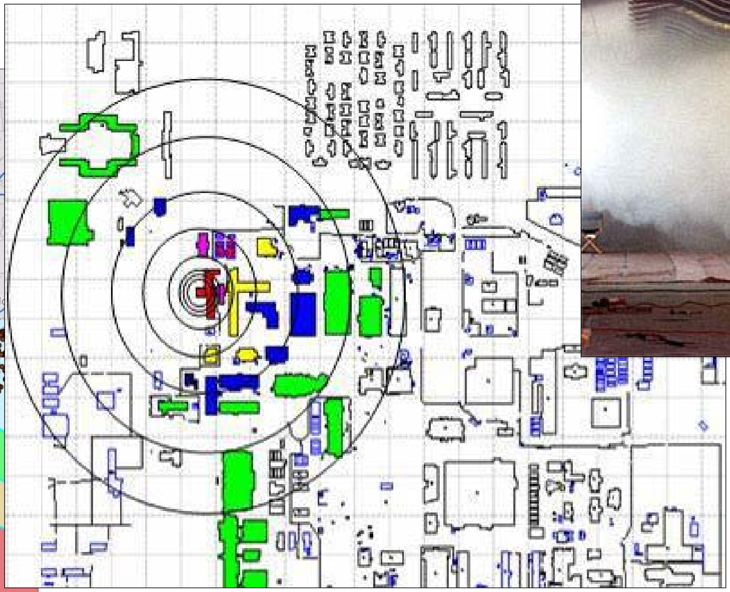
"One scientific community focused on nanoscience integration"

Homeland Security and Defense

Mitigating the risk of catastrophic events and enhancing the nation's ability to respond and recover

Risk Management and Infrastructure Protection





Catastrophic Event Mitigation

Homeland Defense and Force Protection

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Catastrophic Event Mitigation

- Chemical and Biological Countermeasures
- Radiological and Nuclear Countermeasures
- Explosives Countermeasures
- Information Analysis
- Red Teaming
- Border and Transportation Security
- Systems Analysis

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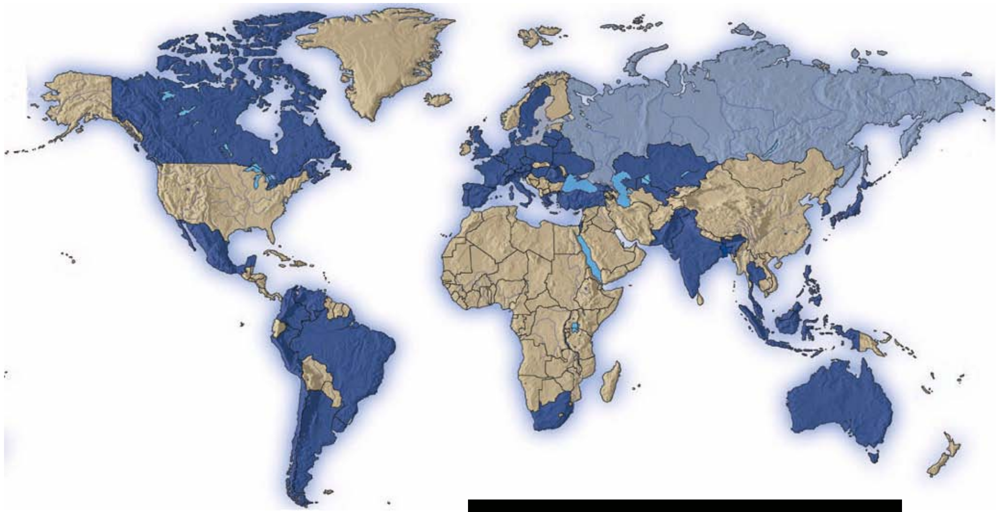
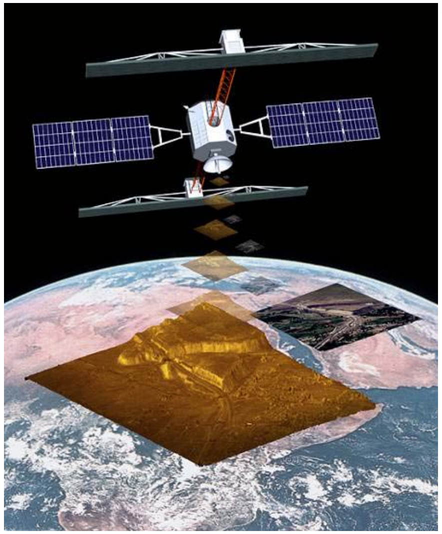
Energy, Resources, and Nonproliferation

Making the World a Safer Place



- Technologies for detecting proliferation activities
- Performance and vulnerability assessments
- Monitoring and verification
- Cooperative international security programs
- Physical security



CMC

National Nuclear Security Administration

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Energy, Resources, and Nonproliferation

Energy, Water, and Security Enabled by Science & Technology

- **Secure energy supplies for national security**
- **Clean, abundant and affordable energy**
- **Water research**
- **Infrastructure protection**

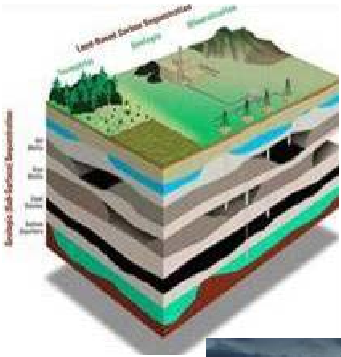




Energy Policy Act of 2005

- Encourages Expanded Energy Supplies (Fossil, Renewables, Nuclear and Hydrogen)
- Supports Siting New Nuclear Power Plants
- Enhances Liquefied Natural Gas (LNG) Facility Siting
- Vehicle Efficiency
- Improved Electric Grid Reliability
- Lighting

Energy Futures Program



Develop and Demonstrate Persistent Energy Sources – Electricity and Transportation
Create a Flexible and Enabling Energy Infrastructure
Enhance Energy Storage Capabilities

Renewable Energy and Storage Activities

- Concentrating Solar Power

- Wind

- Energy Storage

- Photovoltaics

- Geothermal

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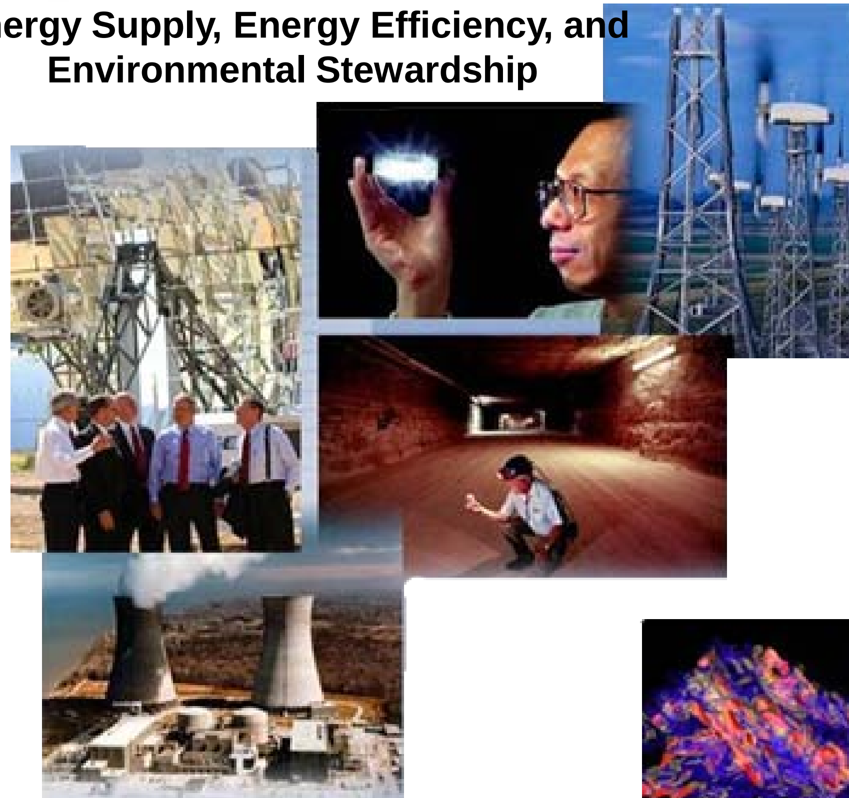
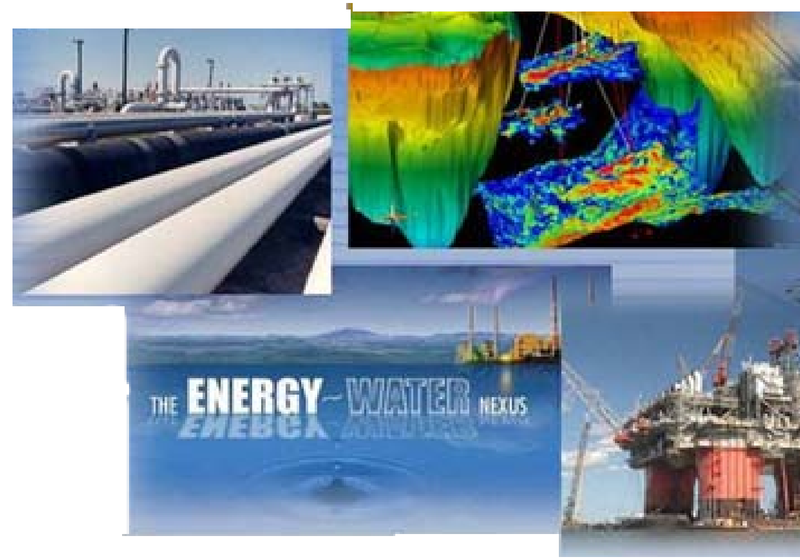
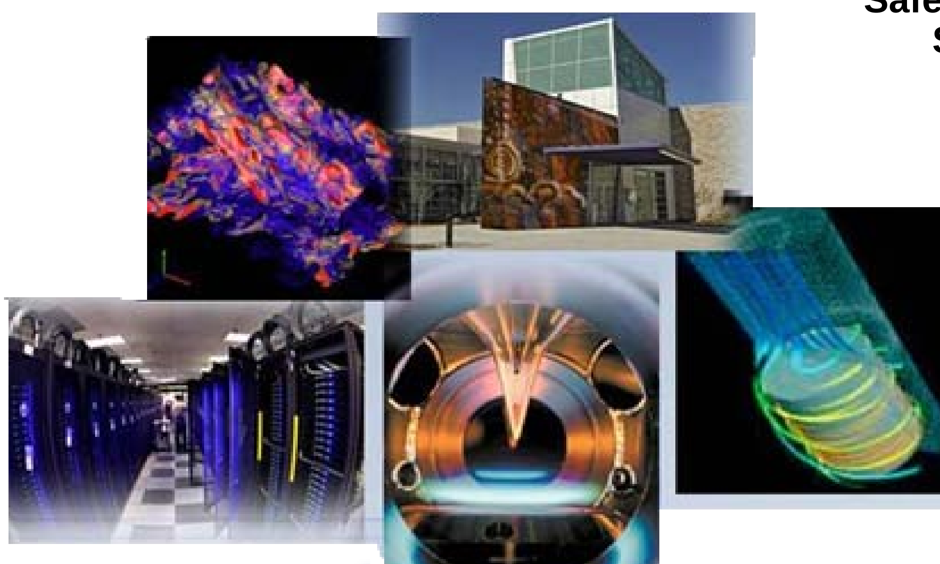
Sandia National Laboratories are Contributing to Our Nation's Energy Future

Energy Supply, Energy Efficiency, and Environmental Stewardship





Safe, Secure, Reliable Energy Supply and Infrastructure



Science and Technology

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Energy

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What is energy?

Energy: the ability to do work

or

the ability to make something happen

Forms of Energy

kinetic

potential

light

chemical

electromagnetic

sound

nuclear

mass

thermal

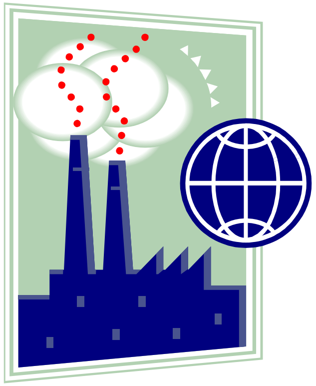
First Law of Thermodynamics

also called: *conservation of energy*

"energy cannot be created or destroyed, it can only be changed from one form to another"

Primary Energy Uses

Heating/Cooking/Industrial



Transportation

Electricity

Heating/ Cooking/ Industrial

coal
natural gas
solar
electricity
oil
geothermal
biomass

Transportation

oil
biofuel?
synfuel?

We are "over a barrel"

Electric cars, H_2 cars
plug-in hybrid cars

Electricity

coal
natural gas
solar
wind
oil
landfill gas
geothermal
nuclear
hydro
biomass

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Heating/ Cooking/ Industrial	Transportation	Electricity
coal	coal	coal
natural gas	natural gas	natural gas
solar	solar	solar
electricity	wind	wind
oil	oil	oil
geothermal	landfill gas	landfill gas
biomass	geothermal	geothermal
	nuclear	nuclear
	hydro	hydro
	biomass	biomass

Electric cars, H_2 cars
plug-in hybrid cars

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Electricity

coal

natural gas

solar

wind

oil

landfill gas

geothermal

nuclear

hydro

biomass

Energy and Power

Units of Energy

joule - one newton acting through one meter

1 joule =

0.239 calorie (1g H_2O ↑ 1°C)
0.000239 Calorie
0.000948 BTU

In practice, global energy use is not usually discussed in units of energy (joules, Calories, BTU)

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Power

Power is the *rate* of energy use

W = watt = one joule per second = $\frac{\text{joule}}{\text{second}}$

kW = kilowatt = 1000 watts
MW = megawatt = 1,000,000 watts
GW = gigawatt = 1,000,000,000 watts
TW = terawatt = 1,000,000,000,000 watts

Power x Time = Energy

If energy is being used at a constant rate (power) for a given amount of time, then you can determine the total amount of energy used

$$\frac{\text{joule}}{\text{second}} \times \text{second} = \text{joule}$$

$$\frac{\text{1000 joules}}{\text{second}} \times \text{3600 seconds} = \text{3,600,000 joules}$$

kW x hour = “kWh” = 3.6 MJ

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(very) Brief Energy History

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Energy and Infrastructure Future

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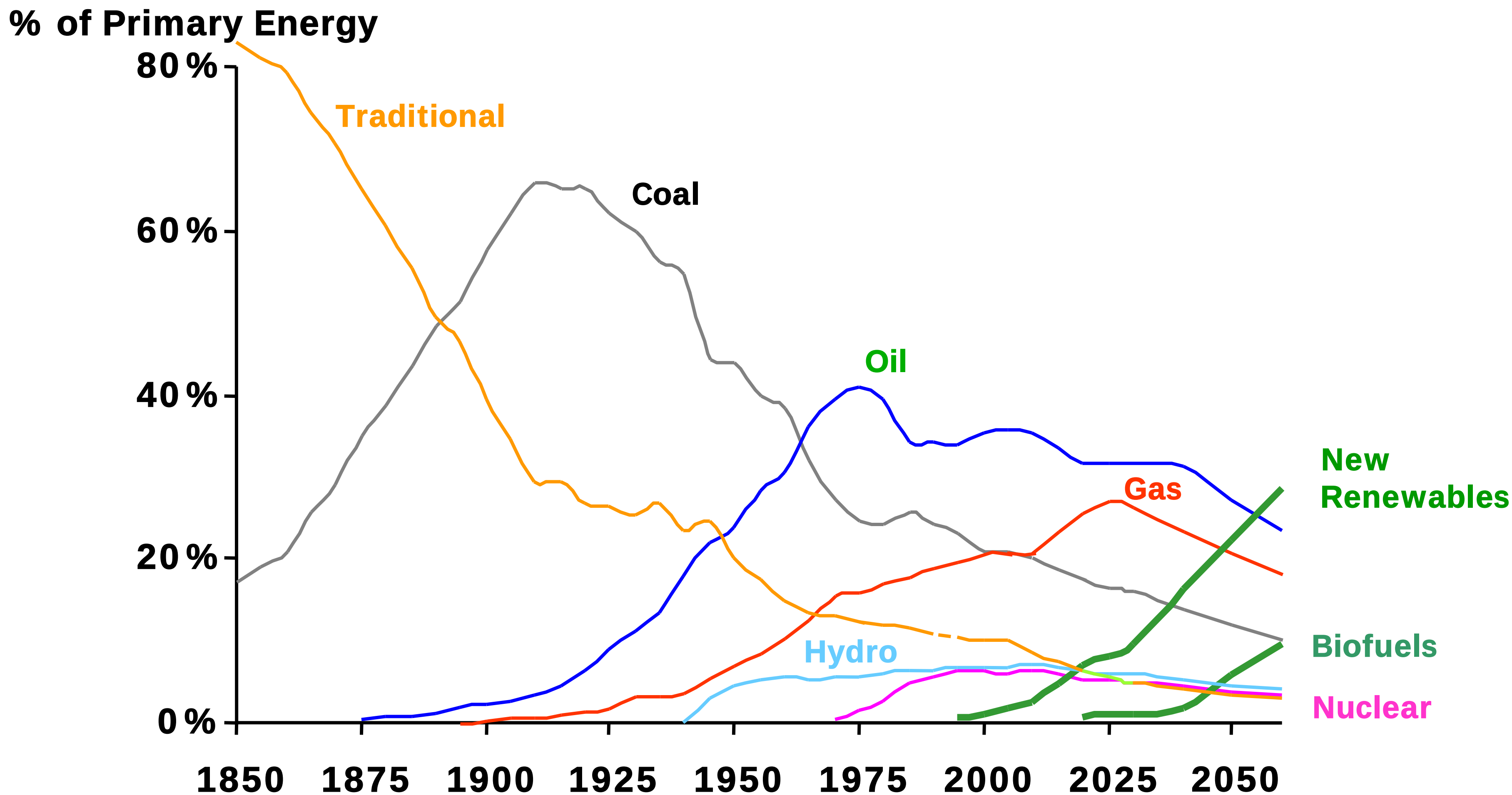
Acknowledgments: Mike Hightower (SNL), Paul Pickard (SNL)

Primary Energy
Global History and Forecast



History

Shell Global Scenarios

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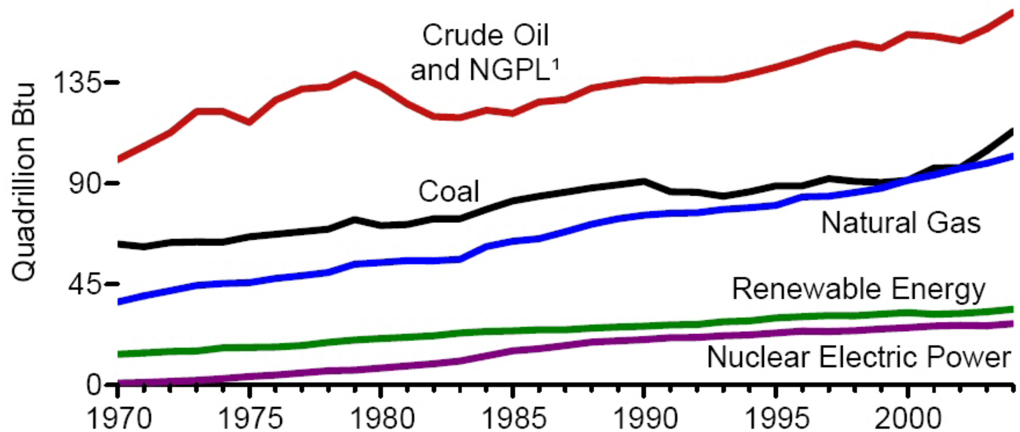
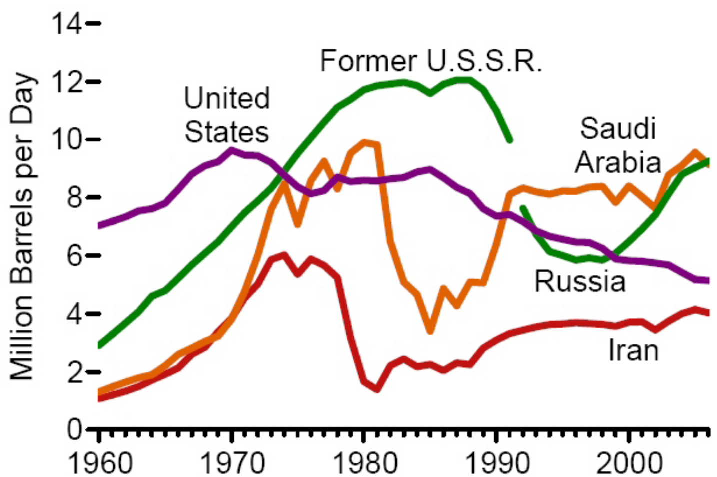
Recent History

Global

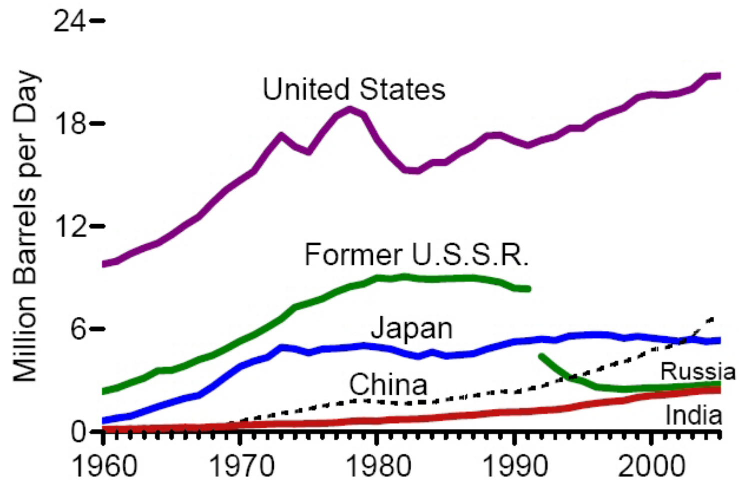
Primary Energy Production by Source



Leading Crude Oil Producers



Leading Petroleum Consumers

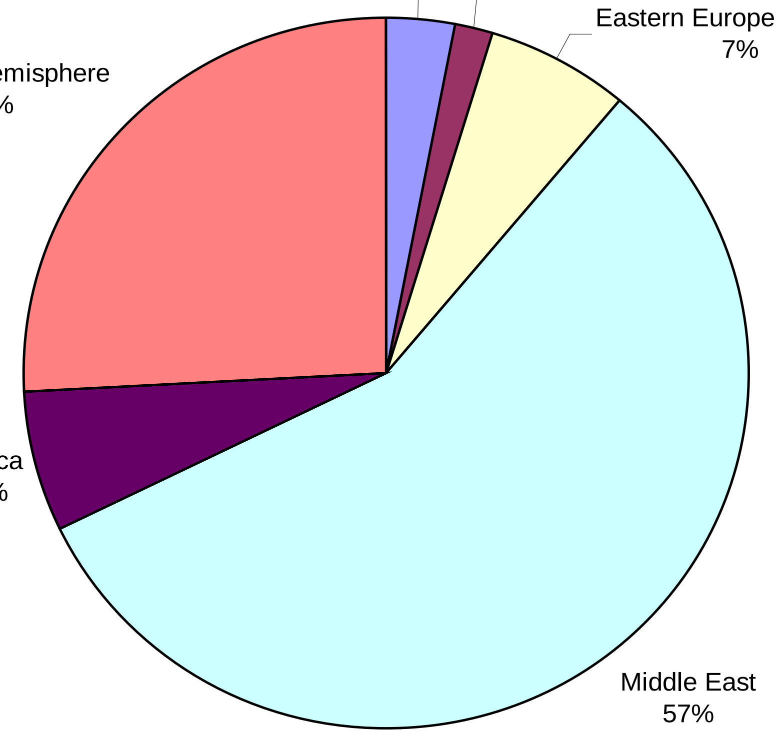


DOE/EIA Annual Energy Review 2006

World Oil Reserves

- Oil – Middle East and Western Hemisphere
- Middle East of Gas-Russia
- Middle East of Coal-United States
- Energy reserves vary based on costs and technology improvements

Percentages of World Oil Reserves in 2002 by Region



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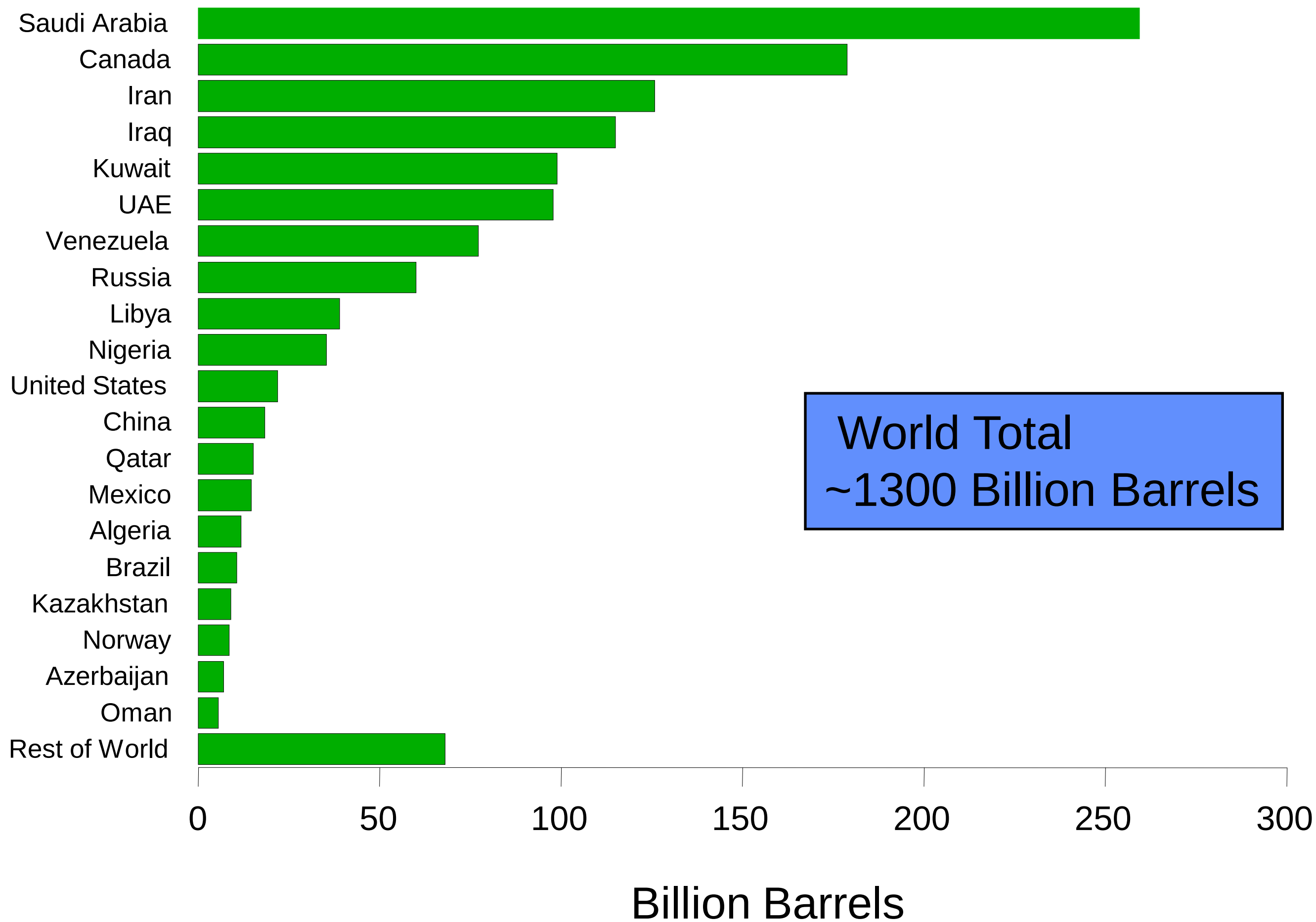
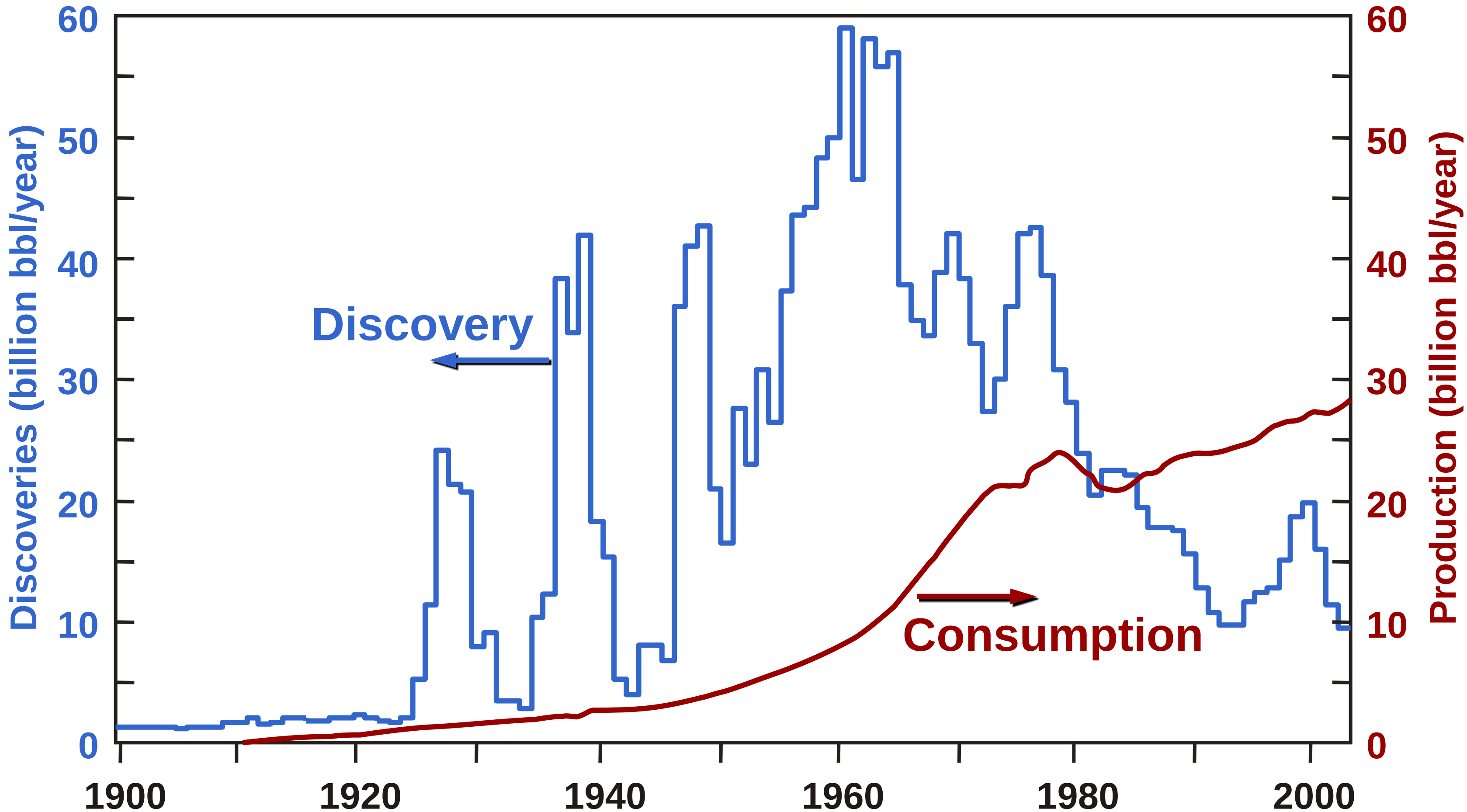
World Oil Reserves by Country as of January 2005

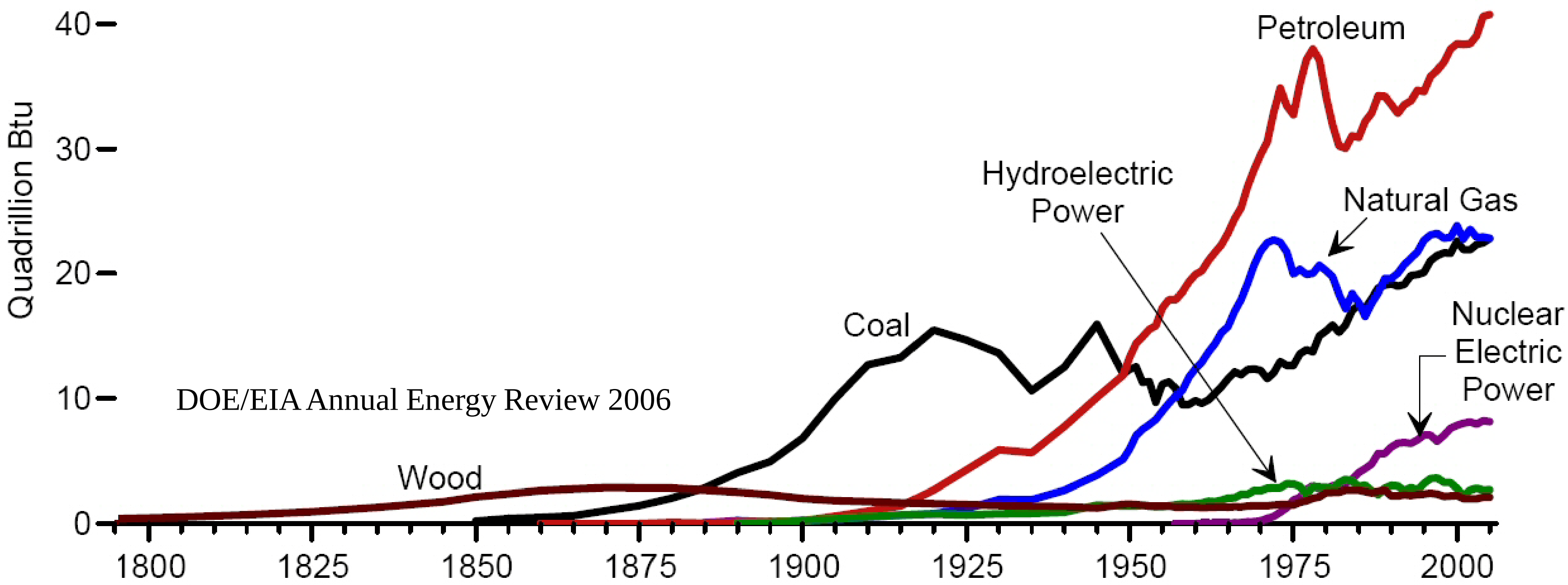


The Age of Low Cost Energy Based on Oil is Closing



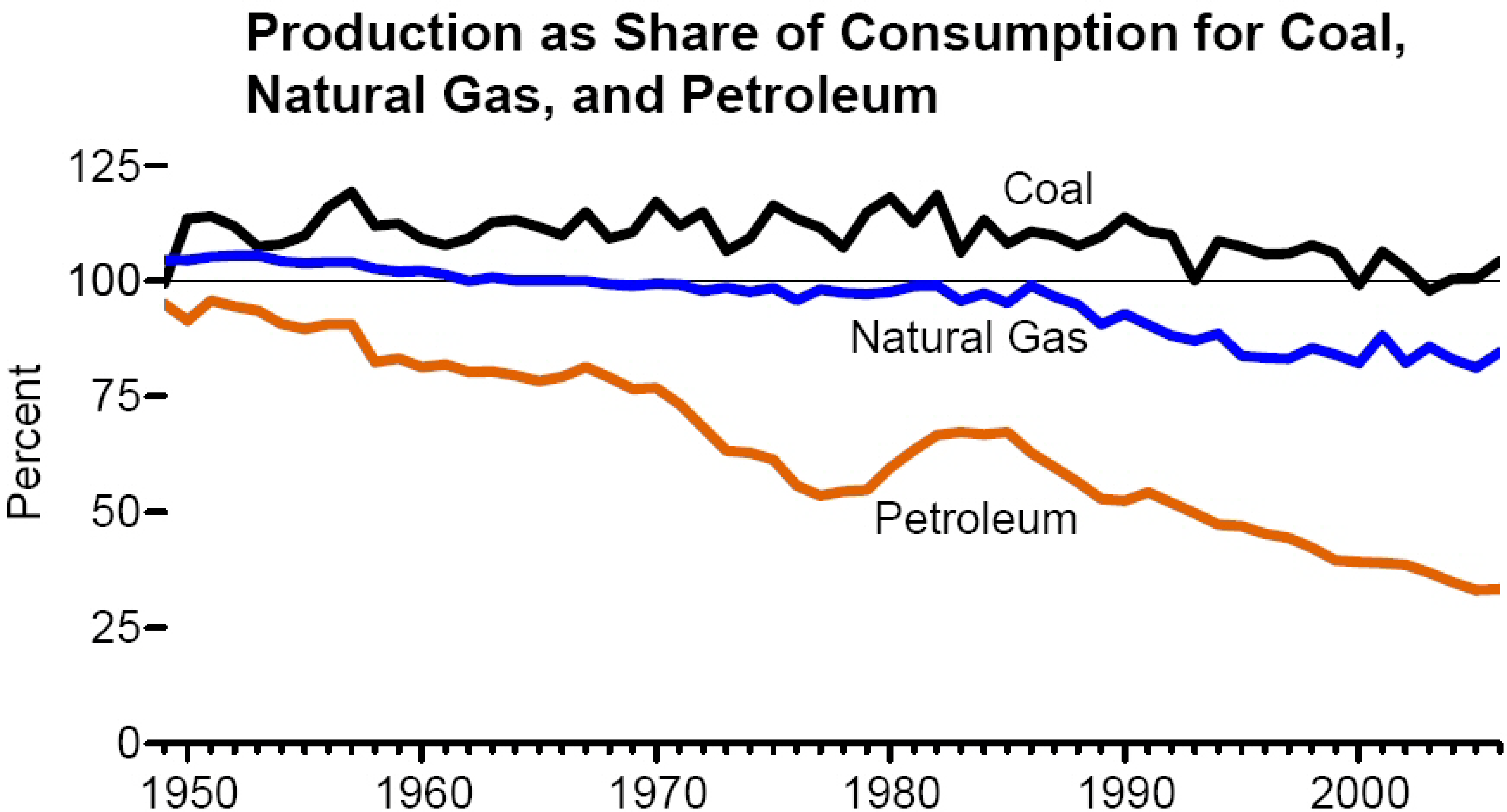
Oil and Gas J.; Feb. 21, 2005

U.S. Energy Trends
Consumption by Source



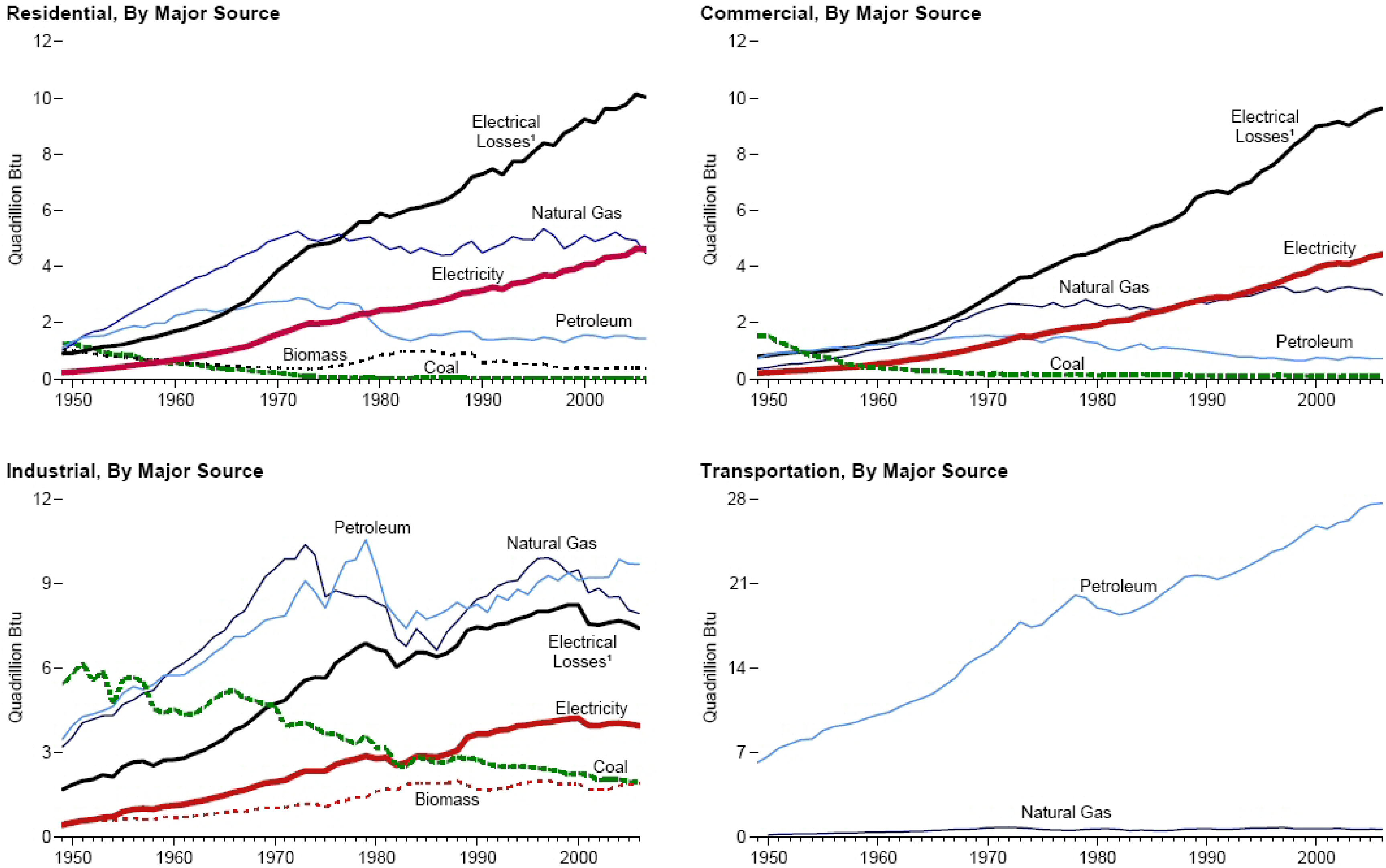
- Inexpensive widely available energy
- Increased federal regulation and direct competition in the power sector (TVA and Bonneville PA)
- Energy supply globalized
- Movement from localized energy infrastructures to regional and nationally connected energy systems
- Growth in Interstate oil and gas pipelines
- Interstate electric transmission

U.S. Domestic Contribution



DOE/EIA Annual Energy Review 2006

U.S. Energy Consumption

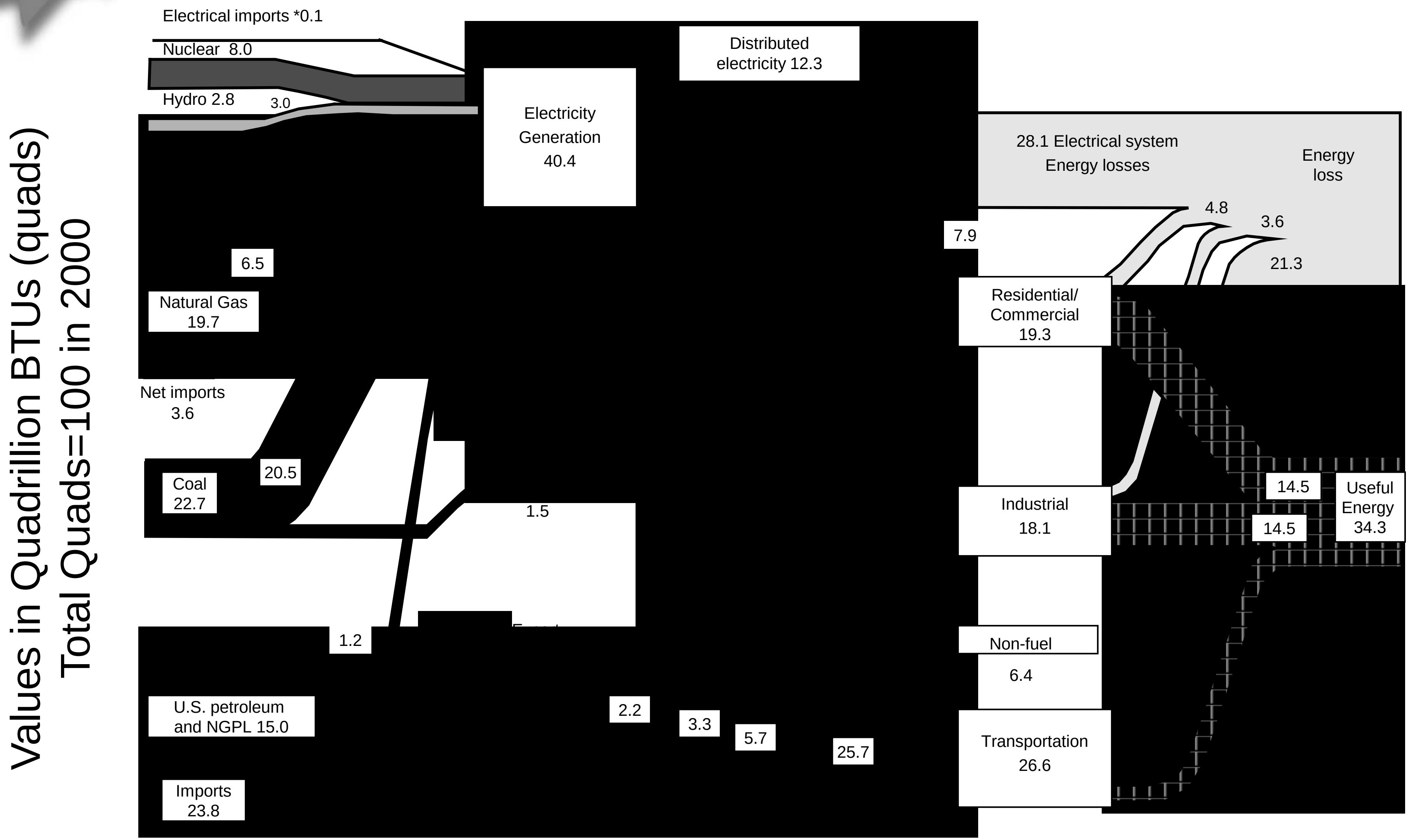


[1] Electrical system energy losses associated with the generation, transmission, and distribution of energy in the form of electricity.

Note: Because vertical scales differ, graphs should not be compared.
Sources: Tables 2.1b–2.1e.

DOE/EIA Annual Energy Review 2006

U.S. Energy Flows (2000)



EIA Annual Energy Review 2000

*Net fossil-fuel electrical imports

**Biomass/Other includes wood and waste, geothermal, solar, and wind.

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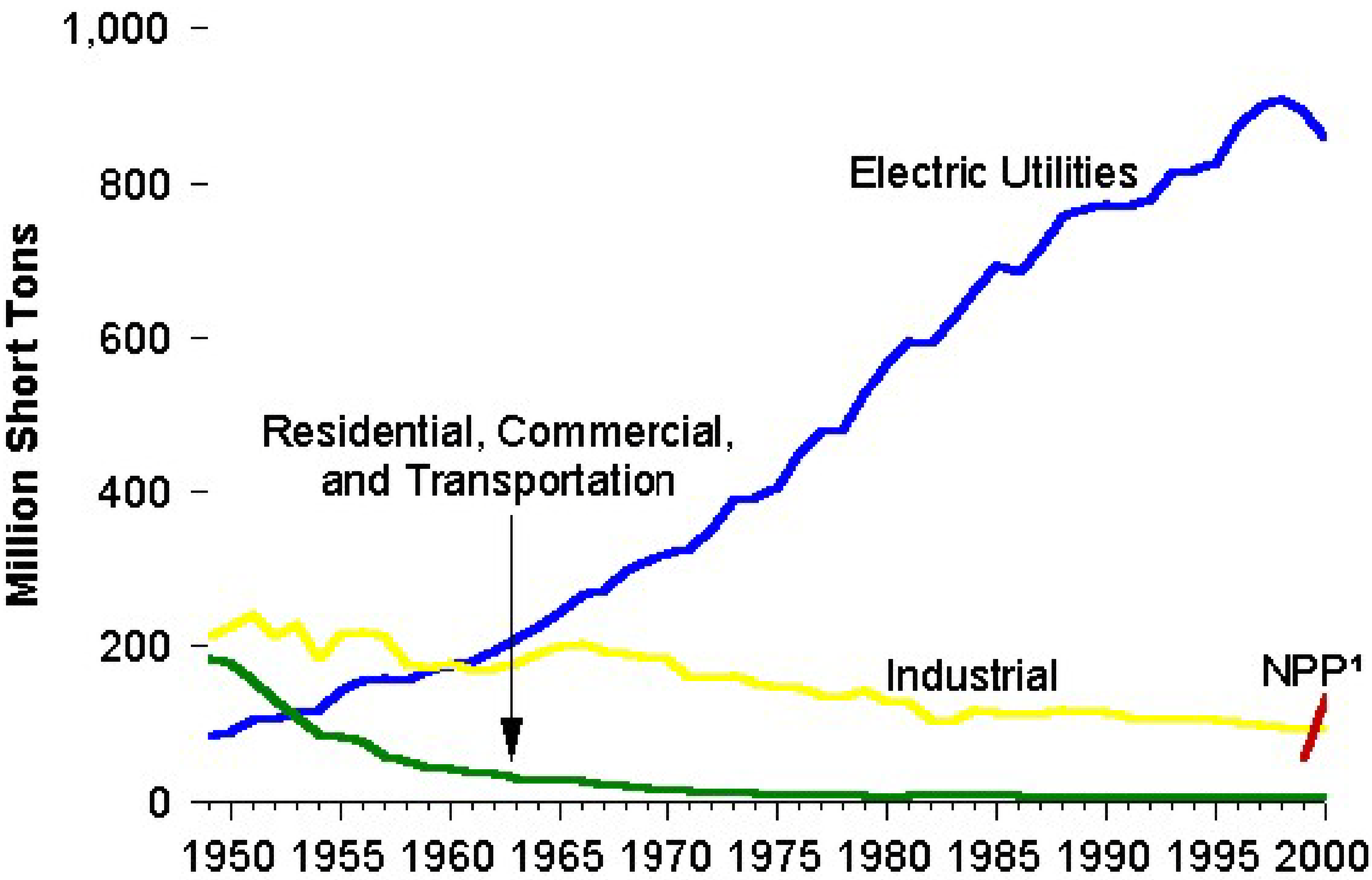
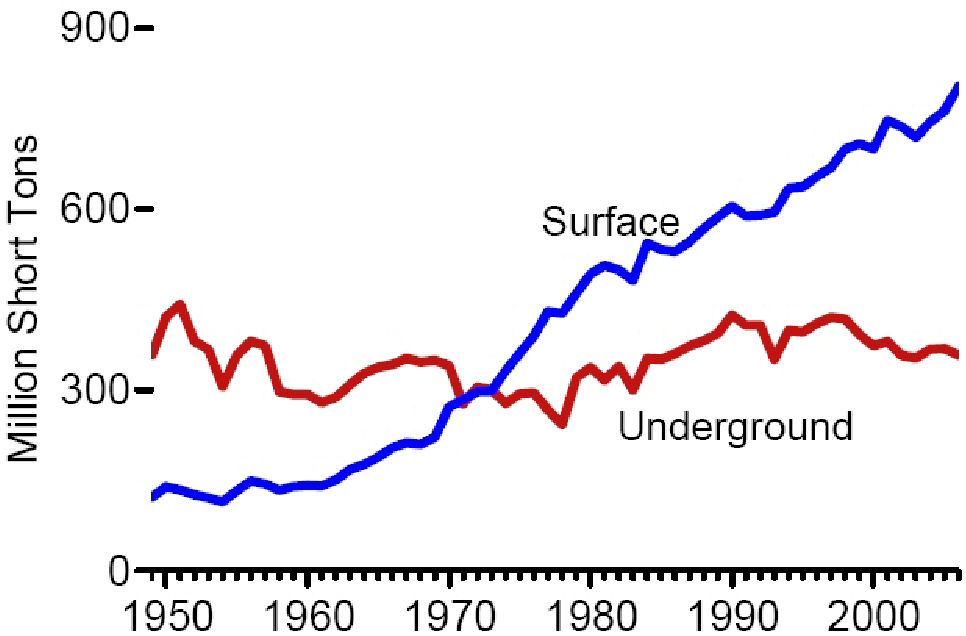
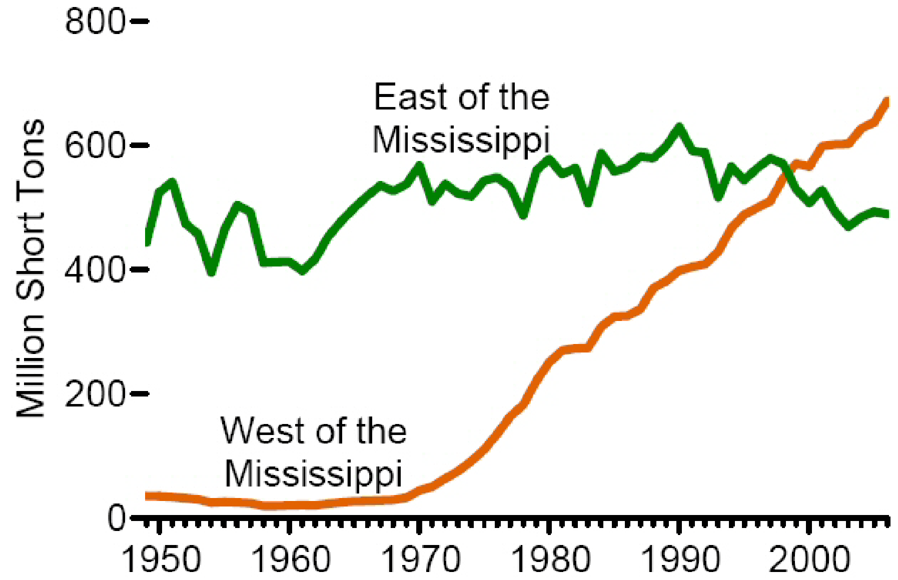
Coal Use by Sector



U.S. Coal Production

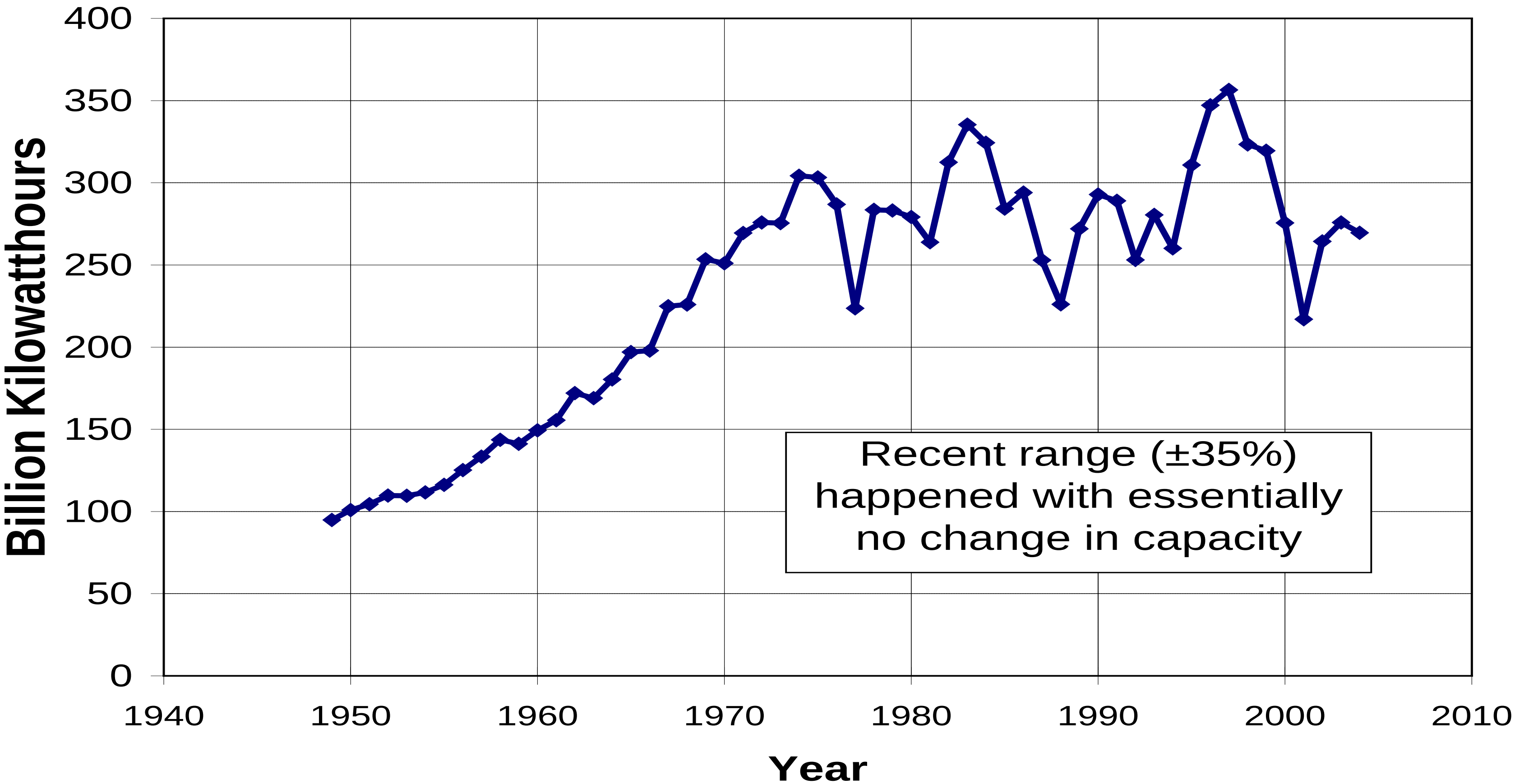




DOE/EIA Annual Energy Review 2006

Move toward low-sulfur western coal in late 1960's
for environmental air emissions and acid rain considerations

Hydropower Growth

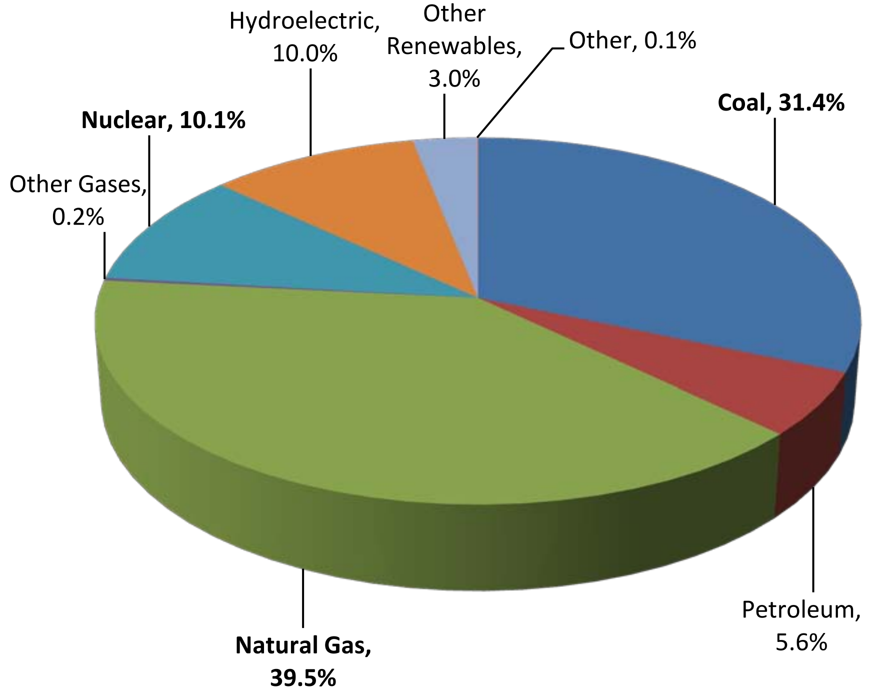


U.S. Hydropower Production

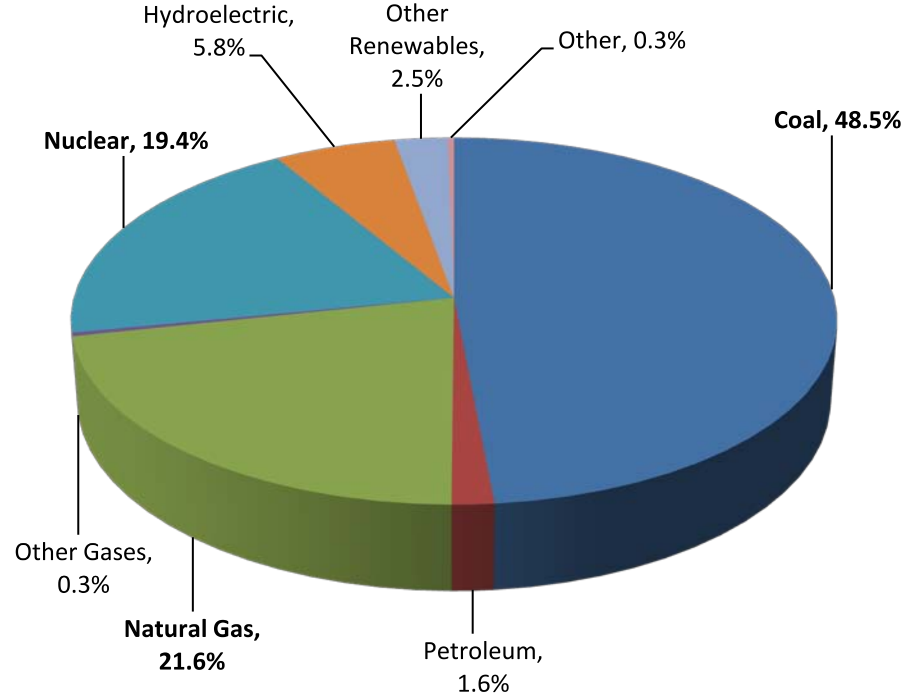
U.S. Capacity and Generation

2007

By Capacity (Summer)
Total = 995,000 MW



By Energy Produced
Total = 4,157 Million MW-h



Source: Energy Information Administration, Form EIA-923, "Power Plant Operations Report" and predecessor form(s) including Energy Information Administration, Form EIA-906, "Power Plant Report;" and Form EIA-920, "Combined Heat and Power Plant Report."

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Hydropower

Daniel Laird

Energy and Infrastructure Future

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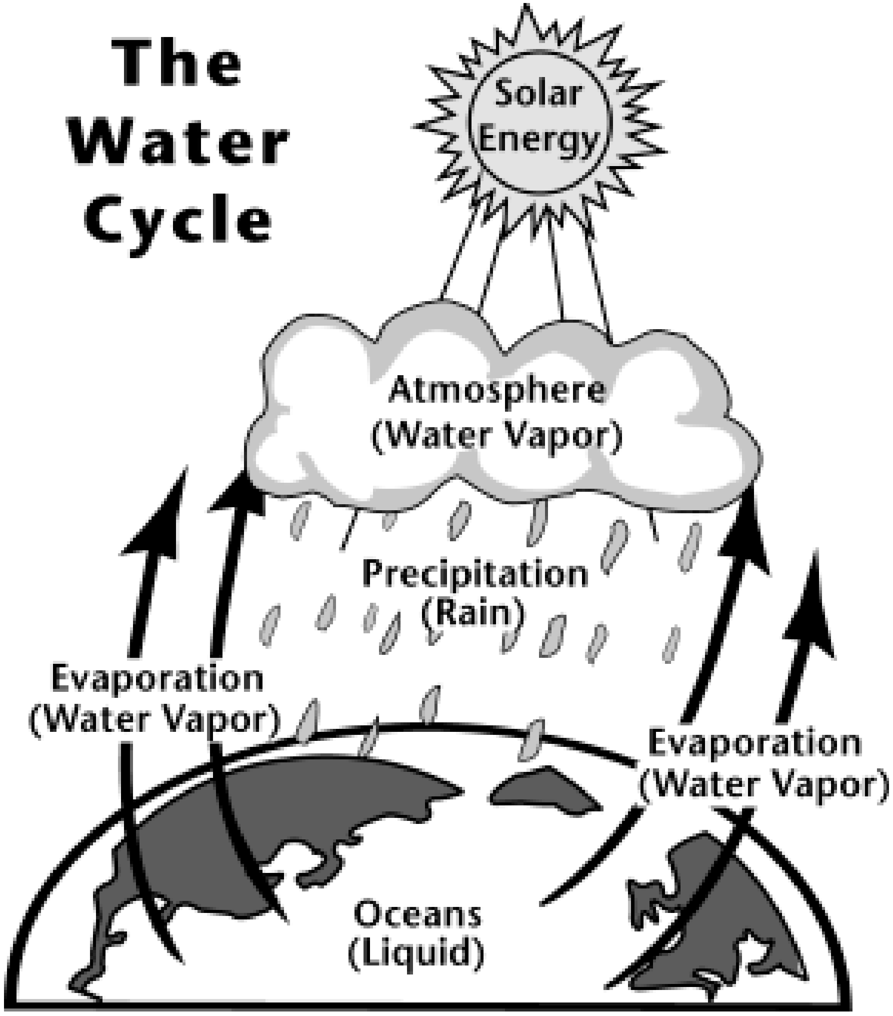
How it works

Heat and sunlight cause surface water to evaporate



DOE/EIA

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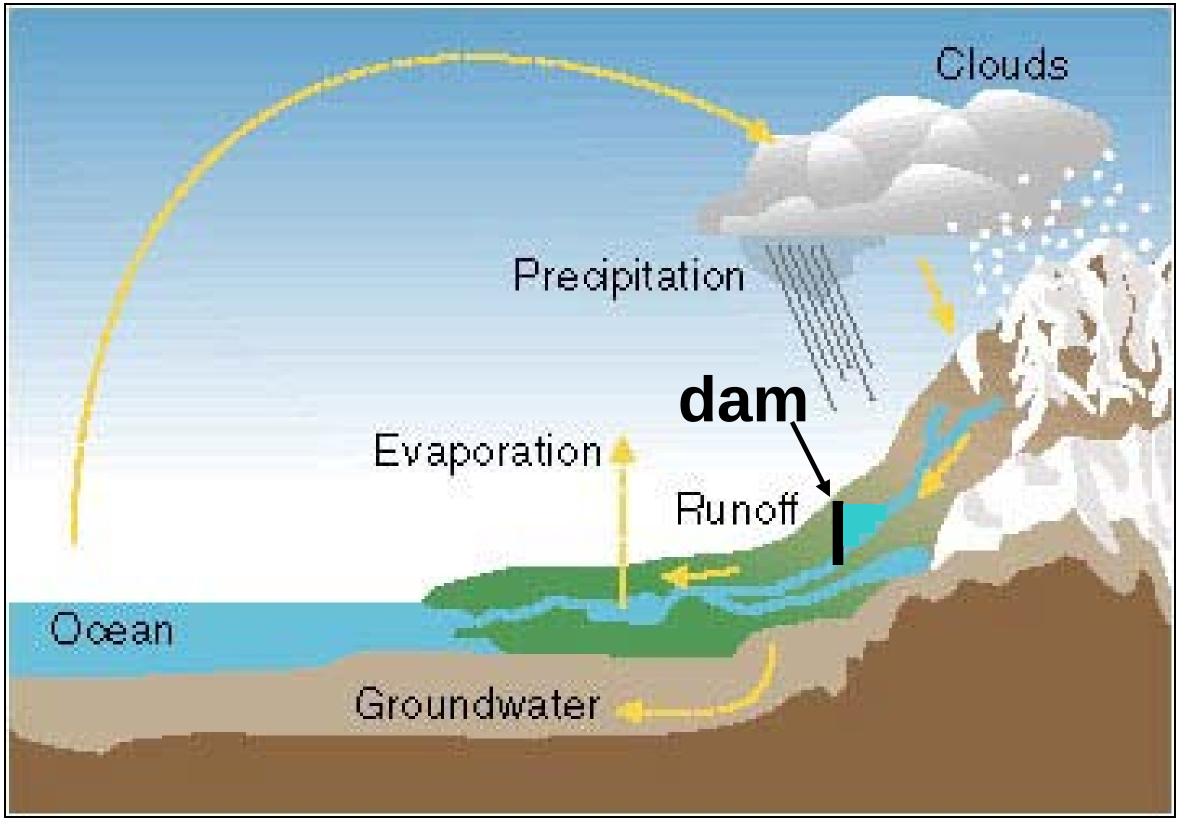
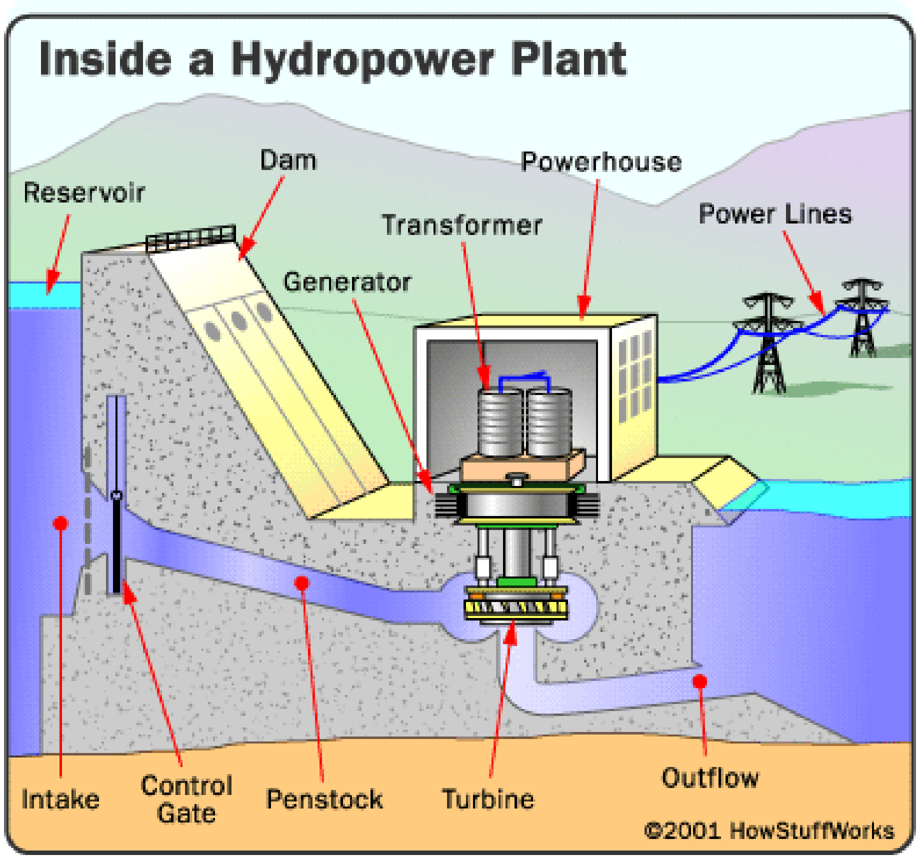
How it works

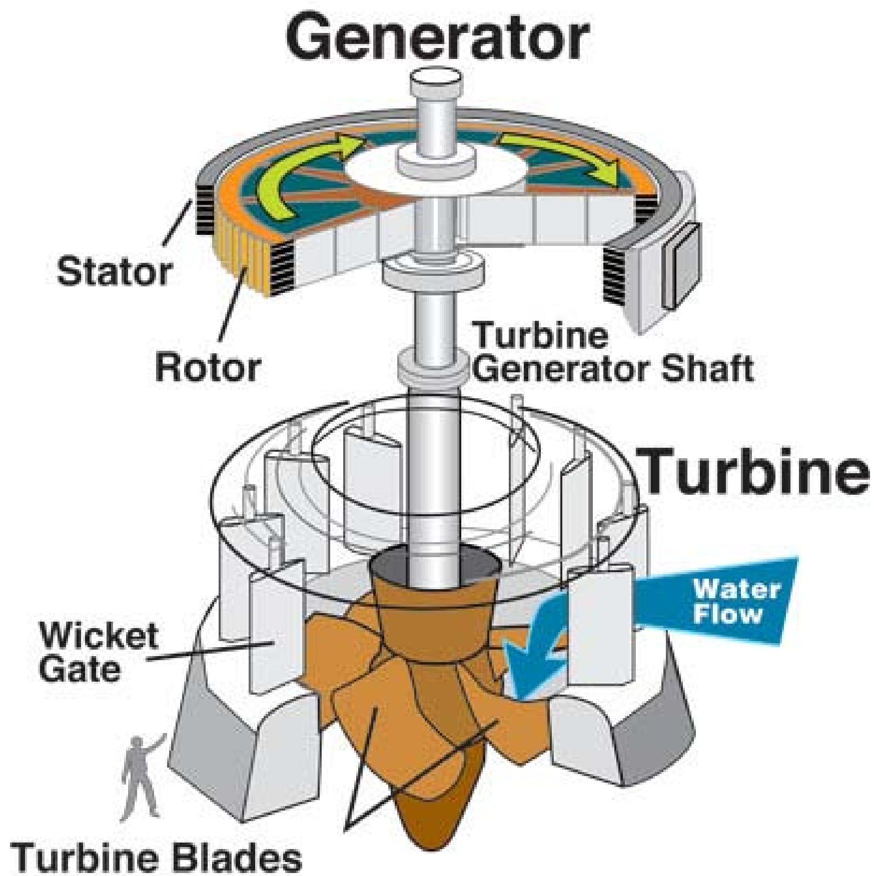
Rainwater flows into a reservoir created by a hydroelectric dam



hydropower.inel.gov

How it Works





Power is generated by running water through turbines as it flows from the high side of the dam, reservoir, to the low side (original river)

U.S. Army Corps of Enginners
ga.water.usgs.gov

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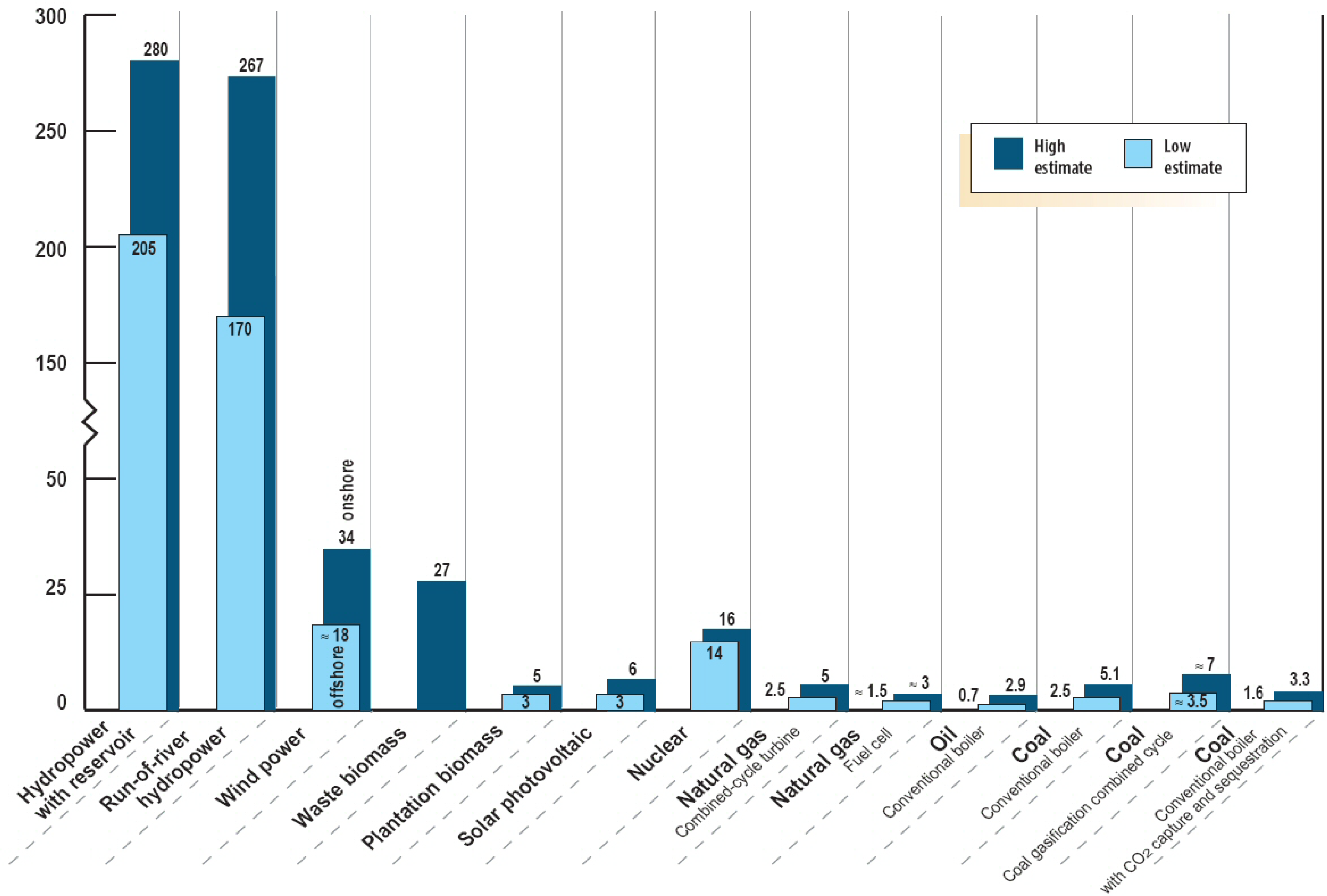
Energy Payback Ratio of Electricity Generation Options Based on Life-Cycle Assessments



Hydro Quebec, 2005

U.S. Renewable Electricity Generation Comparison

(2008)

Hydroelectric	**272 terawatt-hours**
Wind	**71 terawatt-hours**
Geothermal	**15 terawatt-hours**
Solar	**0.81 terawatt-hours**

Source: DOE/EIA

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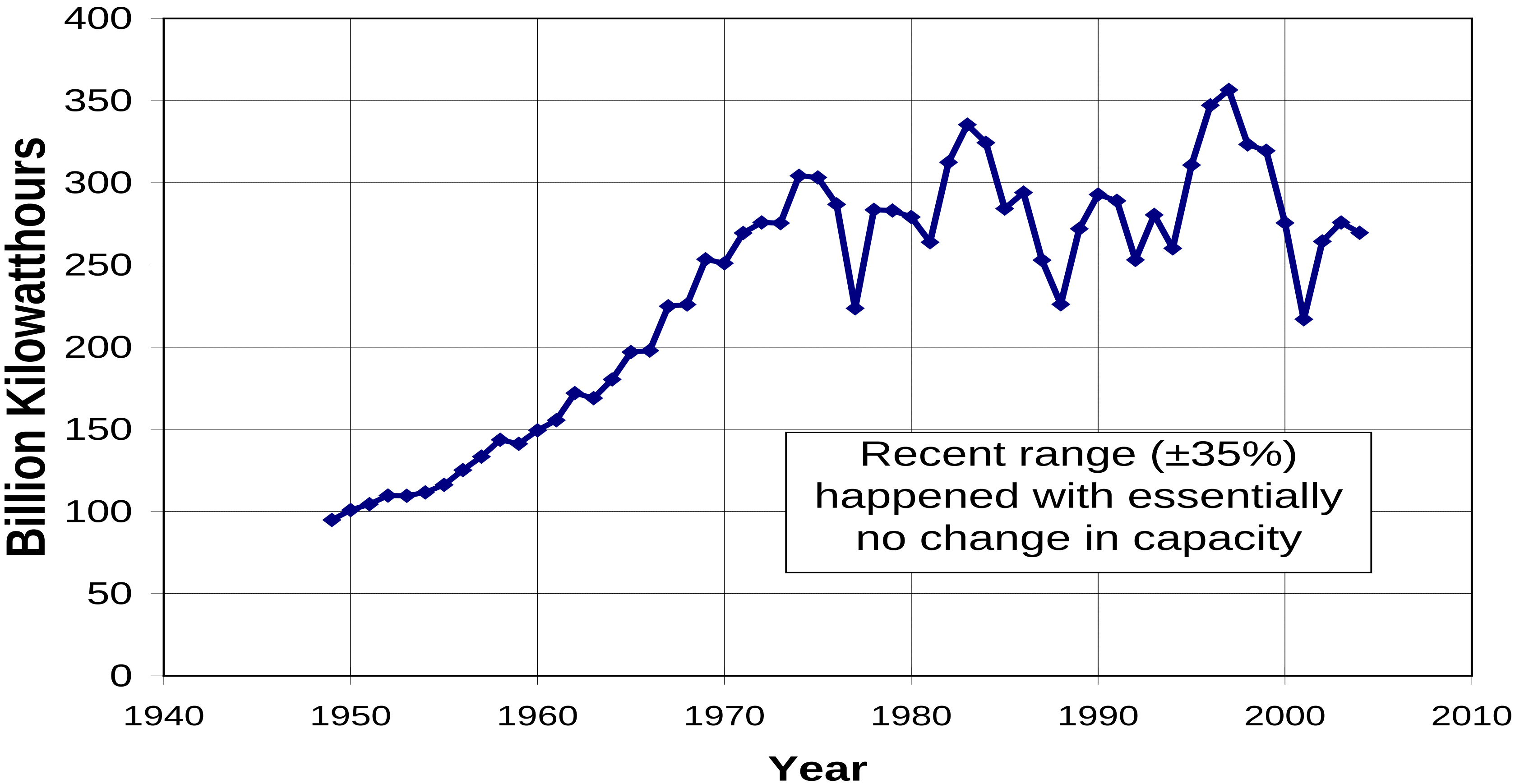
Weather Affects Output



U.S. Hydropower Production

Summary

Highest energy payback for power production

Controls/minimizes flooding

No traditional pollution

No CO_2 during operation

Best hydropower sites already developed

Devastating to some fish species

Hoover Dam

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Old Faithful

GEOTHERMAL ENERGY

Acknowledgments: Roger Hill (SNL),

GEO
GEOTHERMAL EDUCATION OFFICE

http://geothermal.marin.org

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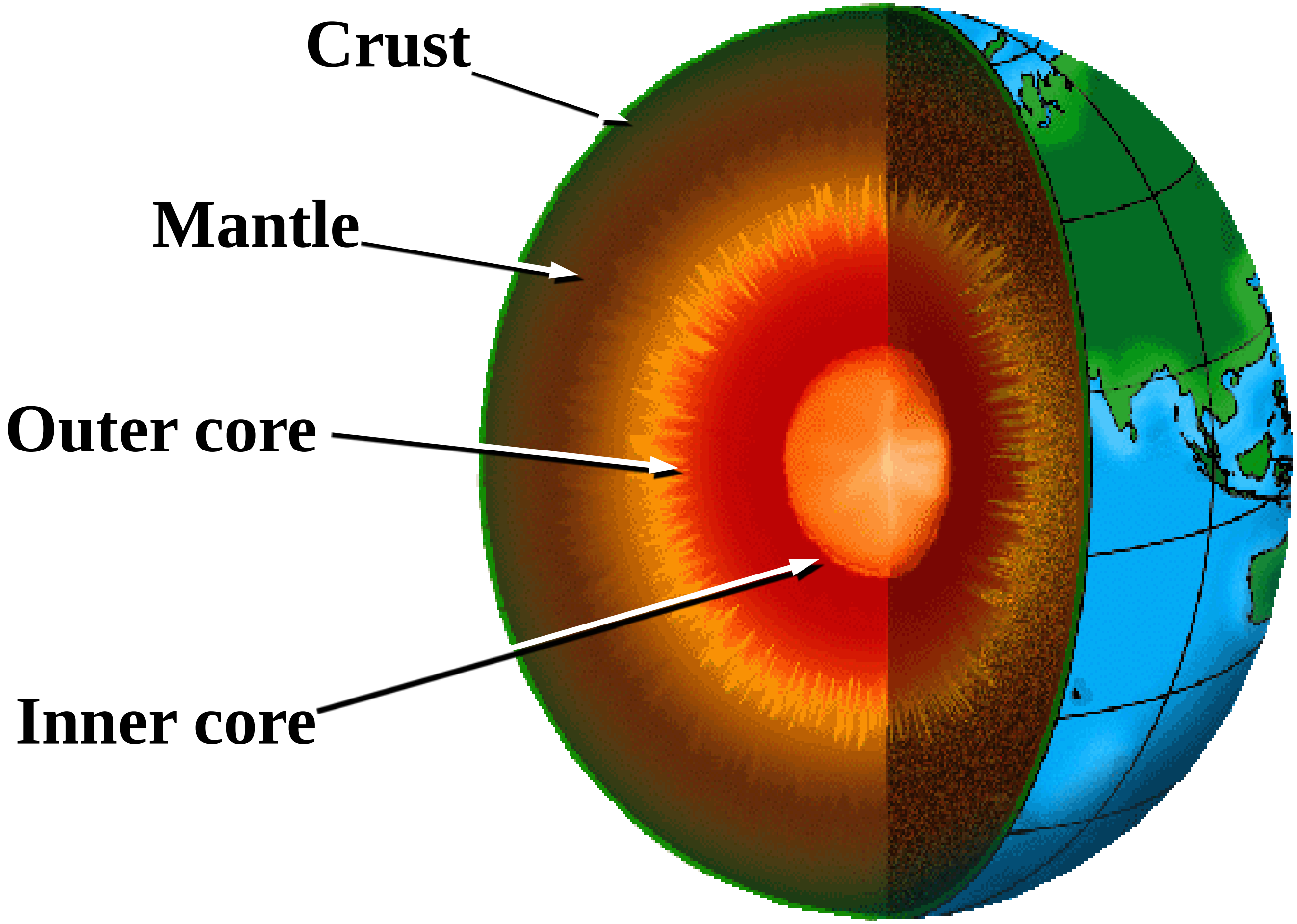
Geo means **Earth**

Thermal means **Heat**

The Earth



Hot rock is everywhere, but there are only a few places where it is hot enough (220° F) near the surface for extracting energy to be economical.

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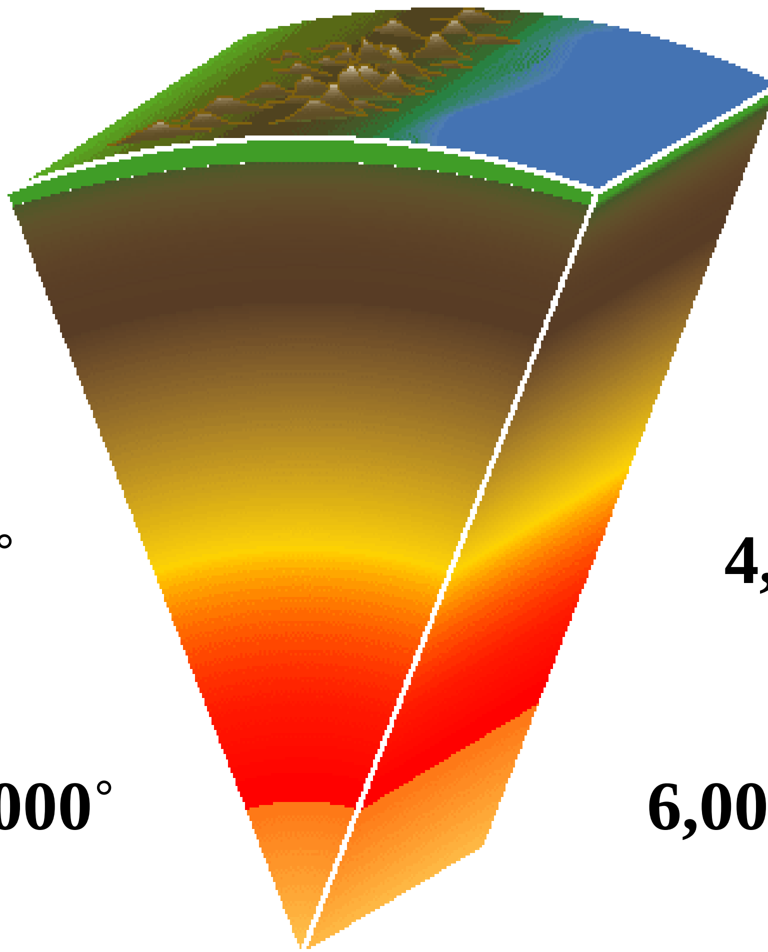
Temperatures in the Earth

Temperatures in Celsius

Depth in kilometers



2,000

4,000°

4,000

5,000°

6,000

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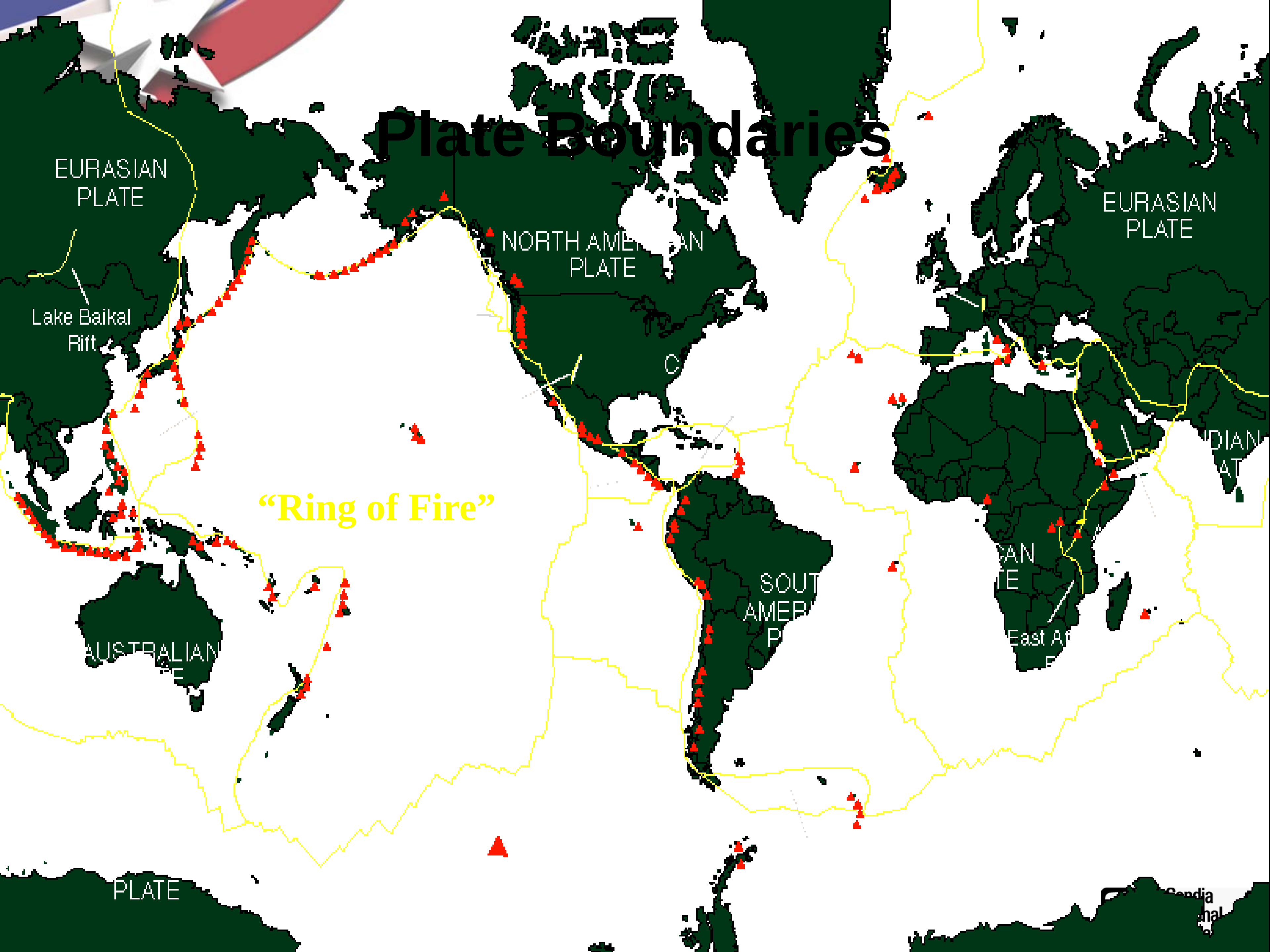
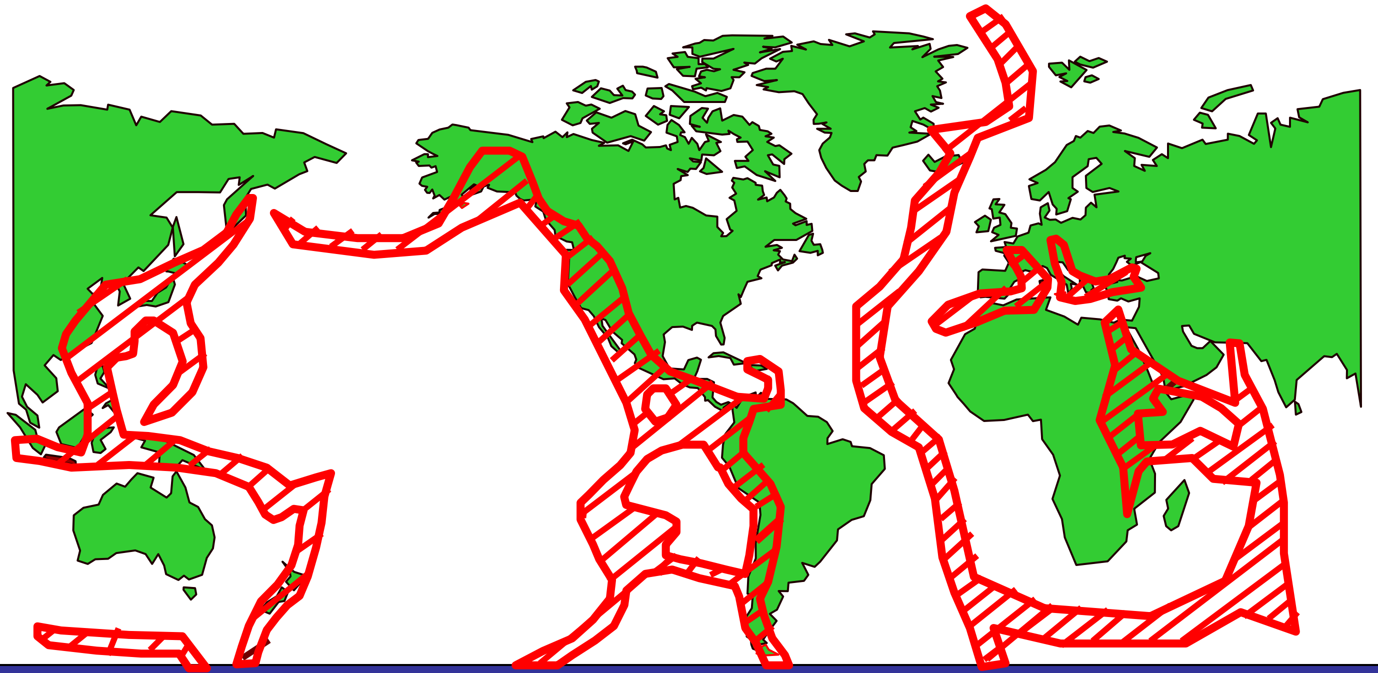
Plate Boundaries



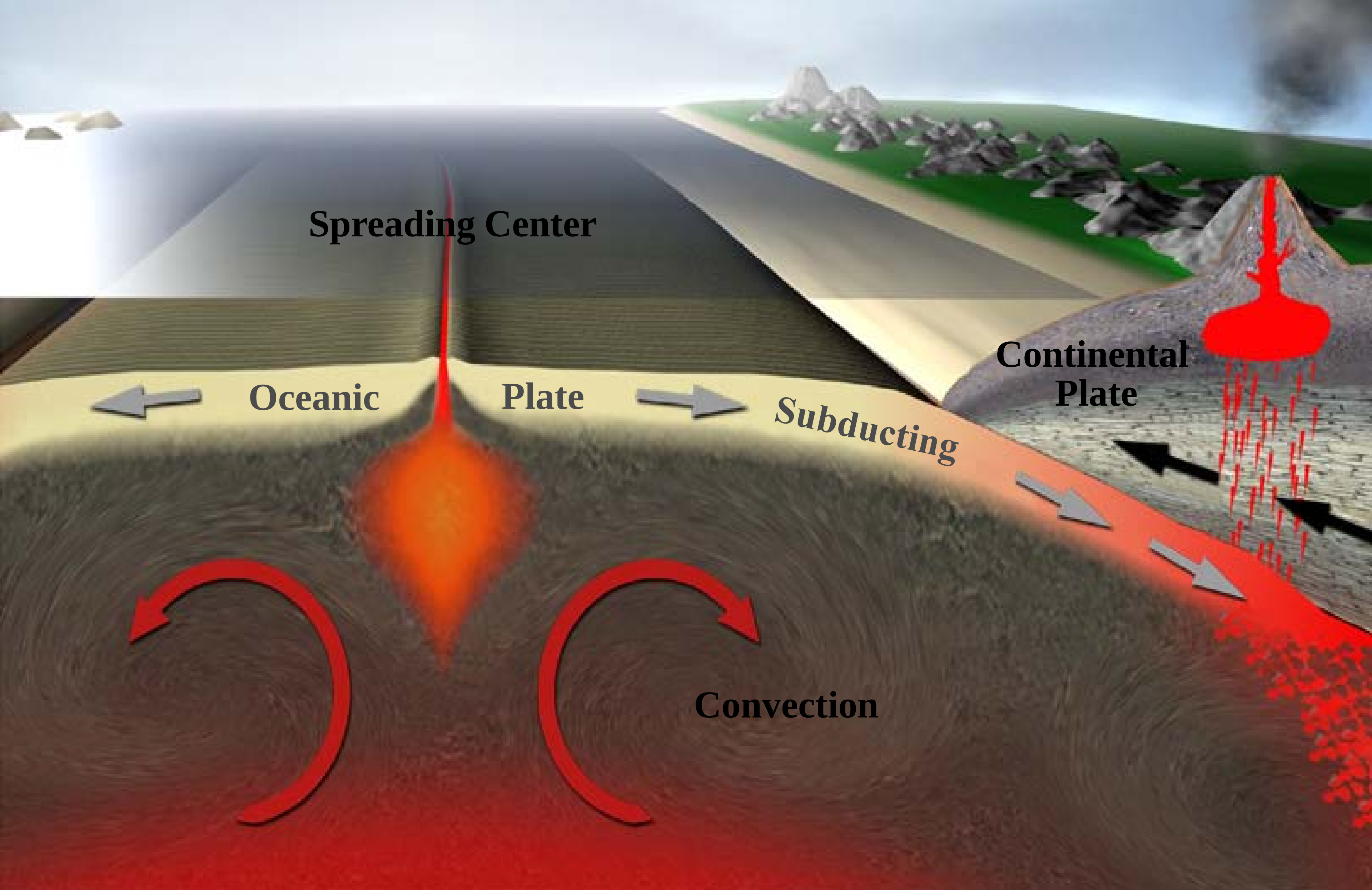
Worldwide Geothermal Electric Potential



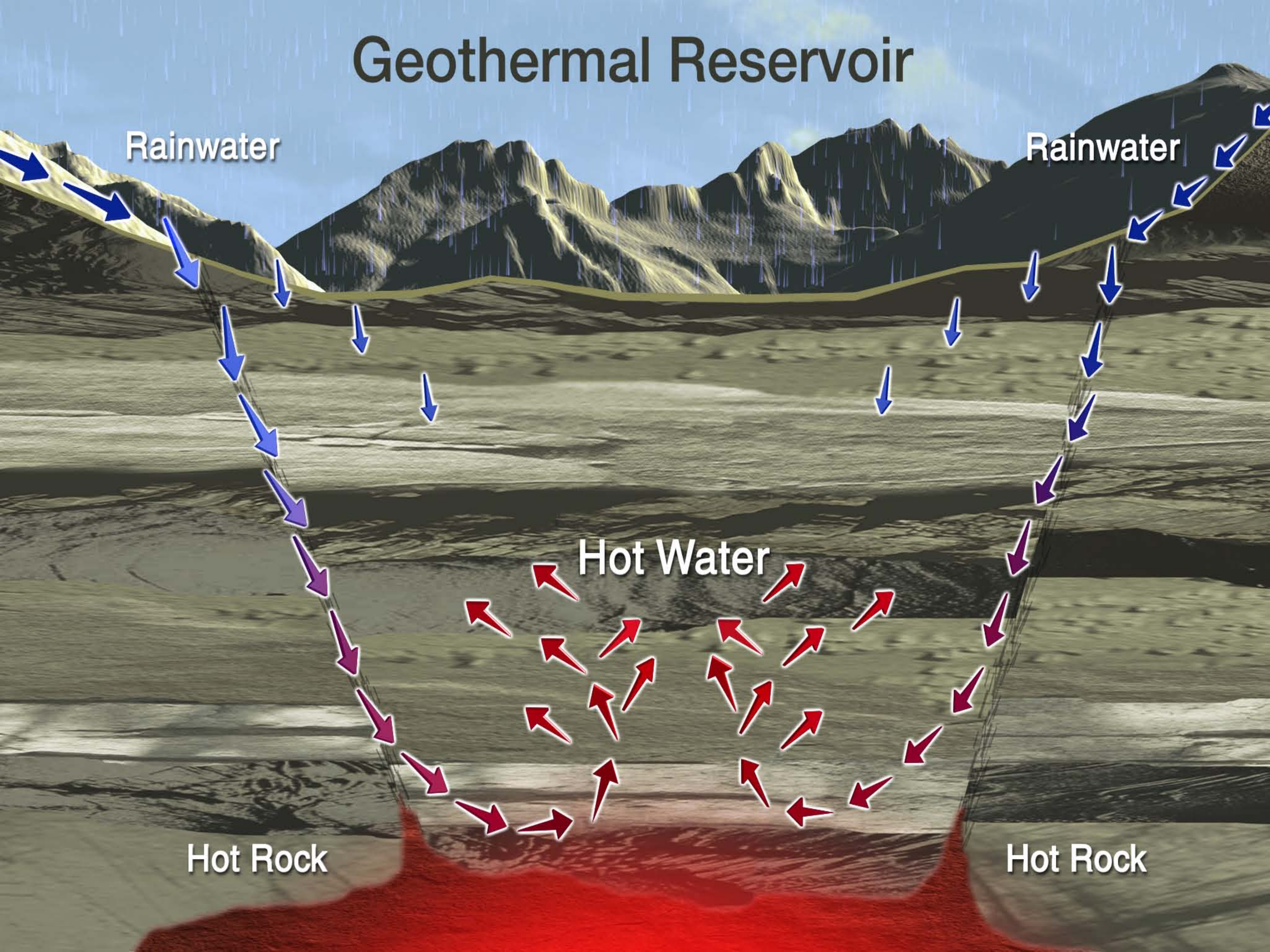
Countries with Potential of 1,000 MW or More

	Potential	Installed		Potential	Installed		Potential	Installed
Indonesia	19,650	144	El Salvador	2,000	105	Colombia	1,000	0
Philippines	8,000	888	Guatemala	2,000	0	Ecuador	1,000	0
Ethiopia	5,000	0	Nicaragua	2,000	70	Peru	1,000	0
Mexico	5,000	752	Kenya	1,700	45	Venezuela	1,000	0
Papua New Guinea	3,000	0	Argentina	1,000	0.6	Russia	1,000	11
Costa Rica	2,000	55	Chile	1,000	0	U.S.	20,000+	2733

Plate Tectonic Processes





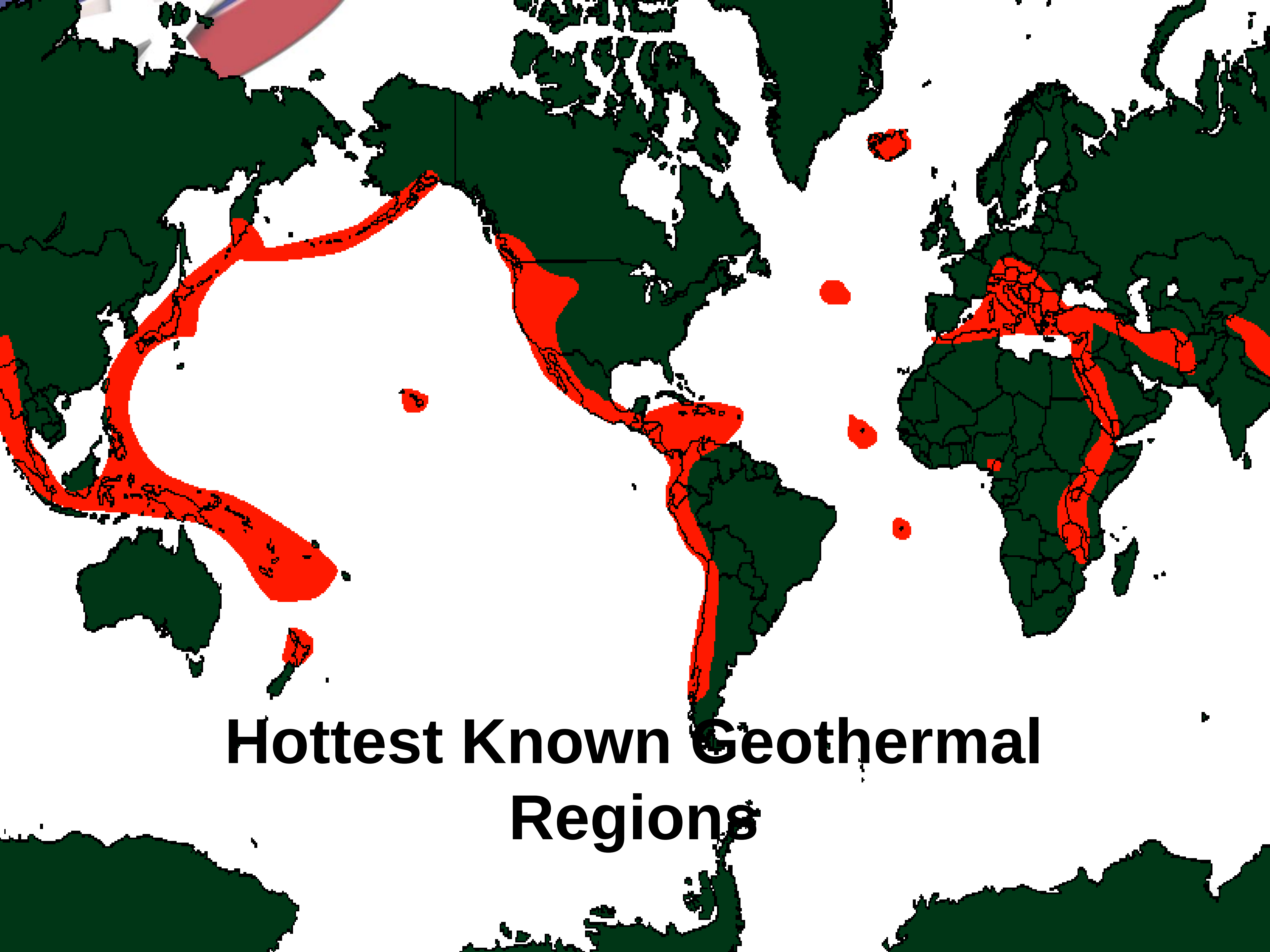


Geothermal Reservoir
Rainwater
Rainwater
Hot Water
Hot Rock
Hot Rock

Powerful Energy Source

- **Geothermal reservoirs can reach temperatures of 700˚F/370˚C (more than 3 times boiling).**
- **A geothermal reservoir is a powerful source of energy!**

Exploration and Drilling

The Early Years!



Hottest Known Geothermal Regions

Geothermal Exploration Surveys

- Satellite imagery and aerial photography
- Volcanological studies
- Geologic and structural mapping
- Geochemical surveys
- Geophysical surveys
- Temperature gradient hole drilling

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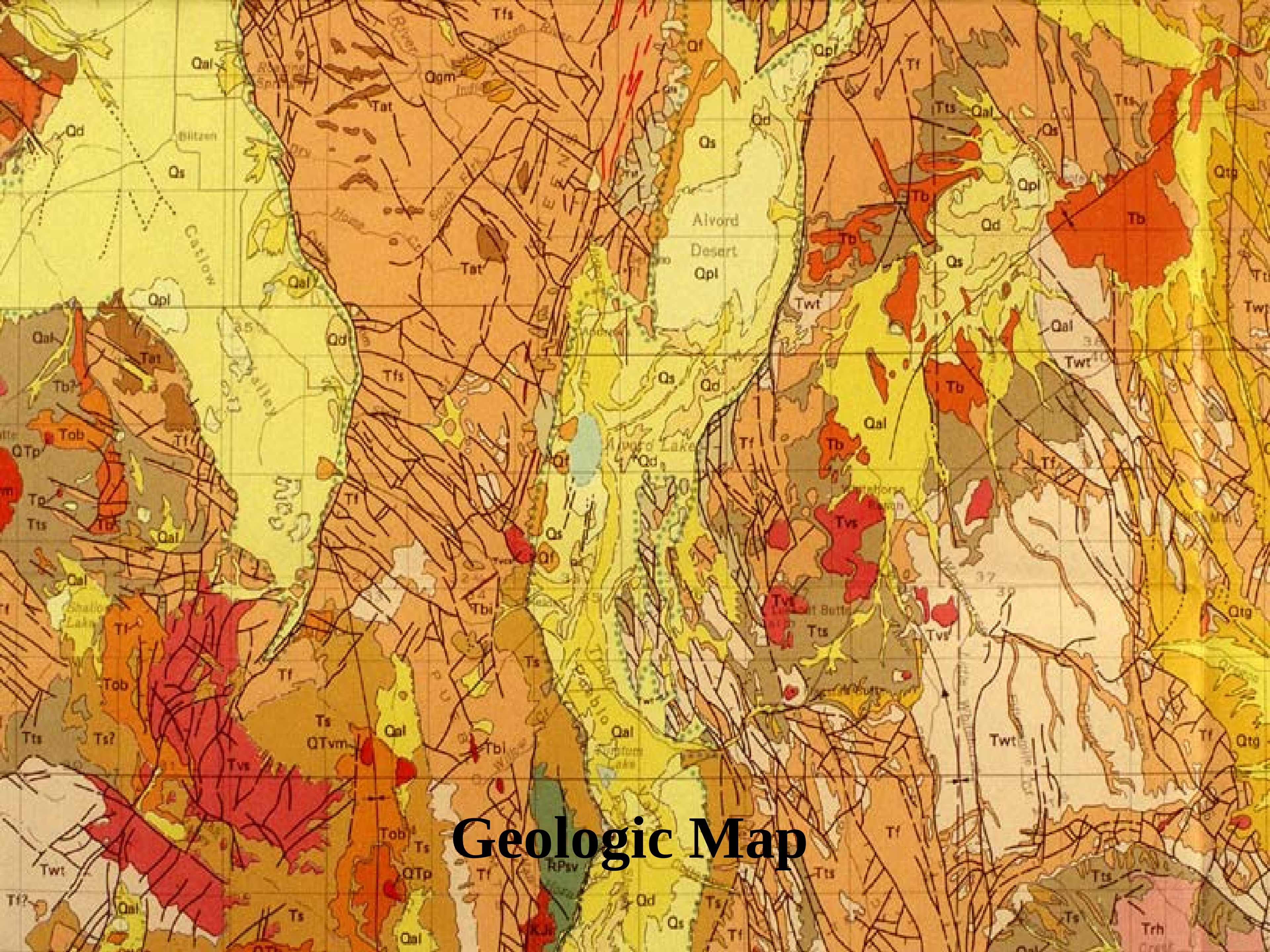
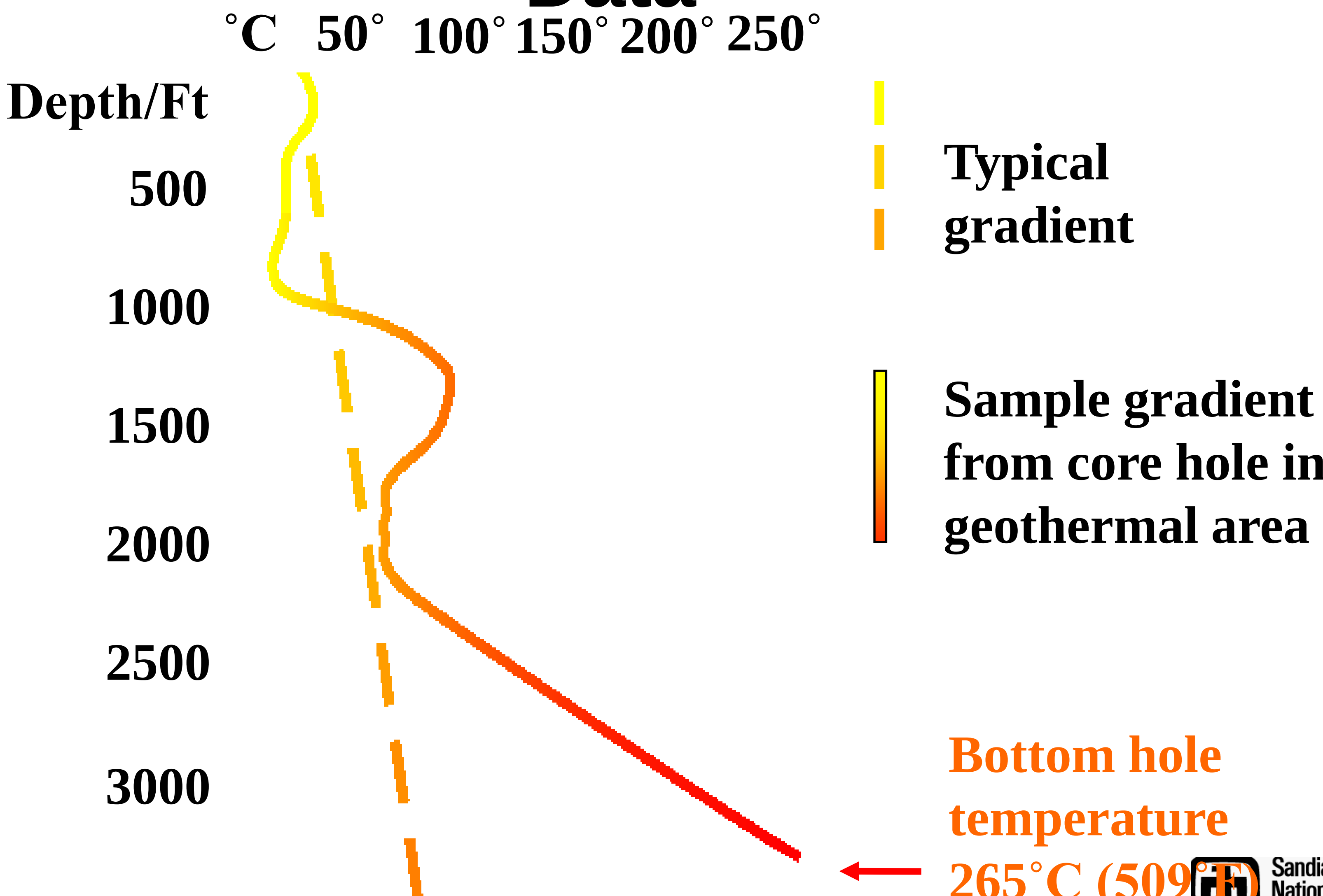
Geologic Map



Sample Temperature Gradient Data



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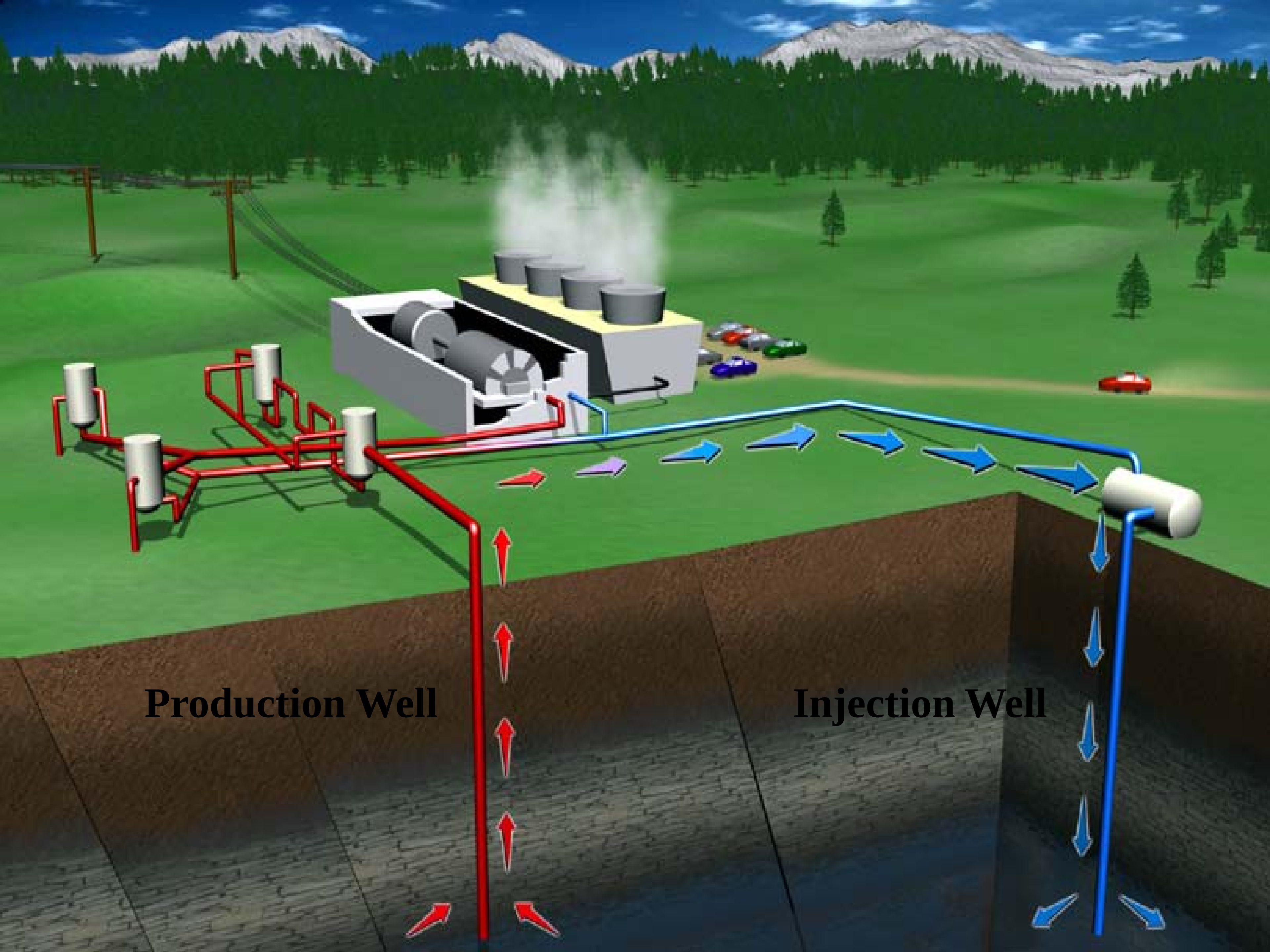
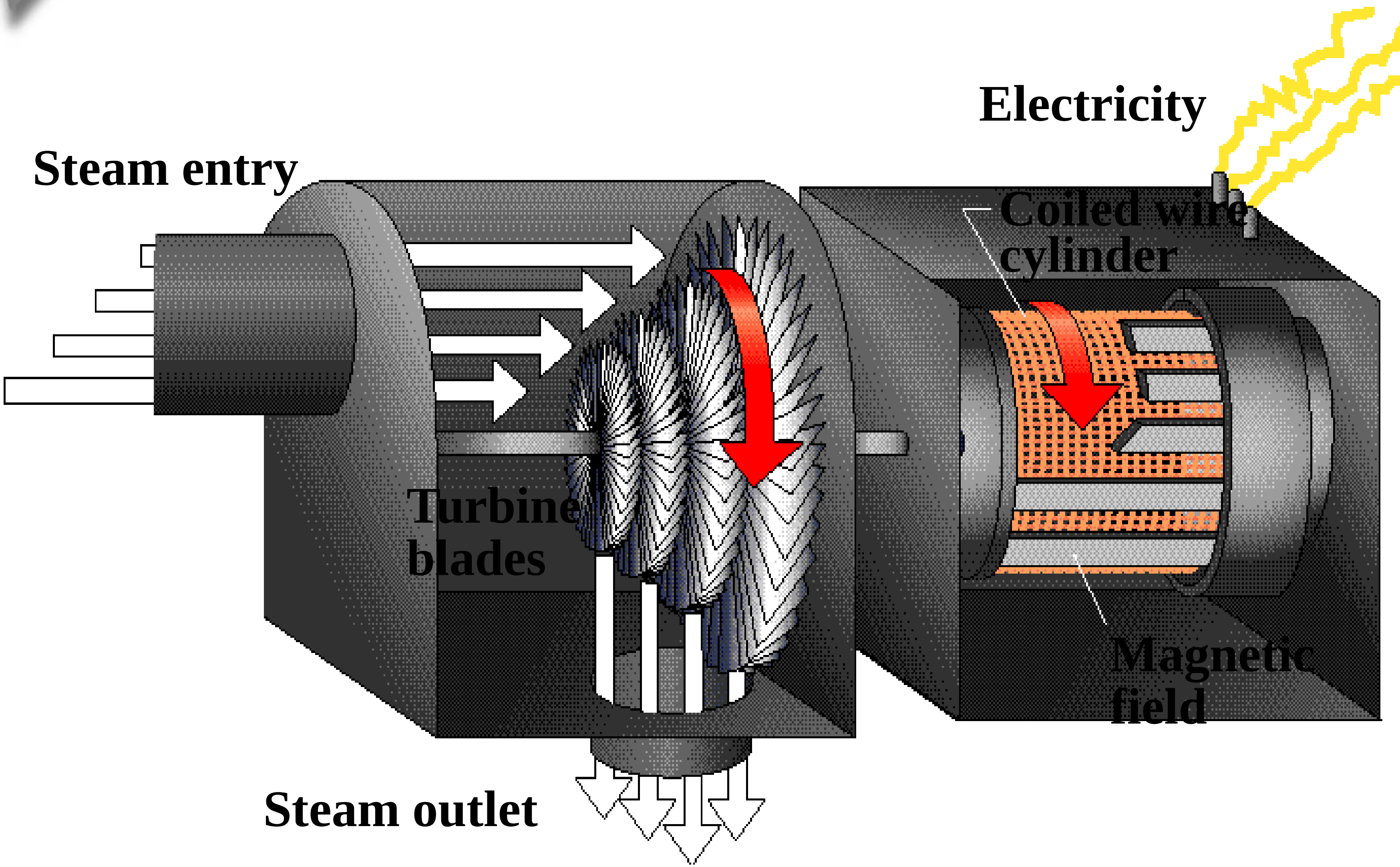
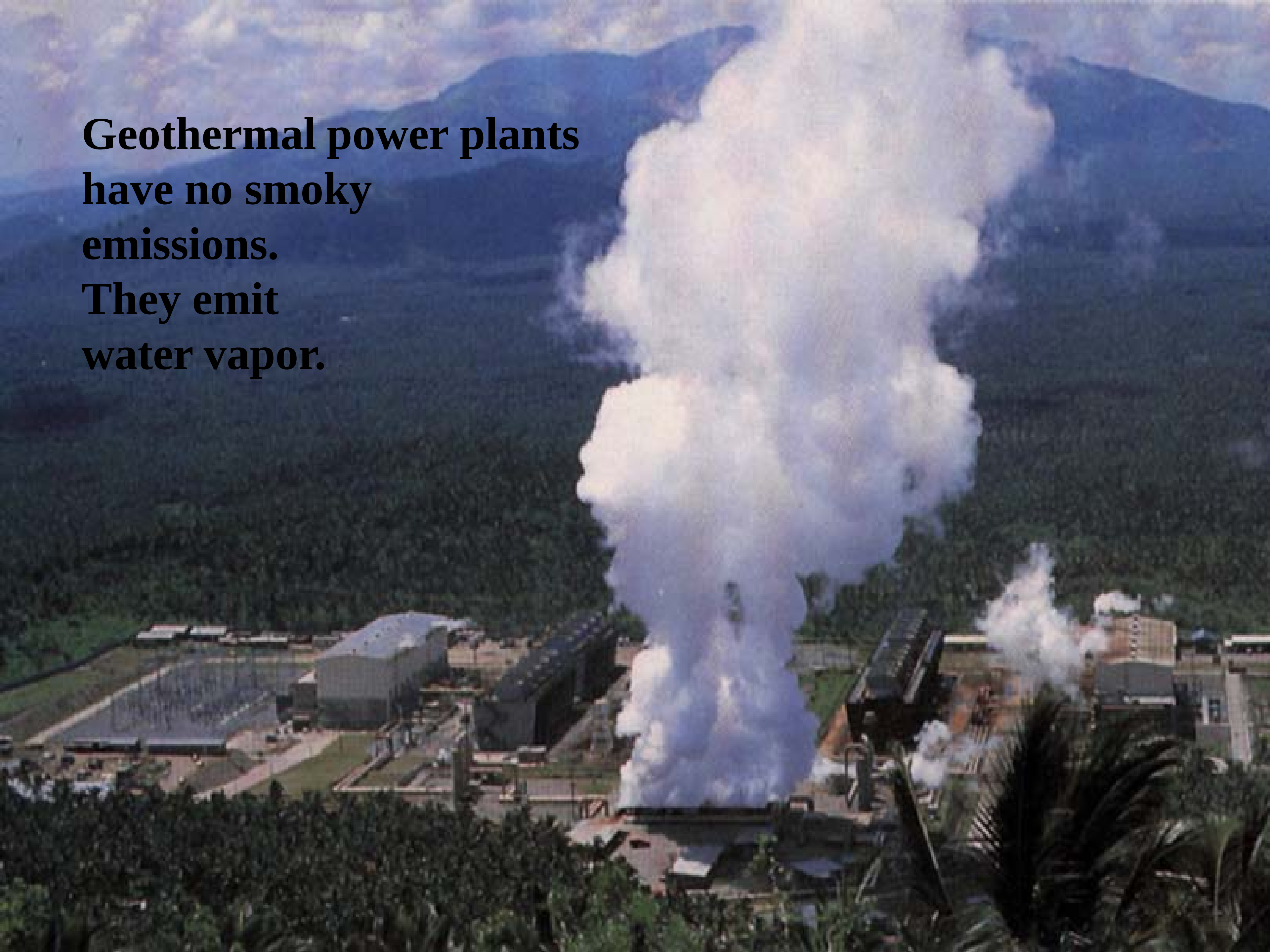
Generation of Electricity


Production Well
Injection Well

Turbine Generator



Geothermal power plants have no smoky emissions. They emit water vapor.



Easy on the Environment

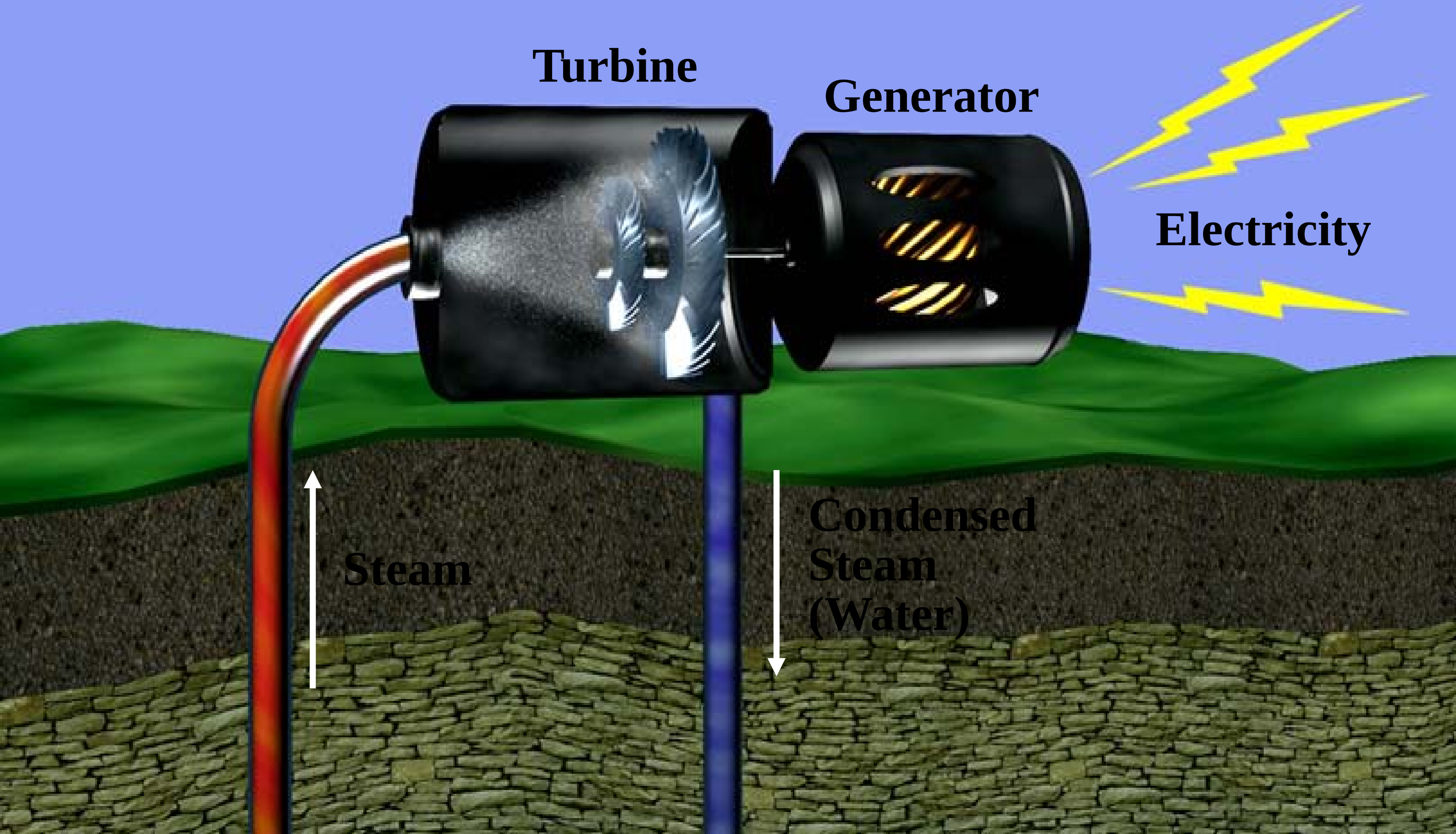
Geothermal power plants have been built:

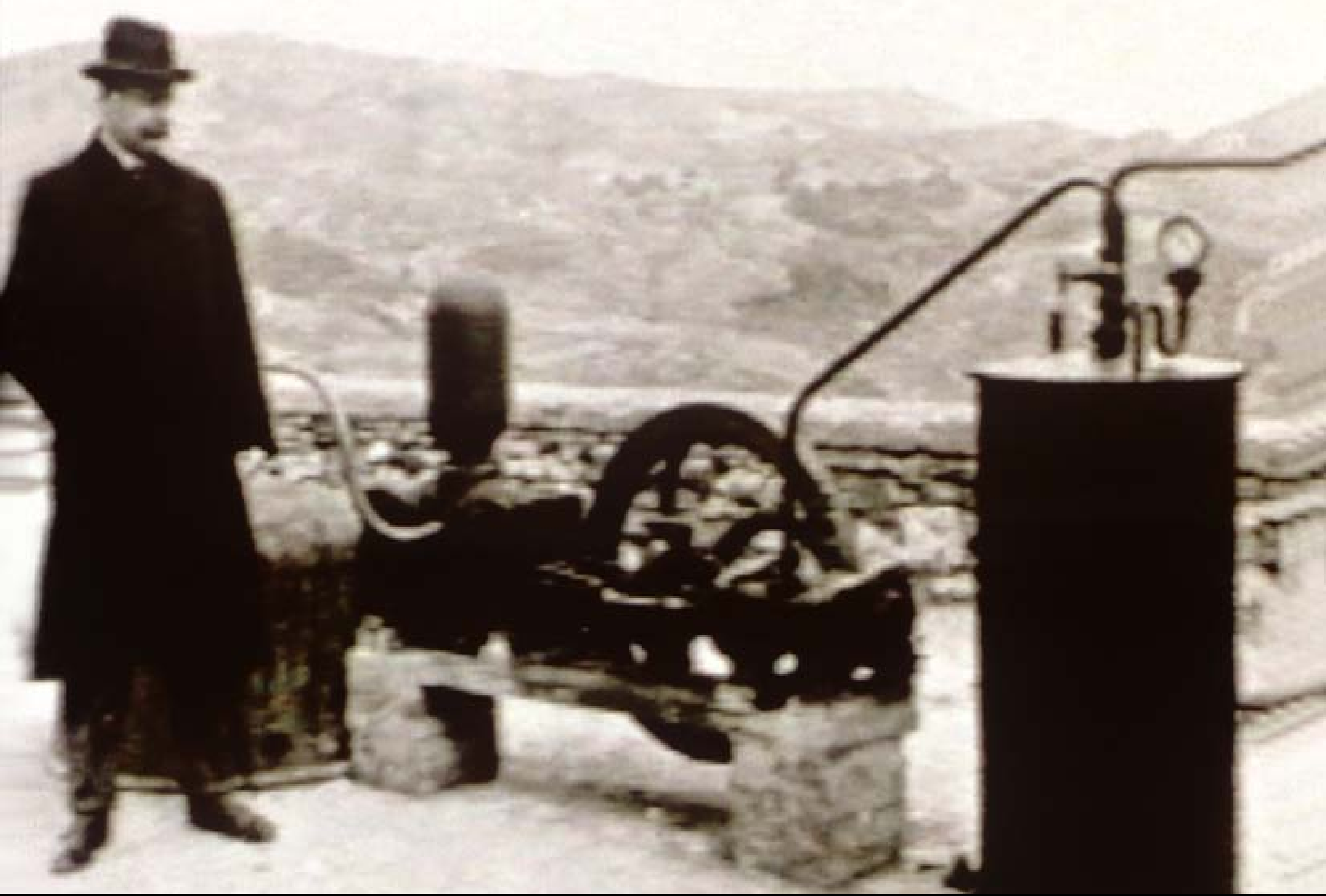
- **In the middle of crops**
- **In forested recreation areas**
- **In fragile deserts**
- **In tropical forests**

Power Plants

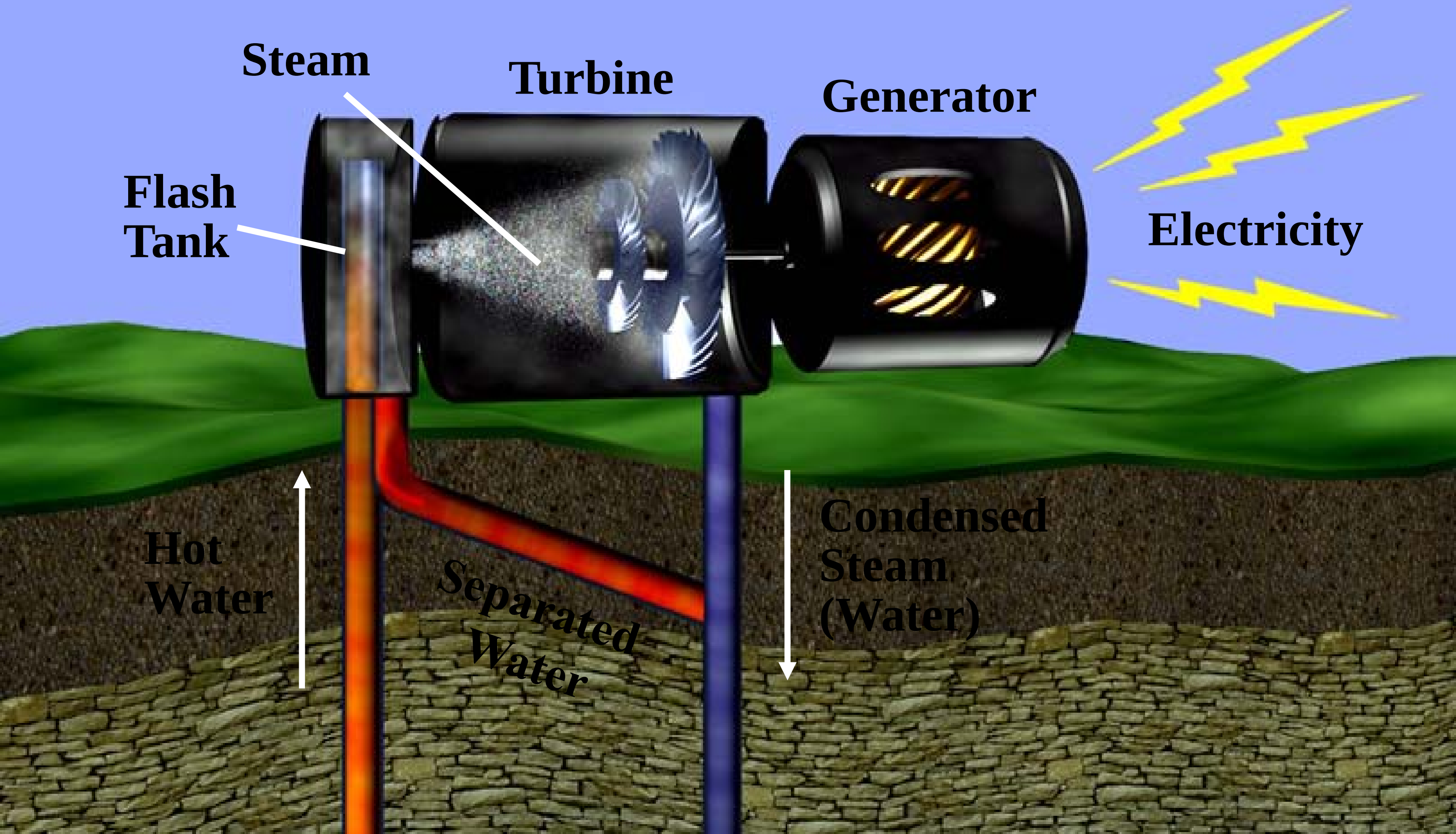
- Dry Steam
- Flash Steam
- Binary Cycle

Dry Steam Power Plant

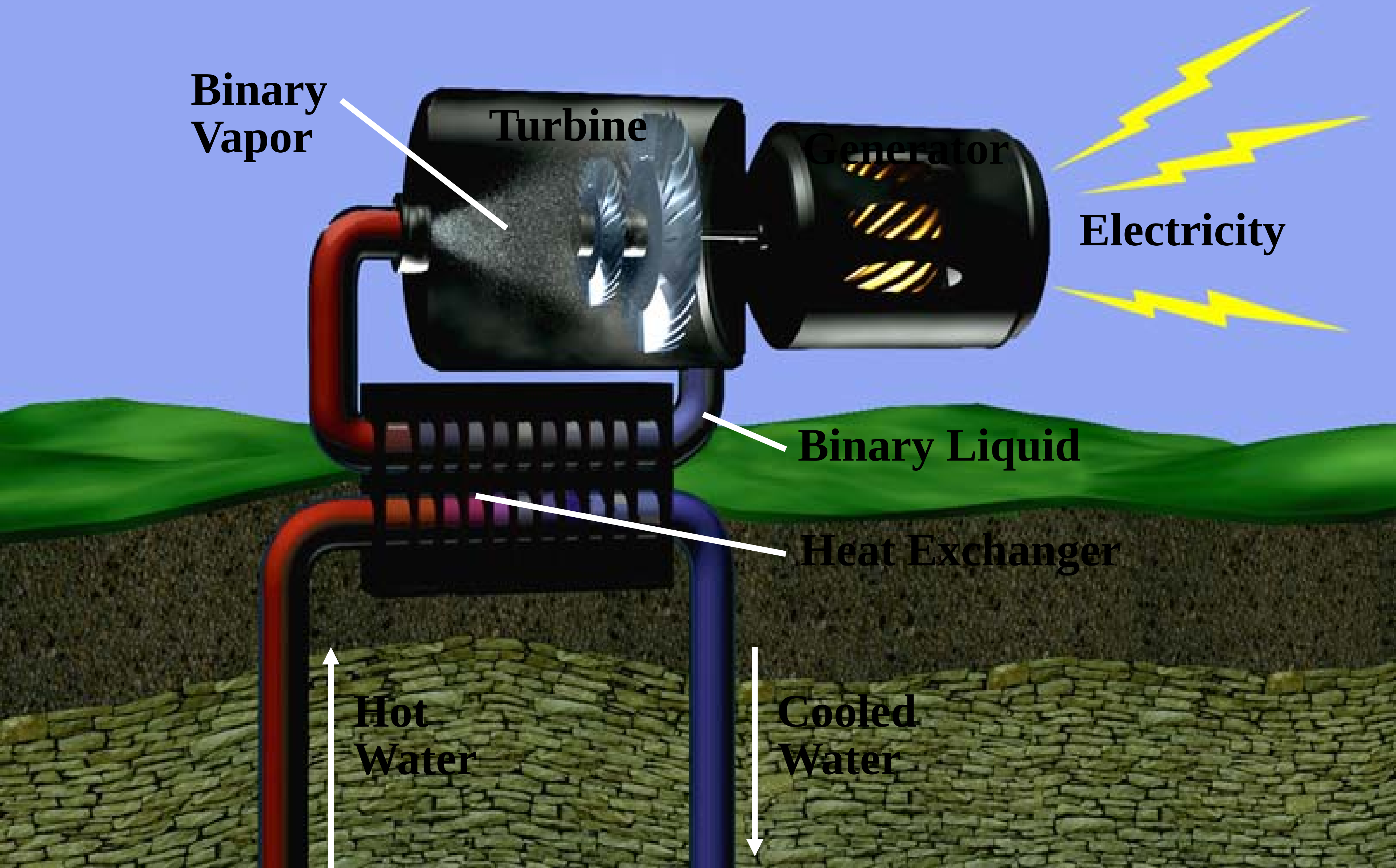




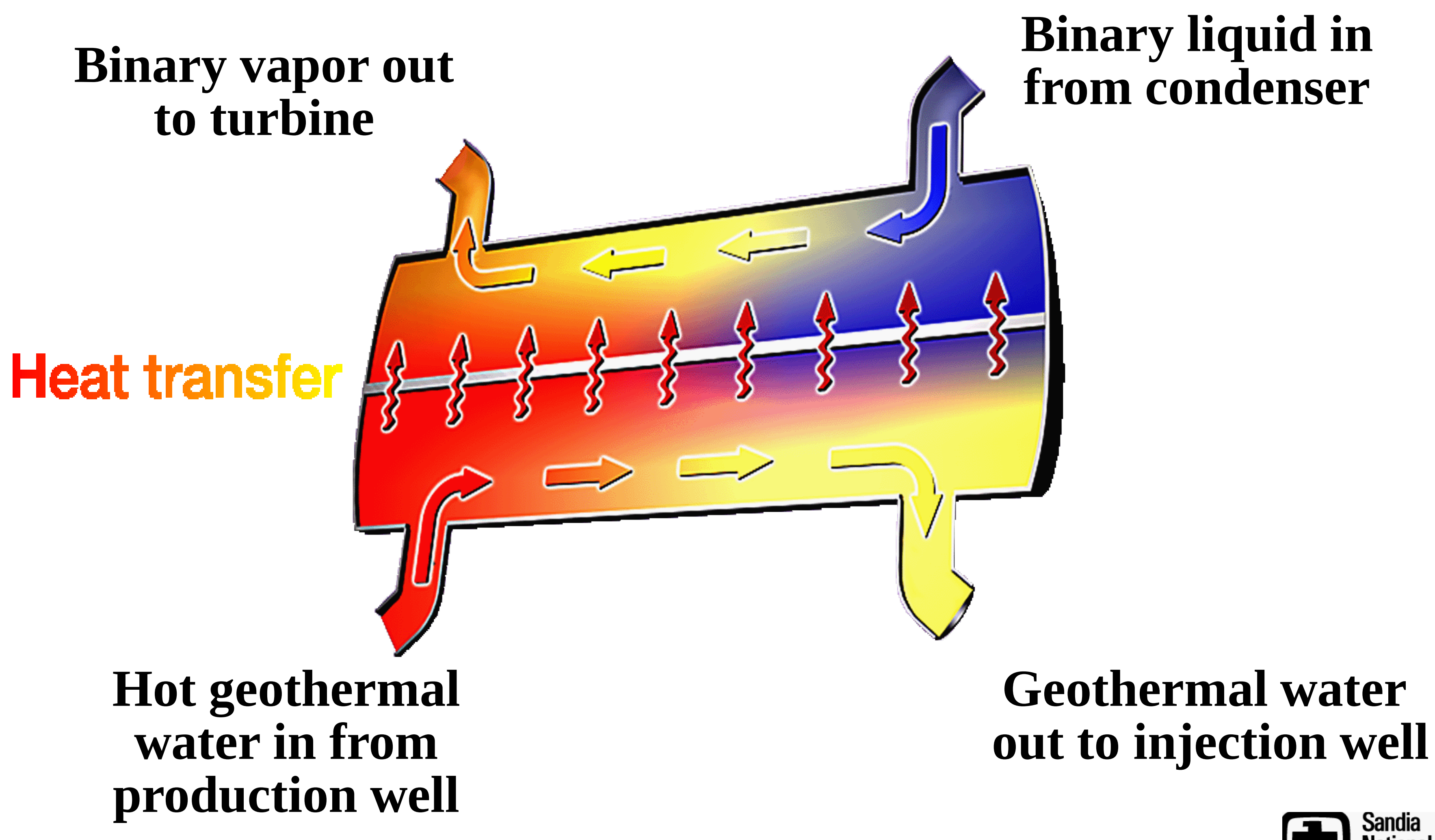
Flash Steam Power Plant



Binary Cycle Power Plant



Binary Power Plant Heat Exchanger



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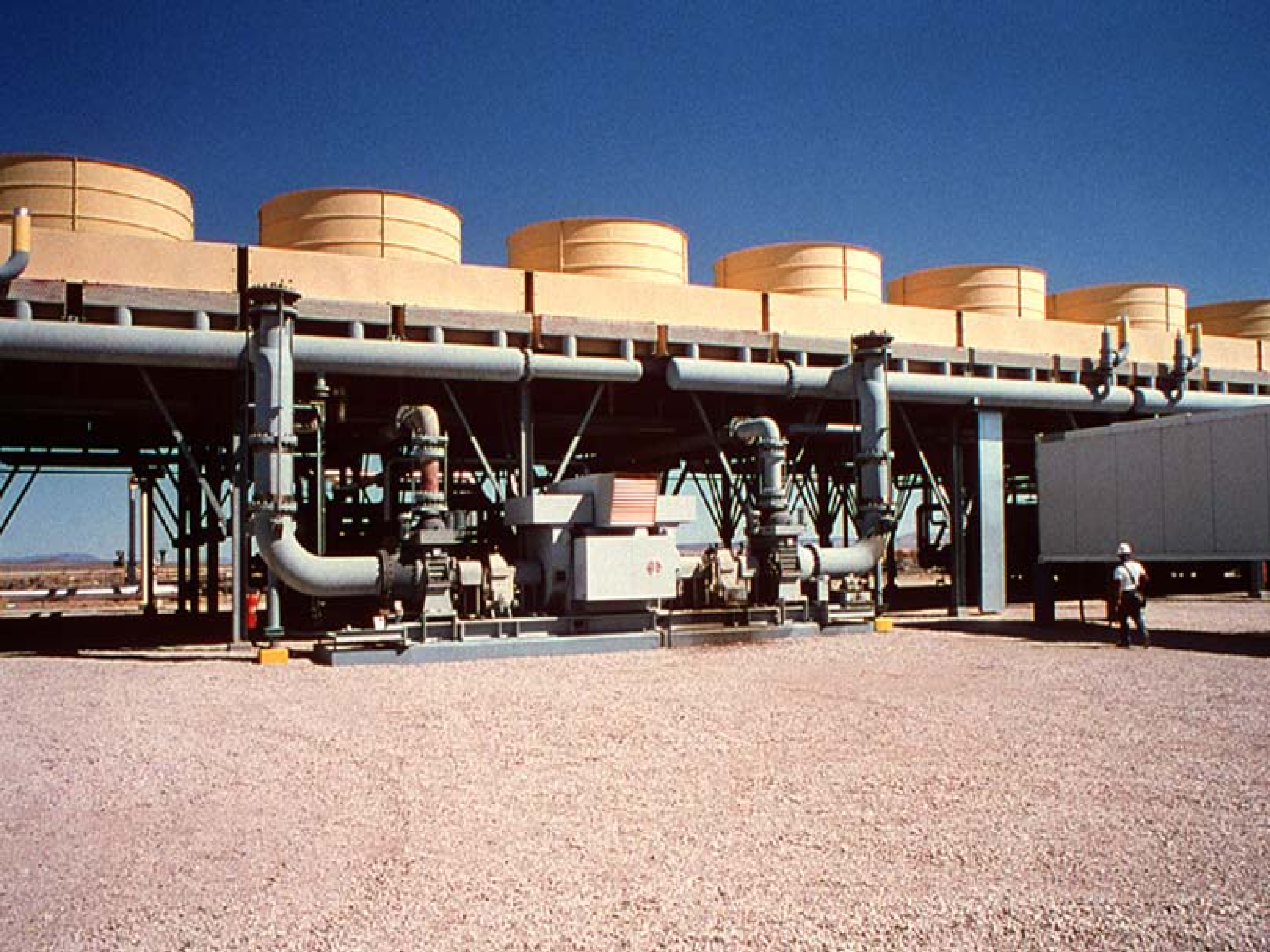
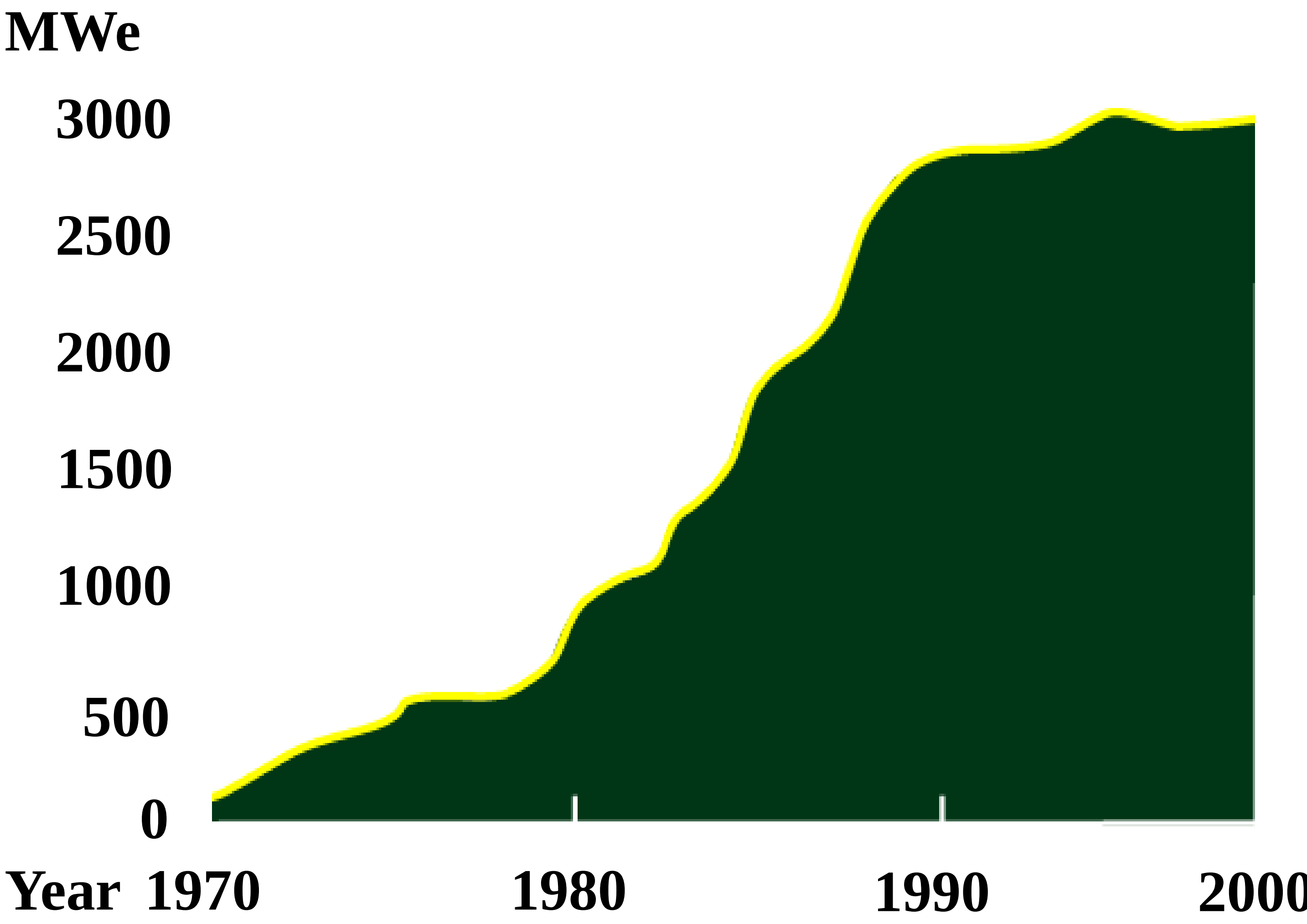


Benefits of Geothermal Power

- Provides clean and safe energy using little land
- Is renewable and sustainable
- Generates continuous, reliable “baseload” power
- Conserves fossil fuels and contributes to diversity in energy sources
- Avoids importing and benefits local economies
- Offers modular, incremental development and village power to remote sites

Growth in U.S. Geothermal Power

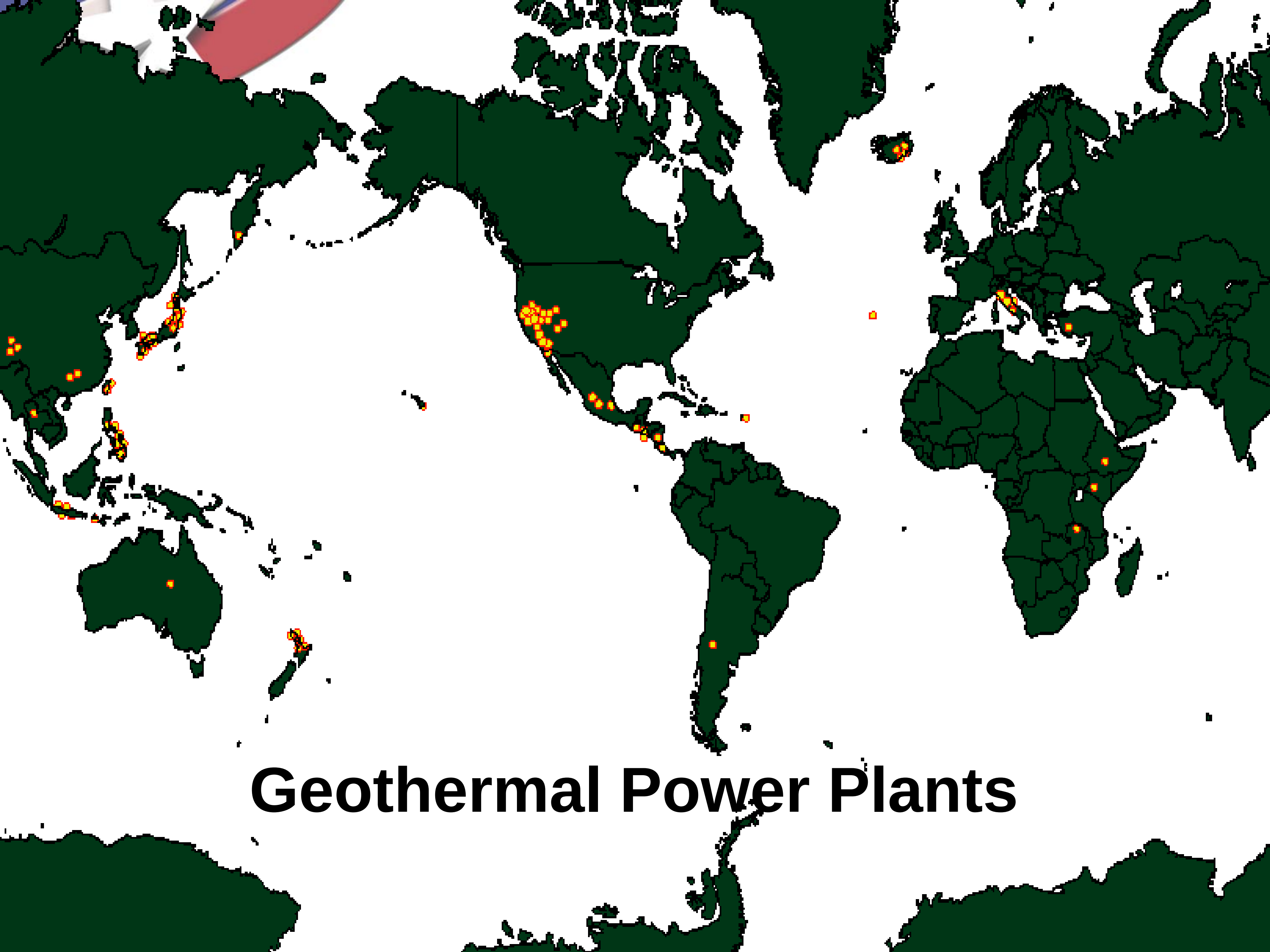


U.S. Geothermal Power

Over 2,800 megawatts of electricity from geothermal power plants are supplying about 4 million people in the U.S.

Worldwide Electricity Generation

Geothermal power plants are producing over 8,200 megawatts of electricity in 21 countries, supplying about 60 million people -- mostly in developing countries.



Geothermal Power Plants

Countries Generating Electricity with Geothermal Resources

Australia
China
Costa Rica
El Salvador
Ethiopia
France (Guadeloupe)
Guatemala
Iceland

Indonesia
Italy
Japan
Kenya
Mexico
New Zealand
Nicaragua
Philippines

Portugal (Azores)
Russia (Kamchatka)
Taiwan
Thailand
Tibet
Turkey
United States
Zambia

…and geothermal power plants are planned in several other countries

Direct Uses

Direct Use Applications

Direct use displaces about 1.6M barrels of oil annually in the United States.

- **District Heating**
- **Process Heat**
- **Agriculture**
- **Aquaculture**
- **Balneology (hot spring and water bathing)**

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Worldwide Geothermal Direct Use

- **Direct uses of geothermal water supply over 11,000 thermal megawatts in over 40 countries.**
- **Another 35 countries use natural hot springs for bathing but have not yet developed their geothermal reservoirs for commercial use.**



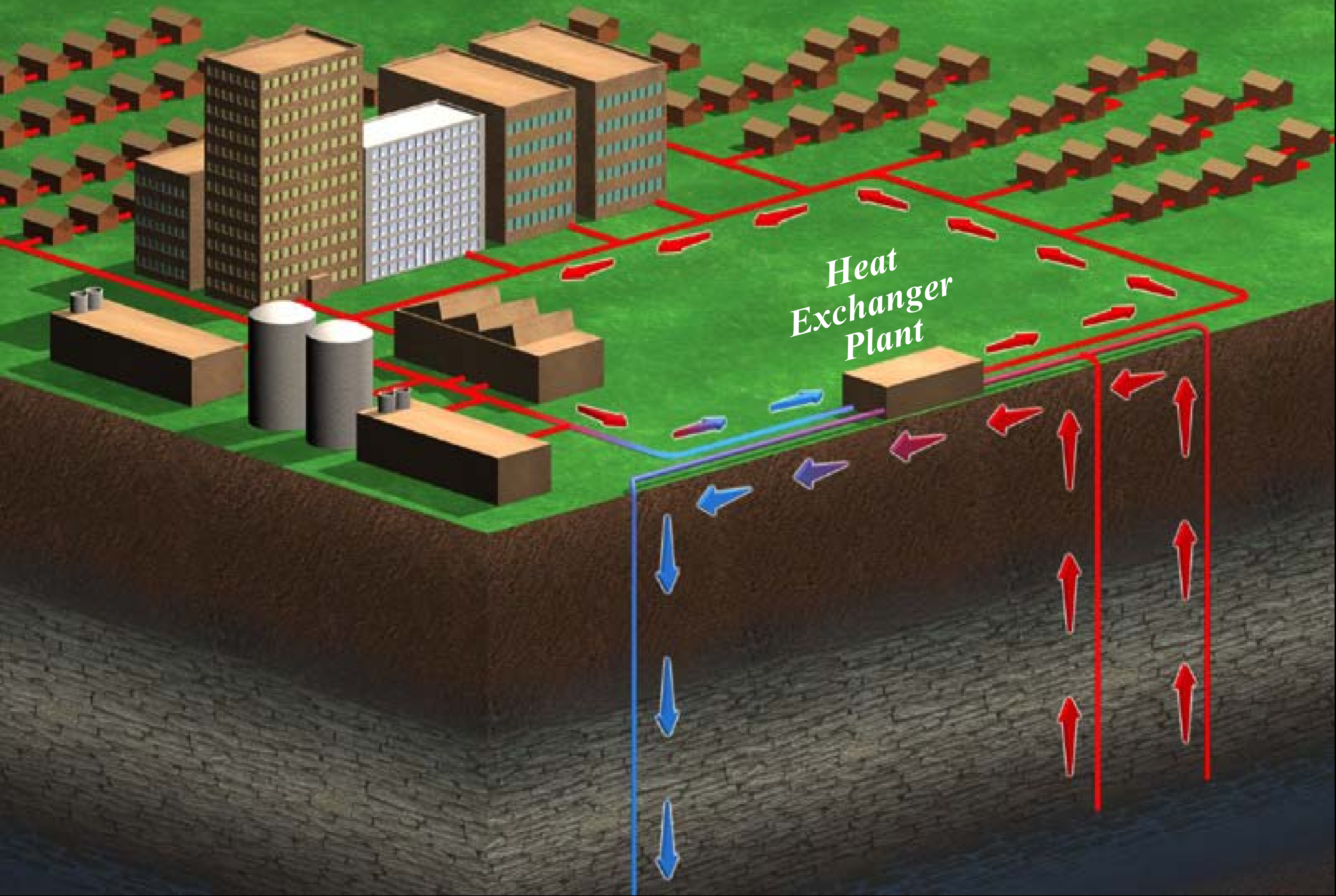




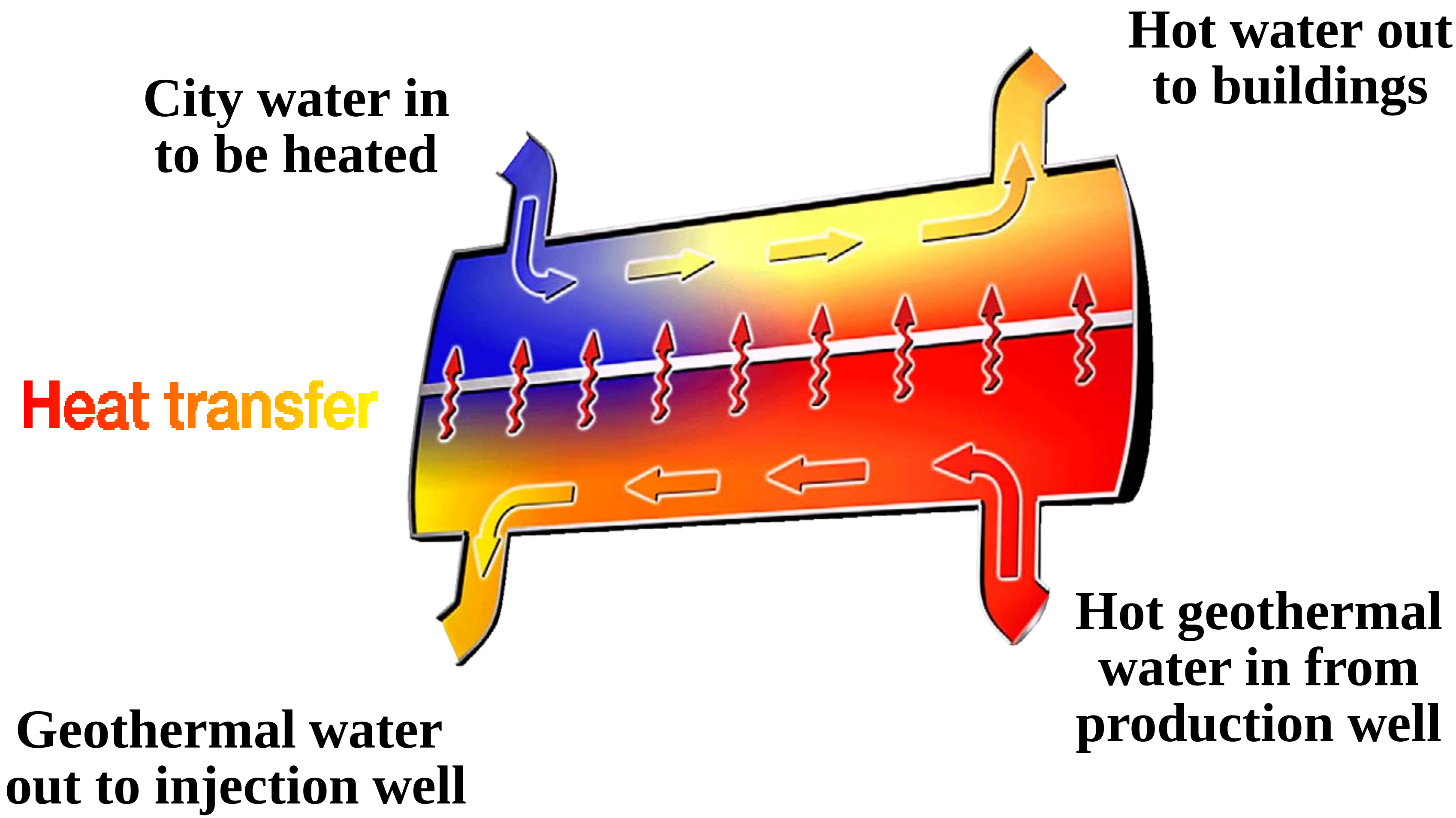

World's First COMMERCIAL
FOOD DEHYDRATION PLANT
TO BE OPERATED WITH GEOTHERMAL ENERGY
SCHEDULED FOR OPERATION SEPT. 1978
FINANCING BY:
NEVADA NATIONAL BANK
WELLS FARGO, N.A.
LOAN GUARANTEED BY:
U.S. DEPARTMENT of ENERGY
OWNERS & DEVELOPERS:
GEOTHERMAL
FOOD PROCESSORS, INC.

Residential Heating

District Heating



District Heating Heat Exchanger



Reykjavik Using Fossil Fuels


Reykjavik Using Geothermal


Geothermal Drilling at
Capitol Building,
Boise, Idaho

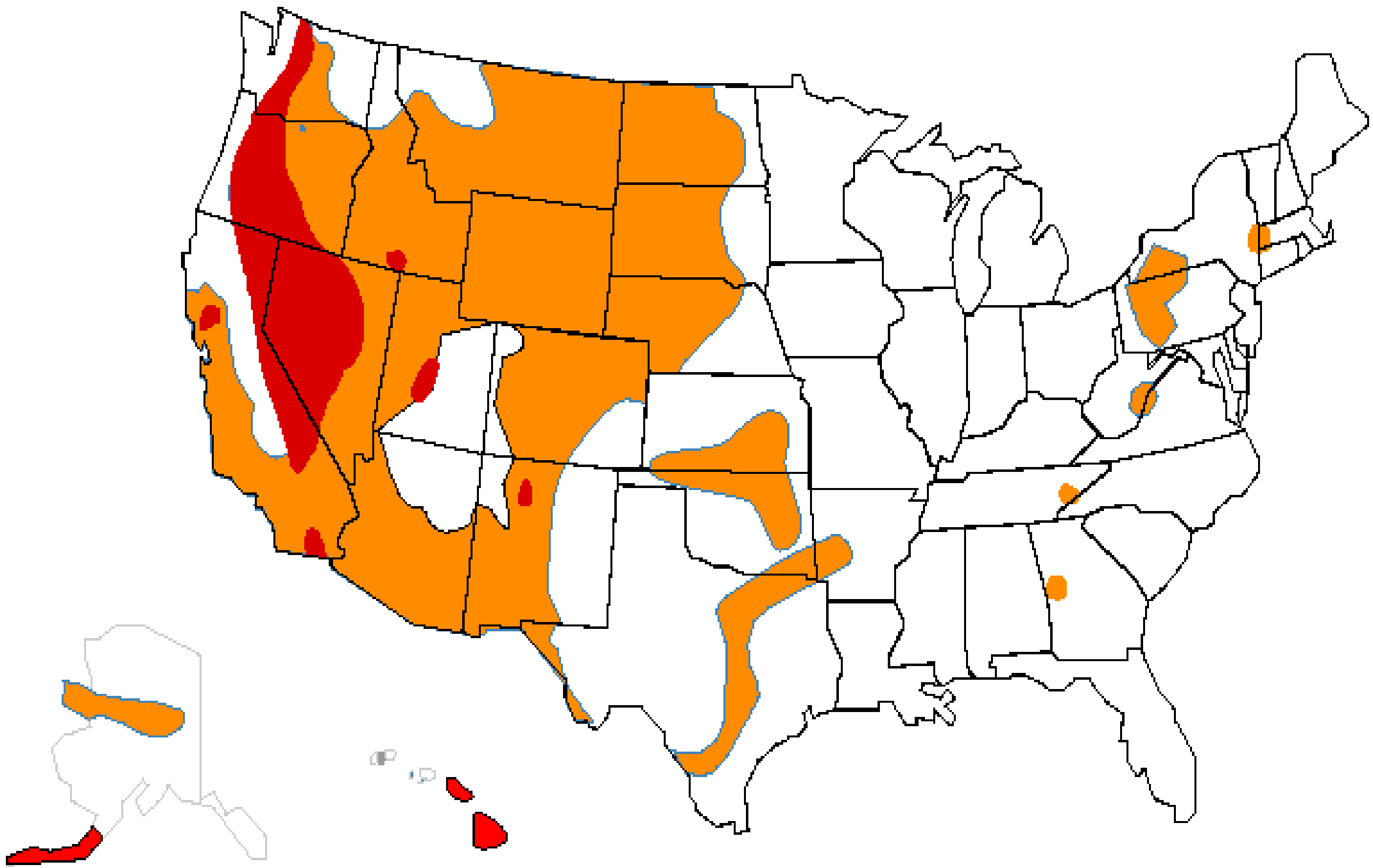
Oregon Institute of Technology: Warmed by Geothermal District Heating

District Heating in Western U.S.

- There are 18 district heating systems operating in the western United States.

- Over 270 cities in the western U.S. are close enough to geothermal reservoirs to use district heating.

U.S. Geothermal Potential



Power Plants and Direct Uses   Direct Uses

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District Heating Worldwide

- There is evidence that people heated their homes
  with geothermal water in ancient Pompeii, and records of geothermal use in France go back over 600 years.

- Modern geothermal district heating systems are operating in Poland, France, Hungary, Iceland, Turkey and the United States.

Geothermal Heat Pumps

(GeoExchange Systems)

Residential and commercial heating and cooling

. . . without a geothermal reservoir

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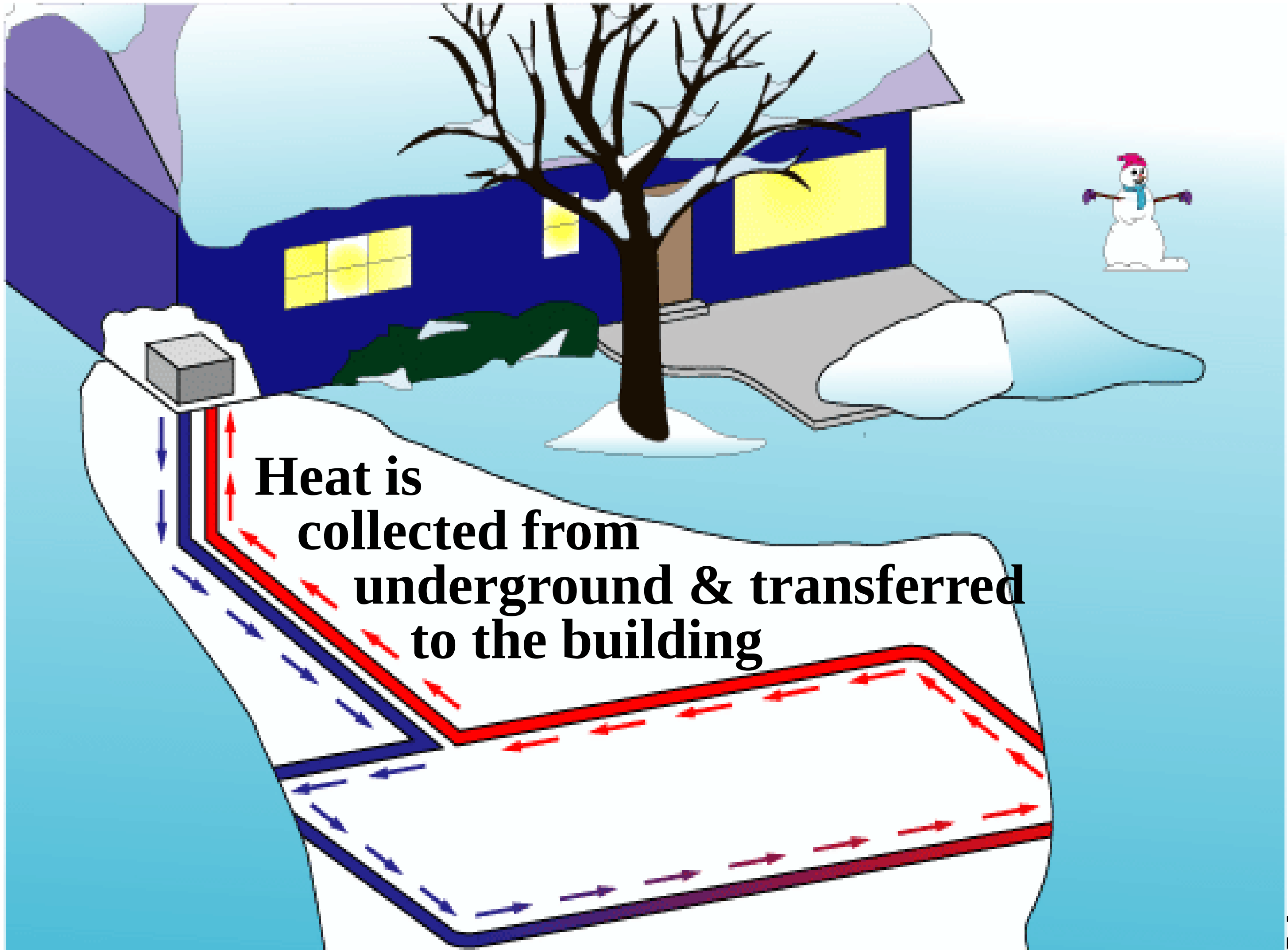
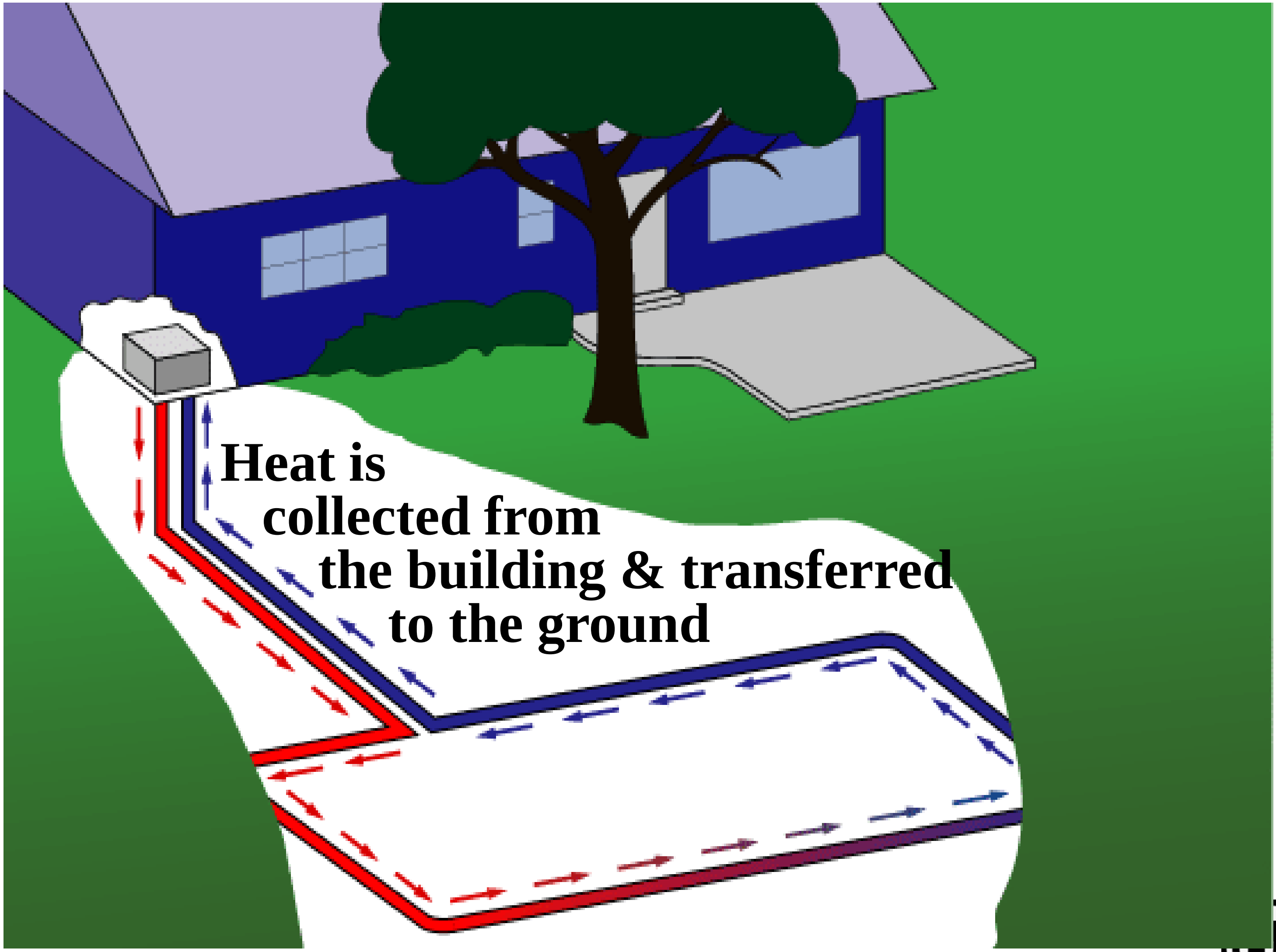
Heat Pump in Winter



Heat Pump in Summer



Benefits of Geothermal Heat Pumps

- Can be used almost everywhere worldwide
- Are energy- and cost-efficient
- Conserve fossil fuel resources
- Provide clean heating and cooling -- no emissions from burning fuels

Geothermal Heat Pump Efficiency

The U.S. Environmental Protection Agency has rated geothermal heat pumps among the most efficient heating and cooling technologies available today.

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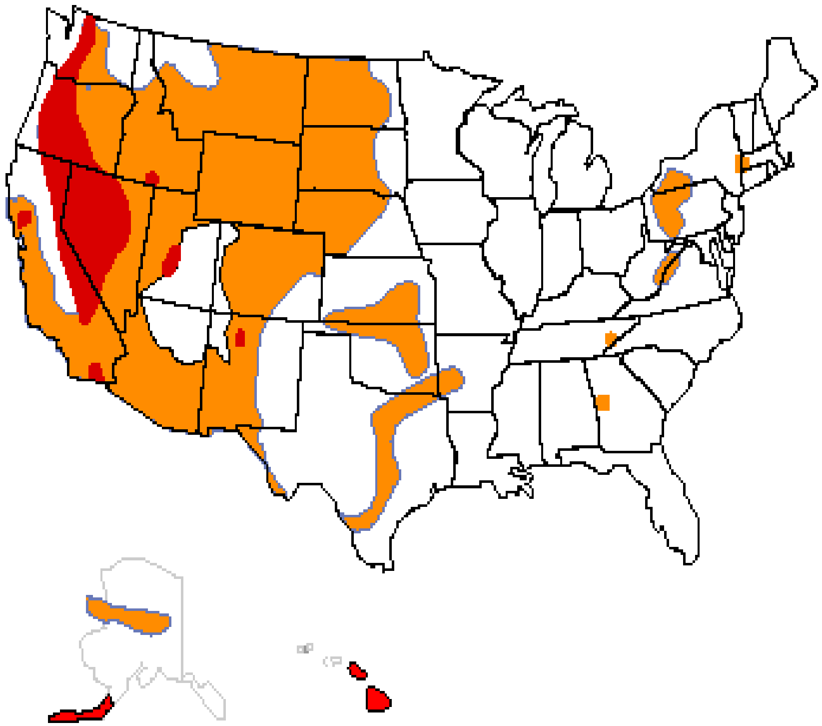
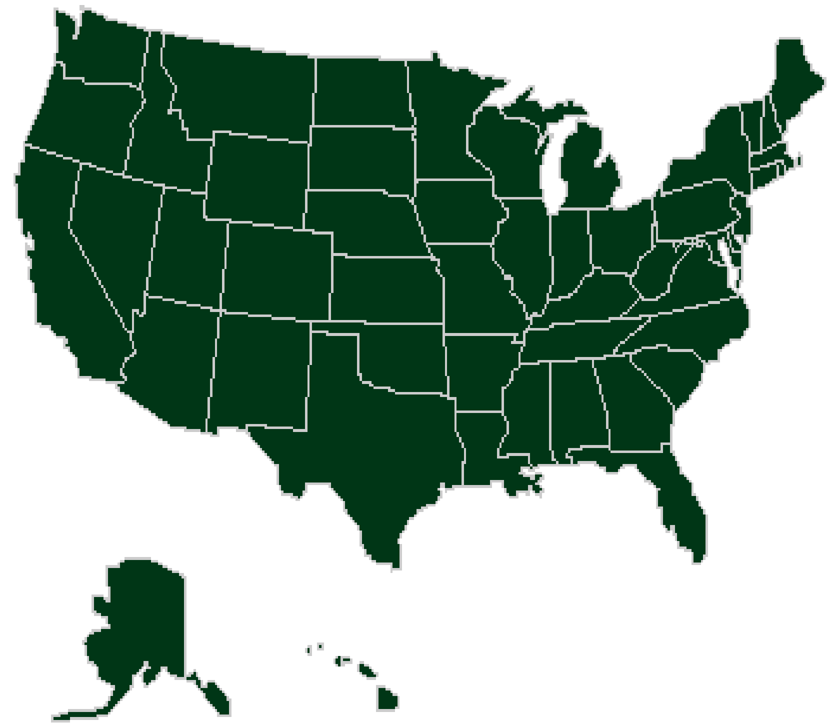
Use of Geothermal Energy in the U.S.

- **2,800 megawatts of electricity supplying 4 million people in western U.S. and Hawaii**
- **500 thermal megawatts of direct uses**
- **400,000 heat pumps nationwide, providing 1,500 thermal megawatts of heating and cooling**

U.S. Geothermal Potential





Direct Uses

Power Plants and Direct Uses

Geothermal Heat Pumps

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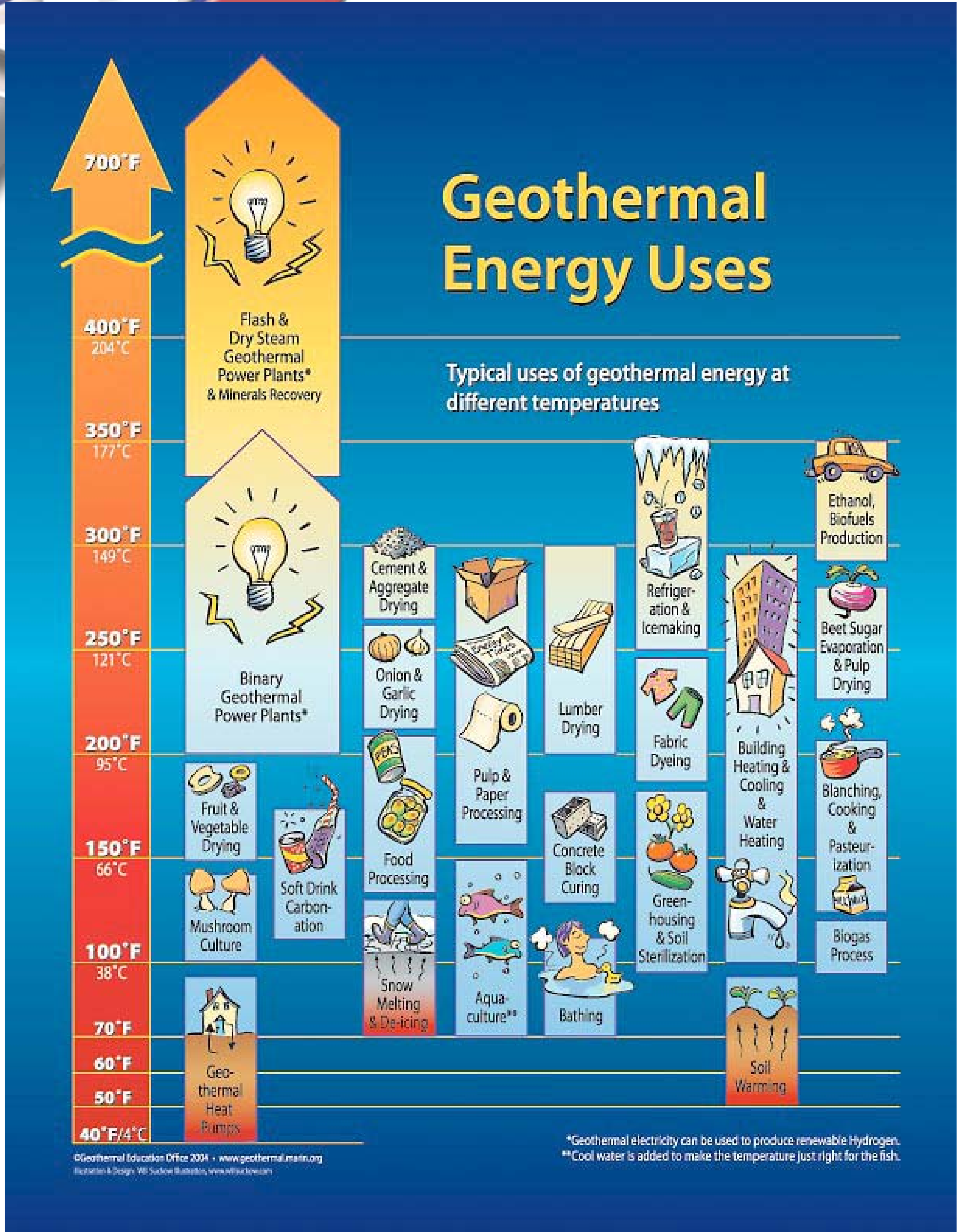
Geothermal Applications in Summary



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GeoPowering the West

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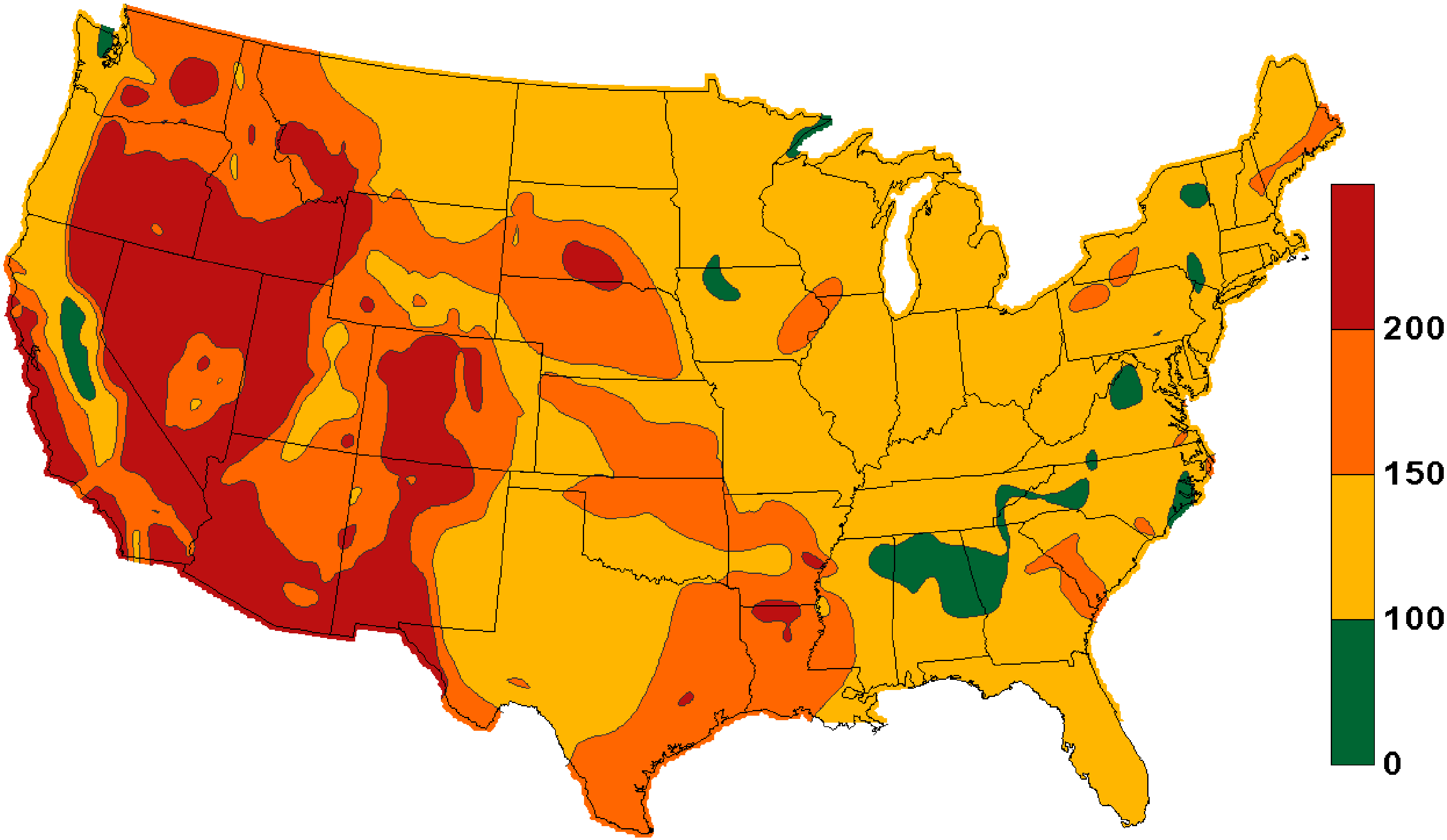
Estimated Earth Temperatures at 6 km Depth (°C)



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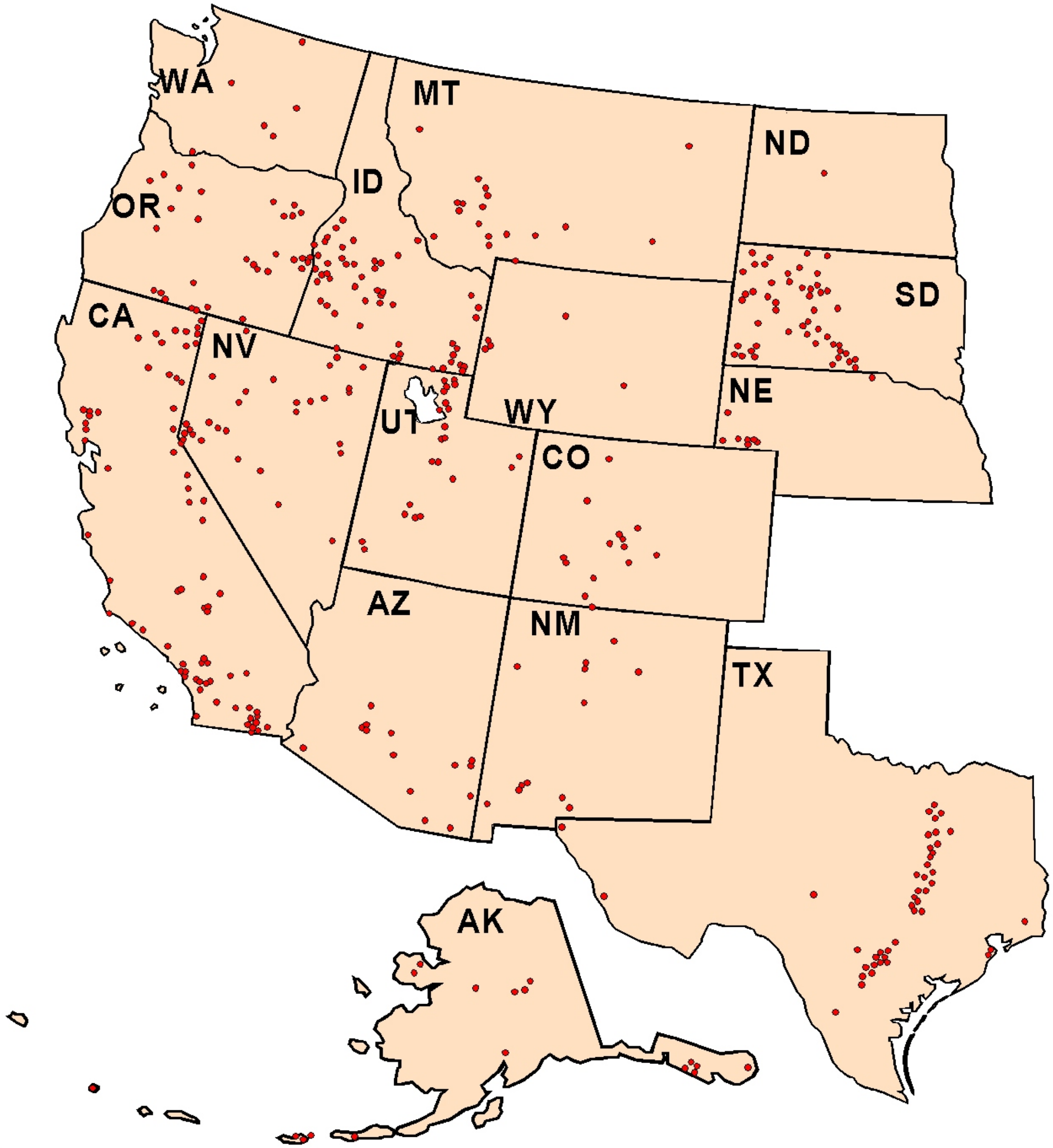
Communities with Geothermal Resource Development Potential

The geothermal resources (wells and springs) shown on this map have a temperature greater than 50ºC (122ºF) and are located within 8 km (5 miles) of a community.



Geo-Heat Center

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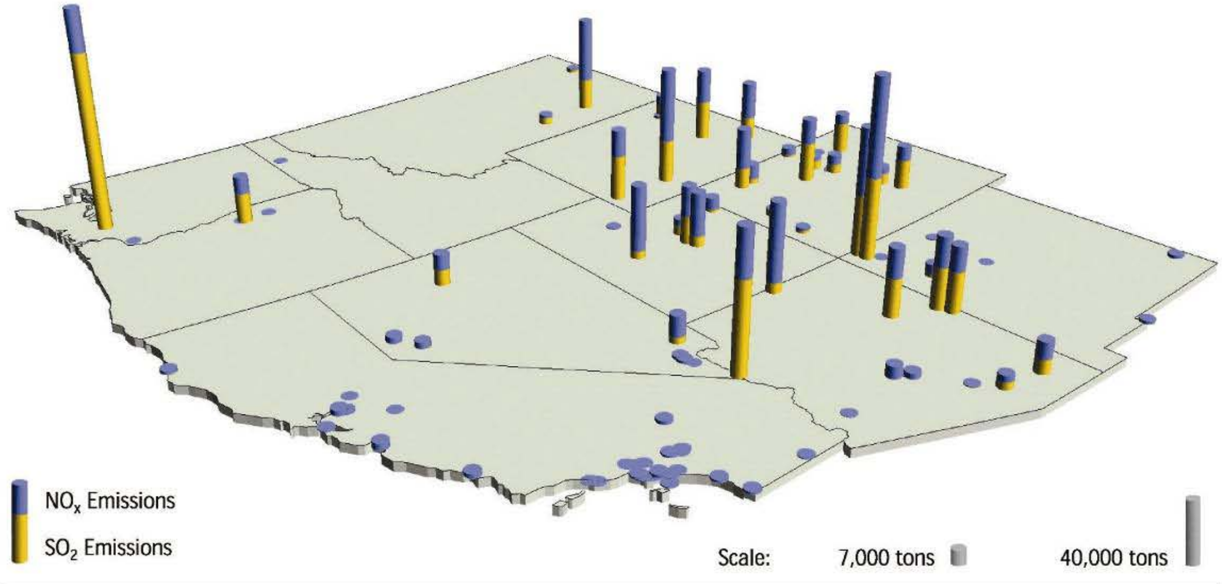
Regional Power Plant Emissions

Power Plant Emissions, 2000

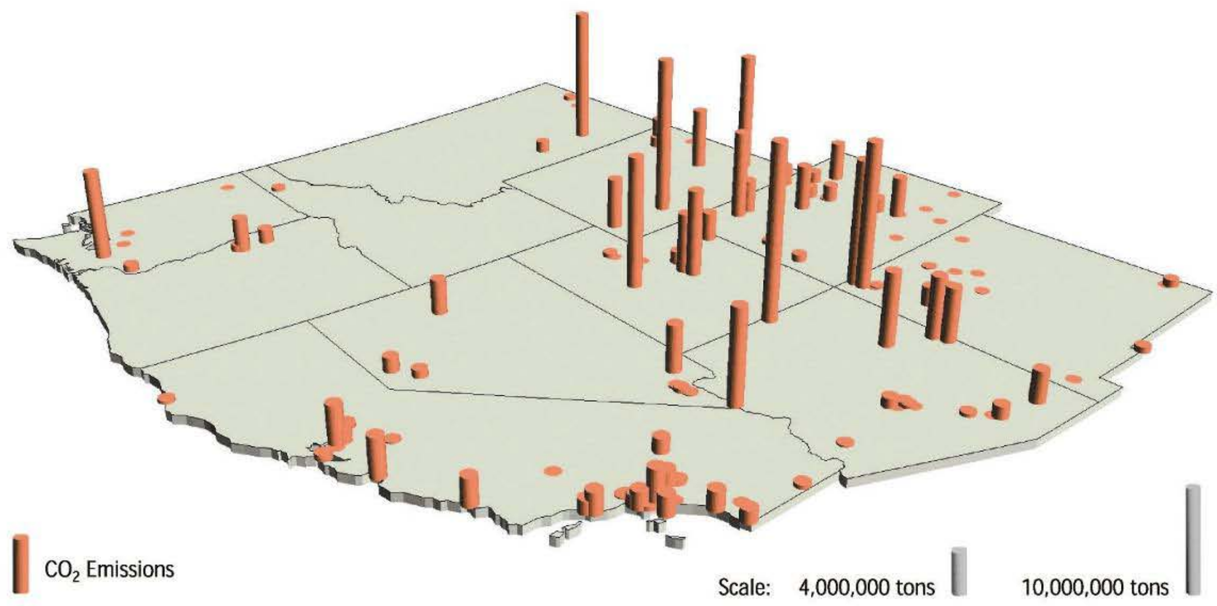
Each bar represents the location of a power plant regulated under the EPAÕ Acid Rain Program (Title IV). The height of the bars is scaled to reßect the emissions levels for each plant. Because CO_2 emissions are so much higher than either SO_2 or NO_x, different scaling factors were used to determine the height of the bars.



Total Emissions in Region from Title IV Plants, 2000

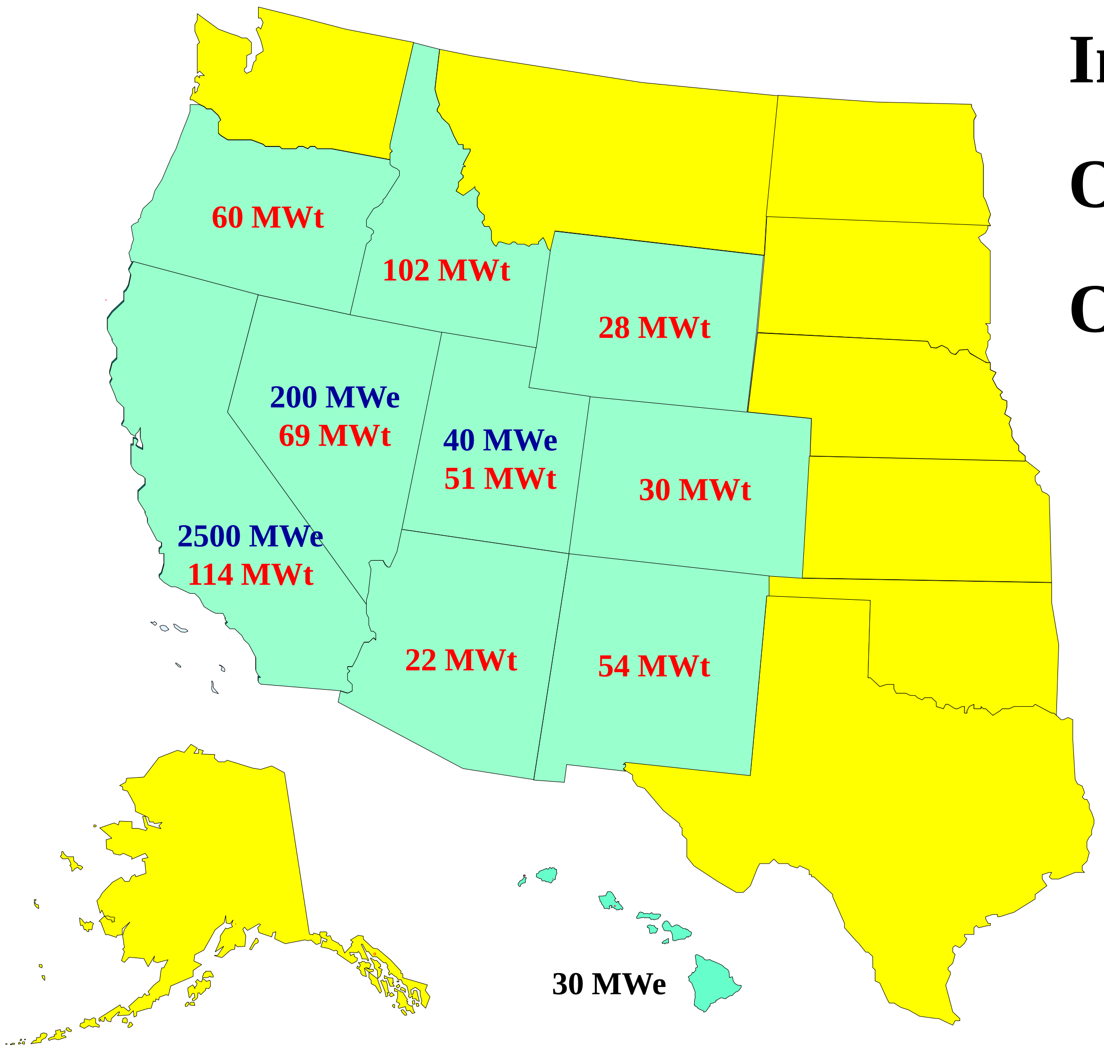
	tons
Sulfur Dioxide (SO_2)	506,662
Nitrogen Oxide (NO_X)	547,754
Carbon Dioxide (CO_2)	316,774,136

Data source: EPA Acid Rain Program (Title IV) Emissions Scorecard, 2000



Renewable Energy Atlas

Heat and Power for the 21st Century



Installed:

Over 2800 MW (electric)

Over 500 MW (heat)

Greater Than 20 MW

Less than 20 MW

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Challenges to Geothermal Development

- Competition with fossil fuels
- Financing
- Long project lead times
- Siting and Permitting
- Obvious sites already taken
- Industry focus overseas
- Large projects at high

Research Needs

- Cheaper drilling
- Better reservoir exploration and identification
- Better reservoir evaluation and management
- More efficient power plants for lower temperatures

$ $

“Expanding Geothermal Power Could Create 100,000 New Jobs”

A recent estimate produced by the Western Governors' Association's geothermal task force indicates a near-term potential to expand this to 8,300 MW in eleven western states. According to GEA, “this would result in the creation of over 100,000 new power plant, manufacturing and construction jobs.”

Source: Geothermal Energy Association press release, September 7, 2005

GEOPOWERING THE WEST

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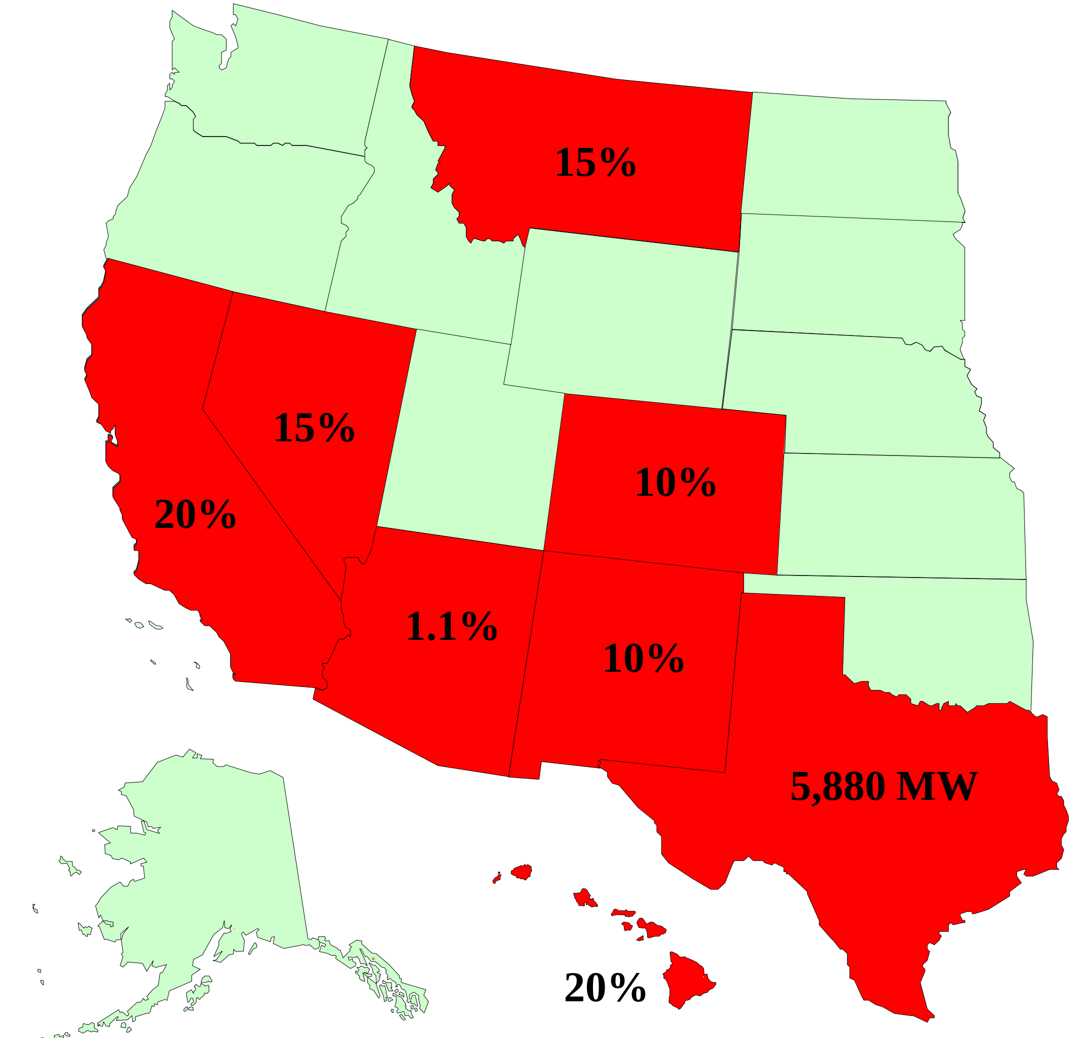
Renewable Portfolio Standards

Western States



Arizona – 1.1% in 2007 - 2012

California – 20% by 2017

Colorado – 10% by 2015

Hawaii – 20% by 2020

Montana – 15% by 2015

New Mexico – 10% by 2011

Nevada – 15% by 2013

Texas – 5,880 MW by 2015

GeoPowering the West

Utility Advantages

- 24–hour, steady, base-load power
- Dispatchable, base-load electricity
- Very reliable, >90% capacity factor
- 90 to 95% availability factor
- Virtually inexhaustible fuel source with good management practices

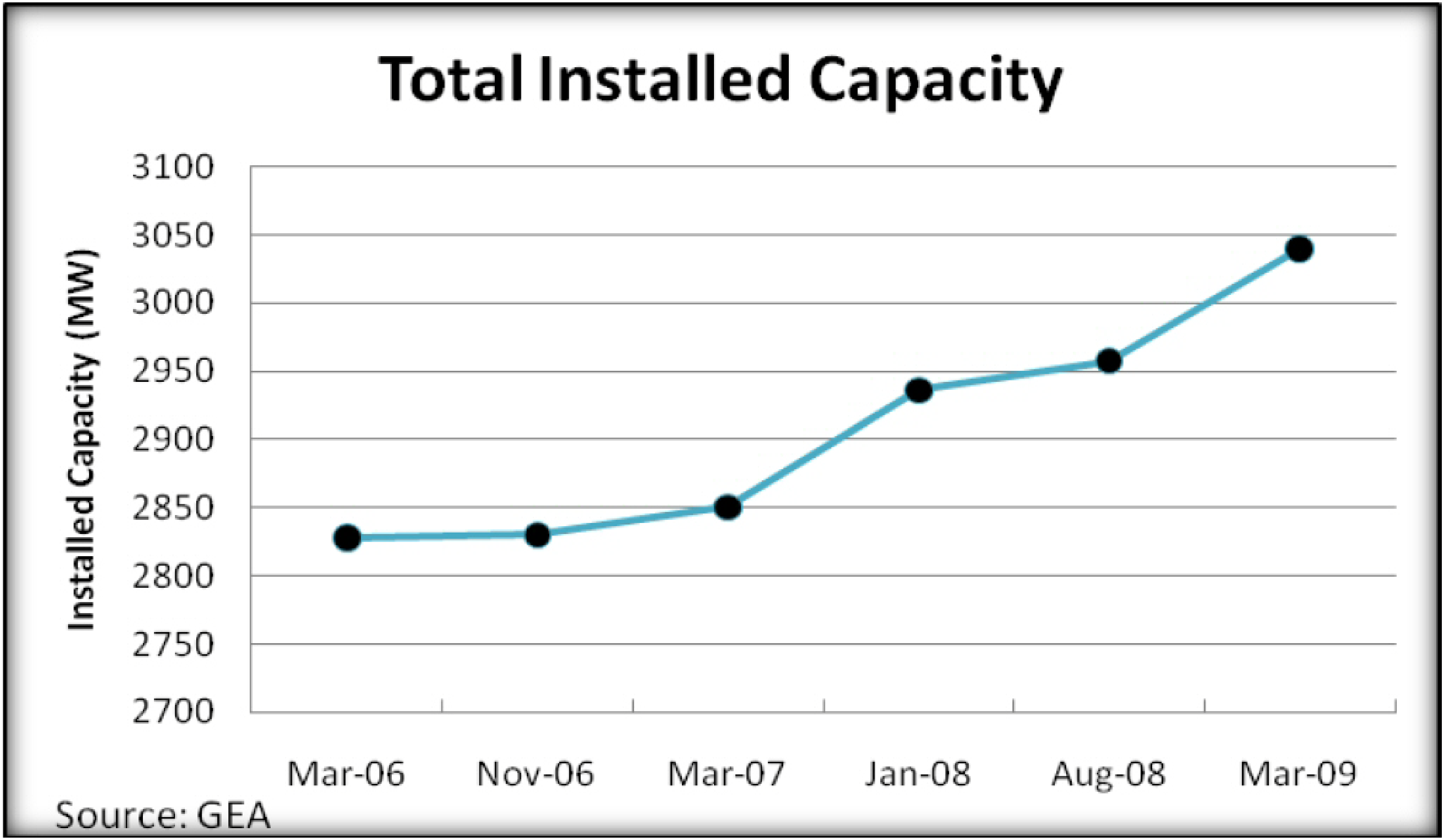
Significant Power Production

Geothermal plants produce 6% of California's electricity (12.2 million MWh in 2001)

Geothermal provides about 30% of the electricity needs of the Philippines.

This hybrid binary/flash power plant provides about 25% of electricity demand on the Big Island of Hawaii →

U.S.



Geothermal Energy Association: U.S. Geothermal Power Production and Development, March 2009

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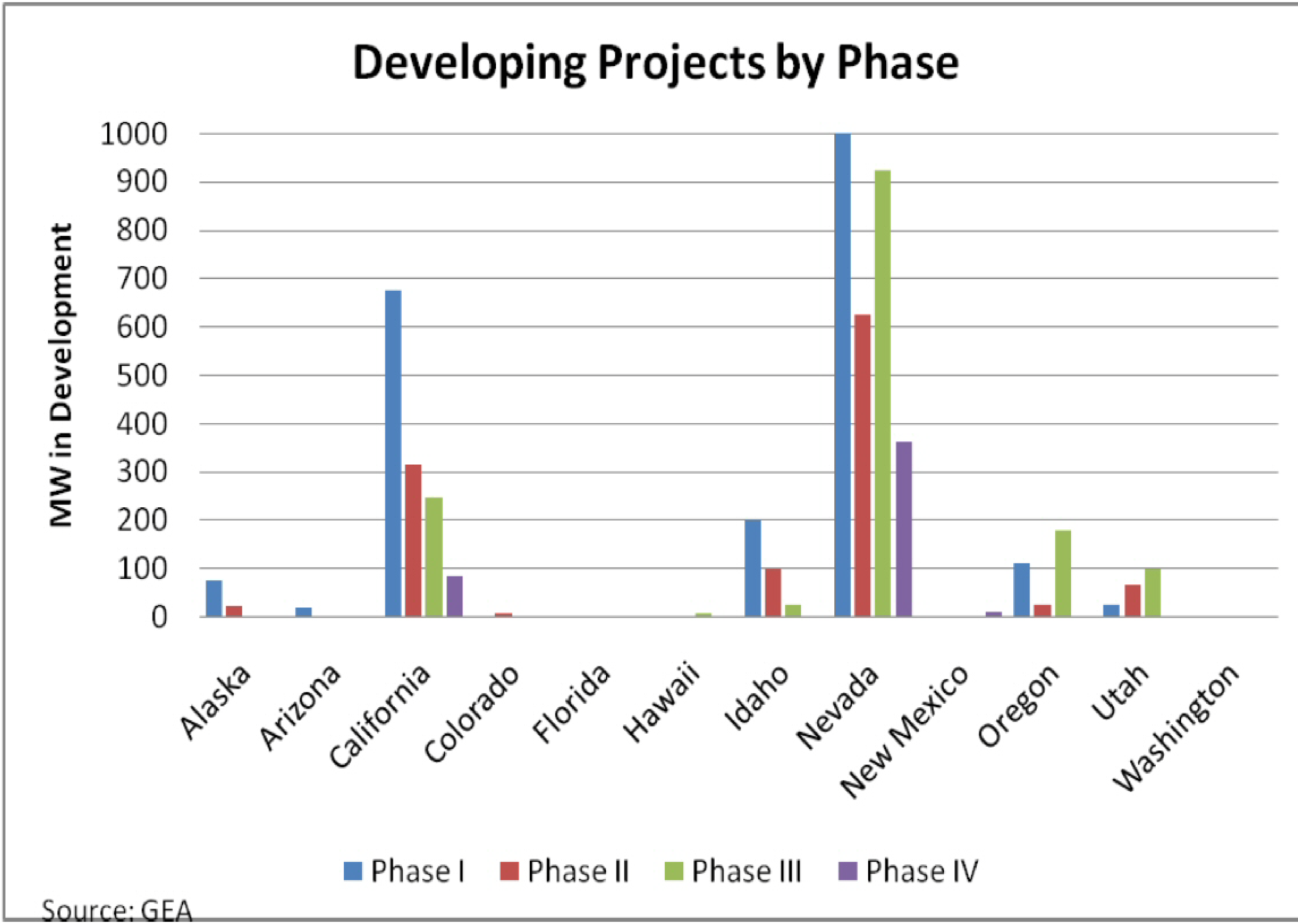


Geothermal Energy Association: U.S. Geothermal Power Production and Development, March 2009

U S

Hydroelectric = 248.05 terawatt-hours

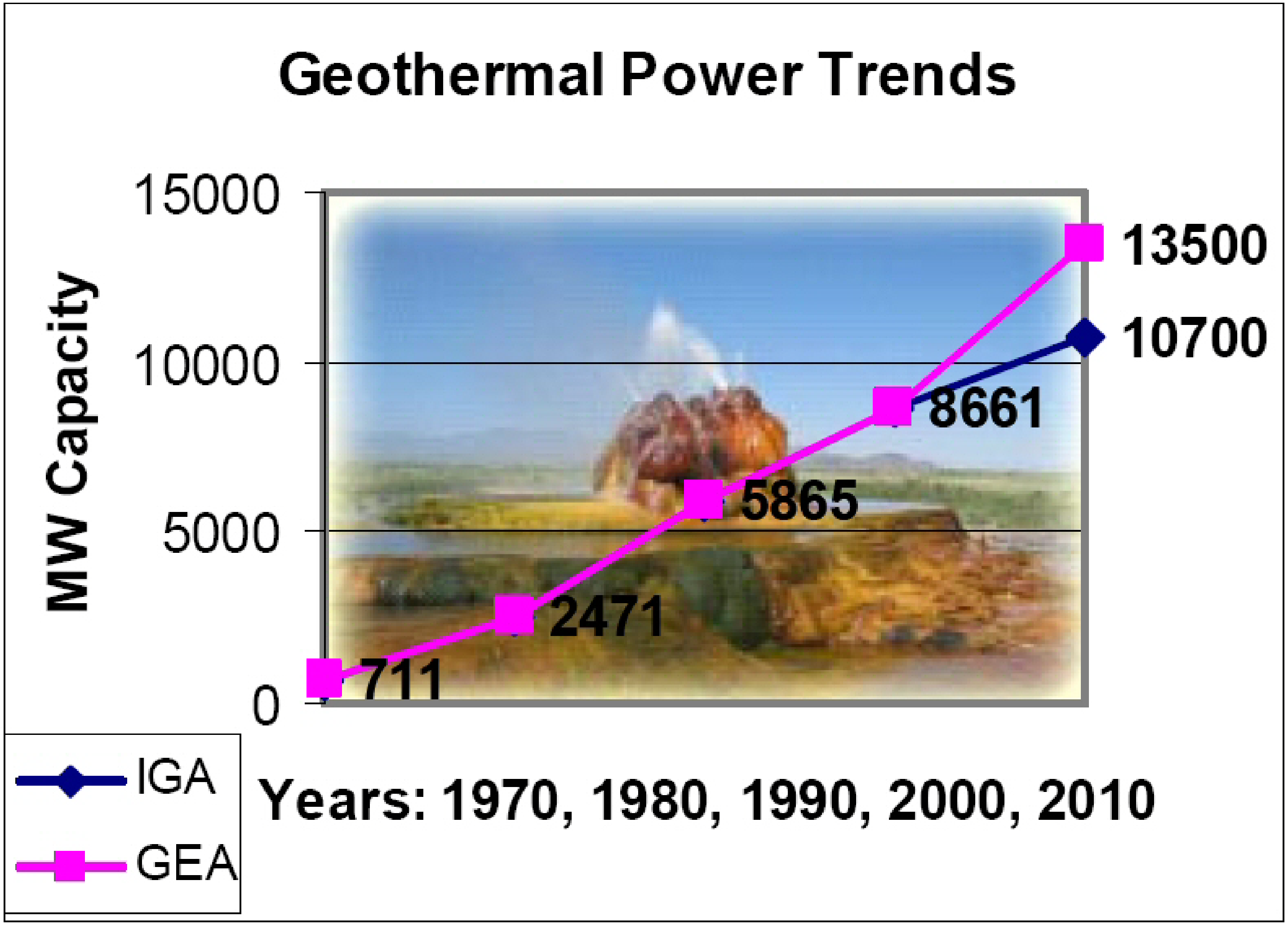
Wind = 52.03 terawatt-hours

Geothermal = 14.86 terawatt-hours

Solar = 0.84 terawatt-hours

Source: DOE/EIA

Geothermal Energy



Geothermal Energy Association

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Solar Energy Technologies

Daniel Laird

Energy and Infrastructure Future

Sandia National Laboratories

Acknowledgments: Tom Mancini (SNL), Charles Hanley (SNL), Jeff Nel

Introduction

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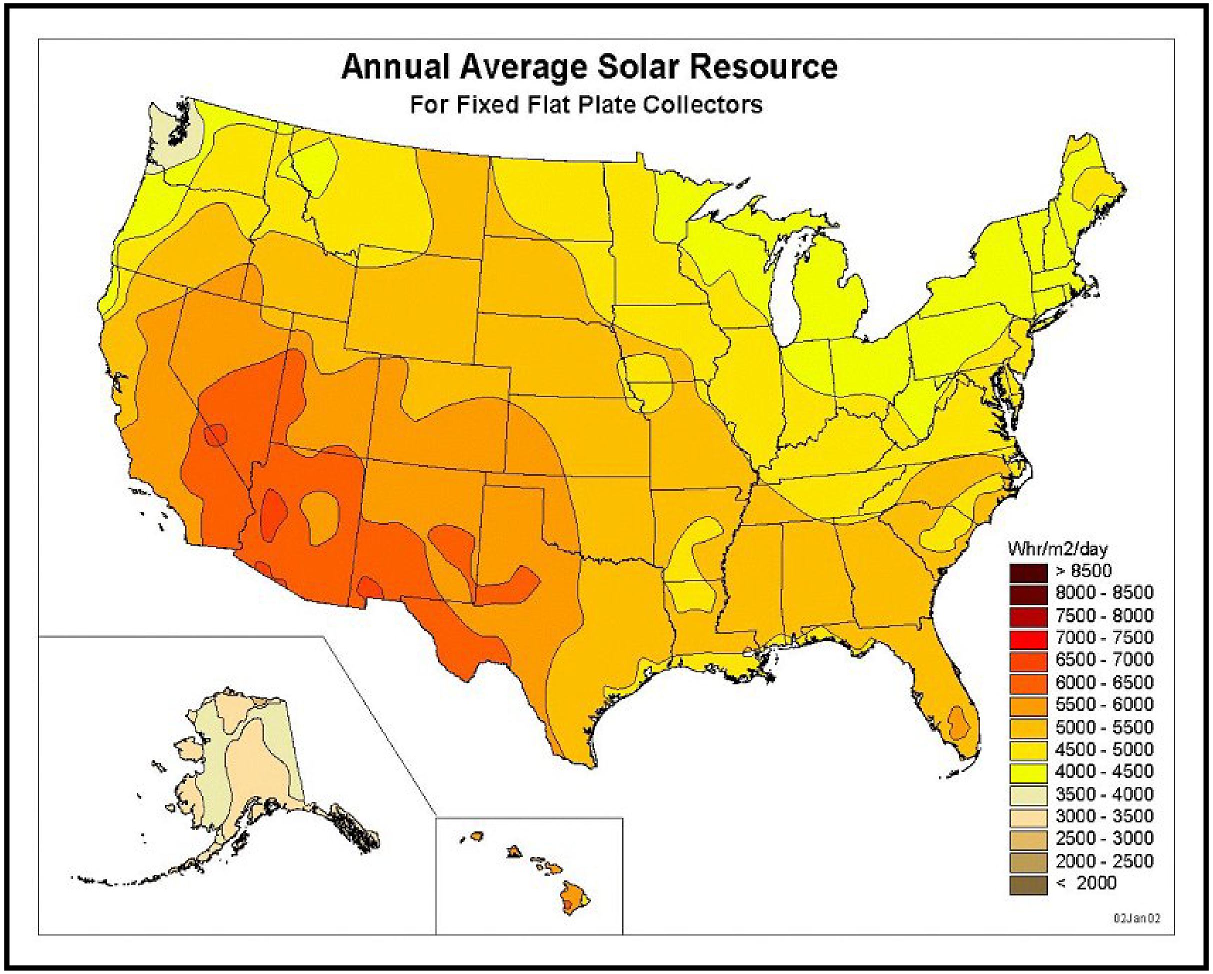
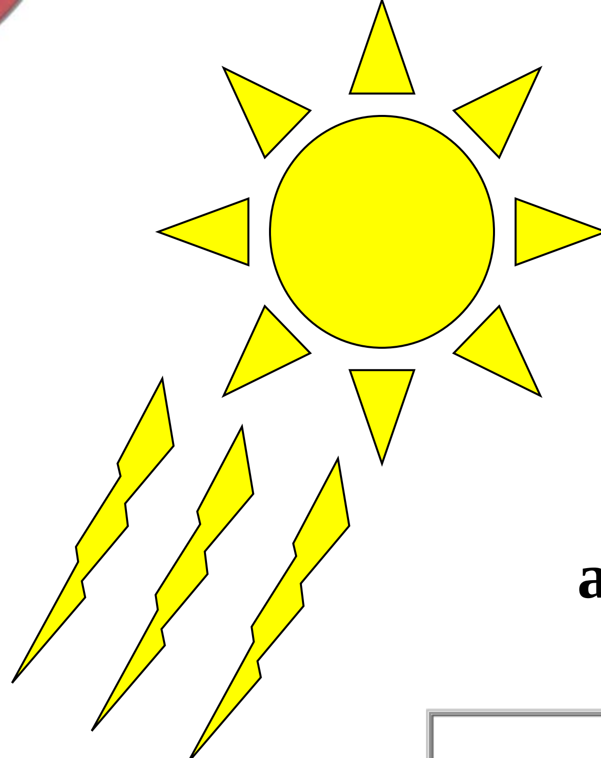
Solar Energy Resource

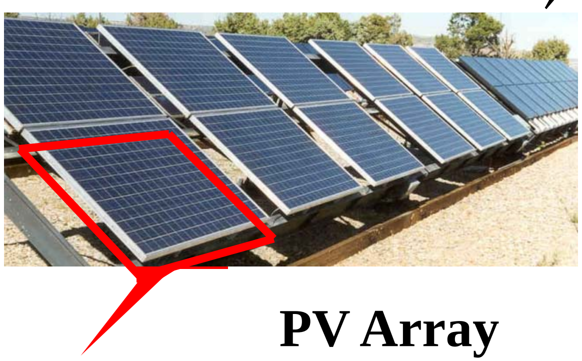


Solar Technologies

- Photovoltaics (PV)
  - c-Si
  - Thin film (CdTe, CIS, a-Si, others)
  - Concentrating PV and multi-junction cells
  - Others (organic, dye sensitized, micro or nano-PV, etc.)
- Concentrating Solar Power
  - Dispatchable
    - Towers
    - Troughs
  - Distributed
    - Dishes
  - Other
    - Solar Fuels
- Solar water heating

PV Systems





dc electricity

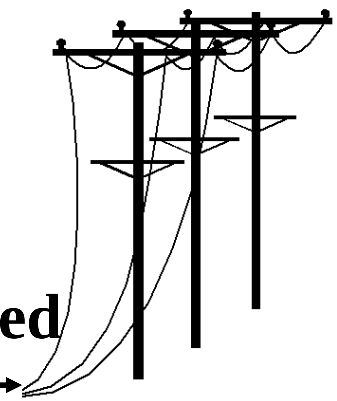
Inverter

ac Load

PV Array

PV Module: Power producing component

Grid-Tied



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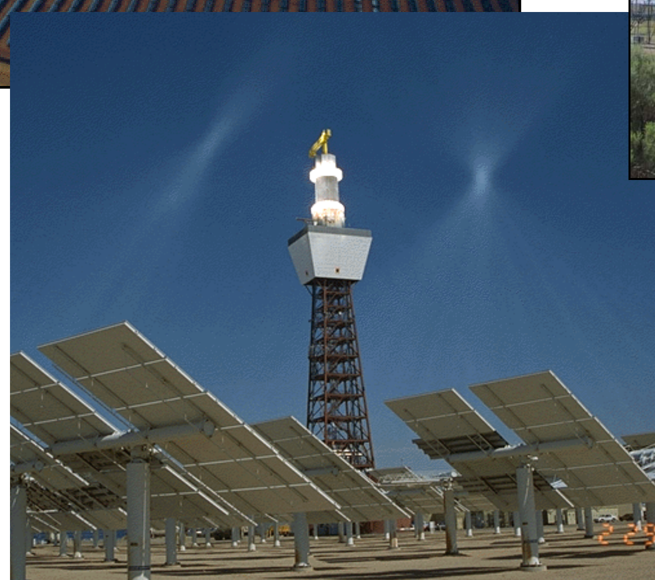
Millennium SportsClub Vacaville 152 kW DC

SolarIntegrated

Concentrating Solar Power



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Solar Fuels

Reversing Combustion

hν OR e^- OR Heat

Electro-Chemical
Photo-(Electro)-Chemical
Thermo-Chemical
Catalytic
Bio-chemical

CO_2

H_2O

Energy Input (Reduction)

CO_2

Fuel

H_2O

Energy Recovery (combustion)

O_2

Transportation Fuels (Gasoline, Diesel, Jet Fuel)
Natural Gas (CH_4)
Chemical Precursors

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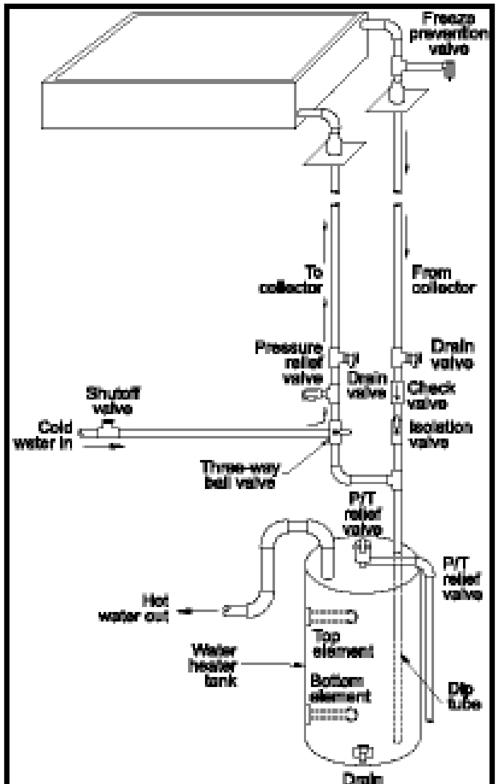
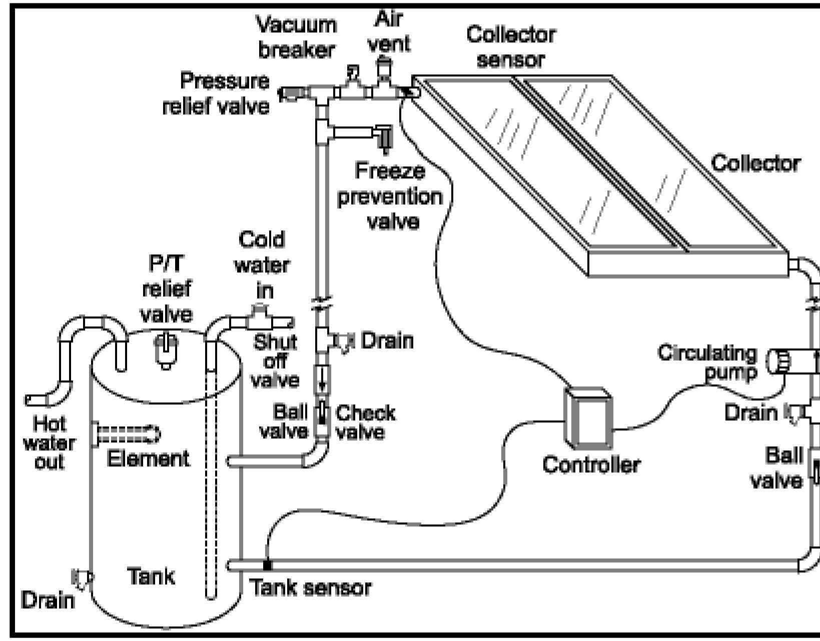
Solar Water Heating



Passive



Active

Solar Water Heating

- **1 million U.S. homes**
- **4.5 million houses in the world**
- **Annual U.S. generation over 2 billion kilowatt-hours of energy equivalent.**
- **U.S. represent more than 1 Gigawatt of installed equivalent power capacity.**

Over 100 million m^2 collectors worldwide

Photovoltaics (PV)

Solar Technologies

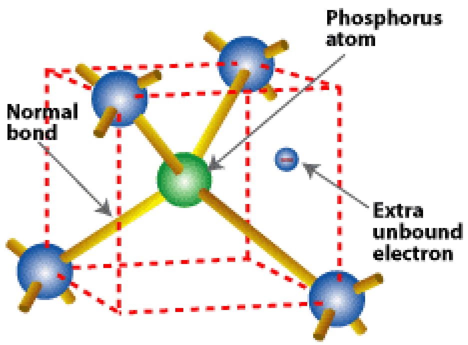
- **Photovoltaics (PV)**
  - c-Si
  - Thin film (CdTe, CIS, a-Si, others)
  - Concentrating PV and multi-junction cells
  - Others (organic, dye sensitized, micro or nano-PV, etc.)
- Concentrating Solar Power
  - Dispatchable
    - Towers
    - Troughs
  - Distributed
    - Dishes
  - Other
    - Solar Fuels
- Solar water heating
- Solar space heating

Photoelectric Effect (history)

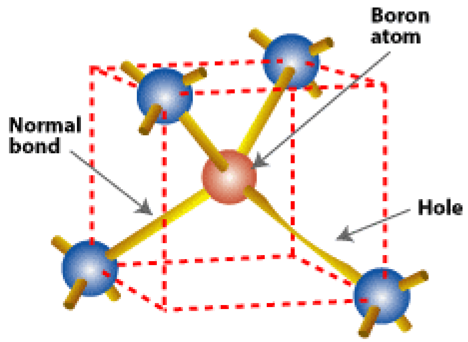
- 1839: Edmond Bequerel, French physicist discovers photoelectric effect
- 1904: Albert Einstein theoretically describes photovoltaic effect, for which he won the Nobel Prize in 1921
- 1916: Robert Millikan practically demonstrates Einstein’s theory
- 1918: Jan Czochralski, Polish physicist discovers method of producing monocrystalline silicon – still in use today
- 1941: first monocrystalline silicon cell produced
- 1954: AT&T Bell Labs publishes reports on solar cells with 4.5% efficiency

http://www.pvresources.com/en/history.php

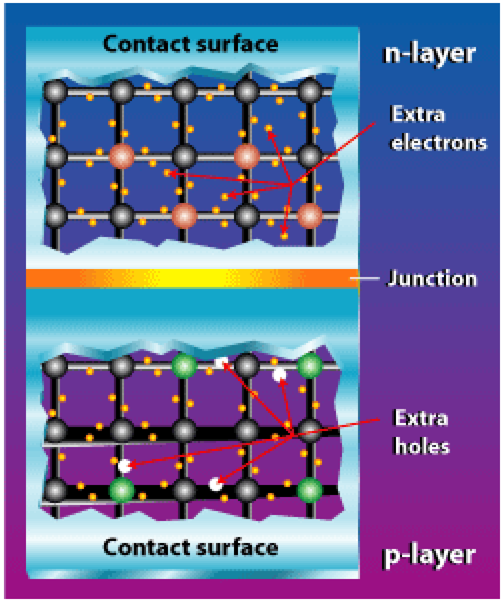
Concept of a Simple Crystalline Solar Cell



Substituting a phosphorus atom (with five valence electrons) for a silicon atom in a silicon crystal leaves an extra, unbonded electron that is relatively free to move around the crystal.



Substituting a boron atom (with three valence electrons) for a silicon atom in a silicon crystal leaves a hole (a bond missing an electron) that is relatively free to move around the crystal.



Although both materials are electrically neutral, n-type silicon has excess electrons and p-type silicon has excess holes. Sandwiching these together creates a p/n junction at their interface, thereby creating an electric field.

http://www1.eere.energy.gov/solar

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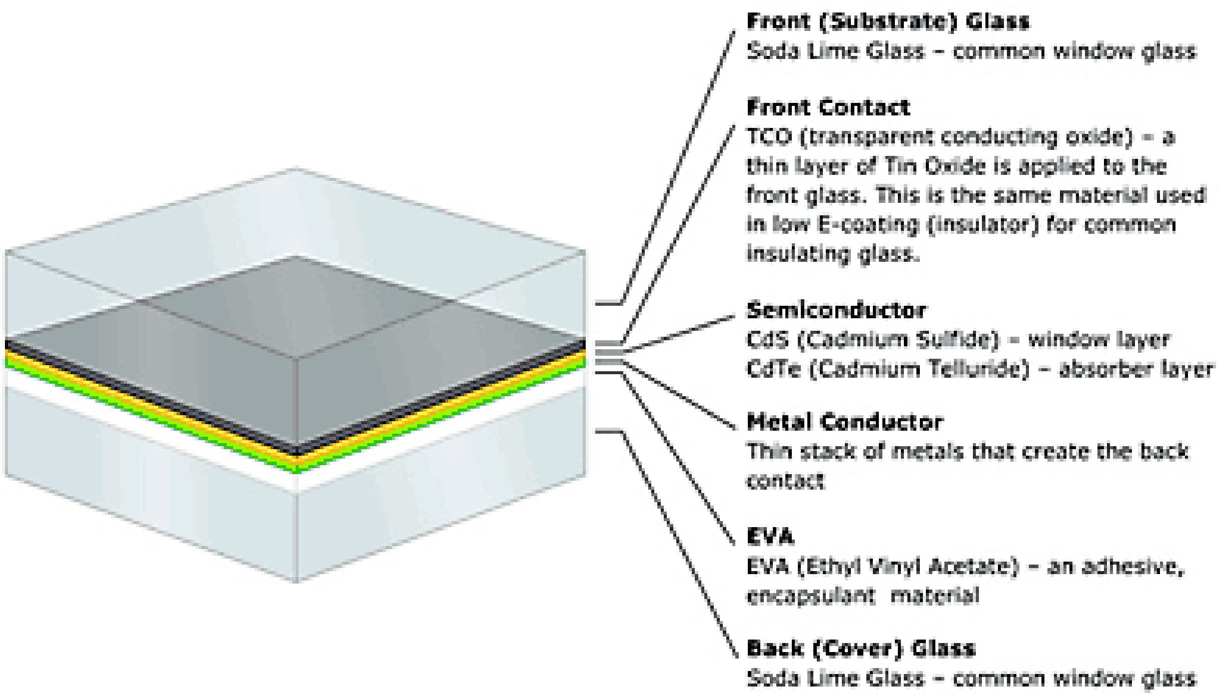
Thin Film Devices Use Much Less Semiconductor Material



- **1-2 microns thick vs. ~180 microns for c-Si**
- **Lower efficiencies mean more balance-of-system**
- **Glass substrate limits usability (weight, flexibility)**

Source for figures: www.firstsolar.com

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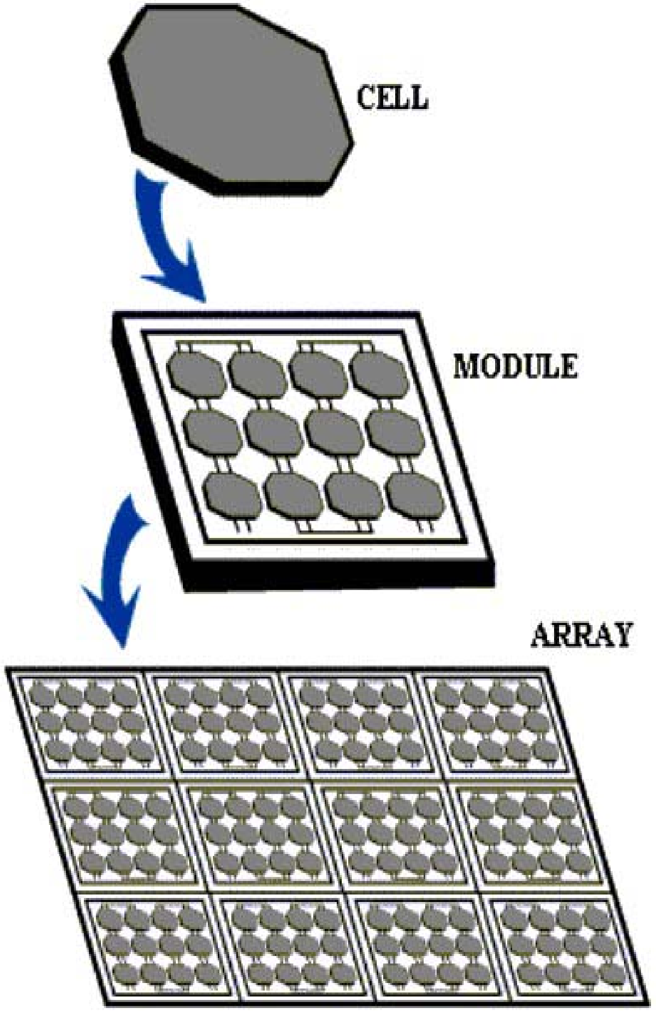
Photovoltaic Building Blocks

Cell—a single unit, typically polycrystalline silicon wafer, capable of producing dc voltage (≈.6V) and current (≈1 ampere/ 50 cm^2 in 1000 W/m^2 sun)

Module—multiple cells connected together in series-parallel configurations to attain higher level dc voltage and current (10-300 Watt packages)

Array—multiple modules connected together in series-parallel configurations to meet user dictated voltage/current/power needed (KW's-MW's)



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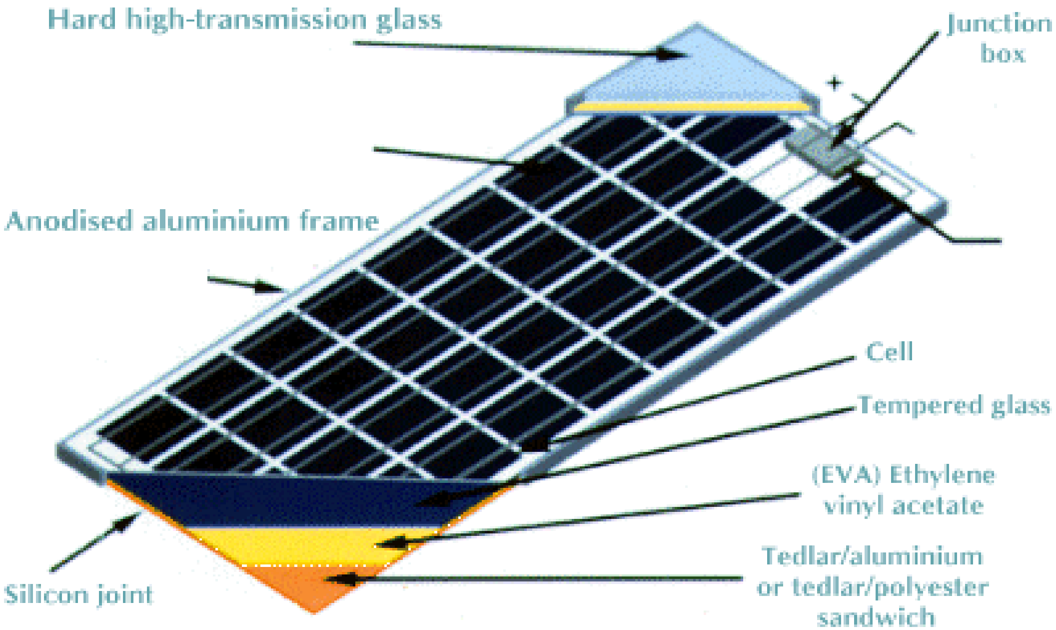
Module Construction

Super and/or substructure—typically tempered glass

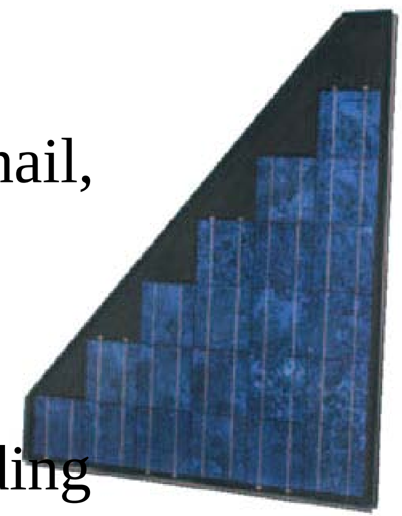
- Cell string(s)— tinned flat wire soldered to cell metallization
- J-box or pigtails
- Backsheet—typically a tri-layer for tedlar/polyester/tedlar (Al sometimes)

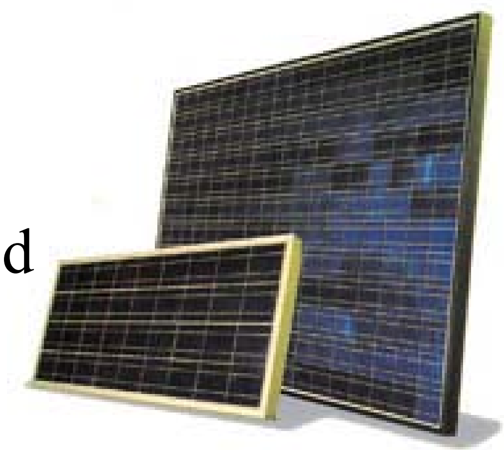
Encapsulant—polymer for adhesion of layers



PV Module Characteristics

- Typically rigid to handle structural loads/mounting-requirements
- Packaged to withstand UV, temperature, humidity, hail, and wind stresses
- Packaged to meet high-voltage bias configurations
- Packaged to meet UL (fire) tests, safety, NEC, building codes
- 15-25 Year manufacturers warranties
- ≈ 1% per year performance degradation predicted
- Packaged to meet architectural needs
- Packaged for easy connection into strings for array configuration





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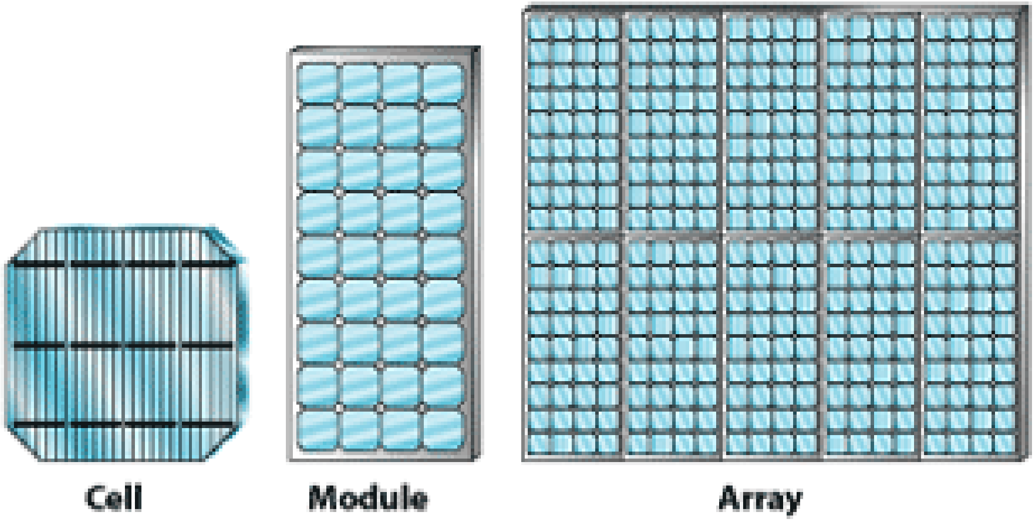
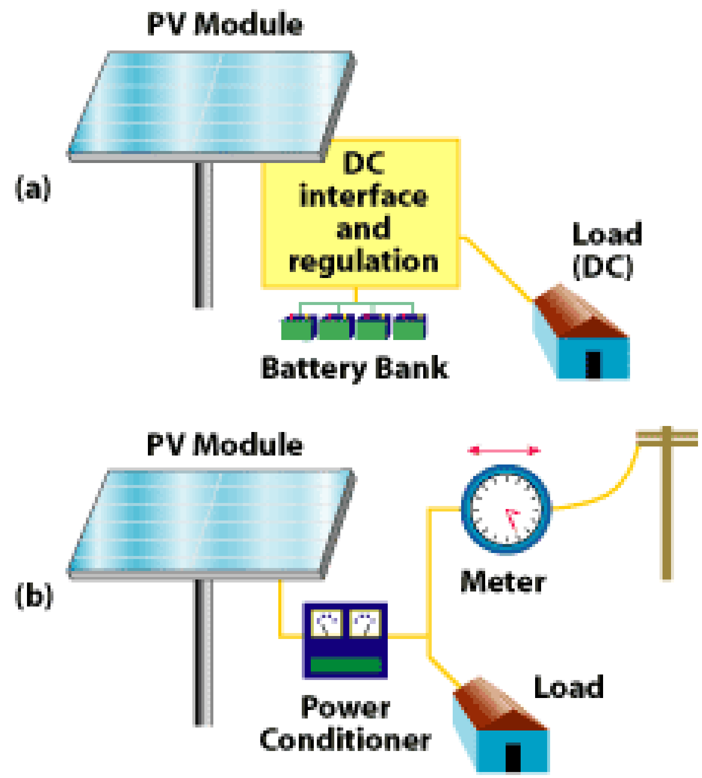
Photovoltaic System





The basic photovoltaic or solar cell typically produces only a small amount of power. To produce more power, cells can be interconnected to form modules, which can in turn be connected into arrays to produce yet more power. Because of this modularity, PV systems can be designed to meet any electrical requirement, no matter how large or how small.

This simple illustration shows the elements needed to get the power created by a PV system to the load (in this example, a house). The stand-alone PV system (a) uses battery storage to provide dependable DC electricity day and night. Even for a home connected to the utility grid (b), PV can produce electricity (converted to AC by a power conditioner) during the day. The extra electricity can then be sold to the utility during the day, and the utility can in turn provide electricity at night or during poor weather.

http://www1.eere.energy.gov/solar

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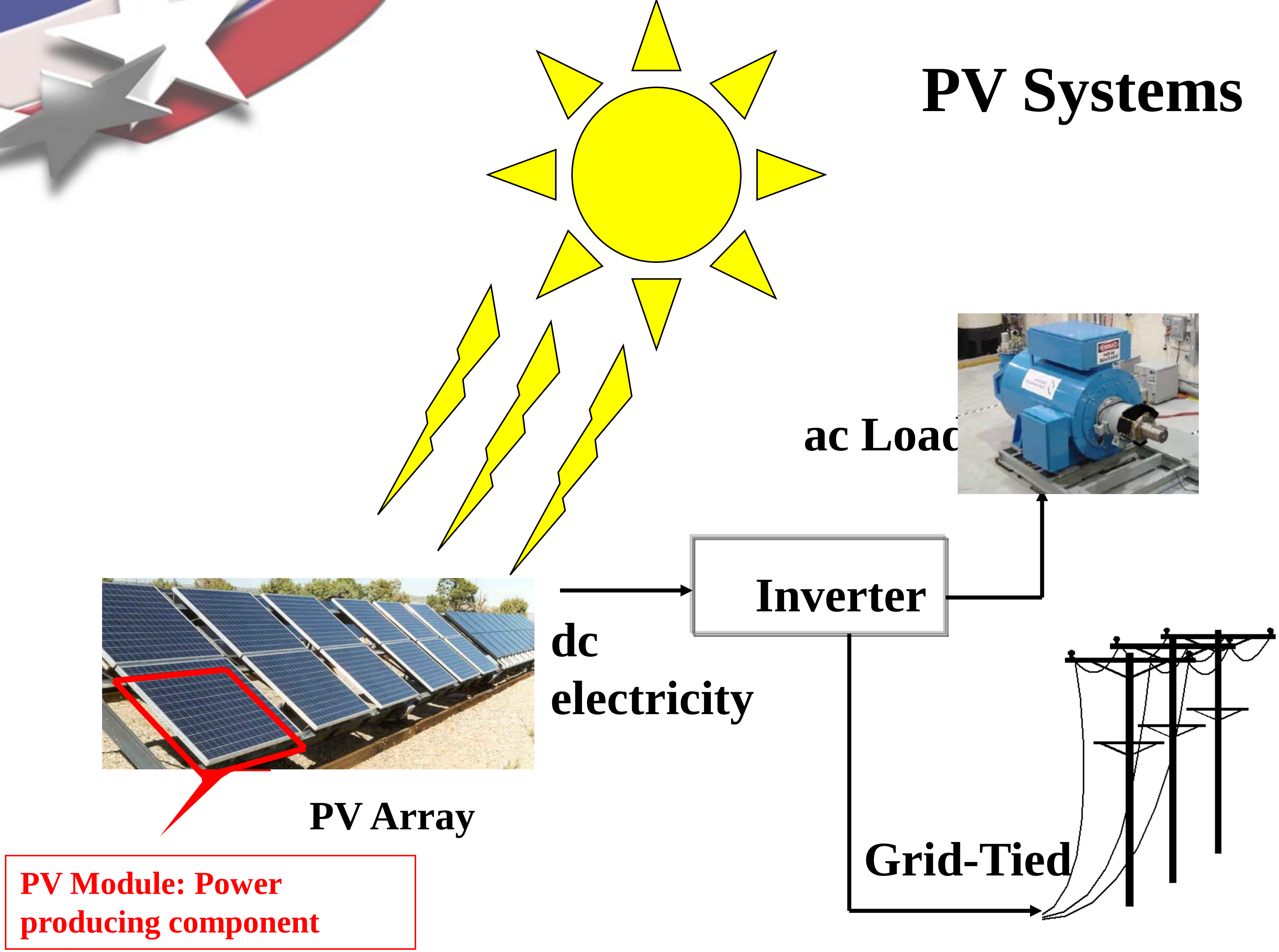
PV Systems



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Applications

Arrays - multiple modules

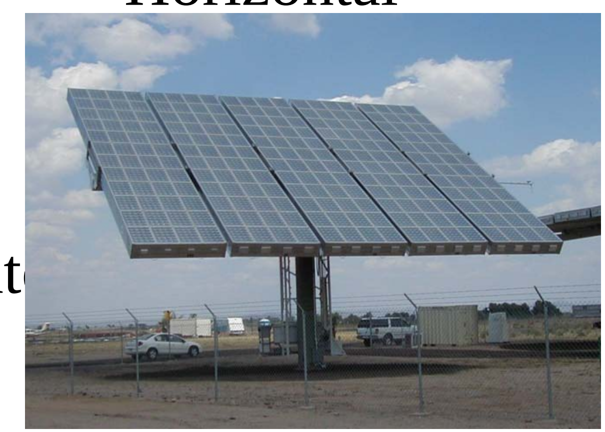
- Form voltage/current requirements—typically 12V to 300V configurations

Latitude-tilt

Horizontal

Tracking

Concentrat



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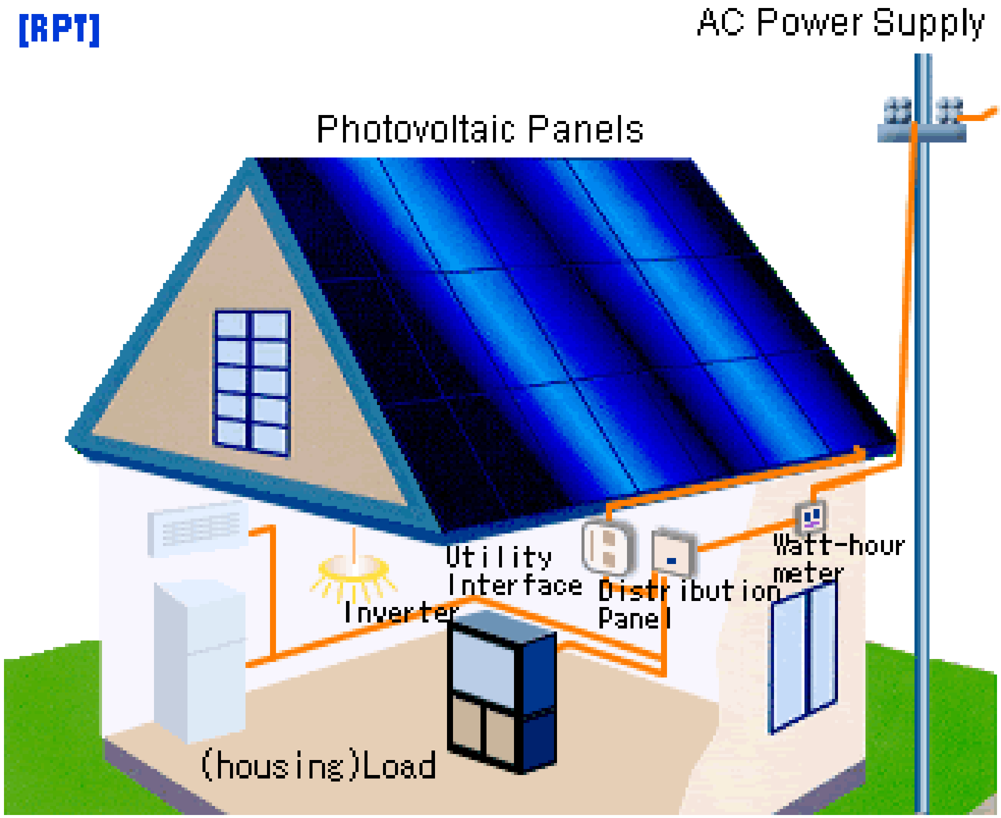
PV Home System

- Photovoltaic arrays produce dc electricity
- Inverters convert dc electricity to ac electricity and interface to the utility grid
- Balance of System components make installation complete
- Energy storage—typically lead-acid batteries with a charge controller



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PV Activities at the Distributed Energy Technologies Laboratory (DETL)

Over 75kW of PV arrays

Inverter assessments of various sizes

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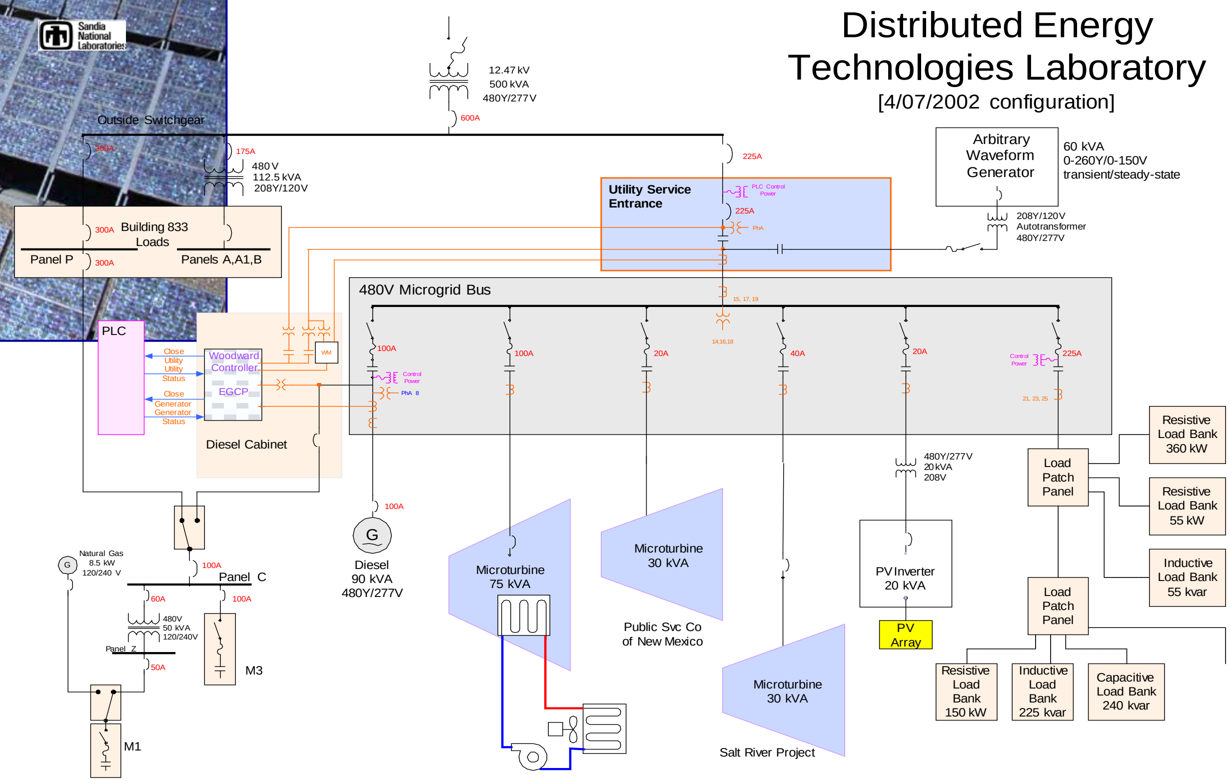
Distributed Energy Technologies Laboratory

Various Distributed Generation schemes under development

Microgrid configurations

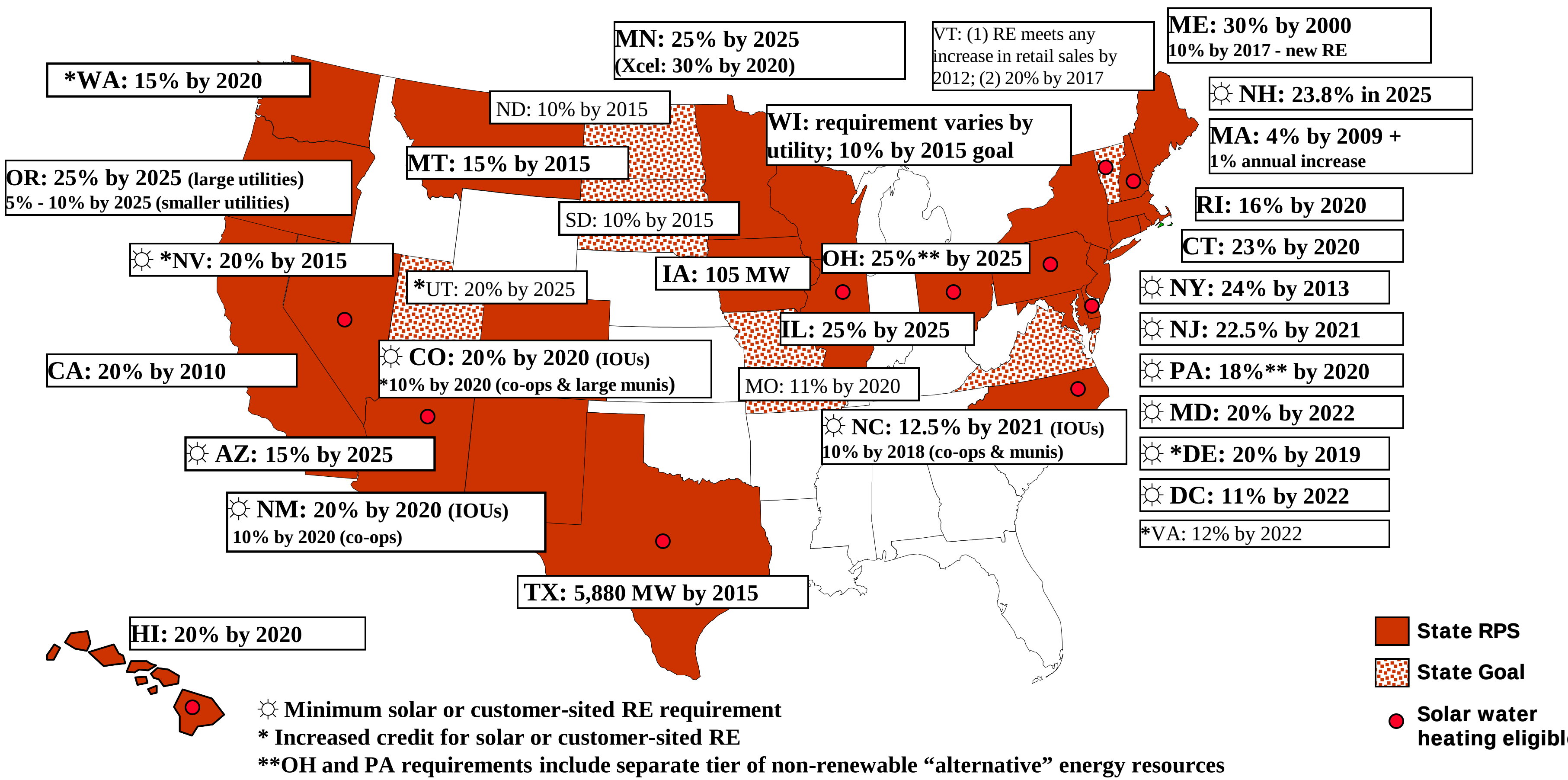
Advanced grid controls and communications



DSIRE: www.dsireusa.org

May 2008

Renewables Portfolio Standards



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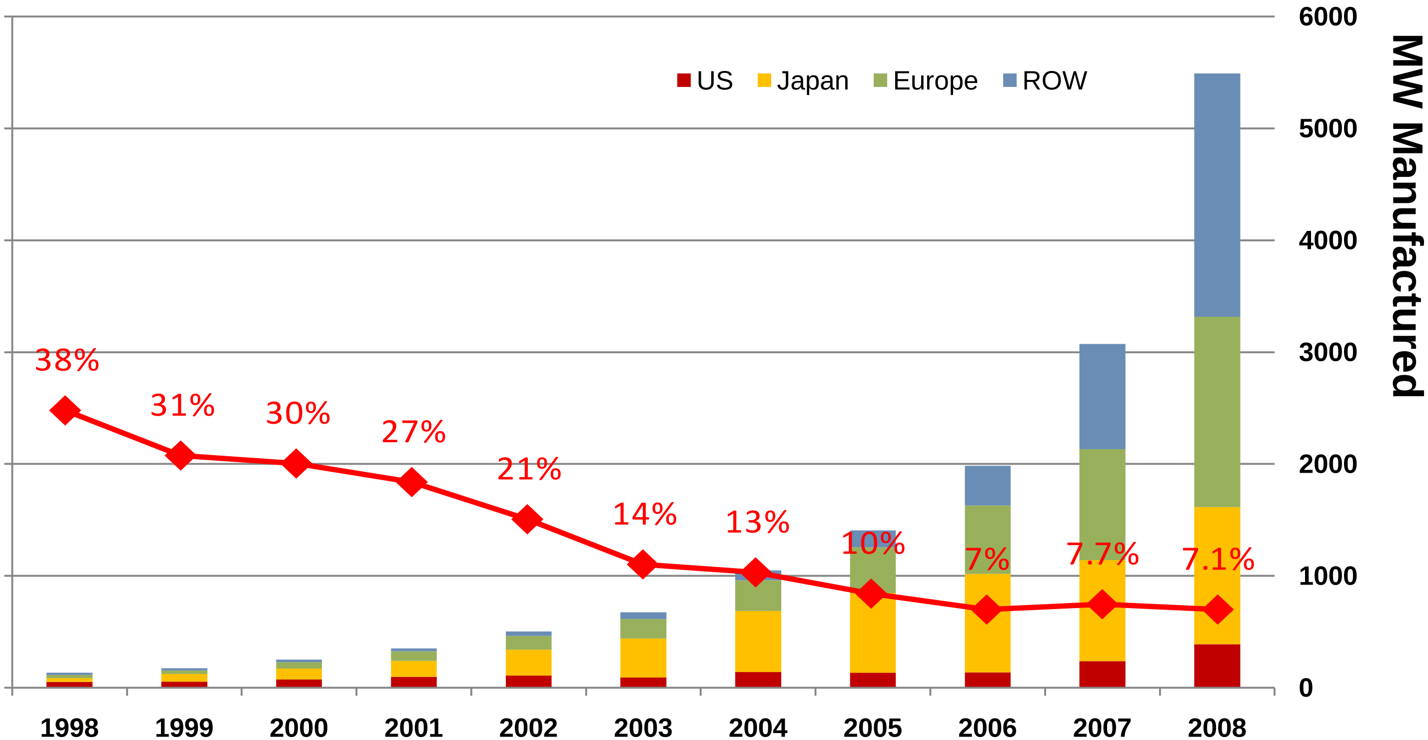
World-Wide Photovoltaic Production Growth

And U.S. Market Share



- Grid-connected PV is fastest growing market.
- Incentives have driven steep growth in installations.
- Average annual global growth rate has been 40+% for the past 5 years.
- Solar could capture > 30% of market share for new capacity additions during next 5-10 years.

Worldwide Power

Photovoltaic Generation

- **2008 = 14,592 MW**
- **2007 = 9,100 MW**
- **2006 = 6,851 MW**
- **2005 = 5,253 MW**

United States

Photovoltaic Generation

- **2007 = 857 MW**
- **2006 ~ 620 MW**
- **2005 = 479 MW**
- **2004 = 376 MW**

Sources: European Photovoltaic Industry Association, February 2008;

Additional info from Paula Mints, Navigant Consulting; Robert Margolis, NREL.

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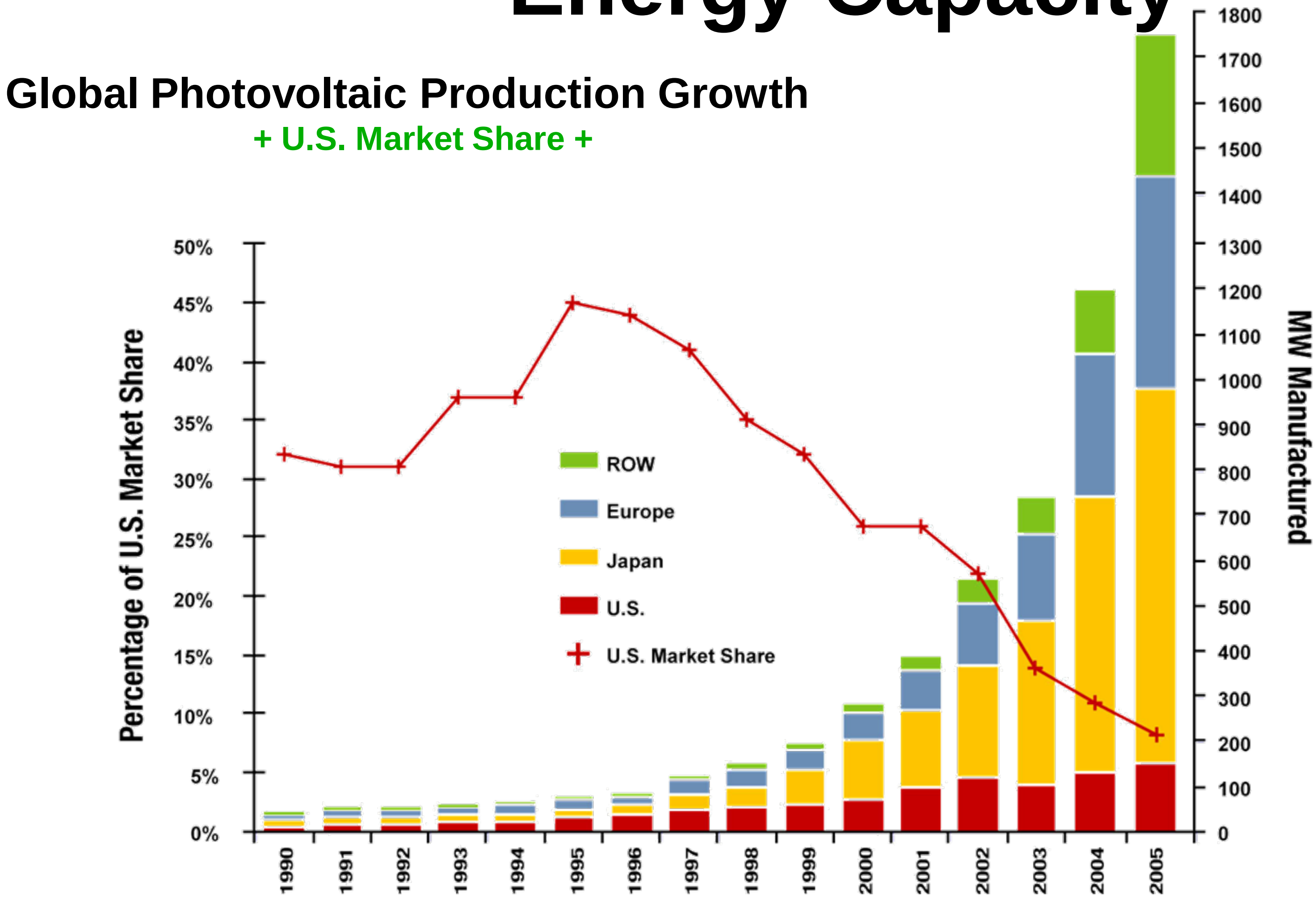
World-Wide Growth of Photovoltaic Energy Capacity



Sources: European Photovoltaic Industry Association, February 2008

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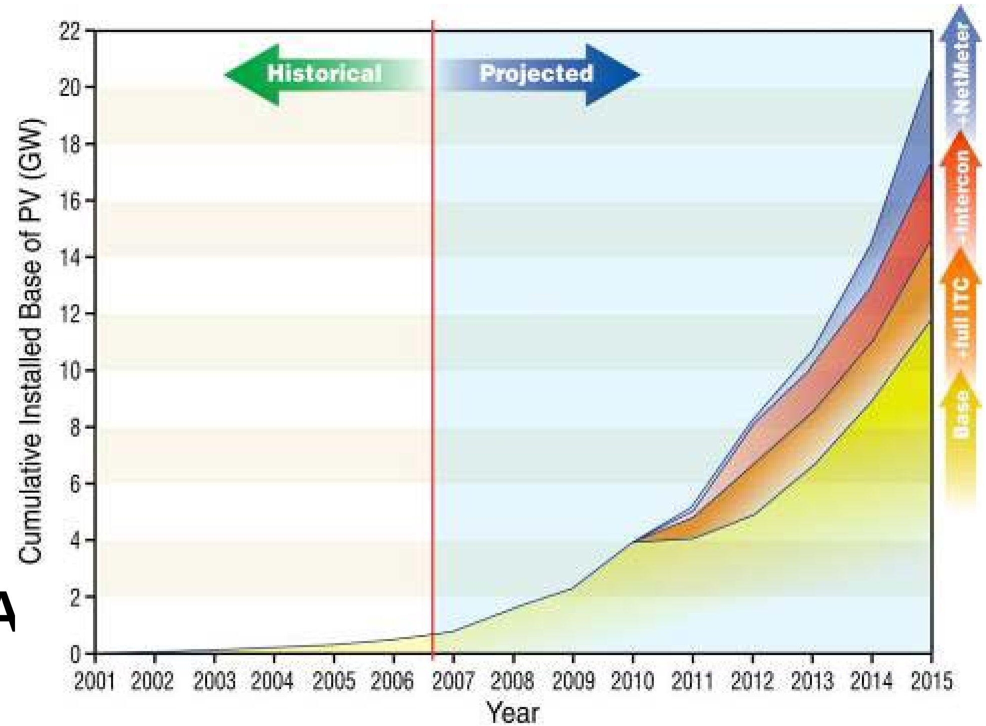
Significant Growth Projected for U.S.

Driving the market:

- **Climate change**
- **State/Federal incentives**
- **Cost reductions**
- **Regulatory/policy drivers**
- **New delivery models: PPA**

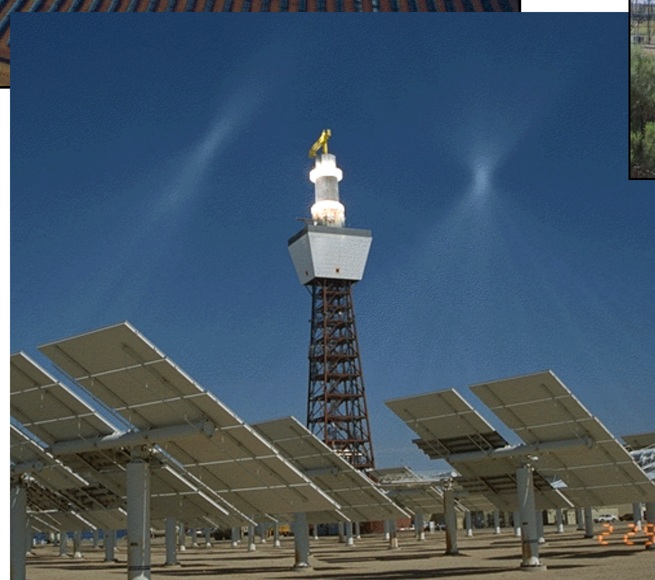


Modeled 4 Scenarios:

1. **Base case, existing policies with continued cost reductions ➔ 11.8 GW by 2015.**
2. **Base (1) plus full extension of federal investment tax credit (ITC) ➔ 14.7 GW by 2015.**
3. **(2) plus improved interconnection standards ➔ 17.4 GW by 2015.**
4. **(3) plus lifting net metering caps / establishing net metering policies (2 GW increase in CA alone) ➔ 21 GW by 2015.**

Concentrating Solar Power
(CSP)

Applications



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Solar Technologies

- Photovoltaics (PV)
  - c-Si
  - Thin film (CdTe, CIS, a-Si, others)
  - Concentrating PV and multi-junction cells
  - Others (organic, dye sensitized, micro or nano-PV, etc.)
- **Concentrating Solar Power**
  - **Dispatchable**
    - **Towers**
    - **Troughs**
  - **Distributed**
    - **Dishes**
  - **Other**
    - **Solar Fuels**
- Solar water heating
- Solar space heating

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- **Utility-Scale Solar Power > 100 MW**
- **354 MW Operating in Southern CA for 18 years**
- **Wholesale Electricity Market**
- **Electricity Generated using thermal- electric processes (heat engines)**
- **Historically, has not included utility-scale photovoltaics**

CSP Technologies

Concentrating Solar Power = Solar Thermal Power

- Power Towers
- Trough Electric Systems
- Dish Stirling Systems
- Concentrating Photovoltaics

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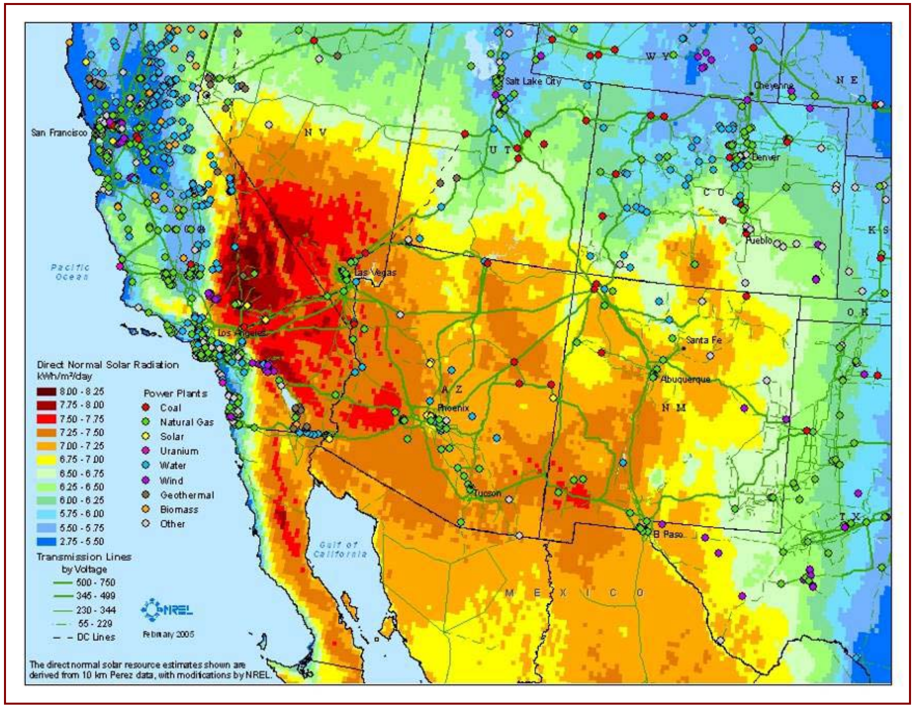
CSP Resource in SW U.S.

Filters applied:

- Direct-normal solar resource.
- Sites > 6.75 kwh/m^2/day.
- Exclude environmentally sensitive lands, major urban areas, etc.
- Remove land with slope > 1%.
- Only contiguous areas > 10 km^2



Data and maps from the Renewable Resources Data Center at the National Renewable Energy Laboratory

State	Land Area (mi^2)	Solar Capacity (MW)	Solar Generation Capacity GWh
AZ	19,279	2,467,663	5,836,517
CA	6,853	877,204	2,074,763
CO	2,124	271,903	643,105
NV	5,589	715,438	1,692,154
NM	15,156	1,939,970	4,588,417
TX	1,162	148,729	351,774
UT	3,564	456,147	1,078,879
Total	53,727	6,877,055	16,265,611

Bottom Line:
Almost 7 TW Available Resource
(Total U. S. Capacity is 1 TW)

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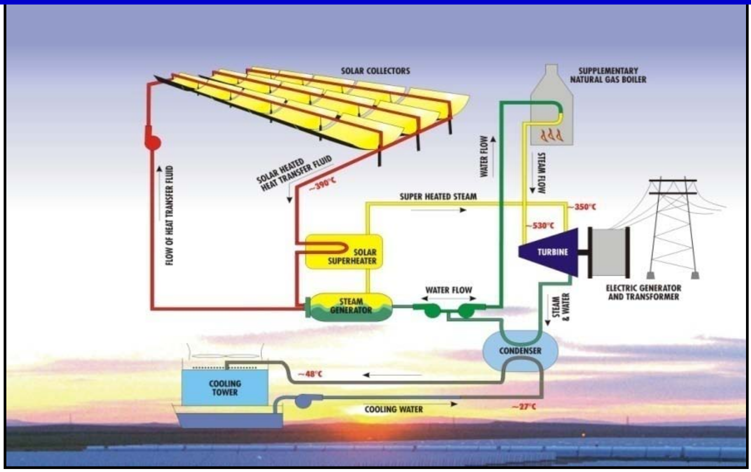
Trough Technology

- **Trough Technology**
  - Trough Collectors (single axis tracking)
  - Heat-Collection Elements
  - Heat-transfer oil (Therminol VP1)
  - Conventional steam-Rankine cycle power block
  - Steam generator



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CLFR Linear Technology

Continuous Linear Fresnel Reflector

- 38 MWe Project In Construction Singleton, NSW Australia
- Low-Cost Reflectors
- Low Profile Flat Glass
  - Low wind load, low steel
- Air-Insulated Absorber
- Subcritical Temps
- 38MWe now in construction
- 175MWe now in permitting in CA

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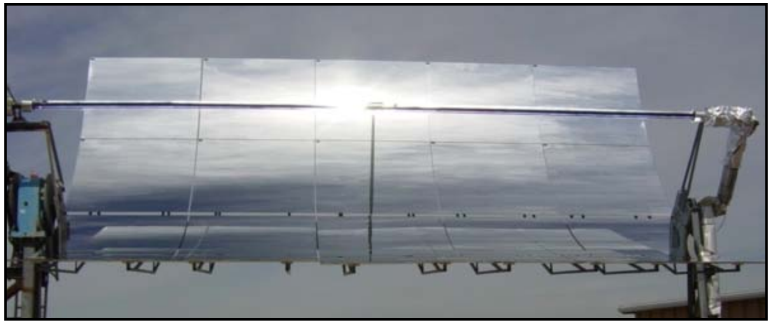
Trough Components

Trough Collector

Drive



Receiver

Controller

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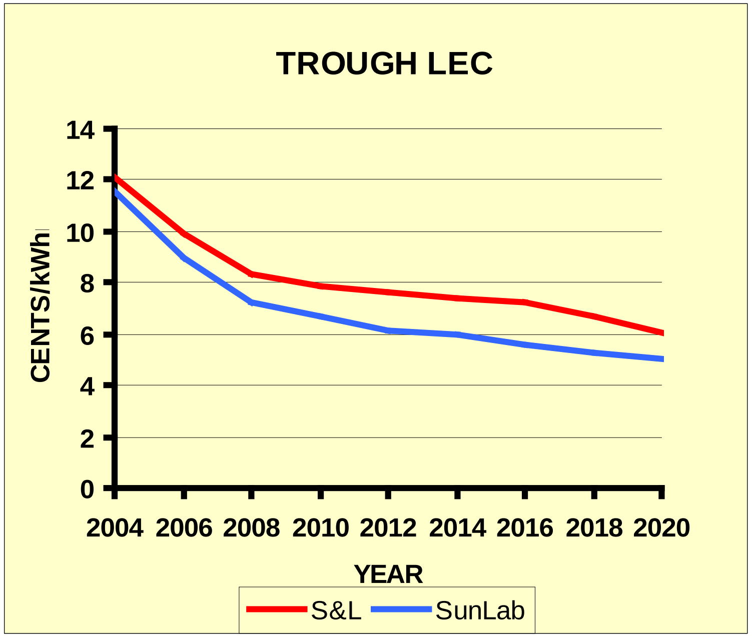
Current Trough Design

- For a 100 MW Trough Plant
  - E-W tracking collector, Area = 624,000 m^2
  - No Storage, No hybrid operation
  - Annual solar-to-electric conversion = 11%
  - Annual Capacity factor = 29%
  - Field operating temperature = 391 C
  - Conventional Rankine steam turbine
  - Water cooled (water is an issue in the West)

Trough Near-Term R&D and Electricity Cost

- **Near-Term R&D**
  - Concentrator Design to reduce cost
  - Advanced Receiver Technology
  - Thermal Energy Storage



Subject to a set of assumptions including: 3 GW deployed by 2020, storage utilized, incentives in place, etc.

**** ASSESSMENT OF PARABOLIC TROUGH AND POWER TOWER SOLAR TECHNOLOGY COST AND PERFORMANCE FORECASTS, SL-5641 MAY 2003.***

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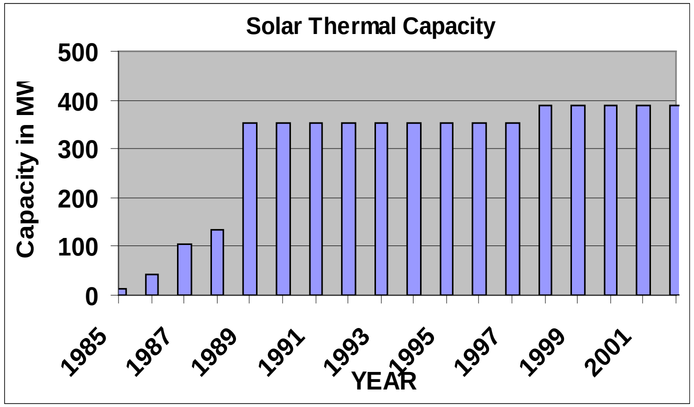
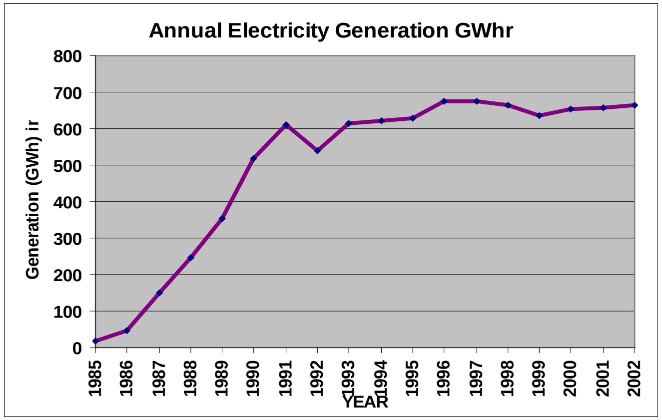
Status of Trough Plants

- SEGS Plants
  - 354+ MW operating in Mojave Desert since 1989
  - Total reflective area > 2.3 Mill. m^2
  - More than 117,000 HCEs
  - 30 MW increment (PURPA reg power block size)
  - Producing > 650 GWhrs annually





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Nevada Solar One

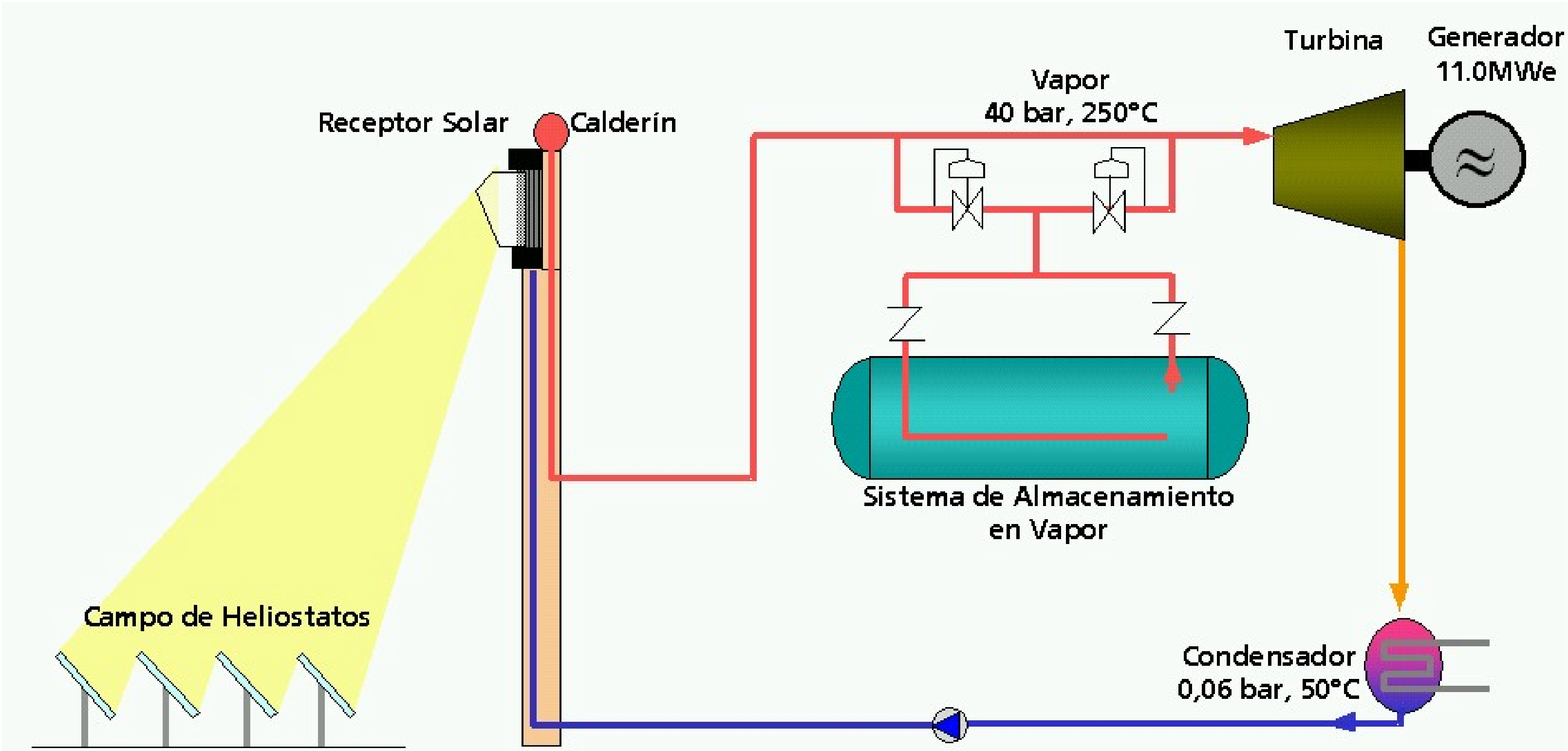
- **64 MW Capacity**
- **357,200m² Solar Field**
- **30 Minutes Thermal Storage**
- **Minimal Fossil fuel**
- **Long term PPA signed with Nevada Power**
- **EPC Notice to Proceed – January 2006**
- **Startup April 2007**

trmanci@sandia.gov

PS 10 Power Tower

PS 10 Plant Operational Nov 2006. Construction started on first PS 20 Plant.

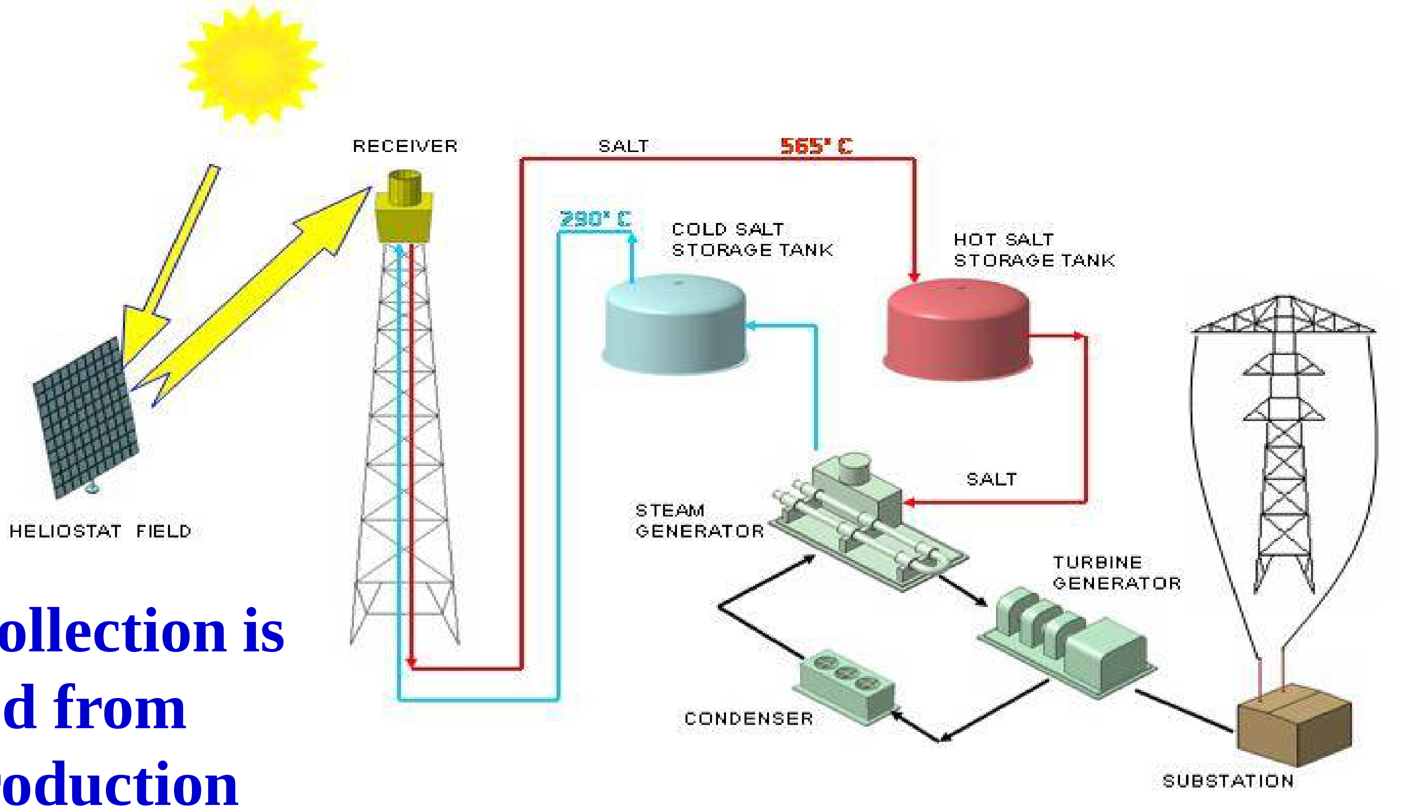
PS 10 Steam Cycle



Once-through steam boiler similar to Solar 1

Molten-Salt Power Tower

Power Tower or "Central Receiver"



Energy collection is uncoupled from power production

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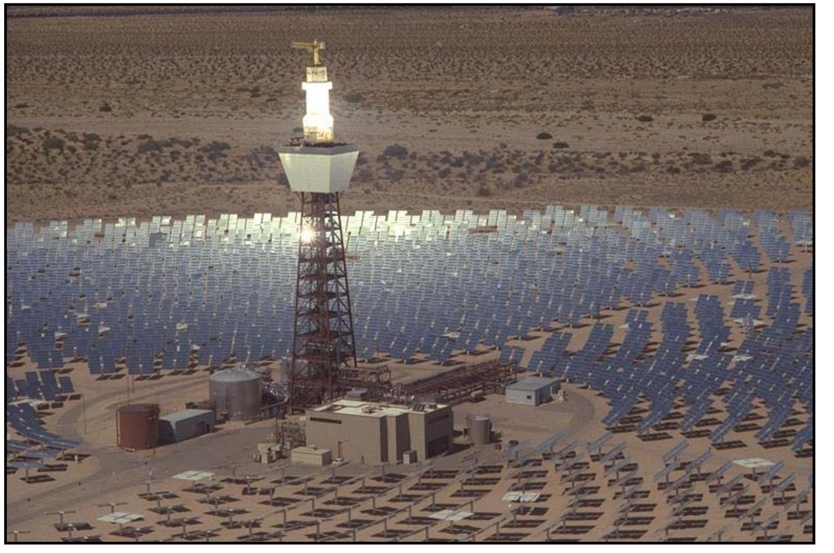
Power Tower Technology

- **Power Tower**
  - Heliostats (two axis tracking)
  - Air or Molten-Salt Working Fluid
  - Thermal Storage
  - Conventional steam-Rankine cycle power block



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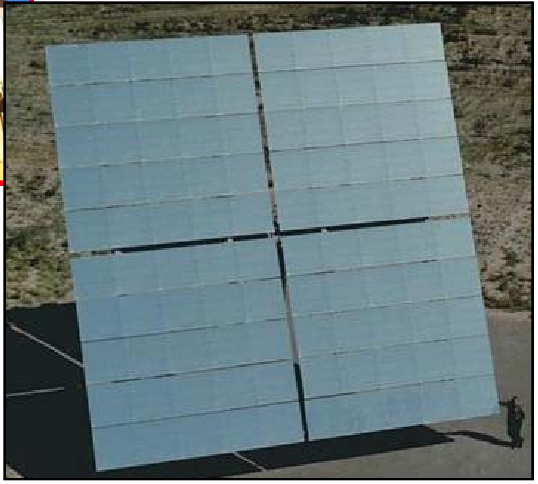
Power Tower Components

Receiver

Storage Tanks

Heliostat



Steam Generator

Current MS Power Tower Design

- For a 100 MW MS Power Tower Plant
  - Collector Area = 144,000 m^2
  - 13 hours of thermal storage
  - Annual Solar-to-electric conversion = 15%
  - Annual Capacity factor = 65%
  - Field operating temperature = 565 C
  - Conventional Rankine steam turbine
  - Water cooled

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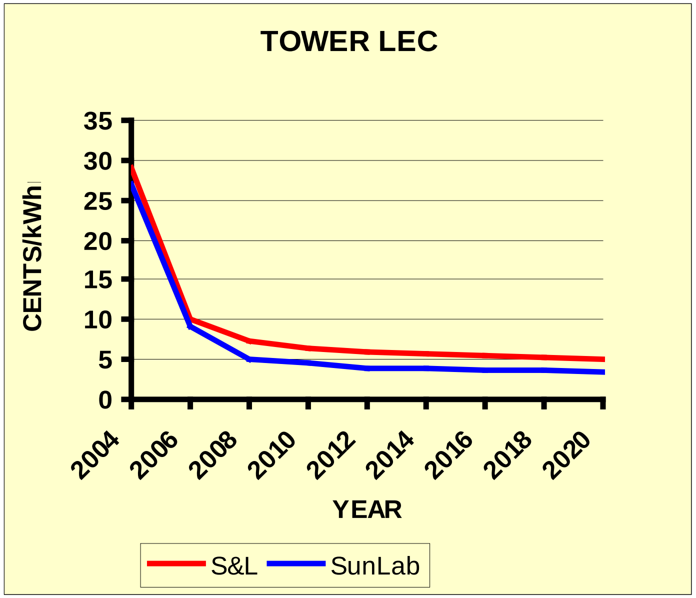
Tower Near-Term R&D and Electricity Cost

- **Near-Term R&D**
  - Heliostat Design to reduce cost
  - Receiver Cost and Operational Strategy
  - Receiver reliability
  - Steam Generator design/operation



Subject to a set of assumptions including: 3 GW deployed by 2020, storage utilized, incentives in place, etc.

****** ASSESSMENT OF PARABOLIC TROUGH AND POWER TOWER SOLAR TECHNOLOGY COST AND PERFORMANCE FORECASTS, SL-5641 MAY 2003.***

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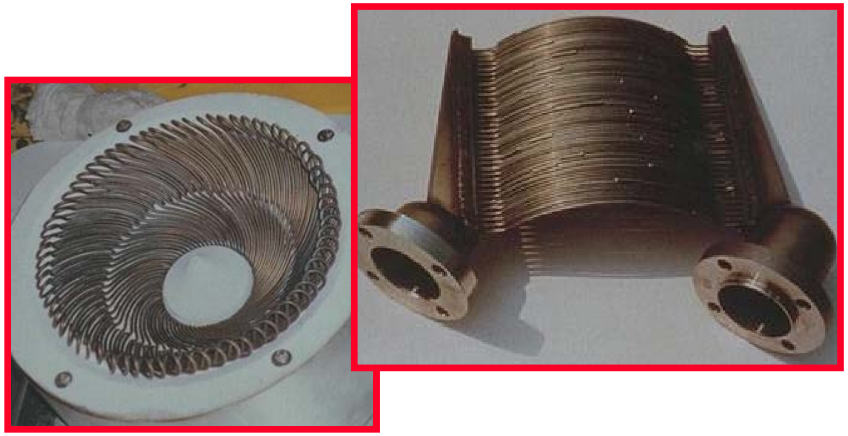
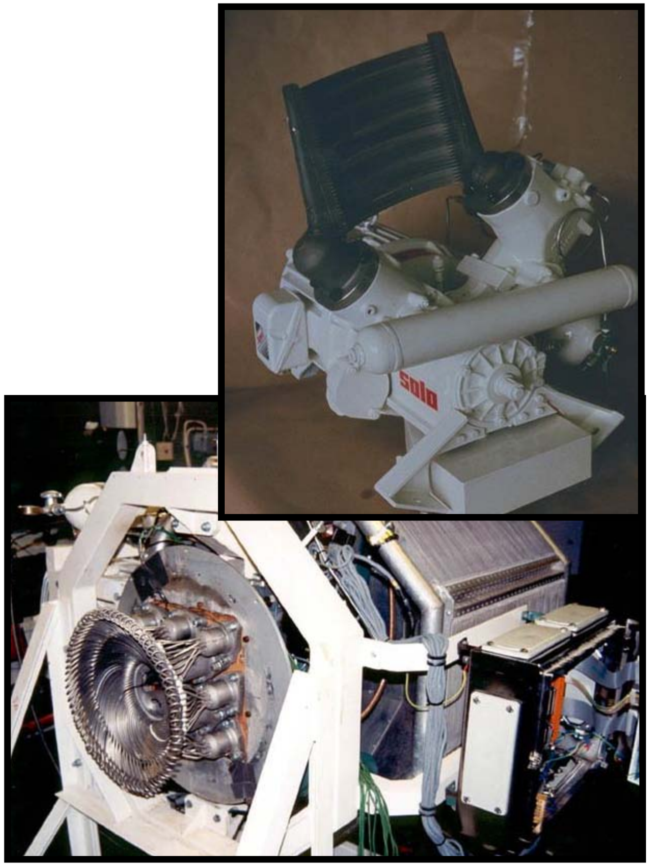
Dish Stirling Technology

- **Dish Stirling Technology**
  - Dish (two axis tracking)
  - 10 and 25 kW Stirling Engines
  - Thermal receivers
  - Distributed generation or bulk power
  - 8 different systems built and tested over the last 20 years

Dish Stirling Components

Receiver





Engine/Generator

Dish

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New World Record for Solar-Electric Conversion

Sandia and Sterling Energy Systems set record on 31-Jan-2008

31.25%, an increase over previous record of 29.4%

SES has power purchase agreements with Southern California Edison (up to 850 MW) and San Diego Gas & Electric (up to

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Dish Near-Term R&D and Electricity Cost

- **Near-Term R&D**
  - Dish design/cost reduction
  - Engine/receiver Cost and Operational Strategy
  - Engine/receiver reliability

Current cost estimated to be 25 - 30 ¢/kWhr

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Projects in SW U. S.

- 1 MW trough/ORC in Arizona (APS, Solargenix) operating
- 64 MW trough electric project in Nevada (Nevada Power, Solargenix) commissioned June 2007
- 500 (option to 850 MW) Dish Stirling plant in Southern California (SCE, SES). (Agr. signed Aug 2005.)
- 300 (option to 900 MW) of Dish Stirling plants in Southern CA (SDG&E, SES). (Agr. signed in Sep 2005.)
- PG&E 553MW (PPA w/Solel) (July 23, 2007)
- ~ 250 MW SW Utility Consortium in planning
- 300 MW AUSRA and FPL (Sept. 25, 2007)
- Other RFPs issued by not announced (SCE, PG&E,LADWP, SMUD, SDG&E, APS, etc.)

Projects Around the World

- <u>Algeria</u>: Abener, 30 MW trough fuel saver; €75M and it must provide 5% solar fraction annually.
- <u>Egypt</u>: Bids for the 150 MW Kuraymat trough plant are due November 2006.
- <u>South Africa</u>: ESKOM in Phase V of molten-salt power tower development; currently performing an EIA.
- <u>Israel</u>: SOLEL signed a contract for a 150 MW trough plant.
- <u>Mexico</u>: Bids expected in December 2006 for the 30 MW solar trough project at Agua Prieta in Sonora.
- <u>Spain</u>: Estimates are that 2 GW or more of CSP plants are in the planning stages. SOLUCAR started operation of PS 10 power tower and construction of the 20 MW PS 20; the first of three 50 MW ANDASOL trough plants with 7.5 hours of molten-salt thermal storage is under construction.

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Government Incentives for CSP

- U. S. Federal Incentive:
  - Investment Tax Credit of 30% through 2016
  - Loan guarantee program
- U. S. State Incentives:
  - Renewable Portfolio Standards
  - Solar “set asides”
  - State production tax credits
  - Property and sales tax relief
  - Possible state loan guarantee programs
- Internationally: Feed- In Laws
  - Spain (~ 47US¢/kWh)
  - Guaranteed purchase, 20 year

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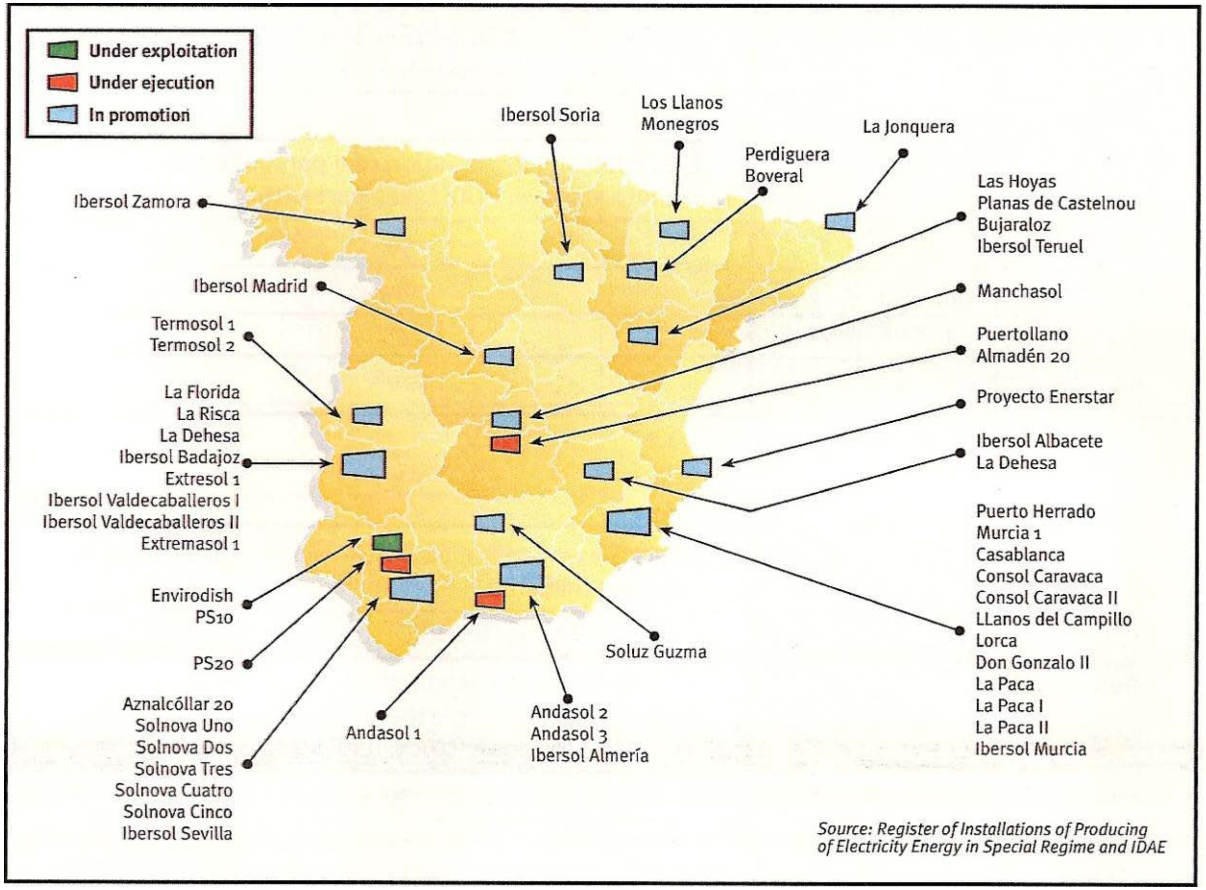
CSP Project in Spain

Feed-In Law incentives have created a favorable environment for the growth of CSP in Spain.



- **748 MW in registered projects**
- **1.8 GW in provisional registration (40 projects)**
- **> 10 GW of Grid access applications**

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Concentrating PV Technology

- **Amonix CPV Technology**
  - 25-kW CPV Module
  - Two axis tracking structure
  - 350 m^2 concentrator
  - 3M Acrylic lens concentrator at 250X
  - Silicon solar cells

AMONIX

Solar Systems Pty of Australia

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CPV Near-Term R&D and Electricity Cost

- Near-Term R&D
  - Reliability validation
  - Module cost reduction (packaging)
  - Advanced cell technology 3-5 multi-junction technology

Current cost estimated to be 25 to 35 ¢/kWhr

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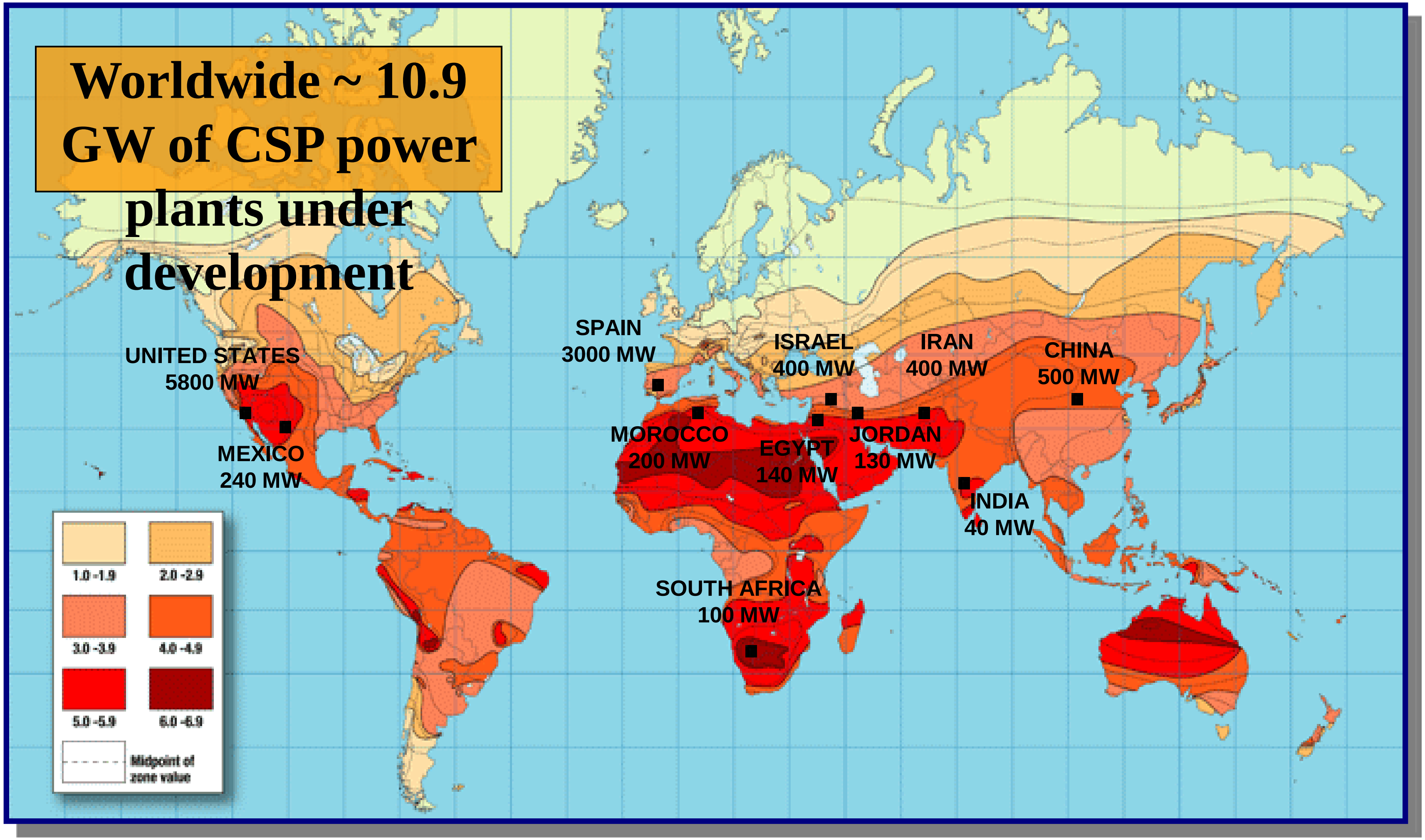
Planned CPV Deployments

- Contracted Deployments
  - AMONIX with Guascor in Spain to install 10 MW
  - An 80 MW plant was announced in California

  Proposed/planned Deployments
  - APS 5 MW over the next couple of years.
  - Sharp has announced a CPV module



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CSP Suppliers/Companies

Trough Systems
- **Acciona**
- **Abengoa Solar**
- **Sener**
- **Solar Millennium**
- **SkyFuel**
- **Solel**

CLFR
- **Ausra**
- **SPG/Mann**
- **SkyFuel**

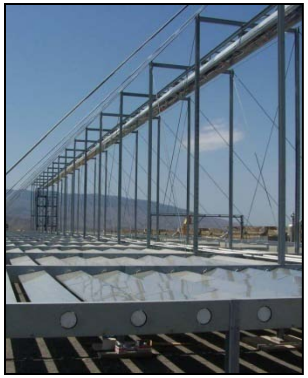
Power Towers
- **Abengoa Solar**
- **Brightsource Energy**
- **SolarReserve**
- **eSolar**

Dish Engine Systems
- **Stirling Energy Systems**
- **Schlaich Bergermann und P.**
- **Infinia Corporation**
- **Brayton Energy**

Stirling Engines
- **Kockums**
- **Solo Kleinmotoren**
- **Stirling Energy Systems**
- **Infinia Corporation**
- **Sunpower**

Molten Salt Components
- **Friatec-Rheinhuete**
- **SQM**

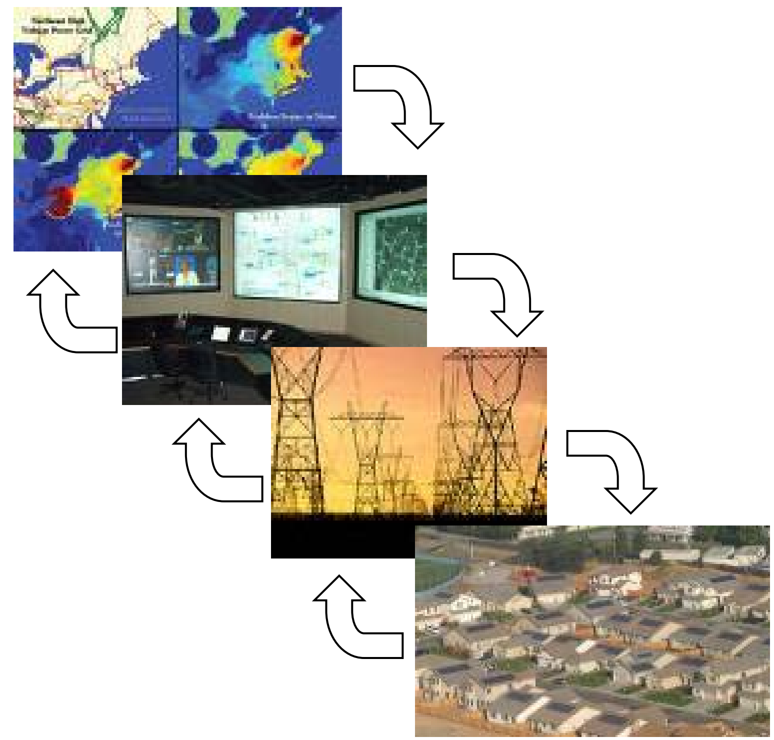





Concerns with Integrating Renewables

Penetration

- Affected by utilities' existing generation mix regulating capabilities, load characteristics, resource availability, and correlations between system load and resources
- Additional systems costs imposed by variability and uncertainty may go up with increasing penetration
- Integration costs are moderate for up to 20-30% penetration levels – depend on balancing authority and market structure

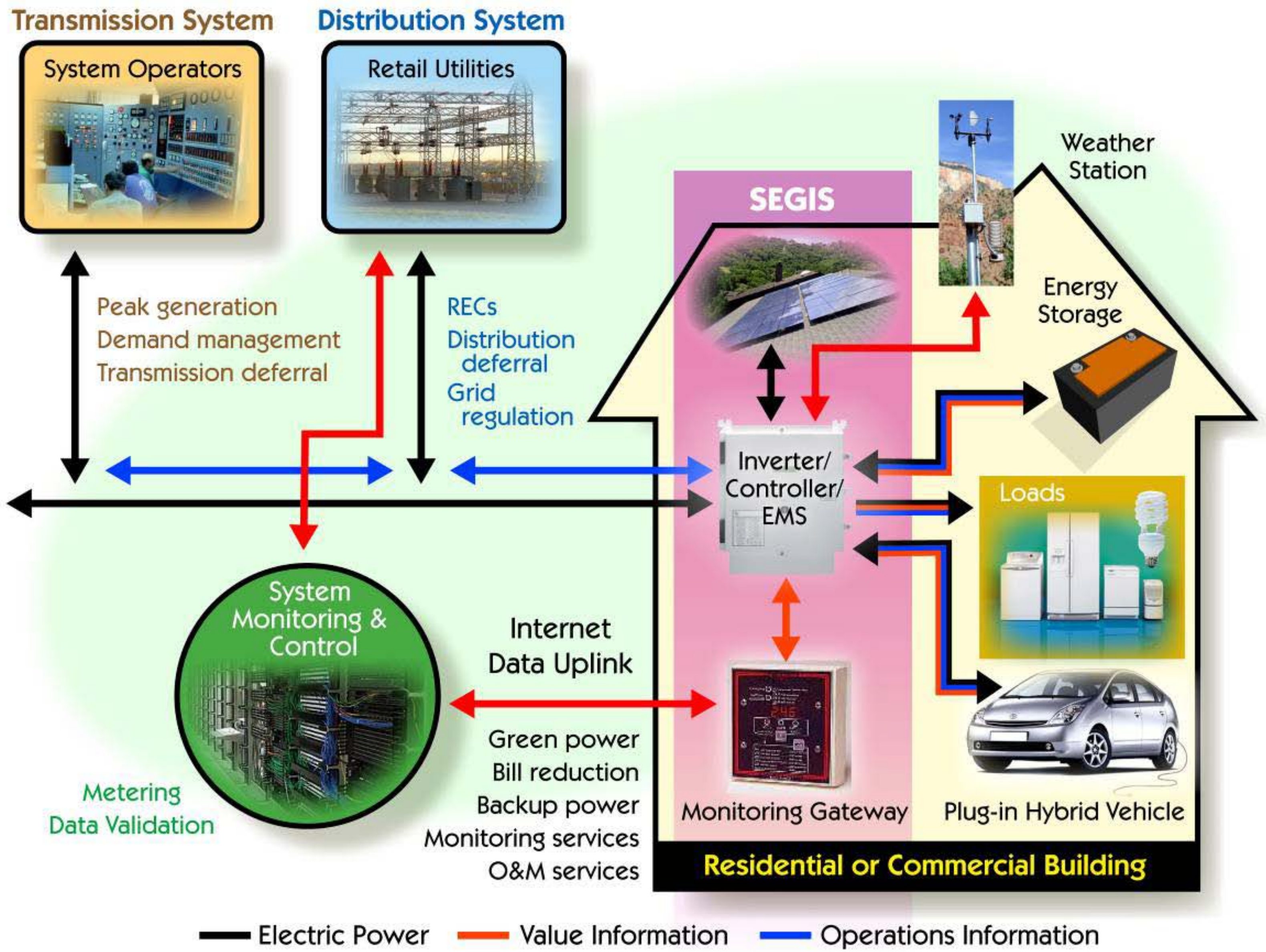


- Fluctuating Generation

  Can be solved by
  - **spatial diversity of the resource**
  - **flexible conventional generation**
  - **grid operations and control areas**
  - **limited curtailment for extreme events**
  - **load management**
  - **energy storage**

- Technical Concerns
  - **Real but solvable**

The Solar Energy Grid Integration System



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Solar Power: The Path Forward

- **Technology**
  - New models for electric grid infrastructure: distributed microgrids, SEGIS
- **Markets:**
  - Power Purchase Agreements will change PV market
  - Utilities will need new business models
- **Policy**
  - DOE actively promoting solar technology development (Solar America Initiative)
  - Extension of Federal Investment Tax Credit key to continued growth
  - Local/state: Berkeley folding costs into property taxes
  - Need for clear solar set-asides in some states

- **Some things to watch for:**
  - Thin Film PV: First Solar leading way, many startups coming along
  - New, home-level energy management systems
  - Significant CSP production in Southwest U.S. – troughs
  - California continues to lead the way

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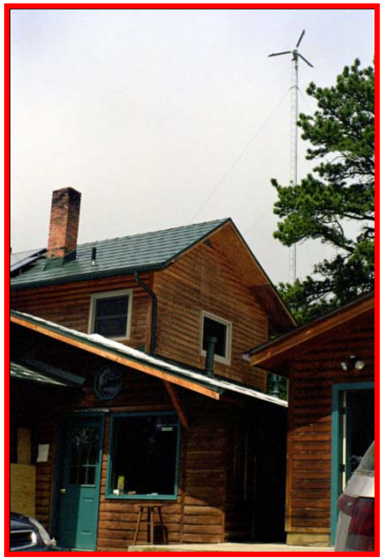
Small Wind



Small Wind Turbines Are Different

-

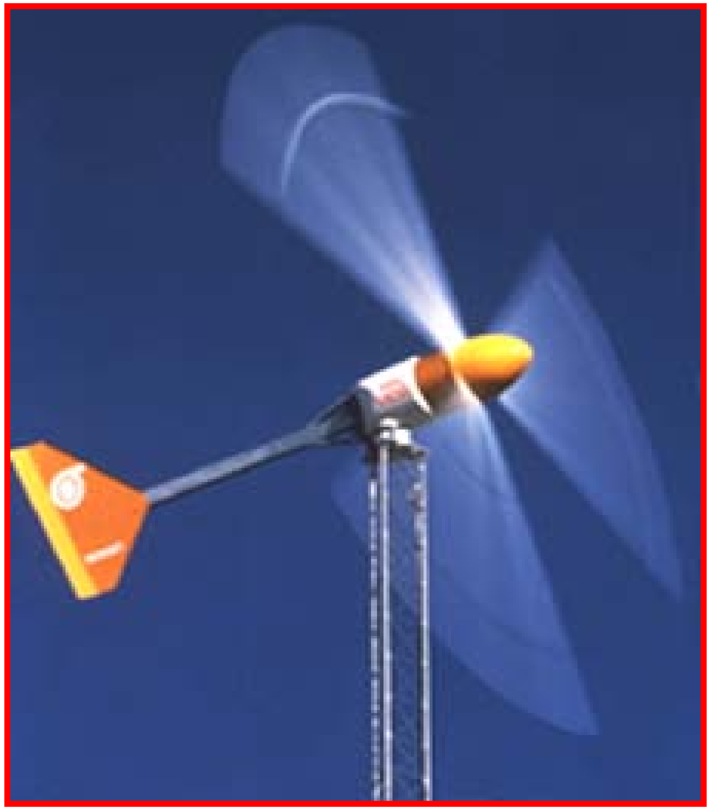
1,500 kW

10 kW

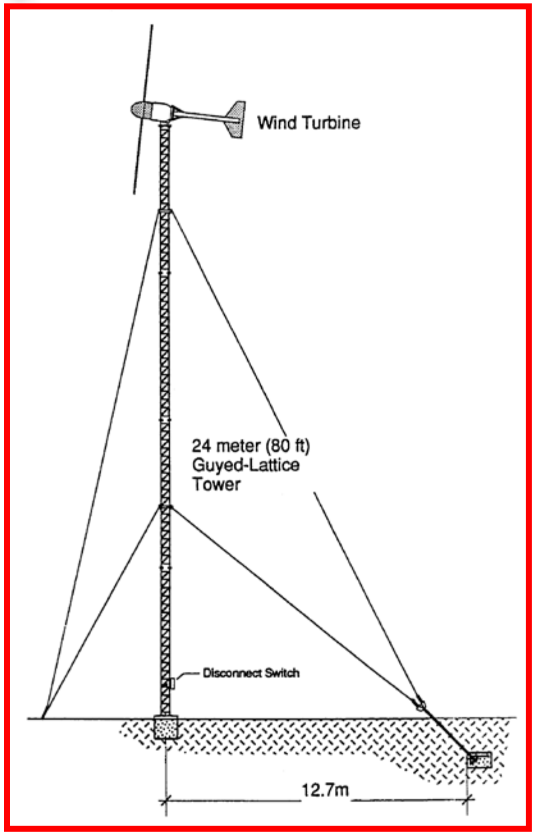
-

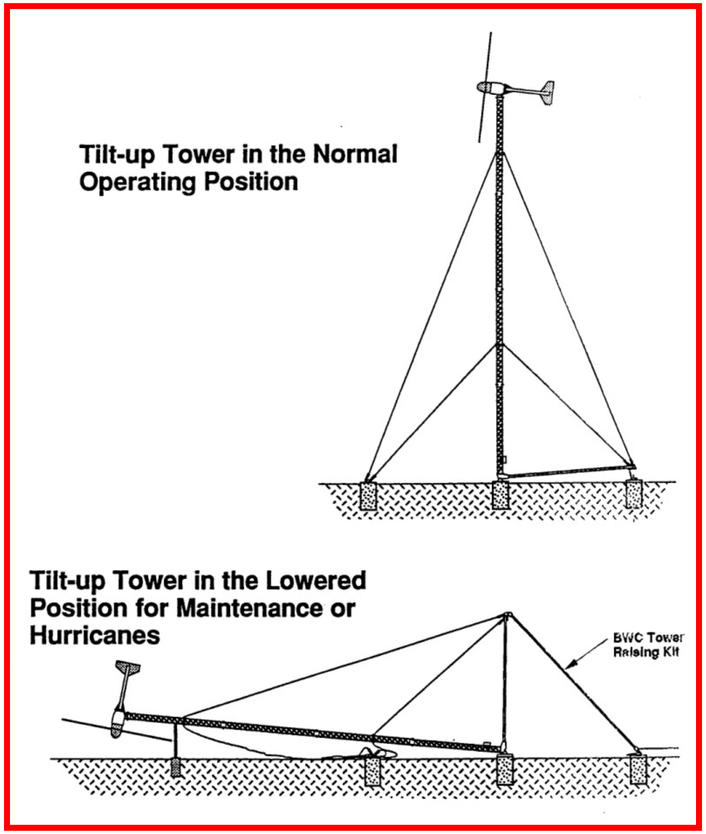
Small Wind Turbines

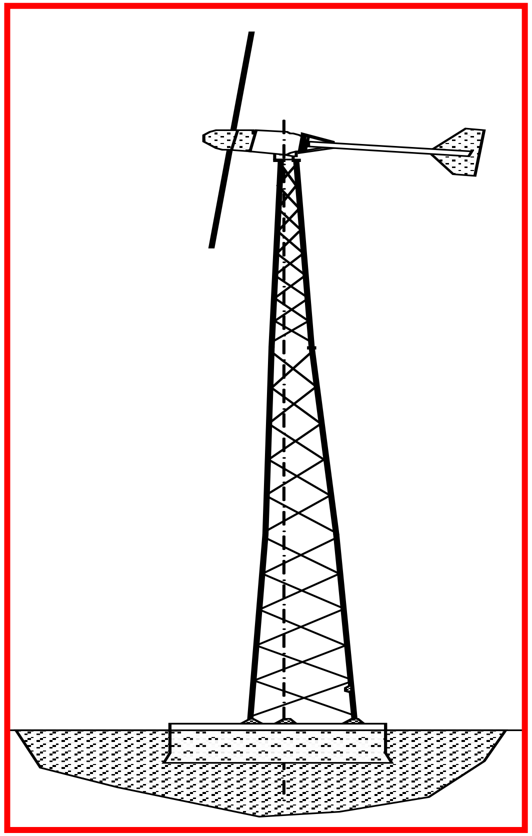
- **Configuration:**
- **Blades:**
- **Over-Speed Protection:**
- **Generator:**
- **Controller:**



Small Wind Turbine Towers







Over-Speed Protection During High Winds

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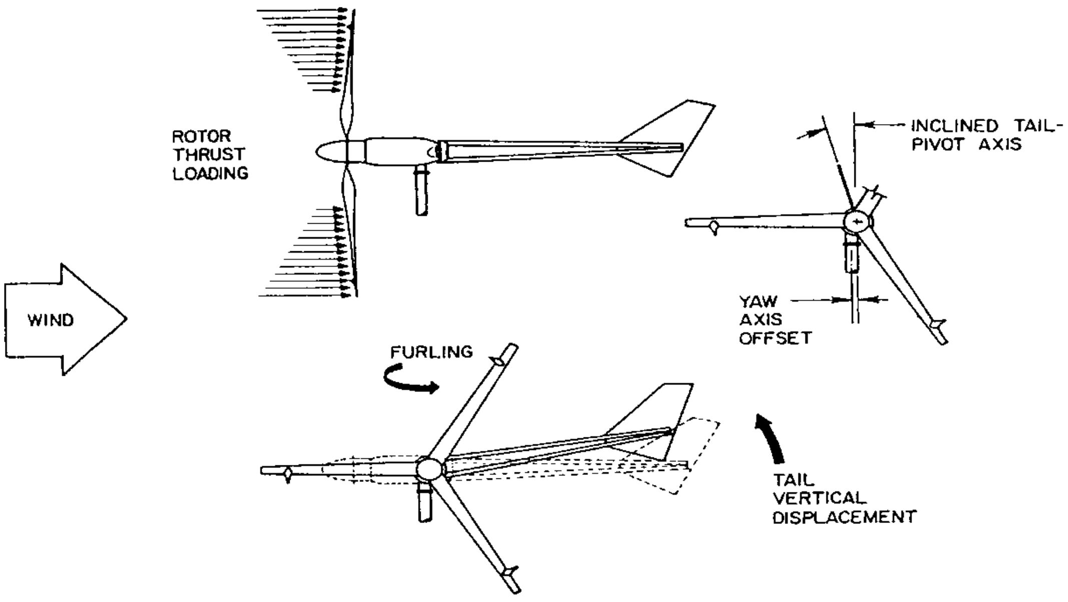
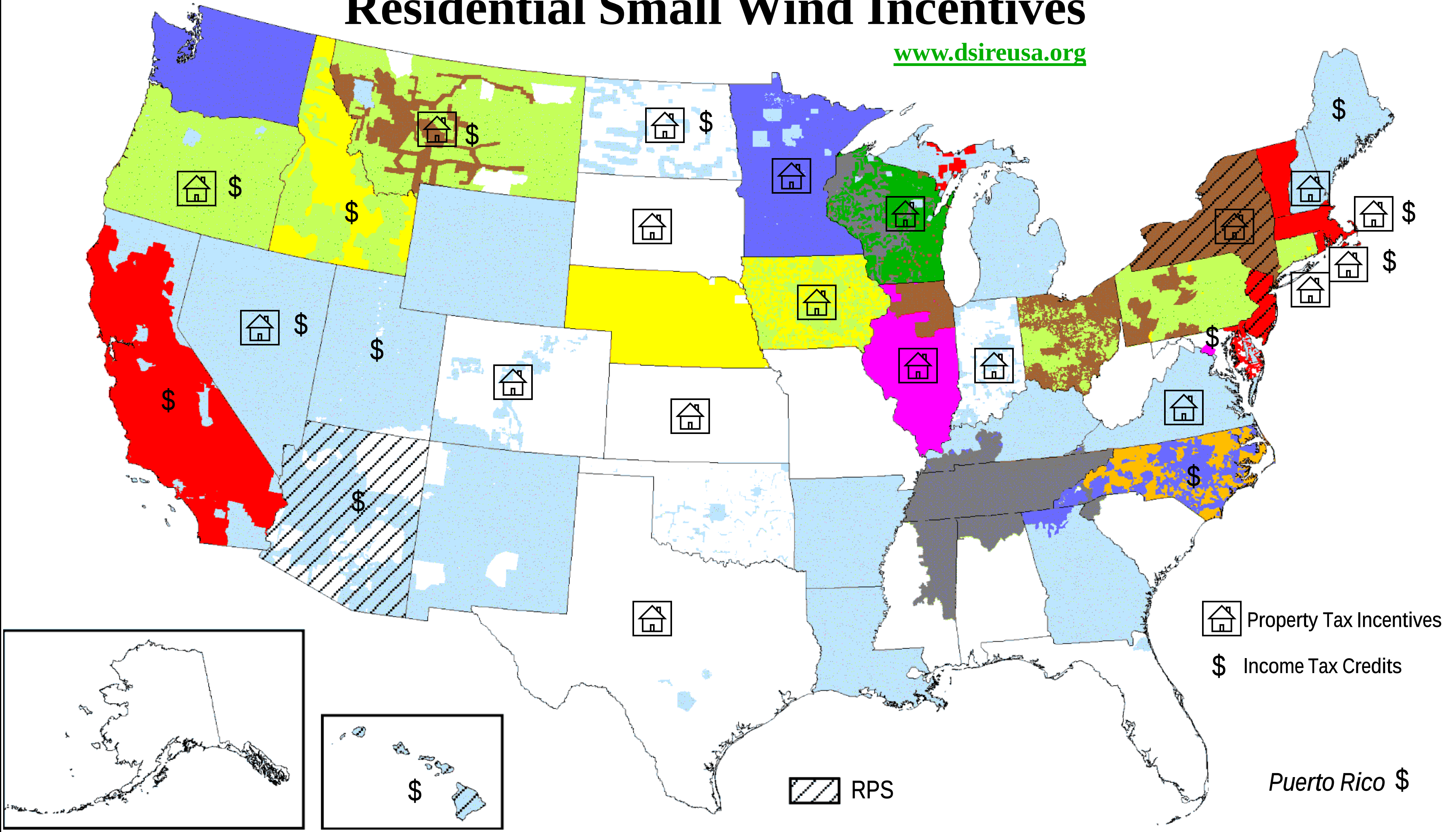


Maintenance, Warranty, and Lifetime

Residential Small Wind Incentives

www.dsireusa.org



BUYDOWNS/GRANTS

- Buydown/Grants
- Buydown/Grants & Net Metering
- Buydown/Grants, Net Metering, & Loans

PRODUCTIVITY INCENTIVES

- Productivity Incentives & Loans
- Productivity Incentives
- Net Metering, Loans & Prod. Incentives
- Net Metering & Prod. Incentives

MINOR INCENTIVES

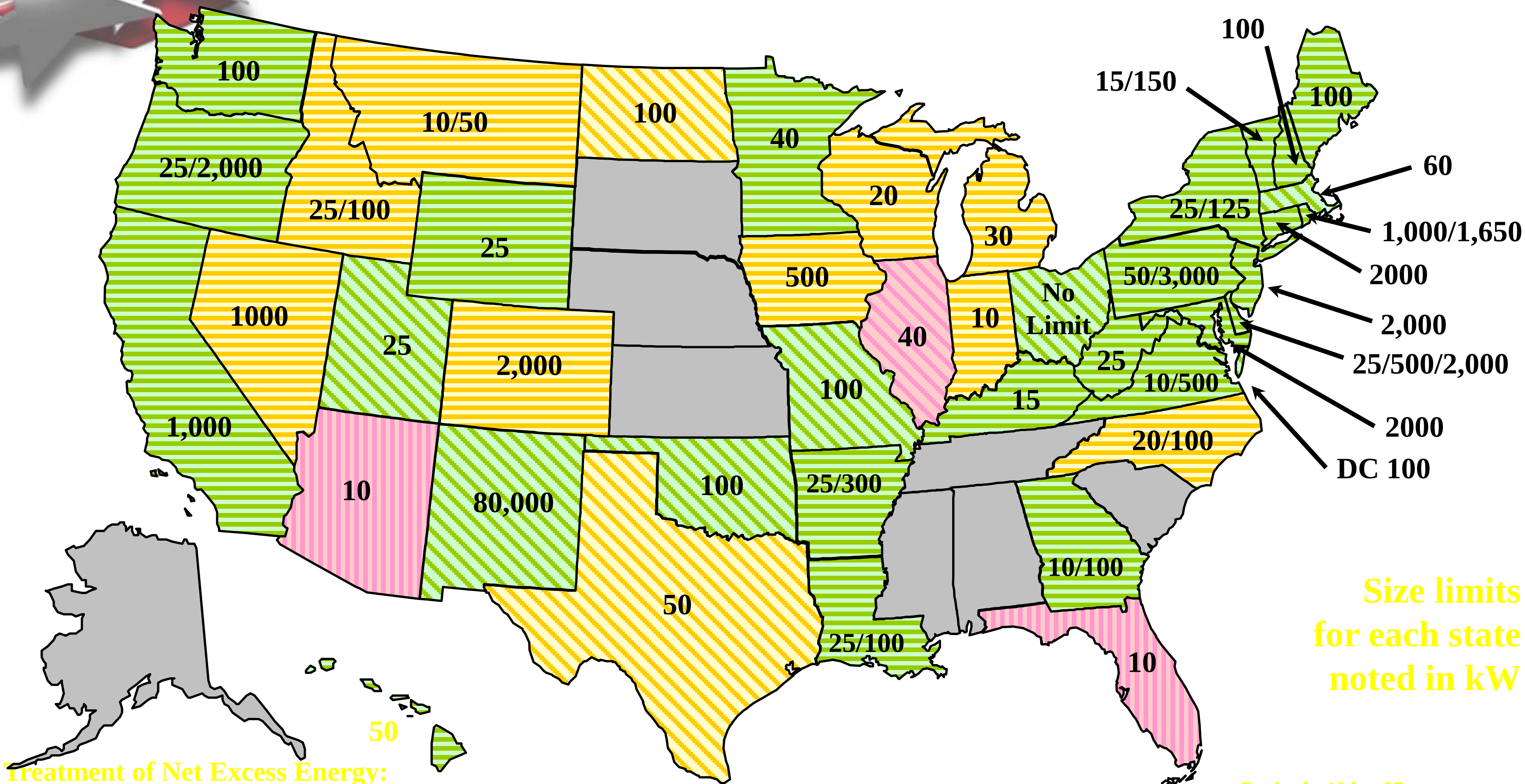
- Loans
- Net Metering & Loans
- Net Metering

Yearly grants through the USDA farm bill are available for Illinois, Pennsylvania, Florida, Iowa, Wisconsin and Ohio.

Federal Incentives: Mainstay Energy – green tag purchase (CA excluded); USDA Federal Farm Bill Title 9006 – grant for rural areas

May 10, 2007

Net Metering for Wind



Treatment of Net Excess Energy:

- Monthly
- Annual or monthly @ retail rate
- Varies by utility

- None
- Individual Utilities
- Investor-Owned Utilities Only, Not Rural Cooperatives
- Investor-Owned Utilities and Rural Cooperatives

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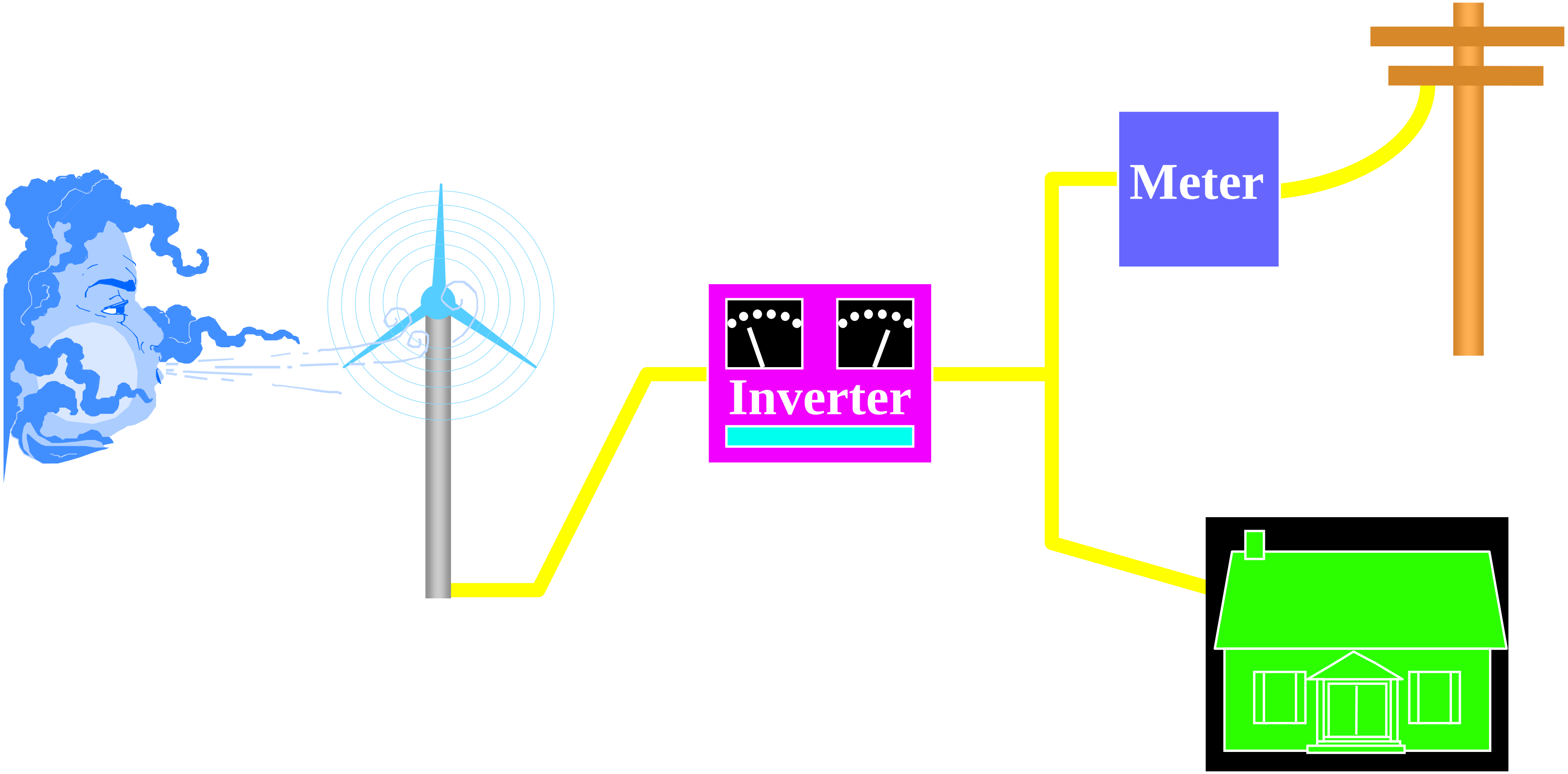
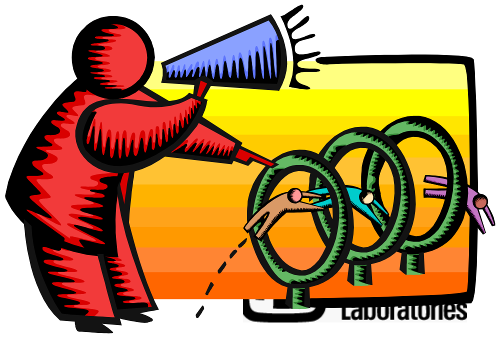
On-Grid Wind System without Storage



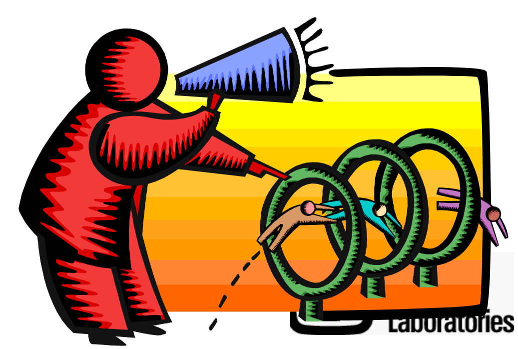
12 Step Program for a Small Wind Project

1. **Assess your electricity consumption, cost, and your utility tariff**
2. **Be more energy efficient → reduce your consumption**
3. **Estimate or measure wind resource**
4. **Select turbine size (model) and tower height**
5. **Investigate incentives & economics**
6. **Get zoning approval**

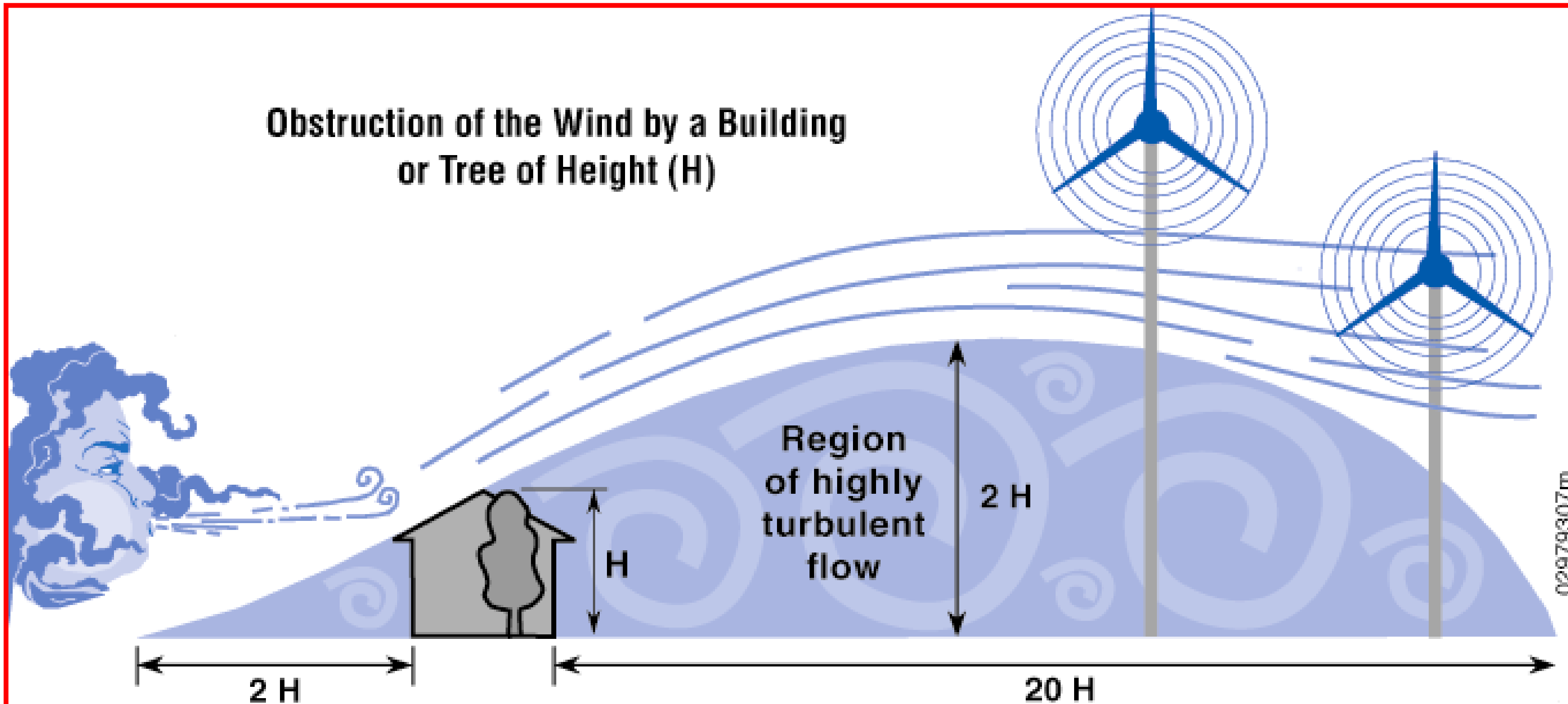


12 Step Program for a Small Wind Project

7. Complete a utility interconnection agreement
8. Obtain building & electrical permits
9. Order turbine and tower
10. Install the turbine
11. Commission the turbine
12. Perform periodic inspections & maintenance



Importance of "Micro-Siting"



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4.4% capacity factor in first year of operation

(July 2007)

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Estimated 7% capacity factor in first 5 months of operation

(December, 2006 – April, 2007)

Example:
Wind Turbine Installed Cost
Red highlights = Turbine System Cost

Updated: 5-Jul-07

Bergey Excel-S (10 kW)		High Cost	Low Cost
Wind turbine & inverter	$27,900	$27,900	$27,900
Tower (100 ft guyed)	$9,200	$31,950	$7,400
Tower Wiring Kit	$1,000	$1,140	$860
Shipping	$1,500	$2,000	$1,000
Installation	$8,000	$18,000	$2,000
Permits/Fees	$500	$6,000	$0
Sales Tax, 2%	$952	9%	none
Total	$49,052	$94,279	$39,160

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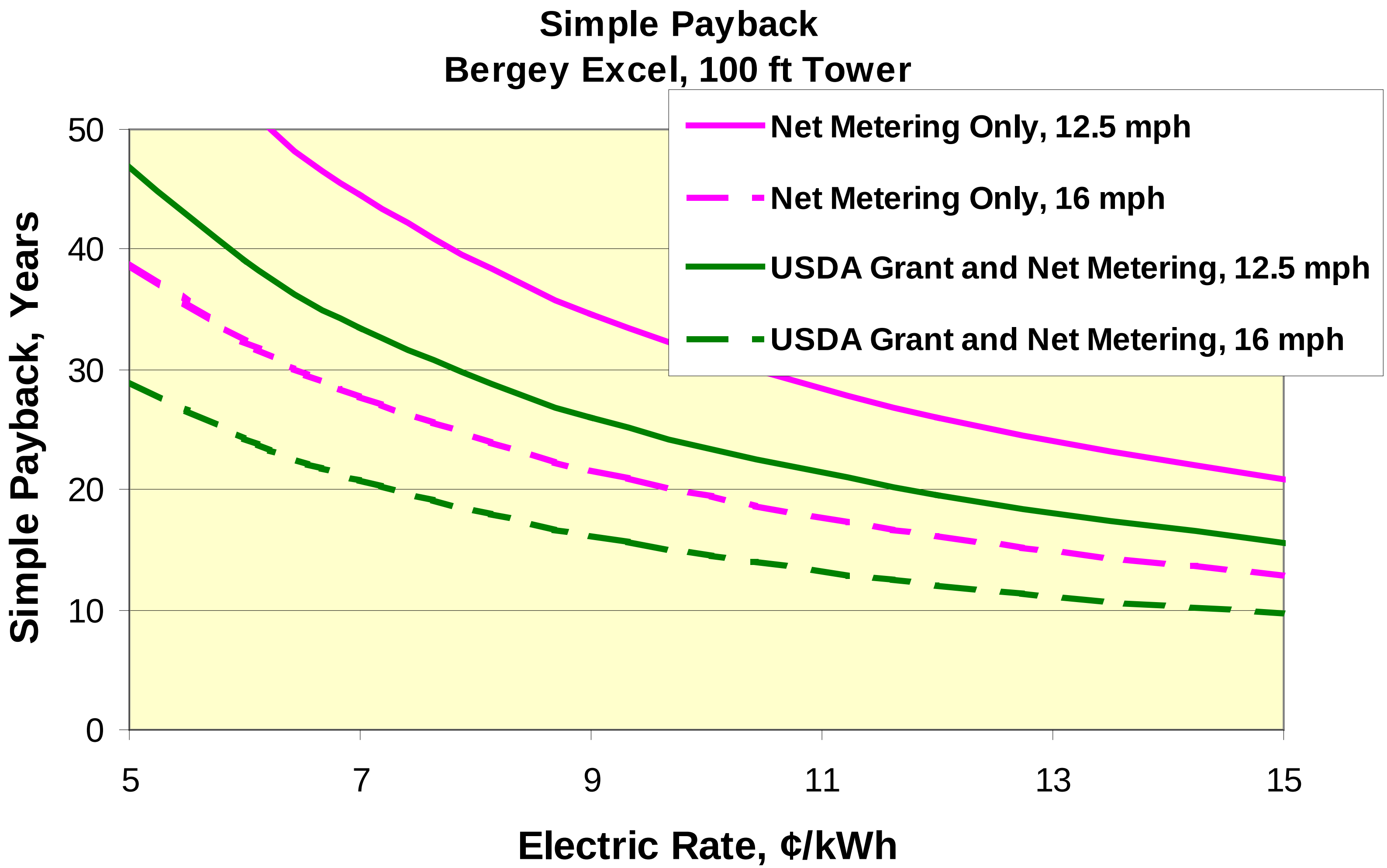
Small Wind Economics



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Frequently Asked Questions - Weather

- **Lightning:** Effectively avoided with proper grounding and use of surge suppressors
- **Severe Storms:** Can be a problem, some turbines have survived hurricanes and tornados
- **Hail Damage:** Have not heard of problems
- **Ice Shedding:** Blades with ice usually don't spin! Ice typically accumulates at the base of the tower.

Frequently Asked Questions - Siting

- **Radio/TV Interference:** Not a problem with today's fiberglass or wood blades (no metal blades!)
- **Noise:**
  - < 30 mph, soft "swoosh" sound
  - > 30 mph, can get either "flutter" or a "helicopter" sound
  - Noise test reports on the Web: http://www.nrel.gov/docs/fy04osti/34662.pdf
- **Impact on Birds:** Bird kills are rare, use common sense in siting turbines
- **FAA Regulations:**
  - Proximity to local airport versus tower height
  - Investigate if within ~3 miles

Southwest Windpower

Flagstaff, Arizona www.windenergy.com

Skystream 1.8 kW

(www.skystreamenergy.com)

Installed costs of

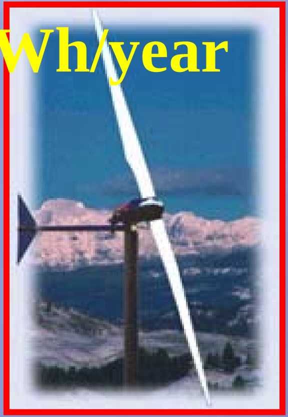
$14k (10m tower) - $22k (20m tower)

Estimated 3,600 kWh/year

AIR-X 300 W

Whisper 100 900 W

Whisper 200 1000 W



Whisper 400 3 kW

Windward Endurance Wind Turbine

5.5 m diameter; 4.25 kW; constant speed - 200 rpm

www.windwardengineering.com

Turbine System Costs $34,995

(105'guyed tilt-down tower)

Estimated kWh 7,700/year

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Abundant Renewable Energy

Newberg, Oregon www.abundantre.com

Bergey Windpower

www.bergey.com Norman, OK

1 kW

Turbine system costs of
$2,600 + $2800 (100’ guyed tower)
Estimated 1,400 kWh/year

Turbine System costs of $27.9k + $9.2
(100’ guyed tower)
Estimated 11,700 kWh/year

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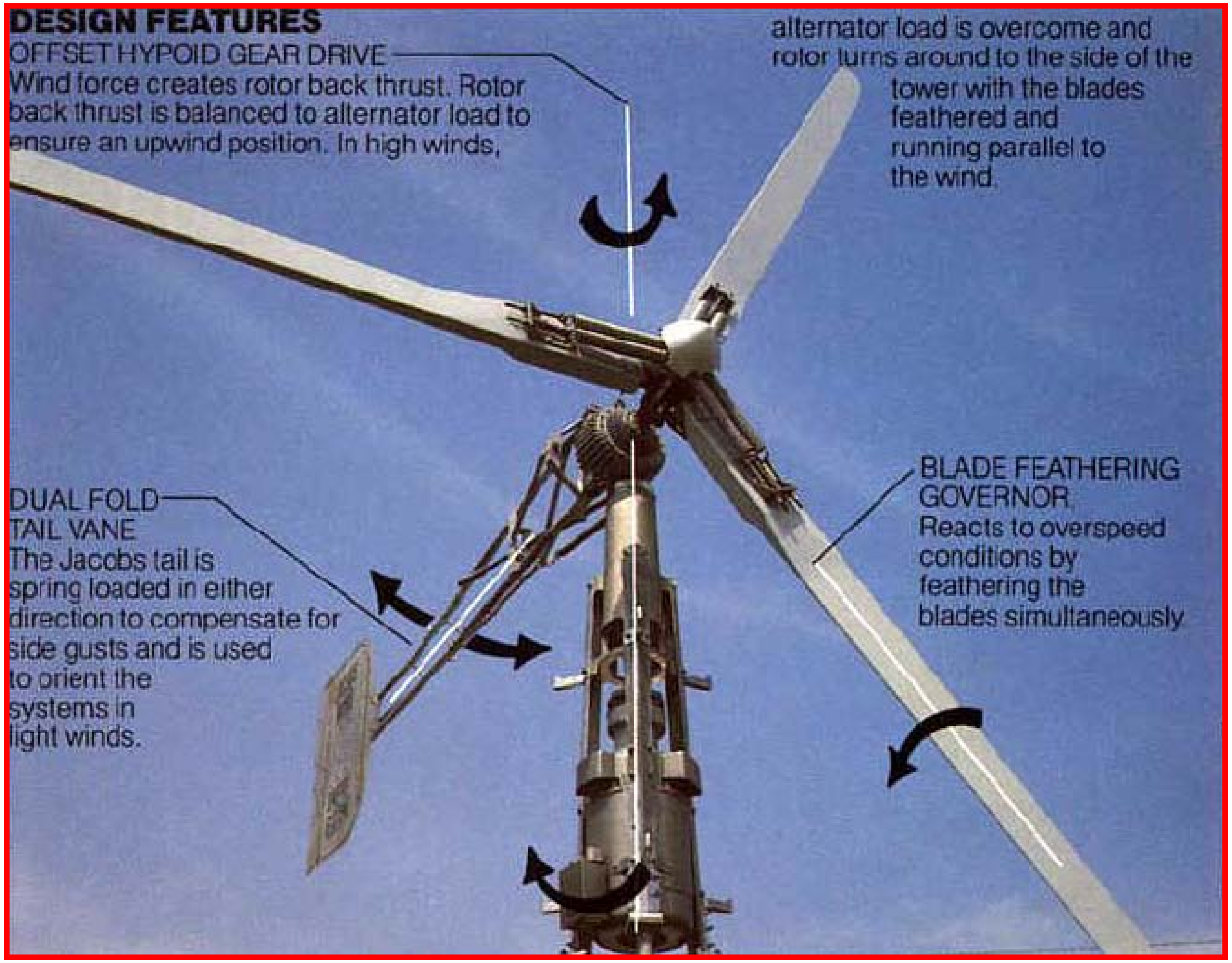
Wind Turbine Industries, Inc.

Prior Lake, MN

Jacobs 31/20
20 kW



Turbine System costs of $53k (100'tower)

Entegrity Wind

www.entegritywind.com

EW15 60 kW

Turbine System costs of $165k (100' lattice tower)

Estimated 96,000 kWh per year

Distributed Energy Systems

Barre, Vermont

www.distributed-energy.com

Turbine Systems costs of $265k (120' tube tower)

Estimated 96,900 kWh per year

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Other Names

(as of June 2007, not comprehensive)

- **Start-Up Companies**
  - **Aerovironment, Earth Turbines (debut June 2008), Endurance (debut June 2007), Energie PGE, Mariah Power, PacWind, Selsam, Ventera (debut June 2007)**
- **Imports**
  - **Aircon, Bornay, Eoltec (Pine Ridge Products, Montana), Fortis (Fortis America), Iskar (DC Power Systems, California), Kestrel (DC Power Systems, California), Proven (3 dealers in North America), Swift, Wind Energy Solutions, various Chinese turbines**
- **Micro Turbines (< 1 kW)**
  - **Aeromag/Aeromax, Hornet, Amp Air, EverFair**

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New Technology Questions

- What is the performance?
  - Power curve or annual energy output
  - System performance (power to the grid)
- Was this performance measured in a field test?
  - Not estimated, not from wind tunnel or truck testing
- Has this performance been independently verified?
- Is it labeled for compliance with UL 1741?
  - For safe interconnection to the utility grid
- Is it compliant with an IEC design/safety standard?
- Who can provide parts and service?
- What is the warranty?
- Where has it been demonstrated?
- Is price estimated, or based on real manufacturing experience?

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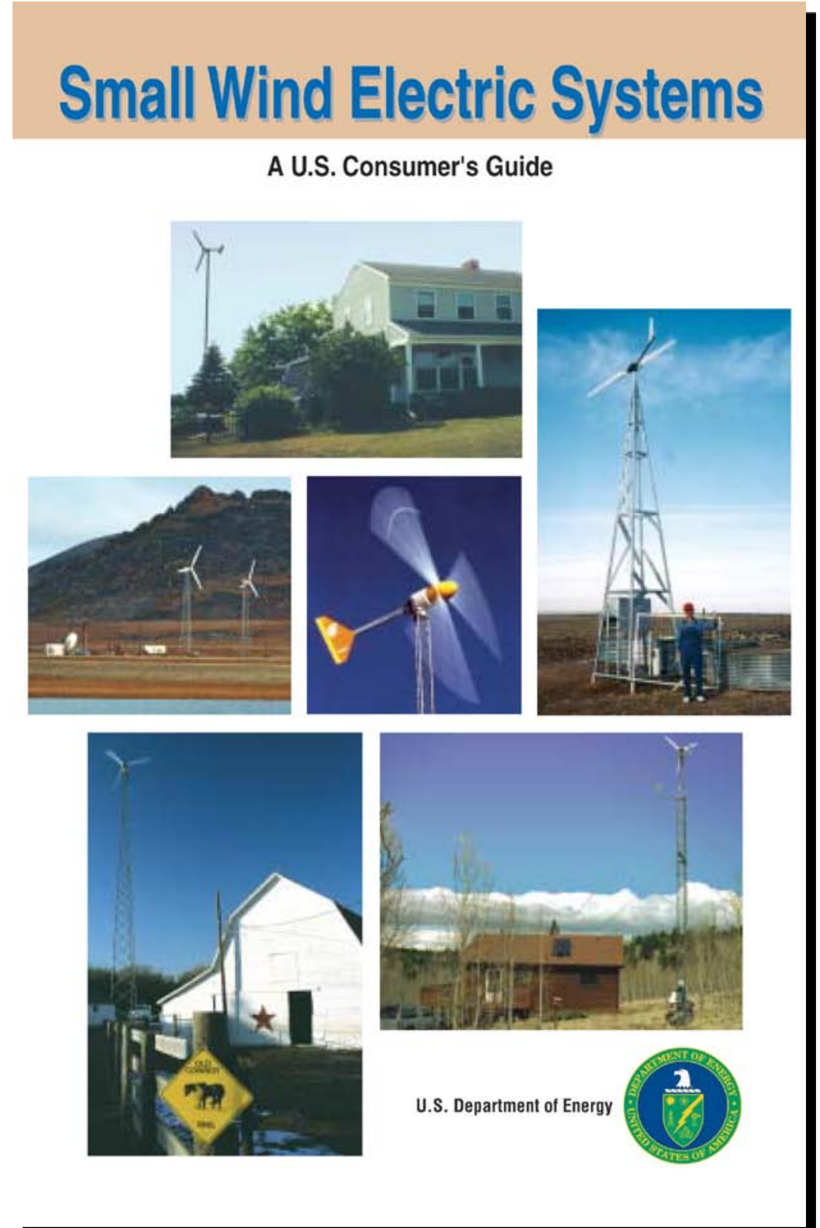
More information

National Renewable Energy Laboratory:
www.windpoweringamerica.gov

American Wind Energy Association:
www.awea.org



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Small Wind Power for Home, Farm, Business, & Schools

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Wind Energy

Daniel Laird

Energy and Infrastructure Future
Sandia National Laboratories

U.S. Power Generation Additions

Net Capacity Change during 2008

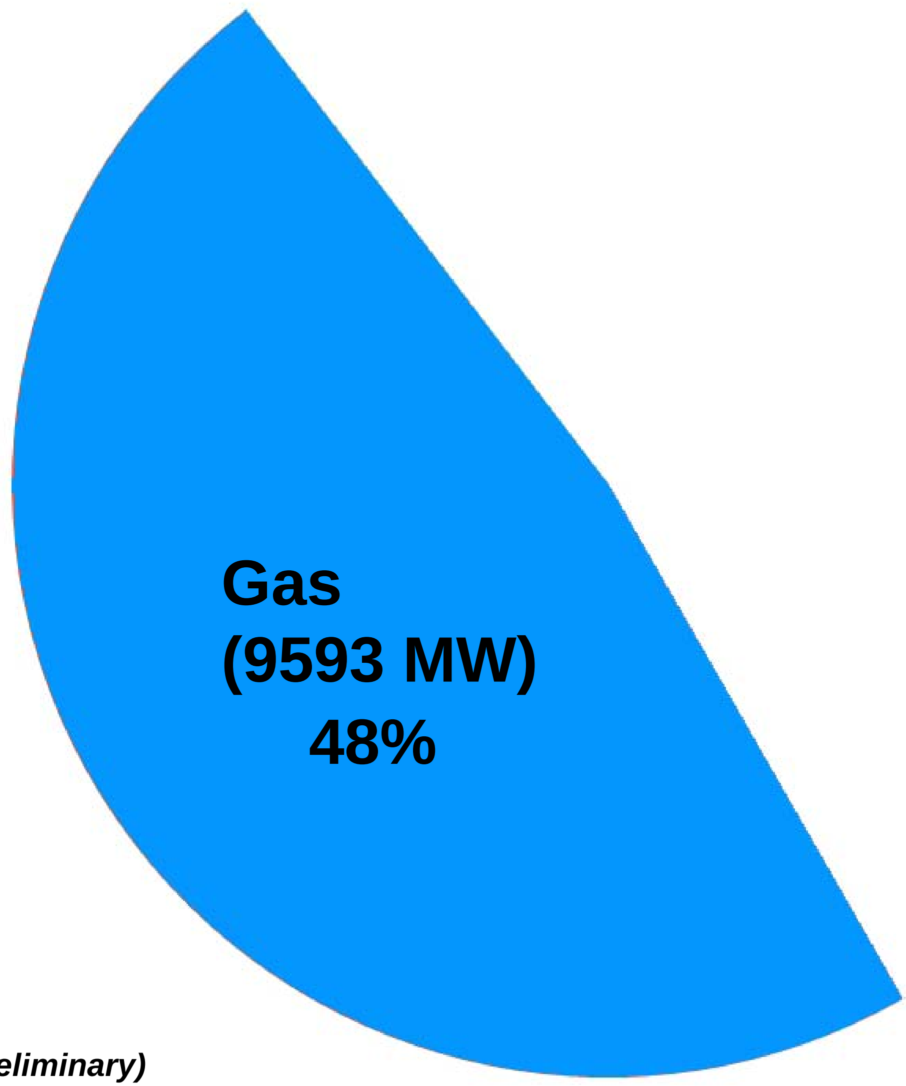
- Coal
- PV
- Petroleum
- Natural Gas
- Nuclear
- CSP
- Wind
- Geothermal
- Biomass
- Landfill gas
- Hydro

Which ones had the most market share?

Power Generating Unit Net Additions

U.S. – 2008

- Coal
- PV
- Petroleum
- Natural Gas
- Nuclear
- CSP
- Wind
- Geothermal
- Biomass
- Landfill gas
- Hydro



source: AWEA (preliminary)

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Power Generating Unit Net Additions

U.S. – 2008

- Coal
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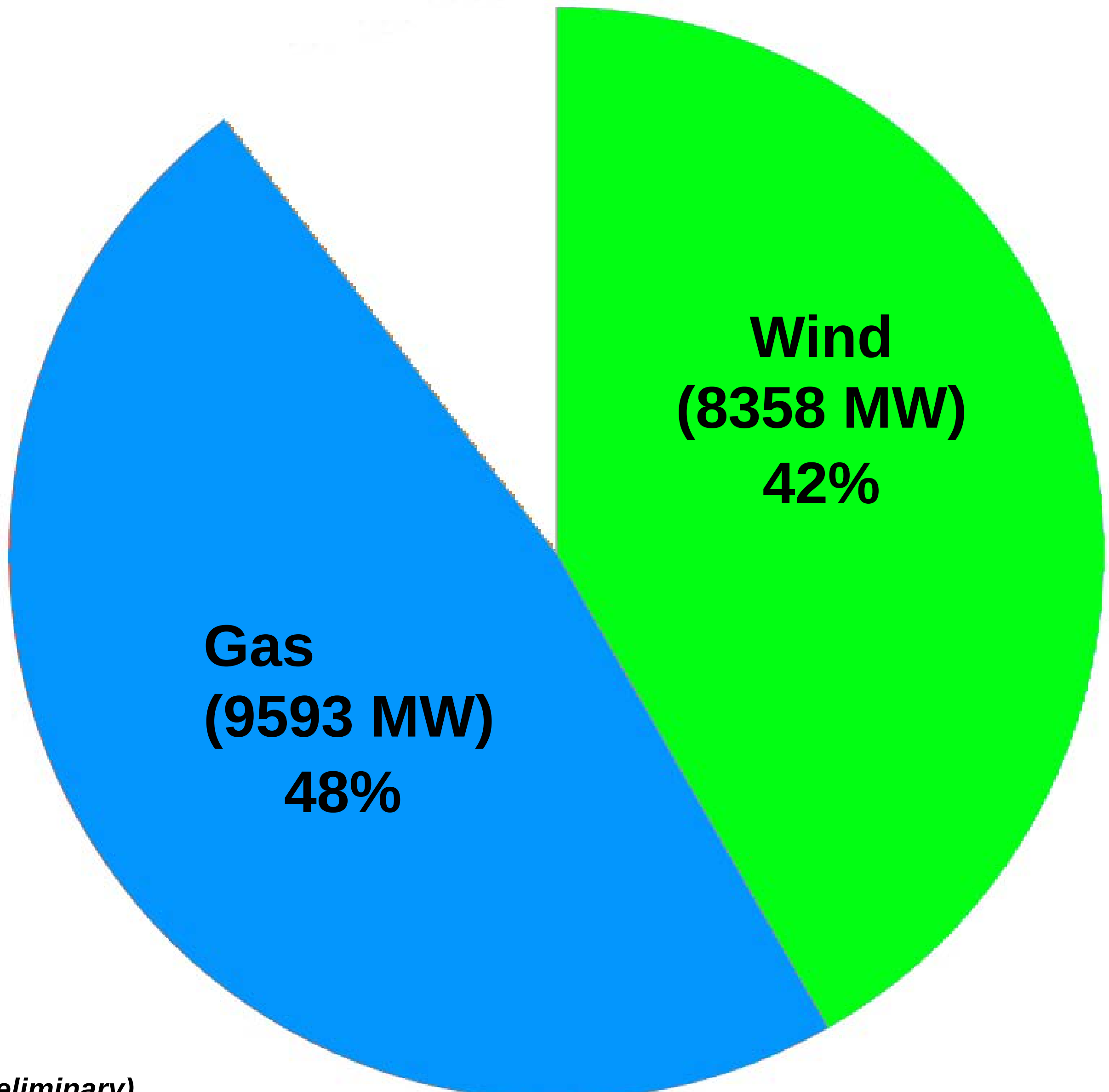

source: AWEA (preliminary)

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Power Generating Unit Net Additions

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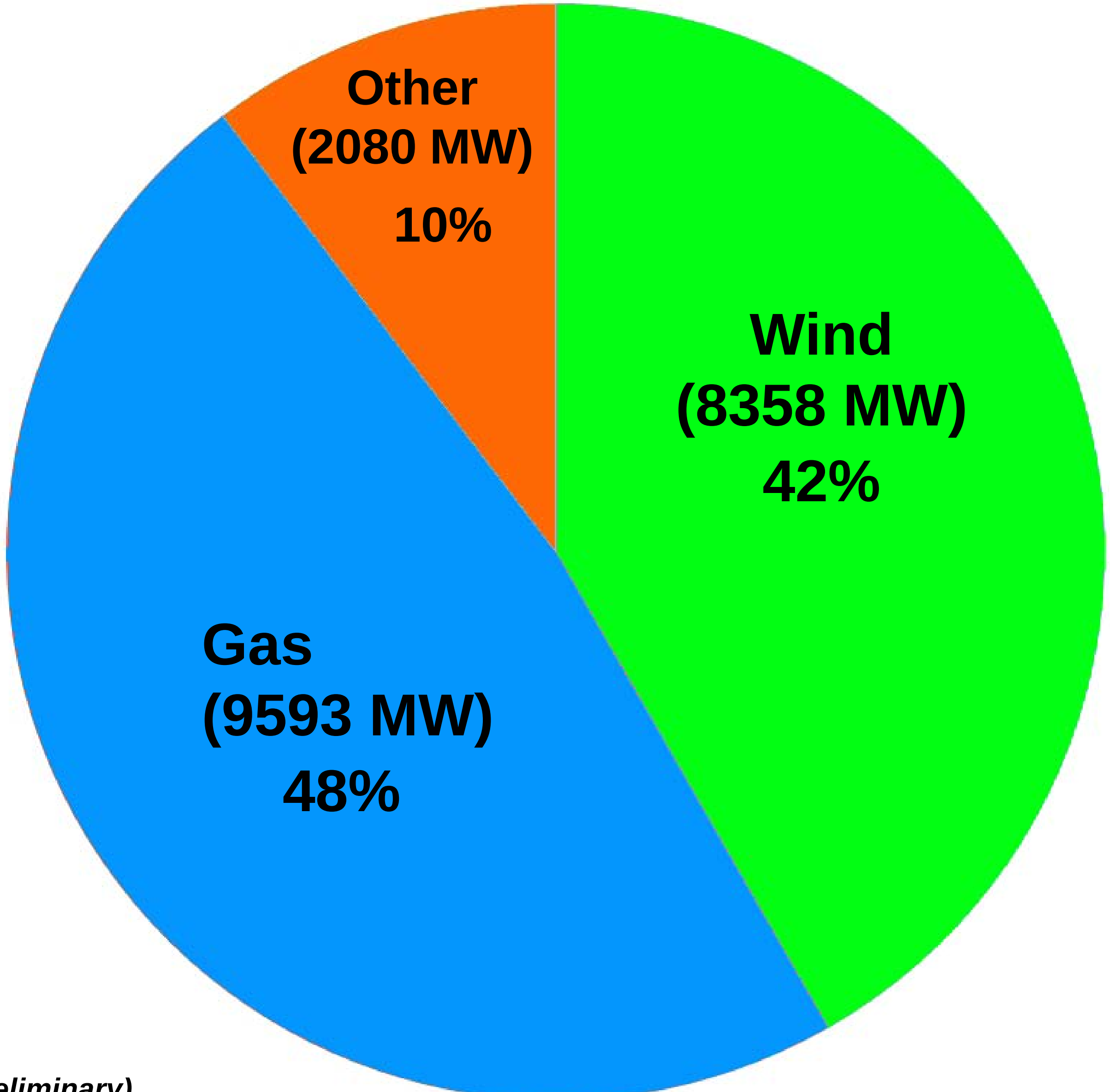

source: AWEA (preliminary)

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Power Generating Unit Net Additions

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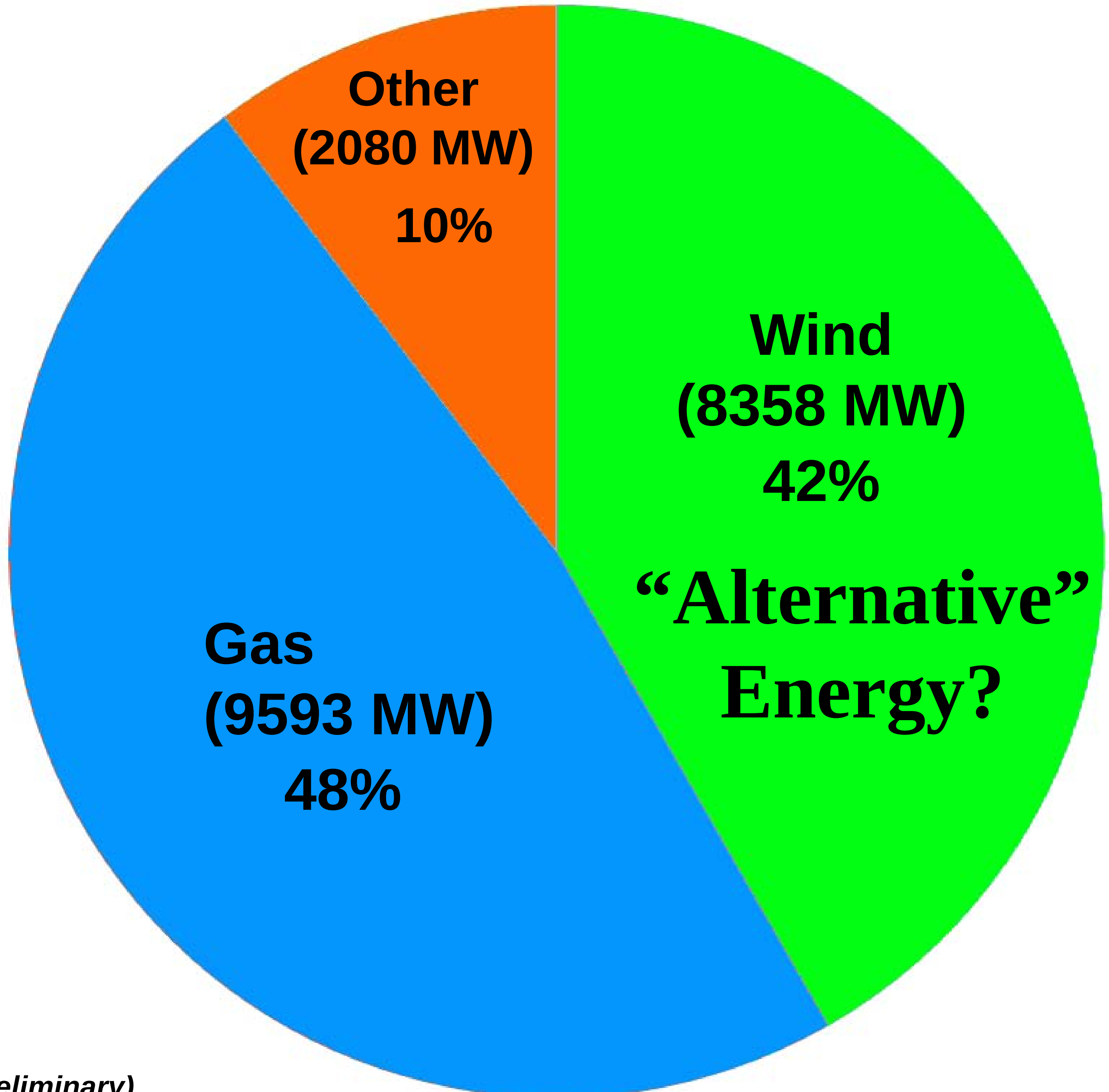

source: AWEA (preliminary)

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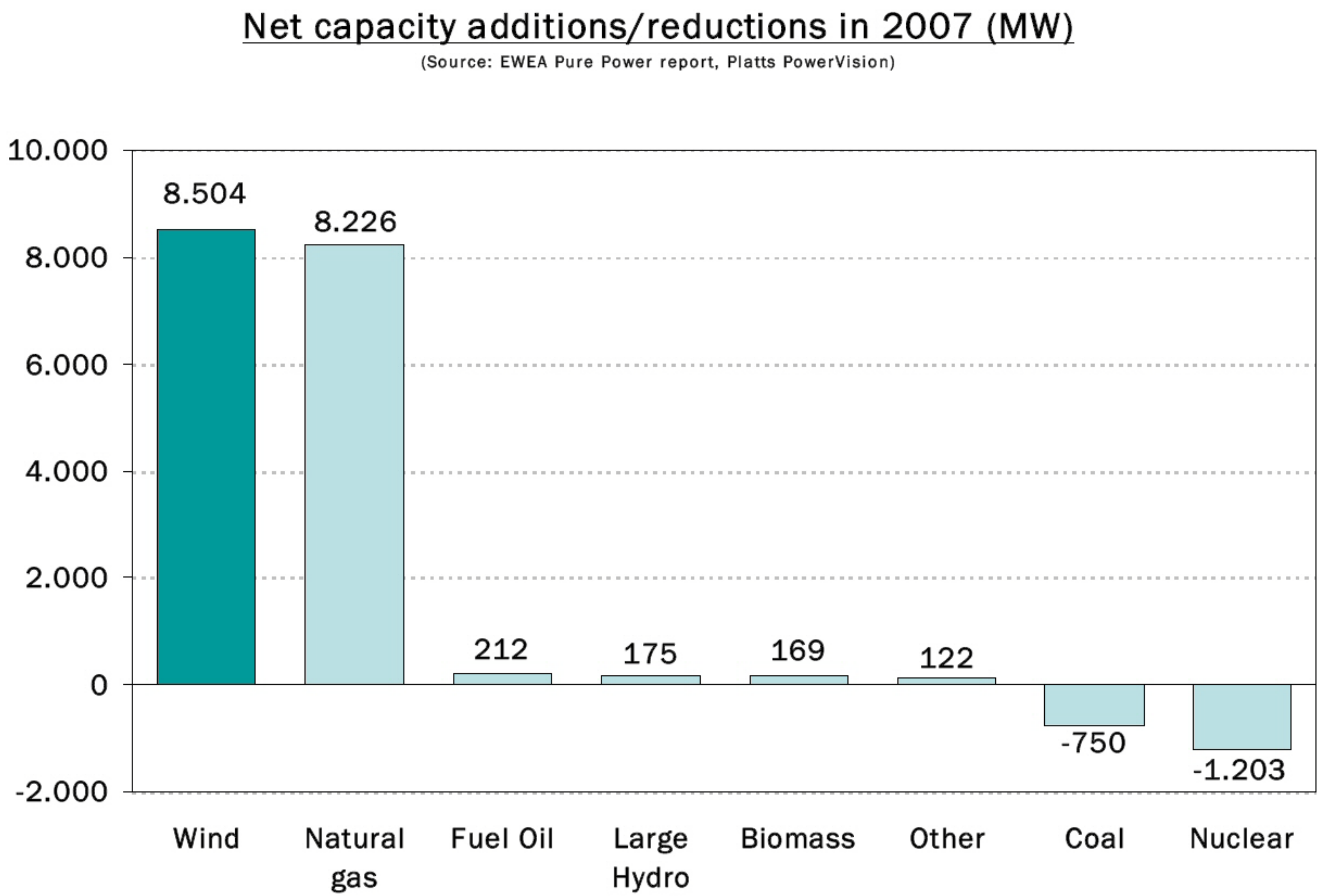
Europe



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Wind

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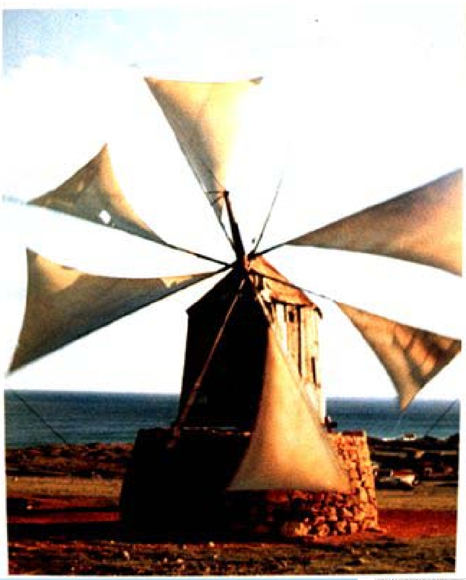
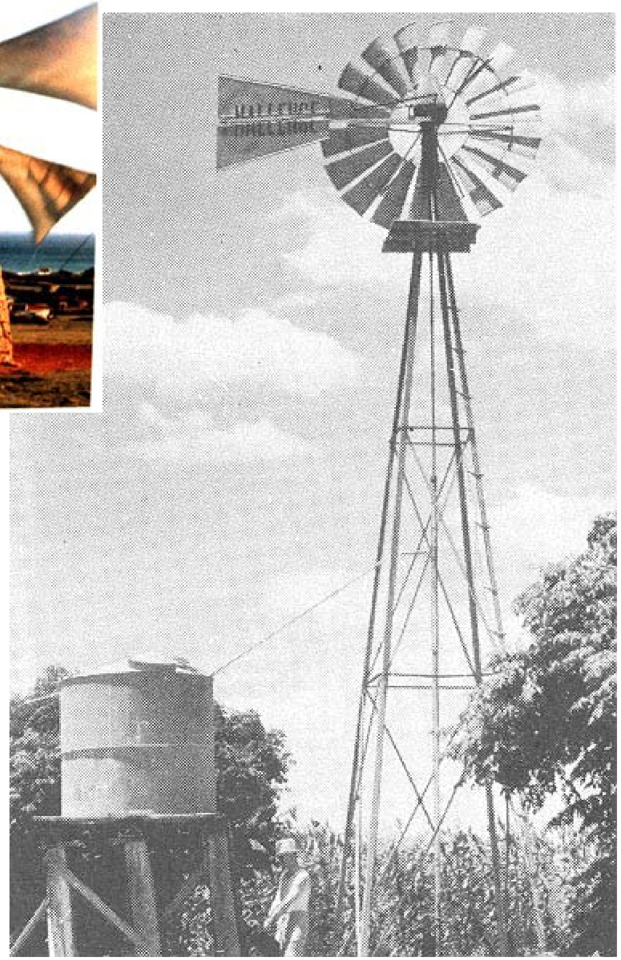
History of Wind Energy
pre - 1970





- **Prehistoric – Maritime (Greek, Viking)**
- **Medieval – Persian, Greek, England**
- **20th Century – Great Plains**
- **First Energy Shortage -- 1974**

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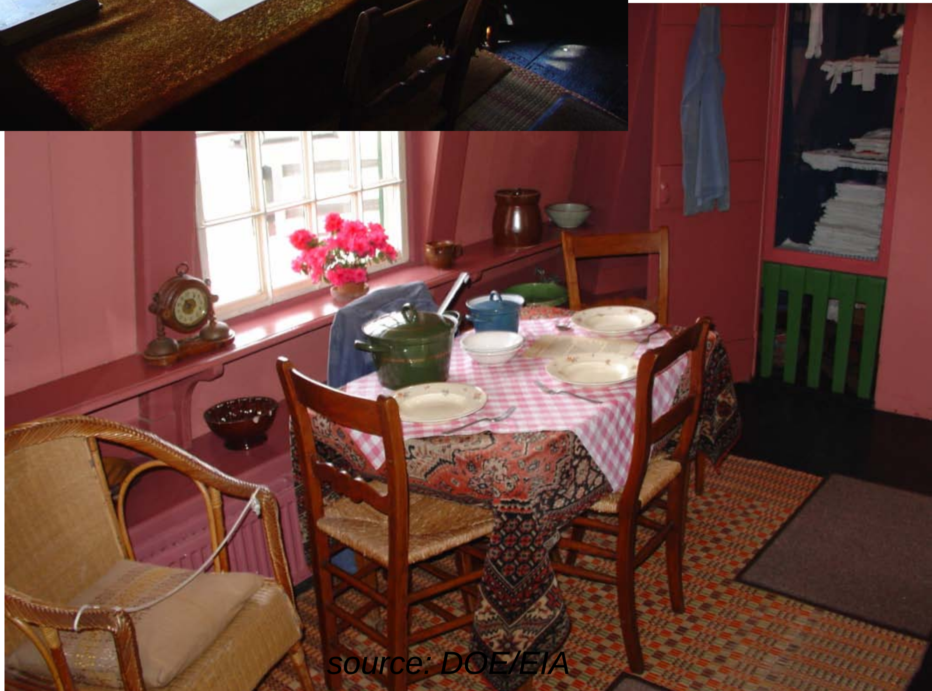
Windmills

Why did the Dutch people need windmills?

Answer: To pump water back to the sea

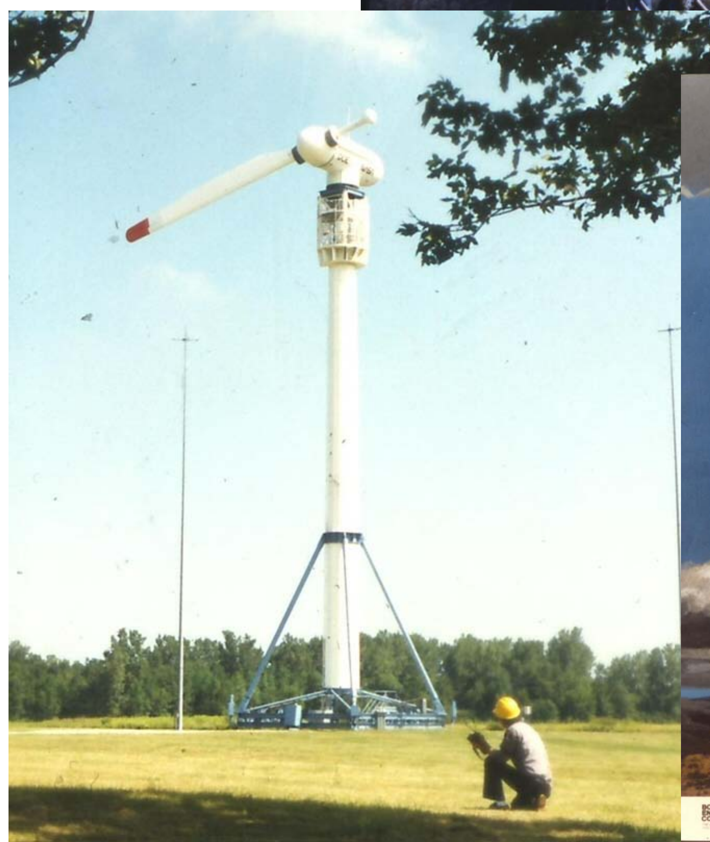
Windmill Operator and Family Lived in the Windmill



source: DOE/EIA

History of Wind Energy
post - 1970

U.S. DOE develops significant research program in response to the energy crisis of 1974



History of Wind Energy
California Boom

Livermore, CA -1982

AWEA

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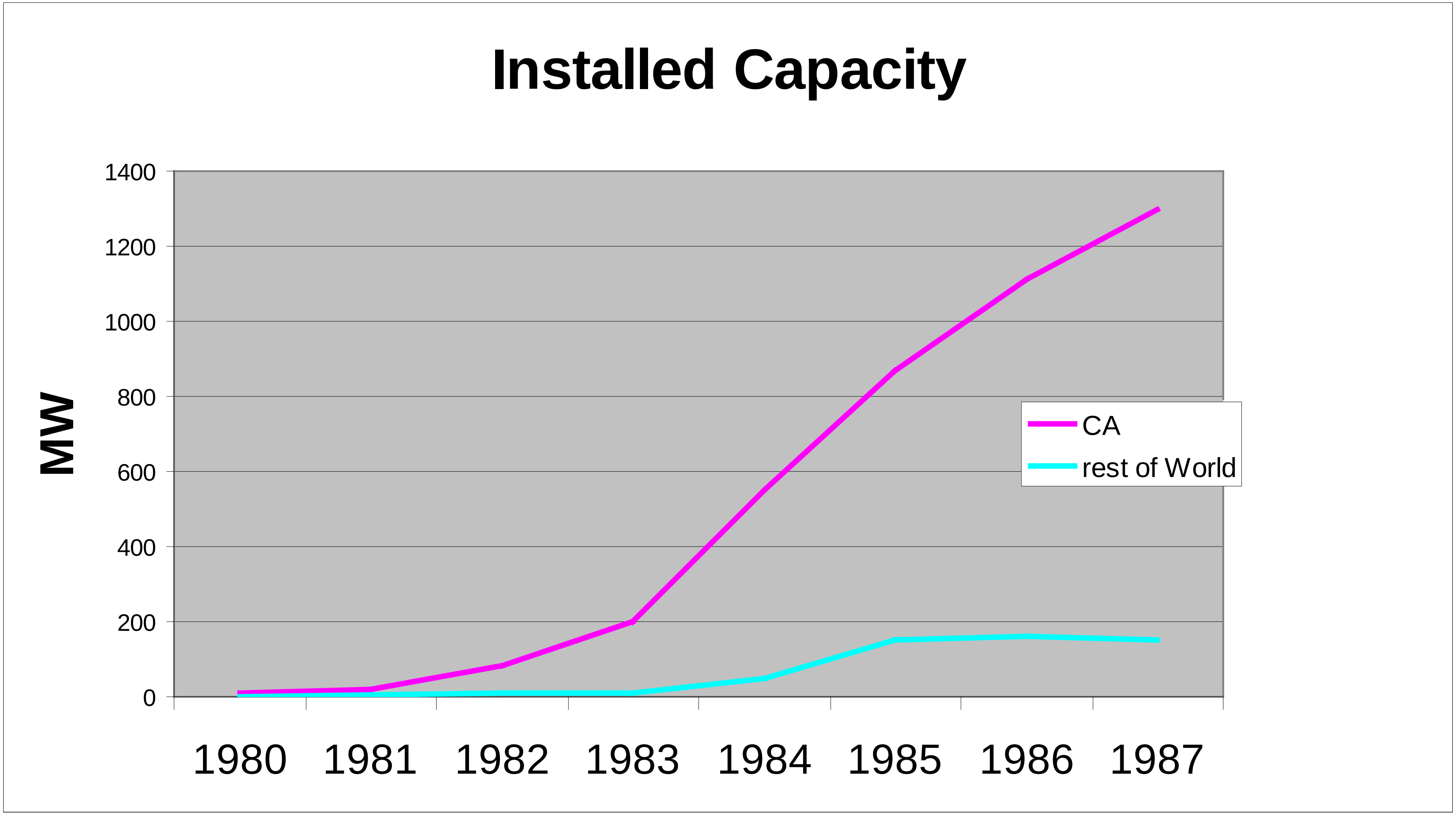
History of Wind Energy

California Boom



AWEA, CEC, Renewable Energy World, Power Engineering, Earth Policy Institute, UC-Irvine

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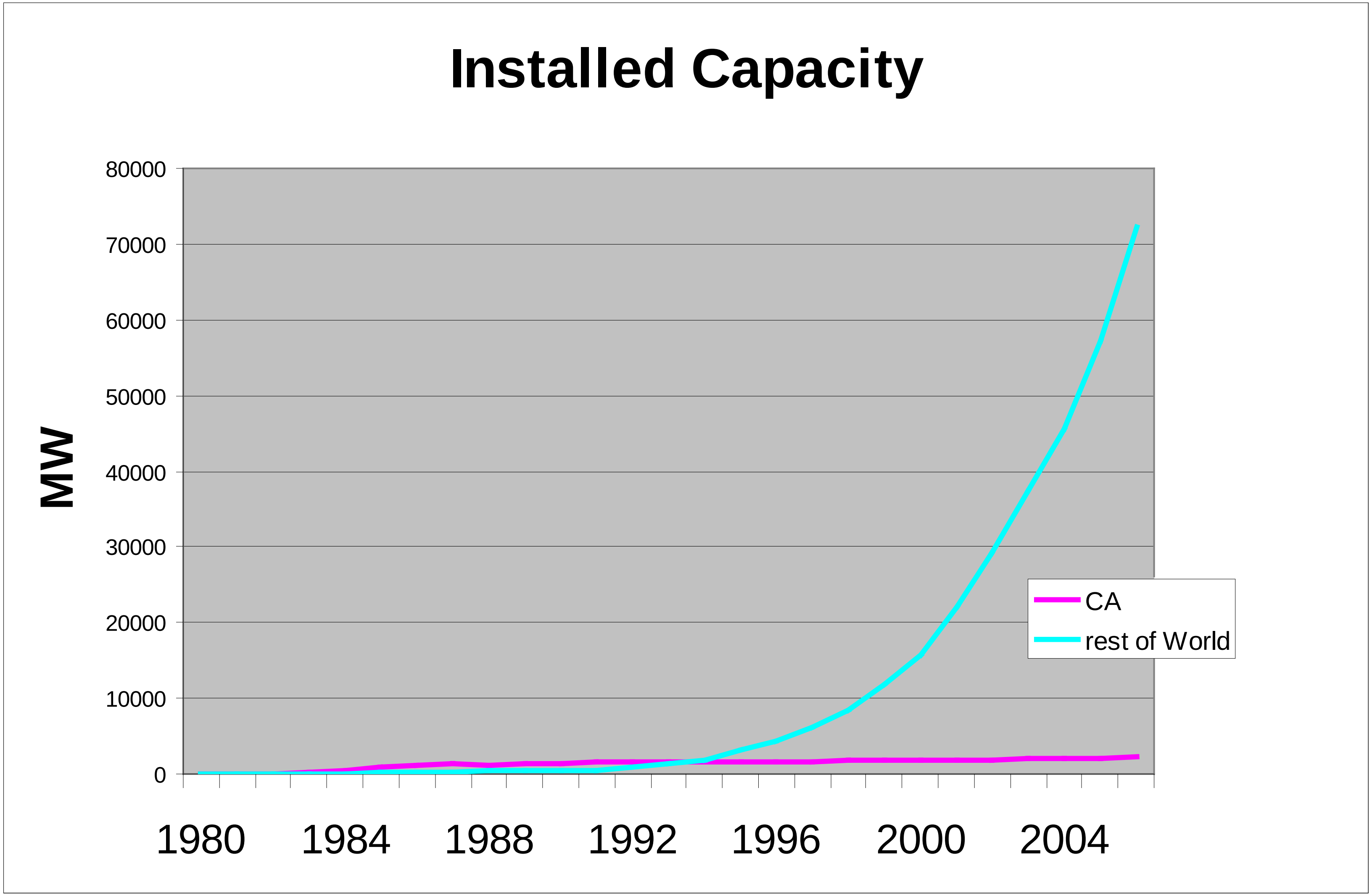
History of Wind Energy
California and World



AWEA, CEC, Renewable Energy World, Power Engineering, Earth Policy Institute, UC-Irvine

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Wind Basics

Wind Power Basics

Air Density → ρ, **Rotor Area** → A, **Wind Speed** → V_∞

$$WindPower = \frac{1}{2}\rho A C_P V_\infty^3$$

Wind Power output is proportional to wind speed cubed.

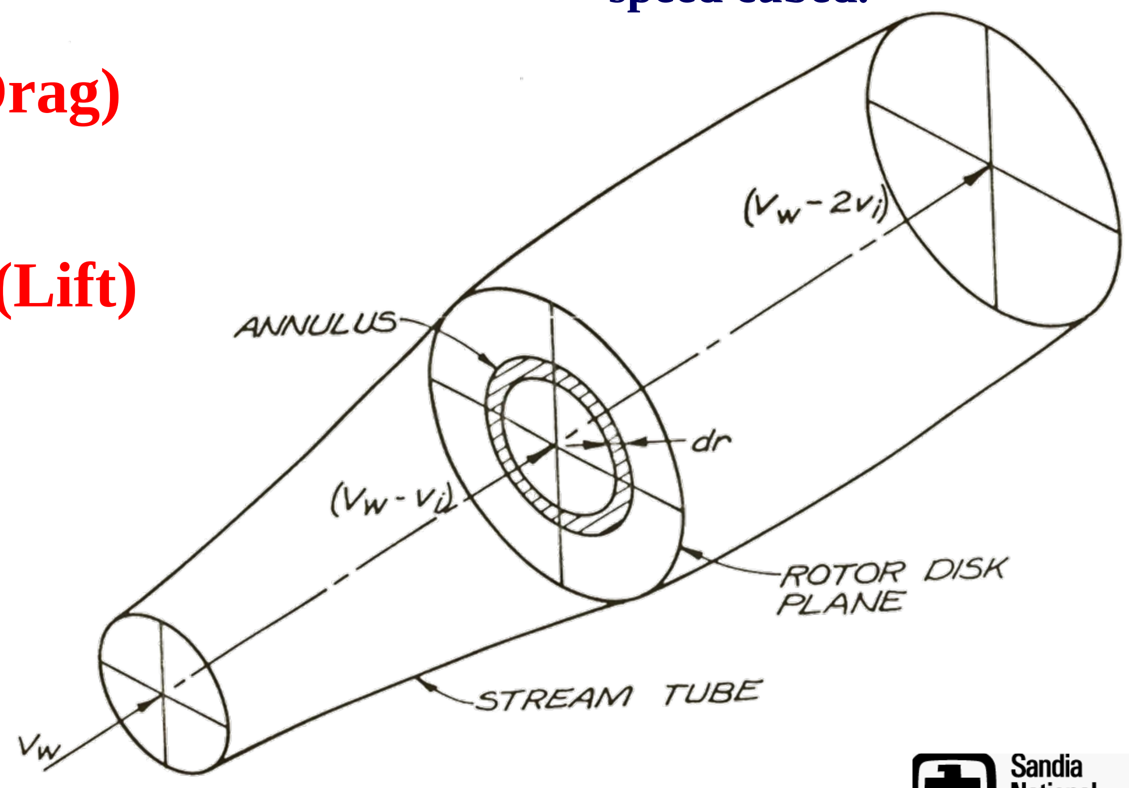
$$C_{P\max} \cong 0.3$$ **(Drag)**

$$C_{P\max} \cong 0.59$$ **(Lift)**

The Betz Limit

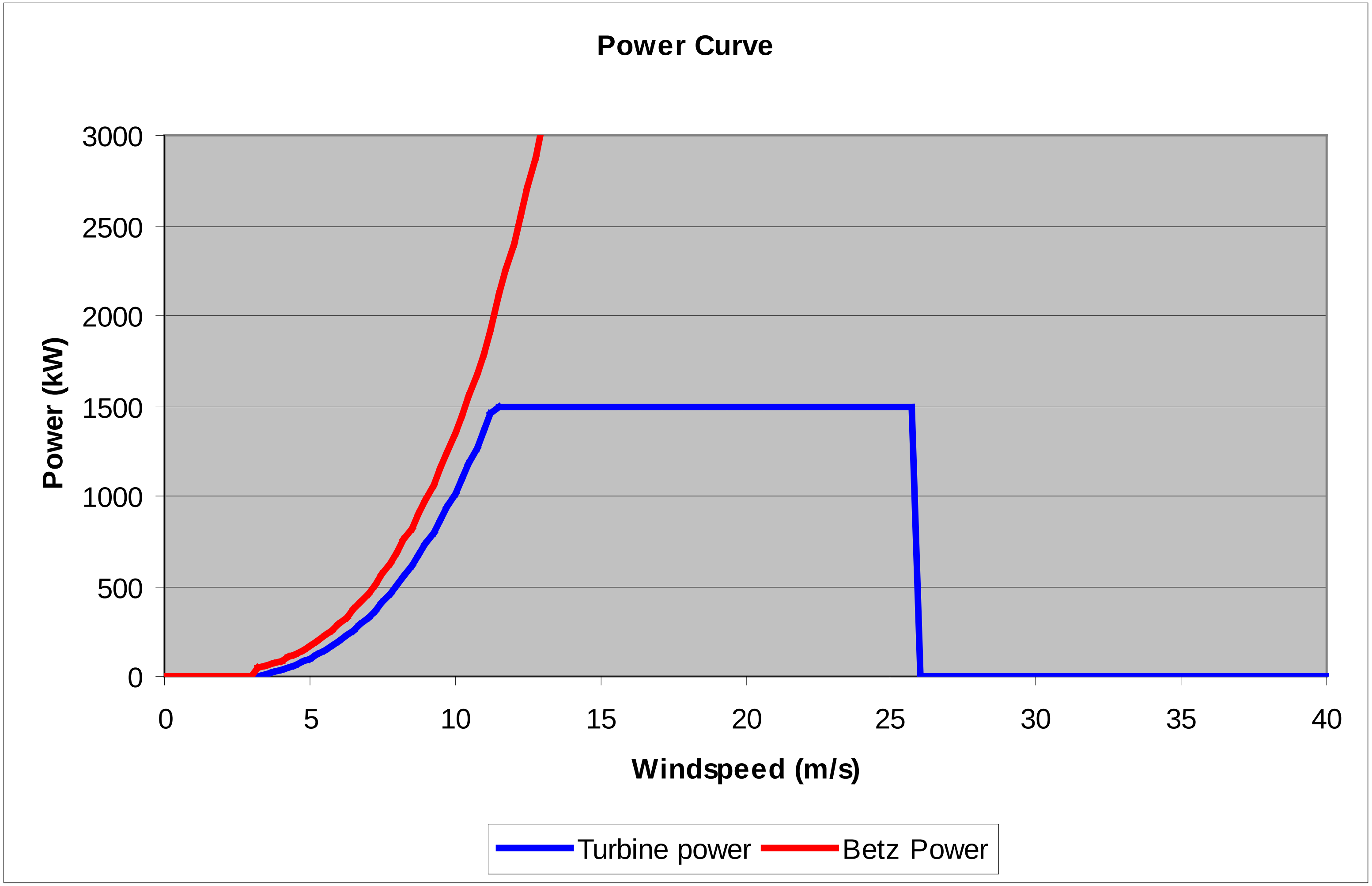
$$V_i = \frac{1}{3} V_w$$

$$P = \frac{16}{27}\left(\frac{1}{2}\rho A V_w^3\right)$$



Turbine Power Basics

Power vs. Wind Speed



Current Technology
and
Energy Cost

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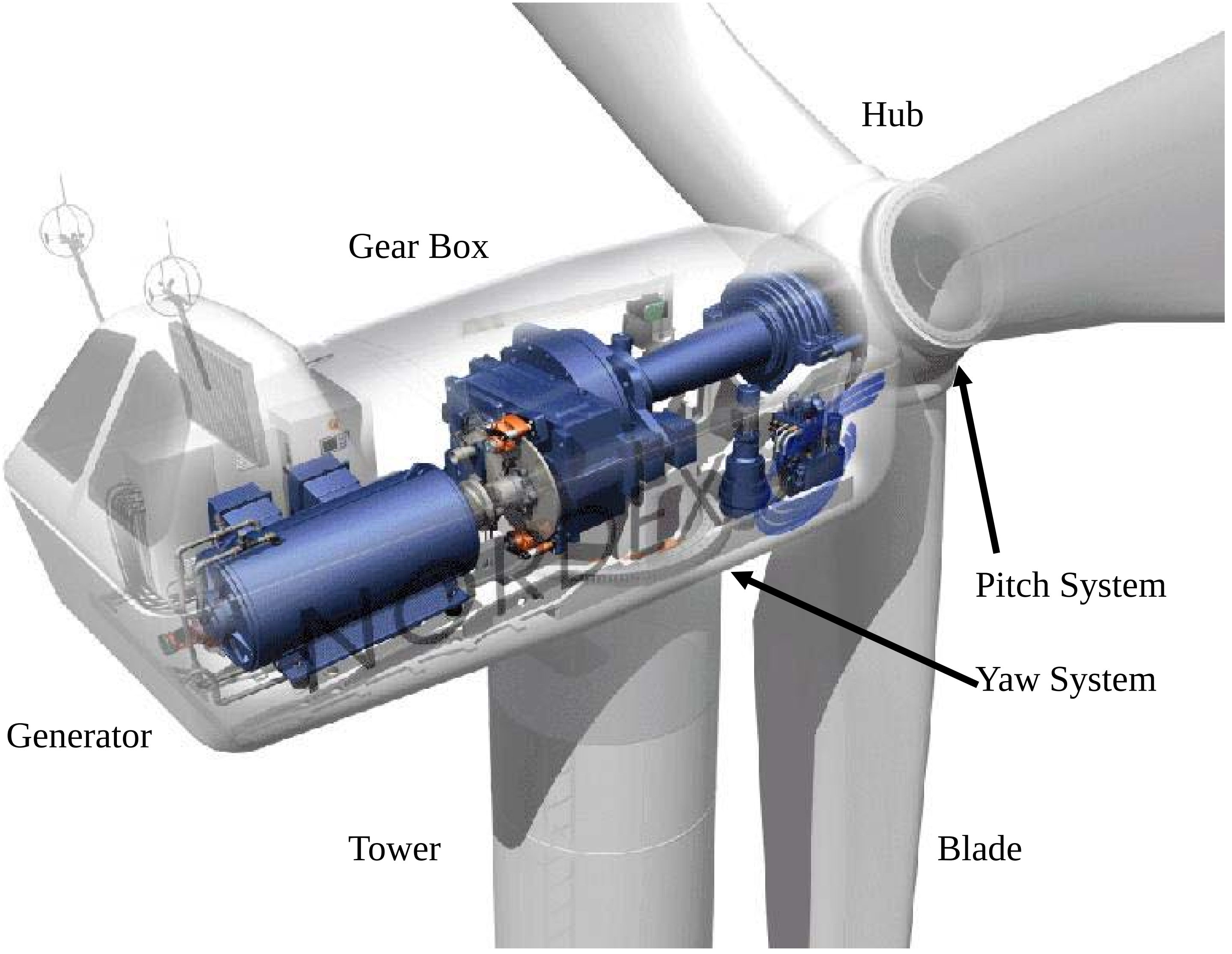
Wind Power

small wind
(1-10 kW)

1 www.bergey.com
2 www.skystreamenergy.com

Current Technology



http://windfair.net/anlagen/enercon-e-112.html

Modern Utility-Scale Turbines are Large

Rated power: 4,500 kW

Rotor diameter: 114 m (374 ft)

Hub height: 124 m (406 ft)

Rotor speed: Variable, 8 - 13 rpm

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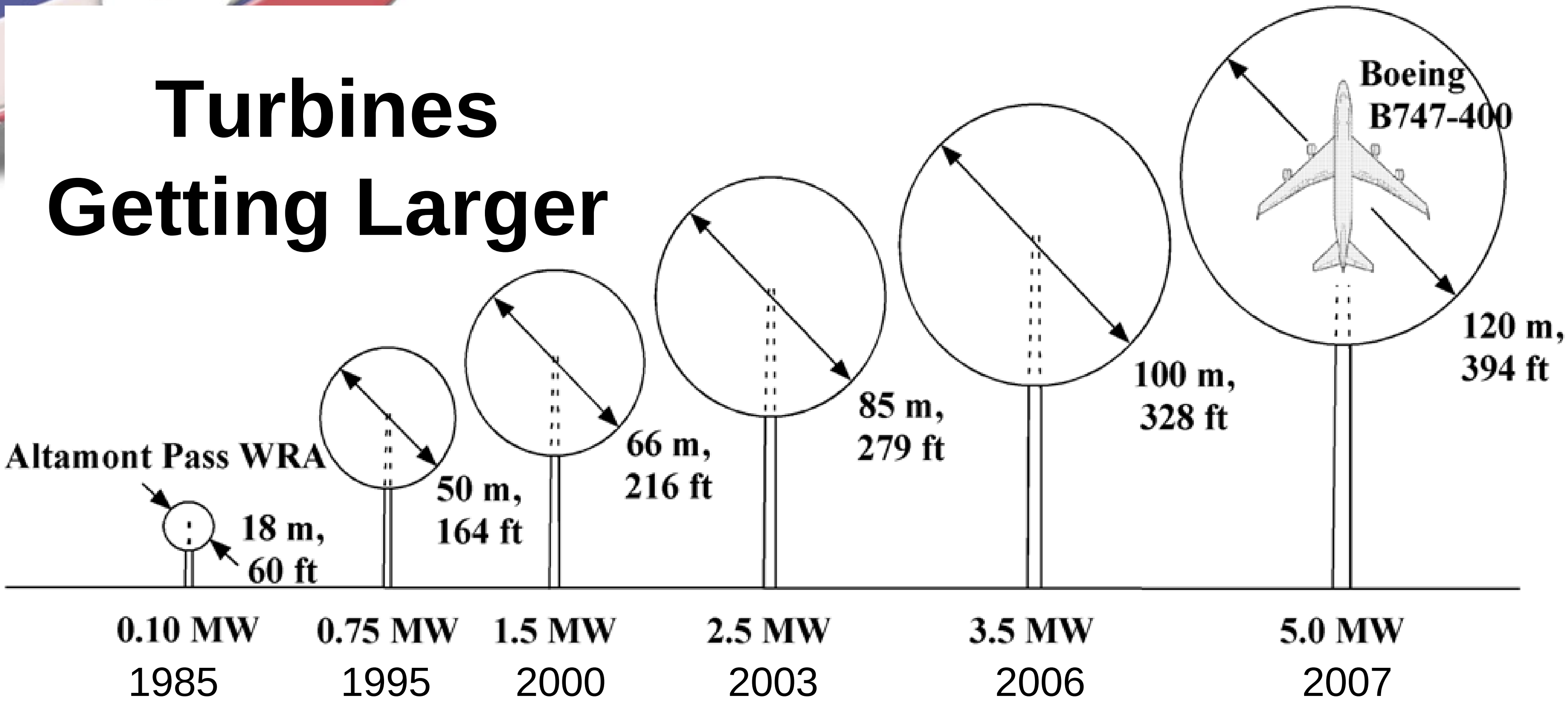
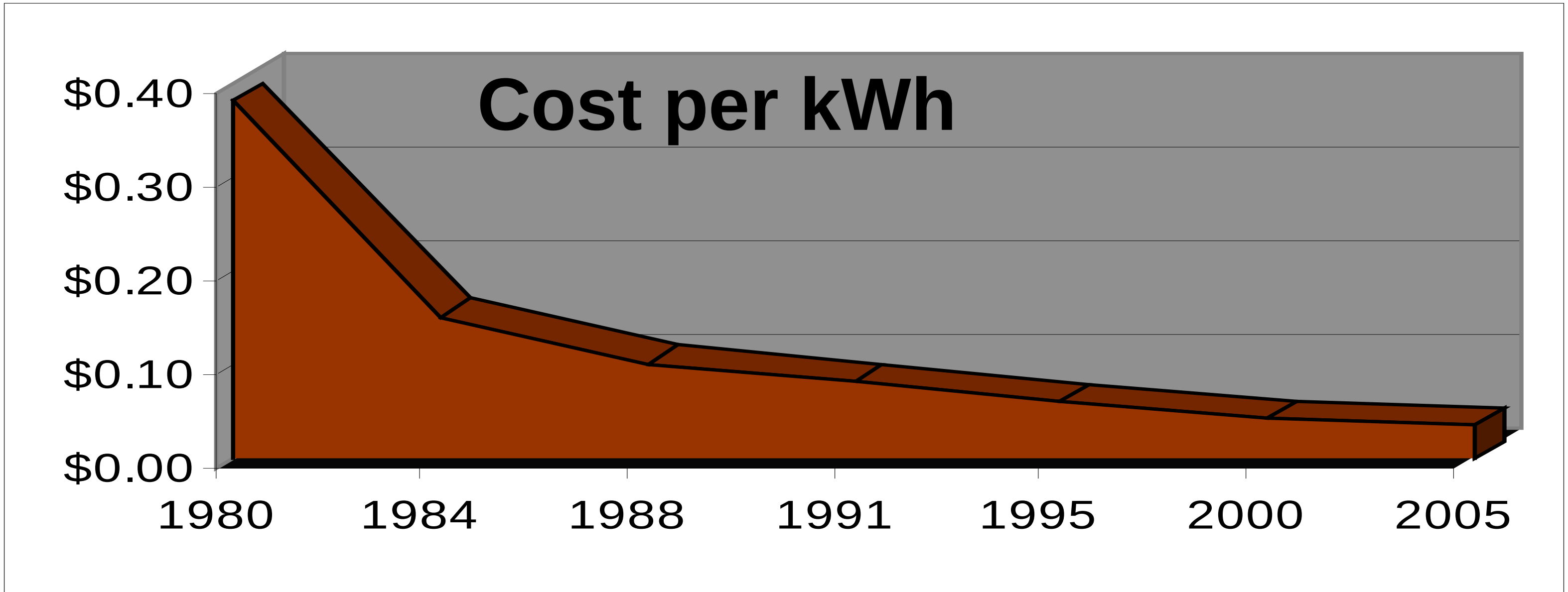
Turbines Getting Larger





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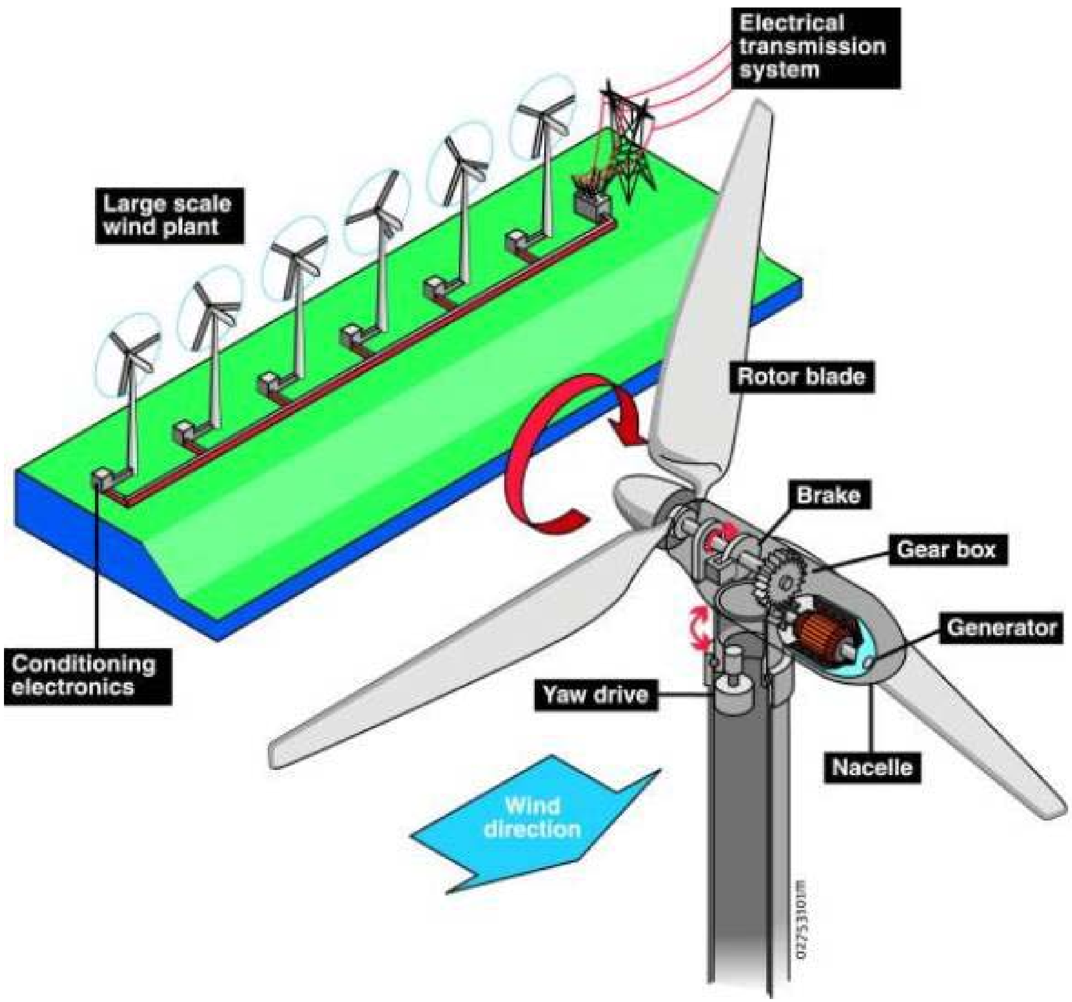
Wind Farm Components

- Turbine
- Foundations
- Electrical Collection System
- Power quality conditioning
- Substation
- SCADA
- Roads
- Maintenance facilities



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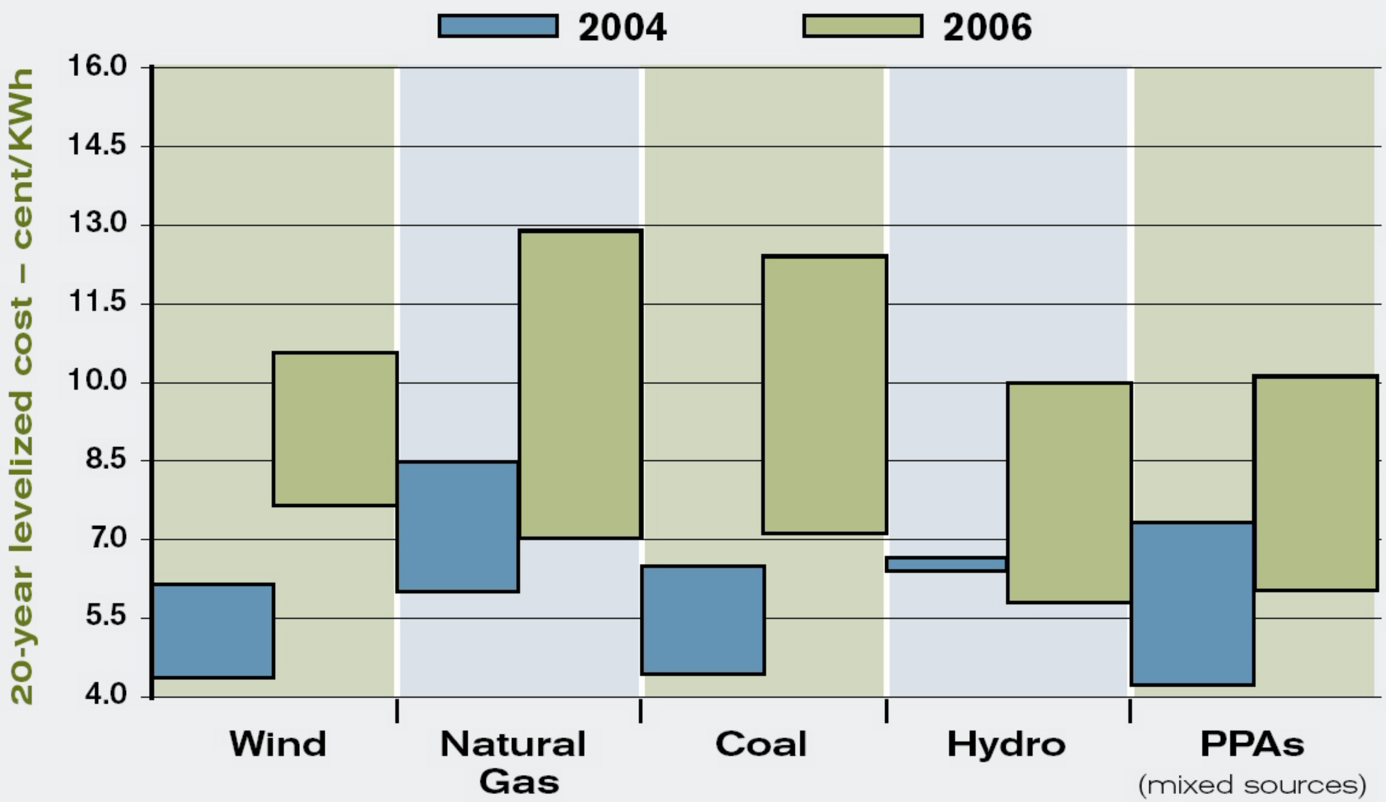
Power Gen Costs Rising

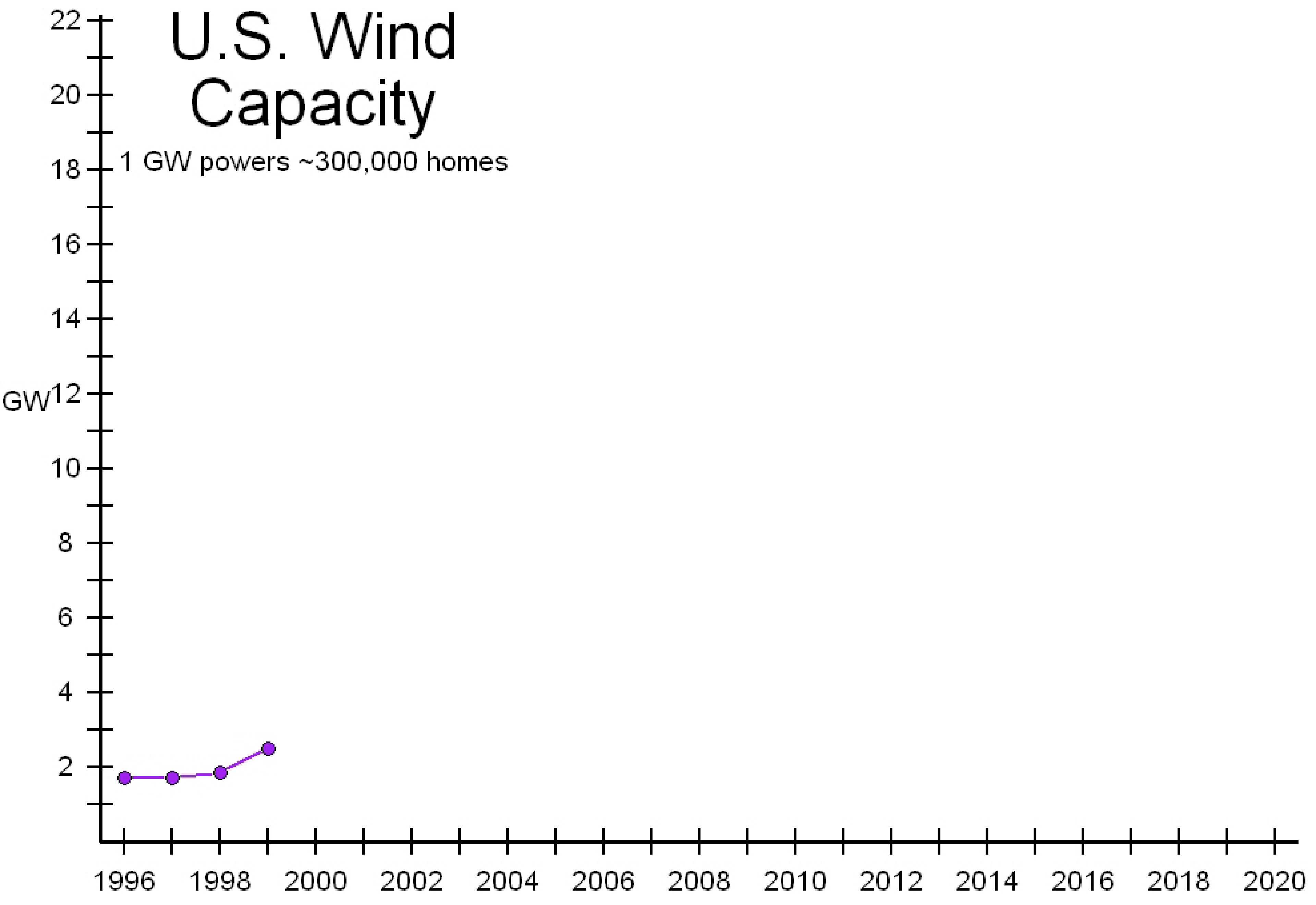


Puget Sound Energy (PSE), like other utilities throughout the country, faces significant increases in resource costs. The company's major investments in wind have made PSE the largest utility producer of renewable energy in the Pacific Northwest.

Data and slide courtesy Puget Sound Energy.

Forecasts and Predictions

"There are three kinds of lies:
lies, damned lies, and statistics."



U.S. Wind Capacity
1 GW powers ~300,000 homes
GW
22
20
18
16
14
12
10
8
6
4
2
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020

Global Wind Industry

Leading Turbine Manufacturers

GE (US)

Gamesa (Spain)

Vestas (Denmark)

Enercon (Germany)

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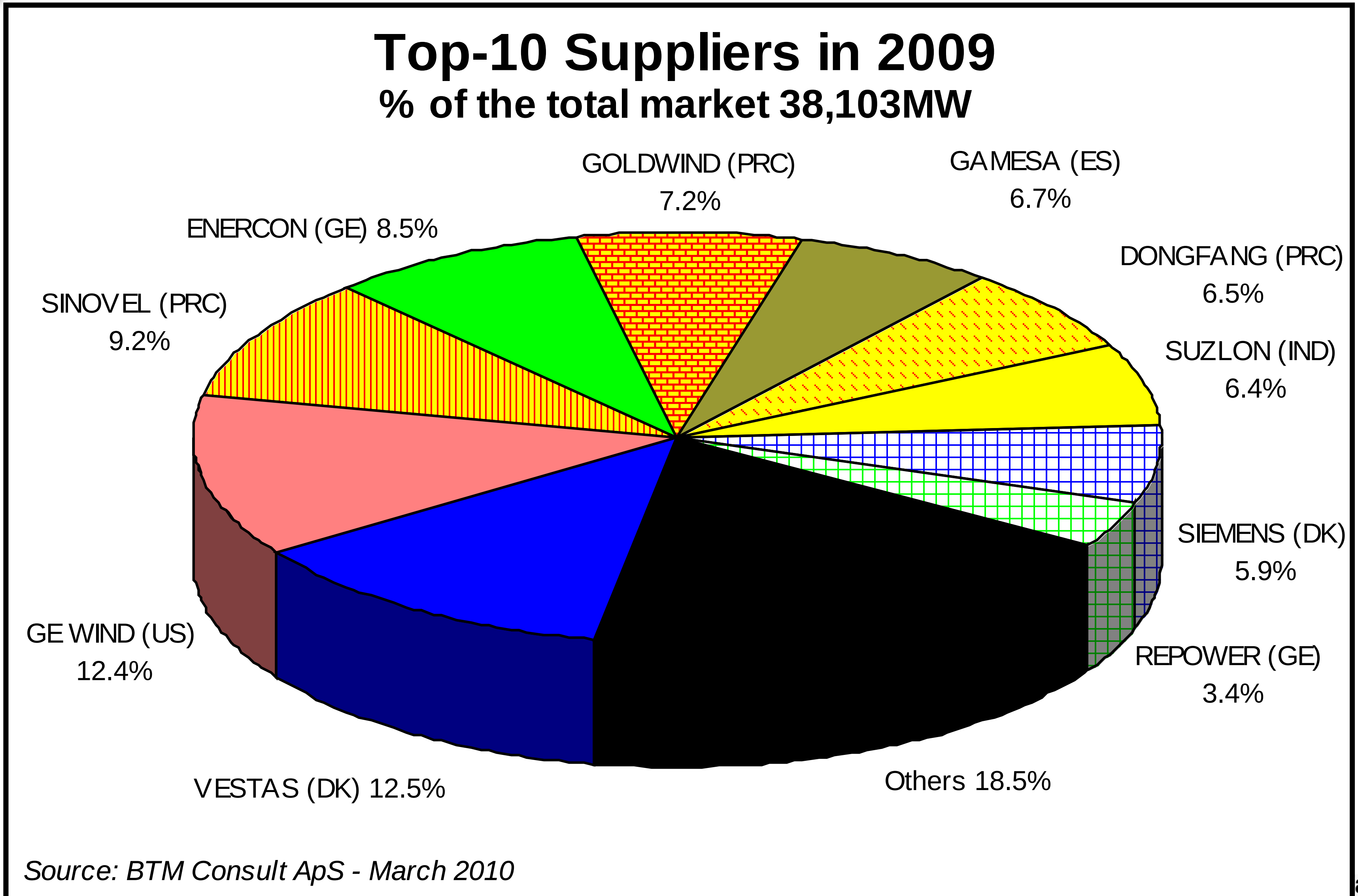
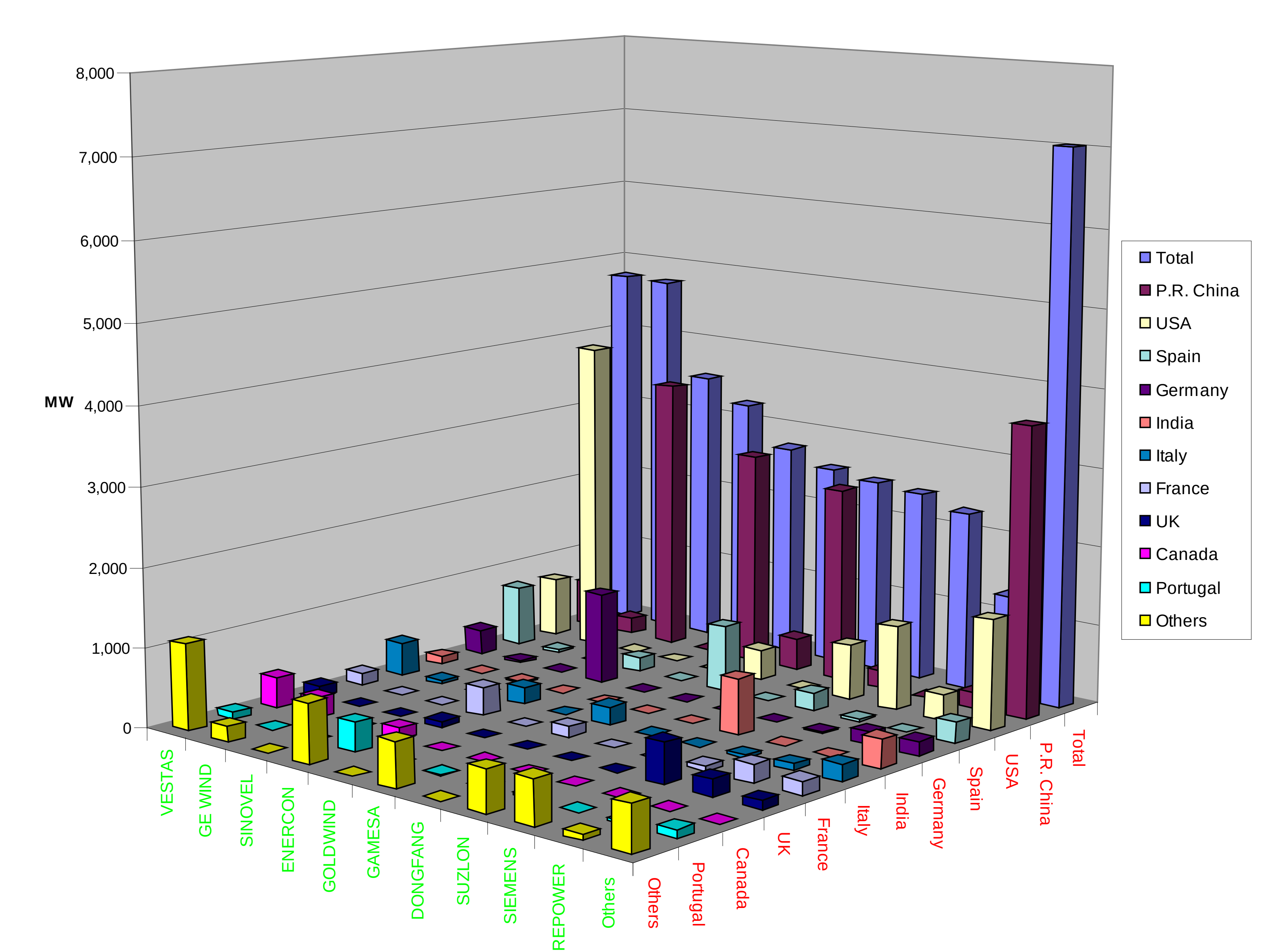
Global Turbine Suppliers



Top Suppliers in Top Markets



Source: BTM Consult ApS - March 2010

Global Market Growth Rate

Year:	Installed MW	Increase %	Cumulative MW	Increase %
2004	8,154		47,912	
2005	11,542	42%	59,399	24%
2006	15,016	30%	74,306	25%
2007	19,791	32%	94,005	27%
2008	28,190	42%	122,158	30%
2009	38,103	35%	160,084	31%
Average growth - 5 years		**36.1%**		**27.3%**

Source: BTM Consult ApS - March 2010

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10 Largest Markets in 2009 (Global)

MW Installed

Country	2007	2008	2009	Share %	Cum. Share %
P.R. China	3,287	6,246	**13,750**	**36.1%**	**36%**
USA	5,244	8,358	**9,922**	**26.0%**	**62%**
Spain	3,100	1,739	**2,331**	**6.1%**	**68%**
Germany	1,667	1,665	**1,917**	**5.0%**	**73%**
India	1,617	1,810	**1,172**	**3.1%**	**76%**
Italy	603	1,010	**1,114**	**2.9%**	**79%**
France	888	1,200	**1,104**	**2.9%**	**82%**
UK	427	869	**1,077**	**2.8%**	**85%**
Canada	386	526	**950**	**2.5%**	**87%**
Portugal	434	679	**645**	**1.7%**	**89%**
Total	**17,653**	**24,102**	**33,982**		
Percent of World	89.2%	85.5%	89.2%		

Source: BTM Consult ApS - March 2010

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10 Largest Markets by end of 2009 (Global)

Cumulative MW Installed

Country	2007	2008	2009	Share %	Cum. Share %
USA	16,879	25,237	**35,159**	**22.0%**	**22%**
P.R. China	5,875	12,121	**25,853**	**16.1%**	**38%**
Germany	22,277	23,933	**25,813**	**16.1%**	**54%**
Spain	14,714	16,453	**18,784**	**11.7%**	**66%**
India	7,845	9,655	**10,827**	**6.8%**	**73%**
Italy	2,721	3,731	**4,845**	**3.0%**	**76%**
France	2,471	3,671	**4,775**	**3.0%**	**79%**
UK	2,394	3,263	**4,340**	**2.7%**	**81%**
Portugal	2,150	2,829	**3,474**	**2.2%**	**84%**
Denmark	3,088	3,159	**3,408**	**2.1%**	**86%**
Total	**80,415**	**104,051**	**137,277**		
Percent of World	85.5%	85.2%	85.8%		

Source: BTM Consult ApS - March 2010

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Growth Rates in Top 10 Markets

Cumulative MW Installed

Country	Accu. end 2006	Accu. end 2007	Accu. end 2008	Accu. end 2009	Growth rate 2008-2009 %	3 years average %
USA	11,635	16,879	25,237	35,159	**39.3%**	44.6%
P.R. China	2,588	5,875	12,121	25,853	**113.3%**	115.4%
Germany	20,652	22,277	23,933	25,813	**7.9%**	7.7%
Spain	11,614	14,714	16,453	18,784	**14.2%**	17.4%
India	6,228	7,845	9,655	10,827	**12.1%**	20.2%
Italy	2,118	2,721	3,731	4,845	**29.9%**	31.8%
France	1,585	2,471	3,671	4,775	**30.1%**	44.4%
UK	1,967	2,394	3,263	4,340	**33.0%**	30.2%
Portugal	1,716	2,150	2,829	3,474	**22.8%**	26.5%
Denmark	3,101	3,088	3,159	3,408	**7.9%**	3.2%
Total "Ten"	**63,203**	**80,415**	**104,051**	**137,277**	**31.9%**	**29.5%**

Source: BTM Consult ApS - March 2010

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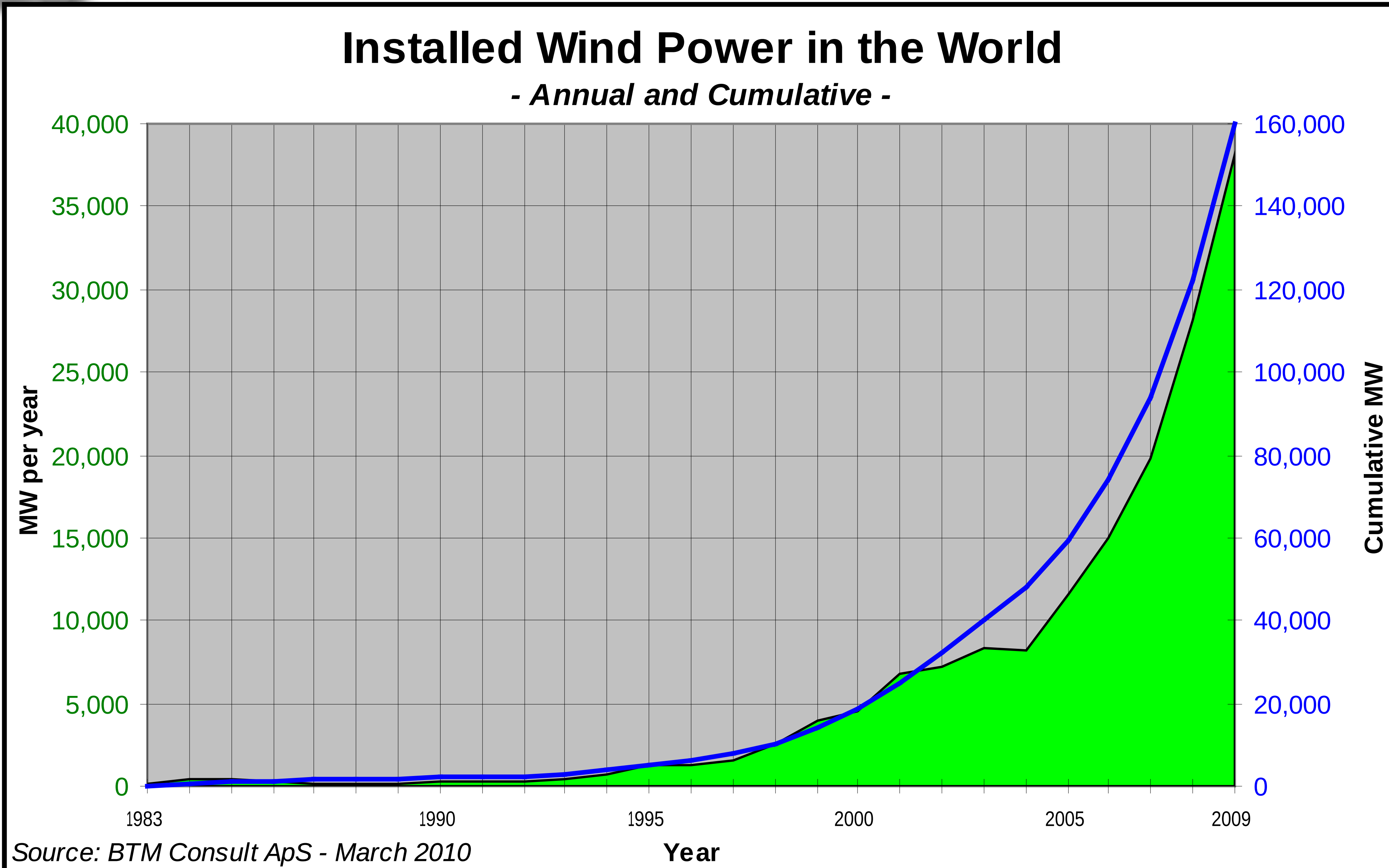
Global Capacity



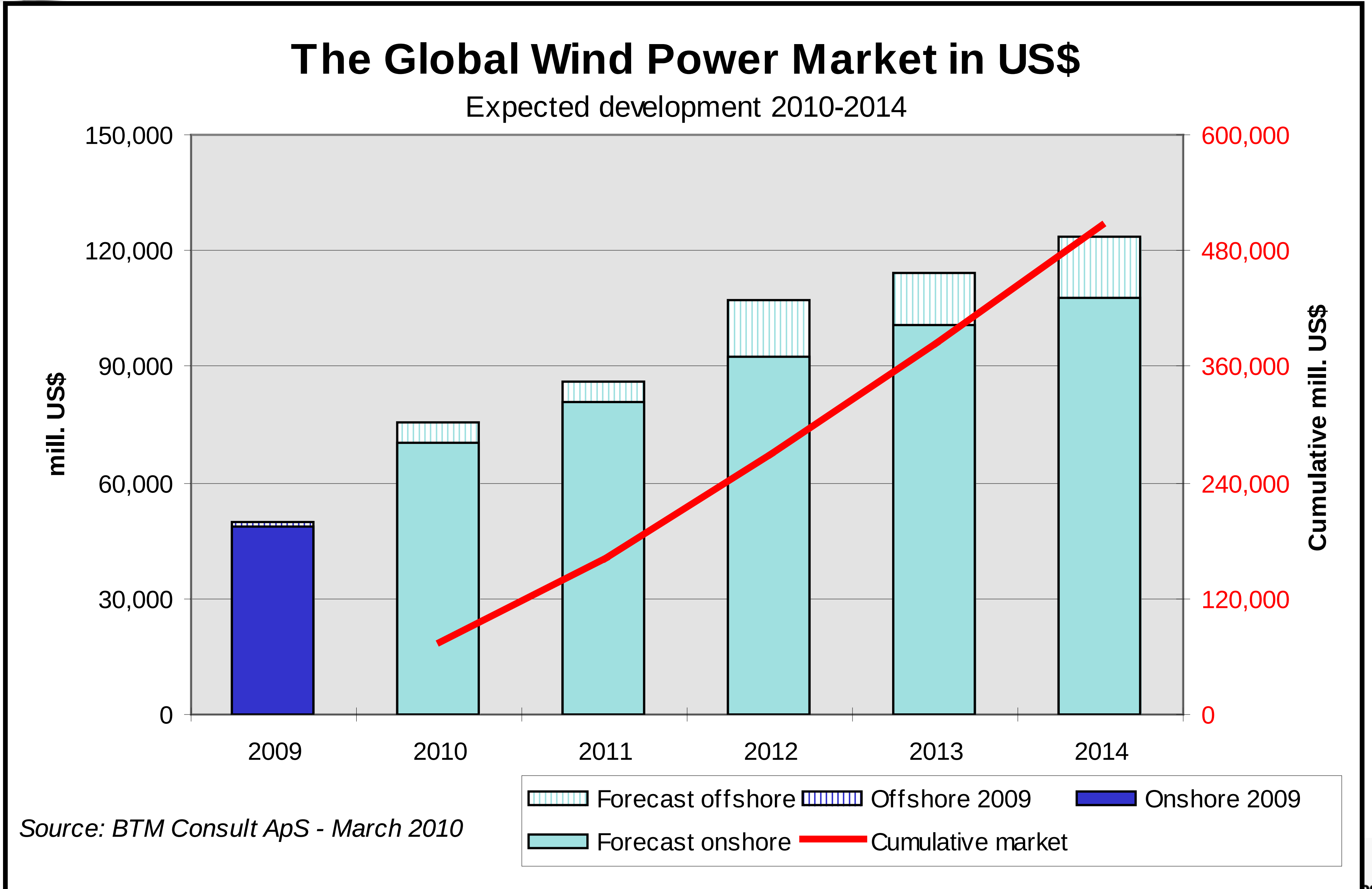
Laboratories

Share of Power Generation

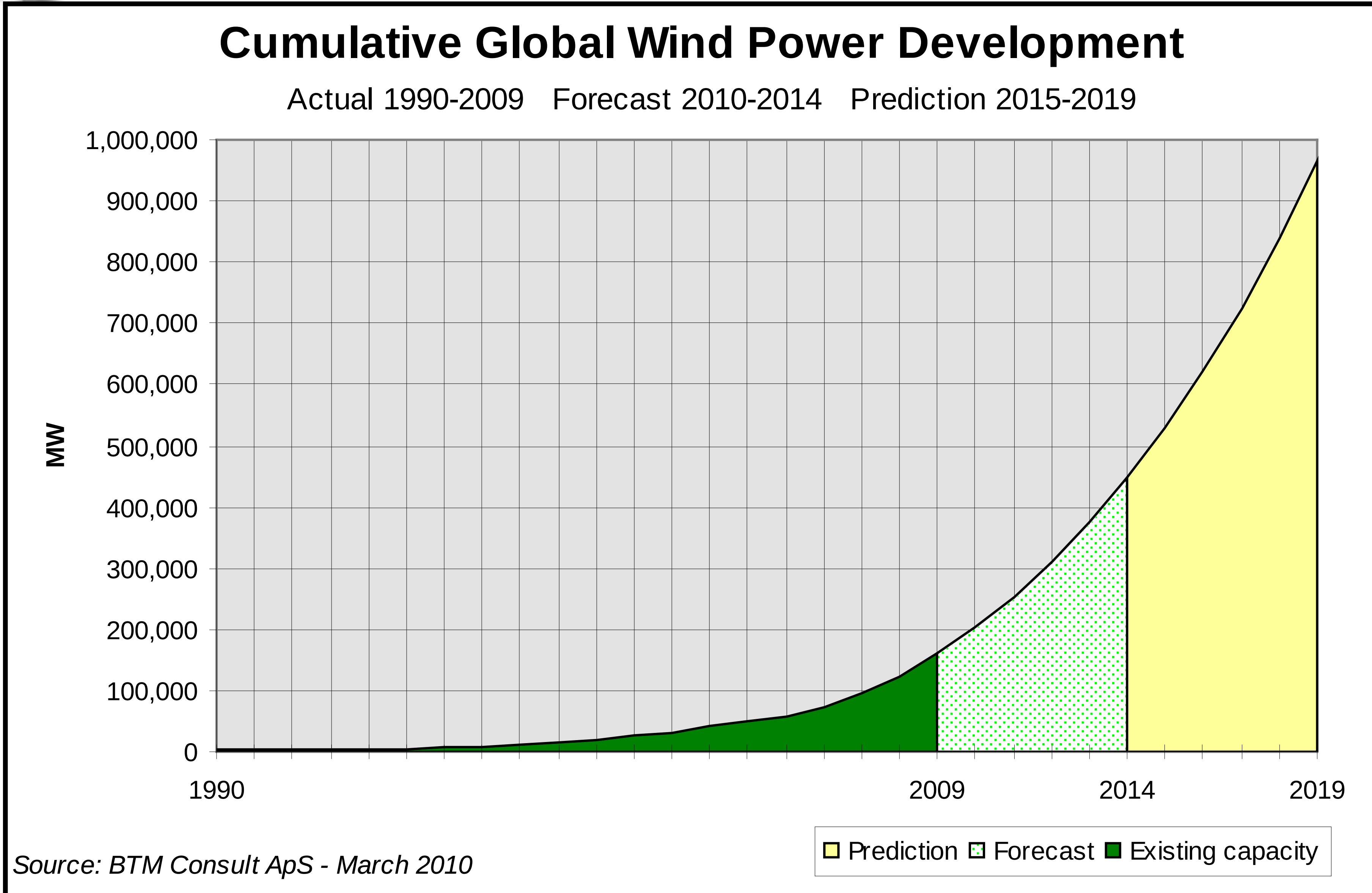
Generation Technology Year:	Electricity gen. by Wind Power (BTM-C) TWh	Electricity from all gen. sources (incl. Wind) IEA TWh	Wind Power's share of the world's electricity generation: %
1996	12.23	13,613	0.09%
1997	15.39	13,949	0.11%
1998	21.25	14,340	0.15%
1999	23.18	14,741	0.16%
2000	37.30	15,153	0.25%
2001	50.27	15,577	0.32%
2002	64.81	16,233	0.40%
2003	82.24	16,671	0.49%
2004	96.50	17,408	0.55%
2005	120.72	17,982	0.67%
2006	152.35	18,576	0.82%
2007	194.16	19,756	1.01%
2008	254.13	20,230	1.30%
2009	**331.91**	**20,716**	**1.60%**
2014 (forecast)	941.2	23,324	4.04%
2019 (est.)	2,200.9	26,247	8.39%

Source: BTM Consult ApS - March 2010 ; World Figures: IEA World Energy Outlook 2009

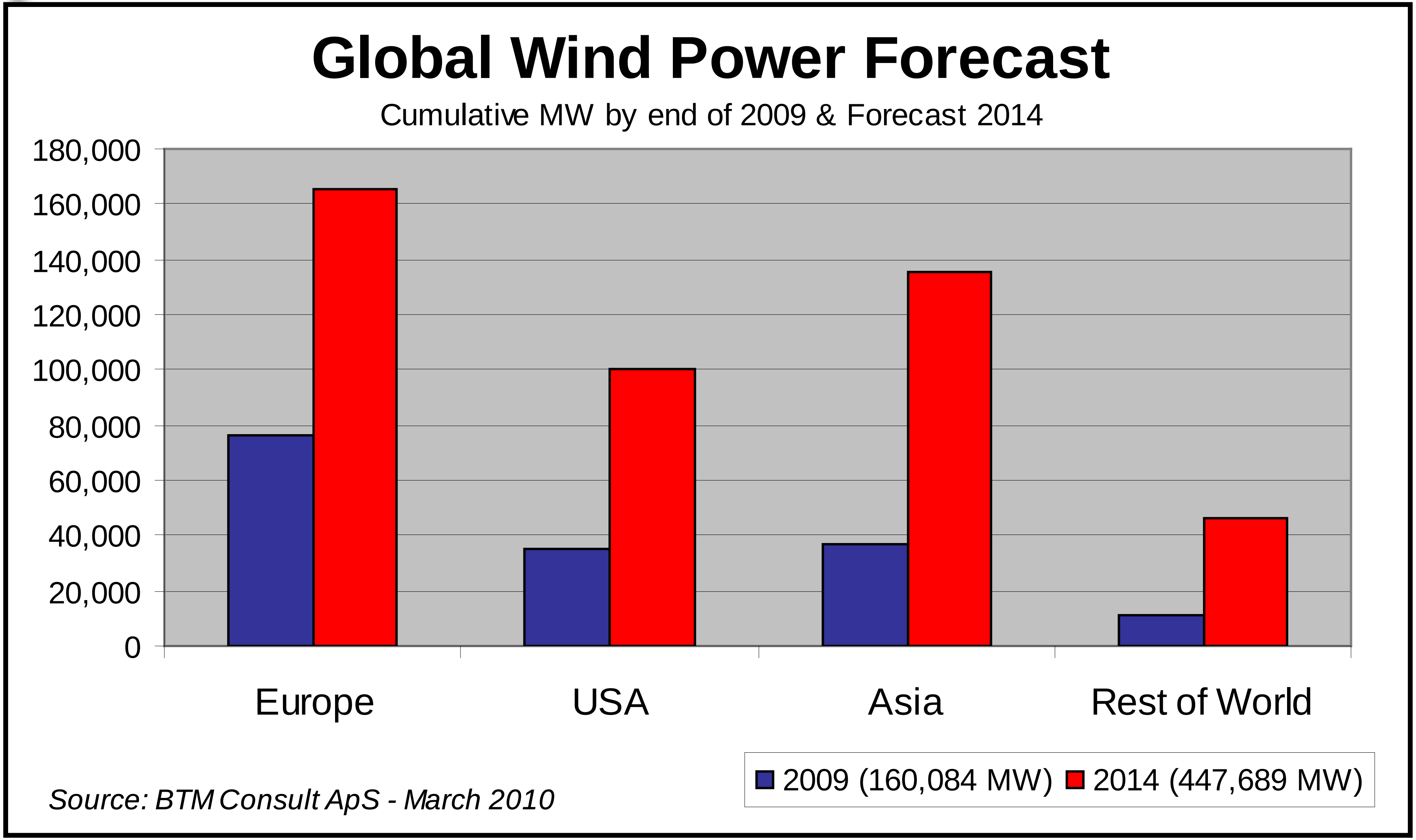
2013 Forecast ($)



2018 Prediction



Regional Forecasts



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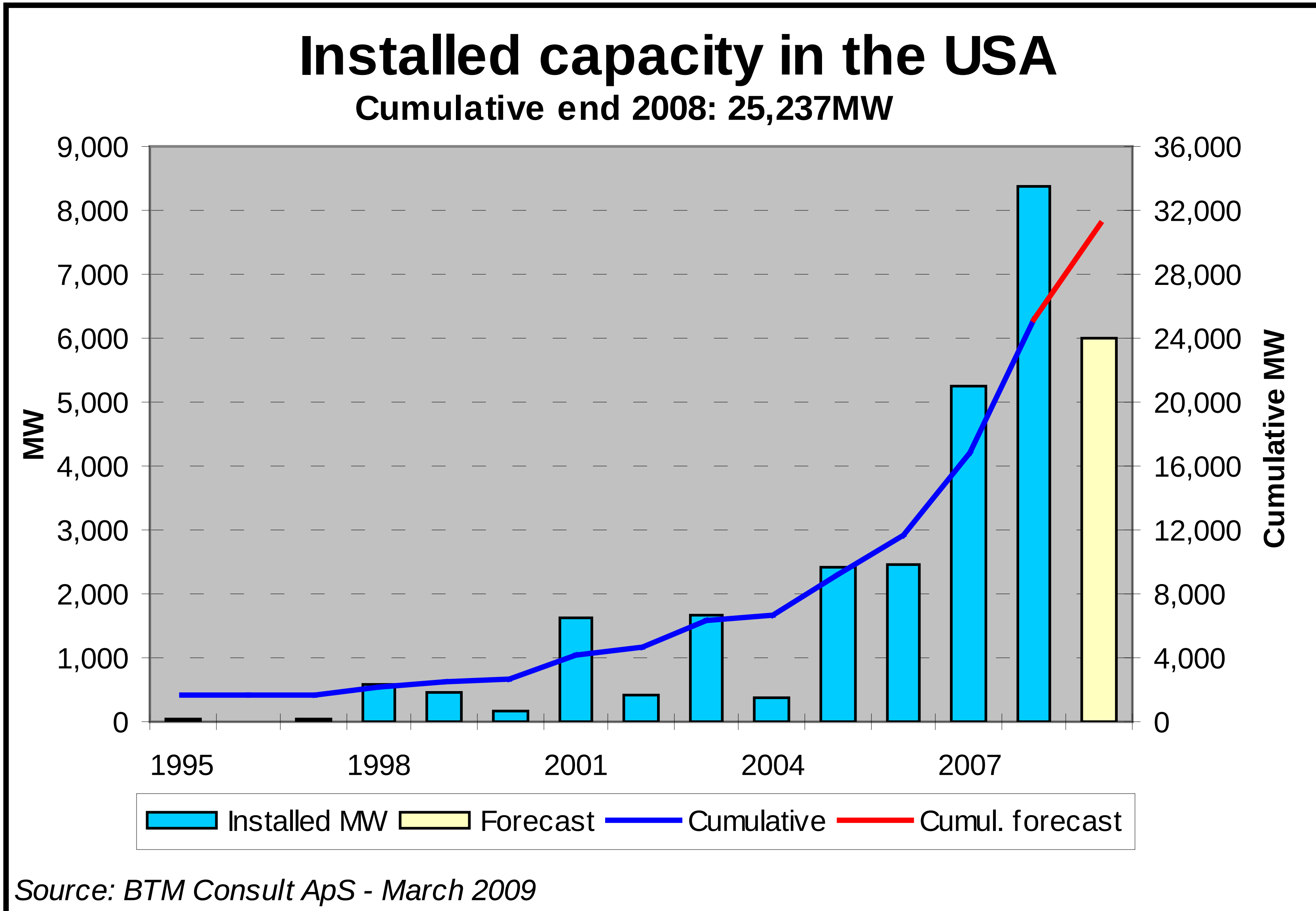
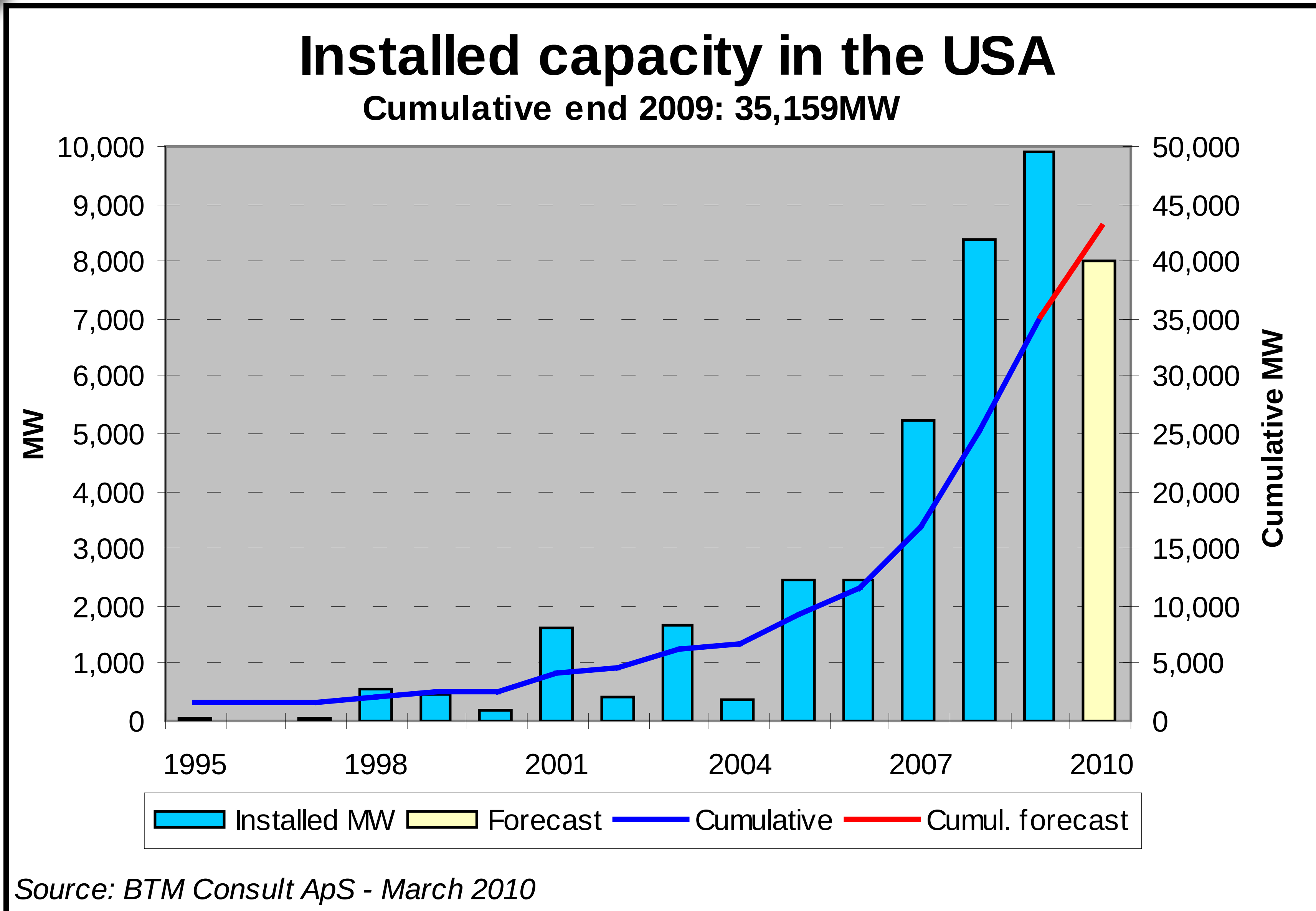
U.S. Wind Industry

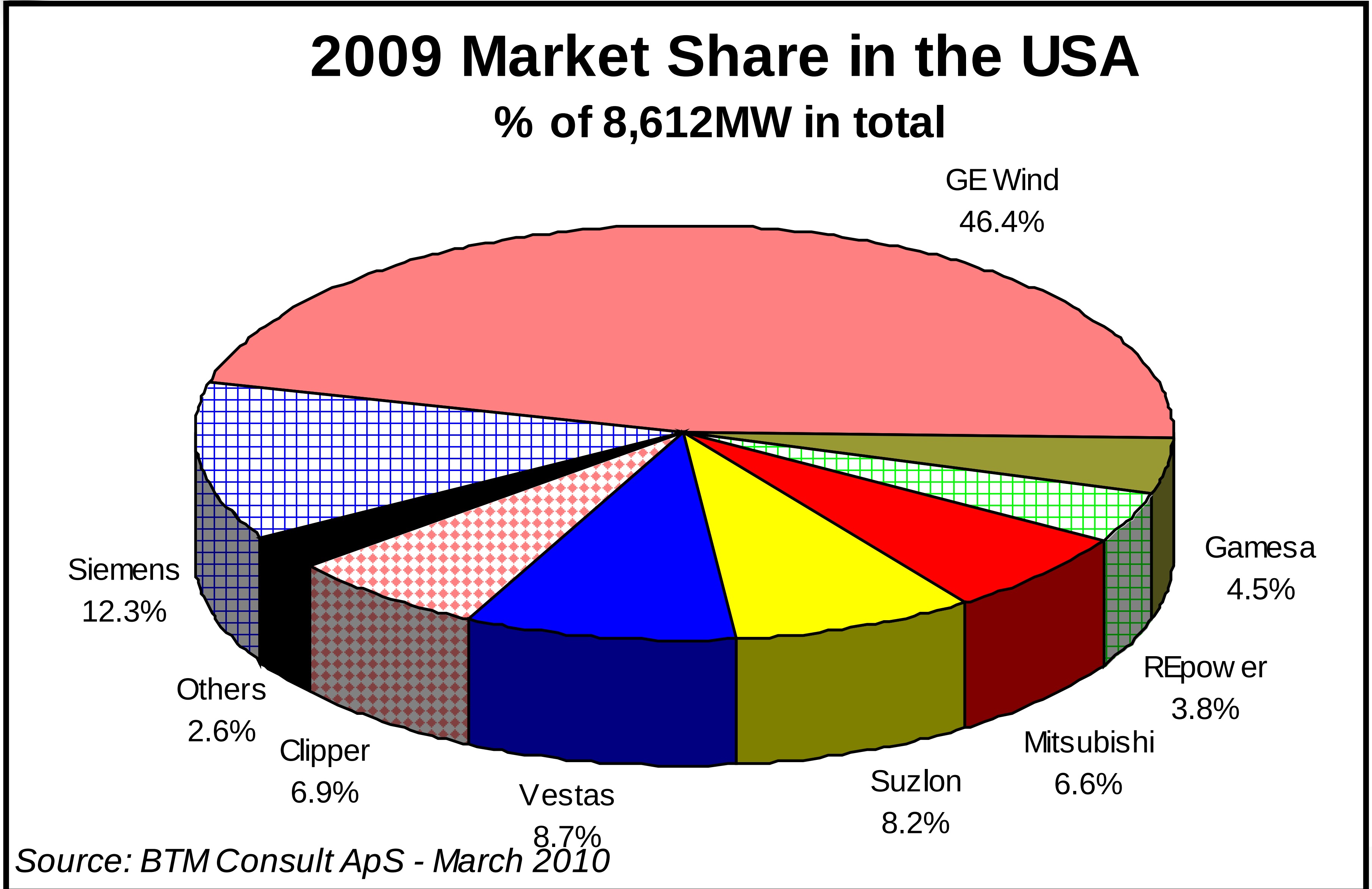
Current U.S. Status (one year ago)



Current U.S. Status



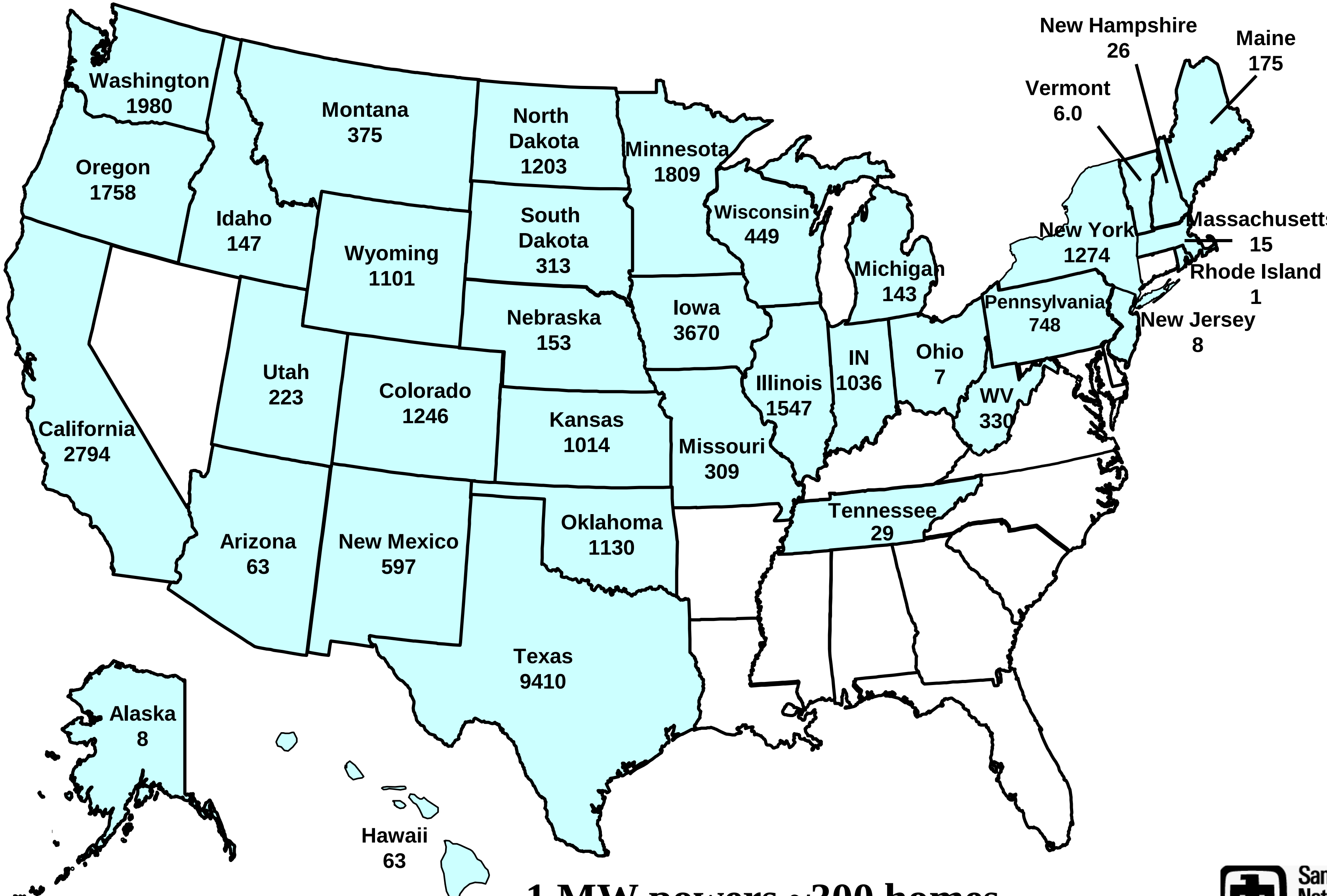
Current U.S. Status



Source: BTM Consult ApS - March 2010

U.S. Installed Wind Capacity

(MW as of December 31, 2009)



1 MW powers ~300 homes

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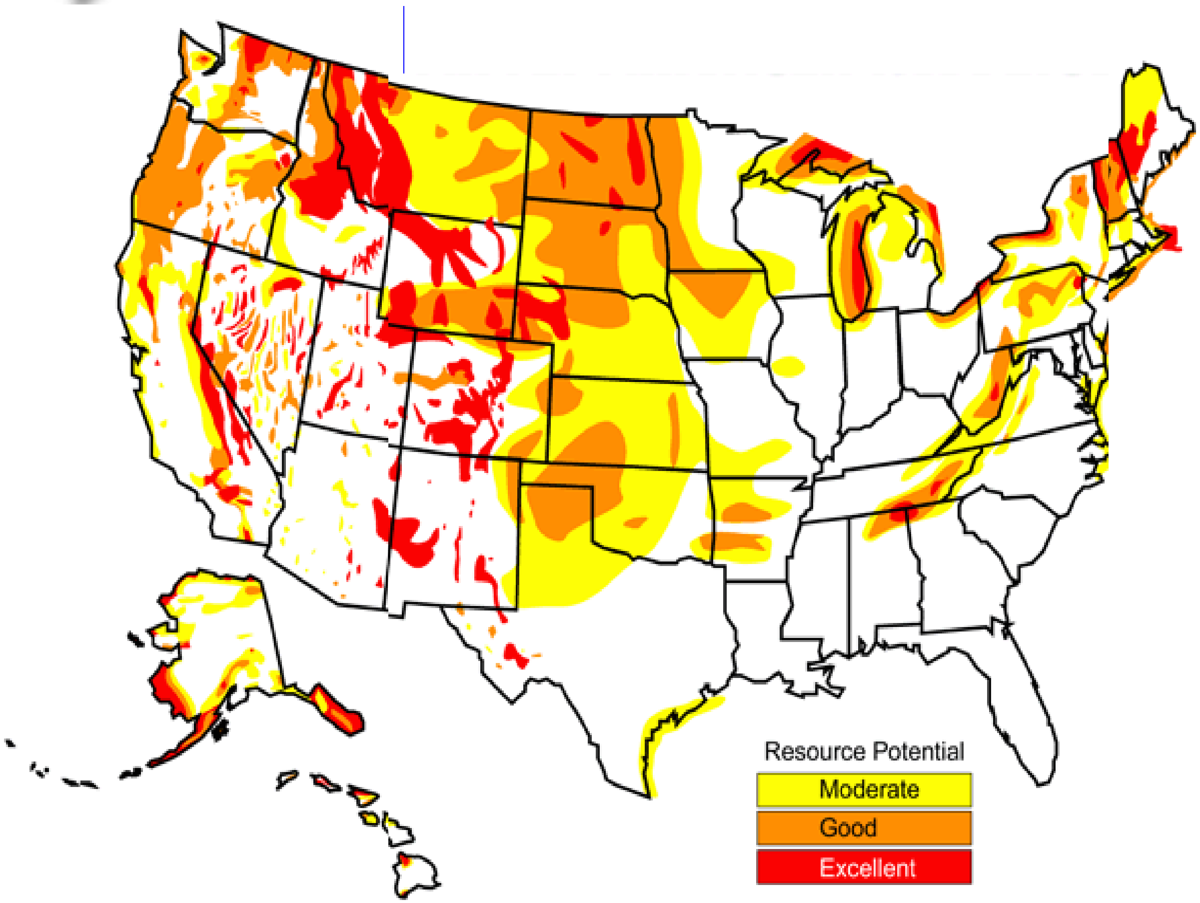
Wind Resource

Land-based



Rank	State	Potential (billion kWh)
1	North Dakota	1210
2	Texas	1190
3	Kansas	1070
4	South Dakota	1030
5	Montana	1020
6	Nebraska	868
7	Wyoming	747
8	Oklahoma	725
9	Minnesota	657
10	Iowa	551
11	Colorado	481
12	New Mexico	435
13	Idaho	73
14	Michigan	65
15	New York	62
16	Illinois	61
17	California	59
	Total U.S. demand (2006)	3800

Germany's On-Land Potential ≈ 100 GW

North Dakota's Potential > 400 GW

source: AWEA, EIA

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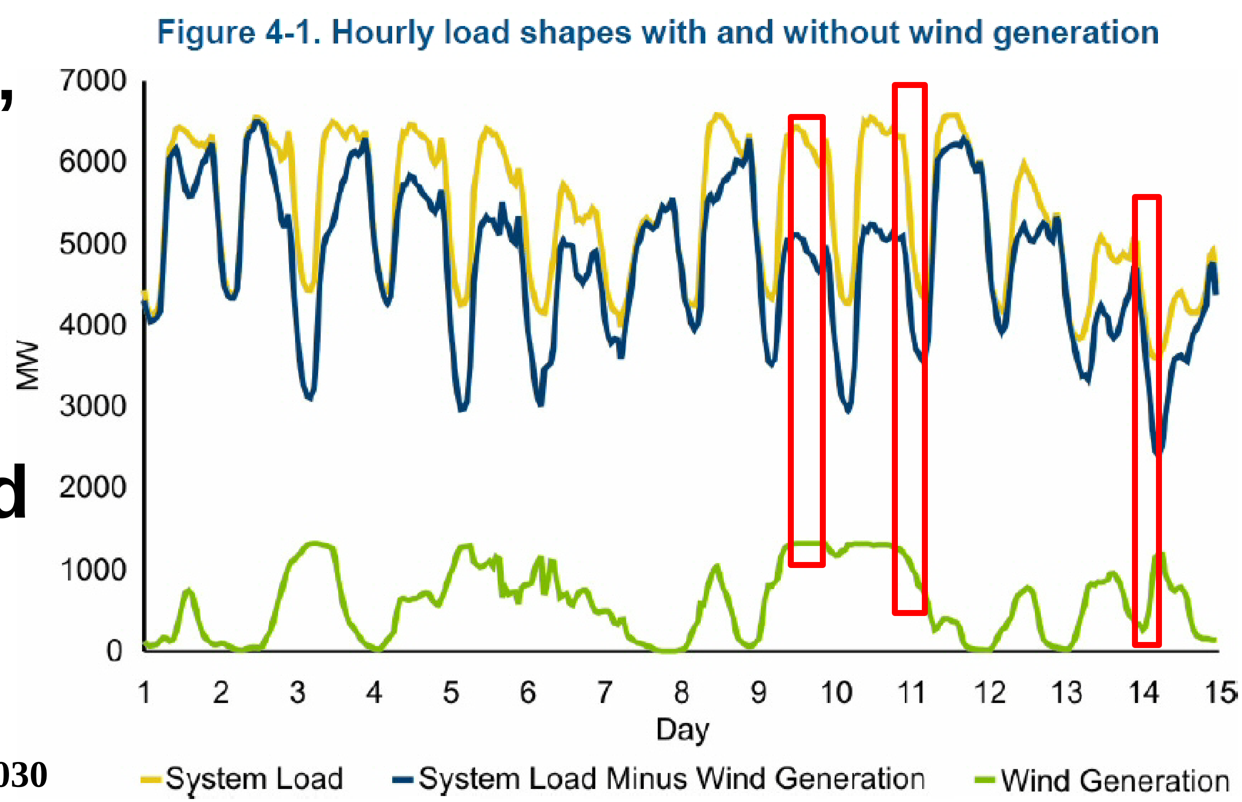
Problems and “Problems”

Production Fluctuates

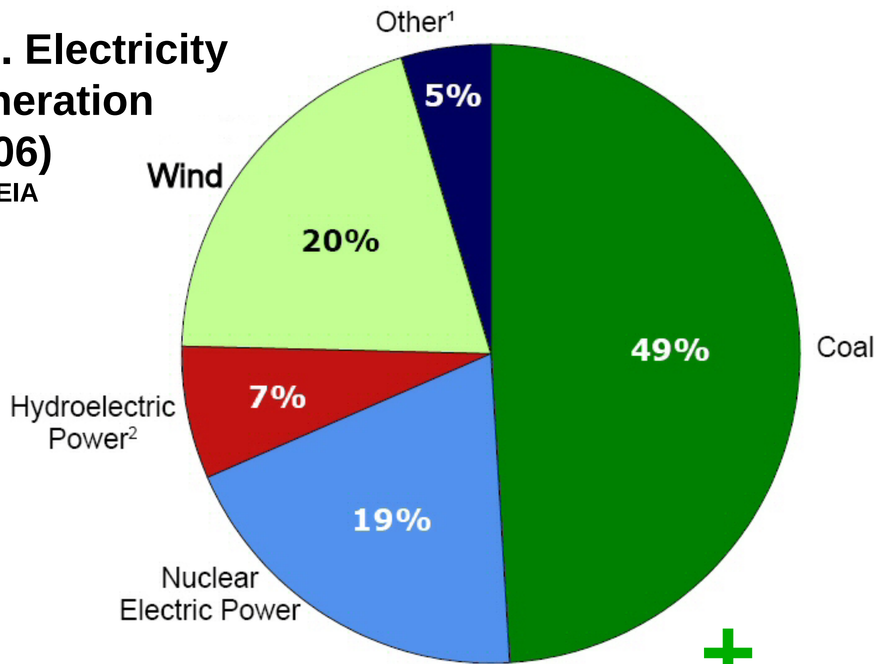
- Load fluctuates significantly
- Even an all-fossil power system must ramp up and down to follow the load
- Wind is a "negative load"
- Effects ramp rates
- Day ahead wind forecasting helps

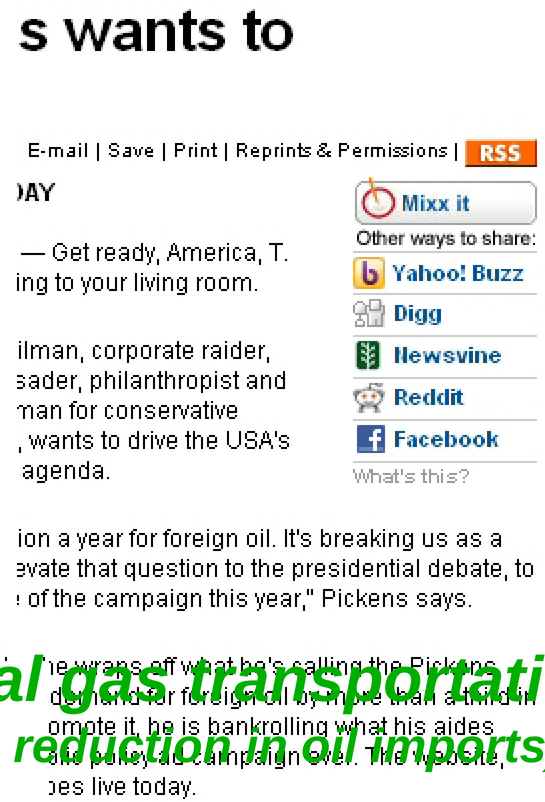


EIA: 20% Wind Energy by 2030

Pickens Plan

U.S. Electricity Generation (2006)
DOE/EIA




s wants to

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)AY

Mixx it
Other ways to share:
Yahoo! Buzz
Digg
Newsvine
Reddit
Facebook
What's this?

— Get ready, America, T.
ing to your living room.

ilman, corporate raider,
sader, philanthropist and
nan for conservative
, wants to drive the USA's
agenda.

ion a year for foreign oil. It's breaking us as a
evate that question to the presidential debate, to
of the campaign this year," Pickens says.

Financier T. Boone Pickens in Sweetwater, Texas, with wind turbines in the

8 July 2008

+

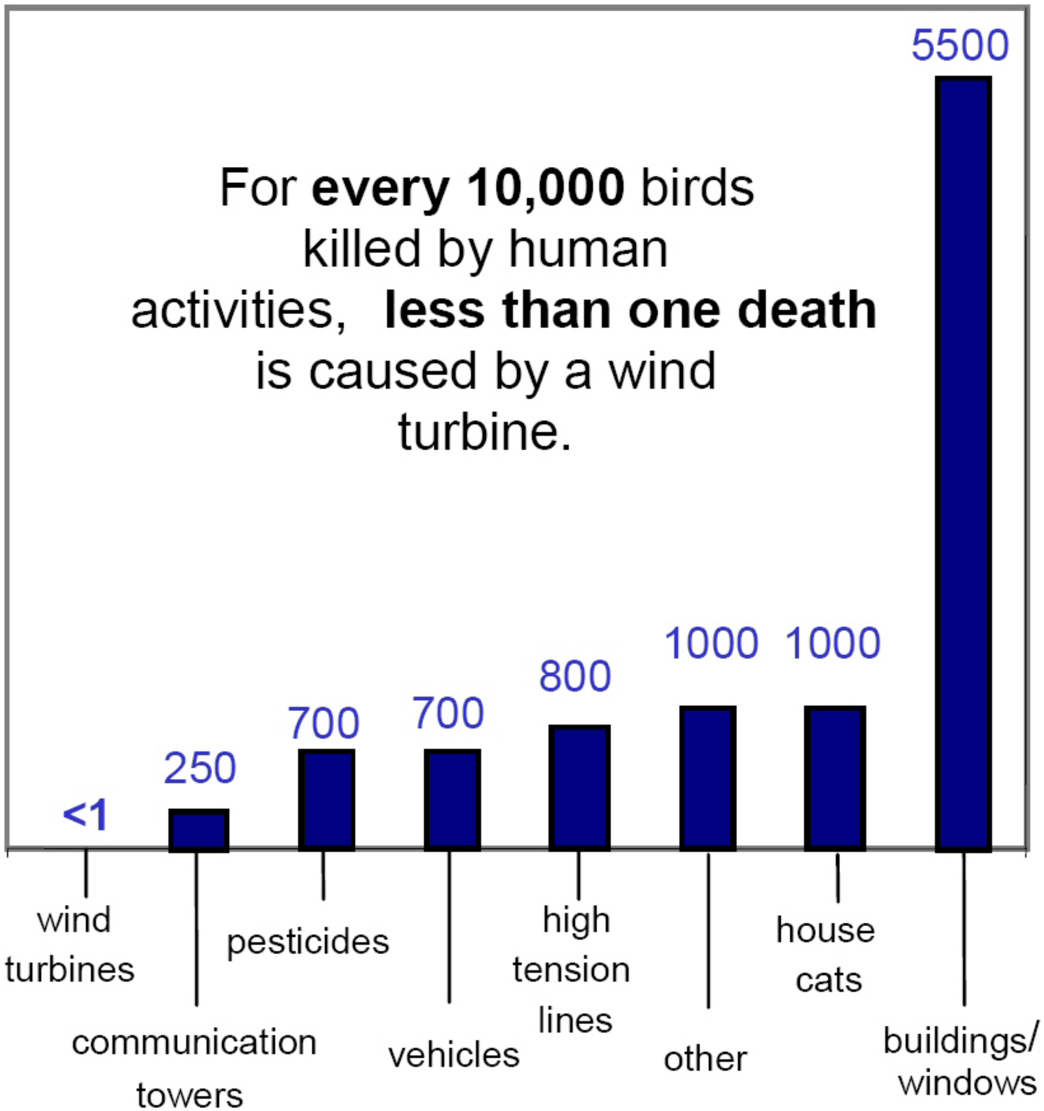
natural gas transportation

(38% reduction in oil imports)

Bird Collisions

- Problem documented in Altamont Pass
  - One of nation's largest concentrations of federally-protected raptors
  - Abundant prey base (migration path)
  - Heavy year-round raptor use

Bird Mortality



Erickson et al., 2002, Summary of Anthropogenic Causes of Bird Mortality

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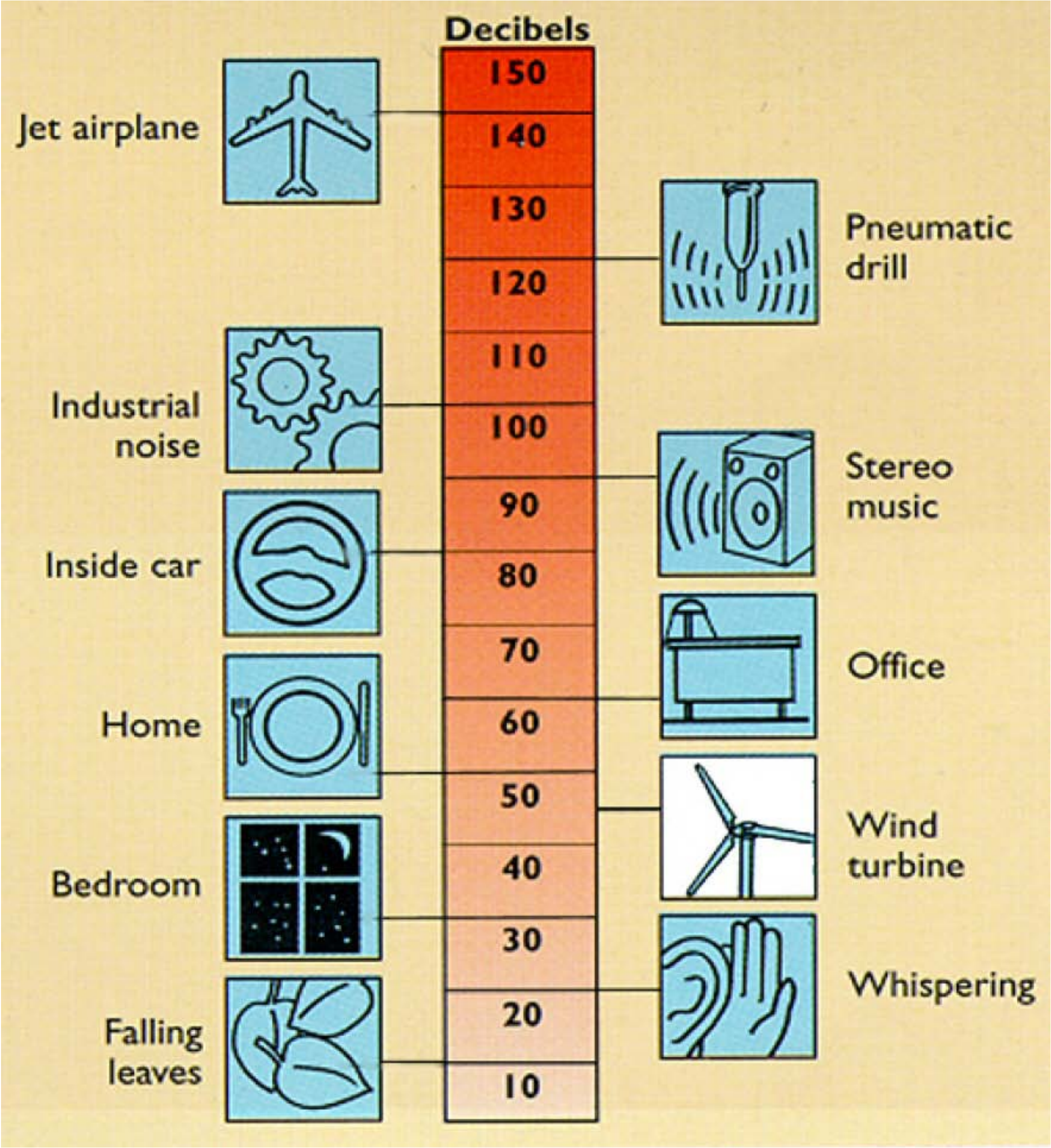
Noise



AWEA

Mod 1
Boone, NC

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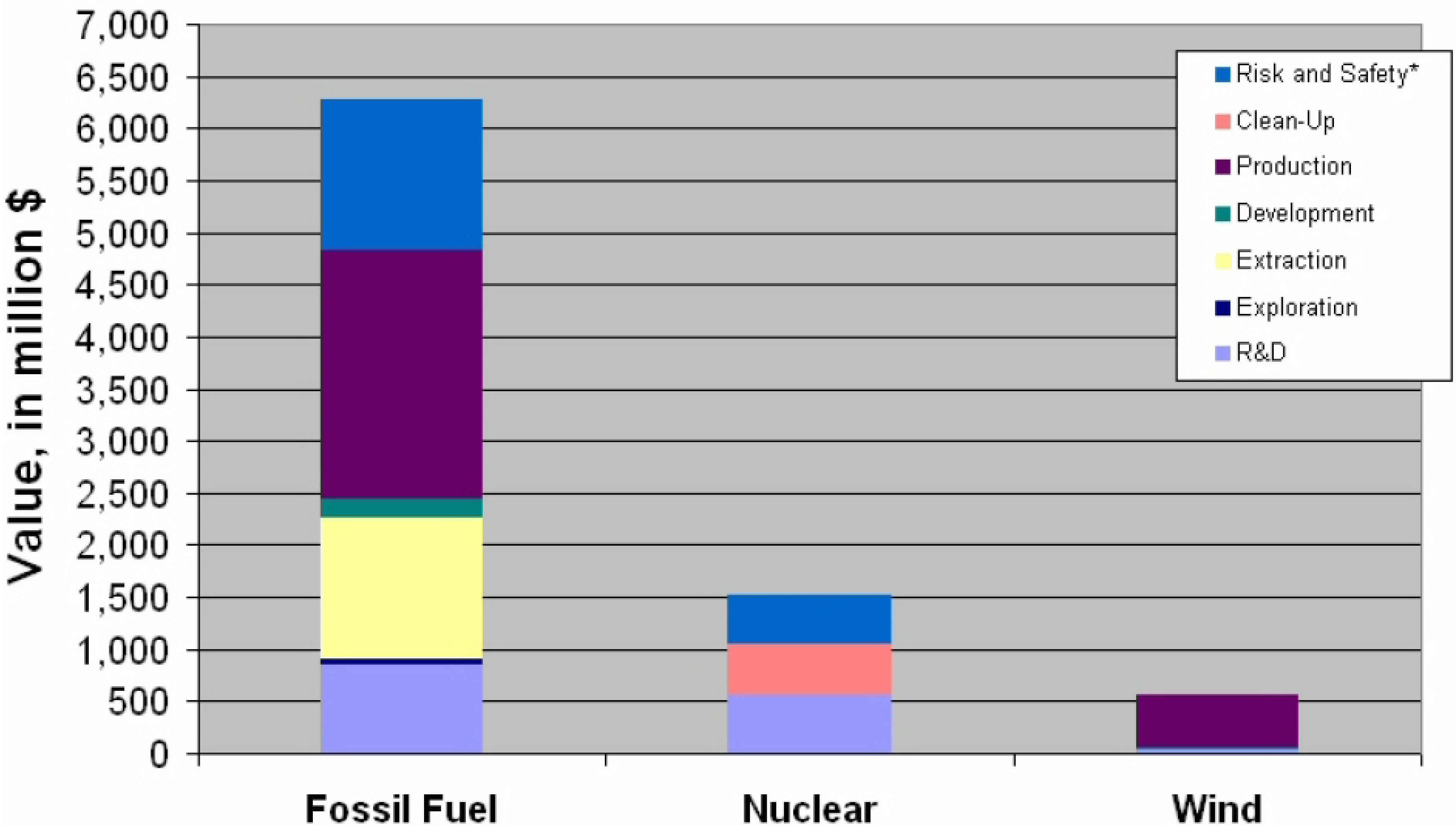
U.S. Federal Energy Subsidies (2006)



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Benefits of Wind Power

- **Economic Development**
  - **lease payments, tax revenue**
- **Cost Stability**
- **Resource Diversity**
  - **domestic, inexhaustible, reduced risk**
- **Environmental**
  - **no CO_2, SO_2, NO_x, mercury**
  - **no mining or drilling**
  - **no waste**
  - **no water use**

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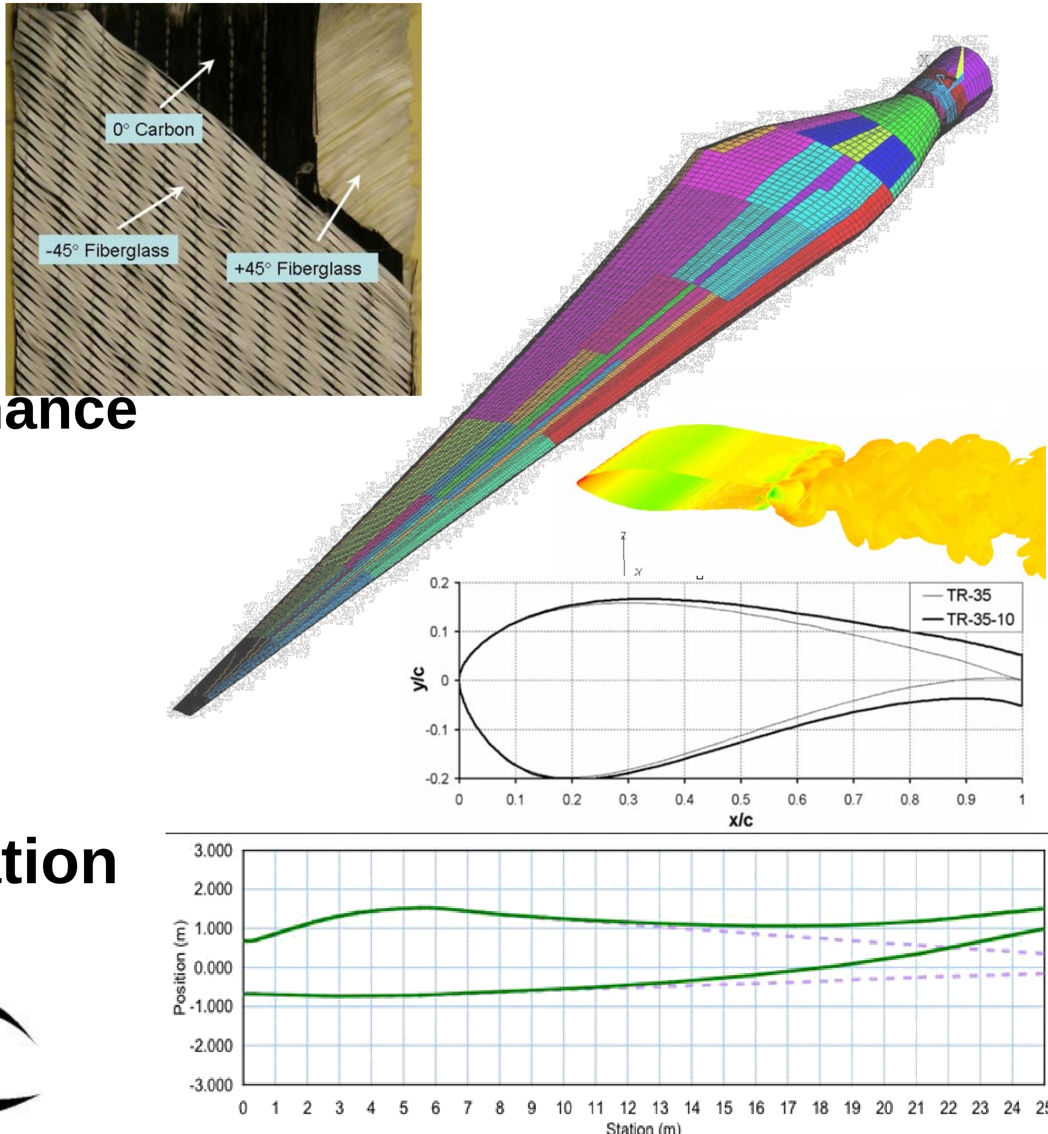
U.S. Wind Research

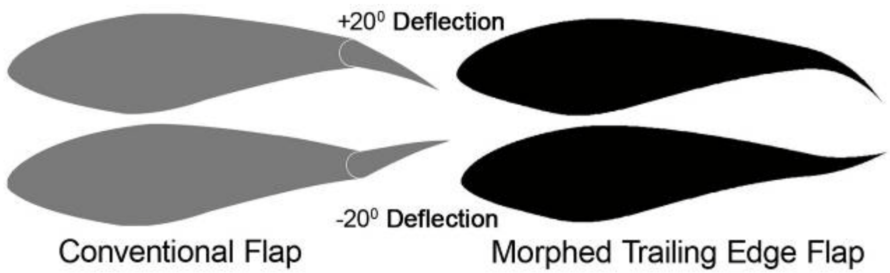
Wind Energy Research in U.S.

- Federal
  - Sandia National Laboratories (SNL)
  - National Renewable Energy Laboratory (NREL)
- University
  - UC-Davis
  - Montana State University (Bozeman)
  - University of Texas (Austin)
  - University of Massachusetts (Amherst)
  - Others
- Industry
  - General Electric
  - Clipper Windpower

Sandia's Efforts in Wind Energy

- **Blades**
  - materials
  - manufacturing
  - structural analysis
  - aerodynamic performance
  - aeroacoustics
  - sensors
  - field testing
- **Reliability**
- **Power System Integration**





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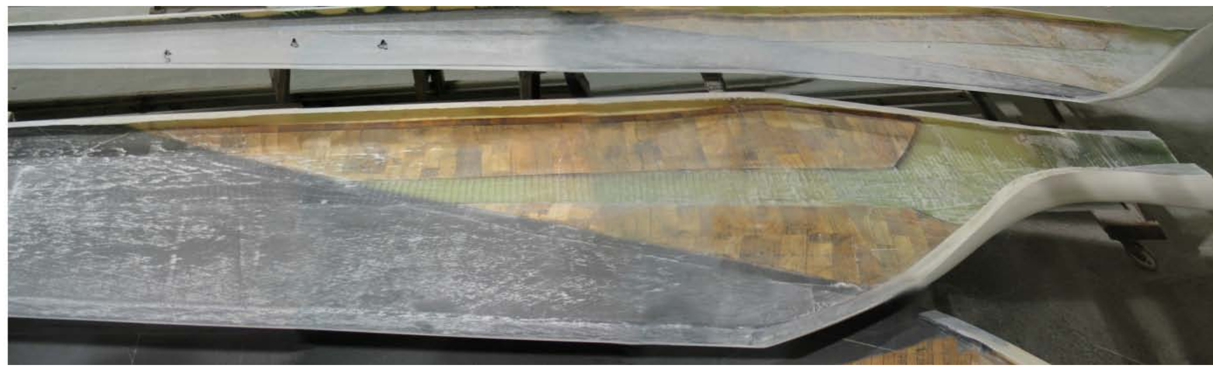
9m Carbon-Glass Subscale Blades

- CX-100
  - carbon spar, glass skins & web, balsa core
  - constant thickness spar cap



- TX-100
  - constant thickness glass spar
  - carbon fibers in skin @ 20º, glass spar cap, balsa core
- BSDS
  - flatback airfoils
  - constant thickness carbon spar cap
  - glass skins & web

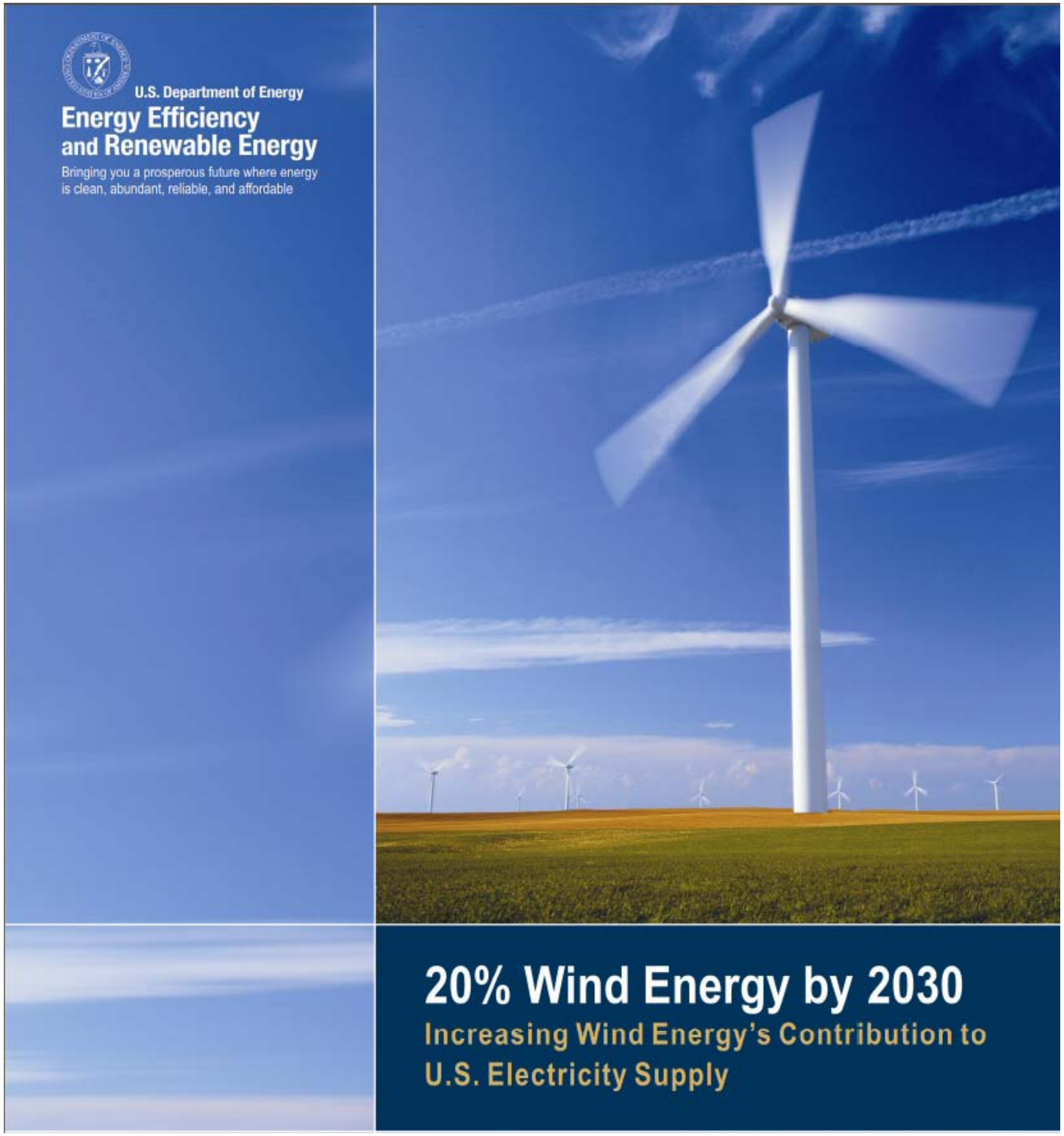
Subscale Blades

Property	SERI 8	ERS-100	CX-100	TX-100	BSDS
Weight (lb)	750*	426	383	361	289
% of Design Load at Failure		110%	105%	197%	310%
Root Failure Moment (kN-m)		122.8	117.0	121.4	203.9
Max. Carbon Tensile Strain at Failure(%)	NA	NA	0.31%	0.59%	0.73%
Max. Carbon Compressive Strain at Failure(%)	NA	NA	0.30%	0.73%	0.87%
Maximum Tip Displacement (m)		1.43	1.05	1.80	2.79

* includes tip brake weight

20% Wind Energy

U.S. DOE Report, May 2008



Addresses Scalability

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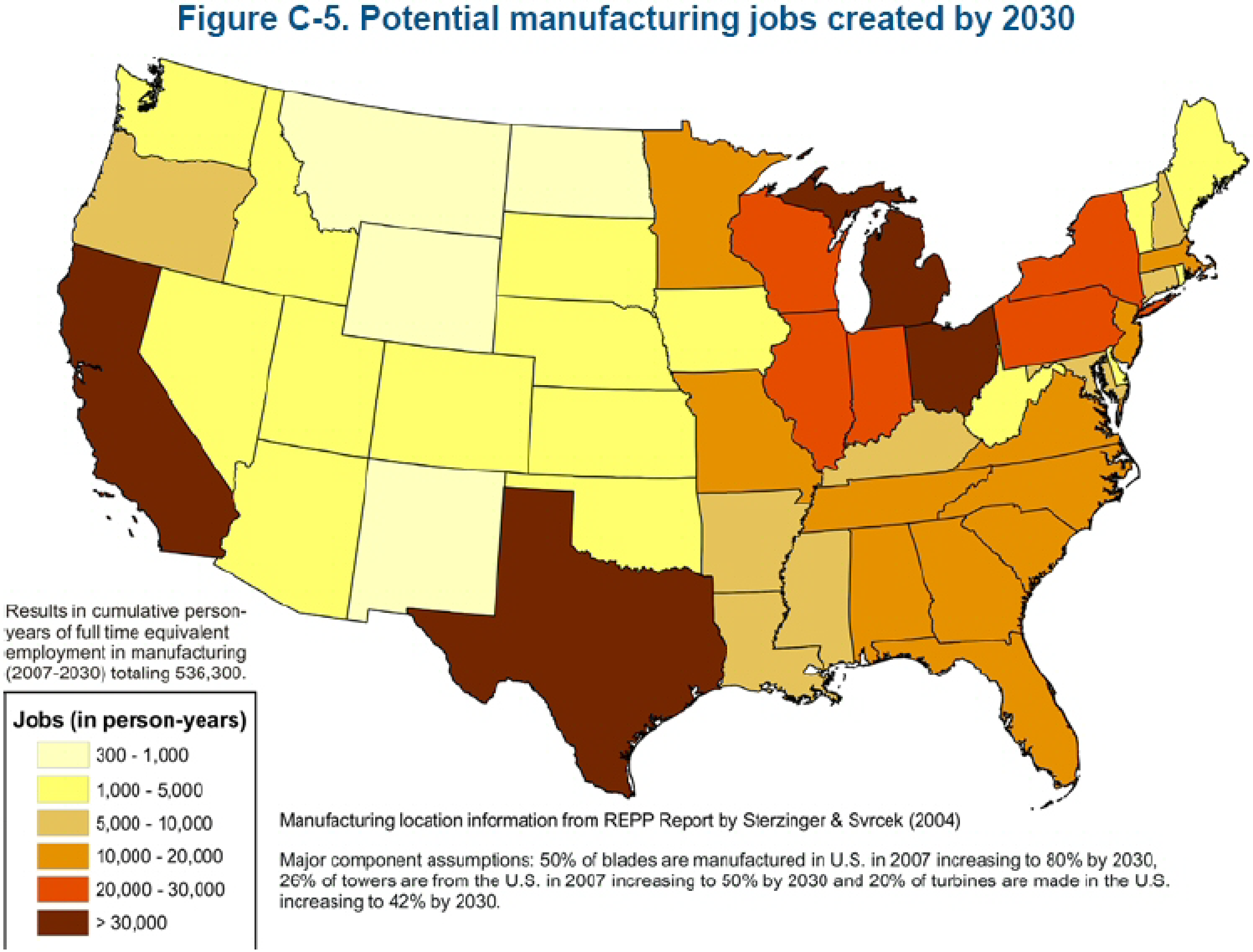
Manufacturing Jobs Growth



EIA: 20% Wind Energy by 2030

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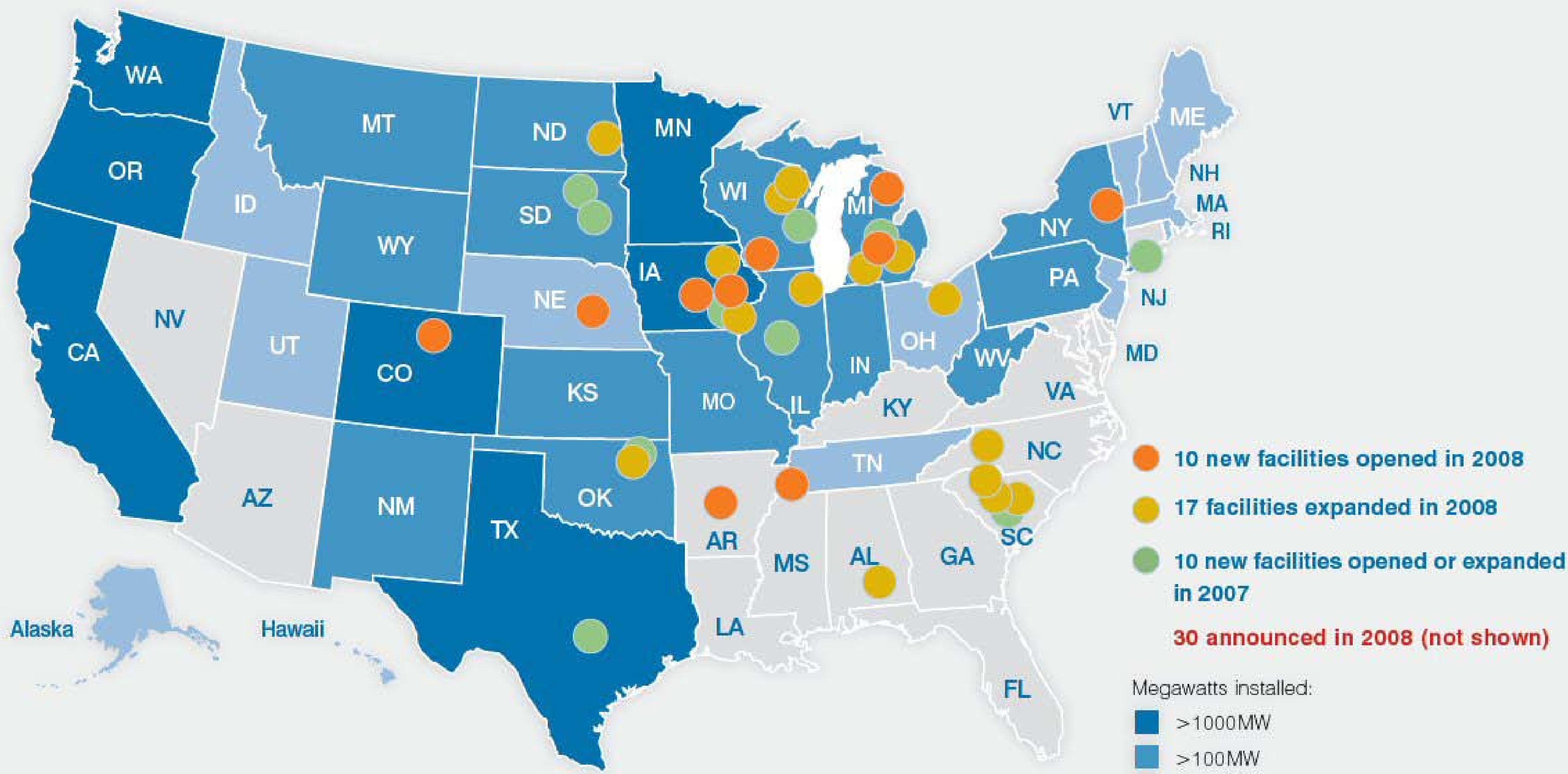
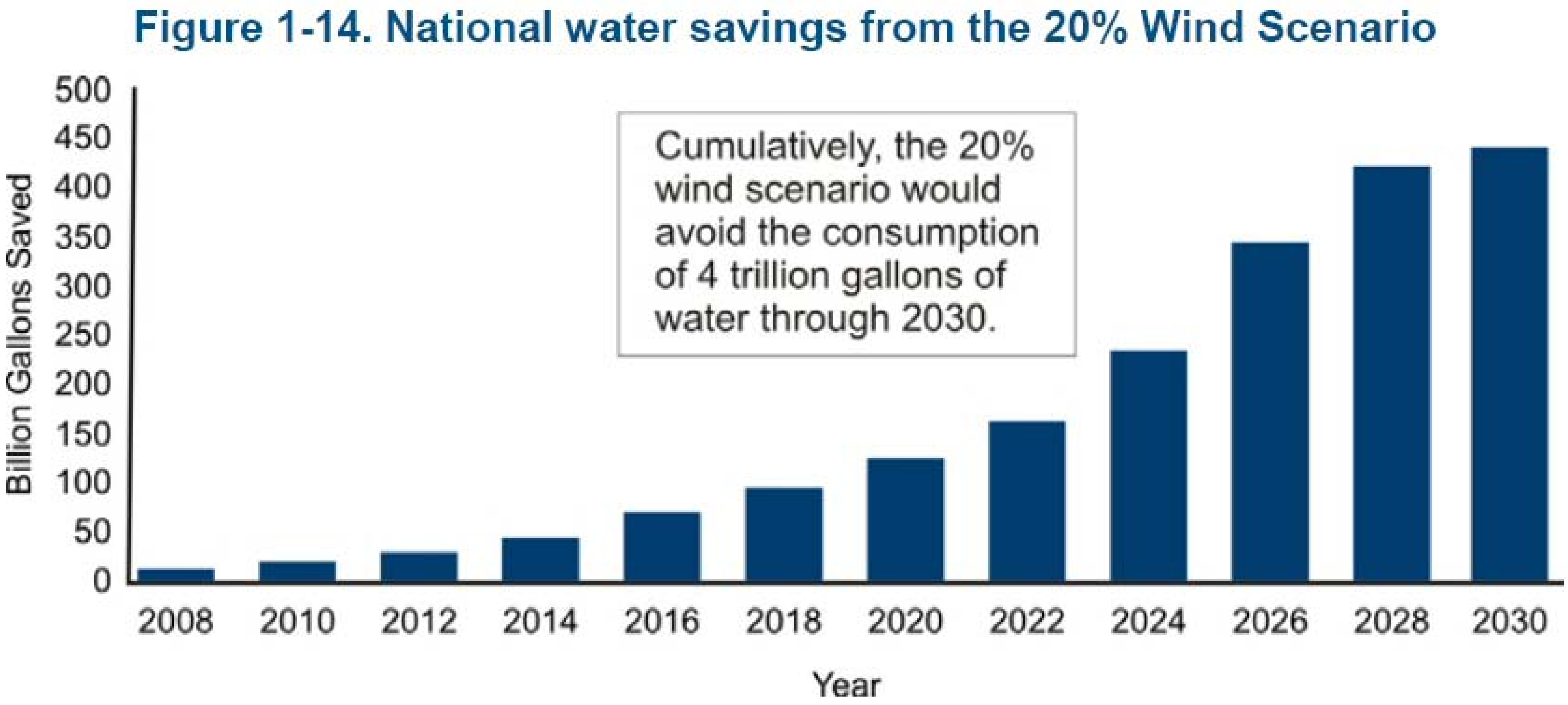
Manufacturing Jobs Growth
new manufacturing

Utility-Scale Wind Turbine Manufacturing: Investment in New Plants



Source: AWEA

Significant Water Savings



EIA: 20% Wind Energy by 2030

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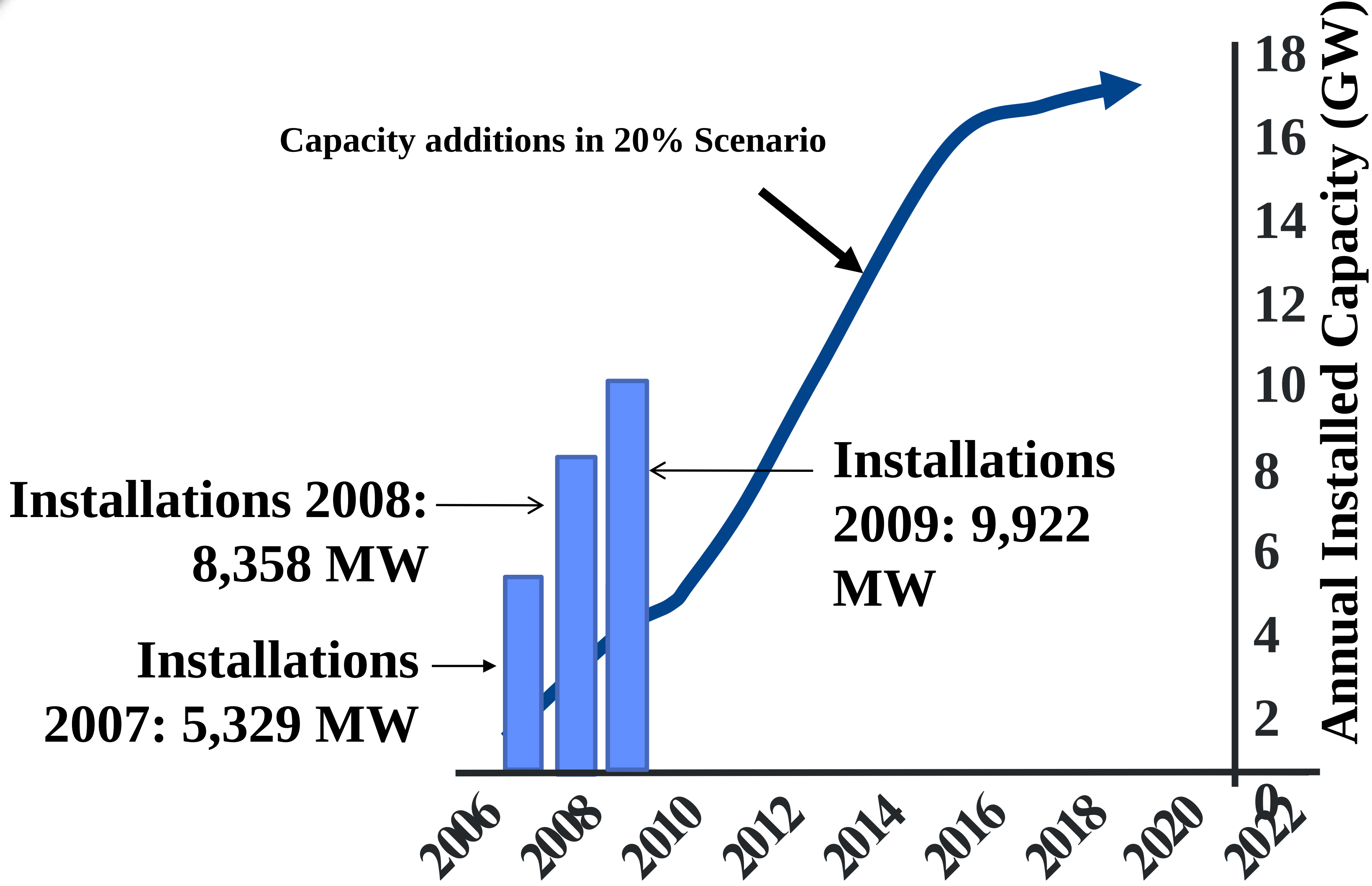
Scenario Installed Capacity vs. Current Installed Capacity



Source*: AWEA, 2010

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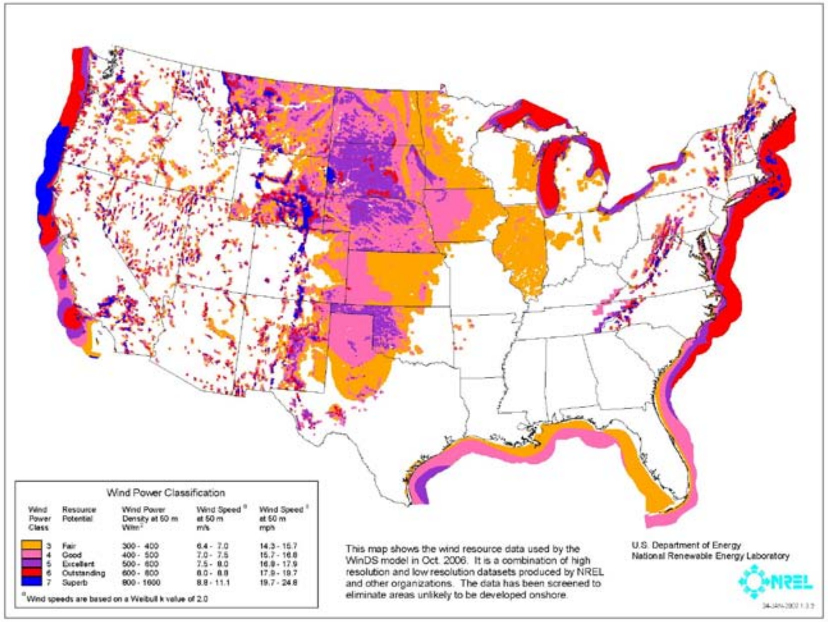
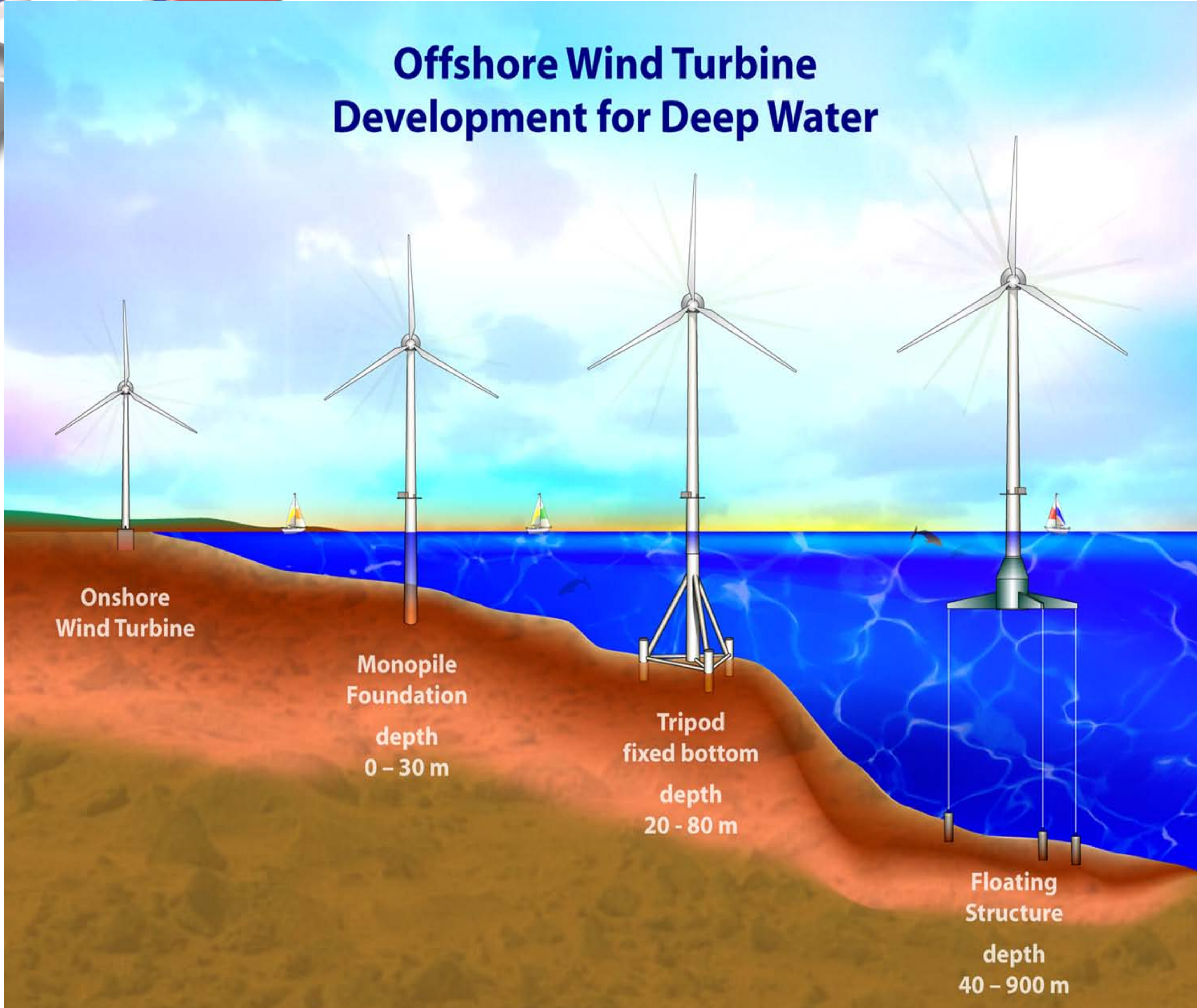
Offshore Wind

- Technical challenges, higher costs
- Close to load centers
- Limited shallow depths in U.S.
- Proposals in U.S.
  - Cape Cod (Cape Wind)
  - Long Island (LIPA)
  - Texas gulf coast
- 1500 MW installed in Europe

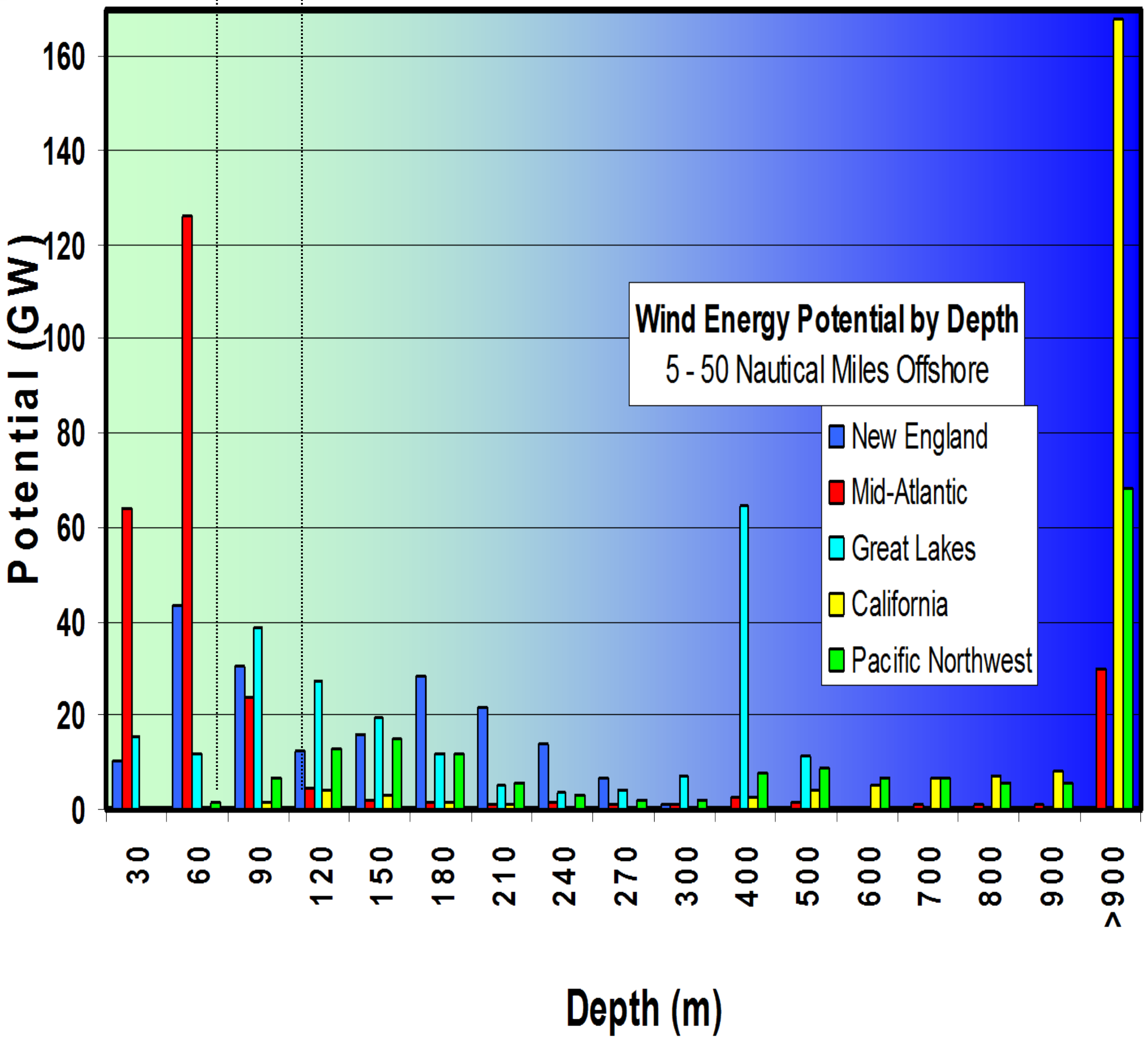
Belgium	30
Denmark	397.9
Ireland	25
The Netherlands	246.8
Sweden	133.3
UK	588
Total capacity - World	**1,421**

Source: BTM Consult ApS - March 2009




Offshore Wind Turbine
Development for Deep Water
Onshore
Wind Turbine
Monopile
Foundation
depth
0 – 30 m
Tripod
fixed bottom
depth
20 - 80 m
Floating
Structure
depth
40 – 900 m

Limited Shallow Water Resource in U.S.



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Wind Energy Summary

- Tremendous growth rate over last 25 years (~25%)
- Absolute numbers large for last 6 years
  - U.S. biggest global market 2005-2009, 2nd in 2010
  - Wind 2nd in U.S. (capacity) since 2005
- Market growth drivers
  - Low cost of energy (due to technology advances)
  - Uncertainty about carbon tax or cap/trade
- Industry fueling new manufacturing job growth
- No significant barriers to 20% scenario
- Tremendous potential offshore

Energy and Water
Water and Energy

Daniel Laird

Energy and Infrastructure Future

Sandia National Laboratories

Telephone: (505) 844-6188

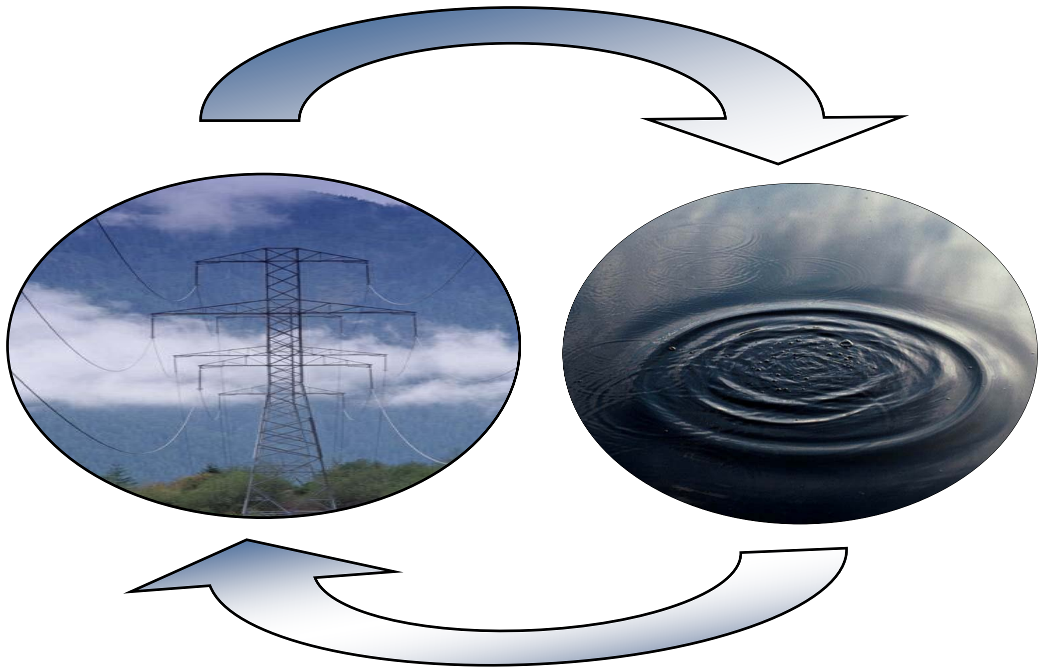
E-mail: dllaird@sandia.gov

Energy and Water are
… Inextricably linked

<u>***Water for Energy***</u> **and** <u>***Energy for Water***</u>

Energy and power production requires water:

- Thermoelectric cooling
- Hydropower
- Energy minerals extraction / mining
- Fuel Production (fossil fuels, H_2, **biofuels**, other non-conventional fuels)
- Emission controls



Water production, processing, distribution, and end-use requires energy:

- Pumping
- Conveyance and Transport
- Treatment
- Use conditioning
- Surface and Ground water

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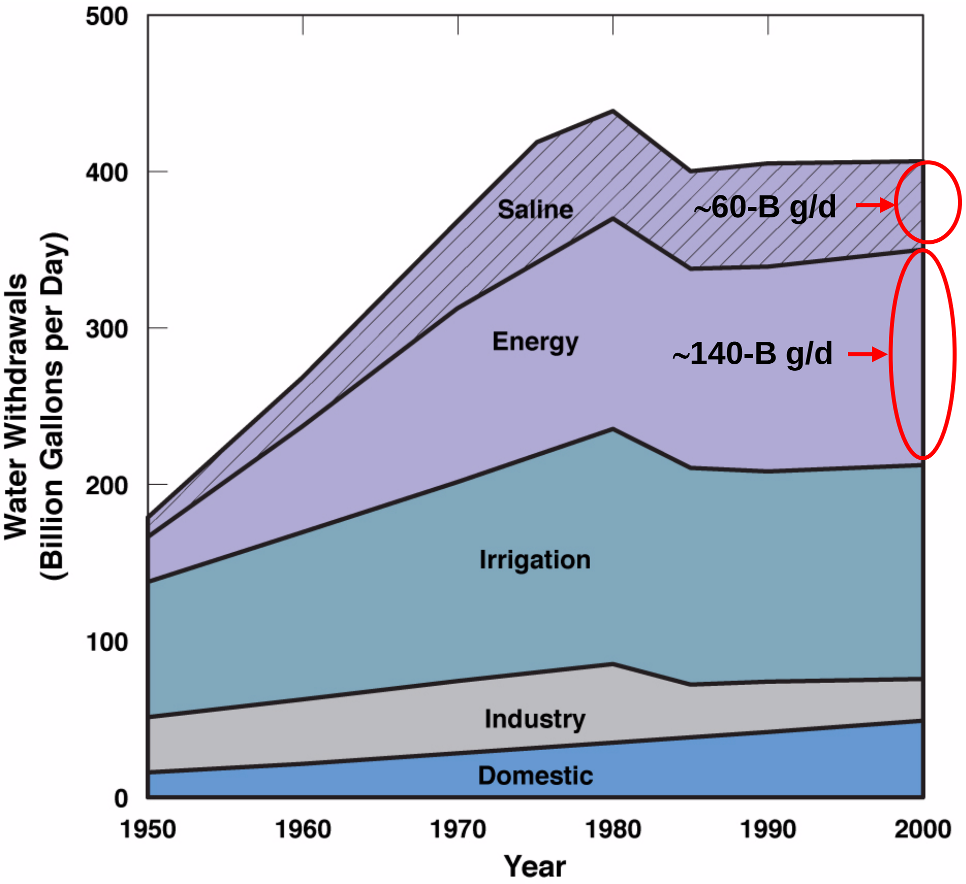
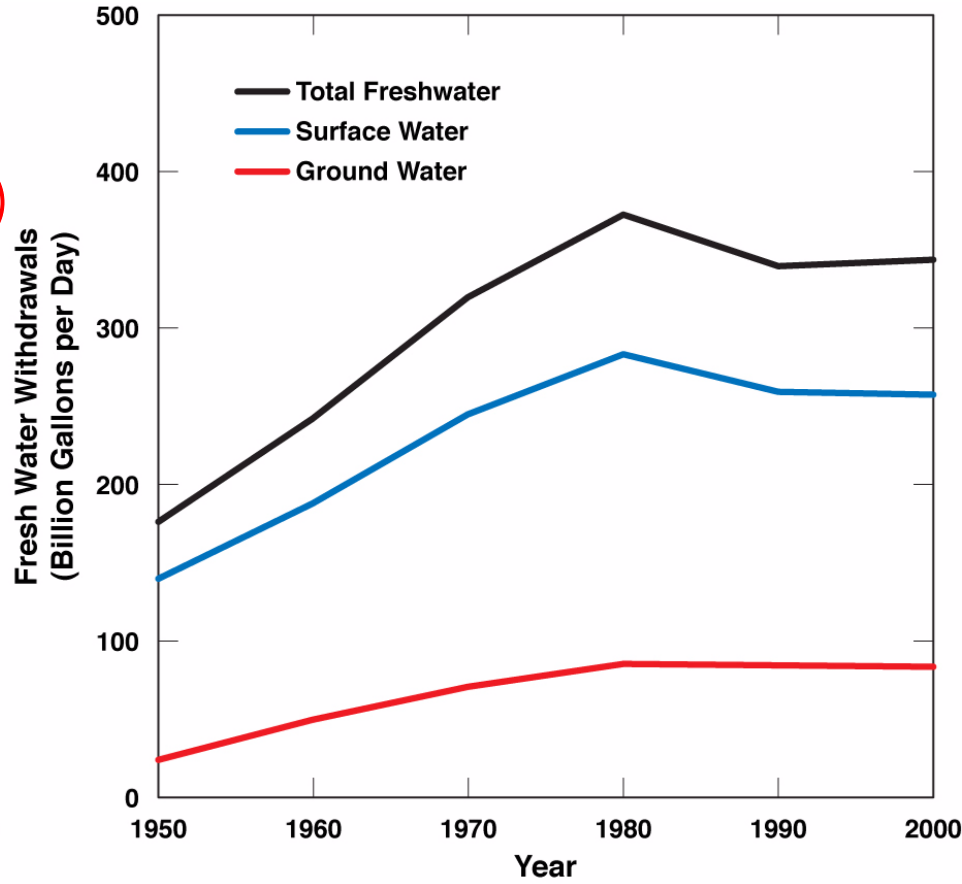
US Energy Sustainability

ENERGY and WATER

Trends in Water Withdrawals



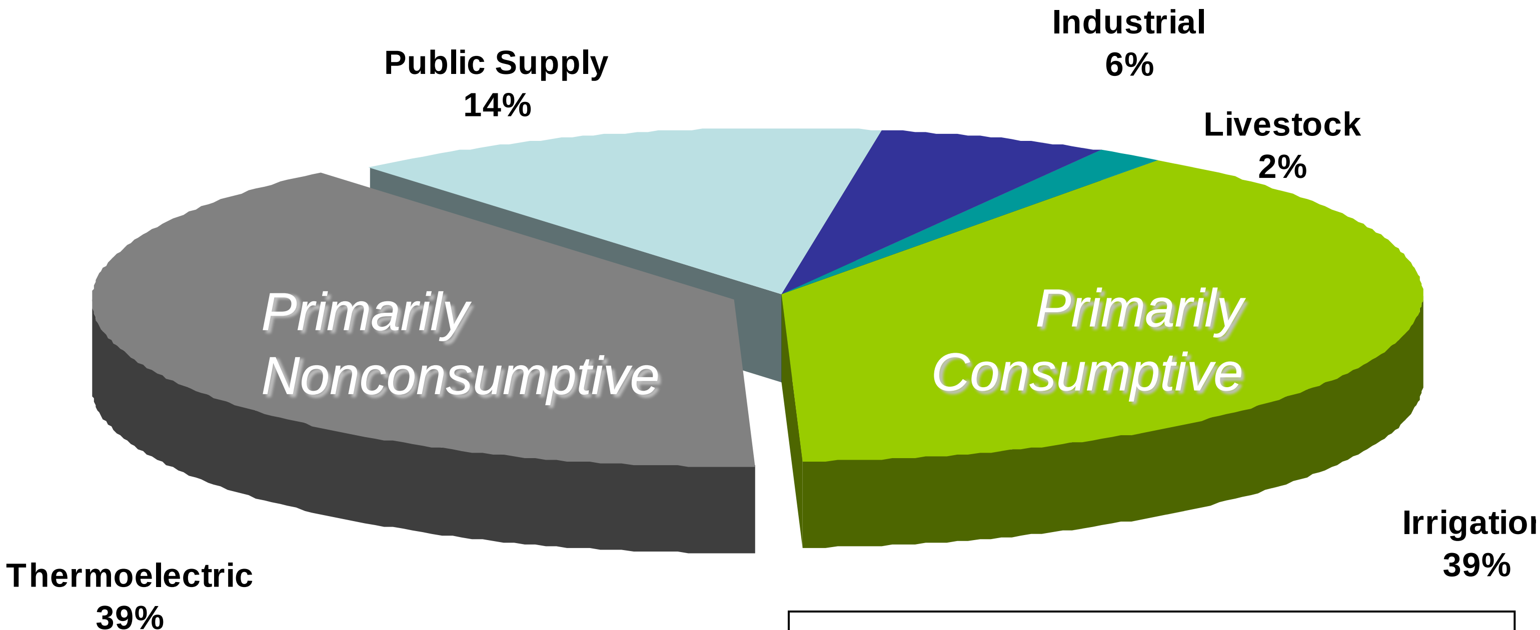


Hutson, et.al., 2004

U.S. Water Withdrawals

U.S. Freshwater Withdrawals ~ 340 Billion gallons/day (in 2000)

Estimated Freshwater Withdrawals by Sector, 2000



Note: Hydropower and saline water uses are not included here!

USGS Circular 1268, March, 2004

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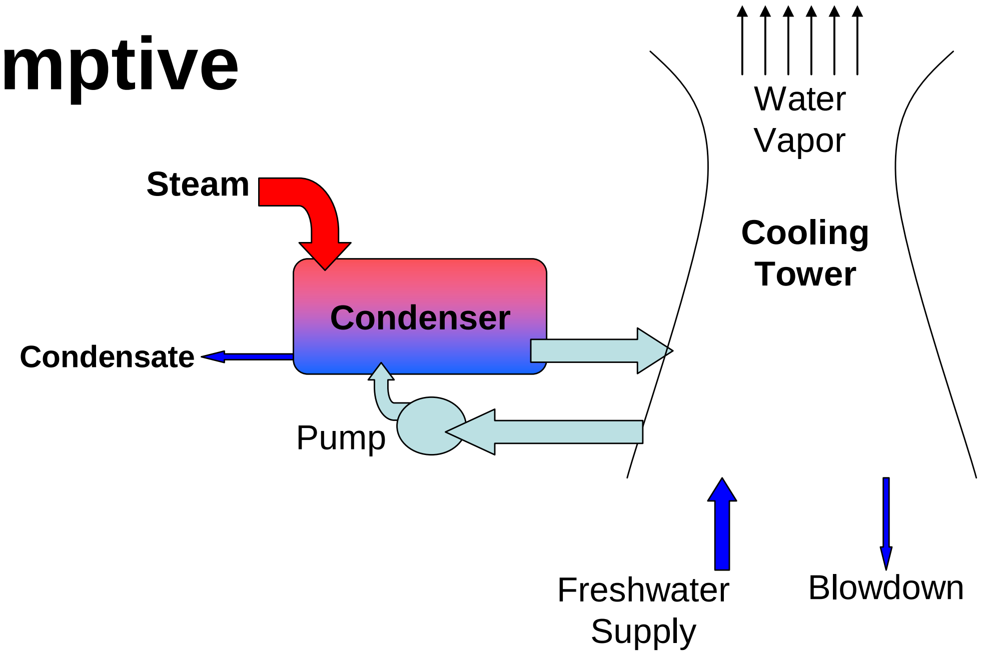
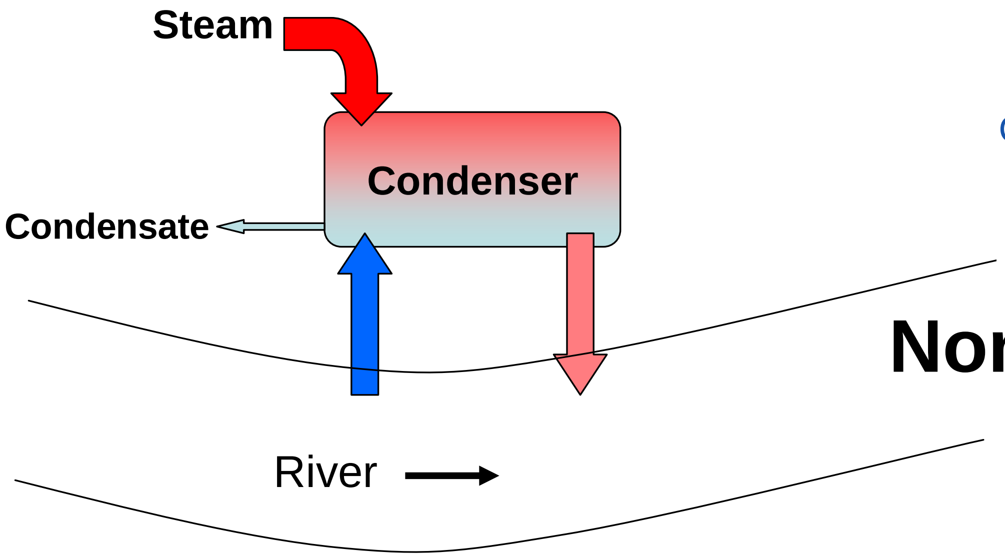
Consumptive versus Nonconsumptive

Consumptive



Constraint: Absolute Water Consumption



Nonconsumptive

Constraint: Thermal Discharge Limits, Water flows

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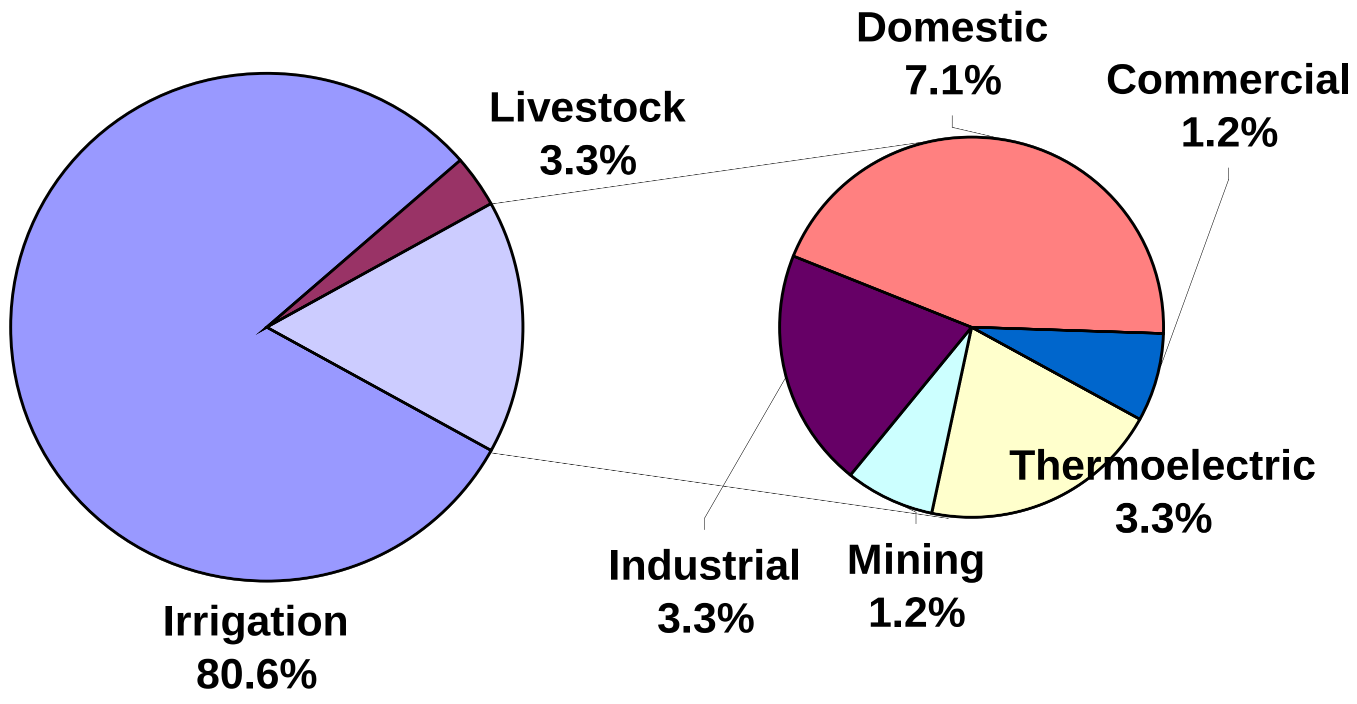
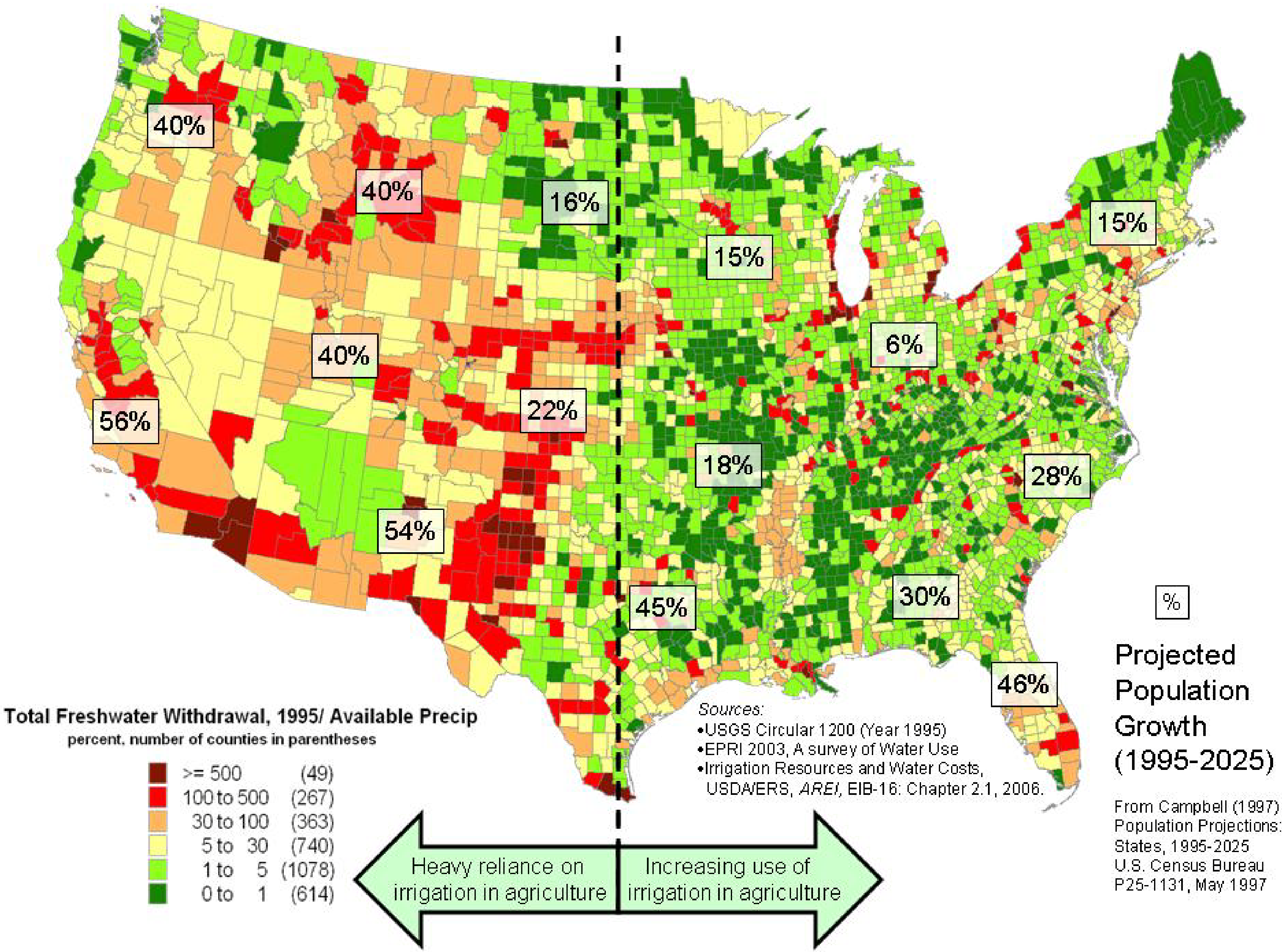
U.S. Freshwater Consumption



Water challenges are nationwide



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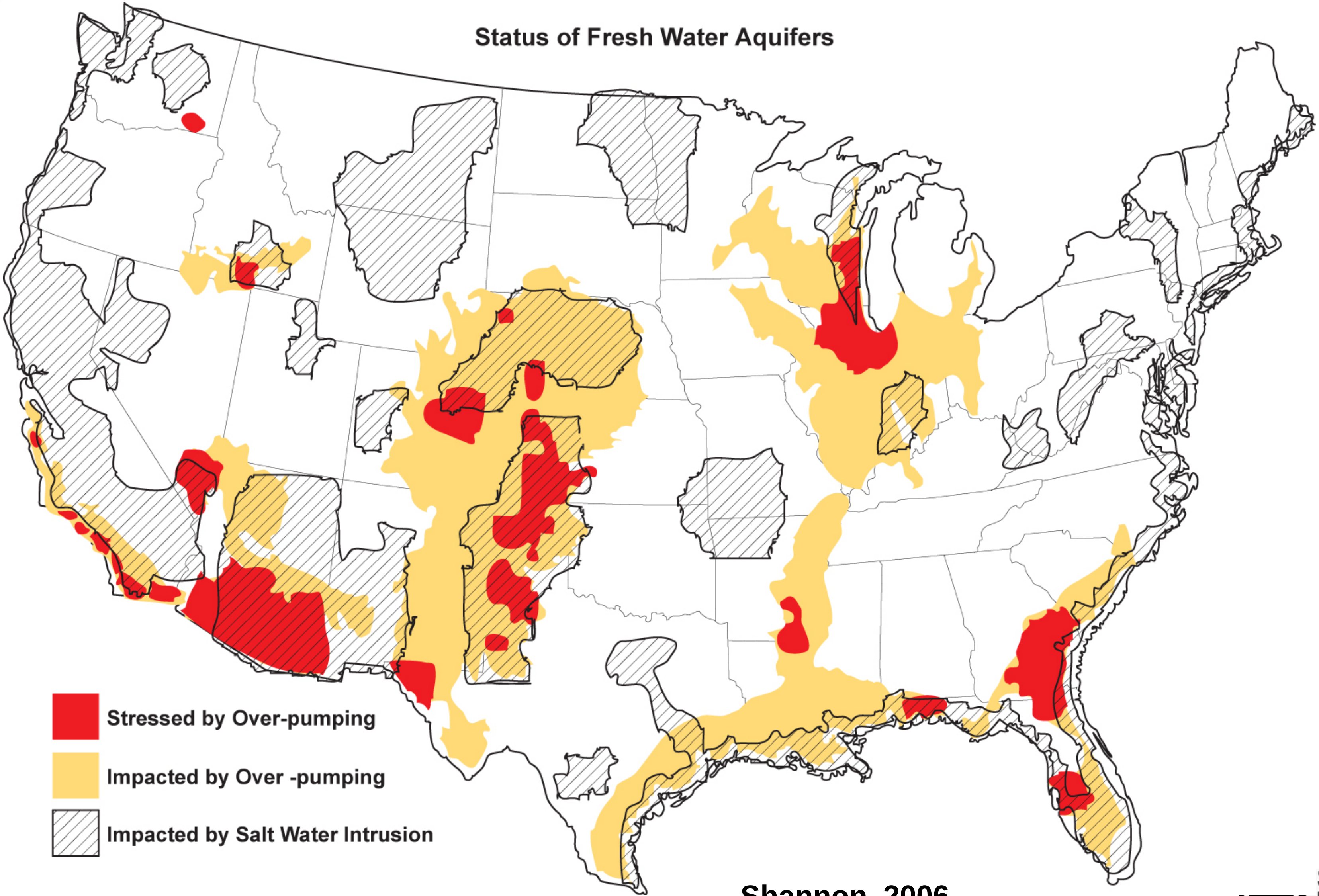
Aquifers Impacted by Over-Pumping



Shannon, 2006

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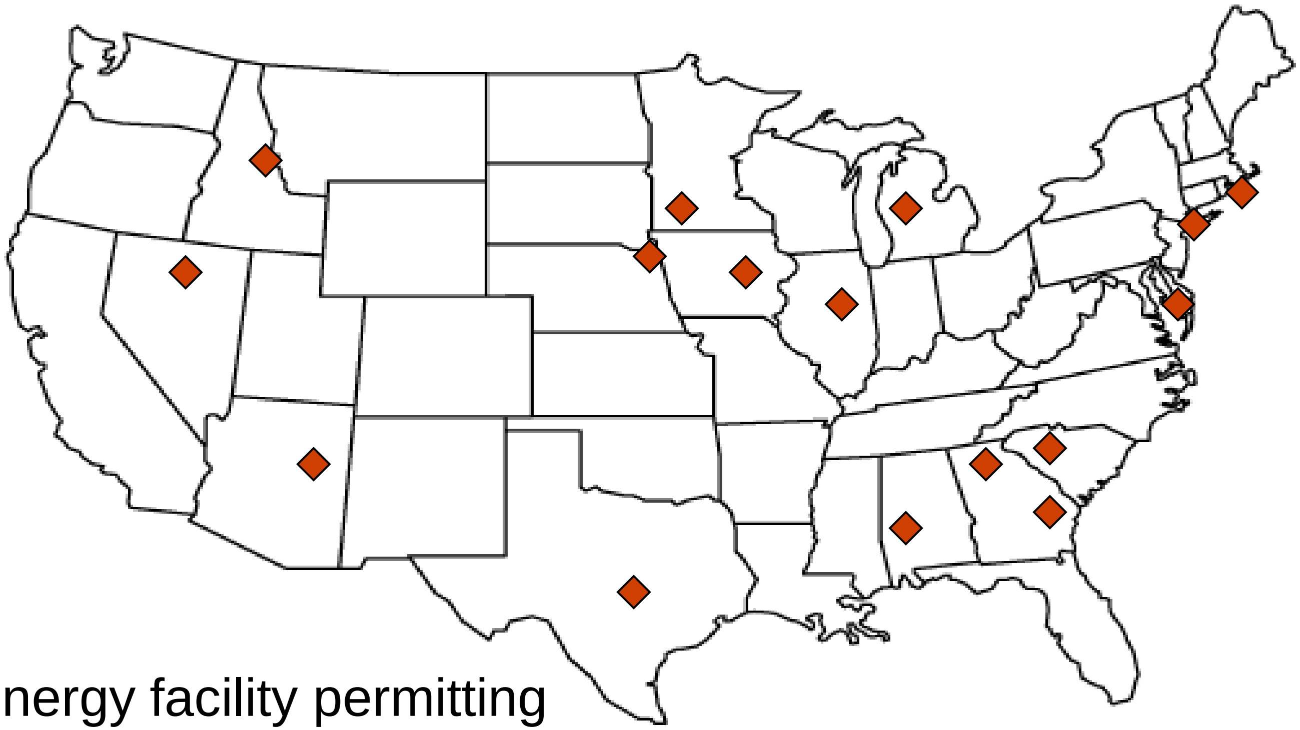
Water Availability Impacting New Energy Development



◆ Recent energy facility permitting issues due to water availability

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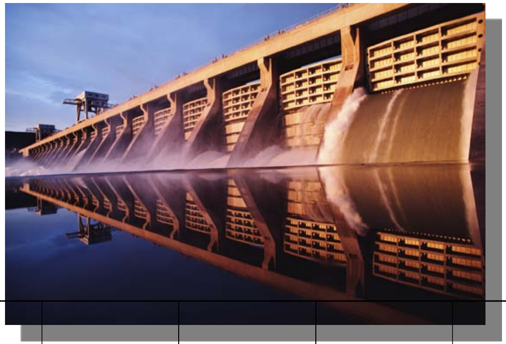
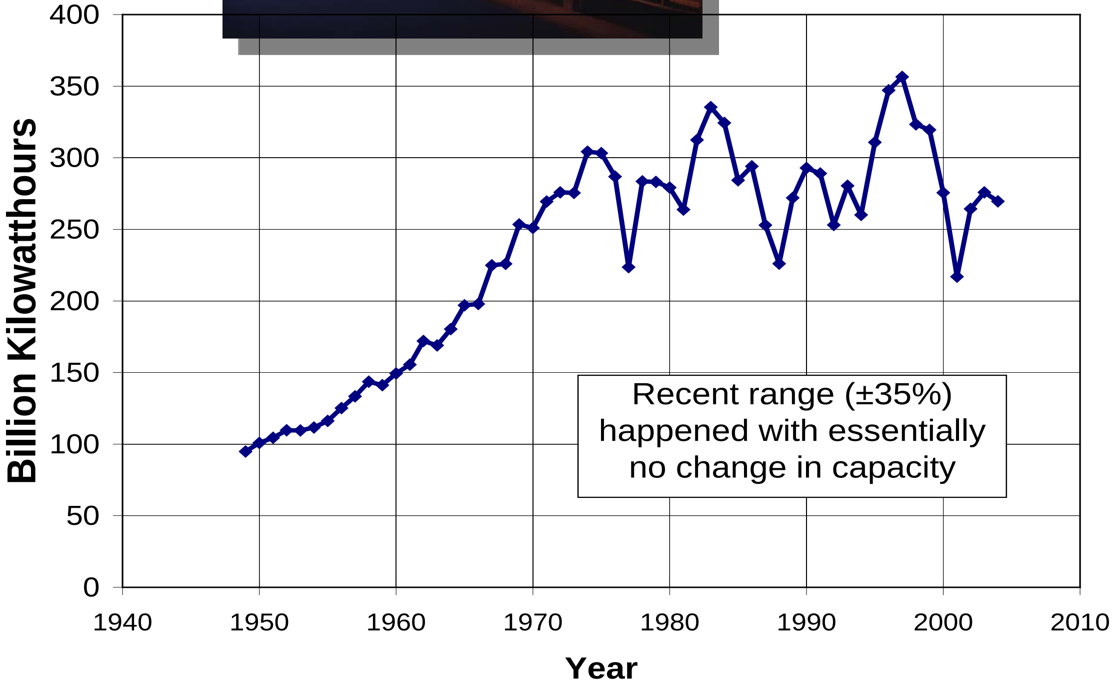
Hydroelectric Power

- Drought and competing demands and priorities have impacted hydropower

- Impacts reliability and grid and emissions benefits





U.S. Hydroelectric Power Production

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2003 Heat Wave Impact on French Power Generation

- Loss of 7 to 15% of nuclear generation capacity for 5 weeks
- Loss of 20% of hydro generation capacity
- Large-scale load shedding and shut off transmission to Italy
- Sharp increase of spot-market prices: 1000 to 1500 $ / MWh for most critical days

Bort-les-Orgues Réservoir

Normal conditions in August

August 27, 2003

Electric Power Generation Water Use for Various Cooling Options

Plant-type	Cooling Process	Water Use Intensity (gal/MWh_e)		
		Steam Condensing[a]		Other Uses[b]
		Withdrawal	Consumption	Consumption
Fossil/ biomass steam turbine[c]	Open-loop	20,000–50,000	~200-300	~30-90[d,i]
	Closed-loop	300–600	300–480	
	Dry	0	0	
Nuclear steam turbine[c]	Open-loop	25,000–60,000	~400	~30[d]
	Closed-loop	500–1,100	400–720	
	Dry	0	0	
Natural Gas Combined-Cycle[c]	Open-loop	7,500–20,000	100	10[e]
	Closed-loop	~230	~180	
	Dry	0	0	
Coal Integrated Gasification Combined-Cycle[c]	Closed-loop	200	170	150[c,e]
	Dry cooling	0	0	150[c,e]
Geothermal Steam[f]	Closed-loop	2000	1350	NA
Concentrating Solar[g,h]	Closed-loop	750	740	10
	Dry cooling	10	0	10
Wind and Solar Photovoltaics[j]	N/A	0	0	1-2
Carbon sequestration for fossil energy generation				
Fossil or biomass[k]	All	~30% increase in water withdrawal and consumption		

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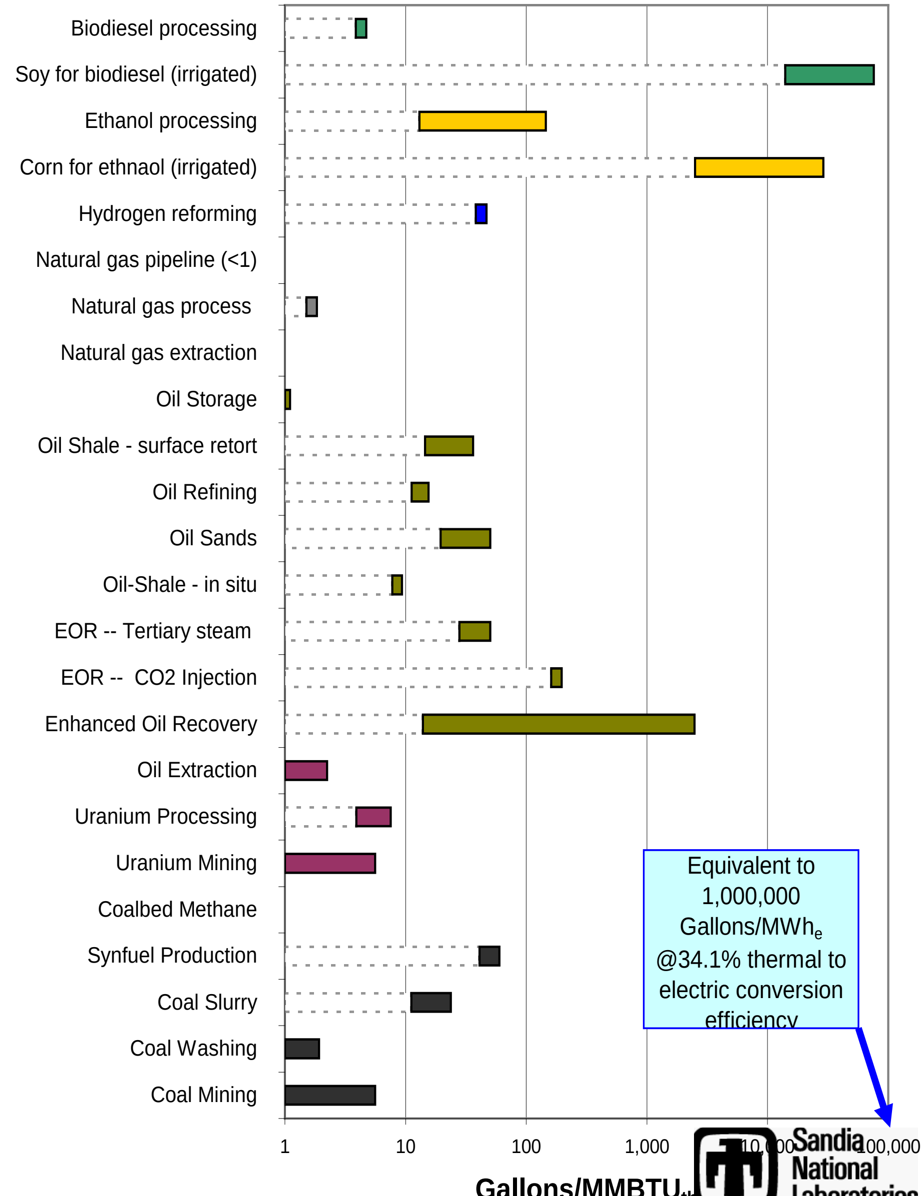
Future energy development will put new demands on water

- **Many newer technologies will be more water intensive**
- **Biofuels and hydrogen economy would require significantly more water than fossil transportation fuels**
- **Constraints will grow for power plant siting because of water for cooling needs, advanced scrubbing, and CO_2 removal**



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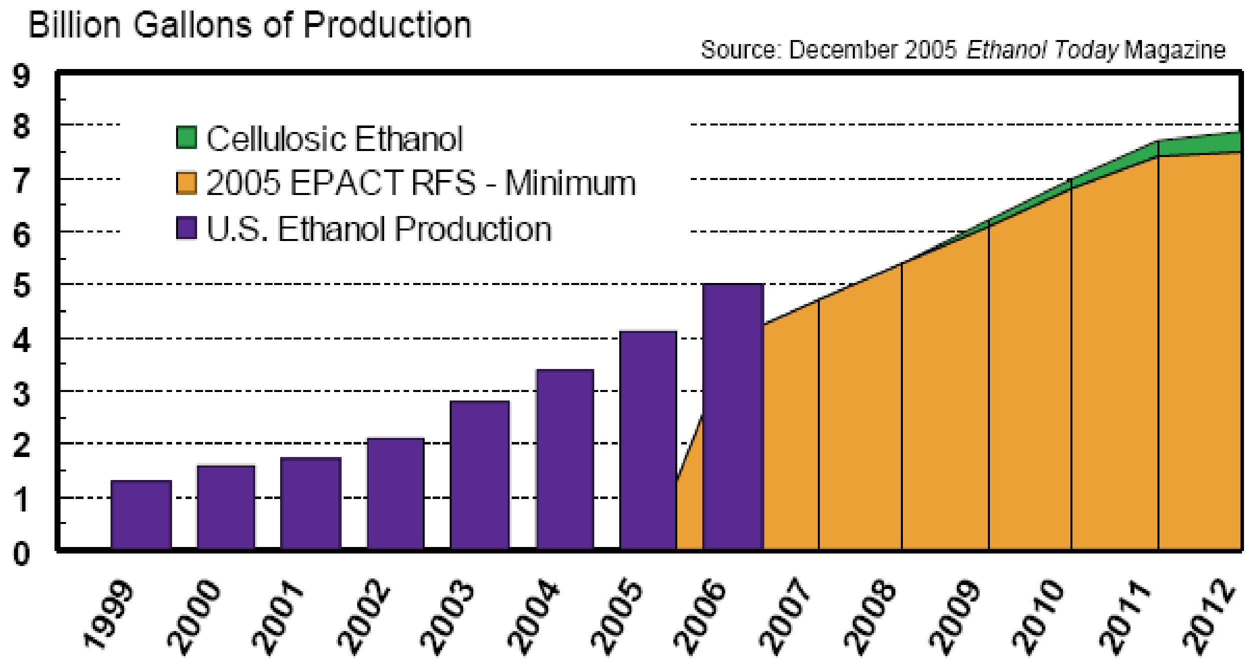
Bioenergy Production Will Increase Water Demands

Ethanol Production

Actual and Projected U.S. Ethanol Production 1999-2012



- **Total U.S. gasoline market ~140 billion gallons/yr**
- **2-6 gallons of water consumed per gallon of ethanol refined**
- **1500 gallons of water consumed per gallon of ethanol if irrigated**

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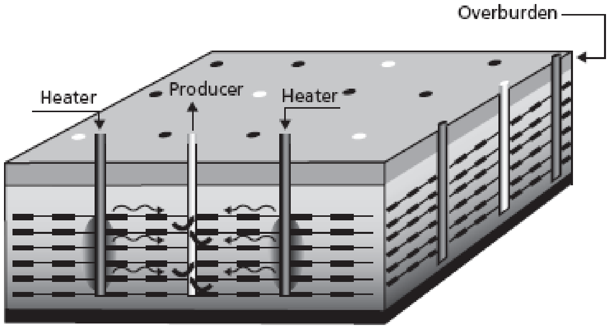
Oil Shale development could impact water availability and quality

- **Reserves are in areas of limited water resources**
- **In situ retort the emerging technology**
- **Water needed for retorting, steam flushing, and cooling**
- **Concerns over *in situ* migration of retort by-products and impact on ground water quality**

Figure 3.2
The Shell In-Situ Conversion Process



SOURCE: Adapted from material provided by Shell Exploration and Production Company.
RAND MG414-3.2

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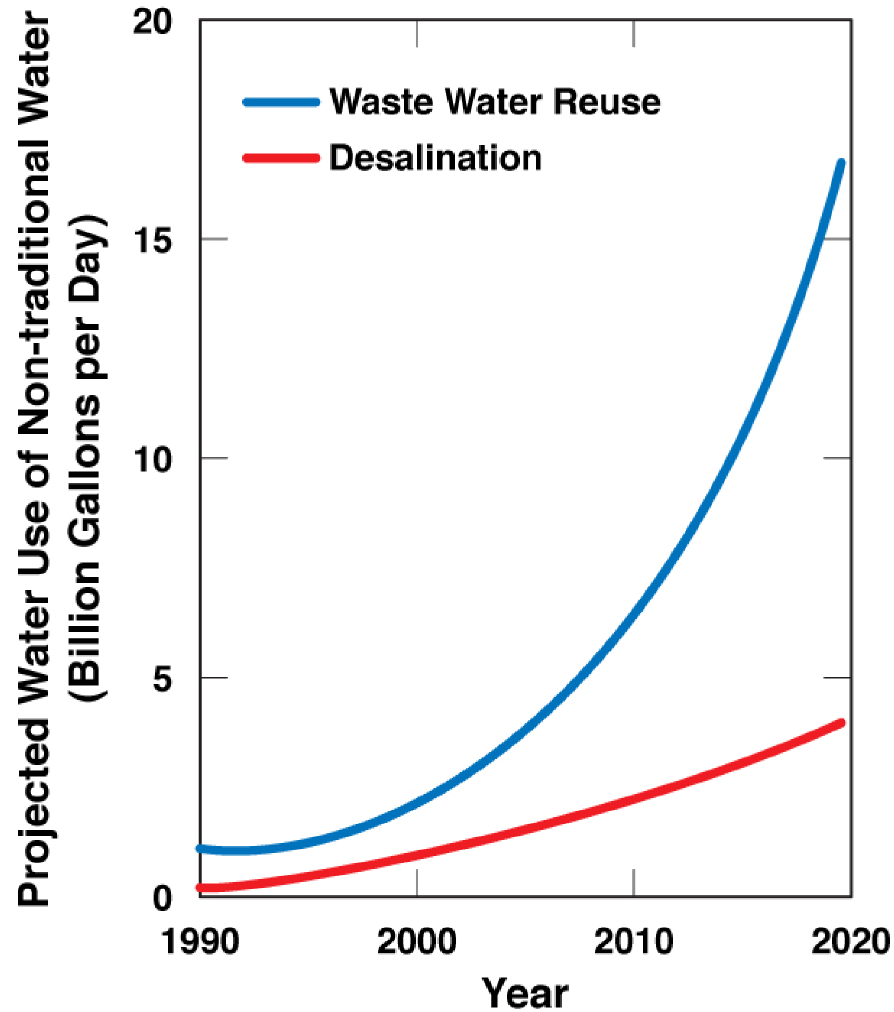
Non-traditional Water Supplies Growing

- Desal growing at 10% per year
- Waste water reuse growing at 15% per year
- Reuse not identified in fresh water withdrawal or consumption data



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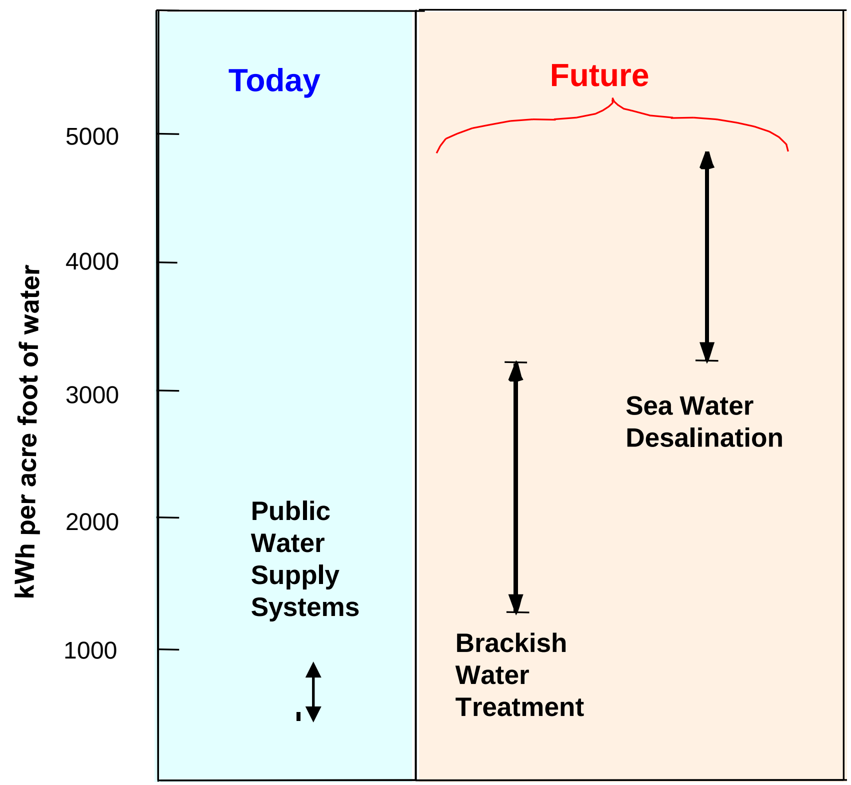
Future water supplies and treatment will be more energy intensive

- **Readily accessible fresh water supplies are limited and have been fully allocated in some areas**
  - **Increased energy for pumping at deeper depths and longer conveyance**
- **New technologies to access and/or treat non-traditional water resources will require more energy per gallon of water**
  - **Impaired water, produced water, brackish water, and sea water**

Power requirements for current and future water supply



Source: EPRI (2000), Water Desalination Task Force (2003)

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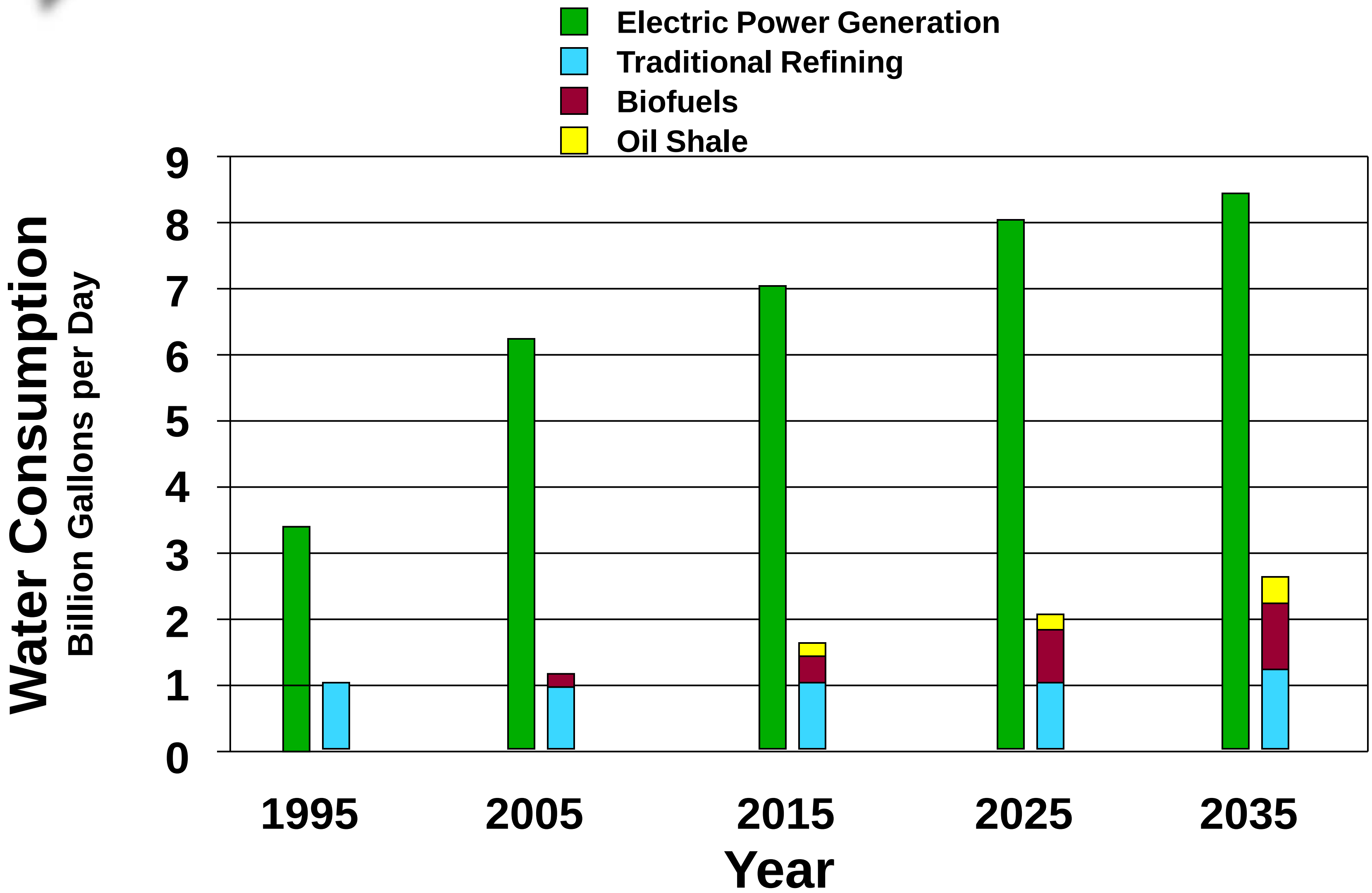
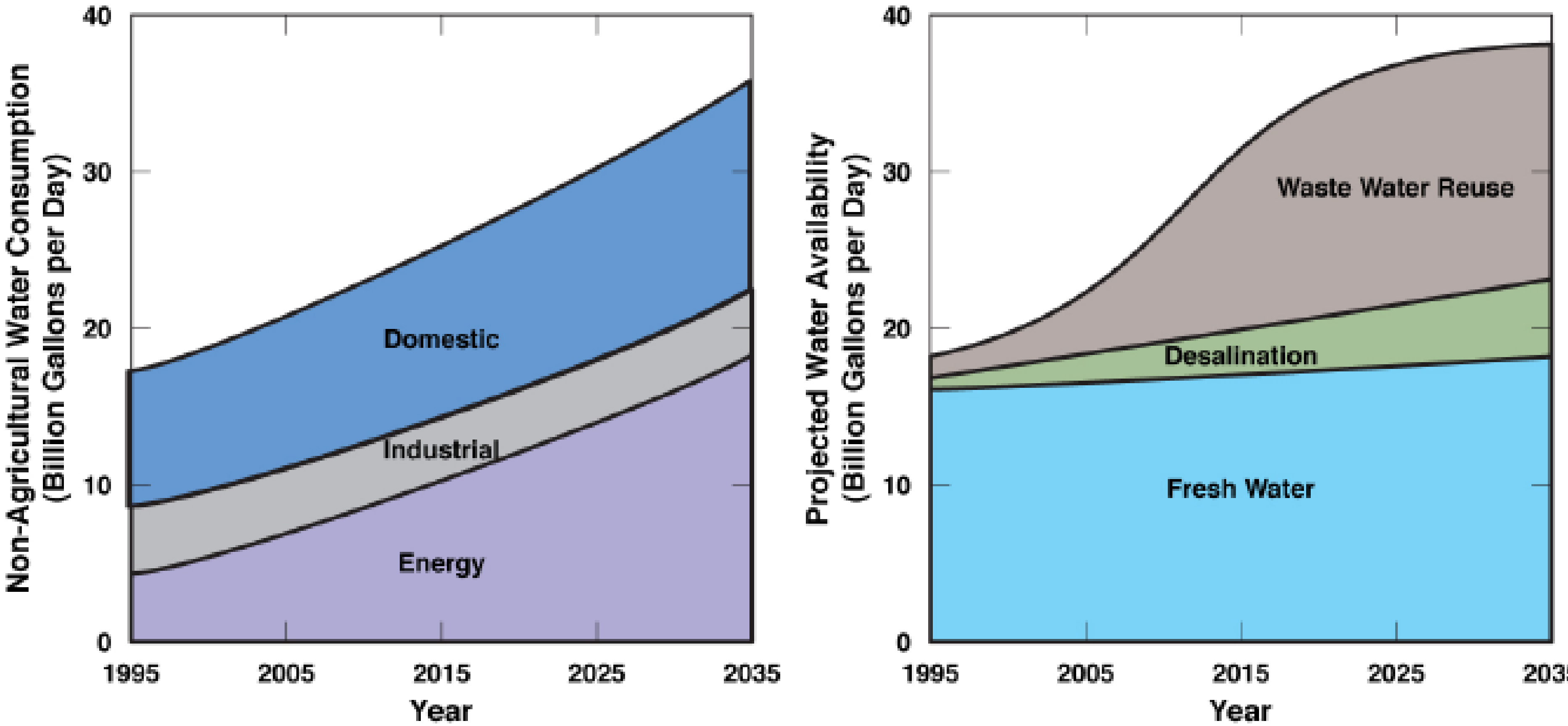
Projected Growth in Water Consumption for Power and Fuels



Projected Trends in Non-Agricultural Water Consumption and Available Water Supplies From Fresh and Treated Sources



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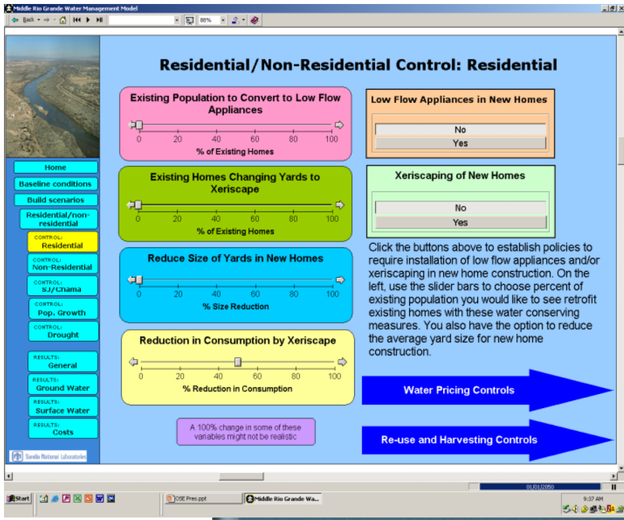
SNL Research Program for Alternative Fuels Sector

- Reduce water use for biofuels and alternative fuels production
- Reduce water use in processing
- Develop low fresh water use technologies such as algal biodiesel
- Assess non-traditional water use for fuels applications
- Assess hydrologic impacts of large cellulose biofuels scale up and oil shale

SNL Research and Development Program for Integrated Resources Management



- Accelerate water resources forecasting and management
- Evaluate impacts of climate variability and improve hydrological forecasting
- Improve common decision support tools
- Develop system analysis approaches for: Co-location of energy and water facilities, improved national transmission capabilities to support renewables, distributed generation of biofuels

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Energy Storage

Daniel Laird

Energy and Infrastructure Future
Sandia National Laboratories

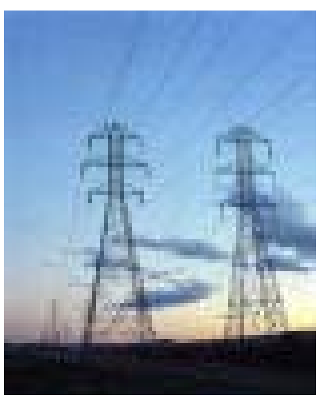
Acknowledgments: Georgianne Peek (SNL), John Boyes (SNL)

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

What is Energy Storage?

Energy Storage Mediates Between

Energy Sources and Variable Loads



Without storage, energy generation must equal energy consumption

Why Store Energy?

1. Economic advantage using predictable price swings
   – Natural gas storage
   – Pumped Hydro electricity storage
2. Improve asset utilization
   • Balance generation and load to minimize capital costs
   • Performance when you want it
   • Strategic hedge against unpredictable interruptions in supply
   • Strategic petroleum reserve
   • UPS

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How is energy stored currently?

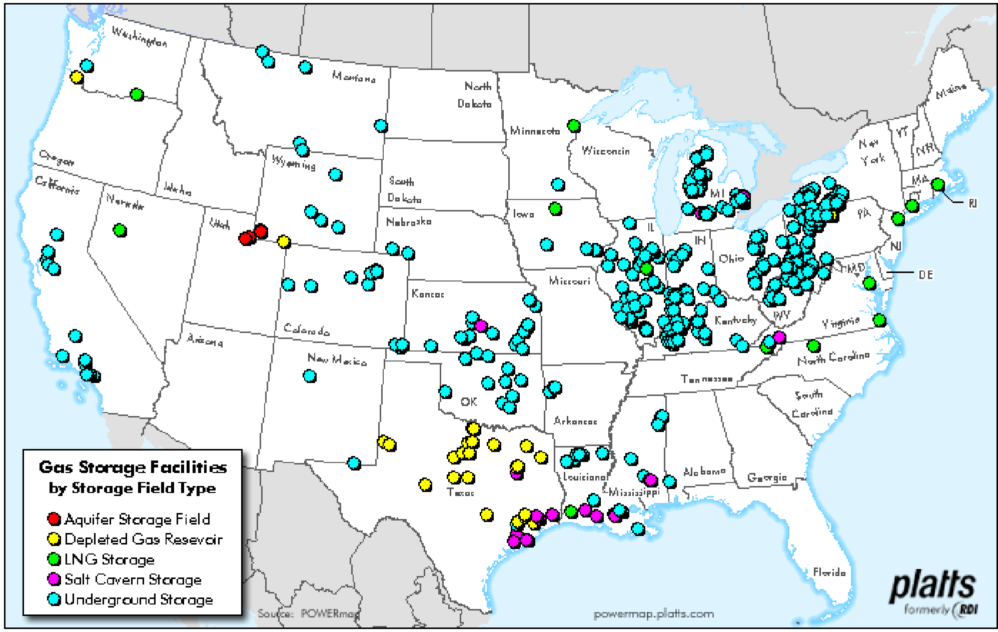
- Oil
  - Strategic Petroleum Reserve
  - Storage Tanks
- Natural Gas
  - Underground Storage reservoirs
  - Pipelines
- Electric Energy Storage
  - Pumped Hydro
  - Batteries/UPS
  - CAES
- Thermal Energy
  - Thermal Mass/Adobe
  - Ice

Oil Storage

- Strategic Petroleum Reserve
  - Underground salt caverns
  - Louisiana and Texas gulf coast
  - 665 million bbls, 40 days supply
  - Strategic Application
  - Funded by Federal Govt.
  - Reserves held for National Emergency
- Storage tanks
  - Asset utilization application
  - Balance refinery output/distribution system/demand

Natural Gas Storage

- **Underground caverns, aquifers and depleted natural gas fields**
- **Dispersed across nation**
- **Reserves built during summer**



- **Reserves drawn during winter**
- **Levels demand/supply imbalance**

Without storage, supply infrastructure would have to be sized to meet peak winter demand

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Thermal Energy Storage

- **Passive solar building**
  - **Large thermal mass**
- **Ice**
  - **Ice generated over night, provides cooling during day**

•Solar thermal

–Power tower system stores energy in hot oil or in phase change salts

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Why Electricity Storage ?

"Power systems have become so **complex** that they exceed man's ability to react to them. They must be designed to give people **adequate time** to manage failure."

- Bruce Nussbaum

Business Week, September 8, 2003

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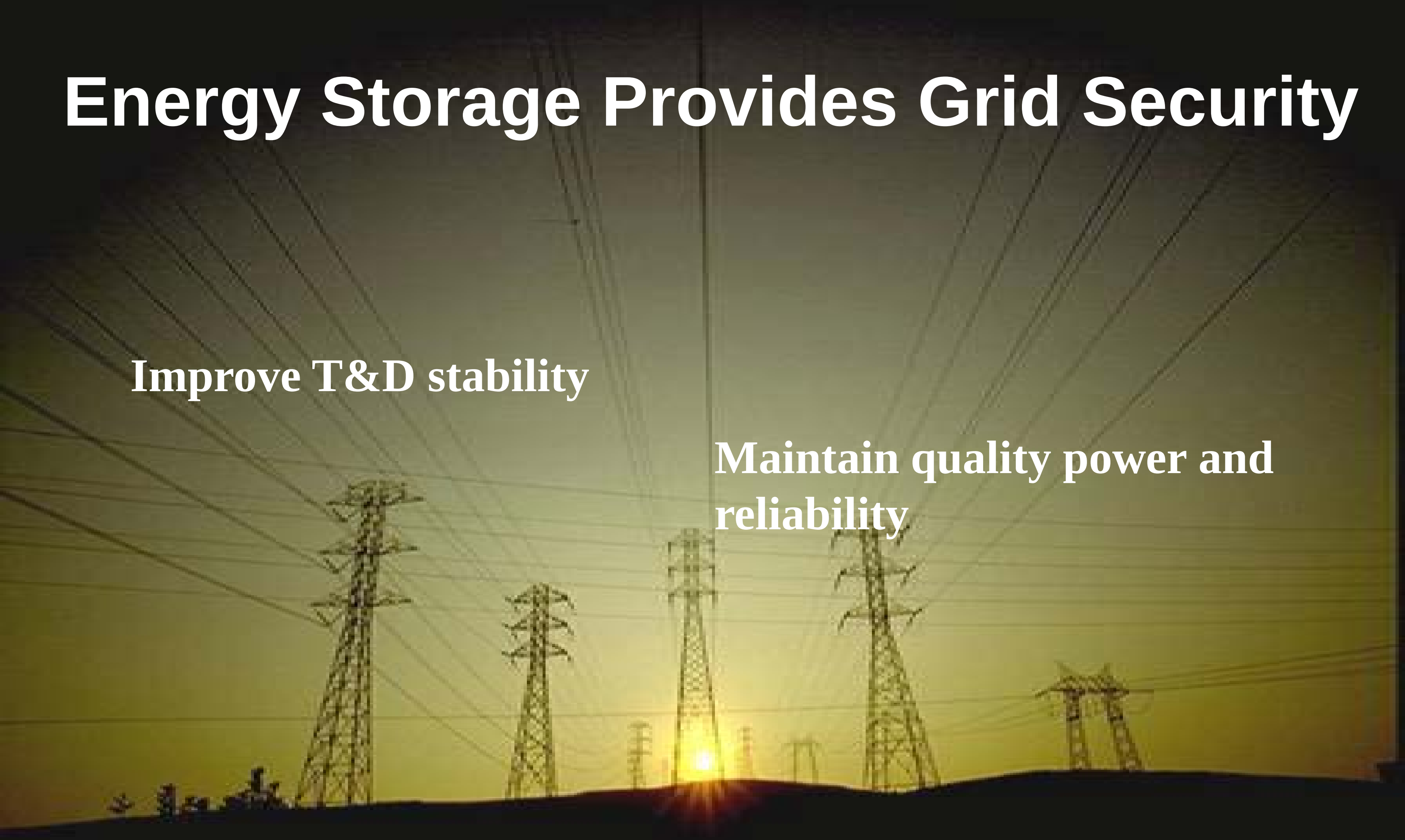
Energy Storage Provides Grid Security



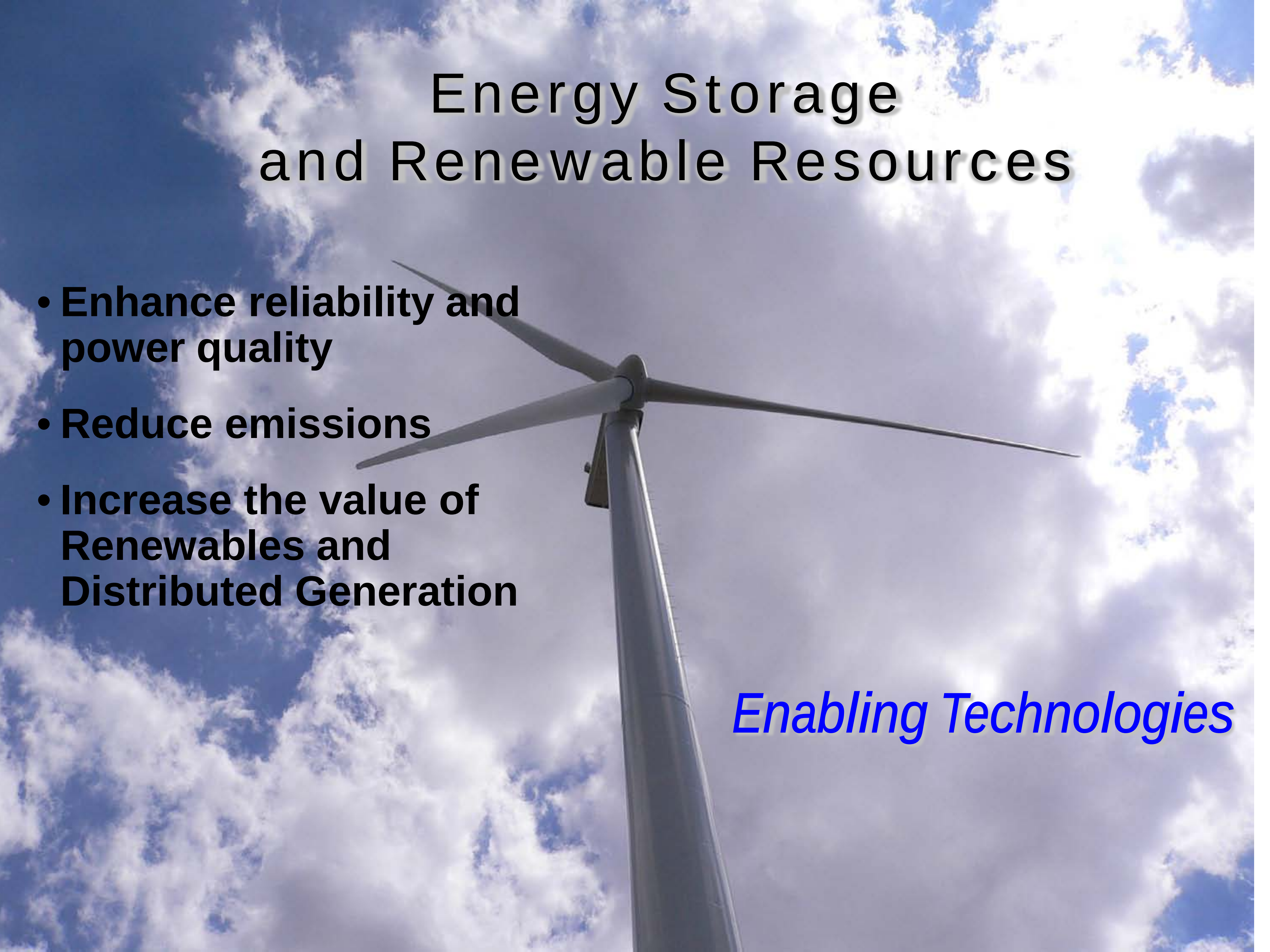
Improve T&D stability

Maintain quality power and reliability

‘Blackouts’ and ‘brownouts’

Fossil Fuels and Energy Storage

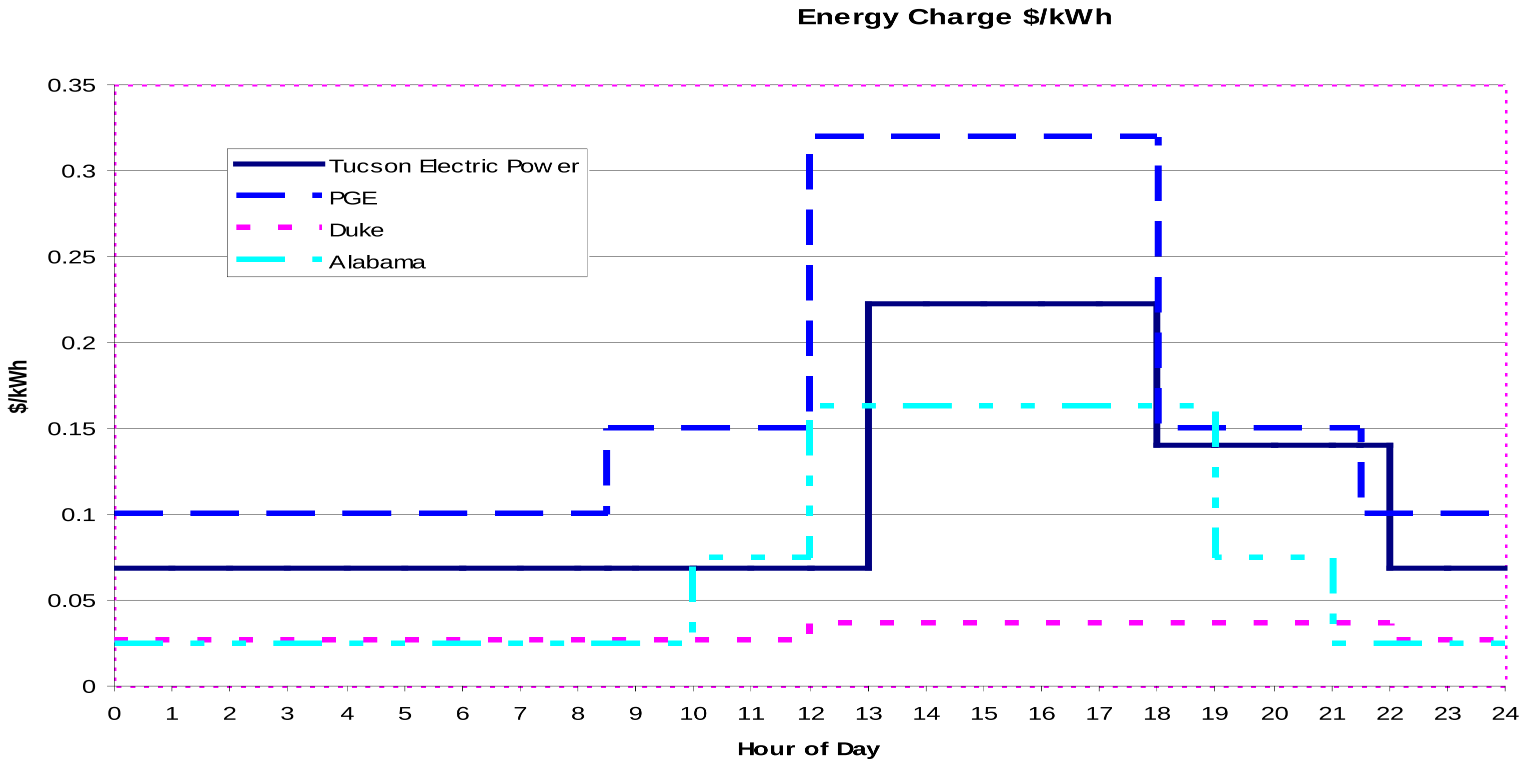
- Enhance asset utilization
- Defer upgrades
- Operate Fossil fuel generators at optimum set point– reduce emmissions


Energy Storage
and Renewable Resources
• Enhance reliability and power quality
• Reduce emissions
• Increase the value of Renewables and Distributed Generation
Enabling Technologies

Benefits Are Utility Dependent

Time of Day Rate Structure Varies Greatly

Benefit Is Dependent On Variability



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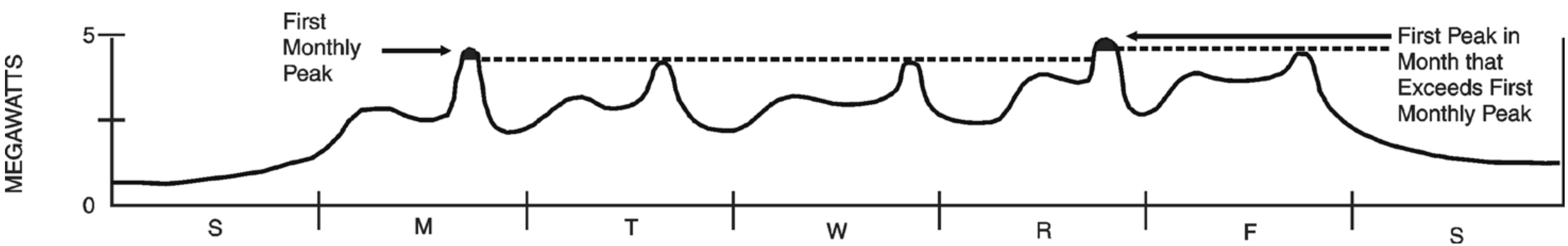
Peak Shaving

- Utility charges a "peak demand charge" based on the highest power drawn during the month
- With experience, peak shaving can be tailored to fit storage system capacity



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Typical "Regulation" Profile

ISO Goal:

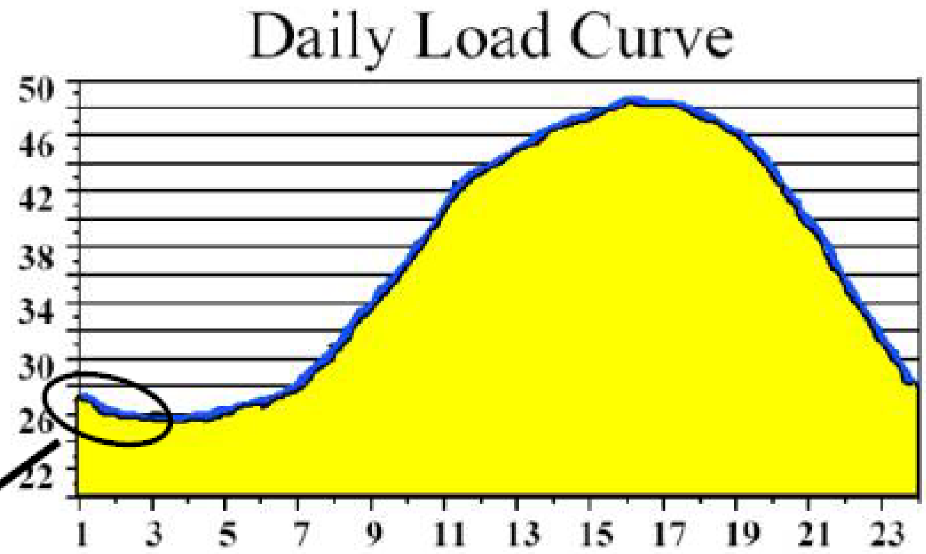
Load = Power Generated

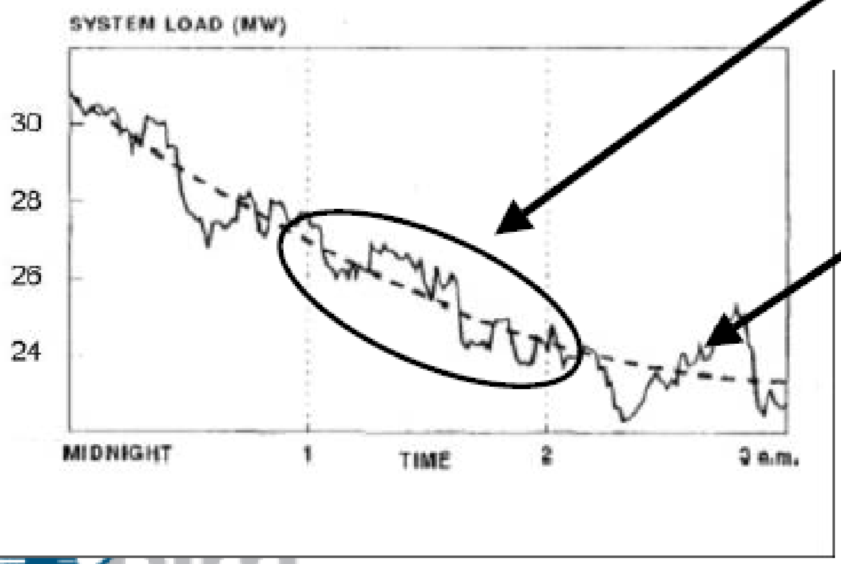
Power < Load:

– Frequency drops under 60 Hz.

Power > Load:

– Frequency rises over 60 Hz.

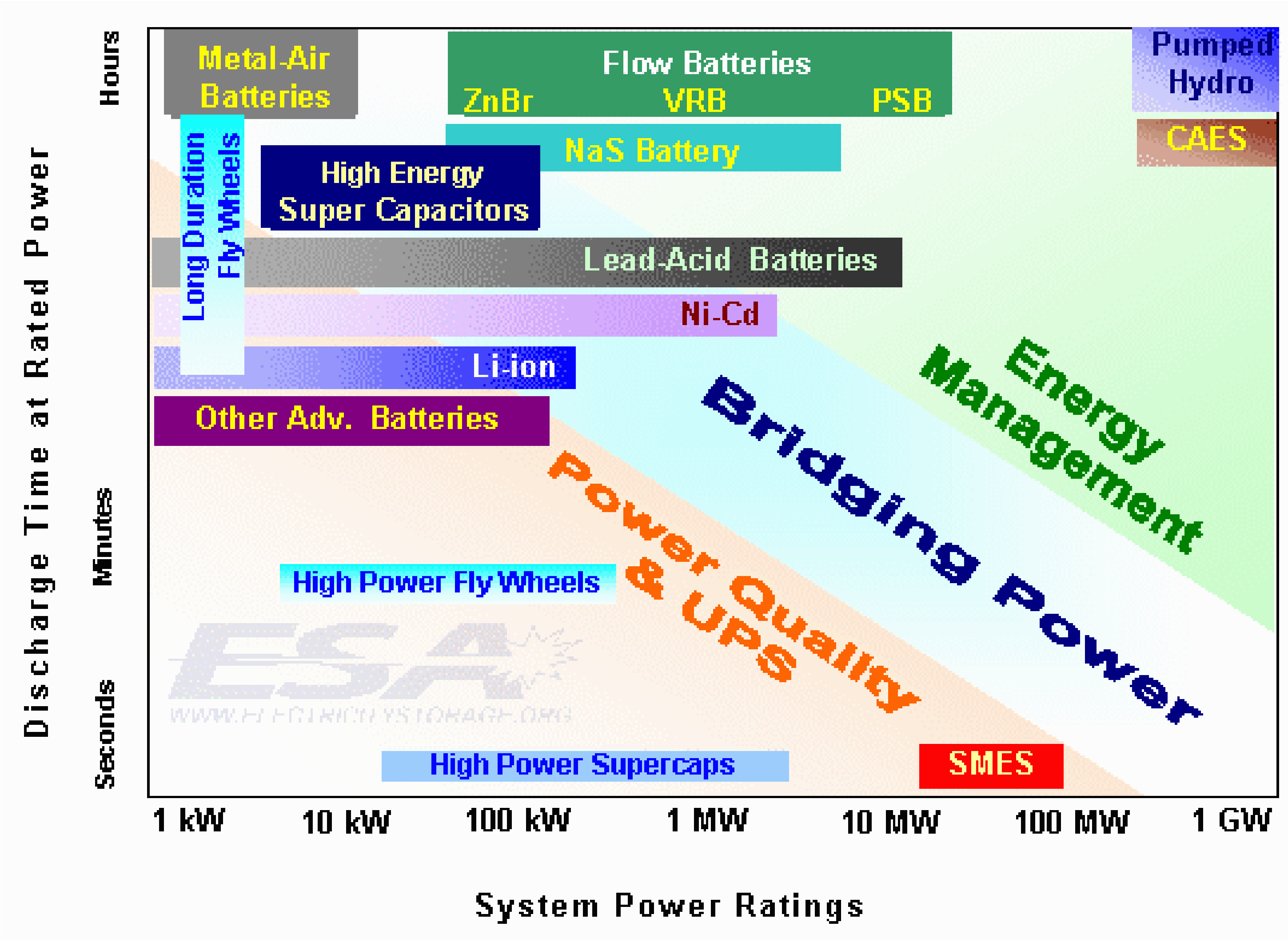




Short term variation

- ~ 1% of daily load
- Managed via regulation
- Fluctuation is net zero

Storage Technologies Available



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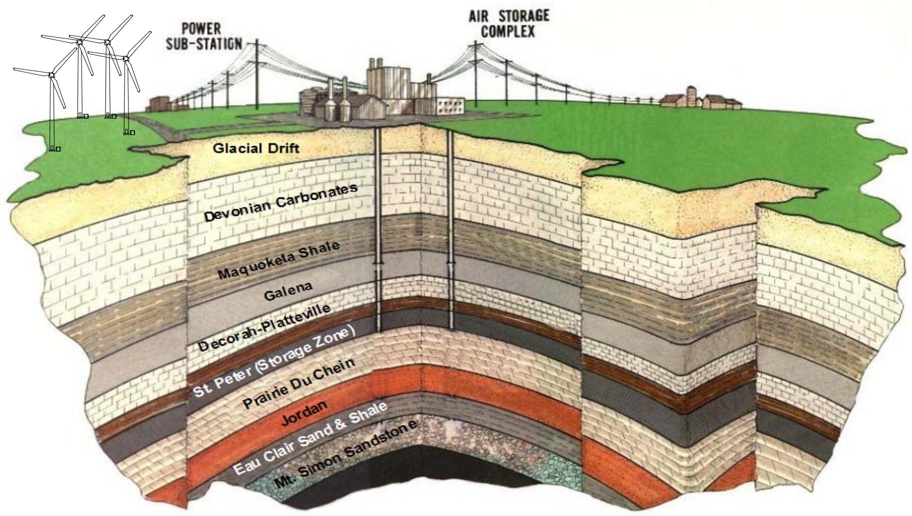
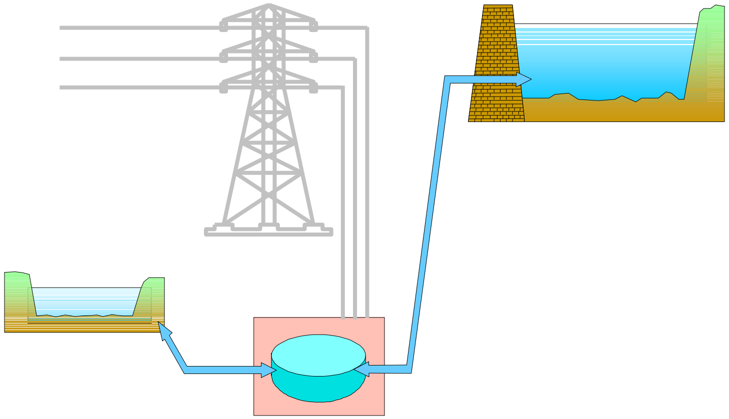
Large Scale Energy Storage

- Pumped Hydro
- CAES





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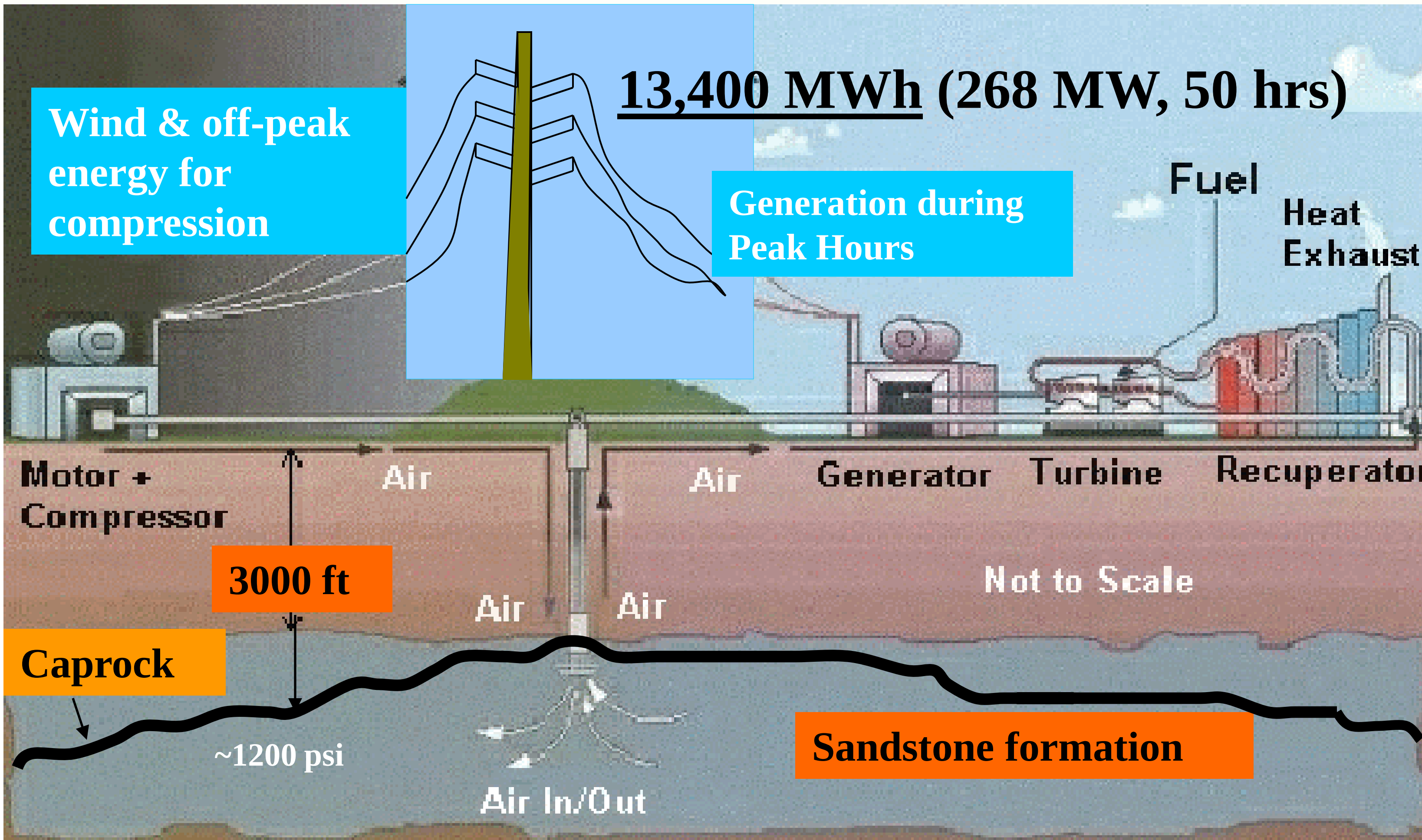
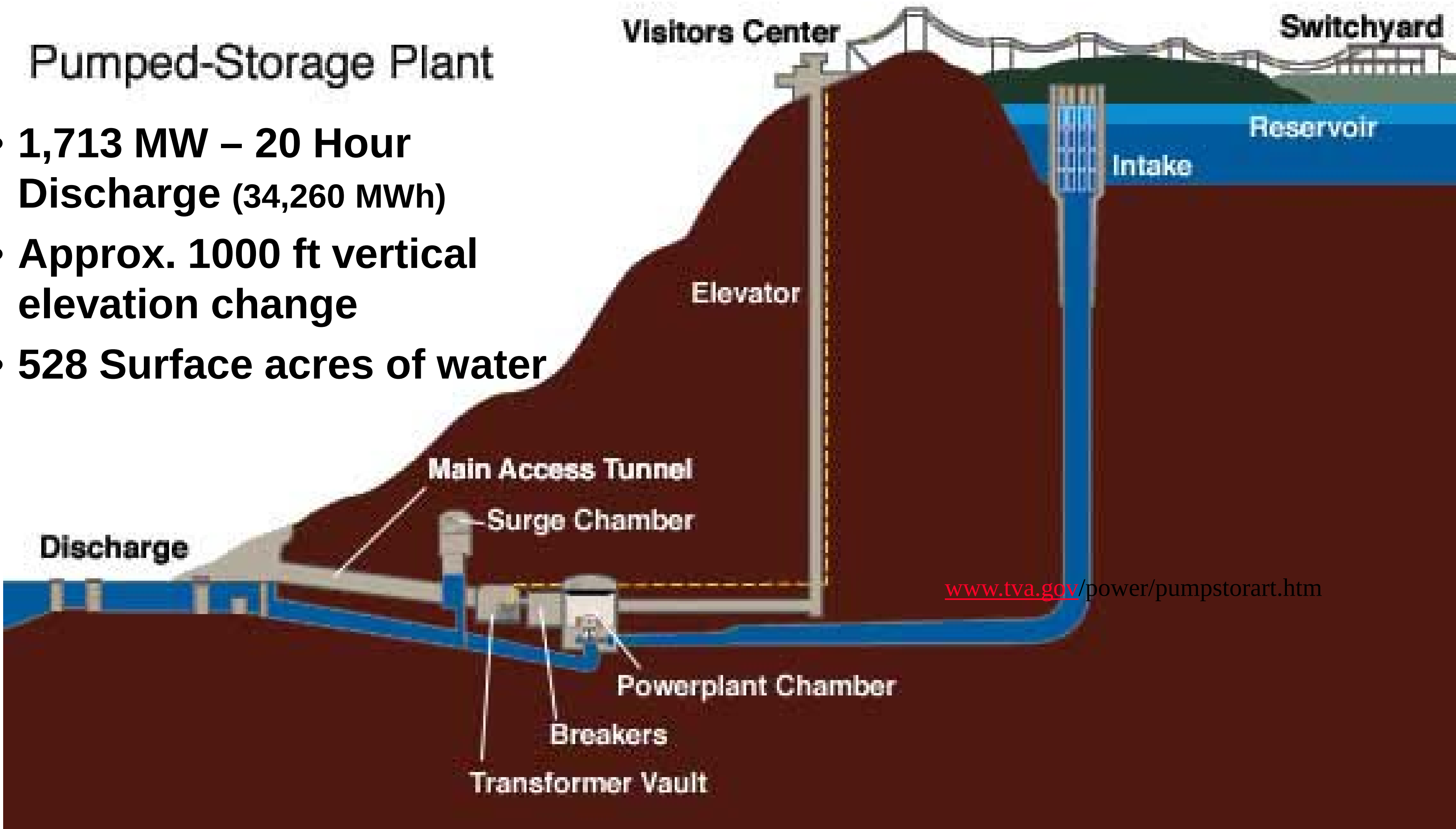
THE IOWA
STORED
ENERGY
PARK



Wind & off-peak energy for compression
13,400 MWh (268 MW, 50 hrs)
Generation during Peak Hours
Fuel
Heat
Exhaust
Motor + Compressor
Air
Air
Generator
Turbine
Recuperator
3000 ft
Not to Scale
Air
Air
Caprock
~1200 psi
Sandstone formation
Air In/Out

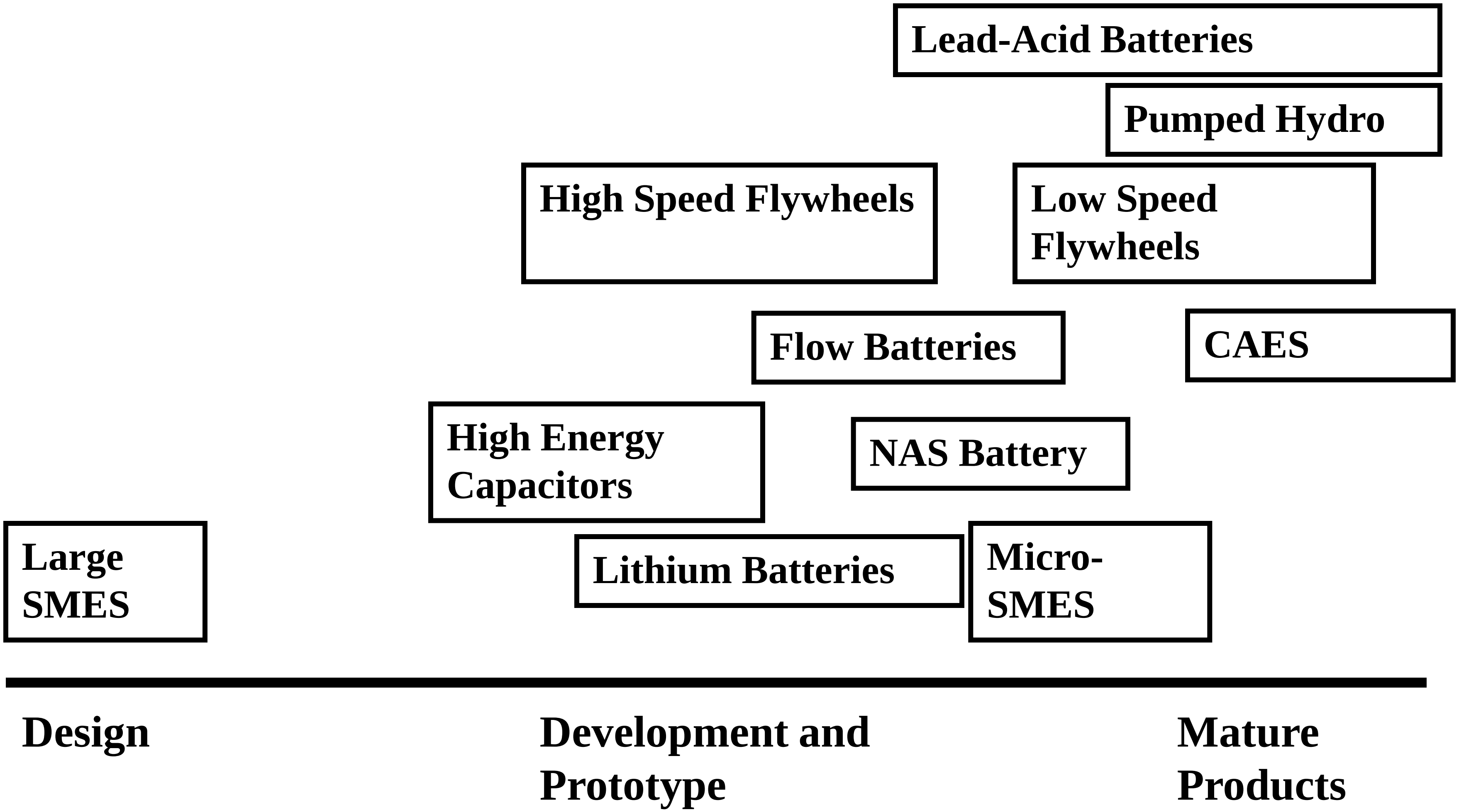
Raccoon Mountain Pumped Hydro

- **1,713 MW – 20 Hour Discharge** **(34,260 MWh)**
- **Approx. 1000 ft vertical elevation change**
- **528 Surface acres of water**



www.tva.gov/power/pumpstorart.htm

Commercial Maturity of Storage Technologies



Electrical Energy Storage

<u>Percentage of generated electricity that is stored</u>

• **Japan**	**15%**
• **Europe**	**10%**
• **USA**	**2.5%**

Barriers to Energy Storage

- Technical
  - System Design
  - Operating Data
- Institutional
  - New Technology Risk
  - Existing Rate Structures
  - Utility Interdepartmental Roles
  - Few System Suppliers

- Market
  - Cost
  - Market Size Uncertainty
  - Utility/Customer Awareness
  - Unquantified Benefits

Electric Energy Storage R&D

- US Department of Energy
  - Sandia National Labs
- California Energy Commission (CEC)
- New York Energy Research and Development Authority (NYSERDA)
- Electricity Storage Association (ESA)
- Electric Power Research Institute (EPRI)

DOE Energy Storage Program

Develop advanced electricity storage technologies, in partnership with industry, for modernizing and expanding the electric supply.

This will improve the quality, reliability, flexibility and cost effectiveness of the existing system

Sandia has led the DOE Energy Storage Program since its establishment in the early 1970's

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ESS Program Scope

Broad Technology Base

- Batteries
- Controls
- Flywheels
- Power Electronics
- SMES
- Ultracapacitors

Applications Focus

- Power Quality
- Distributed Resources
- Peak Shaving
- Renewable Generation

Energy Storage Websites

- DOE Home Page
  - http://www.energy.gov/engine/content.do
- DOE/Sandia Energy Storage Program
  - http://www.sandia.gov/ess/
- Electricity Storage Association
  - http://www.electricitystorage.org/
- EESAT Conference
  - http://www.sandia.gov/eesat

Summary

- Energy Storage is an emerging technology
- Energy storage offers many advantages to small and
  large energy systems
- US industry focusing on power quality and end user applications
- Overseas industry focusing on large scale energy applications
- Potential for storage is very large

Biofuels

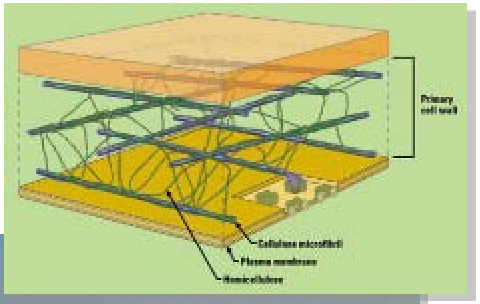
Daniel Laird

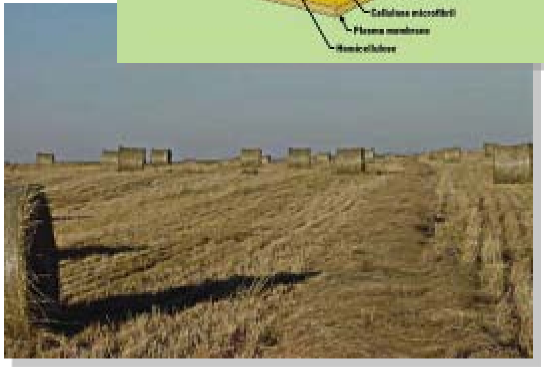
Energy and Infrastructure Future
Sandia National Laboratories

Acknowledgments: Blake Simmons (SNL), Ron Pate (SNL)

- **The nation pays a high price for oil**
  - **Critical national security issues**
  - **Unprecedented environmental harm**
  - **Dwindling supply and price fluctuations**

Energy from biomass holds sustainable energy promise, however:





- **Currently cellulosic ethanol production is expensive and energy intensive**
- **Revolutionary breakthroughs are needed to create energy-efficient, cost-effective cellulosic biofuel**
- **Other starch, sugar, and oil crop based feedstocks and biofuels have sustainable scale-up issues and/or impacts on other food/feed/fiber markets**

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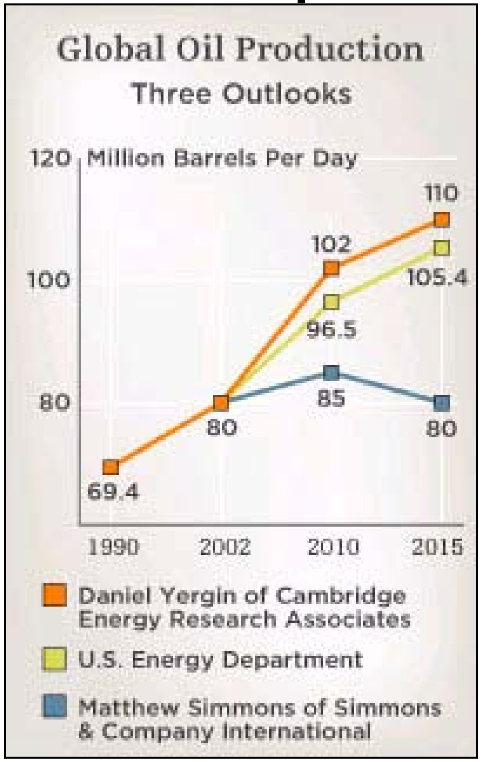
Biofuels Interest & Motivation

- **Energy Security … Heavy U.S. dependence on petroleum imports**

  - Oil imports of ~10-M bbl/day (150+ B-gal/yr)
    … two thirds for transportation fuels
  - Subject to supply disruption from volatile regions
  - Represents $300+ B/yr burden on U.S. economy
    … supports interests hostile to US
  - Increasing competition (China, India, etc.)
    & price volatility for limited global supplies
  - "Peak Oil" concerns
    … decades away?
    ... In 10-years?
    … happening now?

  → Place your bets ! →



- **Finding best paths for build-up/integration with existing production, energy/fuels, and transportation infrastructure**
  - Costs/Benefits/Impacts Tradeoffs
  - Technology, Processes, Systems R&D needs and priorities
- **Energy-Water Nexus and Climate Change Concerns**
  - Mitigate adverse impacts on land use, water, GHG footprint, etc.

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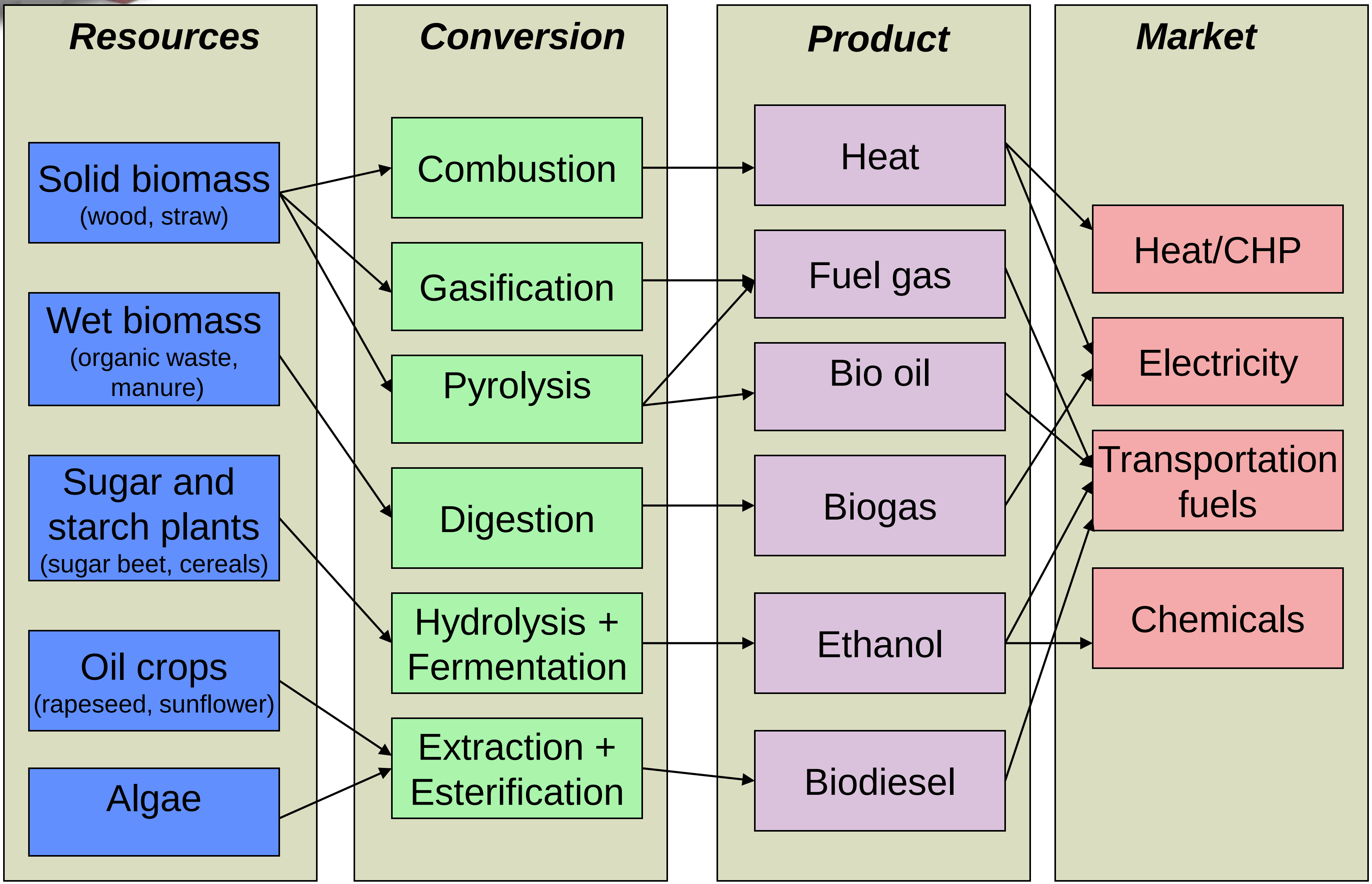
Biomass Interconversion Pathways



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Biofuels: Status

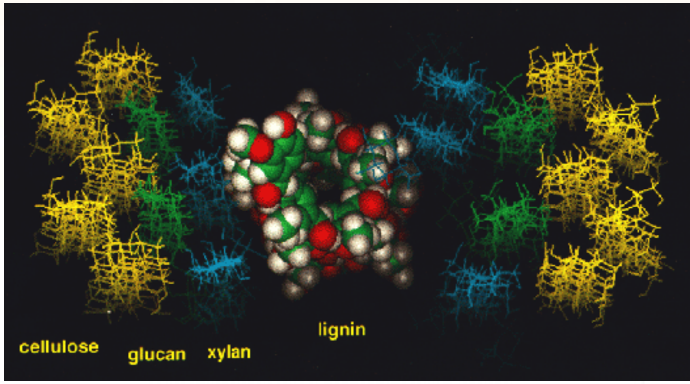
- **Bio-derived liquid fuels address two significant national risks:**
  1) Dependence on foreign oil
  → Biofuels can be produced domestically

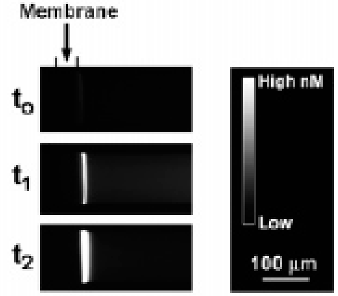
  2) Climate impact of CO_2 emissions from fossil fuels
  → Biofuels are potentially carbon neutral

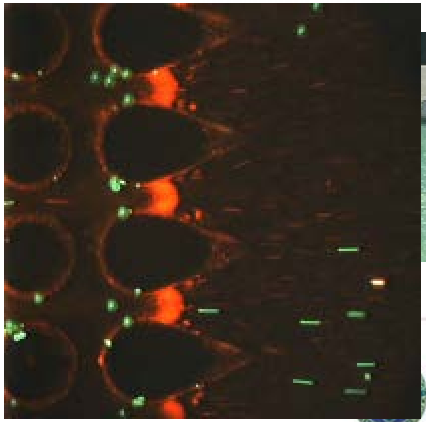
- **Current pathways for biomass-based fuels:**
  - **Ethanol (e.g., from corn seed wet/dry milling) : 4.9-5.2 billion gal produced**
    - **Compare to 140 billion gal/yr for petroleum gasoline**
  - **Lignocellulosic ethanol**
    - **USDA/DOE: ~1.3 billion tons per year available for conversion**
    - **Typical yield: 65-100 gallons/ton**
  - **Biodiesel (e.g., from soy beans): ~250 million gal/yr**
    - **Compare to 62 billion gal/yr for petroleum diesel fuel**
    - **Potential market for up to 1-3 billion gal/yr domestic production from vegetable oils with room for further enhancements**

Advanced new disciplines and capabilities are key

- **New platforms are required to enable discovery and realization of breakthrough S&T**
- **Materials science based approaches to understanding enzyme-substrate interactions**
- **High-throughput microsystem-based techniques for producing and characterizing proteins**
- **New instruments for high-resolution imaging at different scales (molecular, cellular, microbial)**
- **Computational modeling**
- **Synthetic enzymes and new enzyme architectures**







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Ethanol Production Today

- Primary mode of fuel ethanol production: corn kernel (starch) wet and dry milling
  - 4.9 billion gallons produced in 2006
  - Took 13 years to reach 1 billion gallon production levels
- New mandate: double the amount of ethanol blended with gasoline by 2012
- Current tax breaks: $0.51 per gallon
- Nearly half of the gasoline sold in the US contains 10 percent ethanol
- 76 corn ethanol refineries under construction (112 in place already)

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Ethanol Production Today

- Food vs. fuel – corn prices have spiked because of increased demand
  - $4 per bushel, highest in ten years
  - Will result in higher prices across the board for associated products (meat, etc.)
- Ethanol is on track to consume 50% of corn yield (last year 20%)
- Must develop alternative sources of feedstocks and processing to meet Federal goals
- Ethanol derived from cellulosic material is the most viable alternative
  - Believed to cost 5x more today to establish a cellulosic biorefinery

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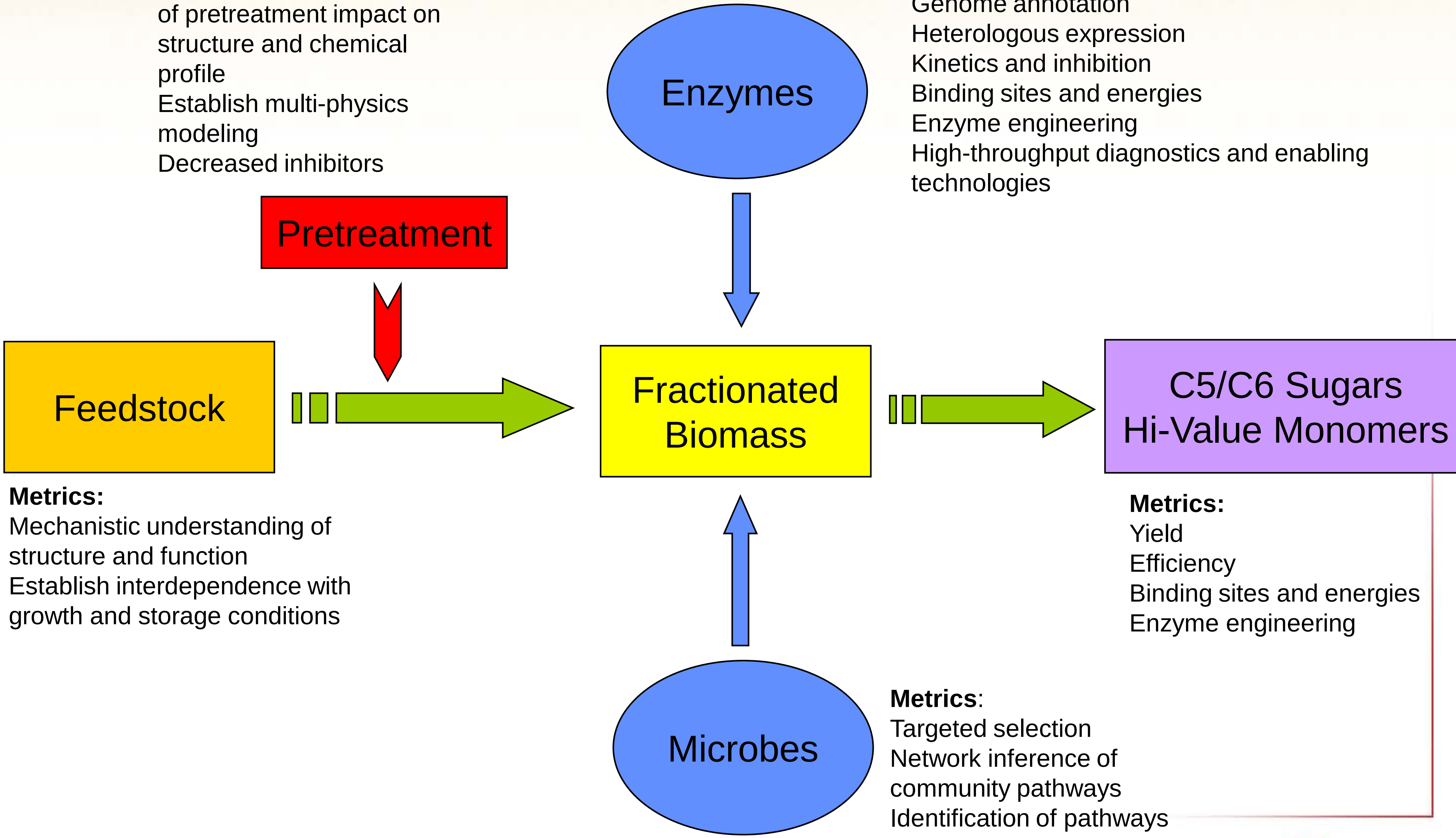
Biomass Processing Flow

Metrics:
Mechanistic understanding of pretreatment impact on structure and chemical profile
Establish multi-physics modeling
Decreased inhibitors

Metrics:
Library development
Genome annotation
Heterologous expression
Kinetics and inhibition
Binding sites and energies
Enzyme engineering
High-throughput diagnostics and enabling technologies



Metrics:
Mechanistic understanding of structure and function
Establish interdependence with growth and storage conditions

Metrics:
Yield
Efficiency
Binding sites and energies
Enzyme engineering

Metrics:
Targeted selection
Network inference of community pathways
Identification of pathways
Isolation of key enzymes
Genome annotation

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A More Sustainable Path? Can it Scale?

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Water & Transportation Fuels Relationship

Fuel Type and Process	Relationship to Water Quantity	Relationship to Water Quality	Water Consumption: Water consumed per-unit-energy [gal / MMBTU] †	Water Consumption: Average gal water consumed per gal fuel
Conventional Oil & Gas	Water needed to extract and refine; Water produced from extraction	Produced water generated from extraction; Wastewater generated from processing;		
- Oil Refining			7 – 20	~ 1.5
- NG extraction/Processing			2 – 3	~ 1.5
Biofuels	Water needed for growing feedstock and for fuel processing;	Wastewater generated from processing; Agricultural irrigation runoff and infiltration contaminated with fertilizer, herbicide, and pesticide compounds		
- Grain Ethanol Processing			12 - 160	~ 4
- Corn Irrigation for EtOH			2500 - 31600	~ 980*
- Biodiesel Processing			4 – 5	~ 1
- Soy Irrigation for Biodiesel			13800 – 60000	~ 6500*
- Lignocellulosic Ethanol and other synthesized Biomass to Liquid (BTL) fuels	Water for processing; Energy crop impacts on hydrologic flows	Wastewater generated; Water quality benefits of perennial energy crops	24 – 150 ‡§ (ethanol) 14 – 90 ‡§ (diesel)	~ 2 - 6 ‡§ ~ 2 - 6 ‡§
Oil Shale	Water needed to Extract / Refine	Wastewater generated; In-situ impact uncertain; Surface leachate runoff		
- In situ retort			1 – 9 ‡	~ 2 ‡
- Ex situ retort			15 - 40 ‡	~ 3 ‡
Oil Sands	Water needed to Extract / Refine	Wastewater generated; Leachate runoff	20 - 50	~ 4 - 6
Synthetic Fuels	Water needed for synthesis and/or steam reforming of natural gas (NG)			
- Coal to Liquid (CTL)		Wastewater generated from coal mining and CTL processing	35 - 70	~ 4.5- 9.0
- Hydrogen RE Electrolysis			20 – 24 ‡	~ 3 ‡
- Hydrogen (NG Reforming)			40 – 50 ‡	~ 7 ‡

† Ranges of water use per unit energy largely based on data taken from the Energy-Water Report to Congress (DOE, 2007)
* Conservative estimates of water use intensity for irrigated feedstock production based on per-acre crop water demand and fuel yield
‡ Estimates based on unvalidated projections for commercial processing; § Assuming rain-fed biomass feedstock production

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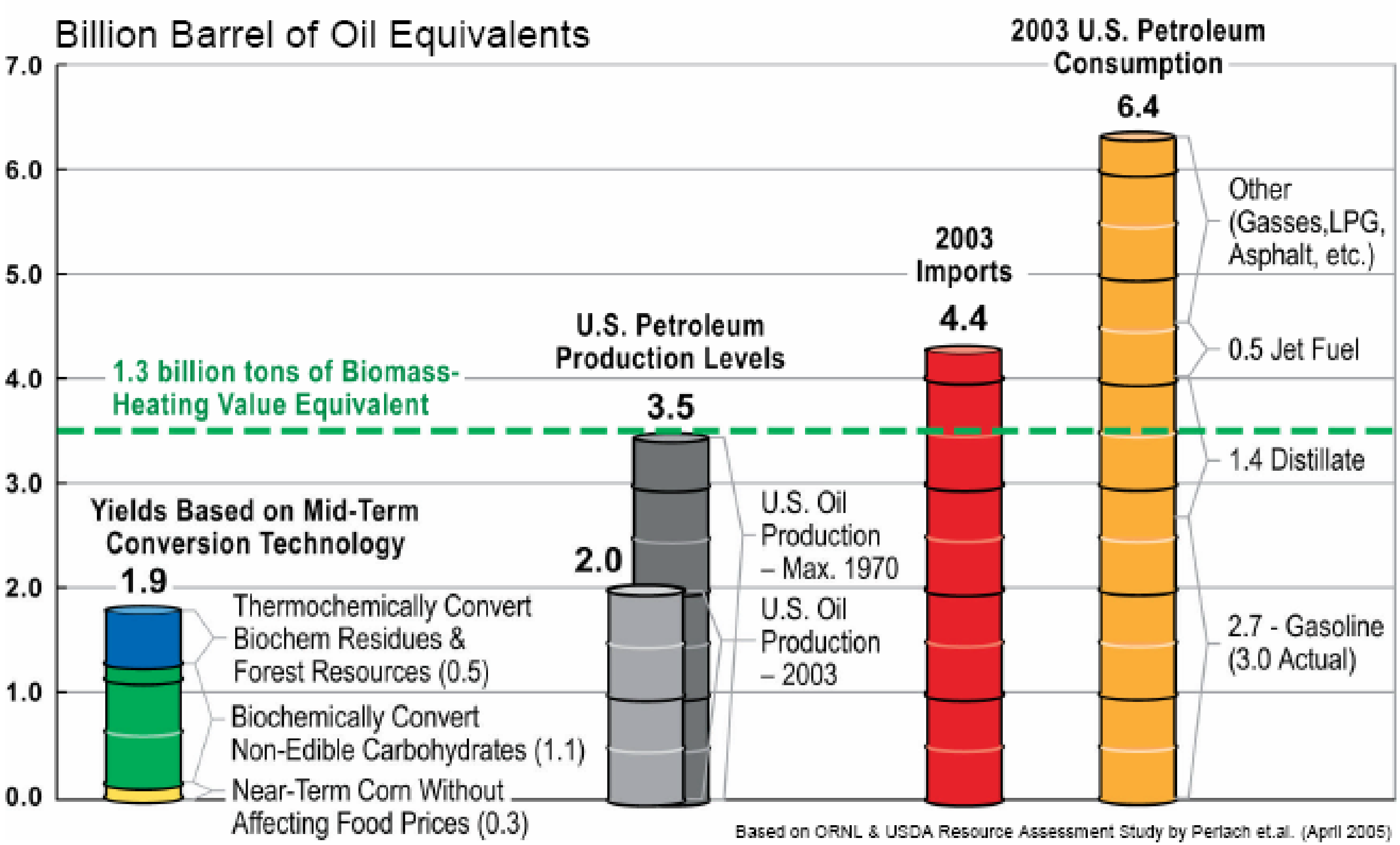
Replacing Petroleum-based Fuels

… is a Huge Challenge !

Significance of the "Billion Ton" Scenario



Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

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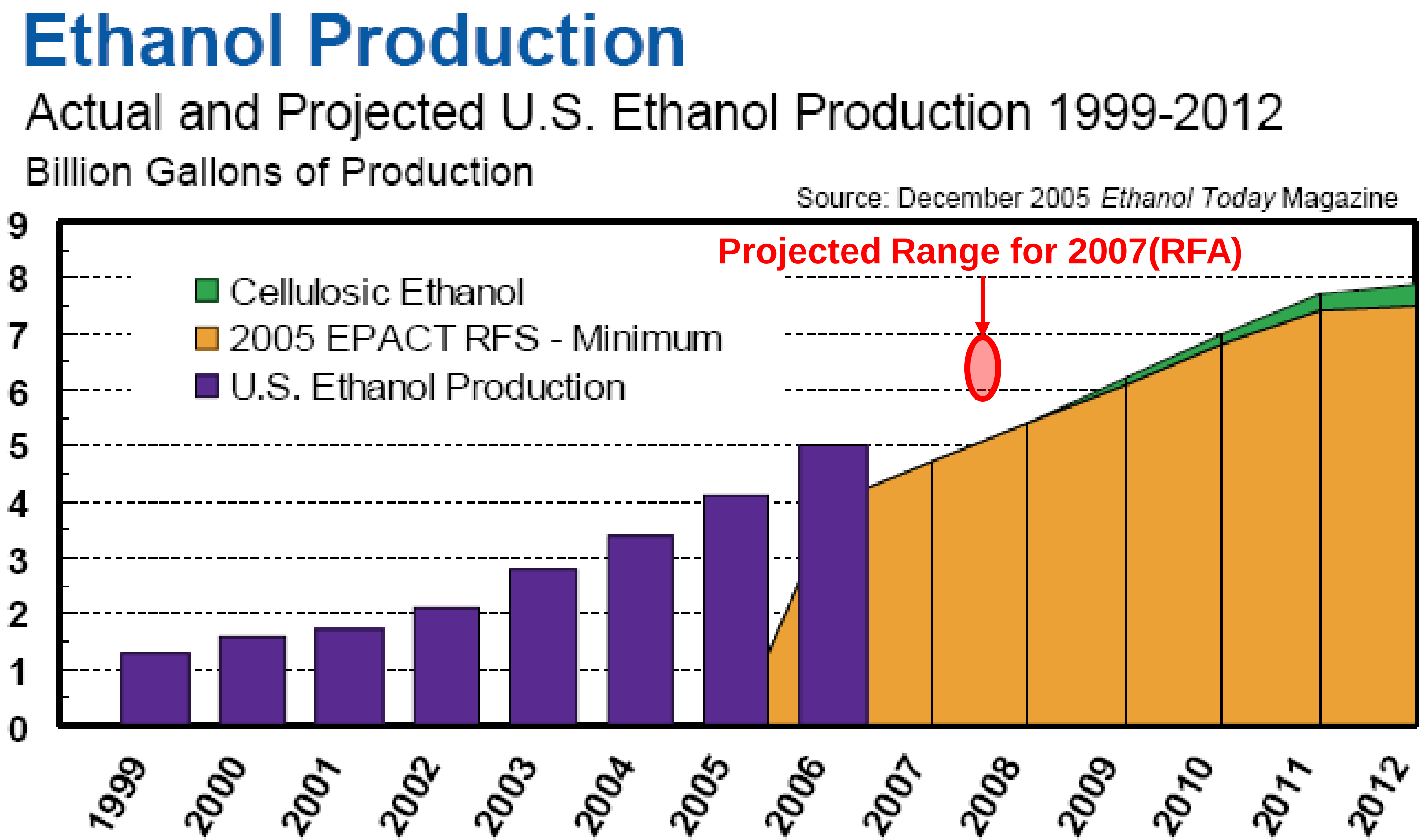
Today's Trends with Corn Ethanol Production Will Increase Water Demand



- **Total U.S. gasoline blend fuel consumption currently ~140 billion gallons/yr**
- **2-6 gallons of water used per gallon of ethanol refined**
- **Irrigated and non-irrigated biofuel feedstock production has potential water concerns**

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Water Impacts of Major Increase in Biofuels and Bioenergy Production

PERGAMON

Global Environmental Change 12 (2002) 253–271

GLOBAL ENVIRONMENTAL CHANGE

www.elsevier.com/locate/gloenvcha

Bioenergy and water—the implications of large-scale bioenergy production for water use and supply

Göran Berndes*

Department of Physical Resource Theory, Chalmers University of Technology and Göteborg University, SE-412 96 Göteborg, Sweden

Abstract

There are major expectations that bioenergy will supply large amounts of CO_2 neutral energy for the future. A large-scale expansion of energy crop production would lead to a large increase in evapotranspiration appropriation for human uses, potentially as large as the present evapotranspiration from global cropland. In some countries this could lead to further enhancement of an already stressed water situation. But there are also countries where such impacts are less likely to occur. One major conclusion for future research is that assessments of bioenergy potentials need to consider restrictions from competing demand for water resources.

MSNBC StarTribune.com
Minneapolis - St. Paul, Minnesota

Water supply can't meet thirst for new industry

By Greg Gordon / StarTribune

"Nowhere is the growing clash between economic development and water conservation more evident than in the push to build ethanol plants that typically guzzle 3½ to 6 gallons of water for every gallon of fuel produced. Minnesota's 15 ethanol plants together consume about 2 billion gallons of water per year, and plants in Winthrop, Windom, Marshall and Granite Falls are straining available water resources."

Decemeber 26, 2005

… Emerging as an energy-water nexus issue
… Needs better understanding
… Needs science-based mitigation strategies

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Why Algae?

- **Greater photosynthetic efficiency than in higher terrestrial plants**
  - Can reach effective levels of 5-10%, compared with typically <0.5% in higher plants
  - Less land "footprint" required relative to biomass production with higher plants
- **Can use impaired waters: brackish, saline, nutrient-rich (contaminated)**
  - Reduced impacts on fresh water supplies
  - Productive use of impaired waters and waste streams
- **Can utilize marginal or otherwise non-agriculturally productive land**
  - Reduced biofuels production impacts on high-value & high-productivity land
  - Reduced impacts on competing agricultural commodity markets
- **Can extract/use CO_2 from Flue gas emissions to enhance growth**
  - >90% efficiency demonstrated in pilot projects (e.g., ASP: Roswell, NM pilot project)
  - Can potentially provide net GHG Abatement "service" and "green credit" value
- **Can extract/use nutrients from contaminated water to enhance growth**
  - Provides wastewater treatment "service" while creating biomass feedstocks
- **Can produce feedstocks for biofuel & other valuable coproducts**
  - Lipid content in algae species can exceed 50%... Input for biodiesel production
  - Coproducts include animal feed, fertilizer, biopolymers, industrial chemicals, etc.
  - Coproducts and services can provide additional energy offset and GHG abatement

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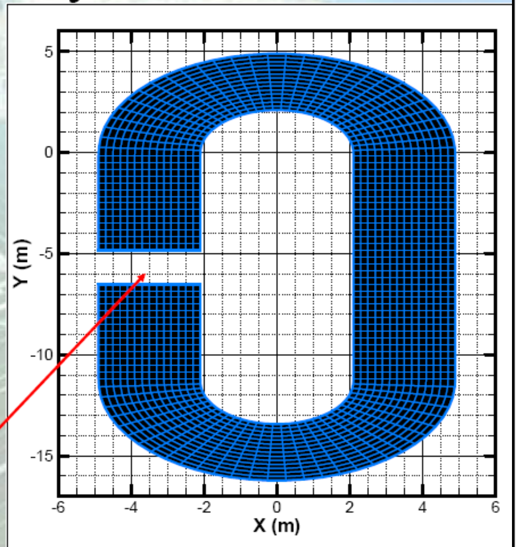
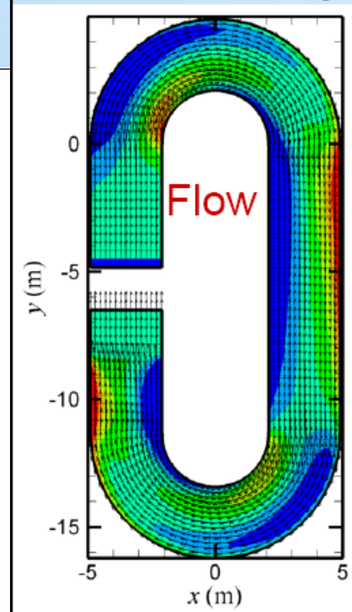
Numerical Example: Algal Raceway Simulation

- Orthogonal grid
- 130 m^2 (0.013 ha)
  - Width: 3 m
  - Length: ~43 m
- 1860 active cells
  - 15 cells across
  - 124 cells around
- Uniform 0.3 m depth
- Withdrawal/return BC added (paddlewheel)



Hydrodynamics



- EFDC solves vertically hydrostatic momentum and continuity equations for turbulent flow
- Withdraw/return BC simulates a paddlewheel
- When properly configured, solution stabilizes quickly
- Explicit numerical solution yields problems amenable for solution on Sandia's large computing clusters

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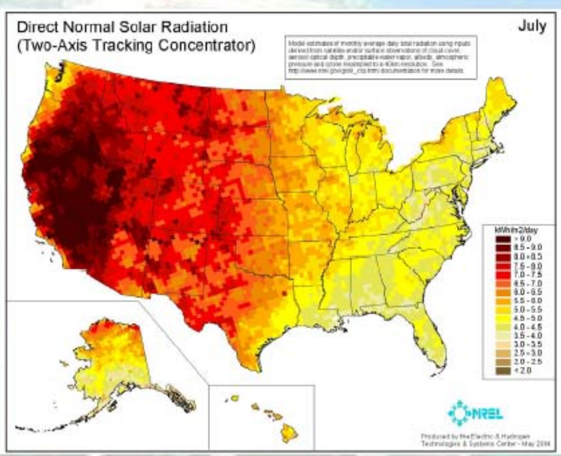
Atmospheric Forcing

- Compiled one year of input data for Palm Springs, CA, 2005
  - January
  - July
- Hourly observations of the following:
  - **Incident radiation**
  - **Temperature**
  - Cloud cover
  - Evaporation
  - Precipitation
  - Relative humidity
  - Atmospheric pressure
  - Wind-driven shear
  - Coriolis forces



*National Solar Radiation Data Base and National Climatic Data Center

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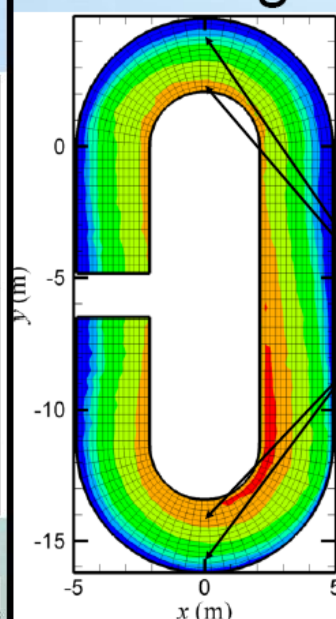
Algal Growth Model



Algal growth is affected by helical flow patterns that mix the water column

- Algal growth kinetics are based on US Army Corp of Engineers' CE-QUAL model
- Includes solar radiation, nutrient availability, predation, temperature, respiration, etc.

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Biofuel Needs and Issues

- **Fundamental understanding of chemical, structural, and electrostatic interactions in biomass as a function of pretreatment and enzymatic hydrolysis.**
- **The role of chemical and structural components in the recalcitrance of biomass.**
- **Understanding substrate affinity and enzyme inhibition due to steric effects and chemical interactions with real-world biomass feedstocks.**
- **Lack of genetic diversity in available registries for cellulase and hemicellulase enzymes that can be used to optimize performance.**
- **Lack of detailed understanding and/or information on cellulosome variance/performance as a function of species isolated from anaerobic communities.**
- **Cost-effective and environmentally benign pretreatments that produce minimal amounts of downstream inhibitors.**
- **Efficient methods of converting lignin into hi-value co-products.**
- **New high-throughput combinatorial screens for pretreatment yields and enzyme activities.**
- **Develop a new philosophy around catalysis design: bio-inspired catalysts capable of performing standard industrial catalytic applications at room temperature with minimal loss in terms of yield, purity, efficiency**

Current Sandia Projects/Efforts Summary

- Internal investment on five projects
- Multi-million dollar investment
- Builds on existing bioscience and modeling capabilities, while establishing new application spaces
- Span several different SMUs → Corporate strategy in place and maturing
- Primarily focused on biochemical processing:
  - Enzyme engineering for enhanced ethanol production
  - Algal biodiesel
  - Co-fermentation of C5 and C6 sugars
  - Microbial communities with enhanced lignocellulose degradation
  - BioFactory Concept Planning (Vipin Gupta)
- Combustion Research Facility projects
- Also have established projects focused in the Energy/Water Nexus
  - Water-Biofuels Interdependencies LDRD

  State of MN Bioenergy/Biotechnology Decision-Support Mod/Sim
  - State of NM Dairy Waste-to-Energy project (with algal biofuel component)
- Prior work has also included thermochemical production of biofuels

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Hydrogen

Daniel Laird

Energy and Infrastructure Future
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Acknowledgments: Paul Pickard (SNL)

Hydrogen

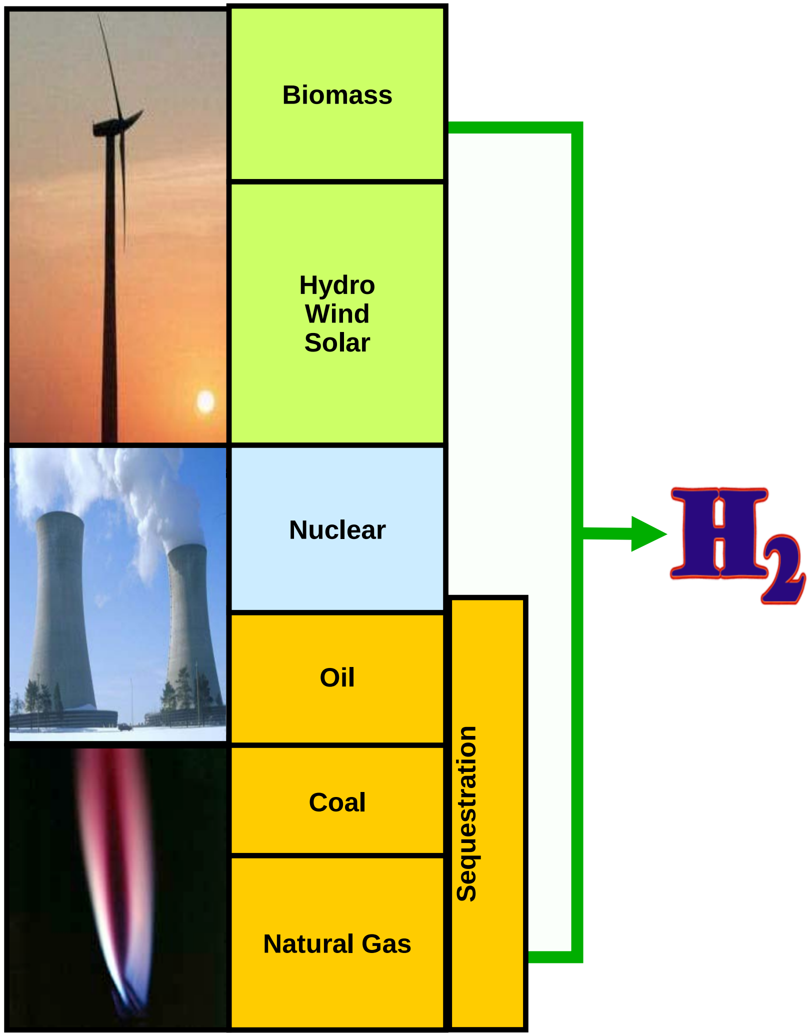
Energy Source

or

Energy Carrier?

Hydrogen Production Options

DOE is examining all possible approaches for H2 production



- **Current Methods**
  - **Conventional Electrolysis**
  - **Methane Reforming**
- **Advanced Methods**
  - ***Thermochemical cycles***
  - ***High temperature electrolysis***
  - ***High temperature interface -- heat exchangers and materials***

Hydrogen Sources

Recent worldwide production data for hydrogen are as follows:

Source	Normal m^3/year (billions)	Share
Natural gas	**240**	**48%**
Oil	**150**	**30%**
Coal	**90**	**18%**
Electrolysis	**20**	**4%**
Total	**500**	**100%**

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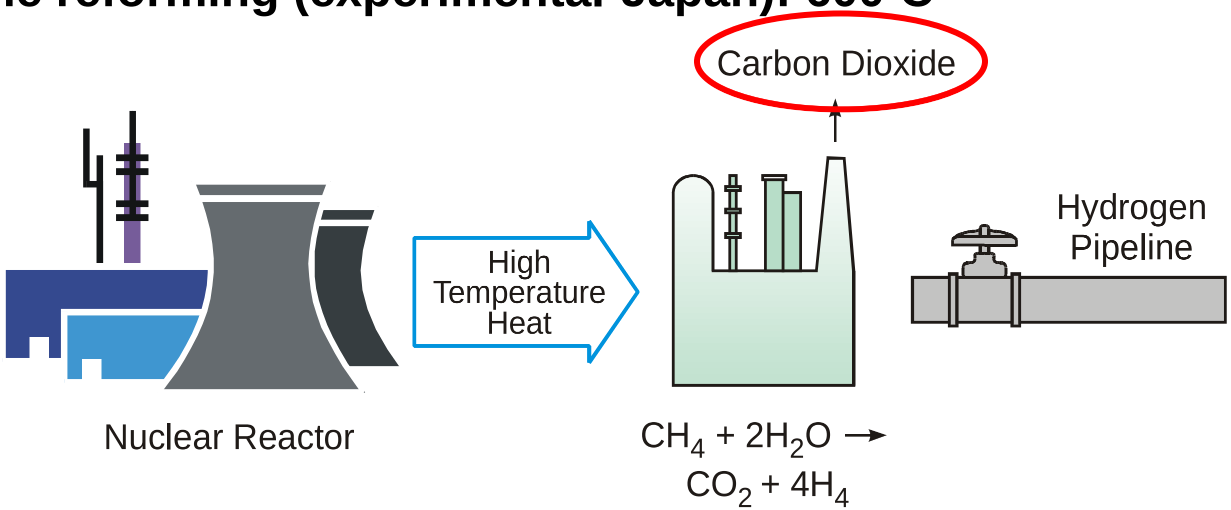
Steam –Methane (Natural Gas) Reforming

High Temperature Heat
Natural Gas as Feedstock

- **Heat + methane (CH_4) + water (H_2O) $\Rightarrow$ hydrogen (H_2) + carbon dioxide (CO_2)**
  - **$CH_4 + H_2O \leftrightarrow CO + 3H_2$**
  - **$CO + H_2O \leftrightarrow CO_2 + H_2$ (Water-Gas Shift Reaction)**
- **Endothermic process**
  - **Current method uses natural gas (CH_4) as heat source (combustion) and the feedstock to make H_2**
  - **Nuclear option replaces the natural-gas heat source**
- **Temperature of heat input dependent upon the process (Traditional: 850°C; membrane reforming (experimental-Japan): 600°C**



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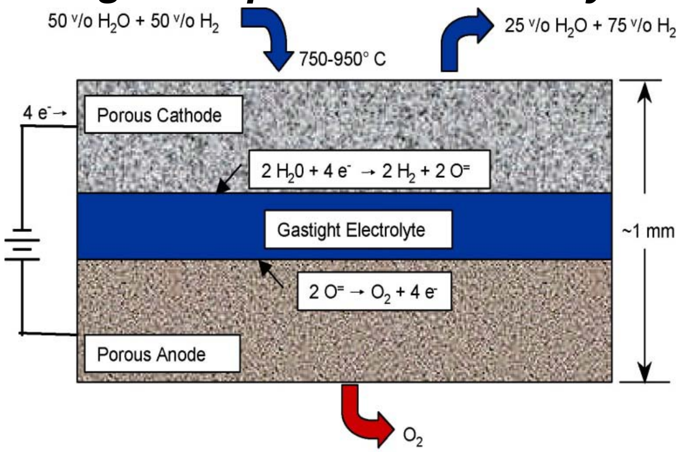
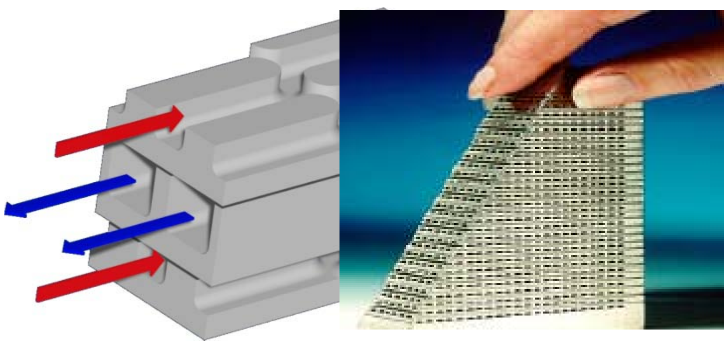
Hydrogen Production Methods for High Temperature Reactors

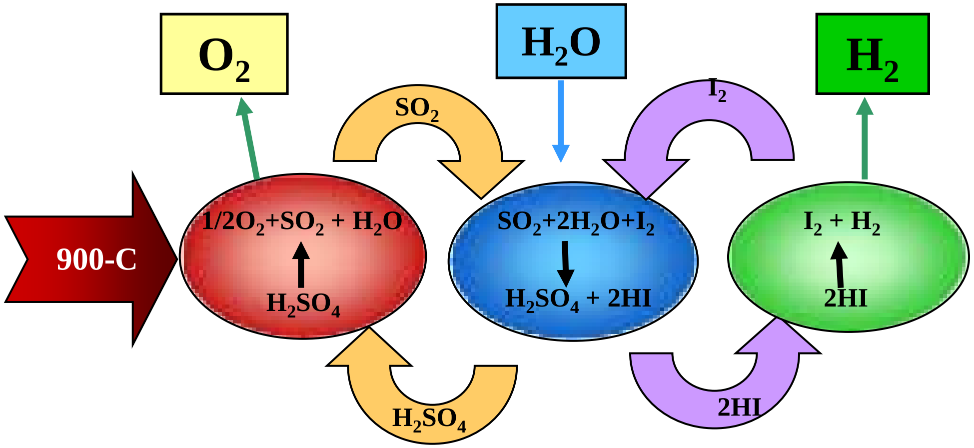
High Temperature Electrolysis



Interface Technologies (HX, Materials)



- Thermochemical Cycles *(Scaling, efficiency)*
- High Temperature Electrolysis *(modular scaling, efficiency)*
- System Interface *(High temp materials and HX design*



Thermochemical Cycles

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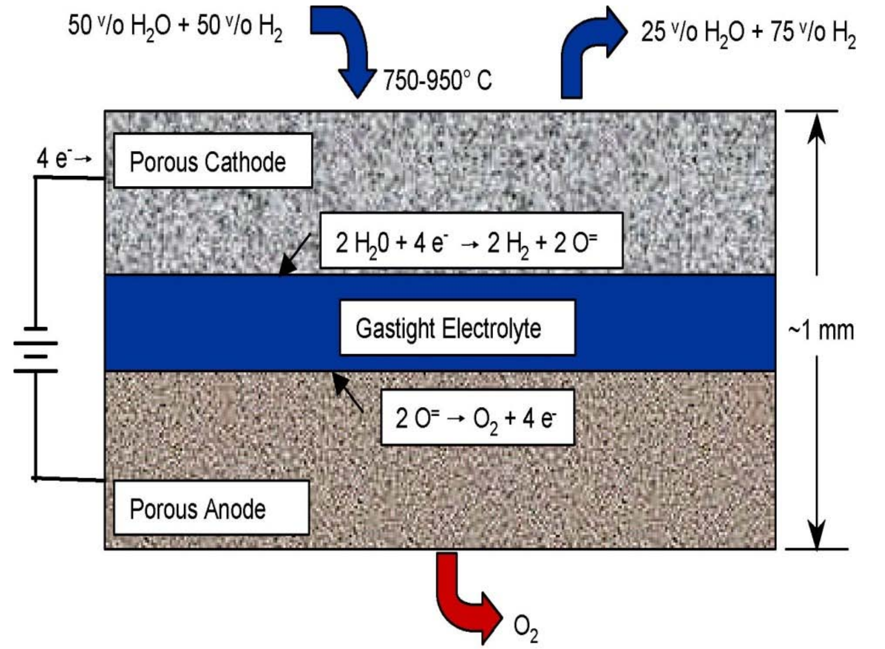
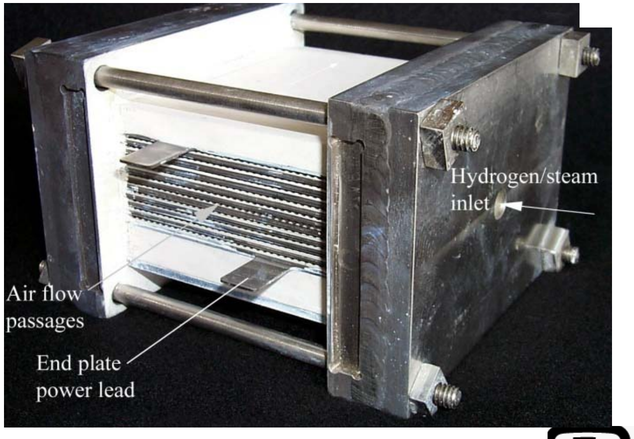
High Temperature Electrolysis has Potential for Higher Efficiency than Conventional Electrolysis

- High temperature (steam) electrolysis
  - potential for higher efficiency (thermal energy fraction, lower cell losses)
- Leverages fuel cell development
  - solid oxide electrolytes
- Technology demonstrated,
  - engineering /cost issues – similar to fuel cell development
- Wider range of source temperatures possible
- No hazardous industrial chemicals

R&D focuses on sealing technology, materials, cell engineering, modular scaling





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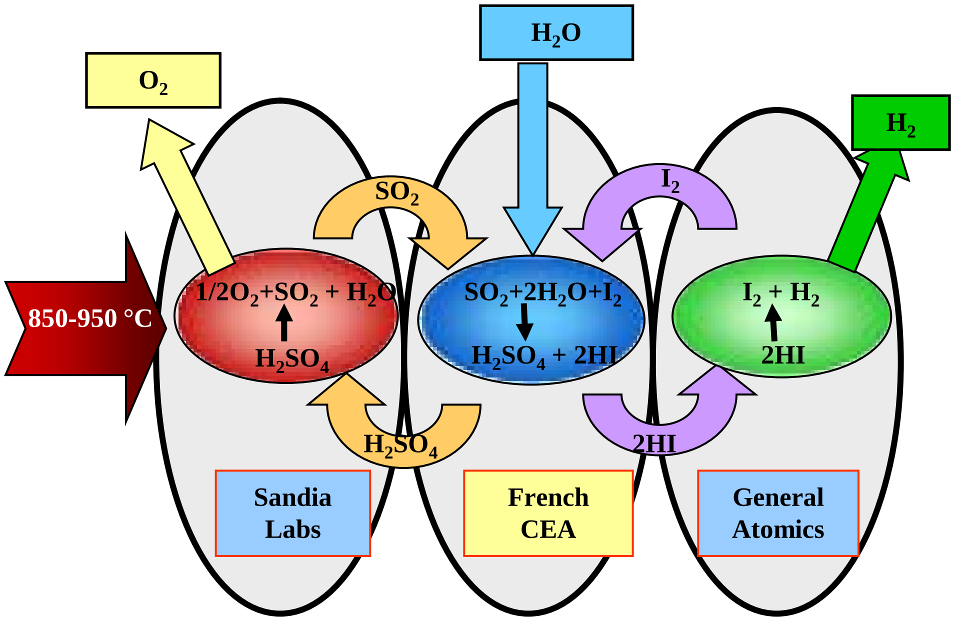
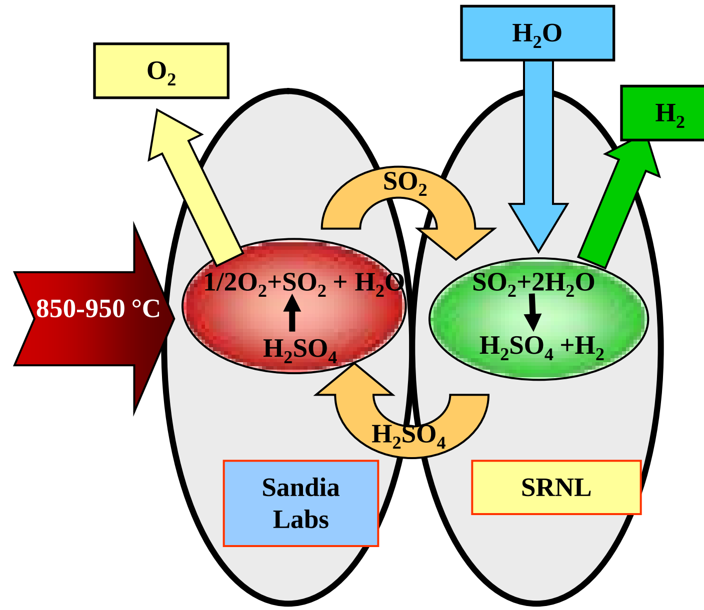
Sulfur Thermochemical Cycles

TC cycles require high temperatures, extensive thermal management, and high temperature, corrosion resistant materials





Sulfur Iodine

(1) $H_2SO_4 \rightarrow H_2O + SO_2 + 1/2O_2$

(2) $2HI \rightarrow I_2 + H_2$

(3) (3) $2H_2O + SO_2 + I_2 \rightarrow H_2SO_4 + 2HI$

Hybrid-Sulfur

(1) $H_2SO_4 \rightarrow H_2O + SO_2 + 1/2O_2$

(2) $2H_2O + SO_2 \rightarrow H_2SO_4 + H_2$

Alternative Cycles

– Hybrid Ca-Br – Argonne National Lab - 45%

- $CaBr_2 + H_2O(g)$ = $CaO + 2HBr$ 750 C
- **$CaO + Br_2$ = $CaBr_2 + ½O_2$ (g) 550 C**
- **2HBr(g) = $H_2 + Br_2$ (g) 25 C**

– K-Bi – Penn State University

- **0.3 $K_3Bi + H_2O$(g) = KOH(l) + H_2 (g) + 0.3 Bi 575 C**
- KOH(l) + 0.3 Bi= .5 O_2 (g) + 0.5H_2 (g) + 0.3 K_3Bi 575 C

– Mg-I – University of South Carolina - 45%

- **6MgO + I_2 (s) = $Mg(IO_3)_2$ (s) + 5MgI_2 (aq) 150 C**
- **$Mg(IO_3)_2$ (s) = MgO + I_2 (g) 600 C**
- **5MgI_2 + 5H_2O(g) = 5MgO + 10 HI(g) 400 C**
- 10 HI (g) = 5H_2(g) + 5I_2(g) 500 C

– Hybrid Cu-Cl – ANL - 42%

- **2Cu + 2HCl(g) → 2CuCl (l) + H_2(g) 450 C**
- **4CuCl → 2$CuCl_2$ + 2Cu 25 C**
- 2$CuCl_2$(s) + H_2O(g) → CuO•$CuCl_2$ (s) + 2HCl(g) 400 C
- **CuO•$CuCl_2$ (s) → 2CuCl(l) + ½O_2(g) 550 C**

– Hybrid Cl - Clemson University - 34%

- Cl2(g) + H2O (g) = 2HCl (g) + ½O2 (g) 850 C
- **2HCl (g) = H2(g) + Cl2(g) 75 C**

– Cu-SO_4 Tulane University - 52%

- CuO + SO2 (g) + H2O = Cu SO4 + H2 (g) 25 C
- **CuSO4 = CuO + SO2 (g) + ½O2 (g) 850 C**

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Future Energy Requirements

Daniel Laird

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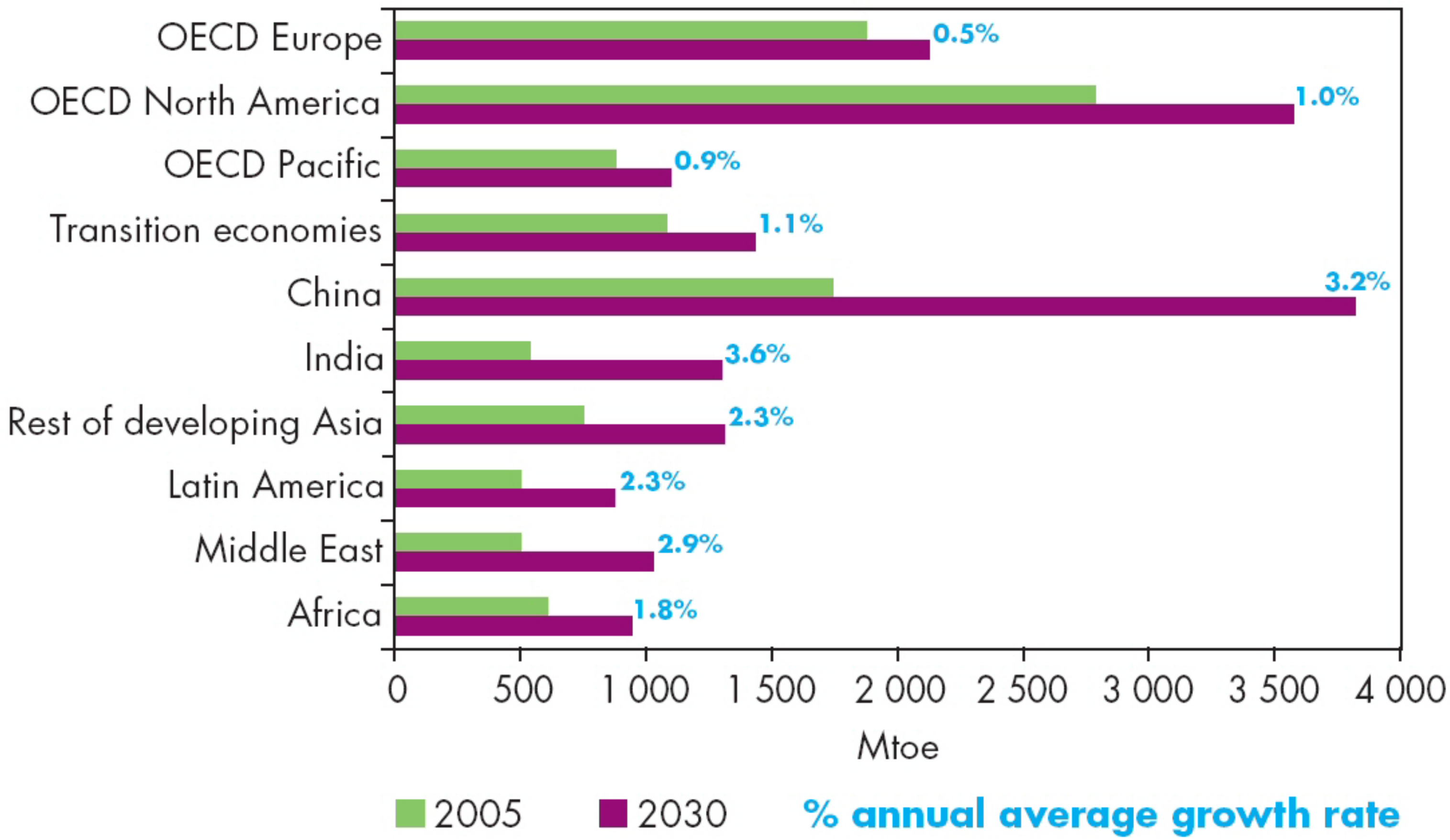
Future Energy Requirements

Figure 1.3: **Primary Energy Demand by Region in the Reference Scenario**



World Total: 11429 17721

IEA WEO2007

Future Energy Requirements

Table 1.8: **World Electricity Demand in the Reference Scenario**
(TWh)

	1980	2000	2005	2015	2030	2005-2030*
OECD	**4 738**	**8 226**	**8 948**	**10 667**	**12 828**	**1.5%**
North America	2 385	4 140	4 406	5 227	6 390	1.5%
Europe	1 709	2 700	2 957	3 467	4 182	1.4%
Pacific	645	1 386	1 585	1 973	2 257	1.4%
Transition economies	**1 098**	**1 015**	**1 099**	**1 381**	**1 729**	**1.8%**
Russia	n.a.	607	647	792	968	1.6%
Developing countries	**958**	**3 368**	**4 969**	**9 230**	**15 180**	**4.6%**
China	259	1 081	2 033	4 409	7 100	5.1%
India	90	369	478	950	2 104	6.1%
Other Asia	129	575	766	1 306	1 927	3.8%
Middle East	75	371	501	779	1 228	3.6%
Africa	158	346	457	669	1 122	3.7%
Latin America	248	626	734	1 116	1 700	3.4%
World	**6 794**	**12 609**	**15 016**	**21 278**	**29 737**	**2.8%**
European Union	*n.a.*	*2 524*	*2 755*	*3 179*	*3 786*	*1.3%*

* Average annual rate of growth.

Higher growth rates than Primary Energy

IEA WEO2007

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Table 3: **Fossil-Fuel Price Assumptions in the Reference Scenario**
(in year-2006 dollars per unit)

	unit	2000	2006	2010	2015	2030
Real terms (year-2006 prices)						
IEA crude oil imports	barrel	32.49	61.72	59.03	57.30	62.00
Natural gas						
United States imports	*MBtu*	*4.49*	*7.22*	*7.36*	*7.36*	*7.88*
European imports	*MBtu*	*3.27*	*7.31*	*6.60*	*6.63*	*7.33*
Japanese LNG imports	*MBtu*	*5.49*	*7.01*	*7.32*	*7.33*	*7.84*
OECD steam coal imports	tonne	39.05	62.87	56.07	56.89	61.17
Nominal terms						
IEA crude oil imports	barrel	28.00	61.72	65.00	70.70	107.59
Natural gas						
United States imports	*MBtu*	*3.87*	*7.22*	*8.11*	*9.08*	*13.67*
European imports	*MBtu*	*2.82*	*7.31*	*7.27*	*8.18*	*12.71*
Japanese LNG imports	*MBtu*	*4.73*	*7.01*	*8.06*	*9.05*	*13.61*
OECD steam coal imports	tonne	33.65	62.87	61.74	70.19	106.14

Note: Prices in the first two columns represent historical data. Gas prices are expressed on a gross calorific-value basis. All prices are for bulk supplies exclusive of tax. Nominal prices assume inflation of 2.3% per year from 2007.

Questionable forecasts of low oil/gas/coal prices going forward

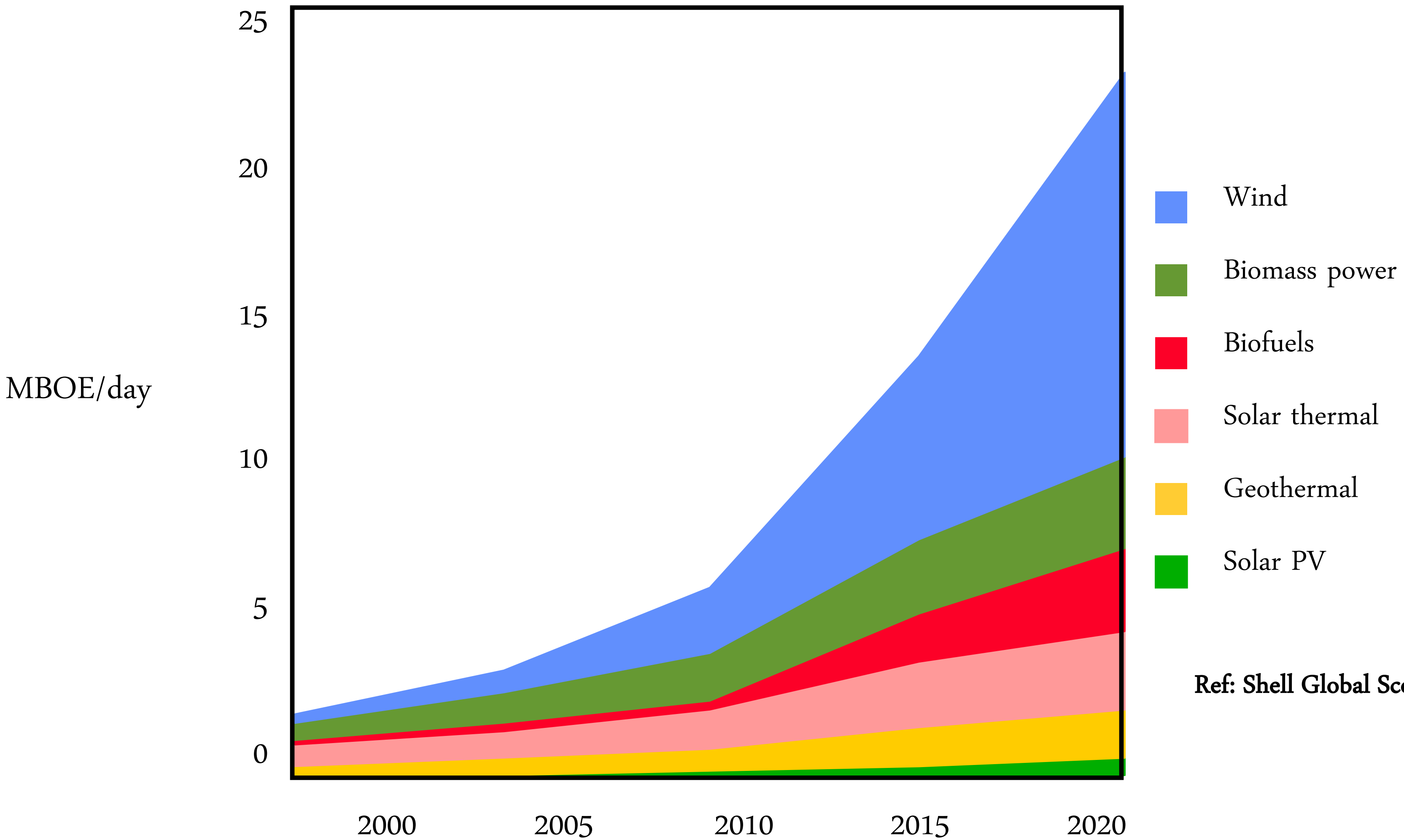
source: IEA WEO2007

EIA Projected New Electric Power Generation Capacity through 2030

- Coal
  - 350, 400 MW steam turbine plants (140,000 MW)
- Natural Gas
  - 150, 100 MW natural gas combined cycle (15,000 MW)
- Renewables
  - 125, 200 MW wind or solar farms (25,000 MW)
- Nuclear
  - 5, 1000 MW nuclear reactors

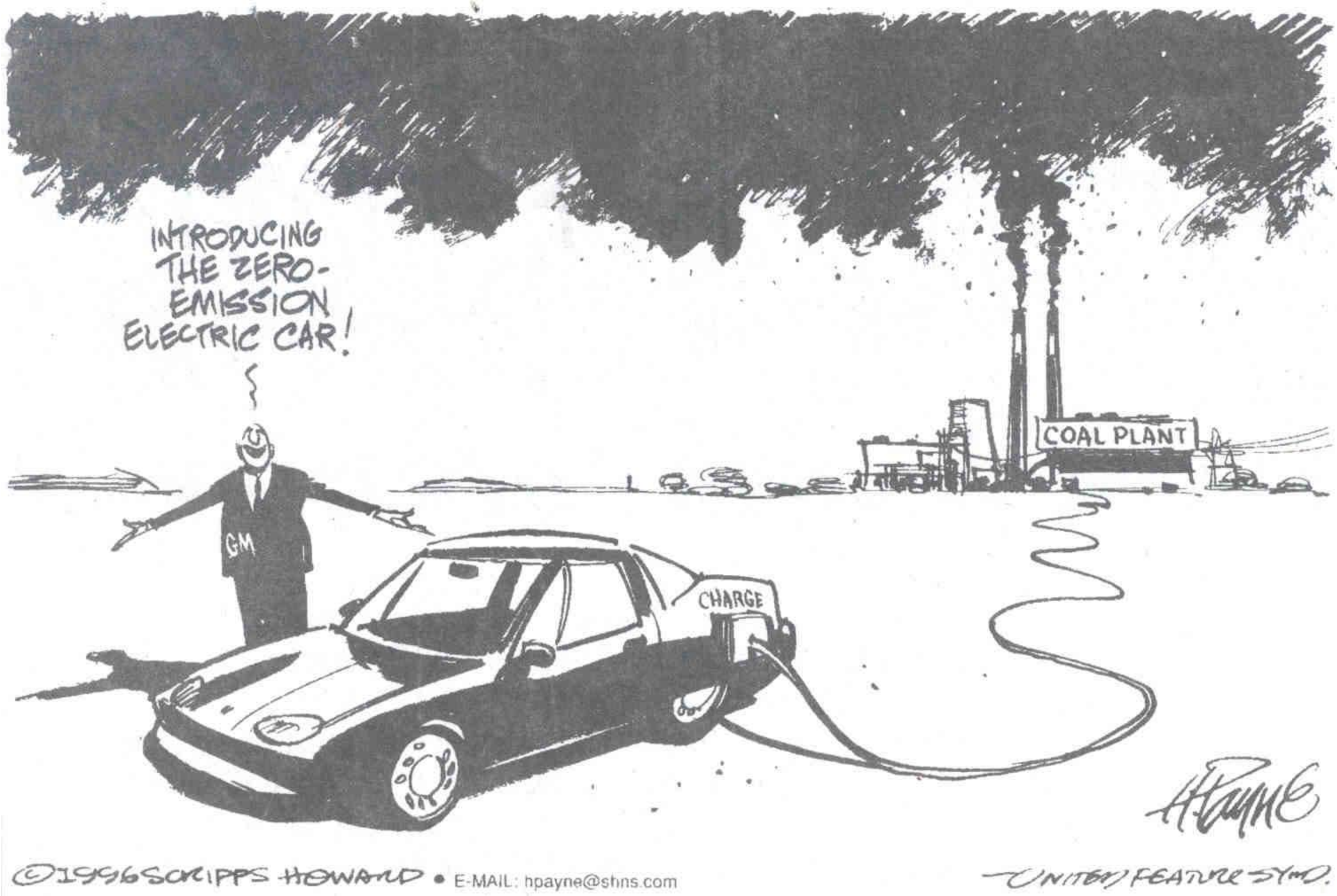
    (5,000 MW)
- Hydroelectric
  - None (~40,000-60,000 MW available)

RE Growth Predictions



Ref: Shell Global Scenarios

Growing Environmental and Ecological Issues and Concerns



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ARRA 2009 (Stimulus Bill)

$22.0 B – PTCs, ITC, Grants, Bonus MACRS

$60.0 B – DOE Loan Guaranty Program for Projects

$ 6.5 B – Bonding authority for BPA and WAPA

$ 2.0 B – 30% ITC for Manufacturing

$ 1.6 B – Added CREBs bonding for public power

$ 4.5 B – Smart Grid funding

$ 1.3 B – DOE R&D funding

$ 2.0 B – Battery research

$ 0.5 B – Worker training

$ 100+B – Total Efficiency & Renewables

Ref: Jim Walker, Renewable Energy World 2009

“Exciting” Future in Energy

- **Limiting carbon may have a profound impact on the global energy picture**
- **Rising prices will cause unrest**
- **Water will be a major issue**
- **Renewable energy technologies**
  - **hydroelectric: significant but limited growth prospects**
  - **geothermal: growing slowly**
  - **solar: growing rapidly, still expensive for bulk power**
  - **wind: growing rapidly, cost competitive source of new bulk power (carbon tax/credits could make it the lowest cost option)**