# From Nano-Electronics and Photonics to Renewable Energy

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*Questions are welcome!*

Carleton UNIVERSITY

# OUTLINE

- Introduction: to EE and Engineering Physics
- Renewable Energy
- Nano-technology

## History -- Energy and information

- Industrial Revolution (1750-1850) – new energy sources water, wind, coal replace humans and animals.

- Oil and Internal Combustion (1850-Now)
  - use of oil, gas
  - advanced mechanical engineering.
  - Electrical Engineering (lights, motors, etc)

- Semiconductor Revolution (1970-Now)
  - Integrated electronics
  - Internet.
  - Ipods!

## History and the future!

- Nano-technology (1990-Now)
  - Quantum computing
  - Biomedical
  - Materials

- New energy revolution
  - Nano tech + semiconductors + mechanical engineering

Gives us:

New power generation and distribution paradigm

# Electrical Engineering What does it do?

**Analysis and design of *systems*, *circuits and devices* used to transmit, store, and process information/energy.**

**Hardware → Software**

# ECE Programs – Carleton

**The Hardware-Software Spectrum**

**More Hardware Oriented** ↔ **More Software Oriented**

| | | | | |
|---|---|---|---|---|
| Lead Department | **Department of Electronics** | | **Department of System and Computer Engineering** | |
| The Programs | Engineering Physics | Electrical Engineering | Computer Systems Engineering | Software Engineering |
| | | Communications Engineering | | |
| | Biomedical and Electrical Engineering | | | |
| New | Sustainable and Renewable Energy Engineering | | | |

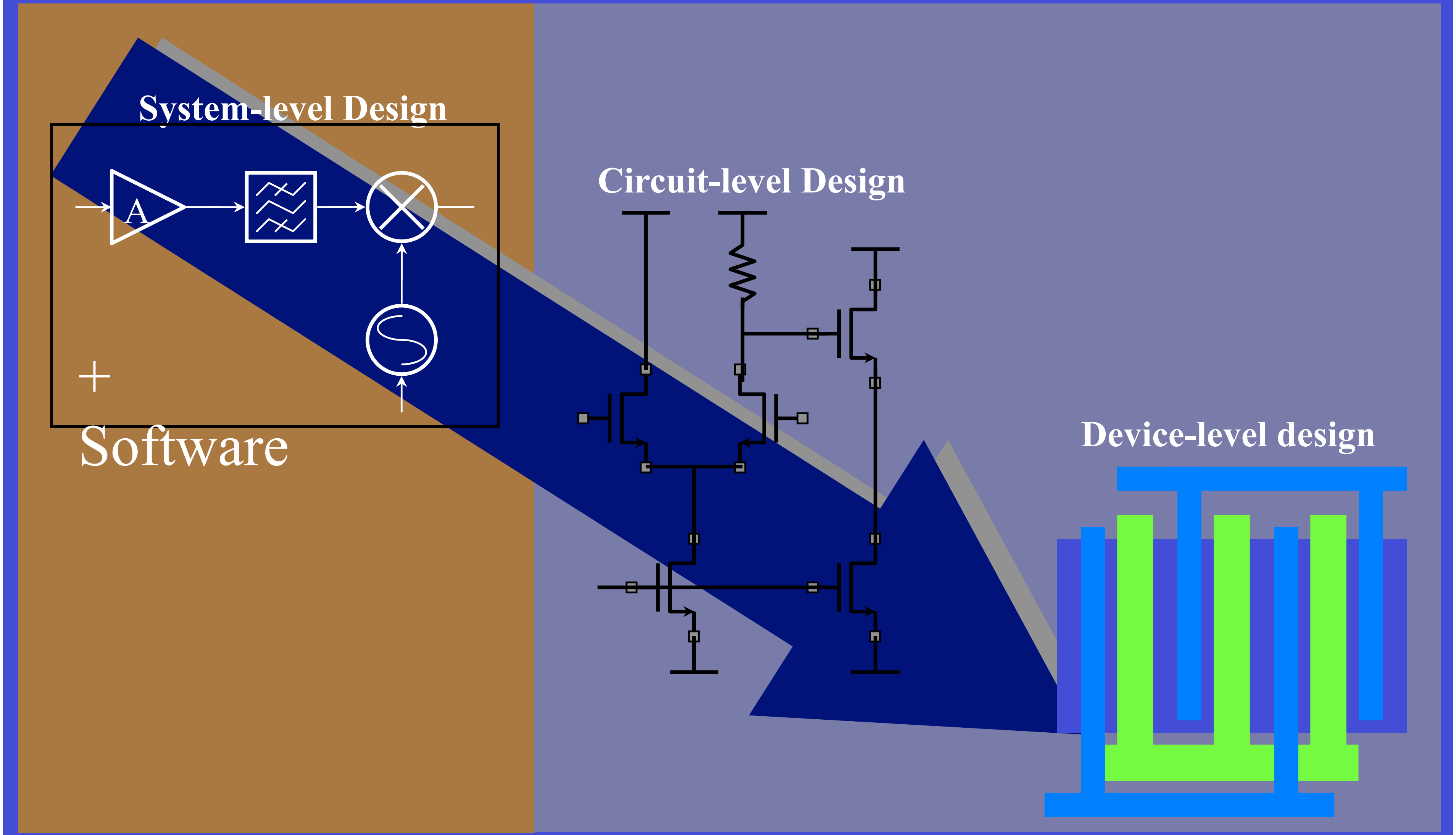
# B.Eng. In
# Engineering Physics

- A focused education which is suitable for our rapidly-changing technological world
- Focus on the physics of optics, photonics and integrated circuits, which are fundamental to the infrastructure of modern society

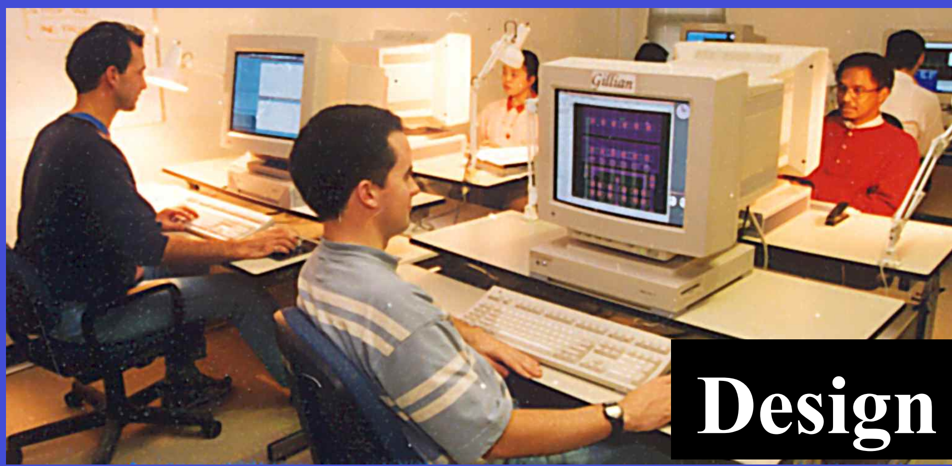
# B.Eng. In Electrical Engineering

- Broad field that provides graduates with a great deal of flexibility
- Our program generally reflects the technology-driven industry in the Ottawa area
- With a wide range of elective courses in integrated circuit design and fabrication, telecommunications systems, and computer hardware and software.

# Hierarchal Design – From small to big



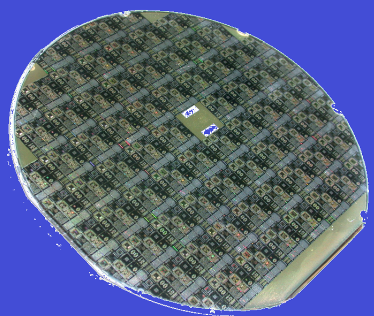
# From Idea to Reality

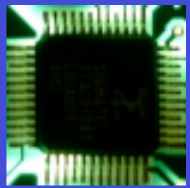




# Electrical Engineers do:

- Integrated Circuits





- Portable Electronics

- Space electronics

- Photonics

# Electrical Engineers also do:

- Electrical Energy Distribution

- Electric Cars & Batteries

- Wind/Solar/Hydro Power Generation

- Robotics

# Technological Revolutions

- Electrical Engineers have been at the heart of a number of revolutions in technology
- These paradigm shifts have radically changed the way Society functions
- Two examples
  - The Internet
  - New Energy Paradigm – to come?

# A Paradigm Shift like the Internet

Pre-1980s

Centralized Mainframes

Paradigm Shift


Distributed Computing

- Shipping 250M pcs/yr.
- Ubiquitous ownership
- Ubiquitous use
- Ubiquitous sharing

Innovation & Industry Transformation

# Paradigm Shift for the Power Industry

Today

Centralized Generation

*Paradigm Shift*

**FREEDM System**

Distributed Renewable Energy Resources (DRER)

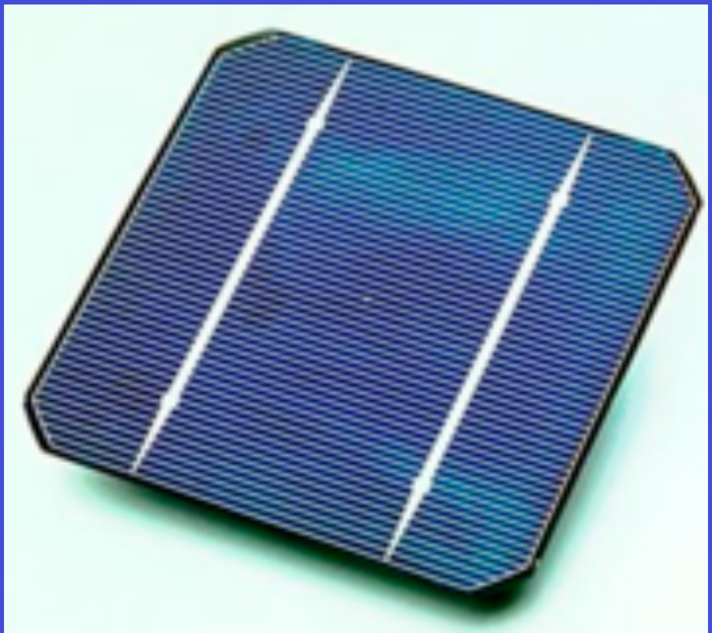
- **Ubiquitous sales**
- **Ubiquitous ownership**
- **Ubiquitous use**
- **Ubiquitous sharing**

**New technologies for distributed renewable energy**

**New energy companies based on IT and power electronics technologies**

**Innovation & Industry Transformation**

# Green Energy



# ENERGY SOURCES

For any energy source, need to consider:

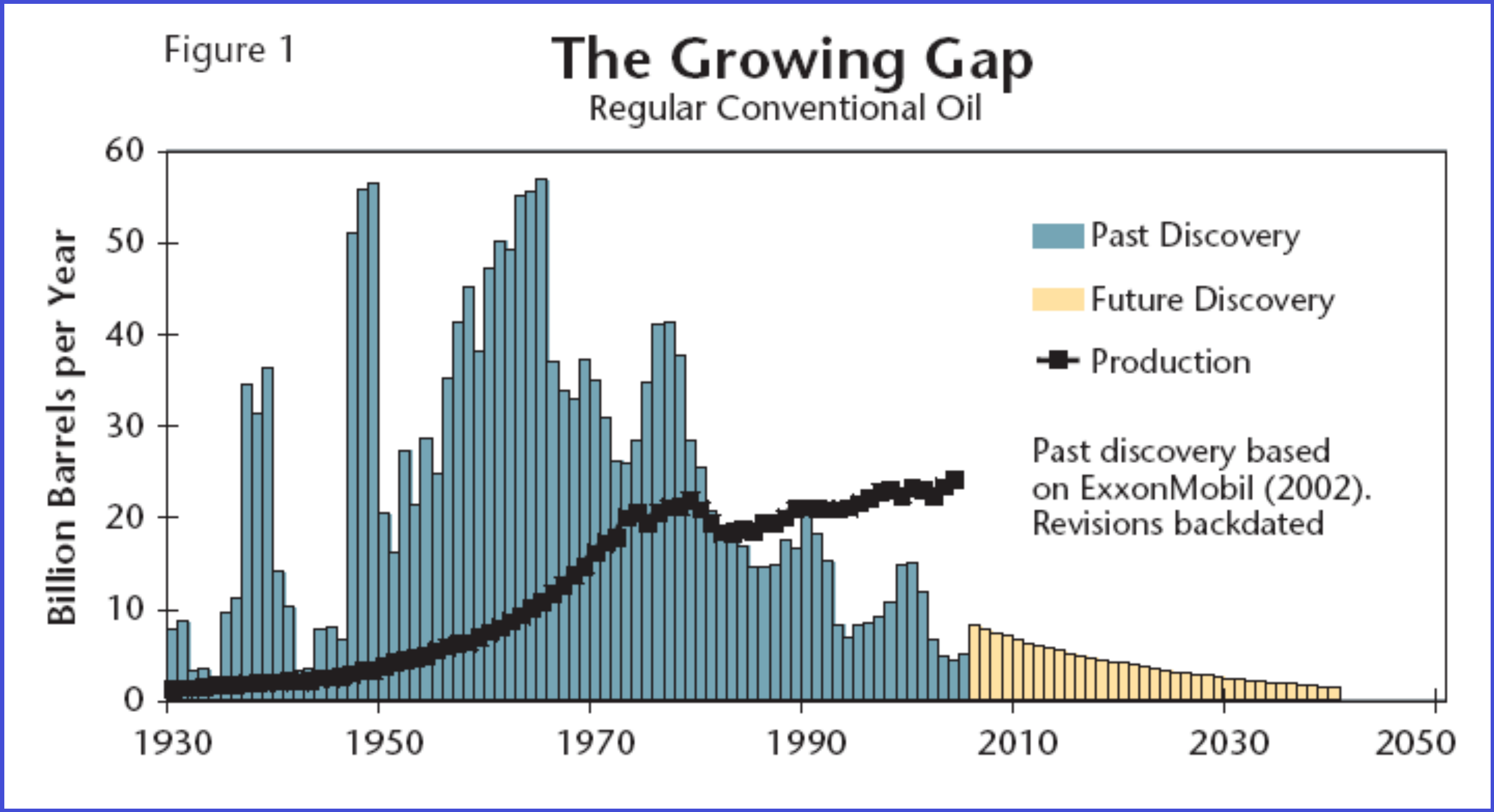
- Is it renewable?
- Pollution associated with use
- Means of storage and distribution

Industrial society has been built on fossil fuel combustion as a primary energy source

- Fossil fuels easy to store and transport
- High energy density (J/kg)
- BUT oil and gas reserves are being rapidly depleted

Cheap Energy built modern Civilization!

# A look at oil discovery and consumption



But global coal reserves are sufficient to last for centuries, and coal can be liquefied or used
to generate electricity!

Unfortunately, coal has severe environmental side effects

## Many issues with fossil fuels

- Dirty
- Limited
- Subject to political manipulation

## An Alternative: “All Electric” Energy Economy

- Use electrical energy extensively
- Generate electricity without using fossil fuels

This requires:

- Alternative methods for energy generation
- Improved electrical energy storage
- More efficient use of energy

Source must be much cleaner!

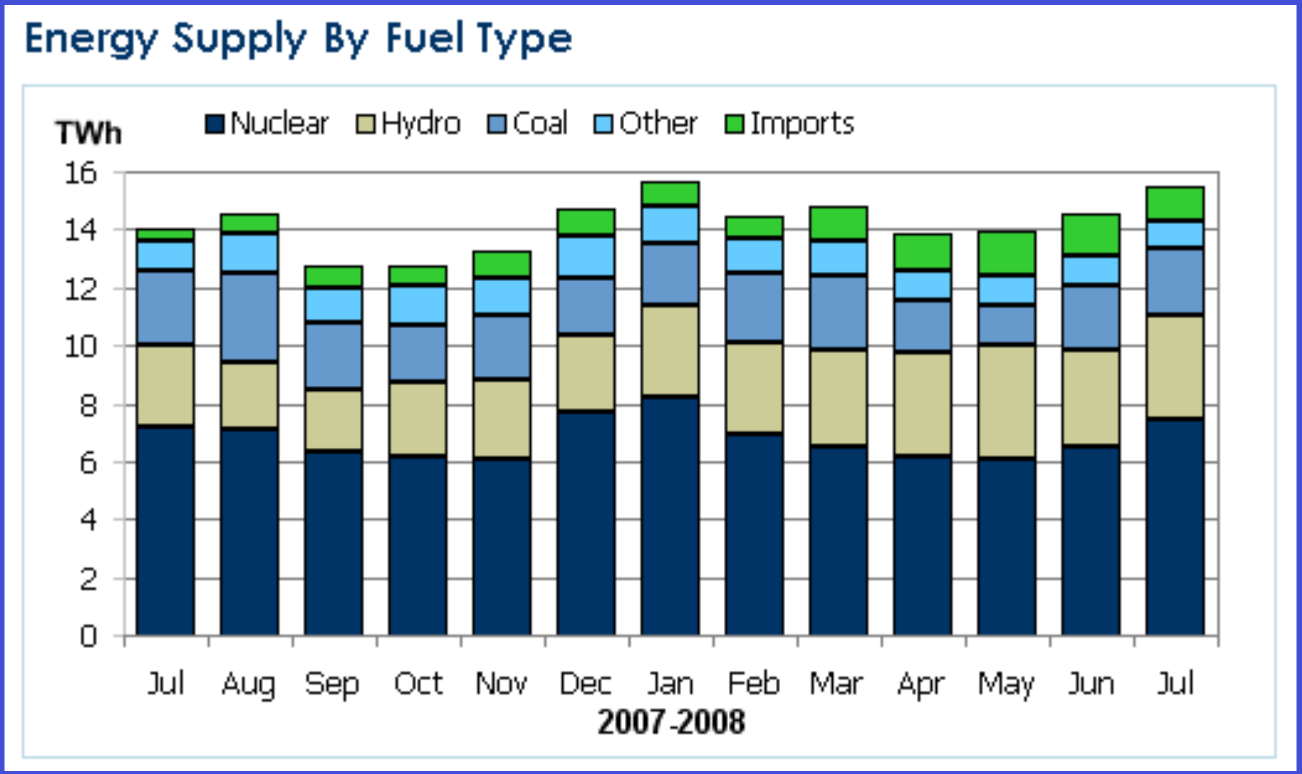
How much electrical energy do we need?

Typical household use:

Computer- 100 W
Fluorescent light bulb- 10 W
Refrigerator- 50 W (average)
etc…

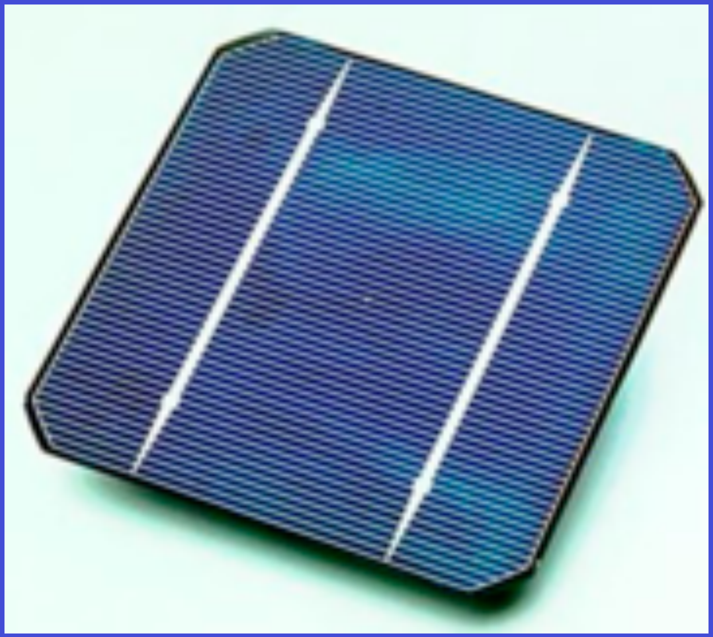
Overall, we each consume about 1 kW averaged over the day (and that doesn't include most heating and transportation!)

# Present sources of electrical energy in Ontario:



# Photo-voltaics

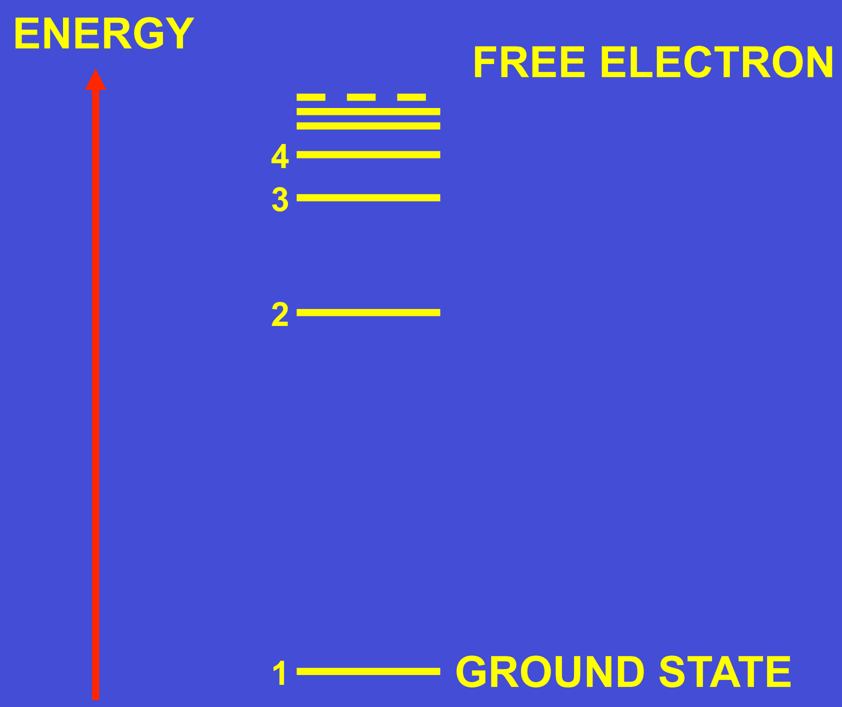
Electricity from sunlight- solar cells

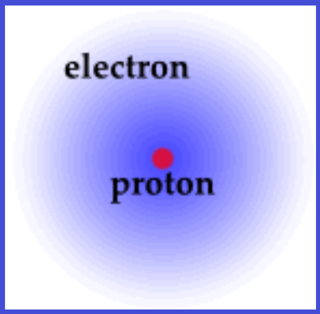


## How does it work?

- Back to basic chemistry and physics
- Physics can compute allowed electron energy levels in atoms and molecules

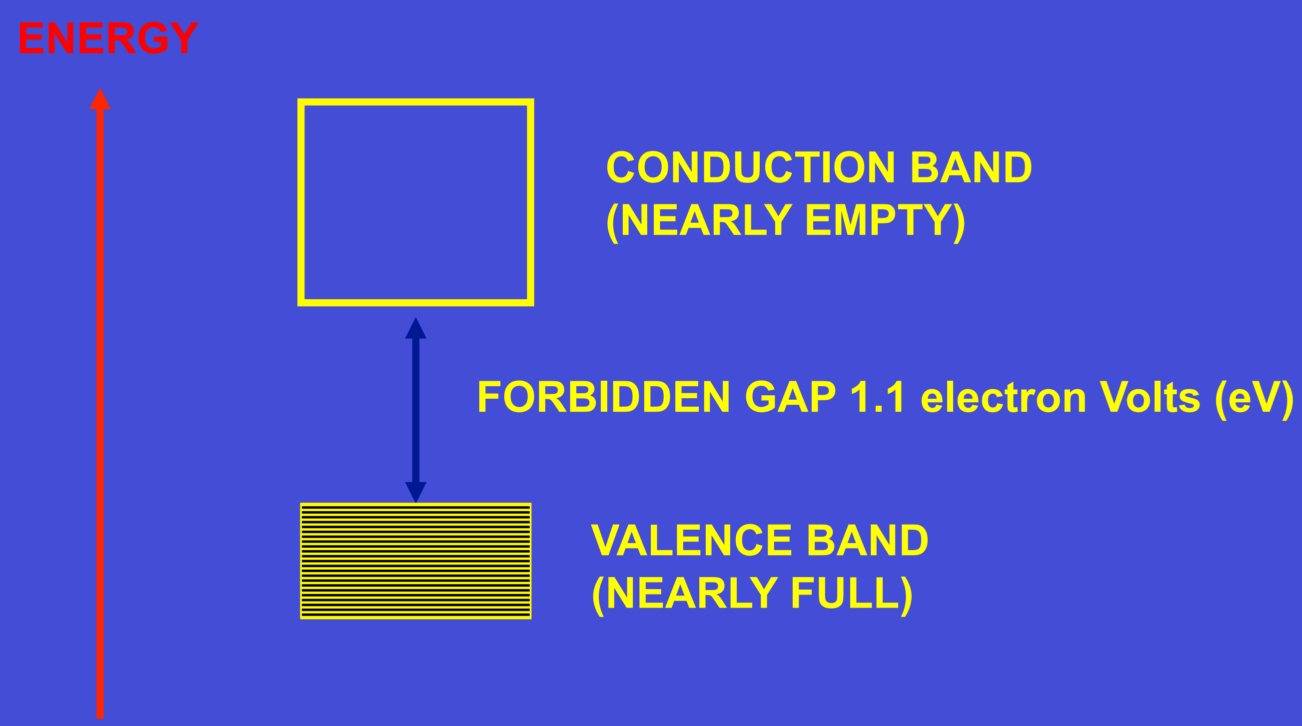
# Electron energy levels of the hydrogen atom




*Quantization*- only certain energies allowed

# Energy Levels in Silicon  (4 valence electrons)




Pure silicon a good electrical insulator

- No free electrons in conduction band
- Full valence band doesn't contribute to conduction

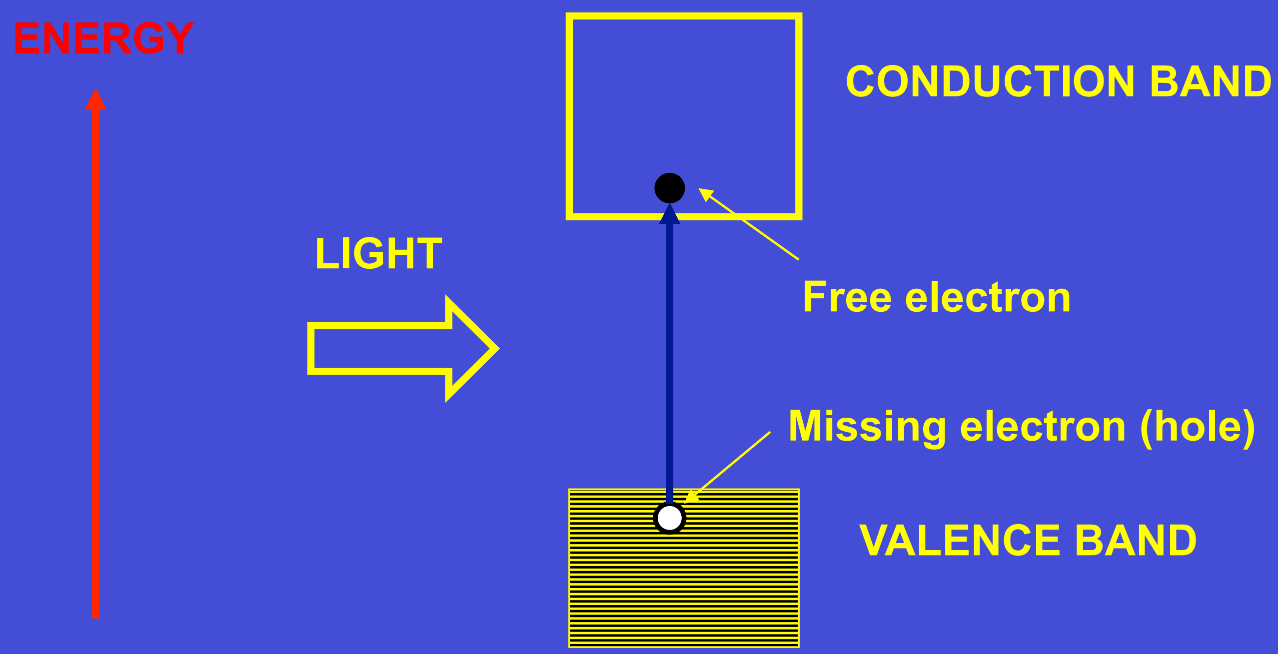
Light is quantized- discrete packets of energy called *photons*

Photon energy is related to wavelength

$$E = hc/\lambda$$

$h$ = Planck's constant
$c$ = speed of light
$\lambda$ = wavelength

# Light interacts with electrons in silicon, breaking chemical bonds



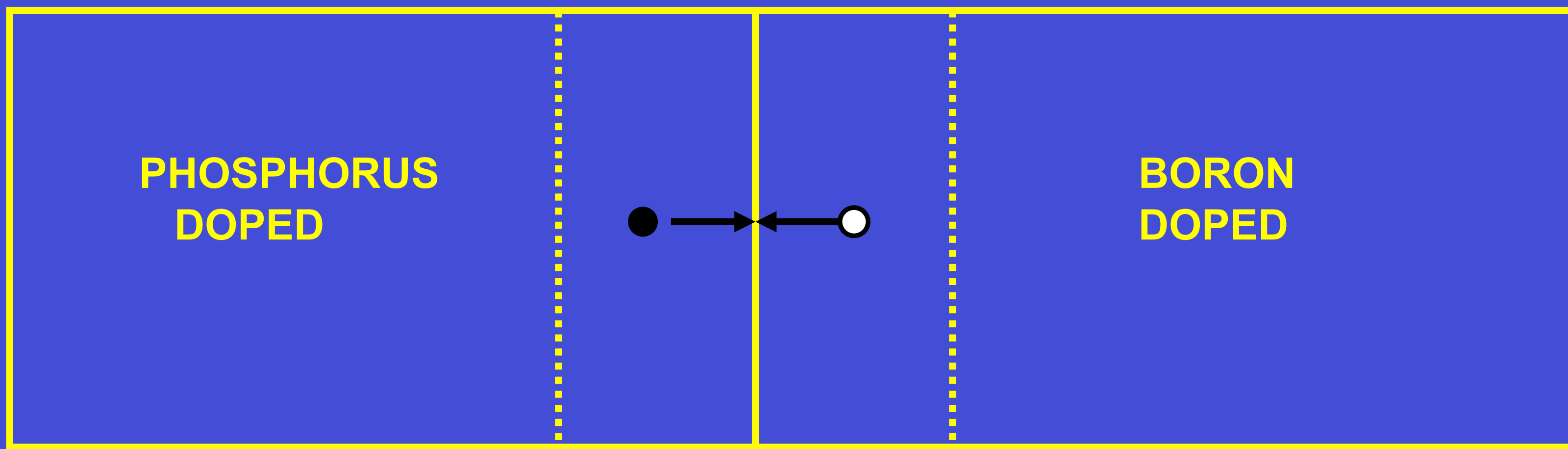

Photons with energy greater than bandgap excite bound electrons from valence band to conduction band

How can we extract their extra energy?

# Engineering the Silicon -- Doping

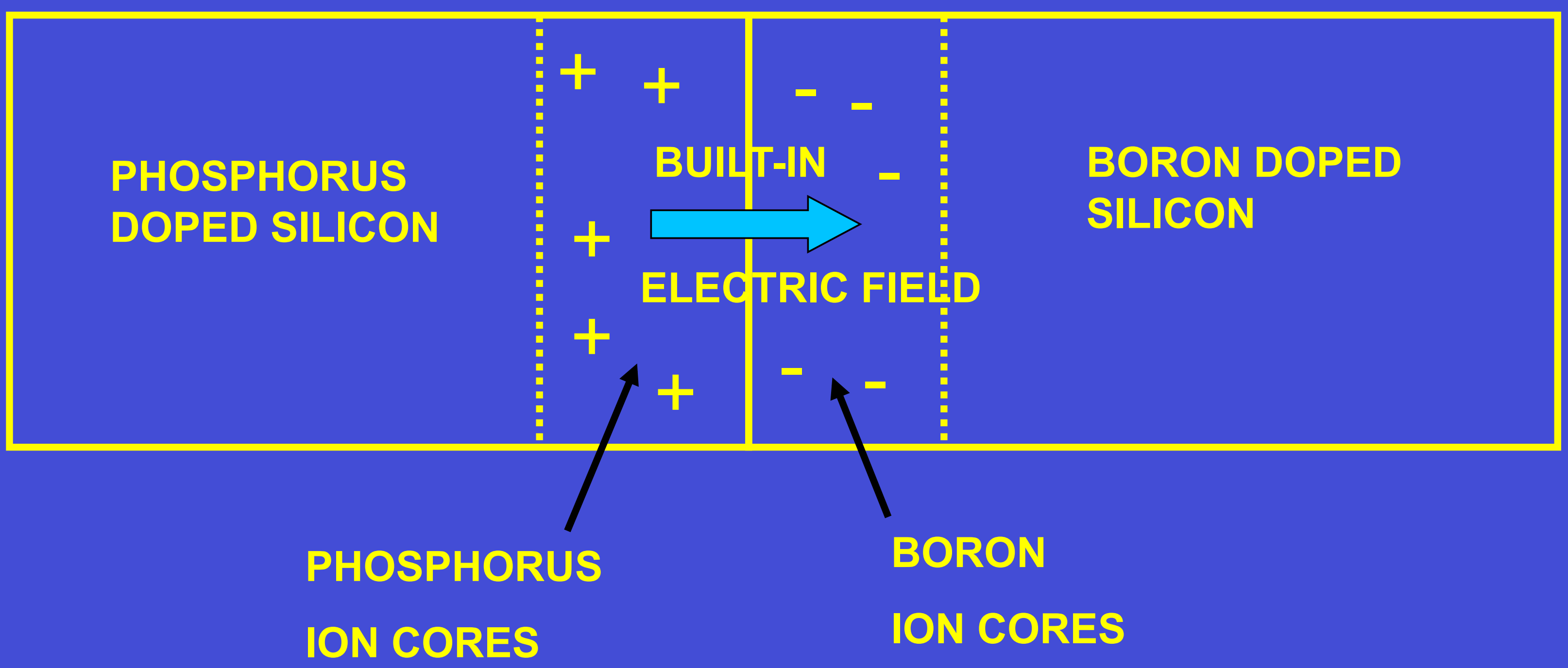
- Adding phosphorous makes the silicon “electron rich”
- Adding boron makes the silicon electron poor – which we call “hole rich”
- Hole is like a “positive electron”
- Now we can “Engineer” the material

Now put phosphorus-containing (electron rich) and Boron-containing (electron poor) silicon together

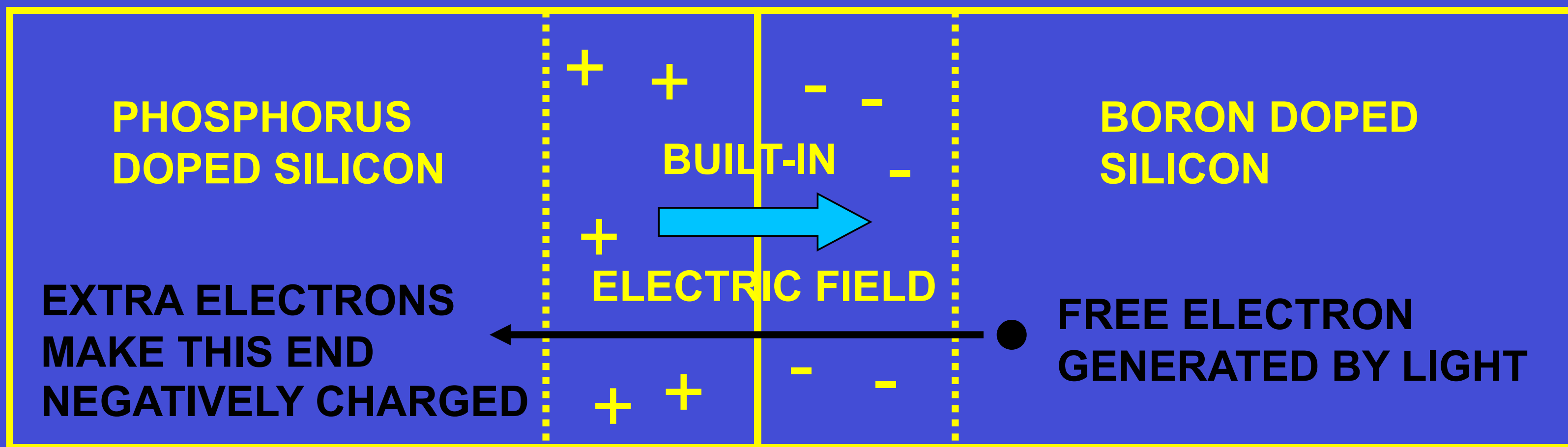



Free electrons from phosphorus supply the extra electrons the boron needs

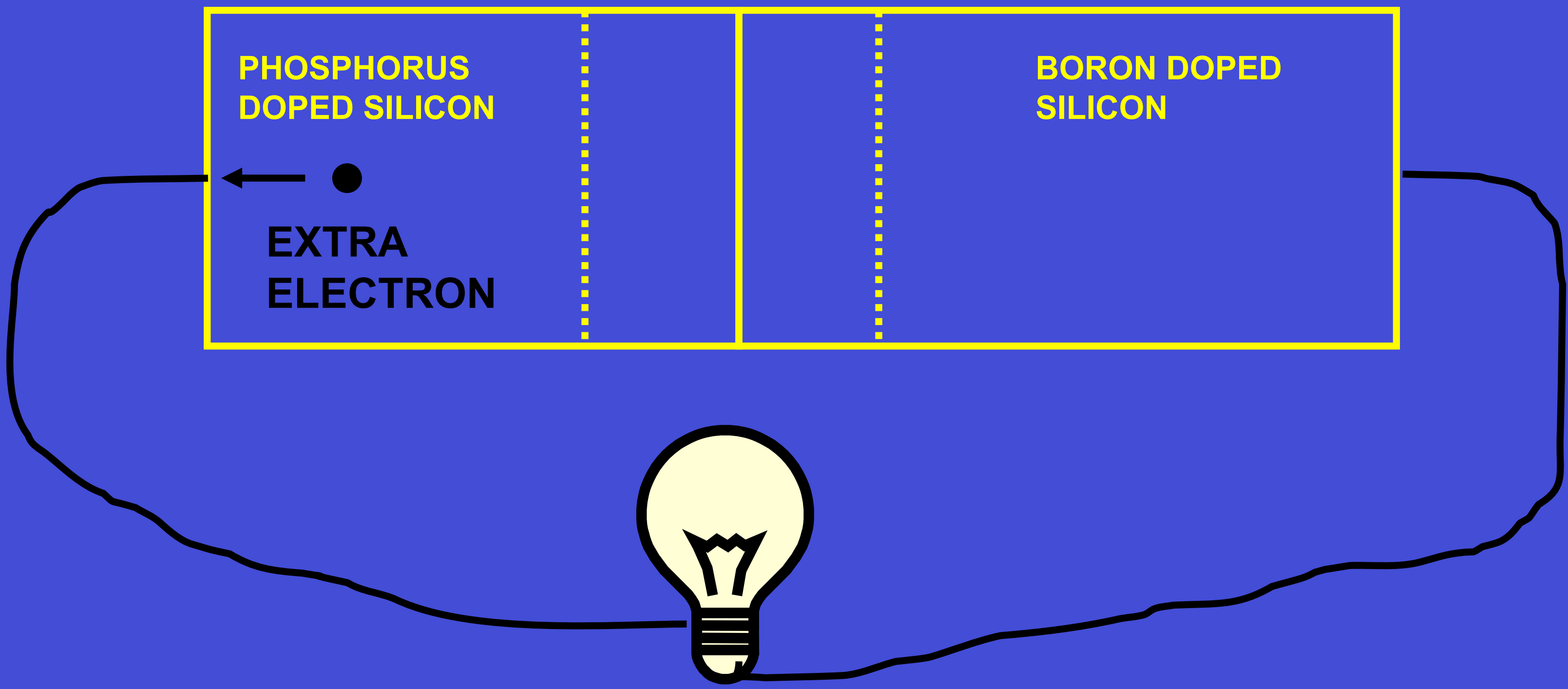
# Positive charge adjacent to negative charge gives a permanent “built in” electric field



Now we have a way to capture the free electron- if it comes close to the junction, the electric field will sweep it into the phosphorus doped material




- Connect the phosphorus and boron-doped regions with a wire
- Captured electron travels back through the wire, doing work along the way!

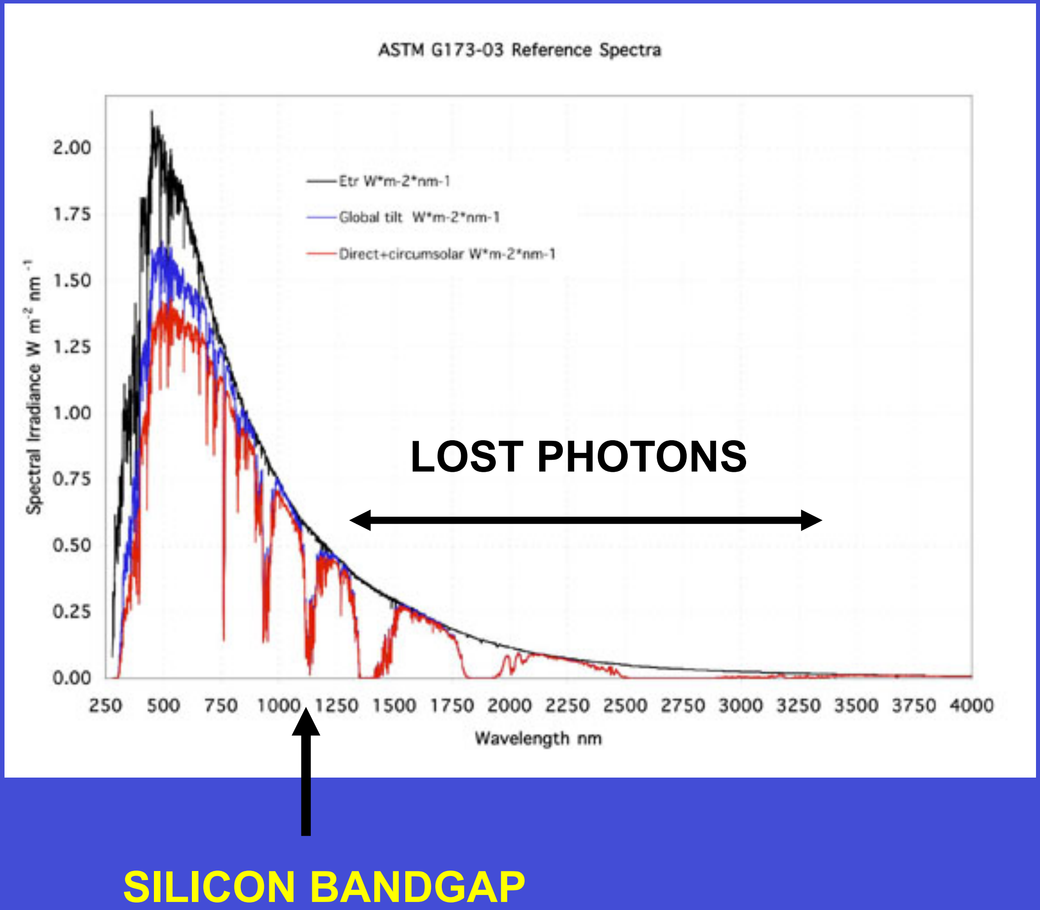


So now we’ve made a “solar battery”- but can we generate a useful amount of electricity?

Total power of sunlight on a clear day with sun overhead about 1 kW per square meter

Sounds good- we need about 1 kW per person- but how much of this power can we extract?

# Solar spectrum:




- Photon energies lower than bandgap are lost
- Energy in excess of bandgap is wasted

Bottom line:

For silicon, at best only about 25% of incident sunlight can be converted to electric power

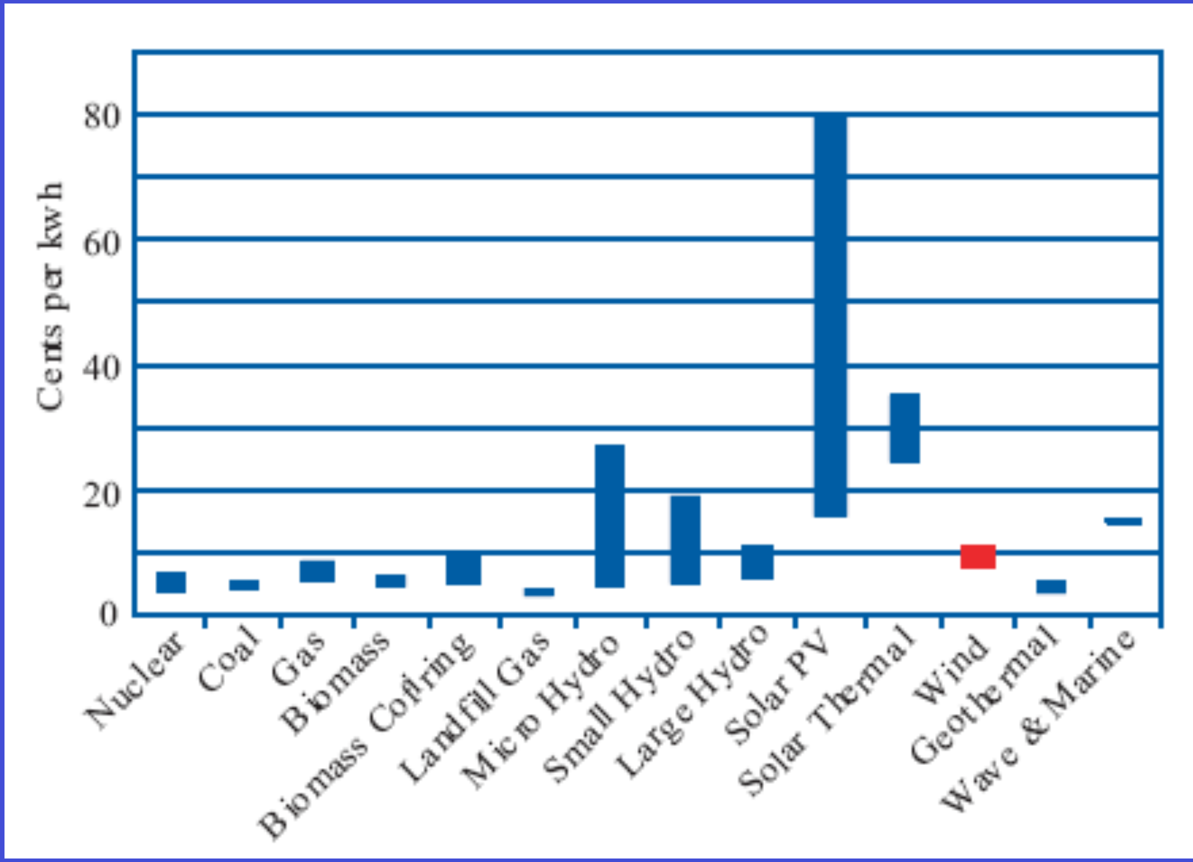
In practice, things like losses to wiring resistance make the practical energy conversion efficiency closer to 15%

So we can only extract about 150 W per square meter in bright sunshine; we will need 7 $m^2$ for 1 kW

We also have to store the energy in batteries for use at night or on cloudy days

Better make that 35 $m^2$ – or more!

Still, that’s only about 6 meters on a side- the roof of a house is bigger than that




Cost of different energy sources

Isn’t there a better way?

First, we should find materials that more efficiently convert sunlight to electricity

Wide bandgap- lost photons

Narrow bandgap- inefficient conversion

The optimum bandgap is around 1.4 eV (bigger than silicon’s)

Next, we'd like our solar cells in a thin, flexible sheet (deposit the photovoltaic material on a cheap plastic substrate)

One leading thin film material under investigation:

Amorphous silicon

Cadmium Teluride (CdTe)

Copper Indium Gallium Selenide ("CIGS")

A more speculative approach- copy the plants!

Some polymers (long carbon based molecules) have an energy bandgap and behave like semiconductors

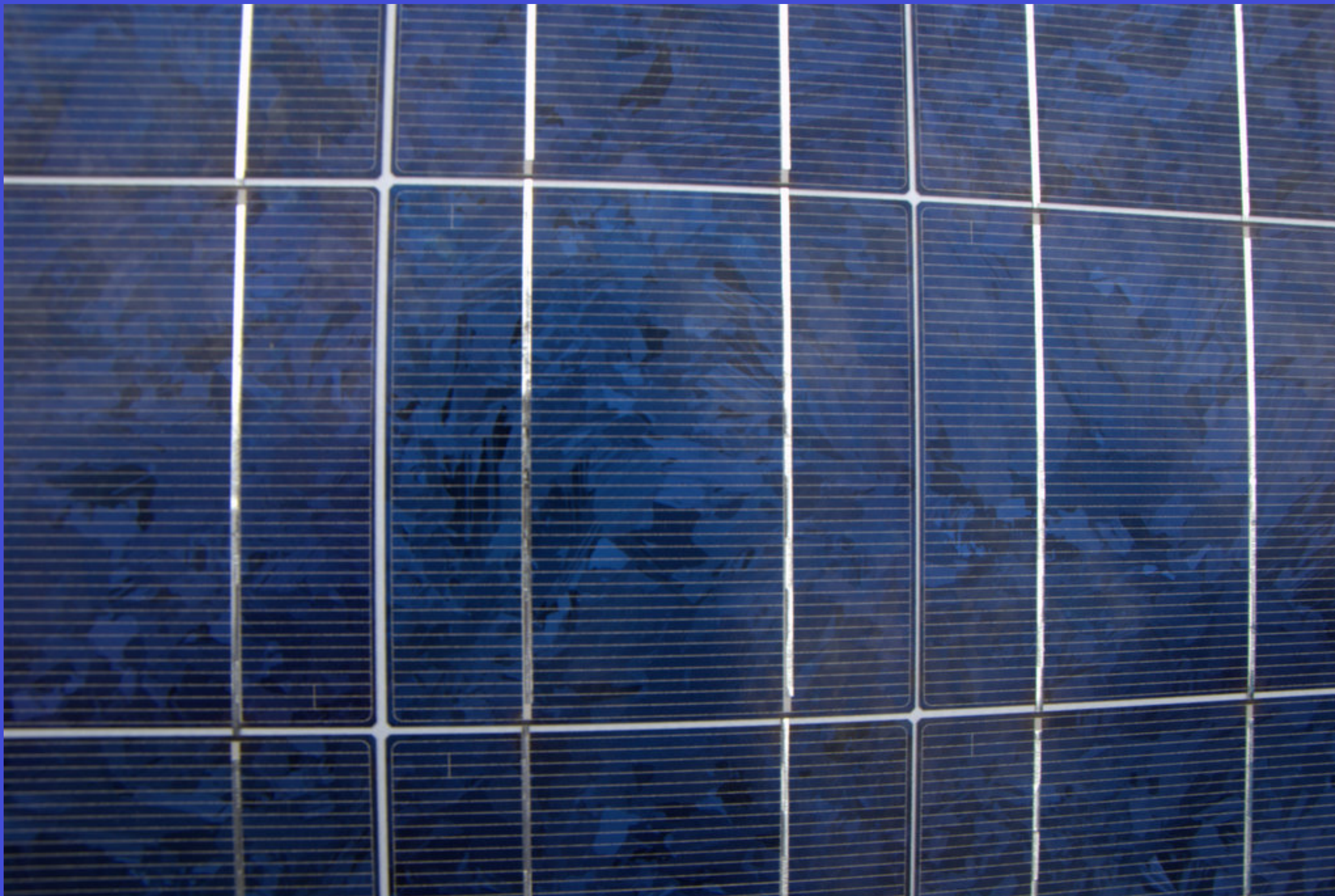
Solar cells can be made from these materials (present efficiency record about 5%)

Stability is a problem- organics don’t like oxygen

A vision-

Thin-film organic solar cells with efficiency >20% integrated in building materials

Large area flexible photovoltaic panel



# Nano Technology

**nano- (nan'oh)**

***pref.***

1. **<unit> A prefix.**
2. **Used loosely to mean “extremely small", e.g. nanotechnology.**
3. **One-billionth ($10^{-9}$): *nanosecond.***

[Greek nanos, nannos, little old man, dwarf, from nannas, uncle.]

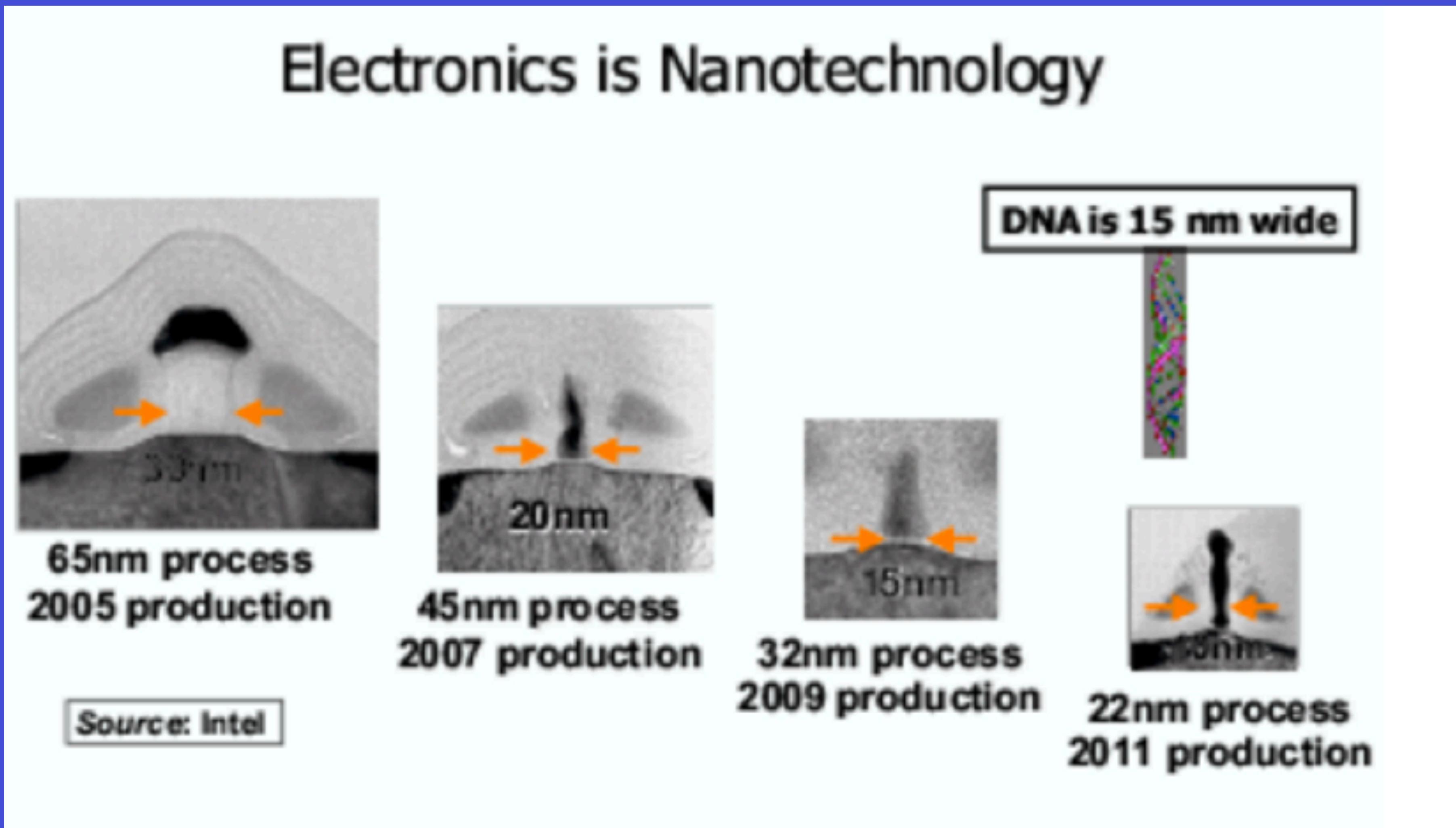
**tech·nol·o·gy (tech*nol'o*gy)**

***n. pl.* tech·nol·o·gies**

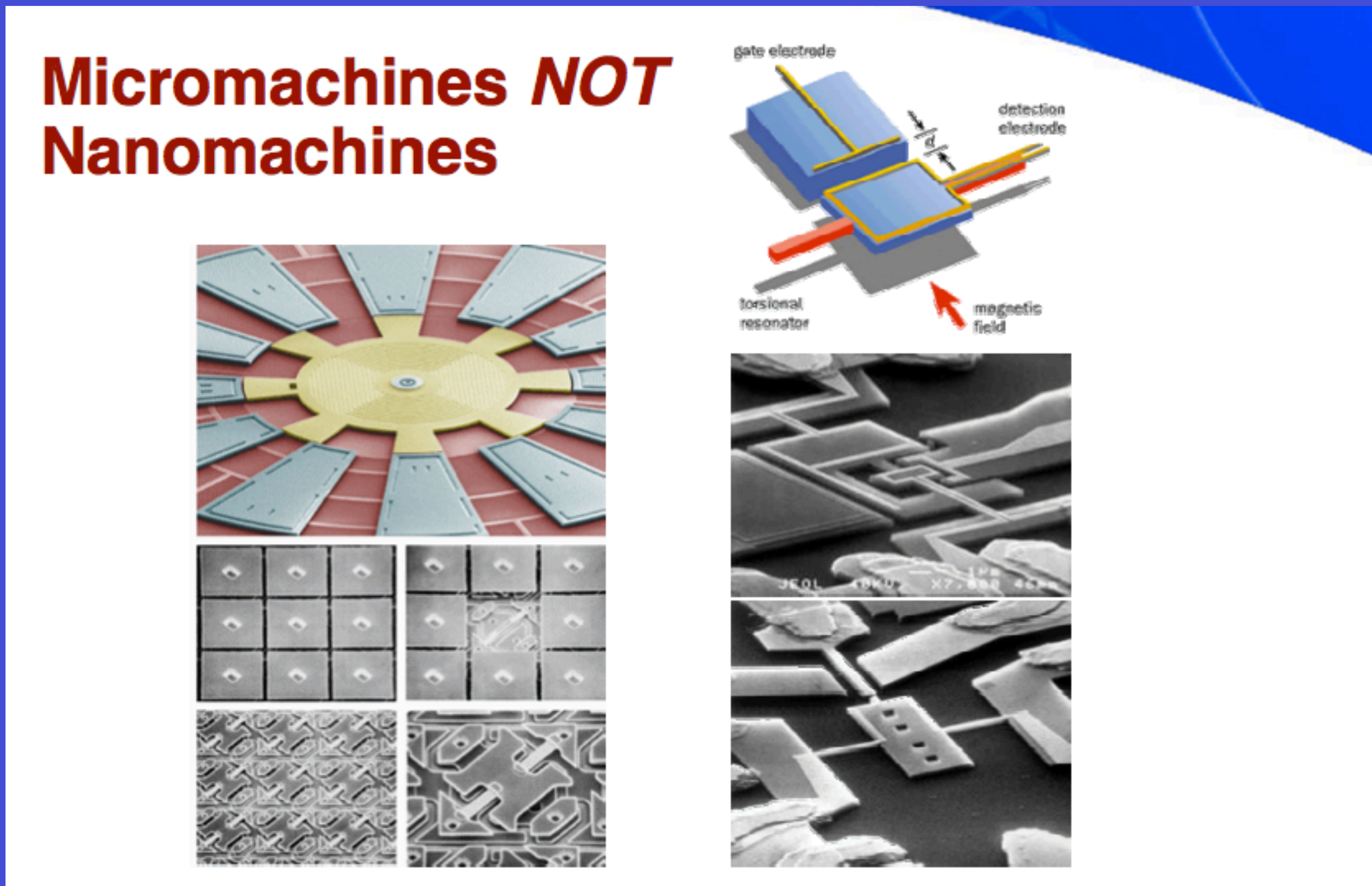
1. **The application of science, especially to industrial or commercial objectives.**
2. **The scientific method and material used to achieve a commercial or industrial objective.**
3. **Electronic or digital products and systems considered as a group: *a store specializing in office technology.***
4. ***Anthropology.* The body of knowledge available to a society that is of use in fashioning implements, practicing manual arts and skills, and extracting or collecting materials.**

[Greek tekhnologia , *systematic treatment of an art or craft* : tekhne , *skill*; see teks- in Indo-European Roots + -logia , *-logy.*]

# We already do it!

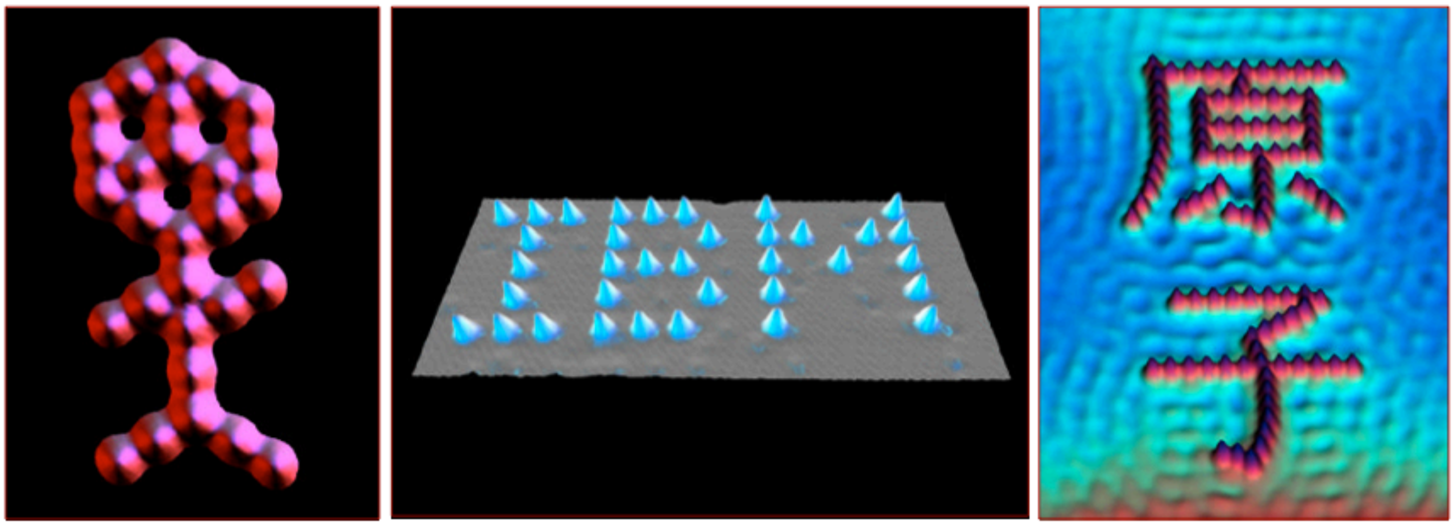


# OR Something just as good!



# But this really is nano

## Some IBM Molecular Manipulation




Carbon Monoxide Man
Carbon Monoxide on Platinum (111)

The Beginning
Xenon on Nickel (110)

Atom
Iron on Copper (111)

# Photonic (light) and Nano

What can it do?

- Better communications
- More efficient solar cells
- Faster computers – artificial intelligence
- Stronger lighter materials
- Bio/medical engineering

- Who knows!

# Announcements

- Short Fab. tour right after this
- Mackenzie (ME) 4124 at 1:00
  - 4th year project presentations, awards, and Industry talks.
  - 20 min tour of labs after this.
  - With pizza served from 12:45

Questions???