Energy and Power for 7.06 Billion People

PHYS 4400, Principles and Varieties of Solar Energy
Instructor: Randy J. Ellingson
The University of Toledo

January 8, 2013
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.
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.
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: $1.0 \times 10^6$, 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:

$$(1240 \text{ eV nm}^{-1}) / 351 \text{ nm} = 3.53 \text{ eV} \; \text{(not 3.53276 eV)}$$
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
Igor Pro 6.1 (www.wavemetrics.com)

Getting Started
This help file contains overview and guided tour material and constitutes an essential introduction to Igor Pro. The main sections are:

- Introduction to Igor Pro
- Guided Tour 1 - General Tour
- Guided Tour 2 - Data Analysis
- Guided Tour 3 - Histograms and Curve Fitting

We strongly recommend that you read at least the first two sections. The material in this help file is duplicated in Volume I of the Igor Pro PDF manual which is accessible through the Help menu.

Introduction to Igor Pro
Igor is an integrated program for visualizing, analyzing, transforming and presenting experimental data. Igor’s features include:

- Publication-quality graphics
- High-speed data display
- Ability to handle large data sets
- Curve-fitting, Fourier transforms, smoothing, statistics and other data analysis
- Waveform arithmetic
- Image display and processing
- Combination graphical and command-line user interface
- Automation and data processing via a built-in programming environment
- Extensibility through modules written in the C and C++ languages

Some people use Igor simply to produce high-quality, finely-tuned scientific graphics. Others use Igor as an all-purpose workhorse to acquire, analyze and present experimental data using its built-in programming environment. We have tried to write the Igor program and this manual to fulfill the needs of the entire range of Igor users.
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 slightly longer than previously indicted in the syllabus – probably 20-25 minutes. The primary goal is not to increase their difficulty but rather to make sure that you’re not as rushed as you might be, and to be certain we can test your knowledge fairly.

Our goal here is 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

2006 ~ 6.5 Billion People
2013 ~ 7.1 Billion People
2050 ~ 10 Billion People

http://www.agci.org/library/presentations/about/presentation_details.php?recordID=16950
Earth’s key natural resources: water and air

Volume of Earth: $1.1 \times 10^{12}$ km$^3$
Volume of water: $1.4 \times 10^9$ km$^3$
Volume of atmosphere: $4.2 \times 10^9$ km$^3$
Solar Radiation Spectrum

- Sunlight at Top of the Atmosphere
- 5250°C Blackbody Spectrum
- Radiation at Sea Level

Spectral Irradiance (W/m²/nm)

Wavelength (nm)

250 500 750 1000 1250 1500 1750 2000 2250 2500

O₂  O₃  H₂O  H₂O  H₂O  H₂O  H₂O  CO₂  H₂O  H₂O
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.

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

- All 2012 measurements show CO$_2$ > 390 ppmv


~2015
400 ppmv

Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii

Annual Cycle
Jan Apr Jul Oct Jan

Global Temperatures

Temperature Anomaly (°C)

- Annual Average
- Five Year Average

Global average temperatures from NASA’s Goddard Institute for Space Studies (Columbia University). Data set follows methodology developed by J. Hansen.
Global distribution of photosynthesis, including both oceanic phytoplankton and terrestrial vegetation.
On watch: global temperatures, atmospheric CO$_2$

http://www.esrl.noaa.gov/gmd/ccgg/trends/
420,000+ years of atmospheric CO$_2$ levels

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

**Energy for People: 2009**

*Primary energy* is the raw fuel used as the input to a system.

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

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...

Food and Agriculture Organization of the UN: http://www.fao.org/index_en.htm
Dealing with **energy** and **power** in:

<table>
<thead>
<tr>
<th>Energy</th>
<th>Standard International Units</th>
<th>Everyday Life*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Joule</td>
<td>kW·hr</td>
</tr>
<tr>
<td>Power</td>
<td>Watts (1 W = 1 J/sec)</td>
<td>Watts</td>
</tr>
</tbody>
</table>

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 $\rightarrow$ typically at the 1,000 W (1 kW) power level.

Leave a toaster on for an hour continuously $\rightarrow$ 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 $\sim$5 W of heat during sleep, and $\sim$24 W walking briskly

1 kW·hr = $3.6 \times 10^6$ J
Household *electrical* energy consumption

According to [http://www.eia.doe.gov/cneaf/electricity/esr/table5.html](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.

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

Contribution of Fuel Sources to Total Electric Generation

**2009**

- **USA**
- **Ohio**

**Data Source:** Energy Information Administration, U.S. Department of Energy

Graphs by Brooks Martner, Lafayette, CO
“Gasoline was great.”
-- from R. Smalley’s energy talk (2003)
Energy Consumption and GDP

From: Wikimedia Commons

... energizing Ohio for the 21st Century
Forms of Energy (physics problems)

- Gravitational potential energy: \( P_{eg} = mgh \)
  
  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 \( E_{ph} = hc/\lambda = hv \), where h is Planck’s constant = 6.63 x 10\(^{-34}\) J s, so that e.g. a photon of wavelength \( \lambda = 500 \) nm has a frequency \( \nu = c/\lambda = (3 \times 10^8 \) m/s)/500 nm = (3 \times 10^8 m/s) / (500 x 10\(^{-9}\) m) = 6 x 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 x 10\(^{-9}\) m) =3.98 x 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

Health

Coal-fired power plants:

- Significant improvement (sulfur dioxide) since 2006
- Majority of total U.S. sulfur dioxide pollution
- ~4% of total nitrous oxides every year (stable)
- Largest polluter of toxic mercury pollution

All U.S. power plants: release over 41% of U.S. CO₂ in 2009
[Sources – U.S. DOE and U.S. EPA]

Acid rain, smog (ozone), soot → unhealthy ecosystems, respiratory problems, unhealthy lungs (incl. asthma)

A developmental toxin, affecting unborn children

Growth in energy consumption

- Growth in global energy consumption predicted to average ~1.6-1.7% per year.
- Includes for 1%/yr. efficiency improvement
- 28 TW global power consumption by 2050 → Or more*
- Population growth primarily in less-developed countries → increased C-intensity.

Energy implications of future stabilization of Atmospheric CO₂ content

M. Hoffert et al.

NATURE, VOL. 395, 29 OCTOBER 1998

1 Mtoe = 41868000 GJ
1998 Global power use of 11.9 TW
2010 Global power use of 15.9 TW
2012 Global power ~16.5 TW
Present annual energy use ~ 0.5 ZJ
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 CO₂ at 450 ppm ~15 TW

By 2100, carbon-free power requirement jumps to ~40 TW.

Total primary energy in 2035

Current Policy Scenario vs. 450 Policy Scenario

CPS 2035
- Hydro: 2.4%
- Nuclear: 6.0%
- Natural gas: 22.4%
- Coal/peat: 29.3%
- Other*: 11.8%
- Oil*: 29.8%

450 PS 2035
- Hydro: 3.5%
- Nuclear: 11.2%
- Natural gas: 20.0%
- Coal/peat: 16.7%
- Other*: 18.6%
- Oil*: 25.6%

2008 global energy consumption = 474 EJ ($\sim5 \times 10^{20}$ J) with $\sim85\%$ derived from the combustion of fossil fuels. The average power consumption rate was 15 terawatts ($1.5 \times 10^{13}$ 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 $\sim5\%$.

http://en.wikipedia.org/wiki/World_energy_resources_and_consumption
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.
## Potential Sources for Significant Carbon-Free Energy

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Potential Capacity (TW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectric (technically feasible)</td>
<td>3.8 TW</td>
</tr>
<tr>
<td>2.1 TW economically feasible, 0.9 TW in 2010</td>
<td></td>
</tr>
<tr>
<td>Geothermal (installed capacity)</td>
<td>10.9 GW</td>
</tr>
<tr>
<td>Tides/Waves</td>
<td>1 TW</td>
</tr>
<tr>
<td>Wind</td>
<td>70 TW</td>
</tr>
<tr>
<td>Solar (120,000 TW solar energy incident on Earth)</td>
<td>600 TW</td>
</tr>
</tbody>
</table>

* 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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http://www.ieahydro.org/reports/Hydrofut.pdf  
http://en.wikipedia.org/wiki/Geothermal_power  
http://www.thecanadianencyclopedia.com/articles/tidal-energy  
http://www.pnas.org/content/106/27/10933.full.pdf
What about ... Nuclear Power?

Marble Hill Nuclear Facility (~2.4 GW), near Hanover, IN
Nuclear never far away in the eastern half of US

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

Power produced depends on factors such as the density of water \( (\rho = 1000 \text{ kg/m}^3) \), the “hydraulic height” \( (h) \), the flow rate in cubic meters per second \( (r) \), the gravitational constant \( (g) \), and the efficiency factor \( (k) \):

\[ P = \rho h r g k \]

- eliminates cost of fuel;
- long-lived power production compared to fuel-fired plants;
- operates without \( \text{CO}_2 \) 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)
Hydroelectric Power – Electromagnetic Induction

Pixii’s dynamo (1832), built by Hippolyte Pixii (1808–1835), an instrument maker from Paris, France.

\[ \mathcal{E} = -\frac{d\Phi_B}{dt} \]

\( \mathcal{E} \) is the electromotive force (volts); \( \Phi_B \) is the magnetic flux (webers). 1 weber/m² = 1 tesla

750 MW water turbine being installed at Grand Coulee Dam (Columbia River).

\( \Rightarrow \) electric motor \( \leftrightarrow \) electric generator

... energizing Ohio for the 21st Century
### Hydroelectric Power – Big Players

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

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

**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 ($44 \times 10^{12}$ J/s)
- Additional heat generated by radioactive decay, 30 TW
- Average thermal power at Earth’s surface: ~ 0.1 W/m²
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.


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

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

Indiana and Ohio Wind Power
Global Wind Power

22% year-over-year growth in 2010

Global Wind Power Cumulative Capacity
(Data: GWEC)

Global Cumulative Capacity (GW)

Year


6.1 7.6 10.2 13.6 17.4 23.9 31.1 39.4 47.6 59 74.1 93.8 120.3 158.7 194.4
What if it's a big hoax and we create a better world for nothing?

- Energy Independence
- Preserve Rainforests
- Sustainability
- Green Jobs
- Livable Cities
- Renewables
- Clean Water, Air
- Healthy Children
- Etc. Etc.
"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

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

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Earth’s Solar Resource

• Theoretical: \(1.2 \times 10^5\) 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

Sunlight at Top of the Atmosphere

Green line marks bandgap of Si

5250°C Blackbody Spectrum

Radiation at Sea Level

Image created by Robert A. Rohde / Global Warming Art

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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
Conventional p-n junction photovoltaic cell

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

$\eta_{\text{max}} = 32.9\%$

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

1 $e^- - h^+$ pair/photon

Hot charge carriers

Electron loses energy to phonons

Hole loses energy to phonons

Usable photovoltage (qV)
World Cumulative Solar Photovoltaics Installations, 1998-2011

70% year-over-year growth in 2010

Source: EPI from EPIA

Megawatts

Earth Policy Institute - www.earth-policy.org
Annual Solar Photovoltaics Production in Selected Countries, 1995-2010

Source: EPI from Worldwatch; Prometheus Institute; Greentech Media
“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”
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

2nd gen.: thin film amorphous Si and CdTe

Xunlight

First Solar

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