Energy and Power for 7.14 Billion People

PHYS 4400, Principles and Varieties of Solar Energy

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The University of Toledo

January 13, 2015

But First, discussions of:

- science
- units
- significant figures
- graphs
- Igor Pro
- quizzes
- office hours

Key Elements of the Scientific Method

Scientific method: ask and answer scientific questions through experiment and observation.

The steps of the scientific method are to:

1. Define the question
2. Gather information and resources (observe)
3. Form hypothesis
4. Perform experiment and collect data
5. Analyze data
6. Interpret data and draw conclusions that serve as a starting point for new hypothesis
7. Publish results
8. Retest (frequently done by other scientists)

The iterative cycle inherent in this step-by-step methodology goes from point 3 to 6 back to 3 again.

It is important for your experiment to be a fair test. A "fair test" occurs when you change only one factor (variable) and keep all other conditions the same.

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Thoughts on the Scientific Method

Ibn al-Haytham (Alhazen, 965–1039), pointed out the emphasis on seeking truth:

Truth is sought for its own sake. And those who are engaged upon the quest for anything for its own sake are not interested in other things. Finding the truth is difficult, and the road to it is rough.

According to William Whewell (1794–1866), "invention, sagacity, genius" are required at every step in scientific method. It is not enough to base scientific method on experience alone; multiple steps are needed in scientific method, ranging from our experience to our imagination, back and forth.

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Scientific Method: Beliefs and Biases

Eadweard Muybridge's (1830 – 1904) studies of a horse galloping

The Epsom Derby (1821) by Géricault, Jean Louis Théodore. Oil on canvas.

On units

Use Standard International units wherever possible, and if in doubt, convert your answers back to SI units.

At times, we will use non-SI units – for example, we often talk about photon energy in terms of eV, and you should/will become familiar with how to convert between J and eV.

When converting from one set of units to another, always show your work (see the example near the top of HW #1).

Units analysis allows you to check your work. If you're trying to calculate the rate at which photons strike a surface (photons/sec) and your units end up showing photons/meter, you'll know something's wrong and that you need to go back and correct your work.

Significant figures

"Sig figs"

What do we mean?

Sig figs include all digits except (a) trailing zeros such as 1,000,000 (feel free to use scientific notation: 1.0×10^6, which shows two sig figs), and (b) extra digits that are not merited, arising either from a calculation with numerous digits in the answer, or more digits than are justified by actual or hypothetical instrumentation.

What do we want to avoid?

Avoid including numbers of digits that are clearly beyond our interest for the answers we seek. What is the energy of a 351 nm photon? Three sig figs should do as a start:

$(1240 \text{ eV nm}^{-1}) / 351 \text{ nm} = 3.53 \text{ eV}$ (not 3.53276 eV)

Creating a good graph

We will create graphs of data at times, and when we do, let's make them useful and visually attractive. Think about what your graph is trying to show, and consider how to best present the data.

Always include: axes, axis numerical values and axis labels (with units!).

Use symbols/lines so that even in black and white one can discern the different traces. If you have multiple data sets graphed, include a legend.

Annotate your graph as necessary to tell your story; sometimes the reader/viewer can actually tell almost everything from the graph, and the caption is non-critical.

Nonetheless, always include a caption such as "Figure 1. My cat's power output as a function of the time of day, averaged over 3 days."

Igor Pro 6.1

Mobius - Igor Pro 6.04

File Edit Data Analysis Macros Windows Graph Misc Help Motofit

Using Igor.ihf

- ## Data Browser

The Data Browser is an extension that lets you navigate through the different levels of data folders,
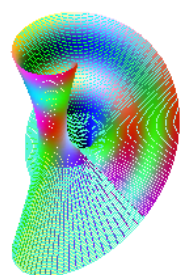
Procedure

```
Function makeMobius(pointsx,pointsy,tmin,tmax)
    Variable pointsx,pointsy,tmin,tmax

    Variable i,j,s,arg,ds,tt,dt
    Make/O/n=(pointsx,pointsy,3) mobius
    ds=2*pi/(pointsx-1)
    dt=(tmax-tmin)/(pointsy-1)

    for(i=0;i<pointsx;i+=1)
        s=i*ds
        for(j=0;j<pointsy;j+=1)
            tt=tmin+j*dt
            arg=1+cos(s/2)*tt
            mobius[i][j][0]=cos(s)*arg
            mobius[i][j][1]=sin(s)*arg
            mobius[i][j][2]=tt*sin(s/2)
        endfor
    endfor
End
```

Notel

0

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Igor Reference.ihf

laguerreGauss(p, m, r)

The LaguerreGauss function returns the normalized product of the associated Laguerre polynomials and a Gaussian. This function is typically encountered in solutions to physical problems where it represents the radial solution with an additional factor $\exp(i*m*\phi)$ which is not included in this case. The laguerreGauss is given by

$$U_{pm}(r) = \left[\frac{2\,p!}{\pi(m+p)!}\right]^{1/2} \left(\sqrt{2}r\right)^m L_p^m(2r^2)\exp\left(-r^2\right).$$

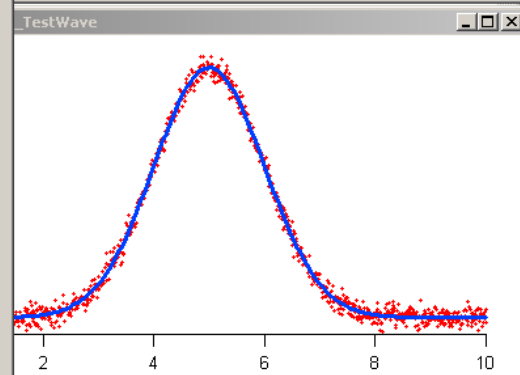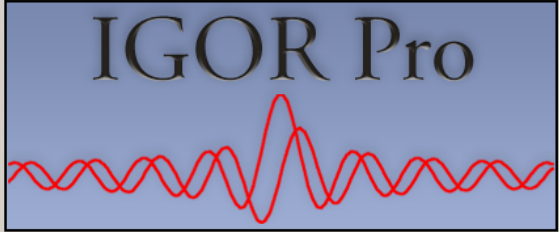**See Also**

Gauss, hermiteGauss.

lameStr)

rns a string containing a semicolon-separated list of keywords
object in a page layout or overall properties of the page layout.
Info is to allow an advanced Igor programmer to write a procedure
hiects

About Igor Pro

Version: 6.0.4.0

IGOR Pro

© 1988-2008 WaveMetrics, Inc. All Rights Reserved
P.O. Box 2088 / Lake Oswego, Oregon 97035 / USA
(503) 620-3001 / sales or support@wavemetrics.com

www.wavemetrics.com

OK

License...

Gizmo0_1

_TestWave

·Display TestWave
·Make/O/N=1000 TestWave
·SetScale/i x,0,10, TestWave
·
·TestWave = Gauss(x,5,1)+gnoise(.01)

StatsCircularTwoSample1
StatsCMSSDCDF
StatsCochranTest
StatsContingencyTable
StatsCorrelation
StatsDExpCDF
StatsDExpPDF
StatsDIPTest
StatsDunnettTest
StatsErlangCDF
StatsErlangPDF
StatsErrorPDF
StatsEValueCDF
StatsEValuePDF
StatsExpCDF
StatsExpPDF
StatsFCDF
StatsFPDF
StatsFriedmanCDF

Help

StatsCorrelation$(waveA\,[,\,waveB\,])$

The StatsCorrelation function computes Pearson's correlation coefficient between two real valued arrays of data of the same length. Pearson r is give by:

$$r = \frac{\sum_{i=0}^{n-1}\left(waveA[i]-A\right)\left(waveB[i]-B\right)}{\sqrt{\sum_{i=0}^{n-1}\left(waveA[i]-A\right)^2 \sum_{i=0}^{n-1}\left(waveA[i]-A\right)^2}}.$$

Here A is the average of the elements in $waveA$, B is the average of the elements of $waveB$ and the sum is over all wave elements.

Details

If you use both waveA and waveB, then the two waves must have the same number of points.

Ready

Igor Pro 6.1 (www.wavemetrics.com)

Igor Pro information (please note)

http://www.wavemetrics.com/support/demos.htm

Download the IgorPro Demo (available for either Mac or Windows), and use this information for the S/N and the Activation Key.

Serial Number: 50023

Activation Key: x

Quizzes and Office Hours

Quizzes will be 20-25 minutes. The quizzes will test your comprehension of fundamental concepts important to understanding solar energy.

Our goal: for you to learn a great deal about solar energy, and if some of the material we're studying doesn't stick, we'll try again on the most important aspects.

My philosophy on office hours is that I am quite available each week and almost each day – you can contact me by email, by phone (530-3874), or in person – and I will respond as quickly as I can. So I normally do not schedule office hours, but I can if you request this.

I encourage students who are facing barriers to keep me informed and feel free to arrange to meet with me. Students are expected to work hard and solve problems on their own, but as the instructor, I am here to help keep you on that path when you need ideas on how to proceed.

Humanity's Top Ten Problems for next 50 years

1. **ENERGY**
2. *WATER*
3. *FOOD*
4. *ENVIRONMENT*
5. *POVERTY*
6. *TERRORISM & WAR*
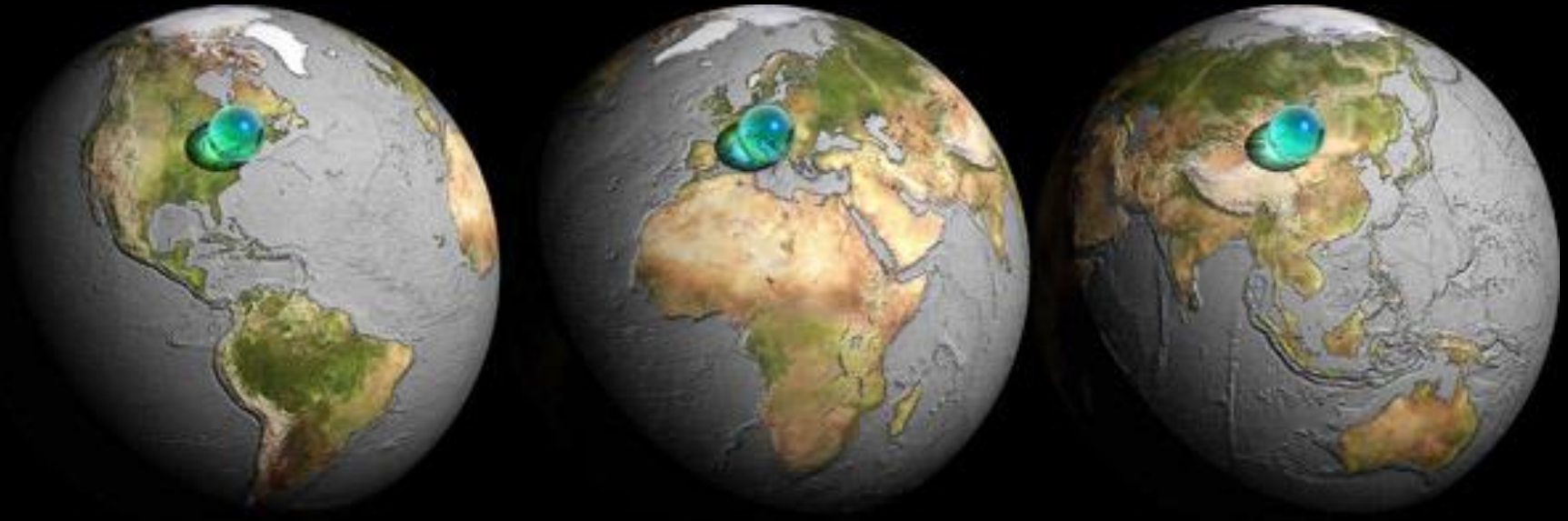7. *DISEASE*
8. *EDUCATION*
9. *DEMOCRACY*
10. *POPULATION*

List developed by Nobel Laureate, Richard Smalley, while surveying colleagues from 2002-2003

Year	Population	
~~2006~~	~~~ 6.5~~	~~Billion People~~
2014	~ 7.15	Billion People
2050	~ 10	Billion People

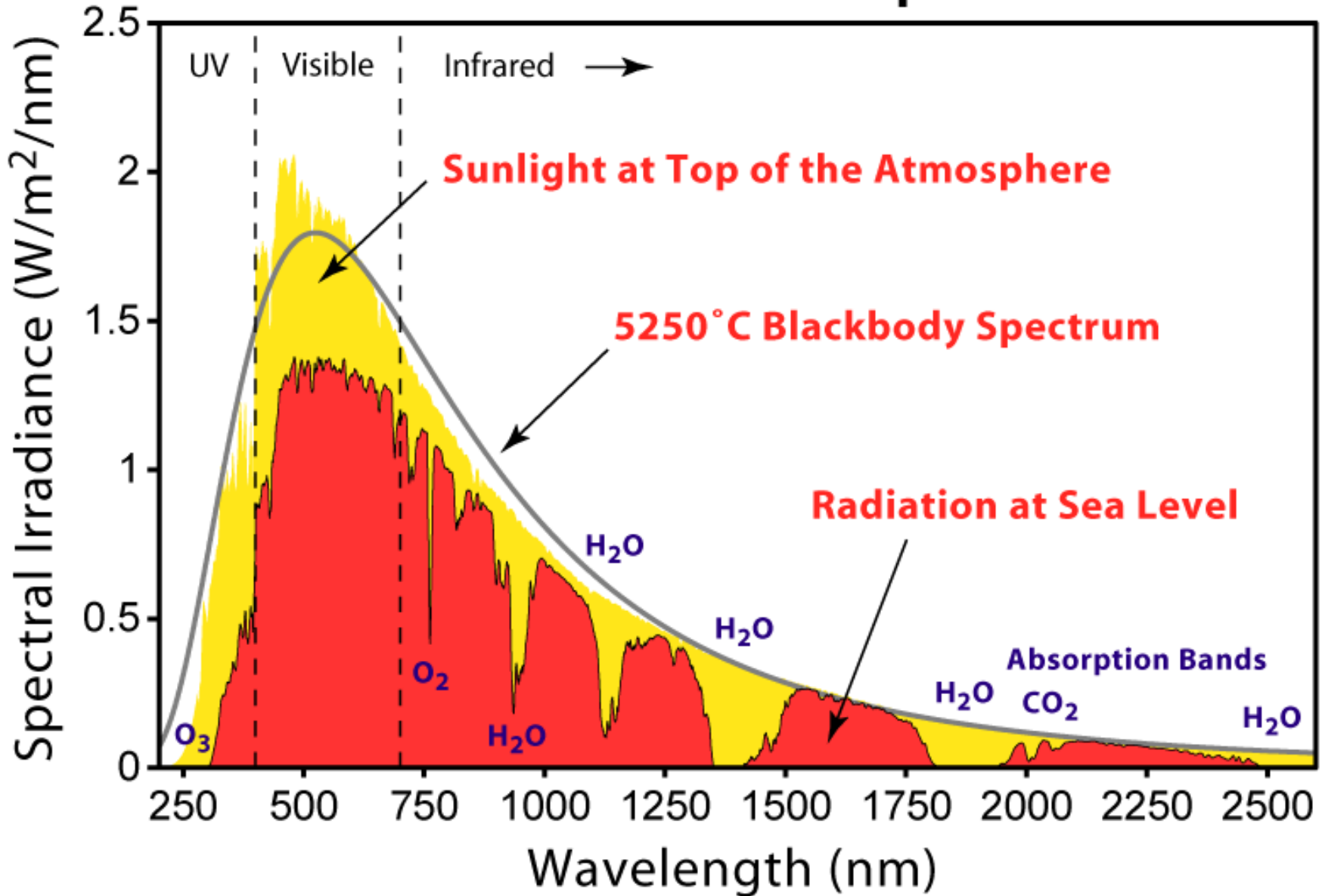http://www.agci.org/library/presentations/about/presentation_details.php?recordID=16950

Volume of Earth: 1.1×10^{12} km^3
Volume of water: 1.4×10^{9} km^3
Volume of atmosphere: 4.2×10^{9} km^3

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Solar Radiation Spectrum

UV | Visible | Infrared →

Sunlight at Top of the Atmosphere

5250°C Blackbody Spectrum

Radiation at Sea Level

H_2O

H_2O

O_2

H_2O

O_3

H_2O

H_2O CO_2

H_2O

Absorption Bands

Spectral Irradiance (W/m²/nm)

Wavelength (nm)
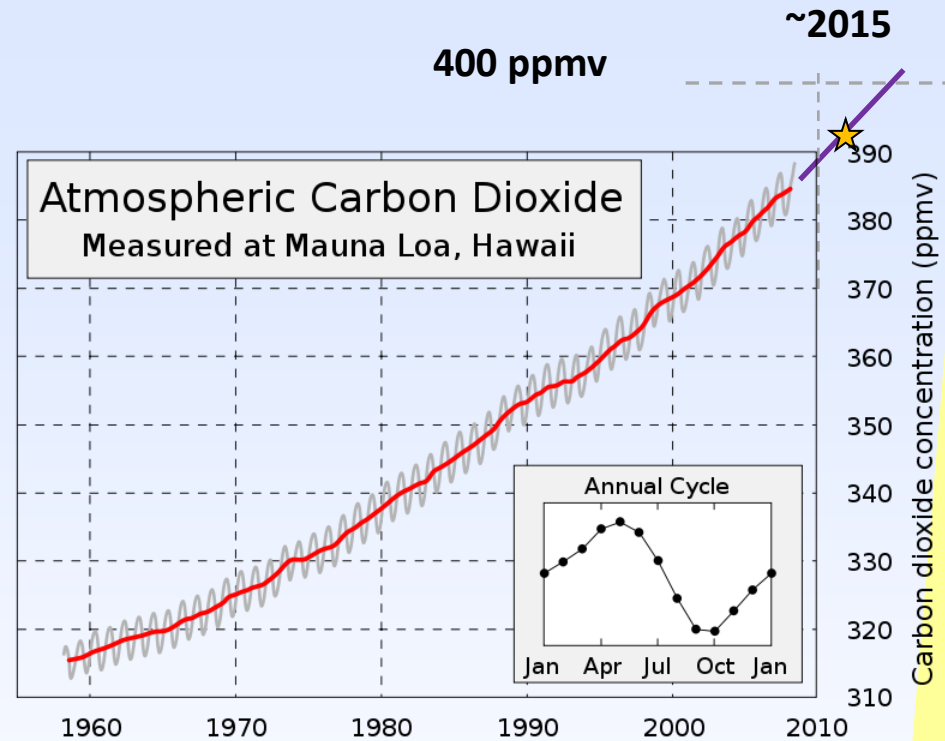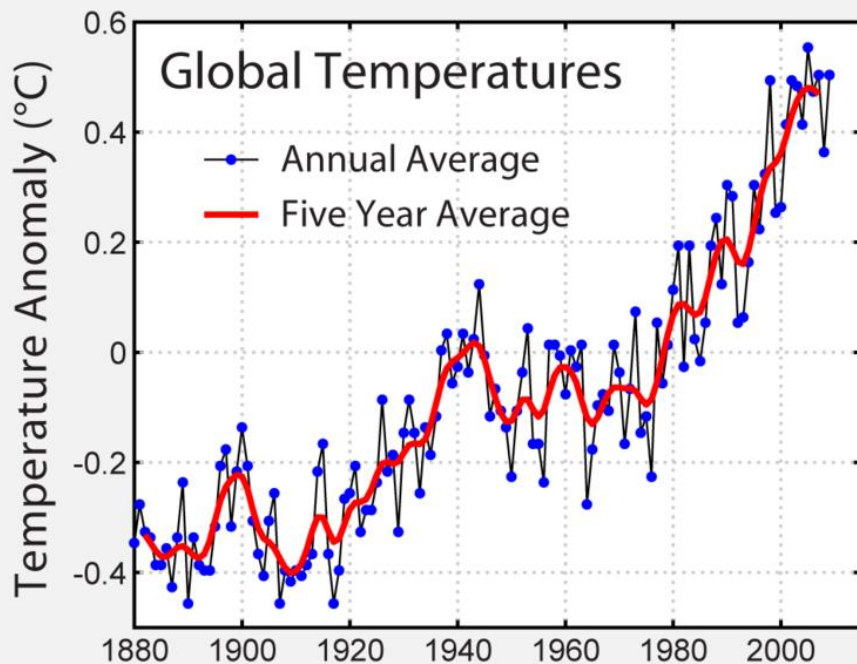
On watch: global temperatures, atmospheric CO_2

Global average temperatures from NASA's *Goddard Institute for Space Studies* (Columbia University). Data set follows methodology developed by J. Hansen.
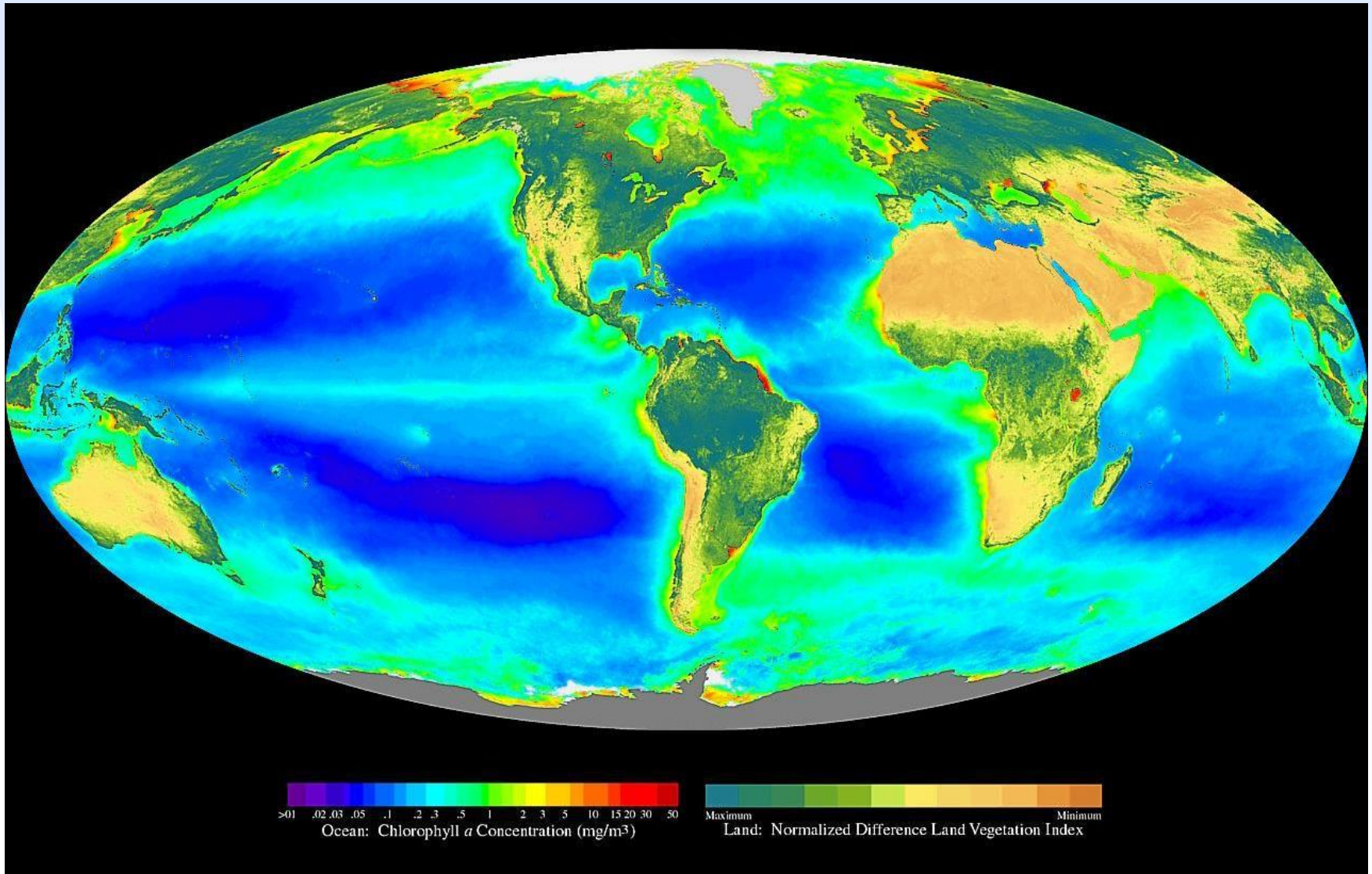
400 ppmv

~2015

Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii

Annual Cycle

Jan Apr Jul Oct Jan

Carbon dioxide concentration (ppmv)

390
380
370
360
350
340
330
320
310

1960   1970   1980   1990   2000   2010

Global Temperatures

- Annual Average
- Five Year Average

Temperature Anomaly (°C)

0.6
0.4
0.2
0
-0.2
-0.4

1880 1900 1920 1940 1960 1980 2000

Keeling curve, data from Mauna Loa, Hawaii. (Charles David Keeling)

- All 2012 measurements show CO_2 > 390 ppmv

Hansen, J., et al. (2006) "*Global temperature change*", PNAS 103: 14288-14293.

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Global distribution of photosynthesis, including both oceanic phytoplankton and terrestrial vegetation

Ocean: Chlorophyll a Concentration (mg/m³)

>01 .02 .03 .05 .1 .2 .3 .5 1 2 3 5 10 15 20 30 50

Land: Normalized Difference Land Vegetation Index

Maximum — Minimum

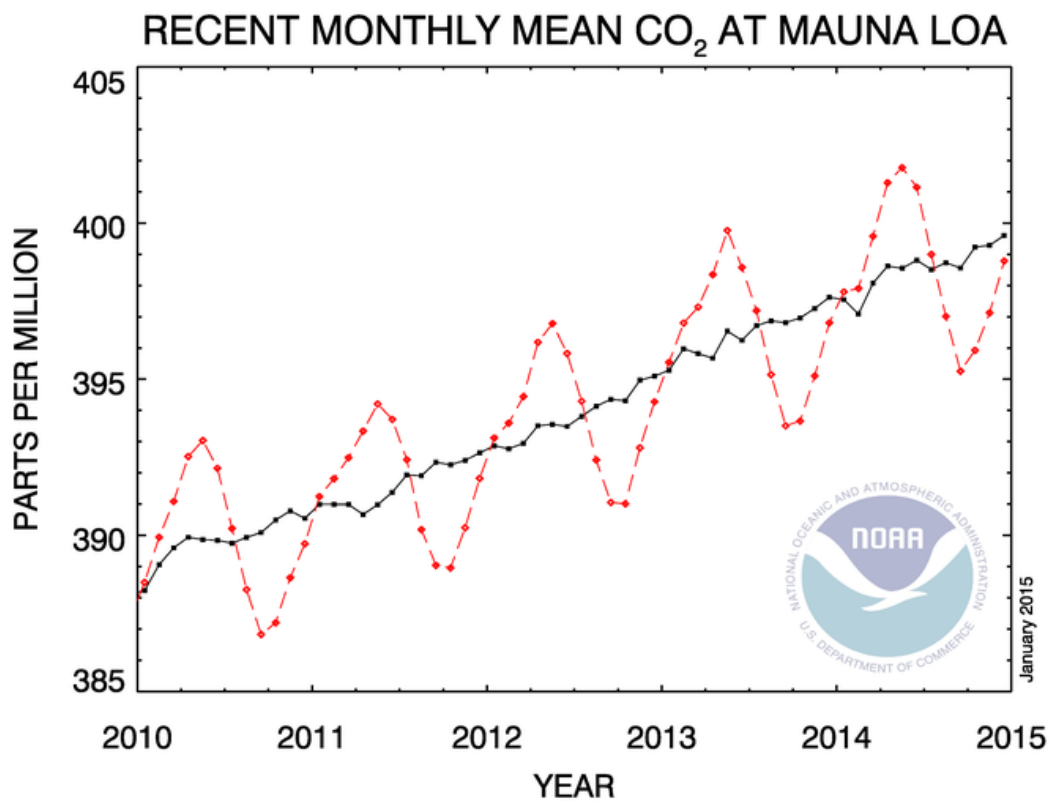*.... energizing Ohio for the 21st Century*

On watch: global temperatures, atmospheric CO_2

Recent Monthly Average Mauna Loa CO_2

December 2014:   398.78 ppm
December 2013:   396.81 ppm
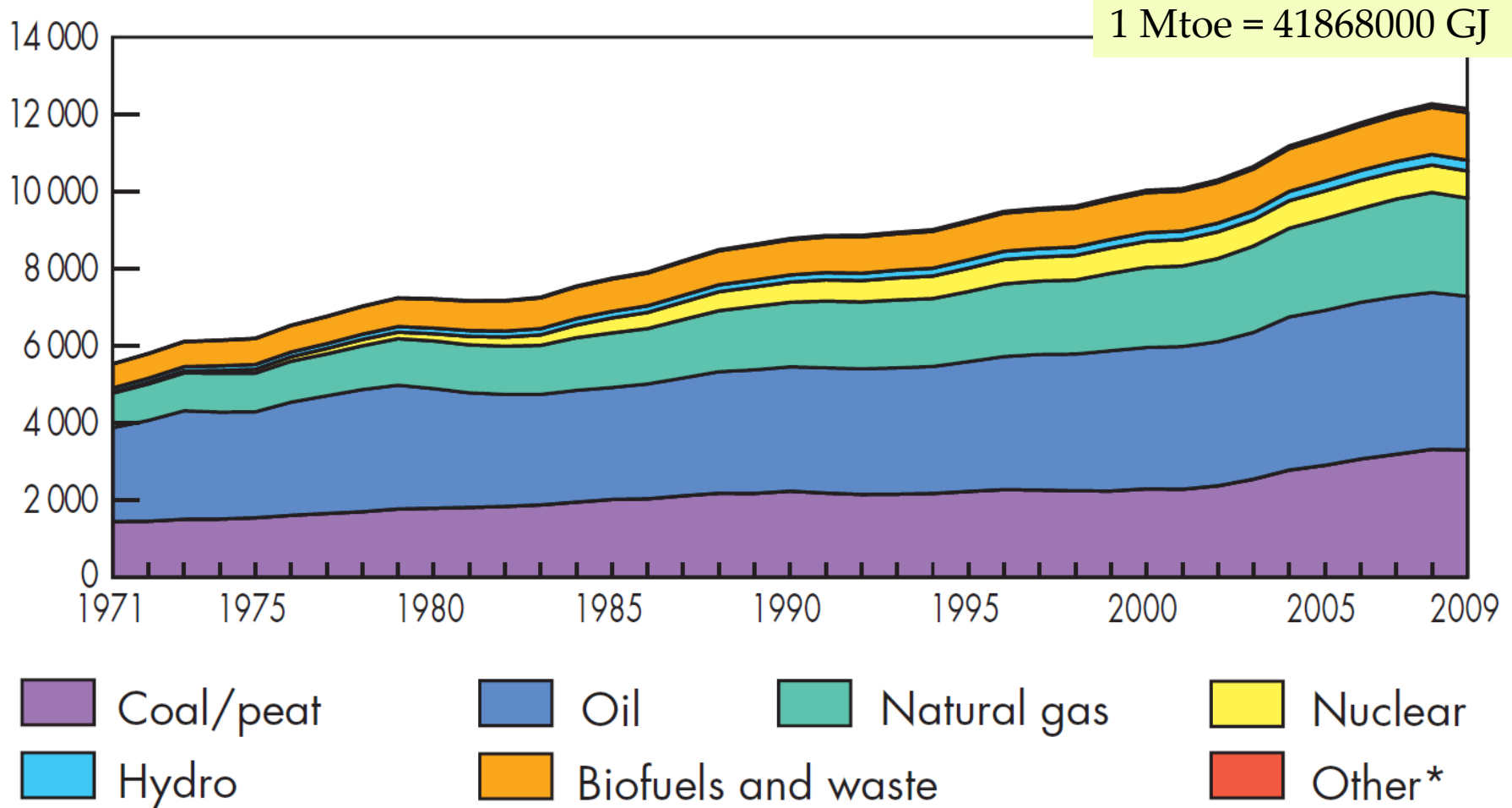
Last updated: January 6, 2015

RECENT MONTHLY MEAN CO_2 AT MAUNA LOA

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420,000+ years of atmospheric CO_2 levels

Keeling atmospheric
CO_2 data set

CO_2 Concentration ppm

Vostok ice core
atmospheric CO_2 data set

Year, kyr BP

from N. Lewis, Cal Tech
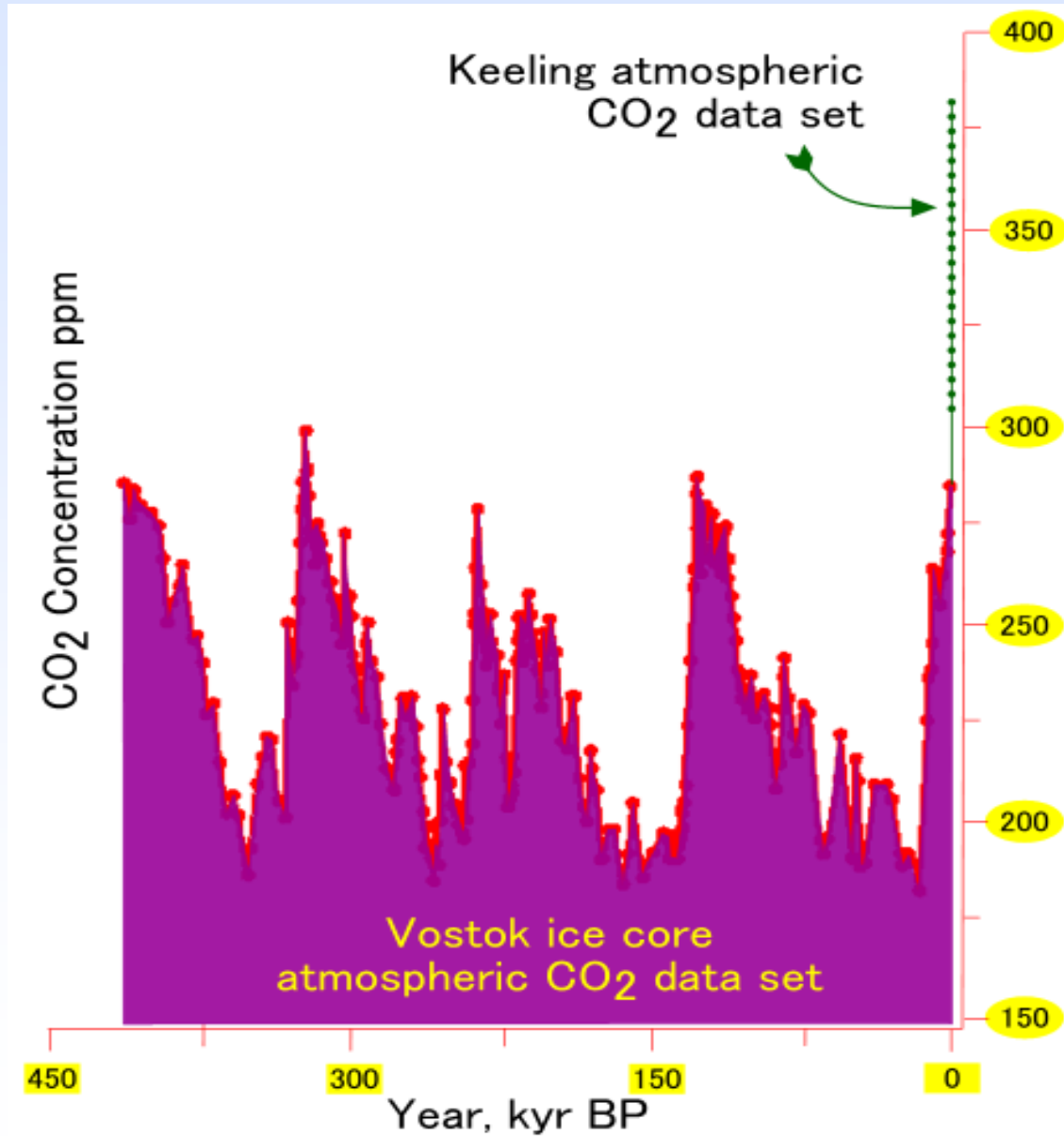
Energy for People (forms of energy)

World total primary energy supply from 1971 to 2009 by fuel (Mtoe)

1 Mtoe = 41868000 GJ

Legend:
- Coal/peat
- Oil
- Natural gas
- Nuclear
- Hydro
- Biofuels and waste
- Other*

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Energy for People: *2009*

Final energy consumed refers to the form of the energy prior to it's ultimate use.

Primary energy pie chart:
- Coal/peat 27.2 %
- Oil 32.8%
- Natural gas 20.9%
- Nuclear 5.8%
- Hydro 2.3%
- Biofuels and waste 10.2%
- Other* 0.8%

Final energy consumed pie chart:
- Electricity 17.3%
- Other** 3.3%
- Coal/peat 10.0%
- Oil 41.3%
- Natural gas 15.2%
- Biofuels and waste 12.9%

Fossil fuels sum to ~81% of our primary energy.

60 EJ represents ~ 12% of the annual global primary energy supply.

How much primary energy goes toward food?

The rest would be photosynthesis...

Figure 1: Global Food Energy Production 1961-2007

Food Energy Production (PJ /yr)

Human Population

Legend:
- Total
- Plants
- Animals
- Population

http://crash-watcher.blogspot.com/

Energy and Power

Dealing with **energy** and **power** in:

$$1 \text{ kW·hr} = 3.6 \times 10^6 \text{ J}$$

	⚡ Standard International Units	🐈 Everyday Life*
Energy	Joule	kW·hr
Power	Watts (1 W = 1 J/sec)	Watts

Energy is the amount of total work that can be completed (by a force).
Power is the *rate* at which the energy is converted (dE/dt).

A toaster is a good benchmark for power → typically at the 1,000 W (1 kW) power level.

Leave a toaster on for an hour continuously → 1 kW·hr. Same as a 100 W bulb left on for 10 hrs. Cost is about $0.12/ kW·hr, but leave one on for a year?

How much energy is used to light this room for 10 hours?

* Average cat generates ~5 W of heat during sleep, and ~24 W walking briskly

Household *electrical* energy consumption

According to [http://www.eia.doe.gov/cneaf/electricity/esr/table5.html], the average US home consumes 920 kW-hr/month, or about 11,000 kW-hr/year.

Usage Information

Usage Comparison

Historical Usage Information

Sep 10	303	Mar 11	302
Oct 10	304	Apr 11	289
Nov 10	326	May 11	352
Dec 10	476	Jun 11	312
Jan 11	458	Jul 11	476
Feb 11	402	Aug 11	213
		Sep 11	277

A-Actual   E-Estimate   C-Customer   N-No Usage
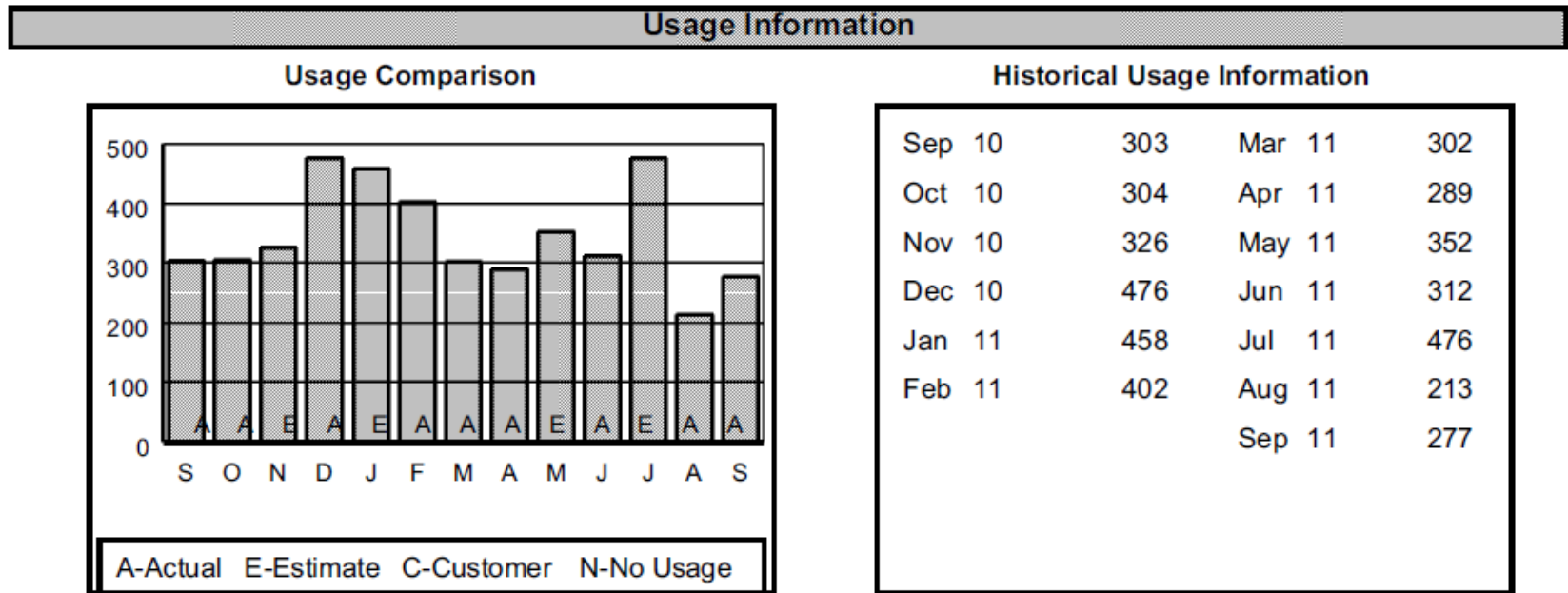
	Sep 10	Sep 11
Average Daily Use (KWH)	10	9
Average Daily Temperature	69	69
Days in Billing Period	30	30
Last 12 Months Use (KWH)		4,187
Average Monthly Use (KWH)		349

Average per-capita (total) energy consumption per day: World average is ~8 kW-hr/day; U.S. average is ~39 kW-hr/day.

How Ohio's Electric Power Generation Stacks Up

CONTRIBUTIONS OF FUEL SOURCES TO TOTAL ELECTRIC GENERATION
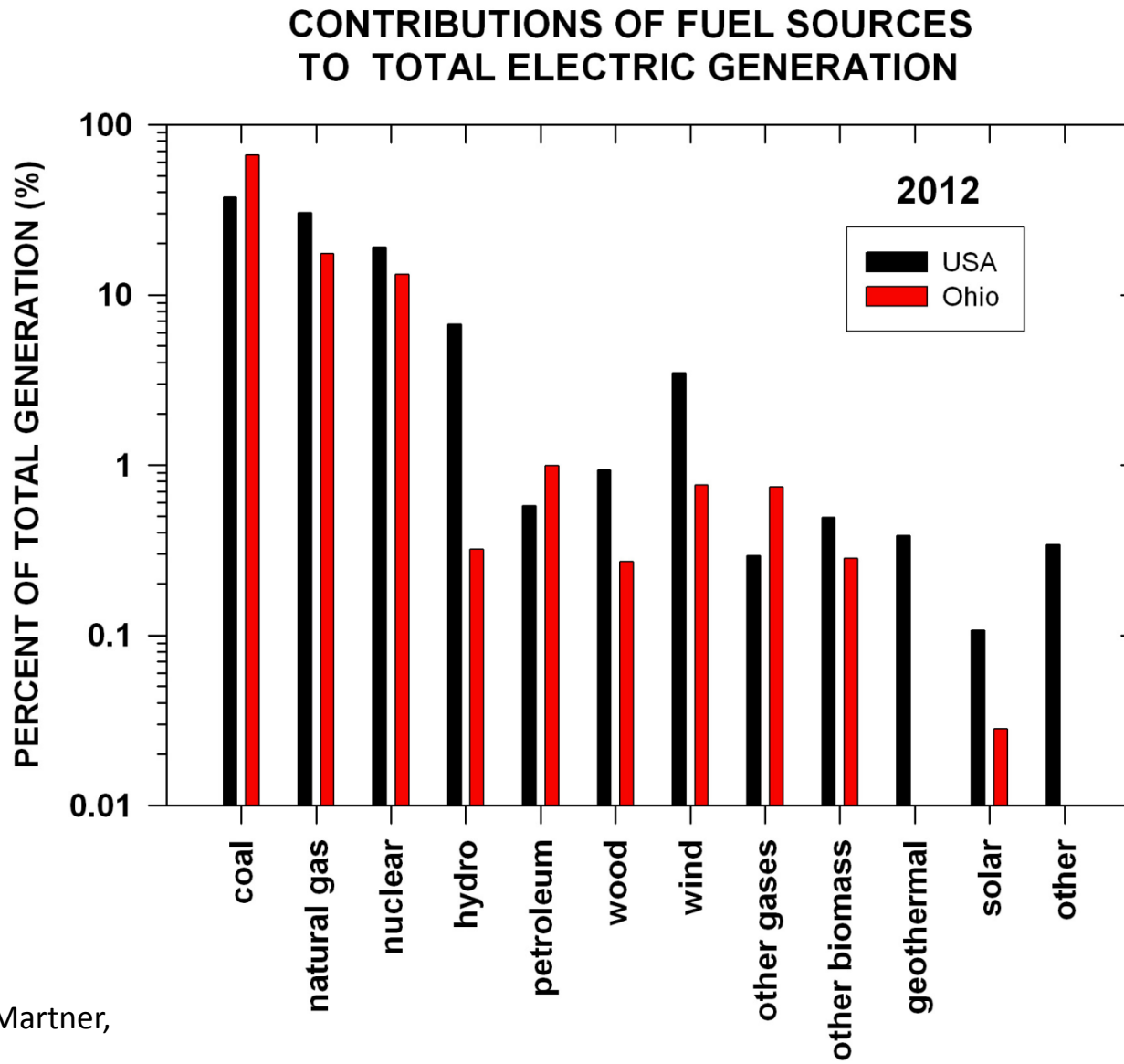
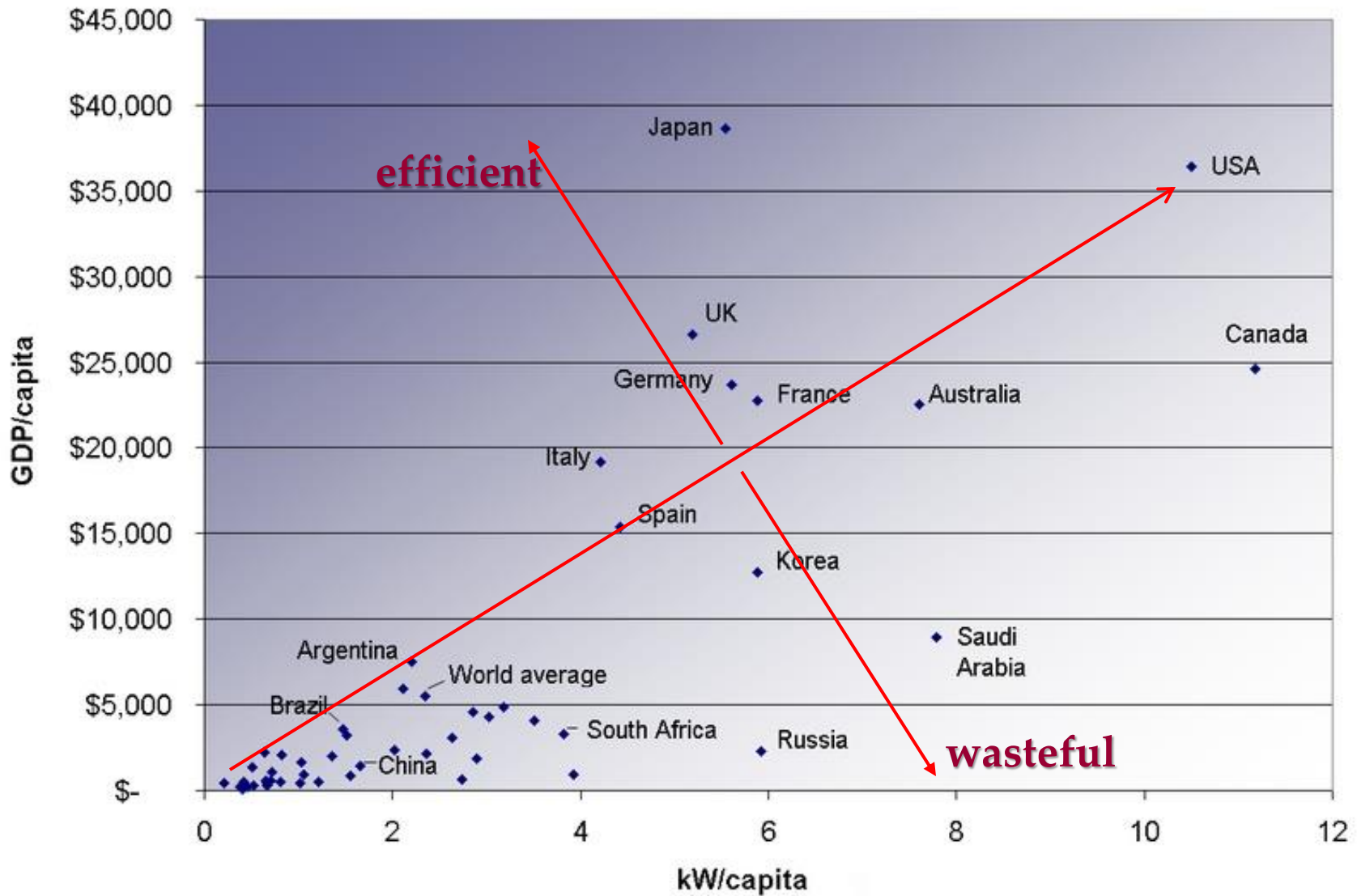Graphs by Brooks Martner, Lafayette, CO
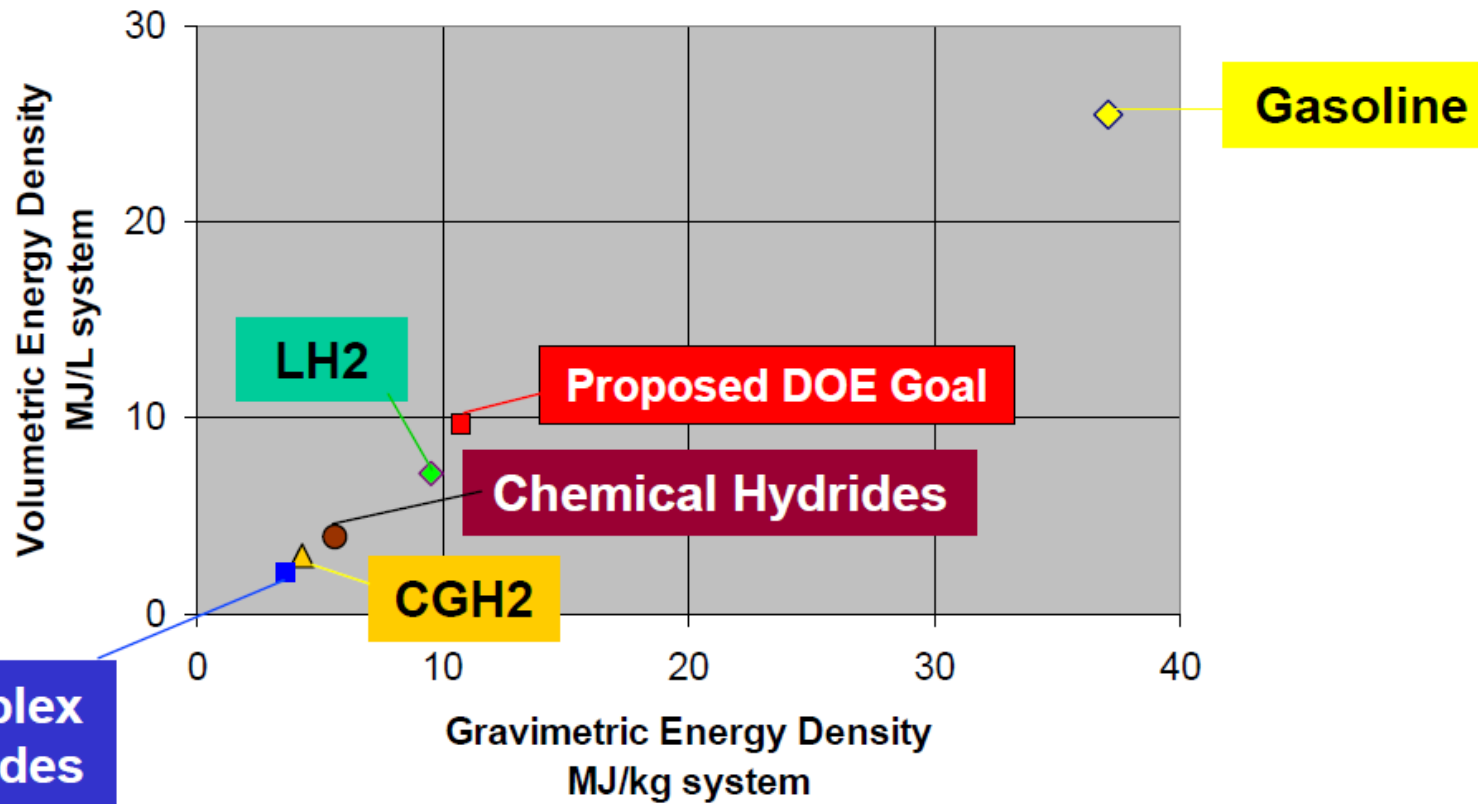
"Gasoline was great."

-- from R. Smalley's energy talk (2003)

Energy Consumption and GDP

From: Wikimedia Commons

Forms of Energy (physics problems)

- Gravitational potential energy: $Pe_g = mgh$
  http://hyperphysics.phy-astr.gsu.edu/hbase/gpot.html
  Note: mass in kg, g in m/s^2, and h in m yields units of kg m^2 s^{-2}, which is equivalent to the joule
  Ignoring air resistance (friction), an object dropped from a height h will reach a velocity such that the PE has been converted fully to KE (see below) by the point just before striking the ground.

- Kinetic energy: $KE = \frac{1}{2} mv^2$, where for m in kg and v in m/s, we again arrive at kg m^2 s^{-2}

- Light energy: the energy of a photon is given by $E_{ph} = hc/\lambda = h\nu$, where h is Planck's constant = 6.63×10^{-34} J s, so that e.g. a photon of wavelength λ = 500 nm has a frequency $\nu = c/\lambda = (3 \times 10^8$ m/s$)/500$ nm $= (3 \times 10^8$ m/s$) / (500 \times 10^{-9}$ m$) = 6 \times 10^{14}$ Hz = 600 THz; and the energy of the photon is $E_{ph} = (6.63 \times 10^{-34}$ J s$)(3 \times 10^8$ m/s$) / (500 \times 10^{-9}$ m$) = 3.98 \times 10^{-19}$ J.

- Thermal energy: What is the (thermal) energy of a sheet of Al foil (weight = 2 g) in an oven at 350 F?

Need for clean energy

NATURE, VOL. 395, 29 OCTOBER 1998
Energy implications of future stabilization of Atmospheric CO_2 content
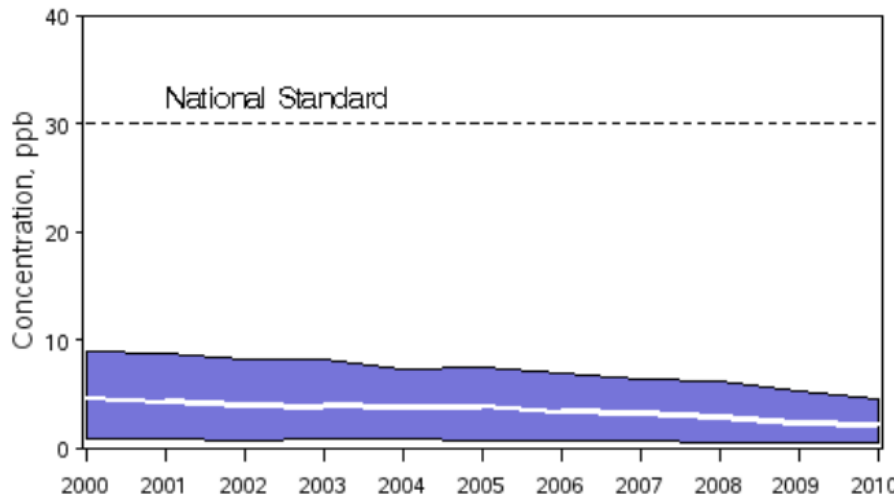M. Hoffert et al.

Growth in energy consumption

- Grow... ...verage ~1.6-1.7% per ... *at a rate of 2.0%*

- Inclu...

- 28 T... *re*

- Popu... ...ries → increased C- in...

SO2 Air Quality, 2000 - 2010
(Based on Annual Arithmetic Average)
National Trend based on 341 Sites

2000 to 2010 : 60% decrease in National Average

Health

Coal-fired power ...
- significant ...
- majority of ...
- ~4% of tota...
- largest poll... ...smog (ozone), soot →
...ecosystems, respiratory
...unhealthy lungs (incl.

...velopmental toxin, affecting unborn children

All U.S. power plants: release over 41% of U.S. CO_2 in 2009

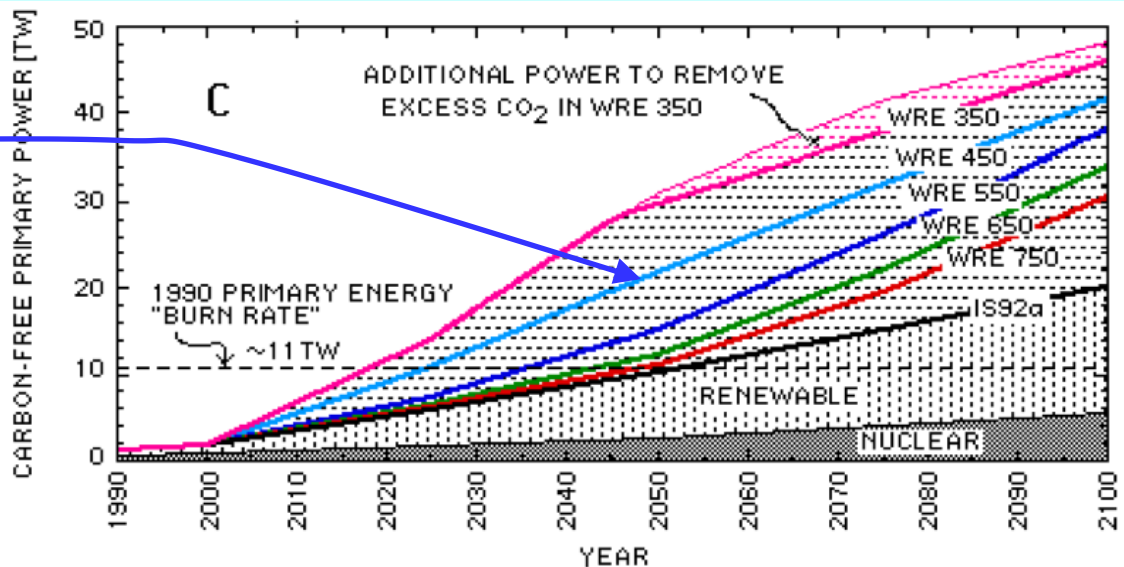[Sources – U.S. DOE and U.S. EPA]

Earth's energy problem
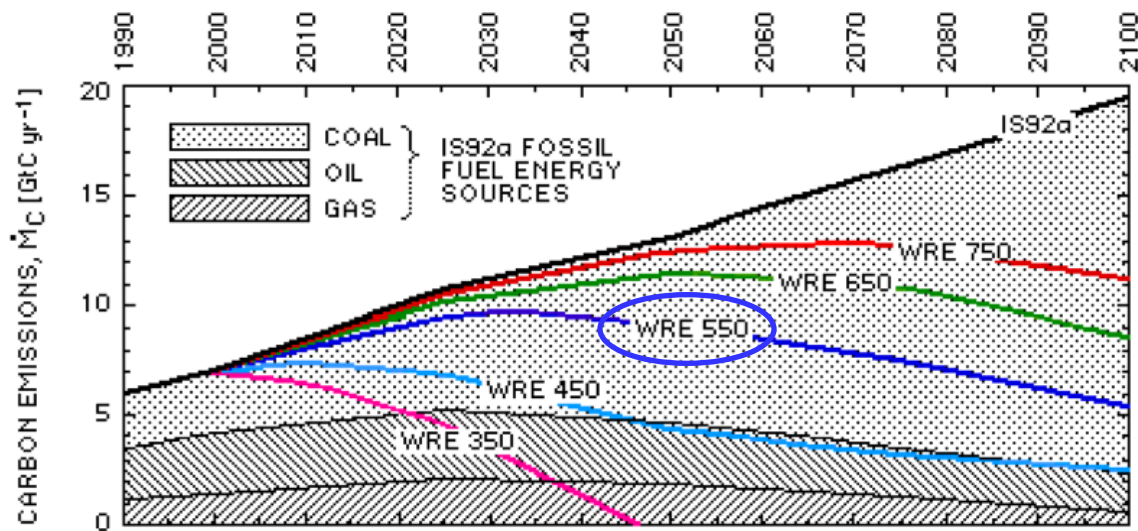
Global power consumption is current ~15 TW; projected need by 2050 of ~30 TW.

Carbon-free power required by 2050 to stabilize atmospheric CO_2 at 450 ppm ~15 TW
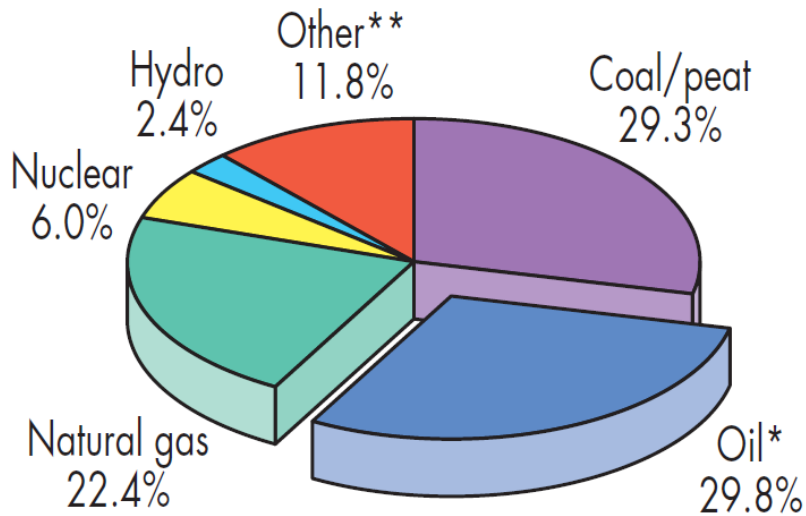
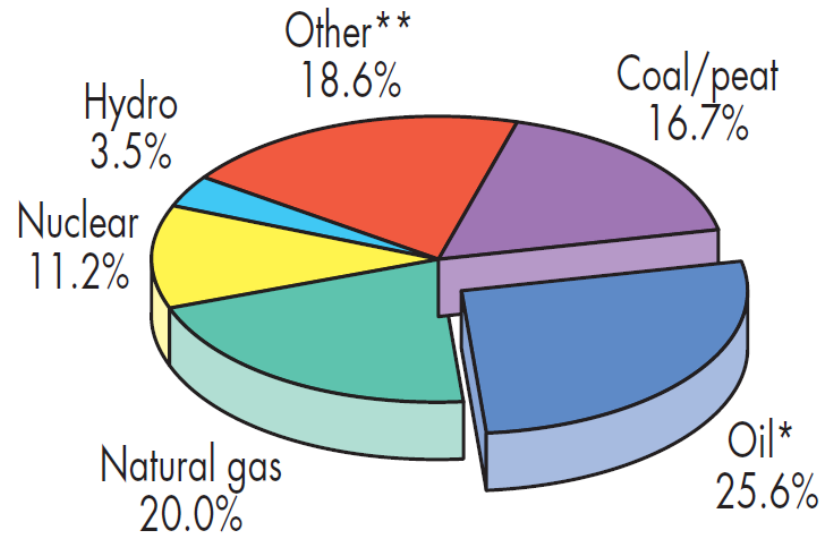By 2100, carbon-free power requirement jumps to ~40 TW.

from M. I. Hoffert et. al., Nature, 1998, 395, 881

Total primary energy in 2035

Current Policy Scenario vs.
450 Policy Scenario

CPS 2035

- Other** 11.8%
- Coal/peat 29.3%
- Hydro 2.4%
- Nuclear 6.0%
- Natural gas 22.4%
- Oil* 29.8%

450 PS 2035

- Other** 18.6%
- Coal/peat 16.7%
- Hydro 3.5%
- Nuclear 11.2%
- Natural gas 20.0%
- Oil* 25.6%

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2008 global energy consumption = 474 EJ (~5×10^{20} J) with ~85% derived from the combustion of fossil fuels. The average power consumption rate was 15 terawatts (1.5×10^{13} W).

Most of the world's energy resources are from the sun's rays hitting earth.

Tough Reality

The Good News

In 2009, world energy consumption decreased for the first time in 30 years (-1.1%) , a result of the financial and economic crisis (GDP drop by 0.6% in 2009). Coal posted a growing role in the world's energy consumption: in 2009, it accounted for 27% of the total. In 2010, world energy consumption increased by ~5%.

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How are We Doing so Far?

The Role of Renewable Energy in the Nation's Energy Supply, 2008

Total = 99.304 Quadrillion Btu

Total = 7.300 Quadrillion Btu

99 Quad = 29,000 TWh
or
3.3 TW needed

Petroleum 37%

Natural Gas 24%

Coal 23%

Nuclear Electric Power 8%

Renewable Energy 7%

Solar 1%
Geothermal 5%
Wind 7%
Hydropower 34%
Biomass 53%
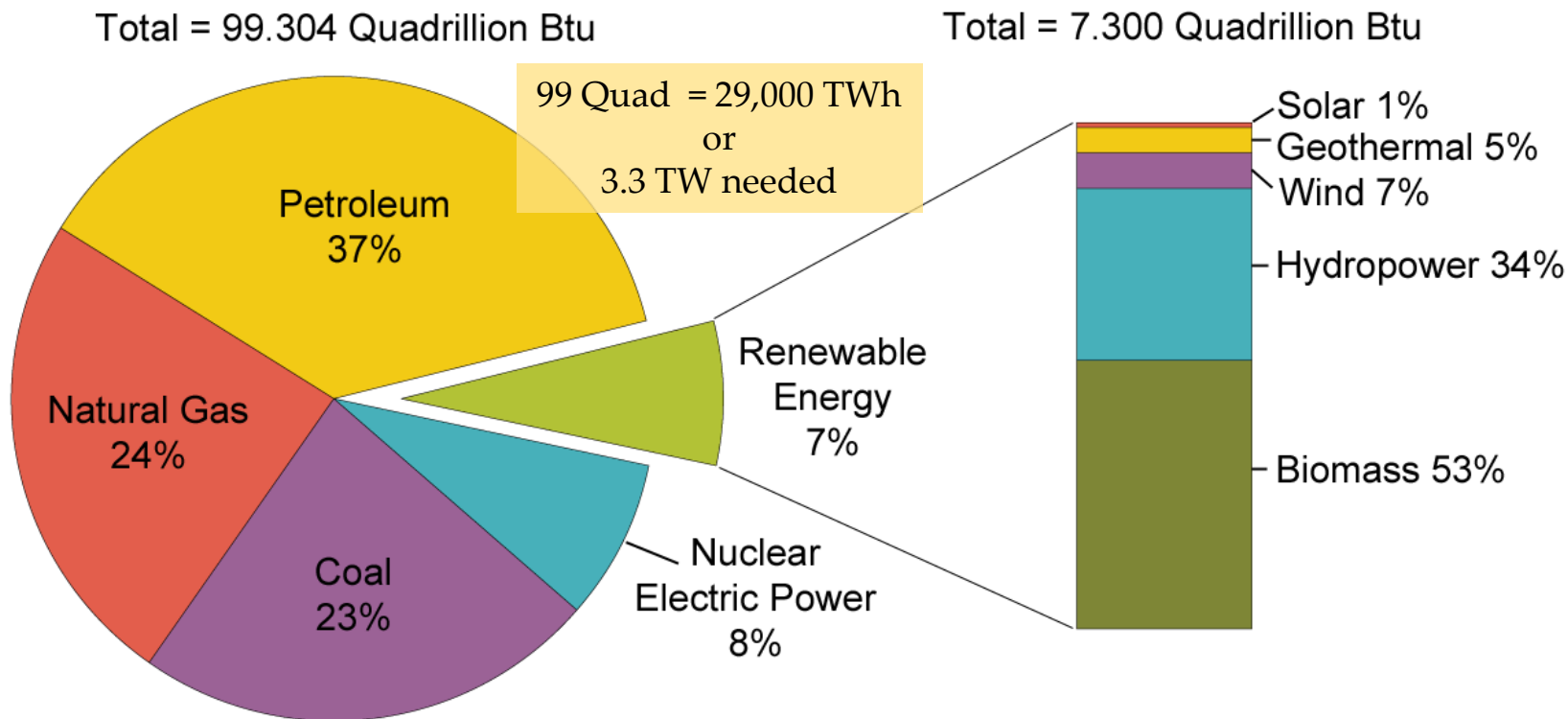
Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Annual Energy Review 2009*, Table 1.3, Primary Energy Consumption by Energy Source, 1949-2008 (June 2009).

- In 2010, total worldwide energy consumption was 132,000 TWh, corresponding to an average annual power consumption rate of ~15.9 terawatts.

- Worldwide in 2010, 81% of energy use was fossil fuels, with another ~5% from nuclear and ~6% from hydroelectric.

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Sources of renewable carbon-free energy

Potential Sources for Significant Carbon-Free Energy

- Hydroelectric (technically feasible)   3.8 TW
  2.1 TW economically feasible, 0.9 TW in 2010

- Geothermal (installed capacity)   10.9 GW

- Tides/Waves   1 TW
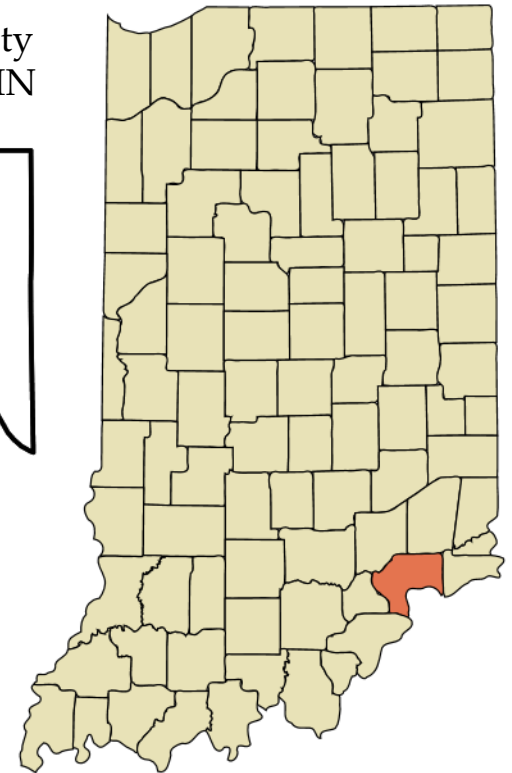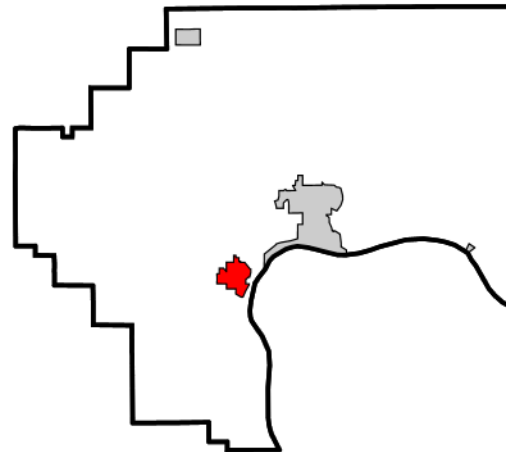
- Wind   70 TW

- Solar (120,000 TW solar energy incident on Earth)   600 TW

> * 50 TW – 1500 TW, depending upon land fraction, etc., and assuming today's typical solar-to-electricity conversion efficiency of 10%.

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Marble Hill Nuclear Facility (~2.4 GW), near Hanover, IN

Nuclear never far away in the eastern half of US

Map: Population within 10 and 50 miles of nuclear power

These are the 65 locations of the 104 commercial nuclear power reactors in the United States, showing po...
Population figures use the 2010 Census.

Davis-Besse

Nearest city
Oak Harbor, Ohio,
population 2,759

Operating reactors
1

Licensed
1977

Chance of core damage from earthquake
1 in 149,254

Population living near reactor
- 50-mile radius: 1,791,856
- 20-mile radius: 106,294
- 10-mile radius: 18,635
- 5-mile radius: 3,426

Change in pop. since 2000
1.4% 18.3% 14.1% 31.9%

Driving distance from Toledo, Ohio to the Davis-Besse plant is 26 miles

LEGEND

Nuclear plants
Roll your cursor over the plants for more information

10-mile and 50-mile radius

Population
Relative size of population living within 50 miles (continuous scale)
- 160 thousand
- 2 million
- 18 million

500 miles

SOURCES: Nuclear Regulatory Commission; U.S. Census Bureau; Longcreative, LLC

NOTE

msnbc.com

Link | Share

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Nuclear Power

- US generates ~30% of total world nuclear energy (2009 IEA)
- Nuclear power provides ~6% of global energy, and ~14% of global electricity
- Differing views abound on:
  - Waste storage
  - Security concerns (nuclear weapons proliferation, terrorist interception of materials)
  - Economics of constructing nuclear power plants
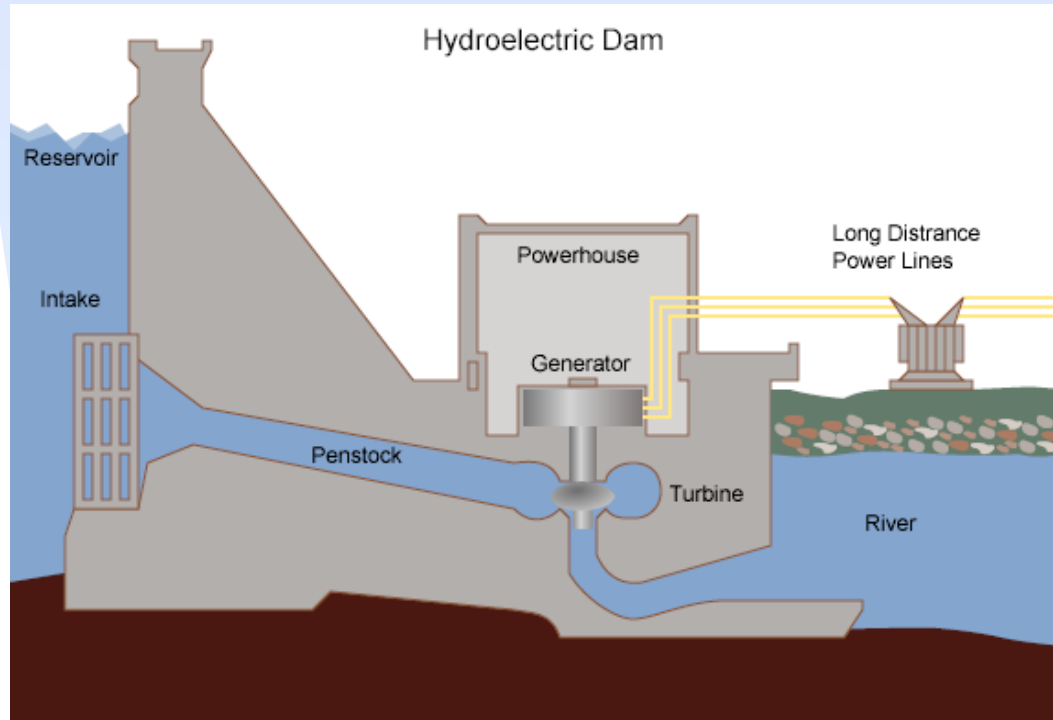 - Safety and acceptability of risk

2011 Japan earthquake: Fukushima Daiichi nuclear disaster

Reactor 4 had been de-fuelled, and Reactors 5 and 6 were in cold shutdown. Reactors 1, 2 and 3 all experience full meltdown. As of Dec. 16, 2011, the plant has been declared stable.

MIYAGI prefecture

ONAGAWA

Earthquake
11 March 2011 14:46 (JST)
9.0 Magnitude

FUKUSHIMA I - Daiichi

FUKUSHIMA II - Daini

TOKAI

TOKYO

Pacific Ocean

JA PAN

Legend
★ Earthquake epicenter
☢ Damaged nuclear power plant
⬤ Radioactive Contamination

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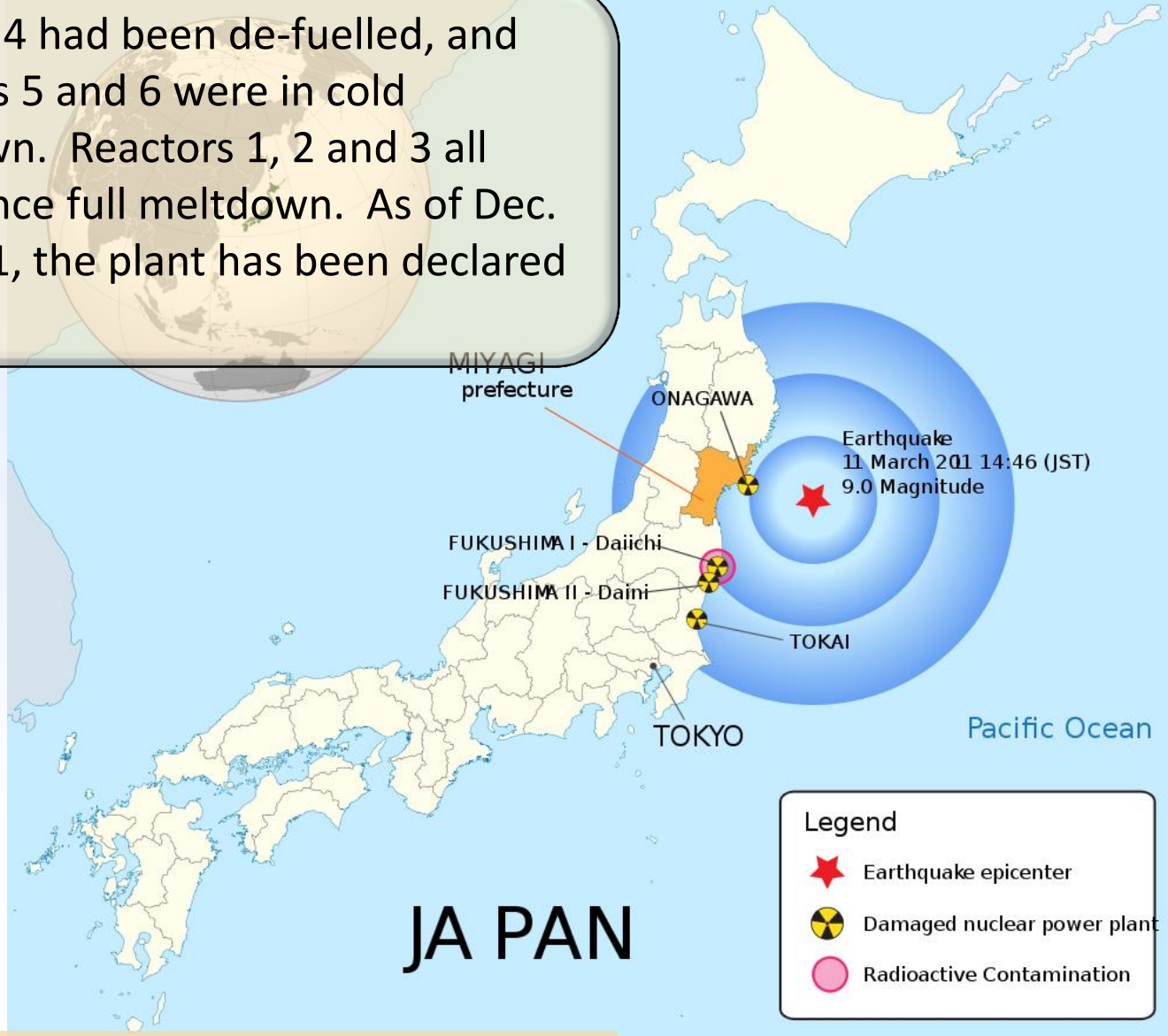
Hydroelectric Power

Power produced depends on factors such as the density of water (ρ = 1000 kg/m³), the "hydraulic height" (h), the flow rate in cubic meters per second (r), the gravitational constant (g), and the efficiency factor (k):

$$P = \rho hrgk$$

- eliminates cost of fuel;
- long-lived power production compared to fuel-fired plants;
- operates without CO_2 emissions;
- no nuclear waste
- sizeable hazard (dam failures among largest human-created disasters);
- siltation ultimately limits "economic" life;
- environmental impacts: spawning, downstream river environment, anaerobic decay of plant material – methane
- population relocation
- flow reduction (global warming)

Fig. 33.

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

750 MW water turbine being installed at Grand Coulee Dam (Columbia River).
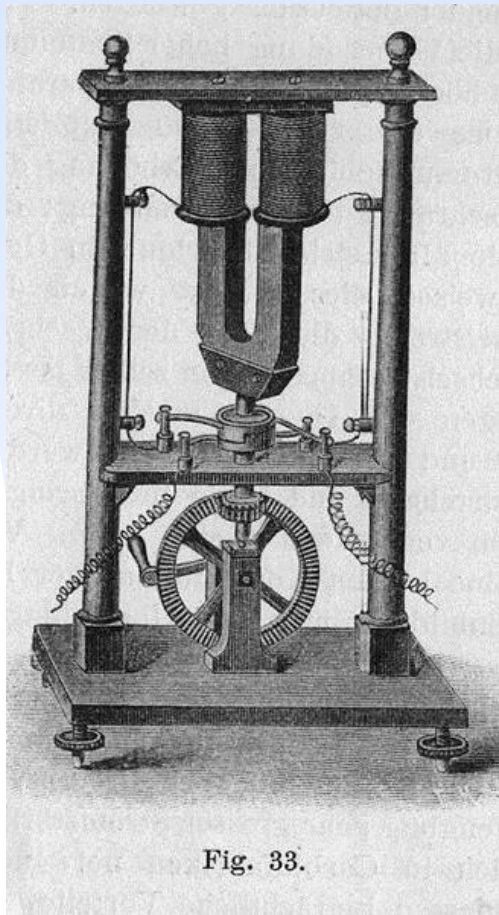
Pixii's dynamo (1832), built by **Hippolyte Pixii** (1808–1835), an instrument maker from Paris, France.

ε is the electromotive force (volts); Φ_B is the magnetic flux (webers). 1 weber/m^2 = 1 tesla

electric motor $\longleftrightarrow$ *electric generator*

Hydroelectric Power – Big Players

Country	Annual Hydroelectric Energy Production(TWh)	Installed Capacity (GW)	Capacity Factor	Percent of all electricity
Norway	140.5	27.528	0.49	98.25[24]
Brazil	363.8	69.080	0.56	85.56
Venezuela	86.8	-	-	67.17
Canada	369.5	88.974	0.59	61.12
Sweden	65.5	16.209	0.46	44.34
Russia	167.0	45.000	0.42	17.64
China (2008)[25]	585.2	171.52	0.37	17.18
India	115.6	33.600	0.43	15.80
France	63.4	25.335	0.25	11.23
Japan	69.2	27.229	0.37	7.21
United States	250.6	79.511	0.42	5.74
Paraguay (2006)	64.0	-	-	

Potential capacity of 3.8 TW; ultimately driven by the Sun.

Reminder: We need 15 – 40 TW total CfP

Geothermal Power

What: thermal energy "in the Earth" from:
- original formation of the planet (hot springs, geysers)
- radioactive decay of minerals
- solar energy absorbed at the surface

Castle Geyser, Yellowstone NP

How much: 10.9 GW of geothermal power in 2010; 28 GW of direct thermal heating capacity.

Notes:
- Earth's heat content = 10^{31} J
- Thermal conduction to surface at rate of 44 TW (44 x 10^{12} J/s)
- Additional heat generated by radioactive decay, 30 TW
- Average thermal power at Earth's surface: ~ 0.1 W/m^2

Origins of Wind

Pressure differentials in the atmosphere produce wind; local effects include variations in heating and cooling (e.g., land vs. a body of water).

Air motion (wind) alleviates these pressure differences. Air has mass, so wind carries kinetic energy that can be converted to electricity through the use of turbines (*electrical generators*).

The two dominant causes of wind in Earth's atmosphere are:

1. the differential solar heating between the equator and the poles, and
2. the rotation of the planet.
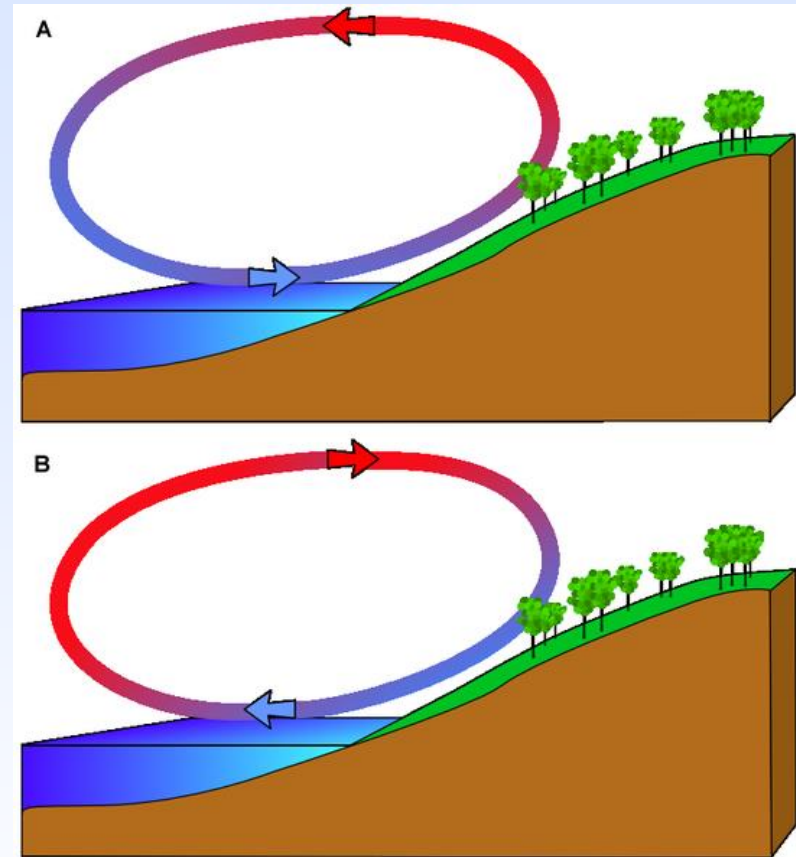
Land is often warmer than water (A) during the day, and cooler than water (B) at night.

Wind Power

"Humans have been using wind power for at least 5,500 years to propel sailboats and sailing ships, and architects have used wind-driven natural ventilation in buildings since similarly ancient times. Windmills have been used for irrigation pumping and for milling grain since the 7th century AD."

http://en.wikipedia.org/wiki/Wind_power

… growth in the forecasts can be attributed to the increasingly common use of very large turbines that rise to almost 100 meters.
Wind speeds are greater at higher elevations. Previous wind studies were based on the deployment of 50- to 80-meter turbines.

http://greeninc.blogs.nytimes.com/2009/07/16/

$$P = \frac{1}{2} A \cdot v \cdot \rho \cdot v^2 = \frac{1}{2} A \cdot \rho \cdot v^3$$

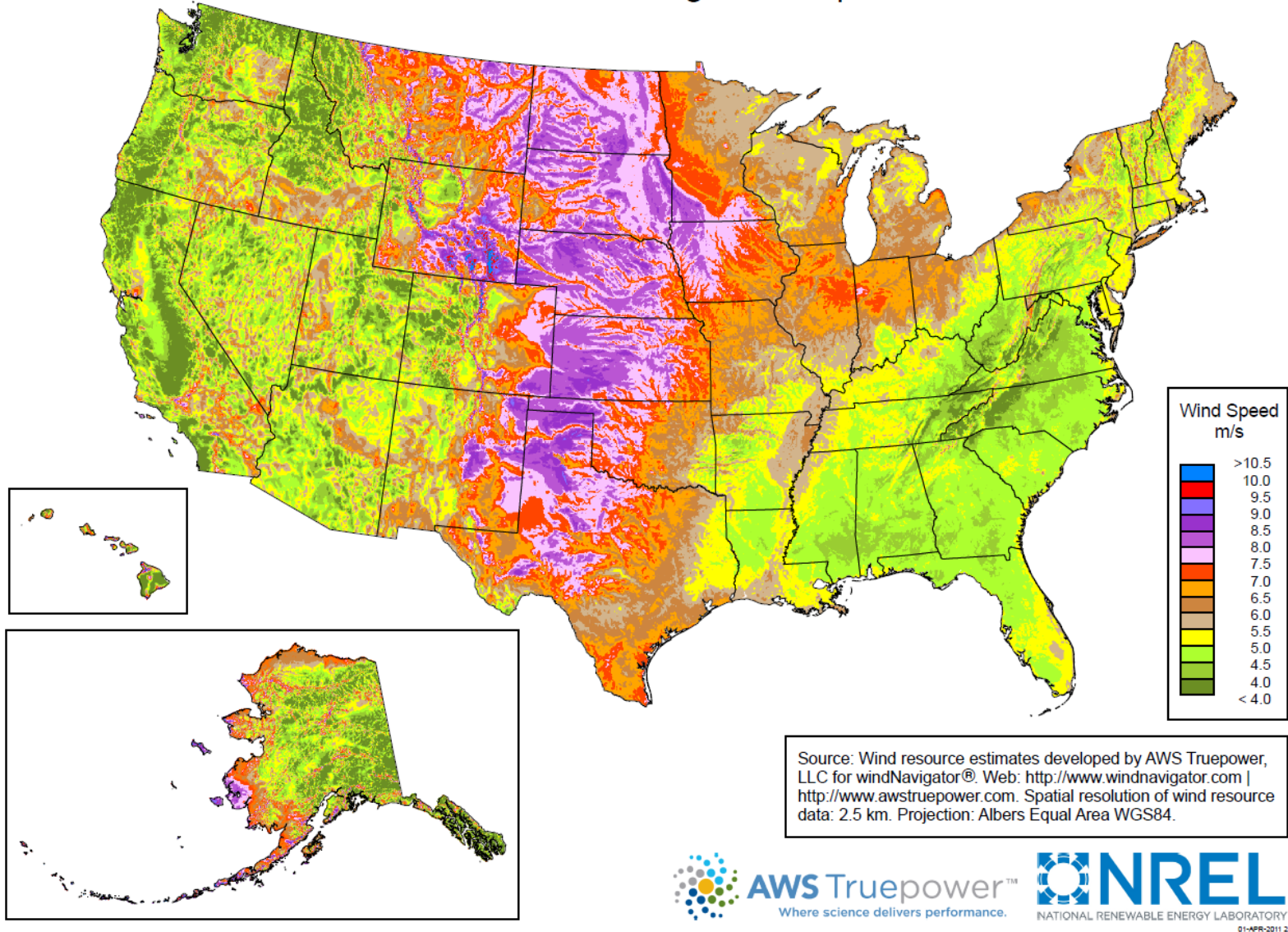**Global potential for wind-generated electricity**
Xi Lu, Michael B. McElroya,, and Juha Kiviluomac
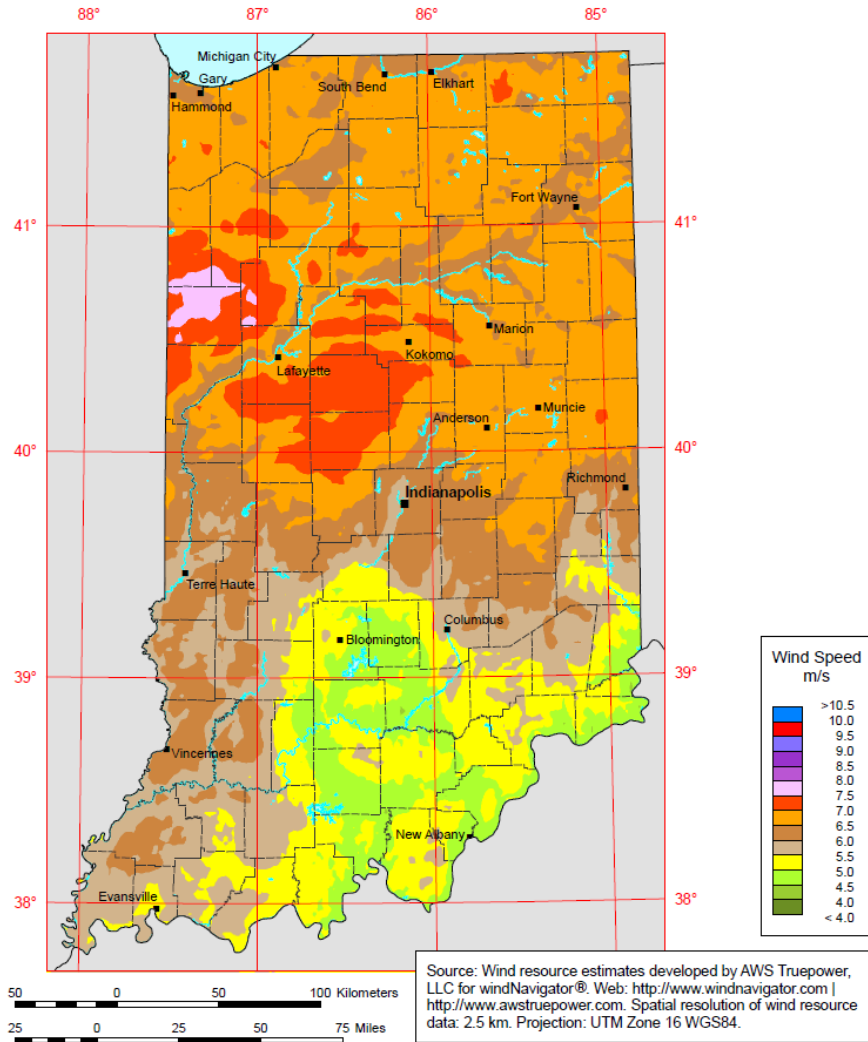www.pnas.orgcgidoi10.1073pnas.0904101106

Wind Power

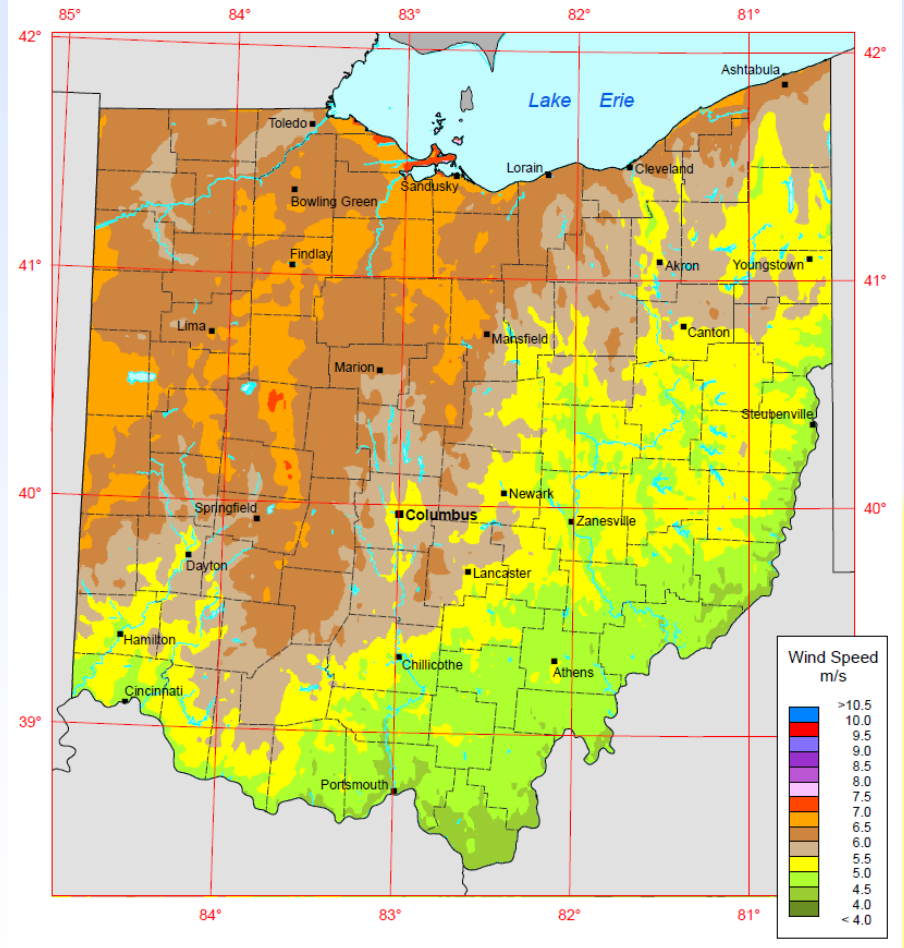United States - Annual Average Wind Speed at 80 m

Wind Speed m/s

- >10.5
- 10.0
- 9.5
- 9.0
- 8.5
- 8.0
- 7.5
- 7.0
- 6.5
- 6.0
- 5.5
- 5.0
- 4.5
- 4.0
- < 4.0

Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.

AWS Truepower™
Where science delivers performance.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

01-APR-2011 2.1.1

Indiana and Ohio Wind Power

Indiana - Annual Average Wind Speed at 80 m

Ohio - Annual Average Wind Speed at 80 m

Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 16 WGS84.

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Global Wind Power

22% year-over-year growth in 2010
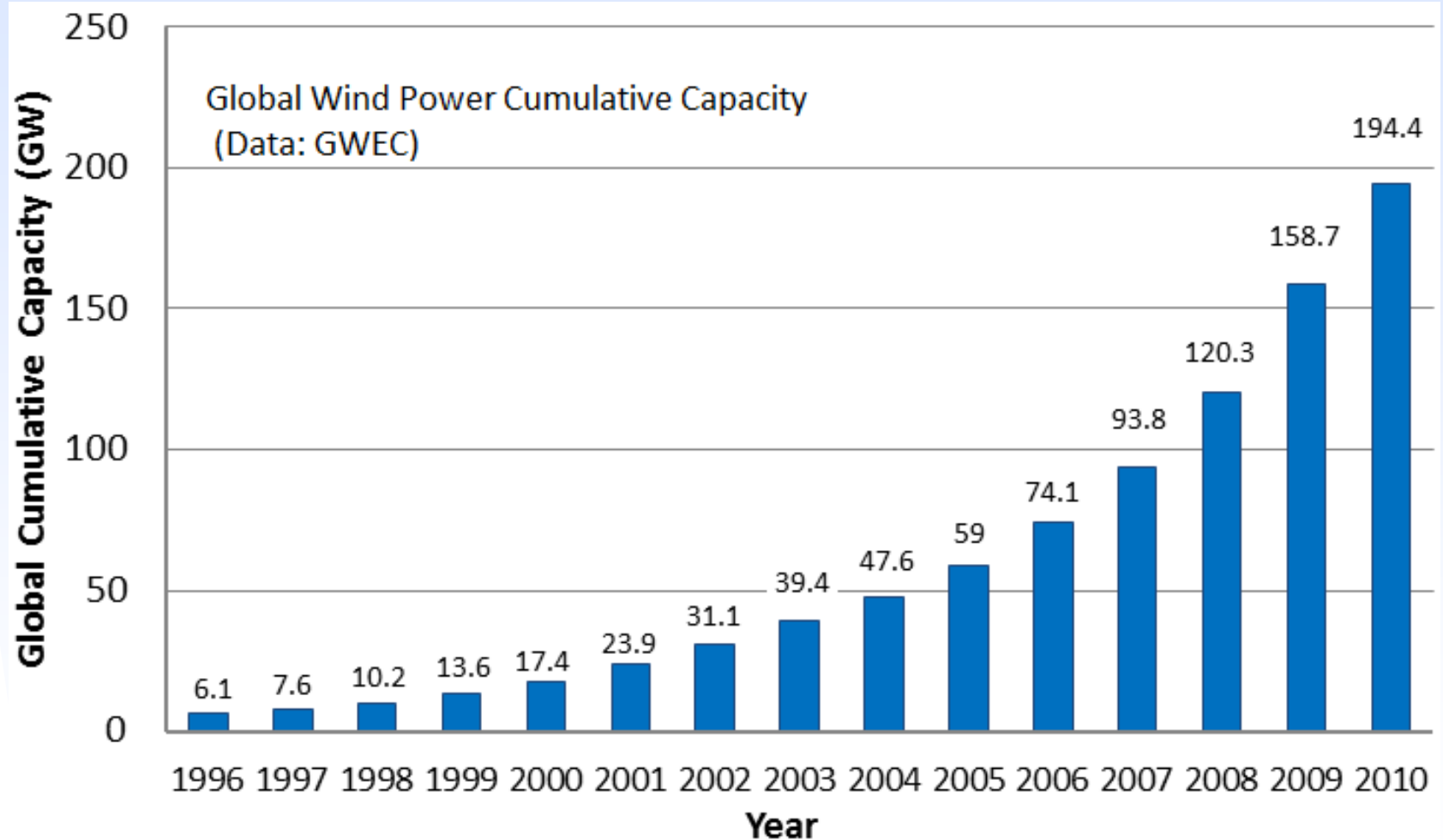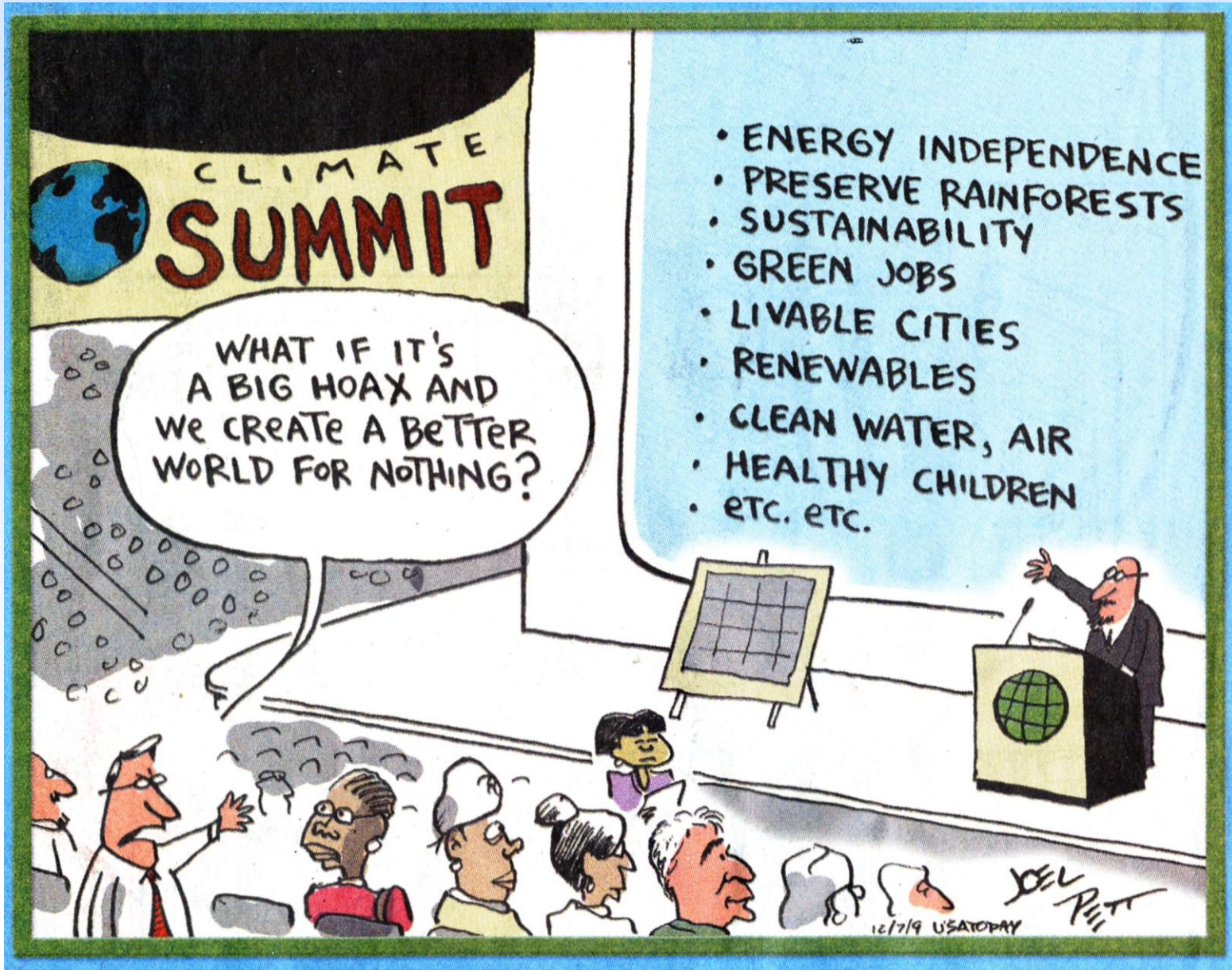
Global Wind Power Cumulative Capacity (Data: GWEC). Bar chart of Global Cumulative Capacity (GW) by Year: 1996: 6.1, 1997: 7.6, 1998: 10.2, 1999: 13.6, 2000: 17.4, 2001: 23.9, 2002: 31.1, 2003: 39.4, 2004: 47.6, 2005: 59, 2006: 74.1, 2007: 93.8, 2008: 120.3, 2009: 158.7, 2010: 194.4
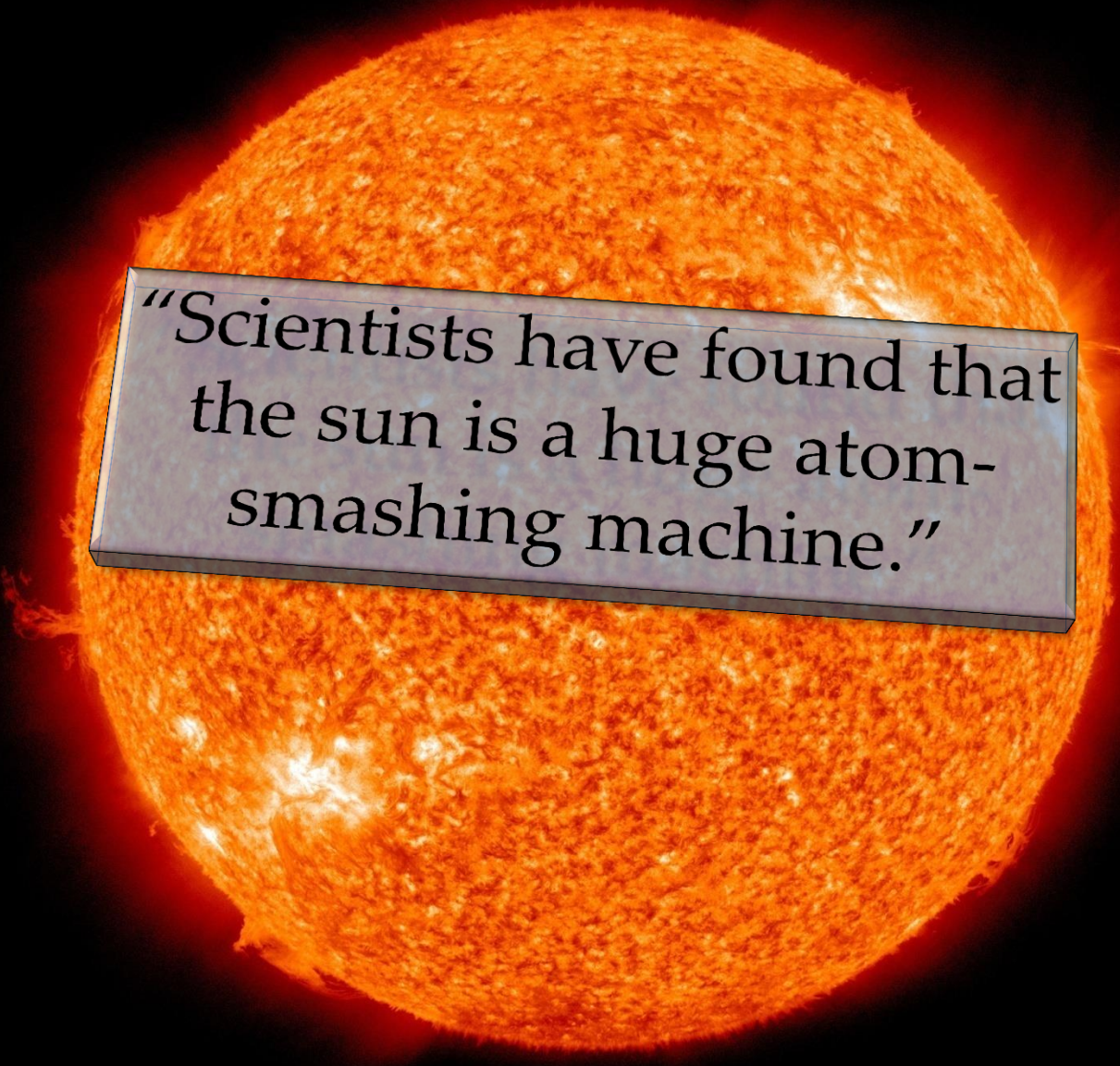
The Sun (worth revering)

"Scientists have found that the sun is a huge atom-smashing machine."

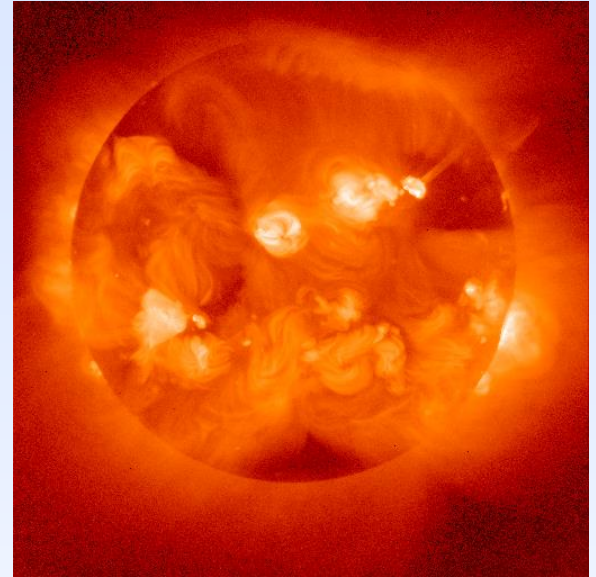"Why Does the Sun Shine?"
by *They Might Be Giants*

The sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

Yo ho, it's hot, the sun is not
A place where we could live
But here on Earth there'd be no life
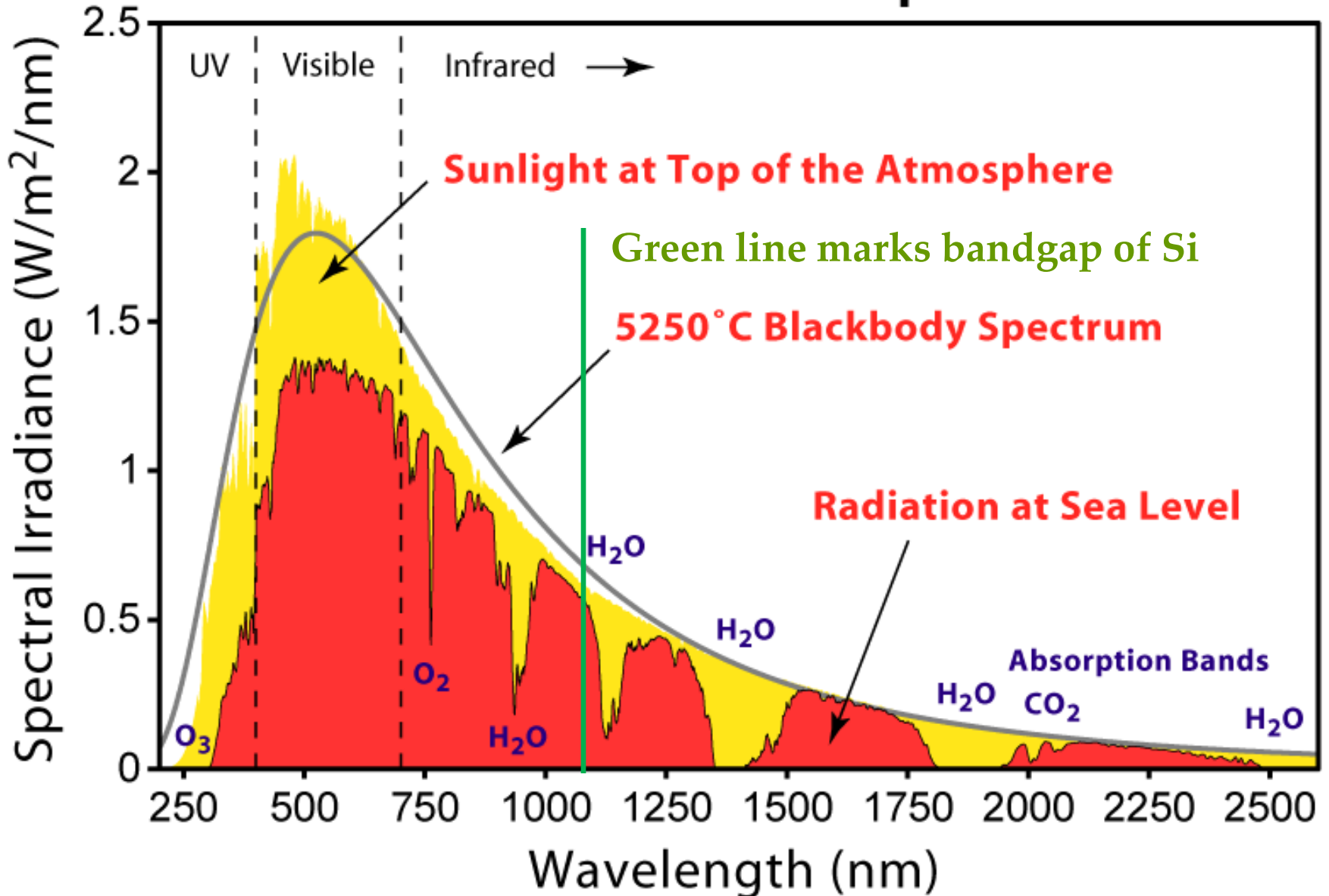Without the light it gives

We need its light
We need its heat
We need its energy
Without the sun, without a doubt
There'd be no you and me

Earth's Solar Resource

- Theoretical: 1.2×10^5 TW solar energy potential (1.76 $\times 10^5$ TW striking Earth; 0.30 Global mean albedo)

- Energy in 1 hr of sunlight $\leftrightarrow$ 14 TW for a year

- Practical: > Onshore electricity generation potential of $\approx$ 600 TW (10% conversion efficiency).

- *Photosynthesis*: 90 TW

- Cumulative installed PV (electricity) capacity:

  - 40 GW as of 2010 (2.5 GW in U.S., 17.3 GW in Germany, and > 3.5 GW in each of Italy, Spain, and Japan)

  - 68 GW as of 2011 (70% growth in a year)

Solar Radiation Spectrum

Spectral Irradiance (W/m²/nm)

UV | Visible | Infrared →

Sunlight at Top of the Atmosphere

Green line marks bandgap of Si

5250°C Blackbody Spectrum

Radiation at Sea Level

H₂O

H₂O

O₂

Absorption Bands

H₂O

H₂O

CO₂

H₂O

O₃

H₂O

Wavelength (nm)

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The Solar Resource in the US

PV covering area of square ~133 miles x 133 miles
more than satisfies all US energy needs.
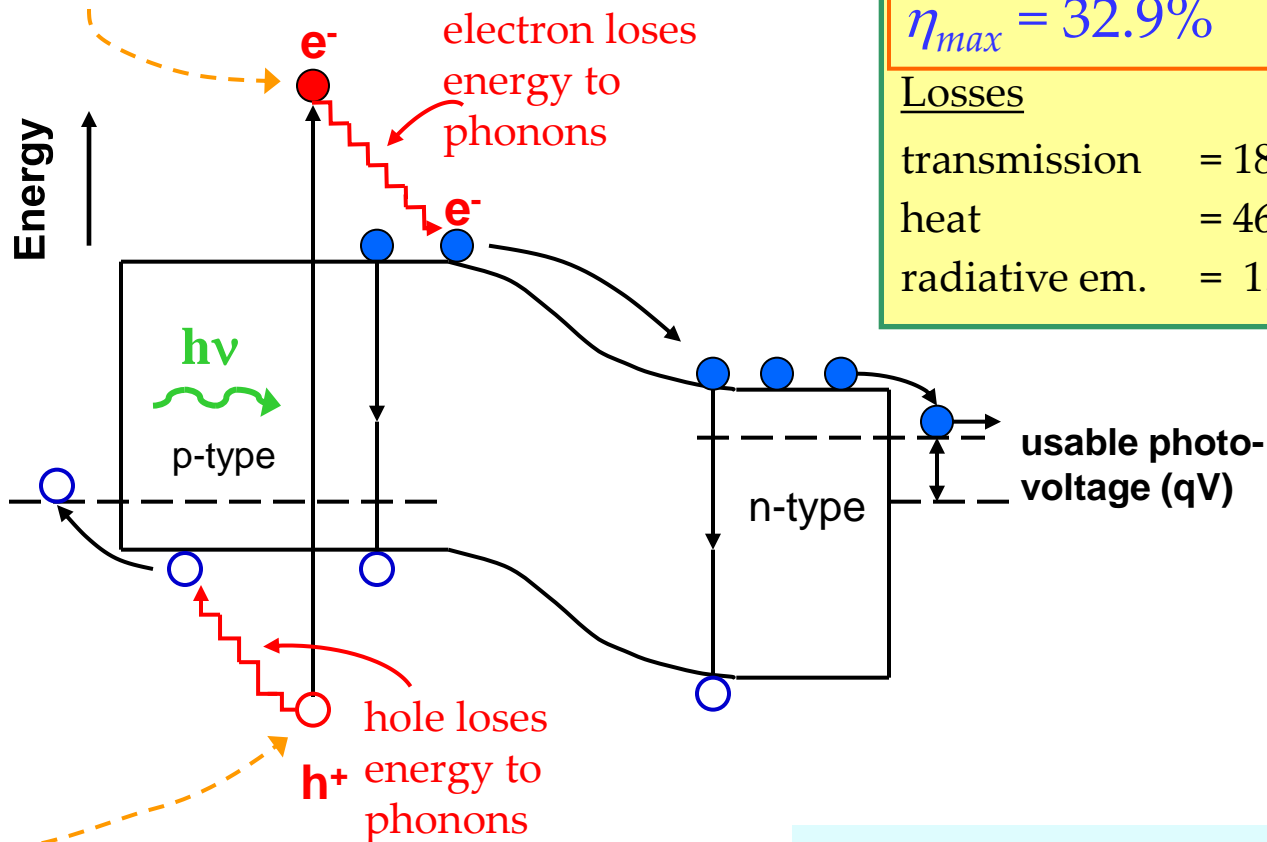
Key functions of a solar cell

- absorbs sunlight efficiently
- separates charge (electrons from "holes")
- creates an electrical current and voltage when illuminated
- acts like a battery under sunlight

http://www.emeraldinsight.com/fig/0870210205001.png
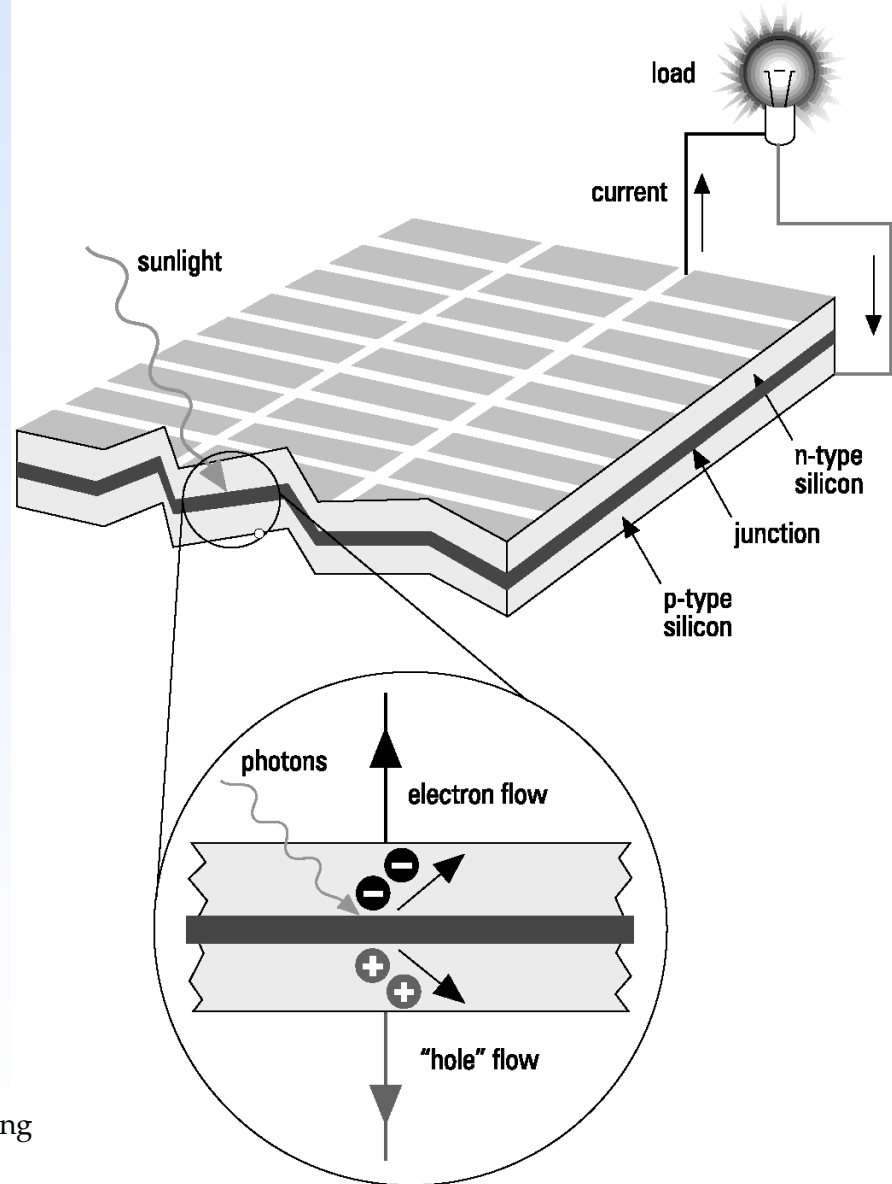
Conventional p-n junction photovoltaic cell

Hot charge carriers

e⁻

electron loses energy to phonons

Energy

e⁻

For Si (E_g = 1.1 eV) at T = 300 K, AM1.5G

$\eta_{max} = 32.9\%$

Losses

transmission	= 18.7%
heat	= 46.8%
radiative em.	= 1.6%

hν

p-type

n-type

usable photo-voltage (qV)

hole loses energy to phonons

h⁺

1 *e⁻-h⁺* pair/photon

World Cumulative Solar Photovoltaics Installations,
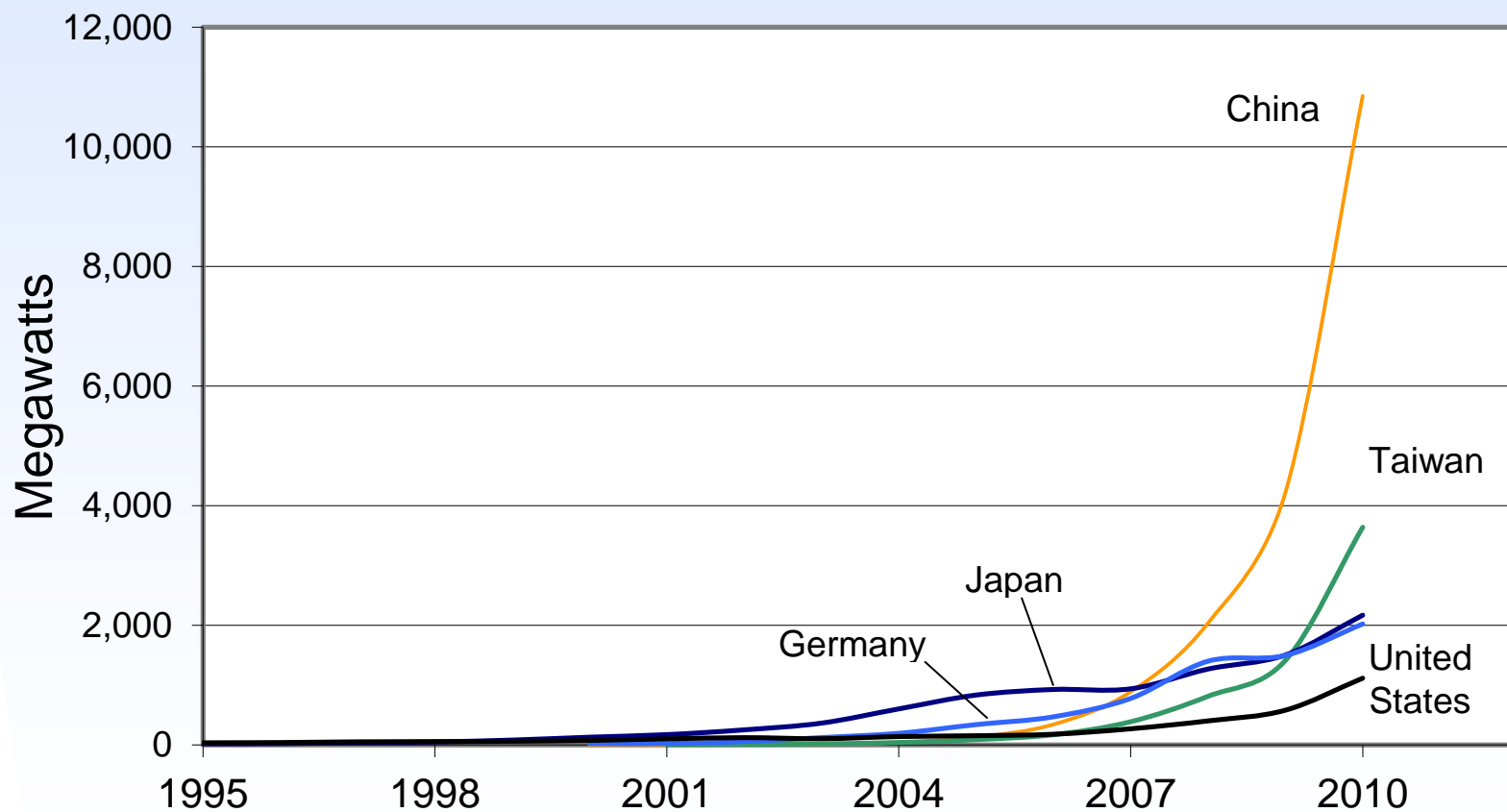1998-2011

Average 60% annual growth past 3 years

Megawatts

Earth Policy Institute - www.earth-policy.org
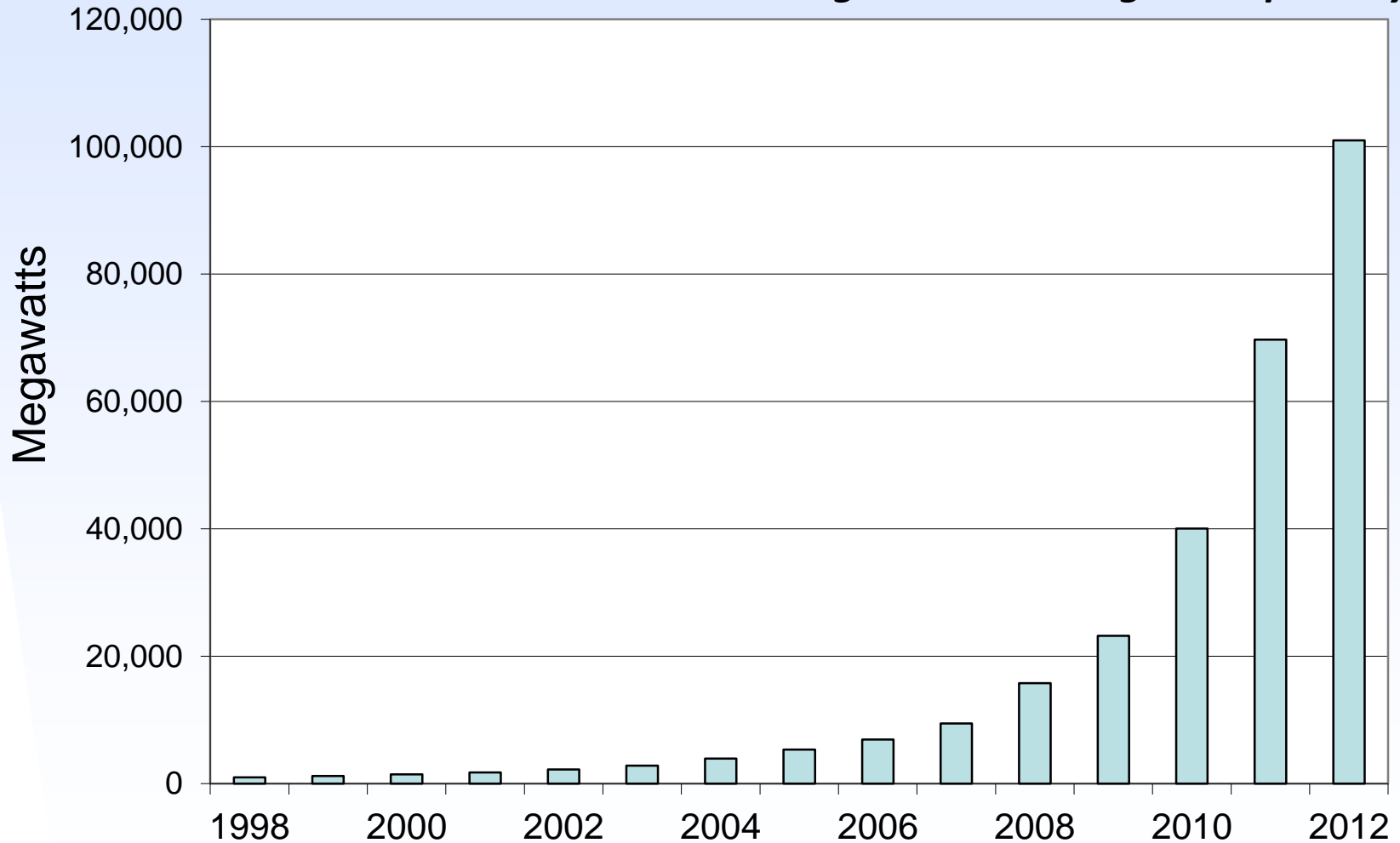
Source: EPI from EPIA

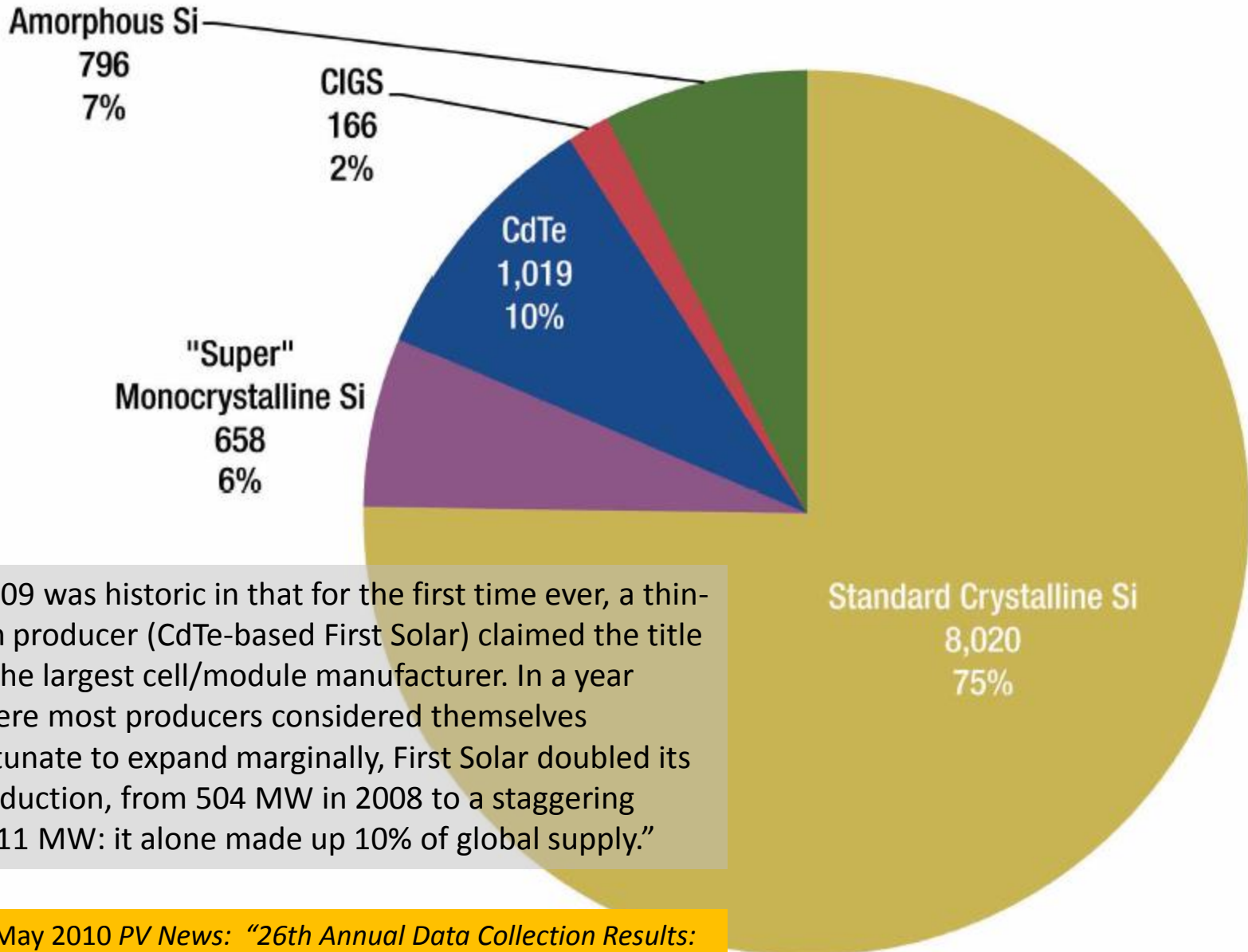*.... energizing Ohio for the 21st Century*

Annual Solar Photovoltaics Production in Selected Countries, 1995-2010

Source: EPI from Worldwatch; Prometheus Institute; Greentech Media

Earth Policy Institute - www.earth-policy.org

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Commercial Photovoltaics as of 2010

Amorphous Si
796
7%

CIGS
166
2%

CdTe
1,019
10%

"Super"
Monocrystalline Si
658
6%

Standard Crystalline Si
8,020
75%

"2009 was historic in that for the first time ever, a thin-film producer (CdTe-based First Solar) claimed the title of the largest cell/module manufacturer. In a year where most producers considered themselves fortunate to expand marginally, First Solar doubled its production, from 504 MW in 2008 to a staggering 1,011 MW: it alone made up 10% of global supply."

from May 2010 *PV News: "26th Annual Data Collection Results: Another Bumper Year for Manufacturing Masks Turmoil"*

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Trends in solar cell efficiencies
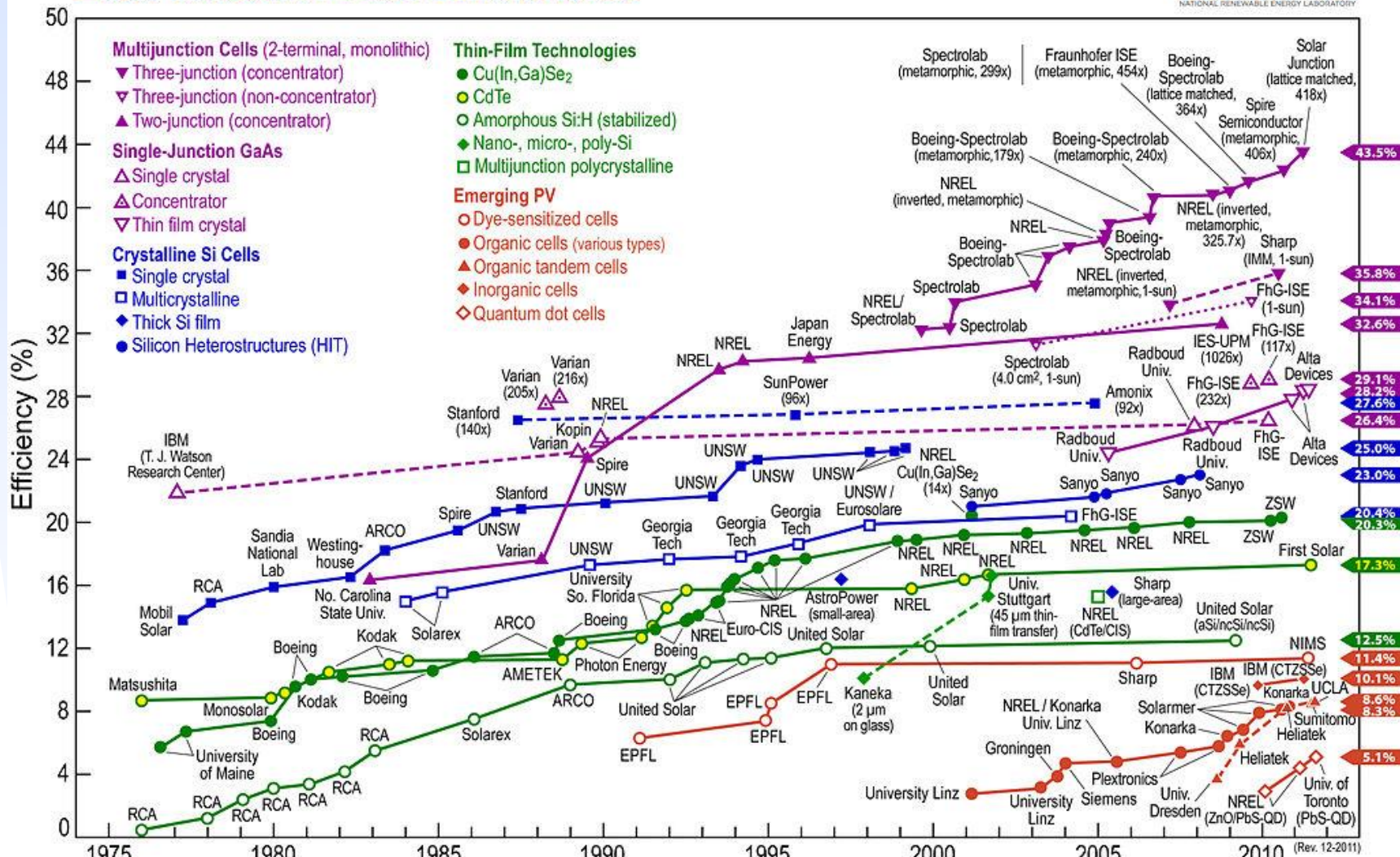
Many different solar cell technologies are being developed, for various applications (rooftops, solar power plants, satellites, backpacks or clothing, etc.).
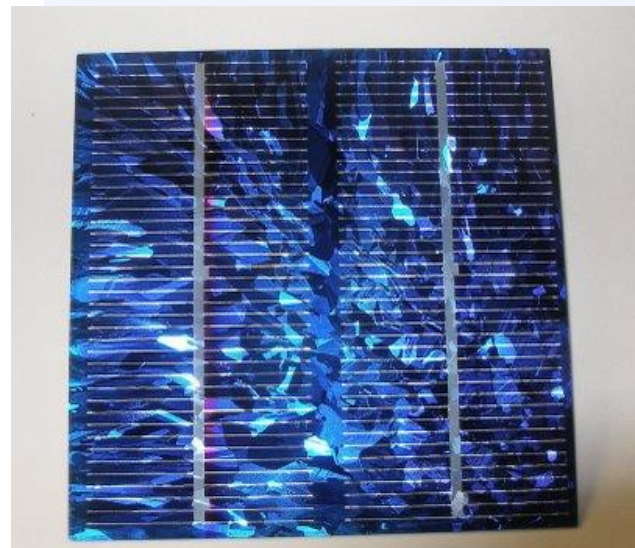
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1st gen.

single crystal Si

Xunlight

2nd gen.: thin film amorphous Si and CdTe

polycrystalline Si

First Solar

One large North American PV power plant

The Sarnia Solar Project is among the largest PV systems in North America (97 MW).