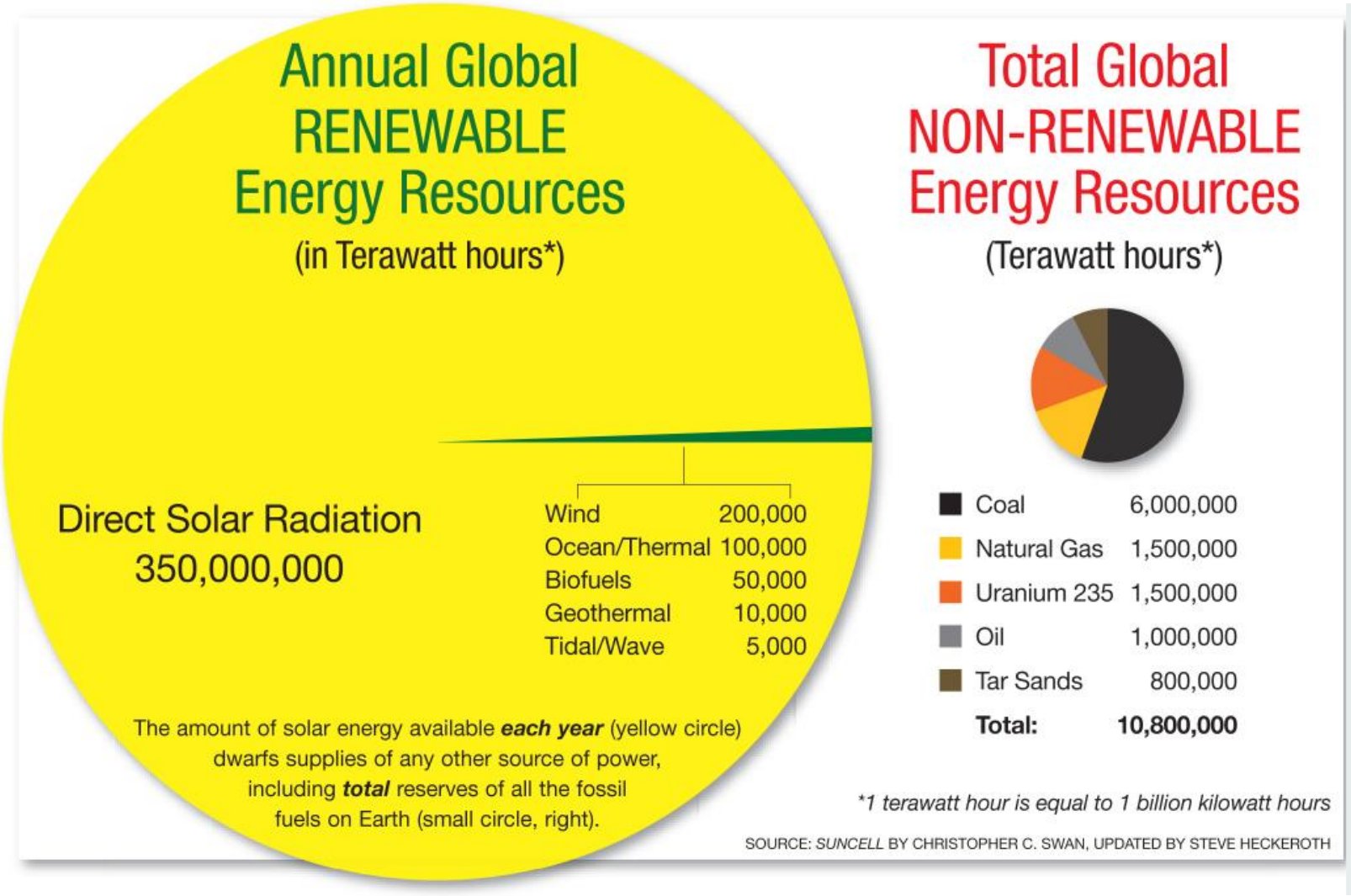
SOLAR

SOLAR POTENTIAL



ALL THINGS FROM SOLAR

- Interesting note: nearly all of our energy sources originated from solar energy:
  - Bio-mass/bio-fuels: Plants need the sun to grow.
  - Coal, oil, natural gas: Solar energy used by plants which became coal after billions of years and lots and lots of pressure
  - Wind: Uneven heating of the air by the sun causes some air to heat and rise. Cool air then comes in and replaces the warmer air.
  - Ocean: Dependent partly on winds, which in turn depend on the sun.
  - Hydro-Electric: The sun heats up water evaporating it. When it rains some of that water ends up behind damns.

- Notable exceptions:
  - Nuclear energy: Uranium or other heavy metal (fission)
  - Geothermal: Energy from the core of the Earth

THE POWER OF THE SUN (US)

- If 150 sq km of Nevada was covered with 15% efficient solar cells, it could provide enough electricity for the entire country.
- What's the problem?

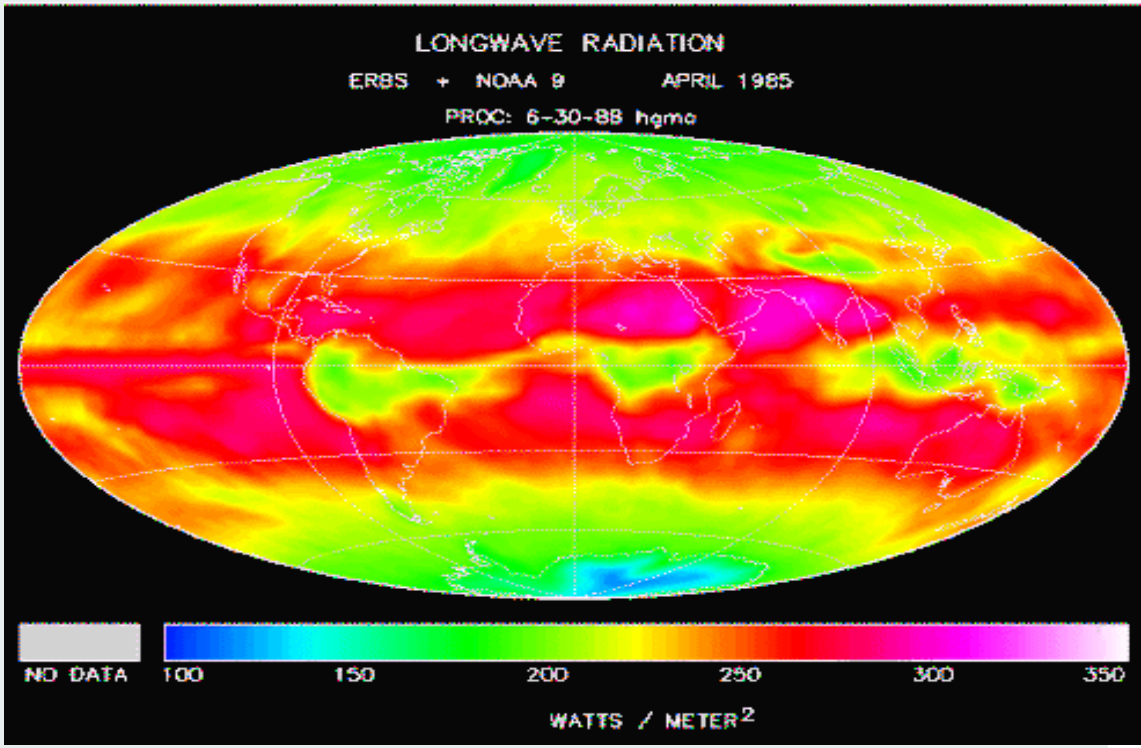
Source: M. McGehee, Stanford University
J.A. Turner, *Science* **285** 1999, p. 687.

THE POWER OF THE SUN (WORLD)

- Insolation is a measure of solar radiation energy received on a given surface area in a given time – measured in $\frac{W}{m^2}$.

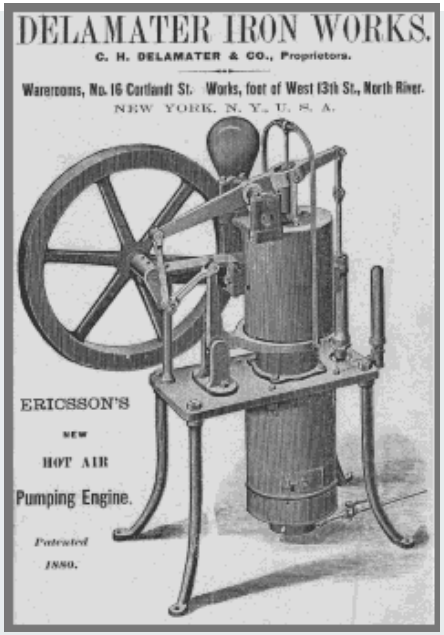
On Earth's surface, insolation depends on location.

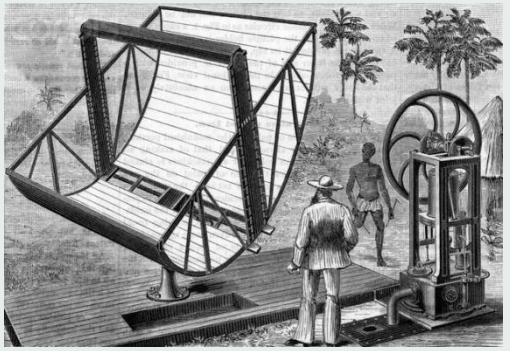
- Sahara desert: 250-300 $\frac{W}{m^2}$ avg
- United Kingdom: 125 $\frac{W}{m^2}$ avg
- Santa Barbara: 200-250 $\frac{W}{m^2}$ avg



SNAPSHOTS OF SOLAR ENERGY THROUGH HISTORY

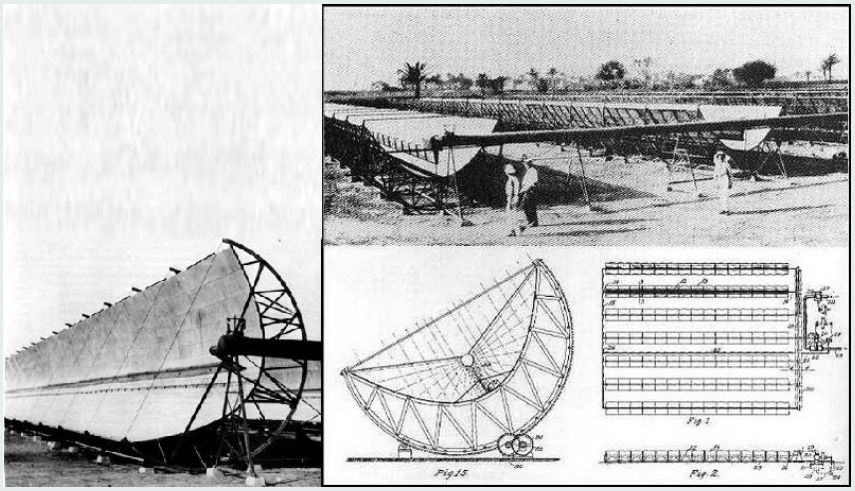
- Early humans
  - Sun for warmth, (tans?)
- ~ 5th Century BC- Ancient Greece
  - Local supplies of coal and wood dwindled, rationed
  - As a result, building of homes to maximize solar energy (homes oriented towards Southern horizon) and city planning
- ~ 1st Century BC- Romans
  - Transparent glass used as a heat trap—"solar furnace"; greenhouses for plant cultivation, Roman baths design
- ~Late 1800s- Augustine Mouchot
  - First attempts at "solar engines" using reflectors, mirrors transparent glass
  - Practicality, economics ultimately doomed these attempts





SNAPSHOTS OF SOLAR ENERGY THROUGH HISTORY

- ~1800's- Becquerel and Fritts
  - Discovery that sunlight can produce electricity (Becquerel in 1839) and invention of first solar cells from Selenium (Fritts in 1884)



- ~1911- Frank Shuman
  - Glass covered black pipes filled with low boiling point liquid put at the focus of trough-like reflectors
  - Trials in Egypt
  - Death of Shuman, discovery of cheap oil ultimately doomed projects.
- 1954- Bell Labs discovery of Si solar cell
  - 6% efficient initially!
  - Not cost effective, but space applications breath life into industry and keep it going.

SNAPSHOTS OF SOLAR ENERGY THROUGH HISTORY

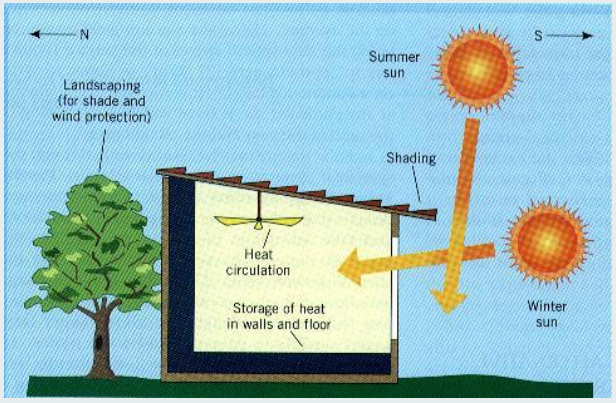
- 1970s - Upsurge of interest in solar energy
  - OPEC oil embargo causes sharp increase in oil prices
  - President Jimmy Carter installs solar panels on the White House roof.
- 1986 - After reduction in oil prices, sharp fall in public interest and political will.
  - Removal of solar panels from White House by Reagan administration.
- If there was no longer any interest (funding) in solar energy, why did scientists keep working on them?
  - Space Travel?
- Are we again doomed to repeat these boom/bust cycles of interest in solar? What would it take for solar to stay interesting?

"In the year 2000, this solar water heater behind me, which is being dedicated today, will still be here supplying cheap, efficient energy."

Jimmy Carter

SOLAR TODAY

Two broad categories

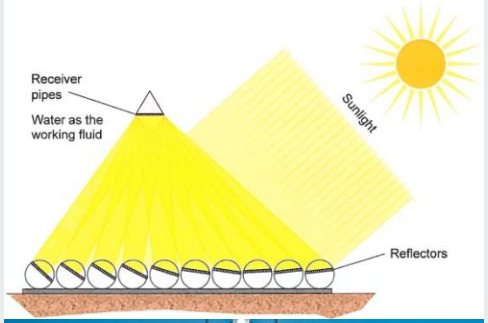


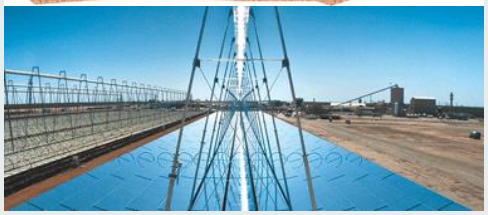
1. Passive Solar
   - Using sunlight without any electrical or mechanical systems
   - Appropriate building design, heat storage, passive cooling.

2. Active Solar for electricity generation
   - Concentrating Solar Power (CSP)
     - Using mechanical/optical means to focus sunlight.
     - Use heat to drive engine (e.g. steam turbine)
   - Photovoltaics (PV)
     - Converts sunlight directly into electricity

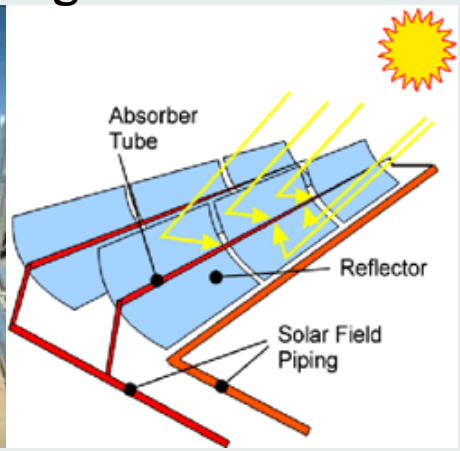
CONCENTRATING SOLAR POWER

Fresnel Reflectors





Parabolic Trough



Power Tower

Solar Dishes

CONCENTRATED SOLAR POWER

Project	Started Producing Electricity	Size	Type	Who the sell energy to
Ivanpah Solar Electric Generating System ★	2014	377 MW	Power Tower	Edison and SDG&E
Solar Energy Generating Systems (SEGS) (1 sites)★	1991	80 MW	Parabolic Trough	Edison
Mojave Solar Project ★	2014	280 MW	Parabolic Trough	PG&E
Genesis Solar Energy Center ★	2014	250 MW	Parabolic Trough	PG&E

Total Concentrated Solar Power: 1.0 GW

CELLS, PANELS, AND ARRAYS

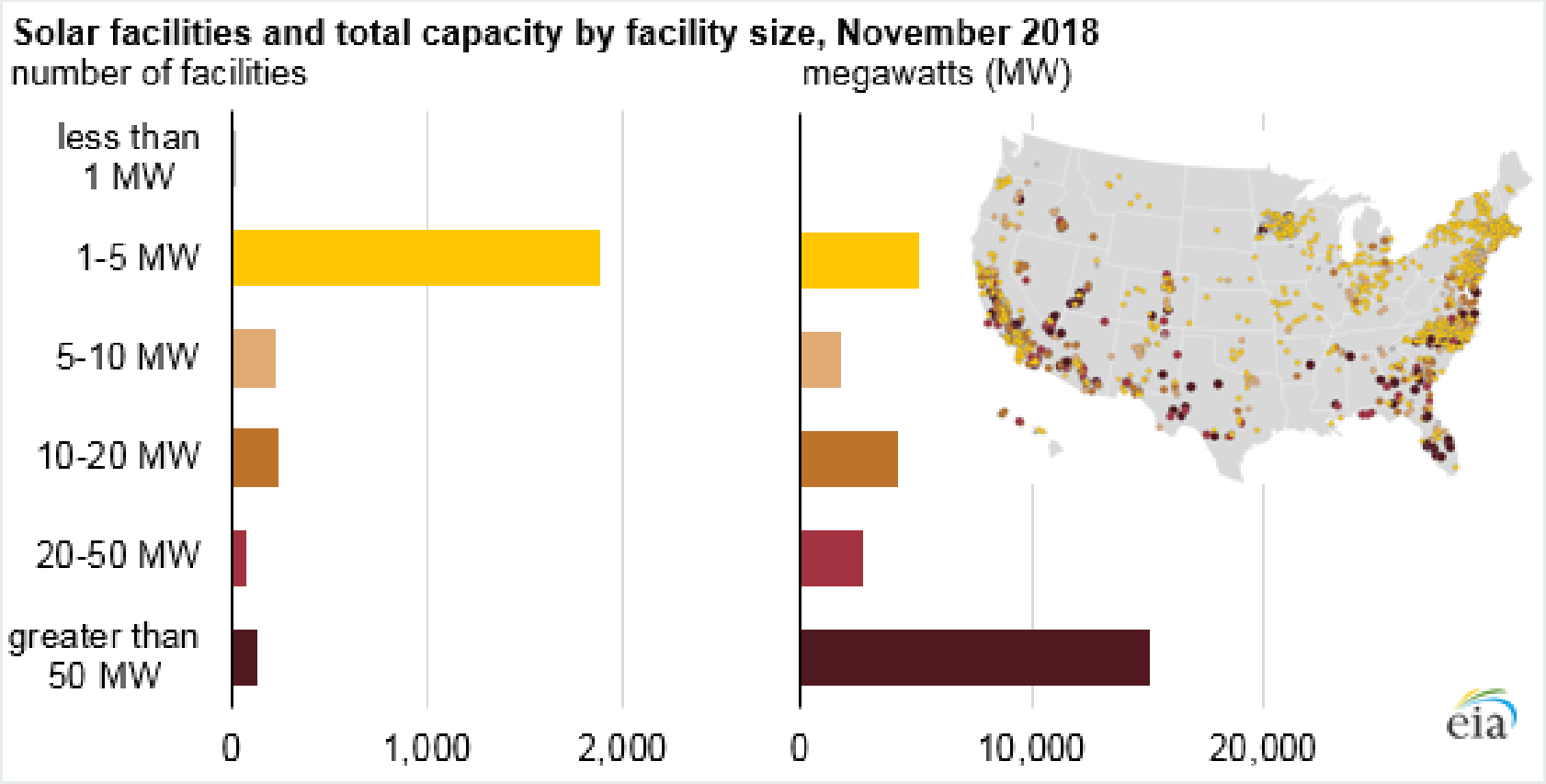
Solar Cell

Solar Panel (a.k.a. Module)

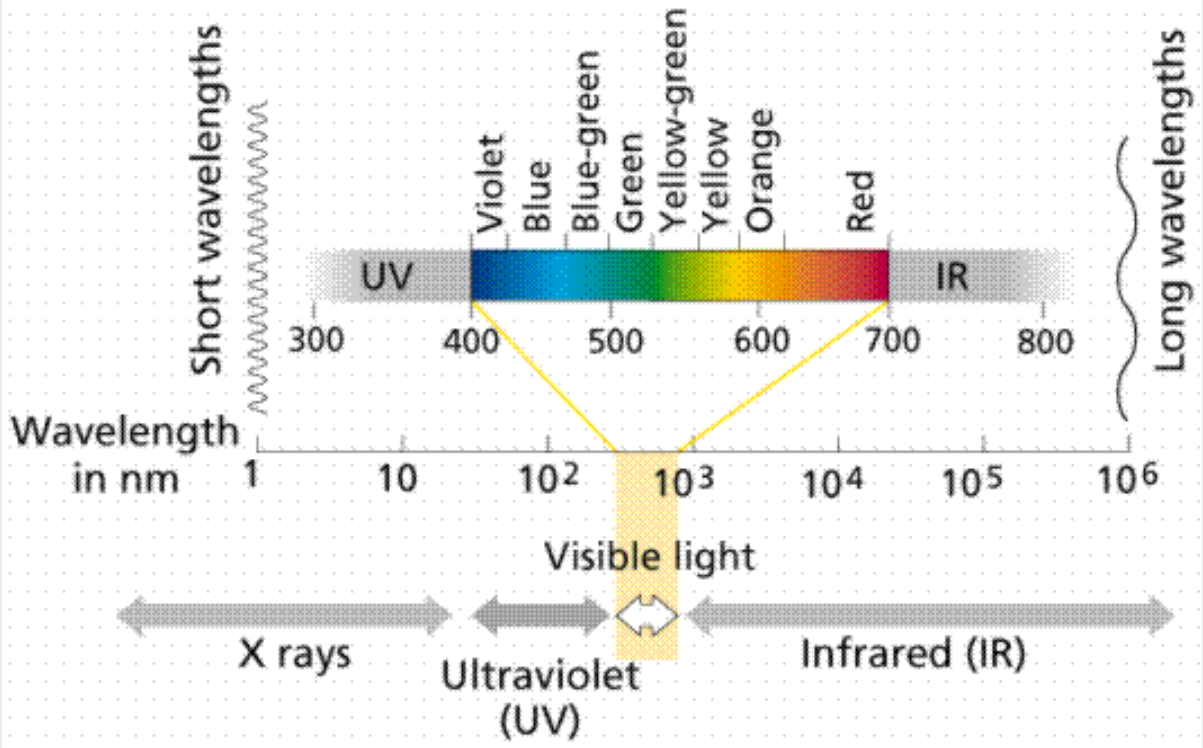
Solar Array

Solar Farm

SOLAR IN THE US

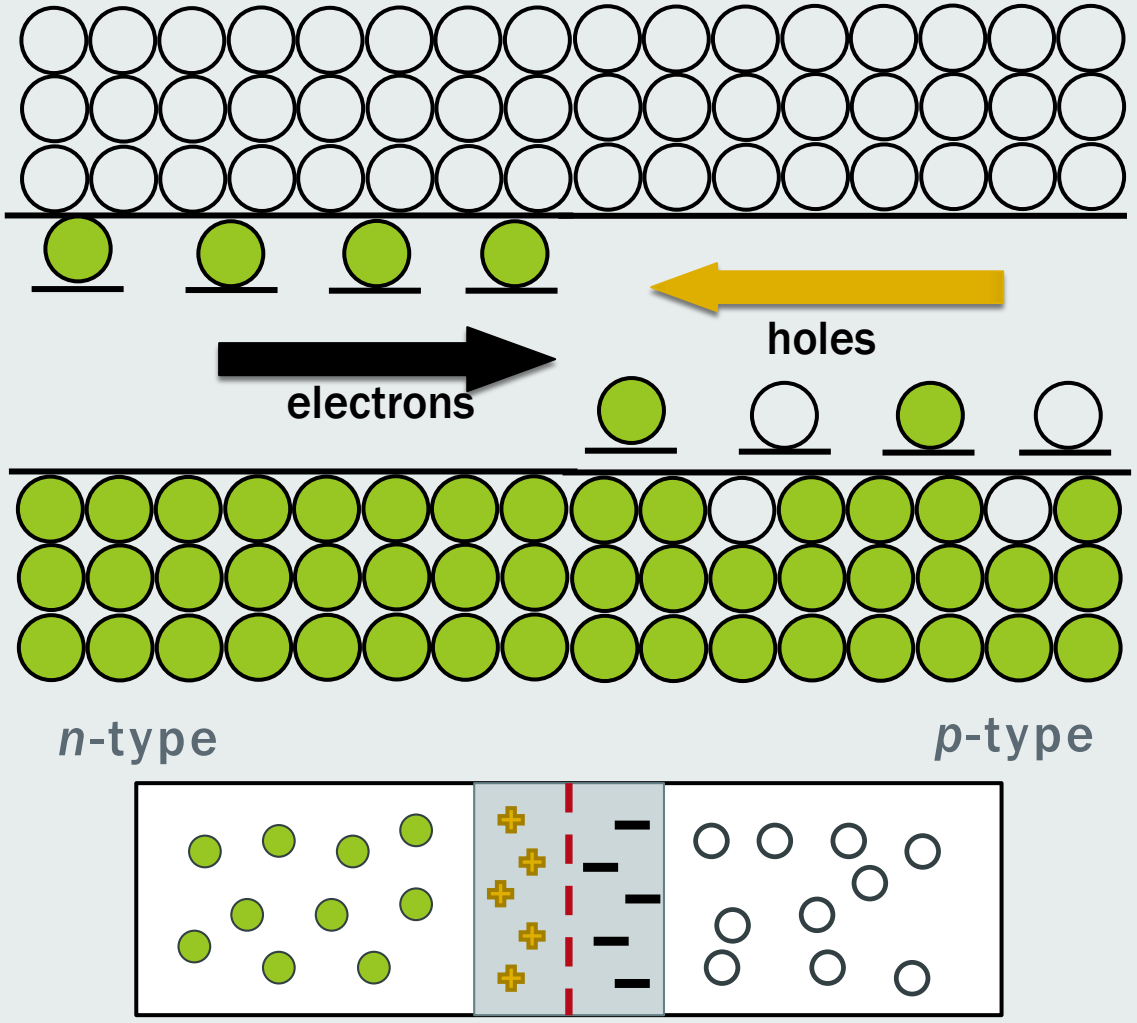


MINI-LAB: MORE FUN WITH LEDS

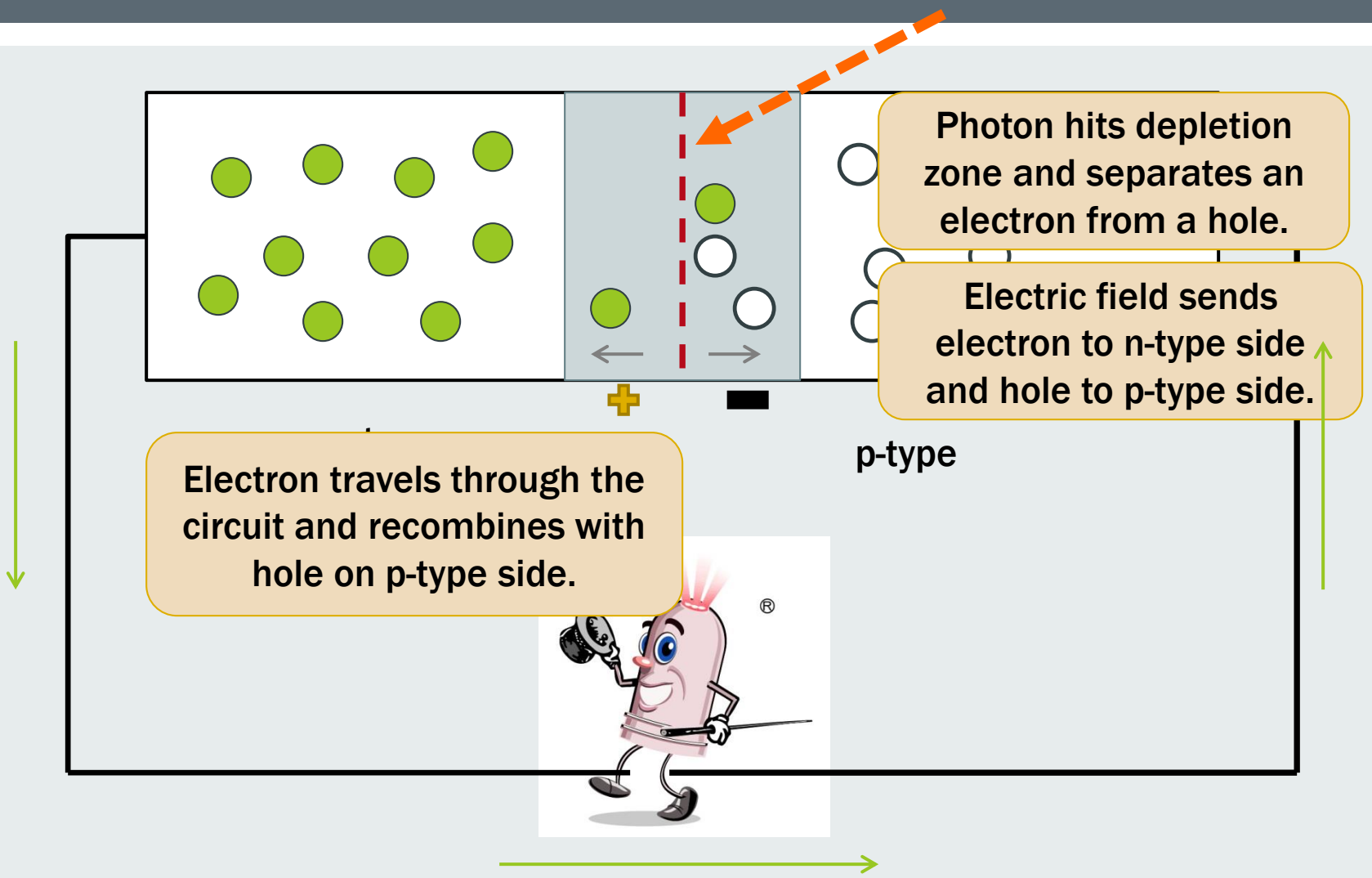


$$E = \frac{hc}{\lambda}$$

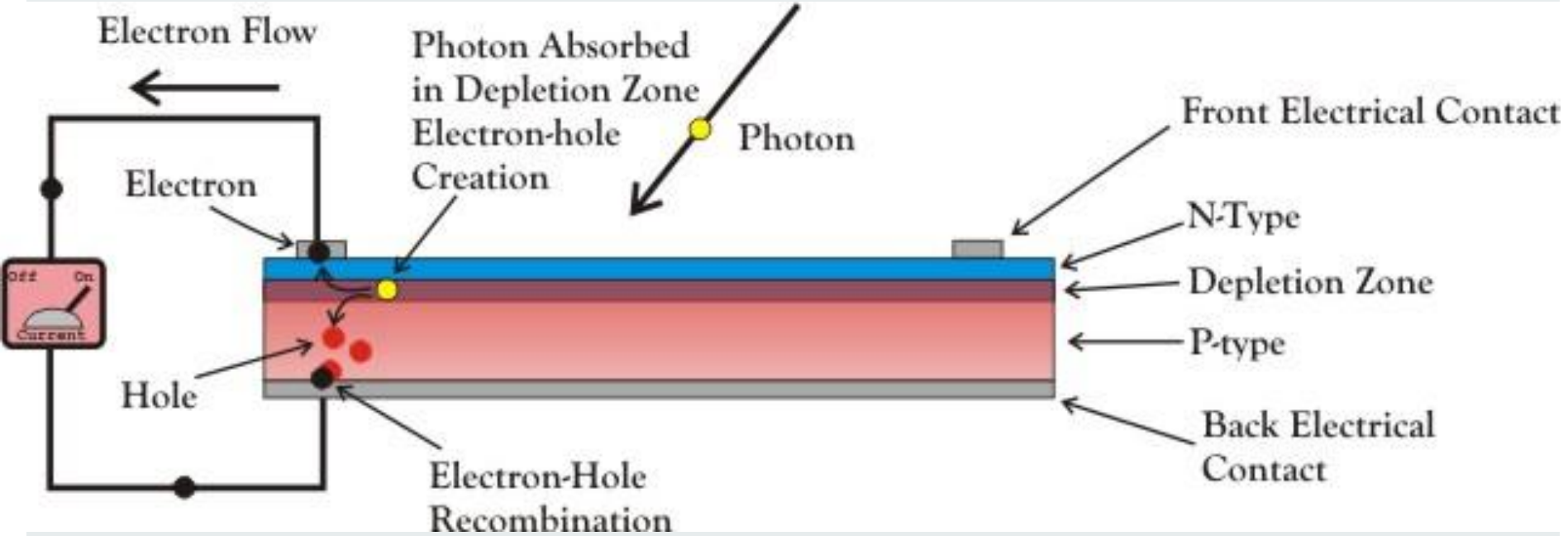
PN-JUNCTION – NO VOLTAGE APPLIED



P-N JUNCTION IN A SOLAR CELL



PHOTOVOLTAIC CELL



Silicon Solar Cell uses Si doped with Phosphorus for n-type material,
Si dopes with Boron for p-type material.

SOLAR CELL EFFICIENCY

- Insolation is a measure of solar radiation energy received on a given surface area in a given time – measured in $\frac{W}{m^2}$.

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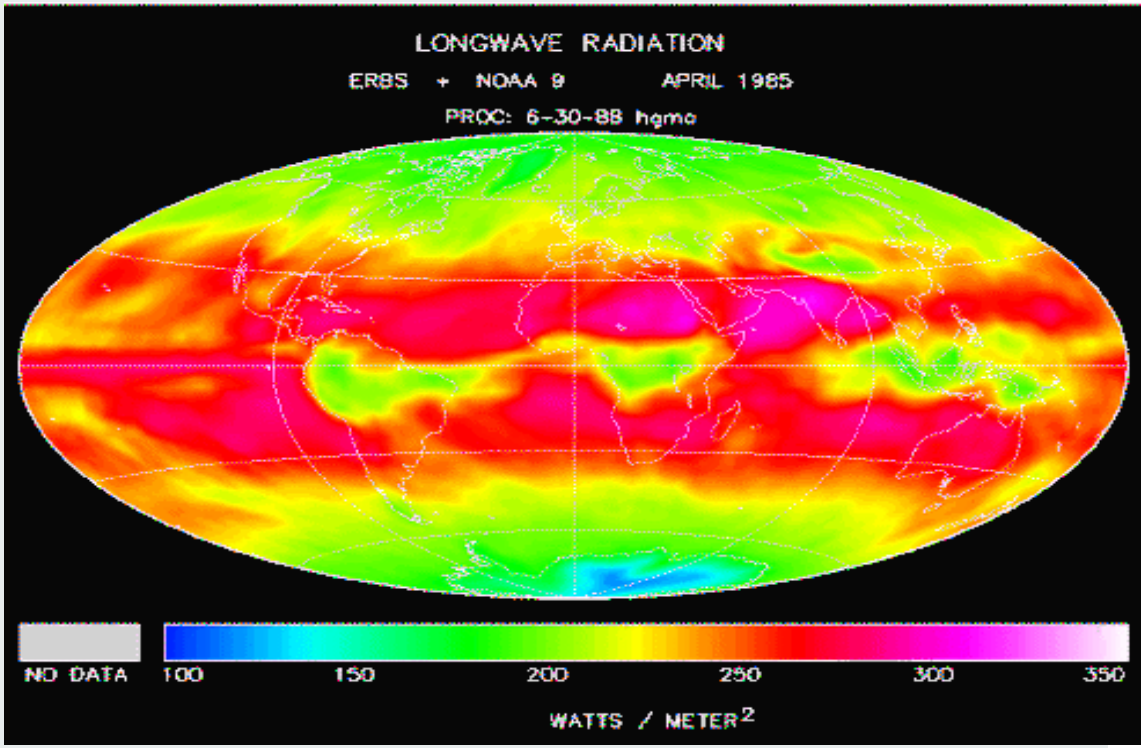


SOLAR CELL EFFICIENCY

Efficiency = percentage of radiant energy (light) used to produce electricity

$$Efficency = \frac{Useful\ Energy\ Produced}{Total\ Energy} 100\%$$

$$Efficiency = \frac{Power_{device}}{Power_{sun}} 100\% \qquad Power = V \cdot I \text{ (units of power are Watts (W))}$$

- What is the efficiency of a solar cell based on the following measurements?
  - Insolation = 200 $\frac{W}{m^2}$
  - Panel voltage = 15 Volts
  - Panel Current = 1 Amp

0.5 m

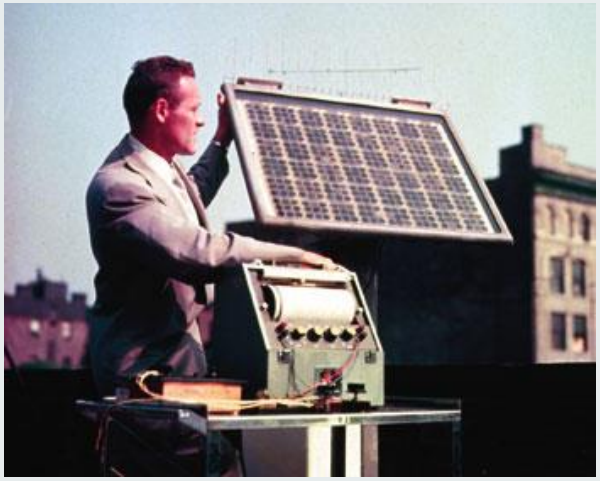
1 m

*Note: 1 Watt = 1 Volt * 1 Amp*

SOLAR CELL EFFICIENCY

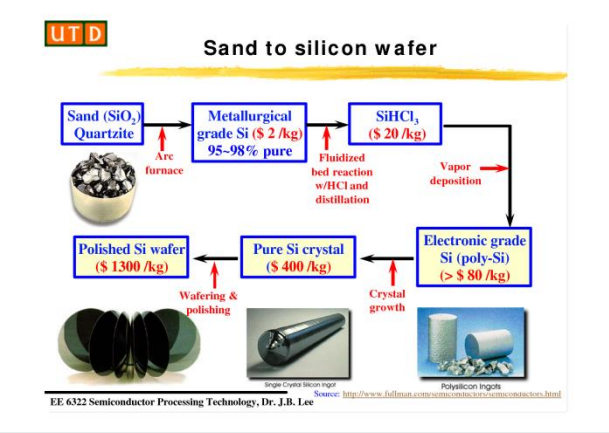
- First Selenium solar cells were about 0.5% efficient.
- 1954 Bell Labs – Silicon Solar Cell was 6% efficient.

- Today's Silicon solar cells are around 20% efficient.
  - In 2022 Longi broke efficiency record with their 26.8% efficient solar sell.
  - Silicon solar cells have a theoretical limit of about 33% efficiency.



SILICON SOLAR CELLS

- Sustainability/supply of materials/manufacturability?
  - Si, 2nd most abundant element—28% of the earth's crust
  - We get Si from SiO_2 (basically sand) and purify it in very large, expensive facilities called foundries.
  - Supply of *purified* Si is keeping costs high right now.
    - until more Si foundries come online in next couple of years



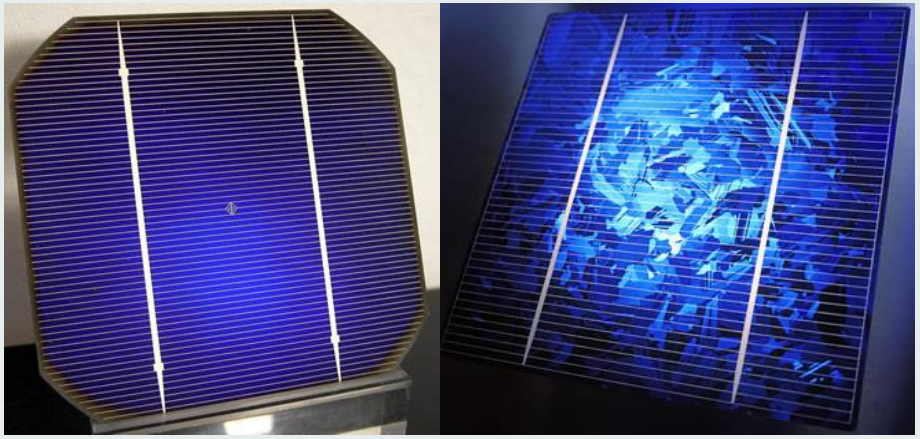
- Other drawbacks
  - Si is brittle like glass, will break if it falls.
  - Si is fairly light and thin, but because it's brittle, needs to be enclosed in Al framing and casing to provide support → end result is fairly bulky and heavy.

WHAT'S THE CATCH

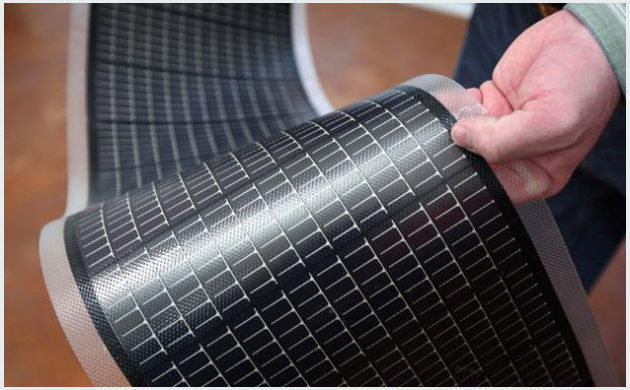
- Energy Critical Elements (ECE): e.g. Indium, Gallium, Tellurium
  - No problem in supply. Problem with availability.
- ECEs are byproducts. Challenge to extract from other mineral.
  - Gallium is obtained as a by-product of aluminum and zinc processing.
  - Germanium is typically derived as a by-product of zinc, lead, or copper refining.
  - Indium is a by-product of zinc, copper, or tin processing.
  - Selenium and tellurium are most often by-products of copper refining.
  - To recover 1 gram of Te, you need to mine 1 ton of Copper.
- Located in inconvenient places – e,g., China produces the vast majority of these elements.
  - Environmental concerns
  - Social concerns
  - Political concerns

THE PV CONTENDERS

- Silicon (Si) Solar Cells—90% of the market
  - Single Crystalline Si
  - Multi-crystalline Si

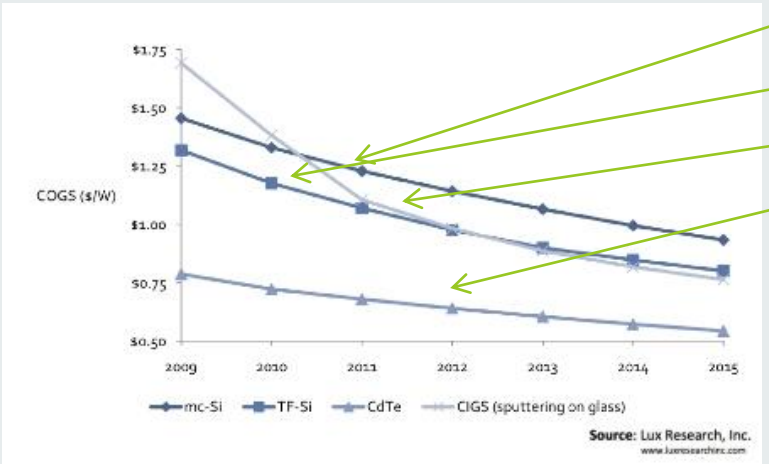


- Thin-film solar
  - Amorphous Silicon
  - Cadmium Telluride (CdTe)
  - Copper-Indium-Gallium-Selenide (CIGS)
  - Organic solar cells



- Other more exotic materials, more advanced designs
- Limited to space applications because of high expense ~$50,000 / sq m.
- Record is 47.1% efficiency in the laboratory.

AMORPHOUS SI/CDTE/CIGS



MC Si

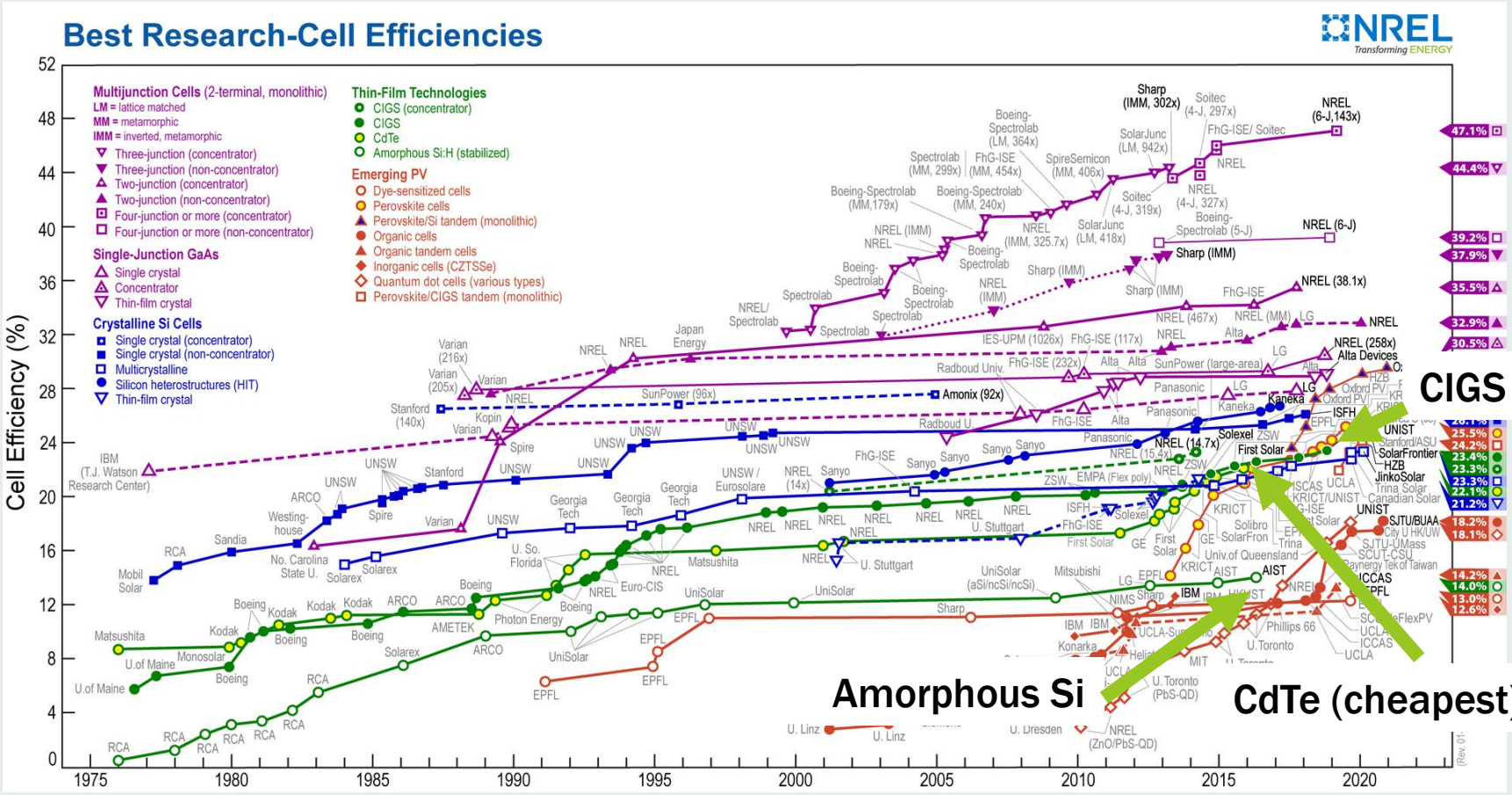
Thin Film Si

CIGS

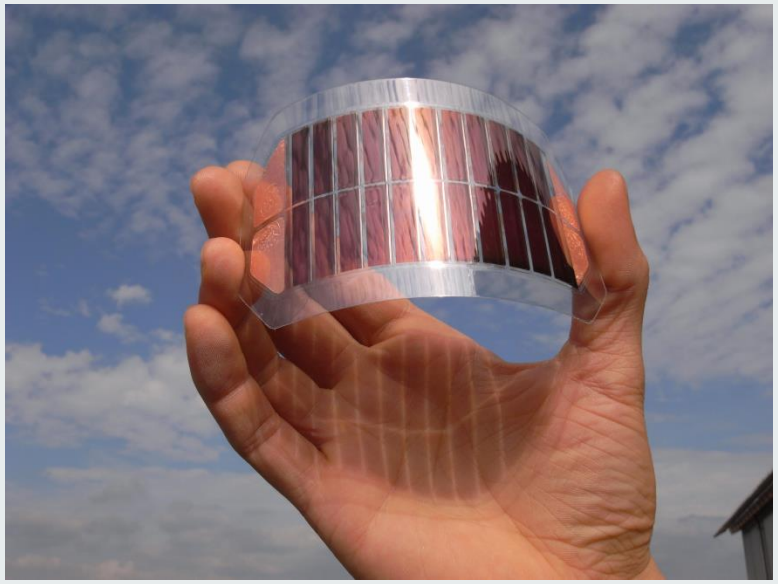
CdTe (cheapest)

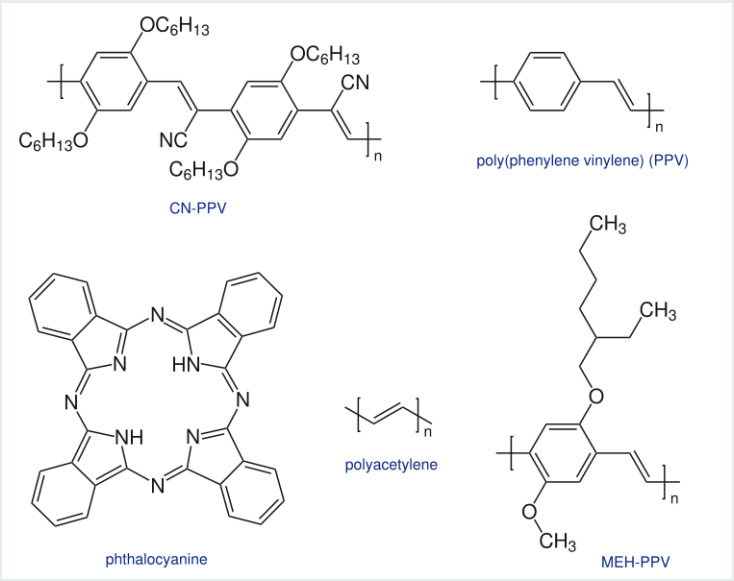
- Efficiency is around 10 – 20%.
- Cheaper than Si and multi-crystalline solar cells.
- Light, thin, and durable.

AMORPHOUS SI/CDTE/CIGS



ORGANIC



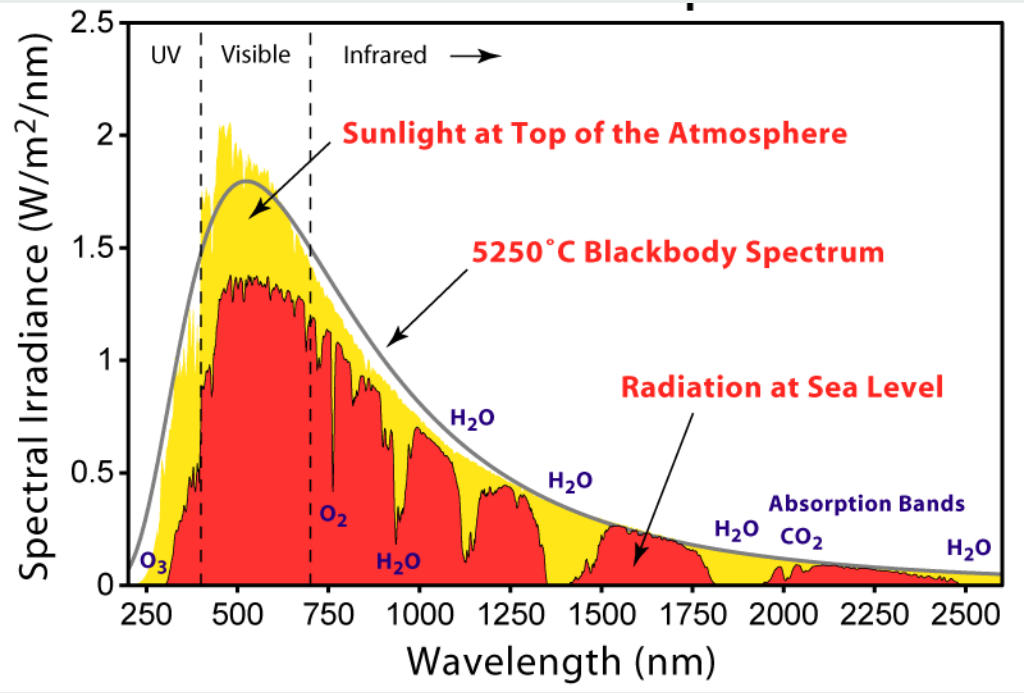


- Printable
- Efficiency is around 6%.
- Very Cheap (experts estimate they can reduce cost by ~15%)
- Light, thin, and durable.

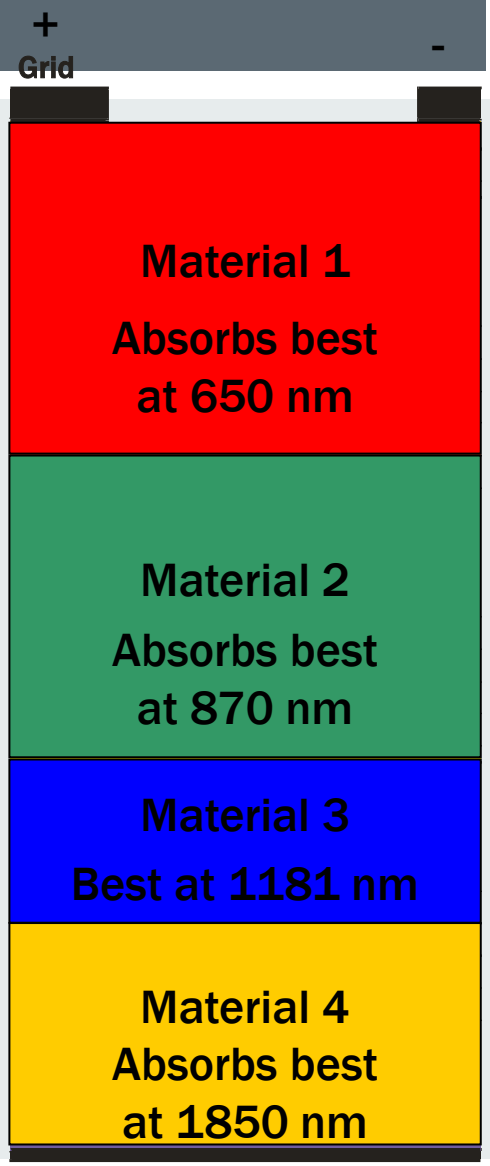
A BRIEF LOOK AT ADVANCED METHODS

Solar radiant energy: visible light (44.6%), infrared (46.3%) light, and some UV (9.1%) light

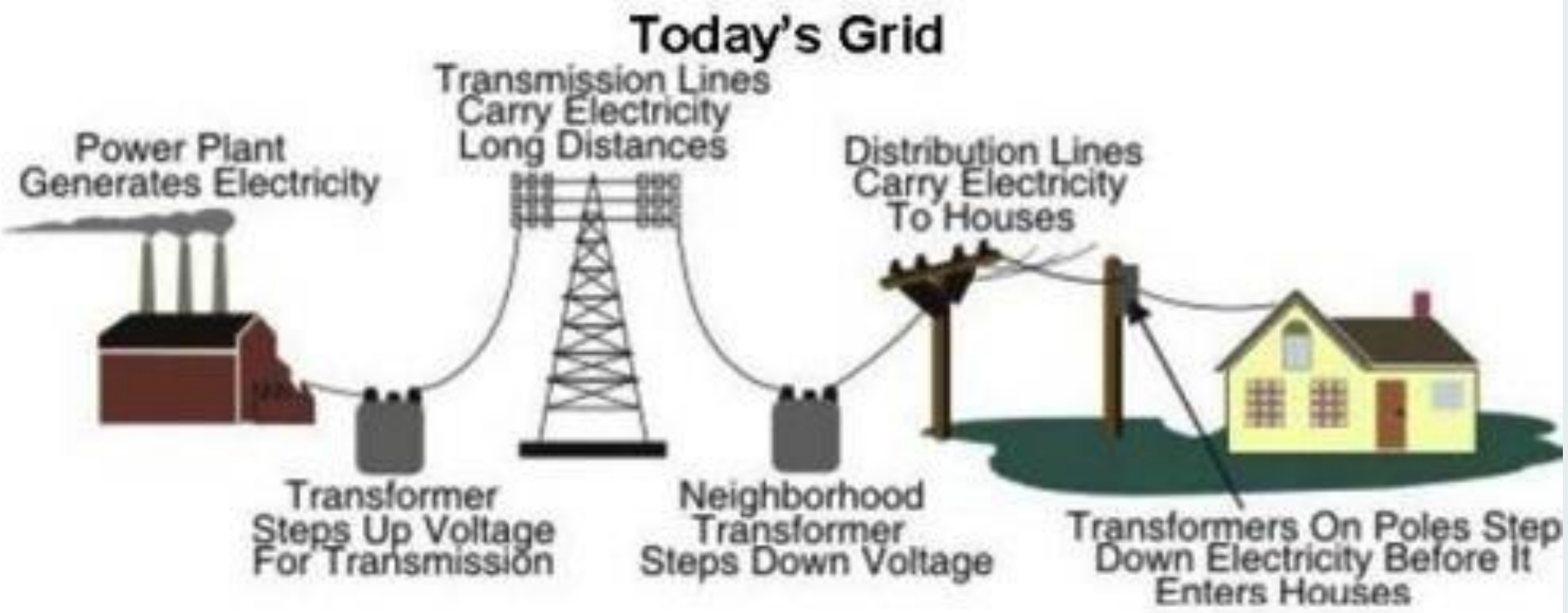
Exotic materials and advanced construction methods used to make solar cell with 47% efficiency (in the laboratory).



Goal is 50% efficiency in the next few years!



THE GRID TODAY



From www.gridwise.org

ELECTRICITY SUPPLY AND DEMAND

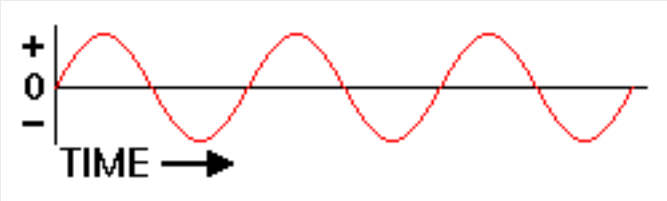
- In the power grid, supply must match demand at all times or the grid will become unstable.
  - There is no way to store extra electricity for later.

- **How to meet changing demand?**

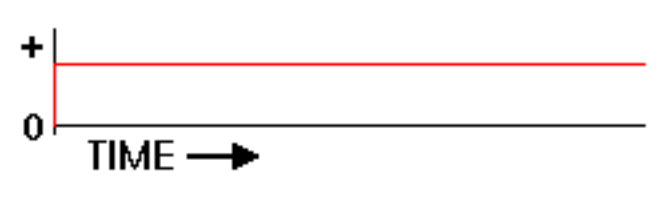
- How does solar complicate the grid?

TYPE OF POWER GENERATED

- Electricity in the power grid is alternating current.



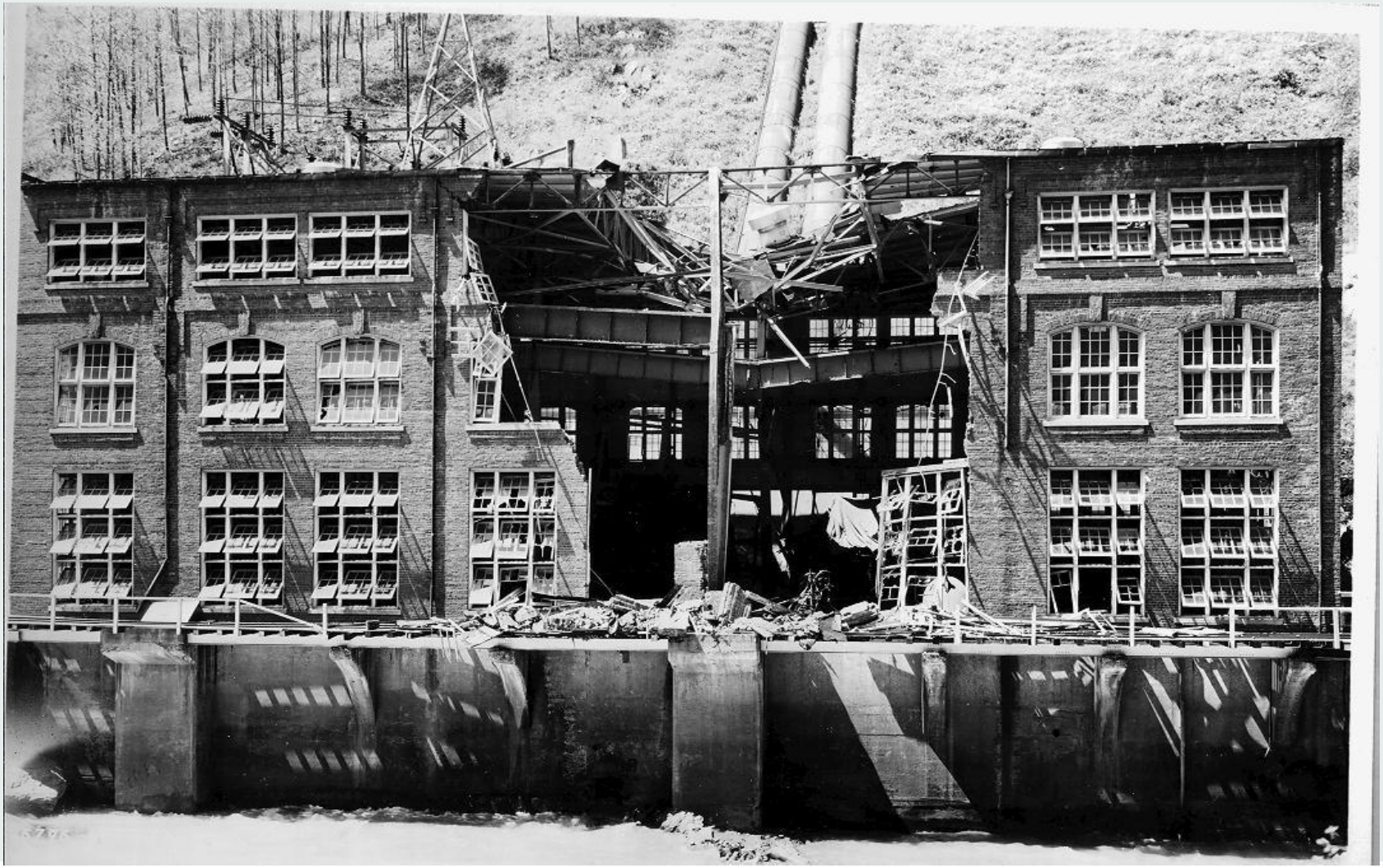
- Solar cells generate direct current.



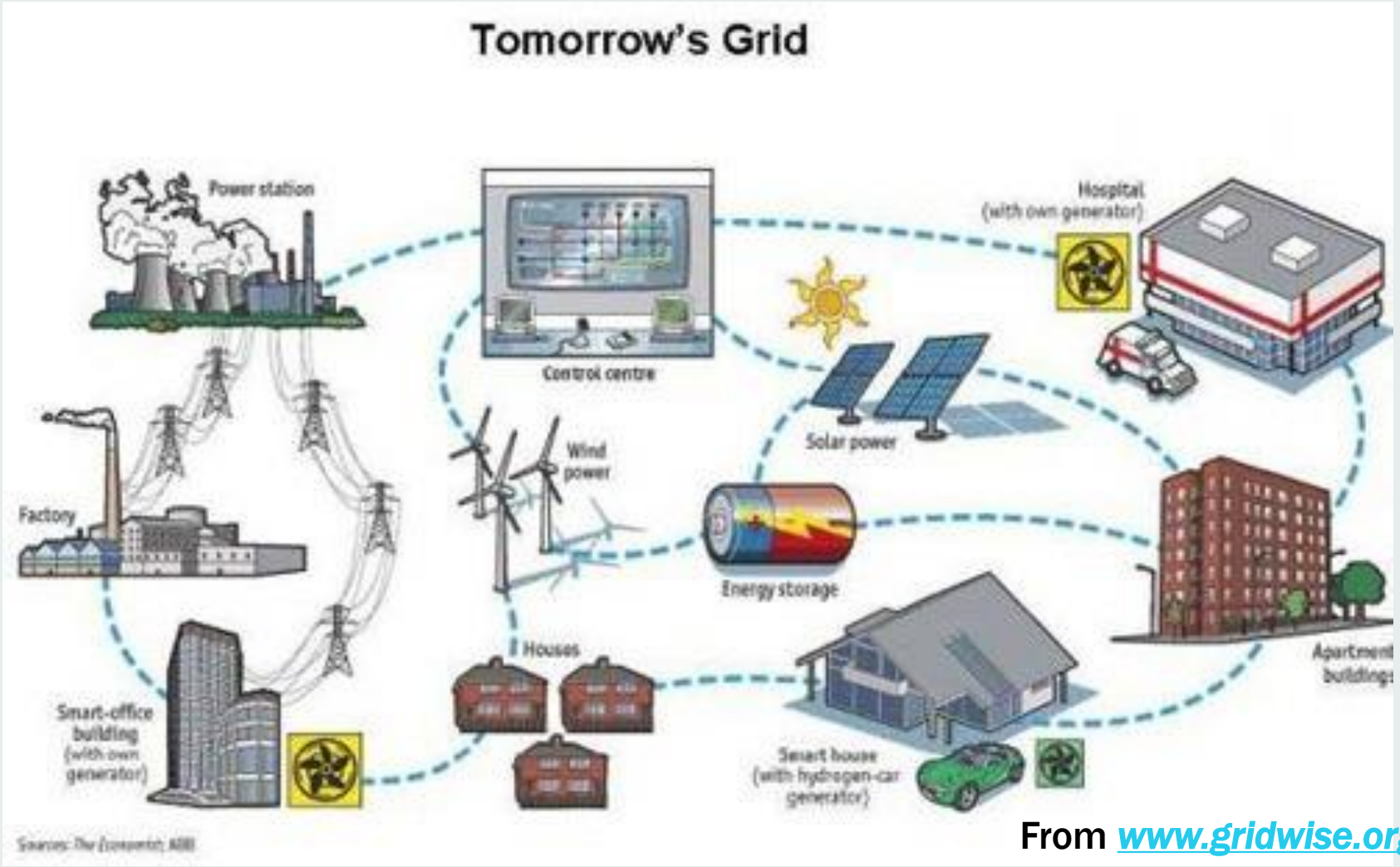
- When solar cells are hooked up to the grid, direct current must be converted to alternating current using an inverter.

- Phases of different AC power sources must be synchronized.

WHEN THINGS GO WRONG…



THE SMART GRID



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