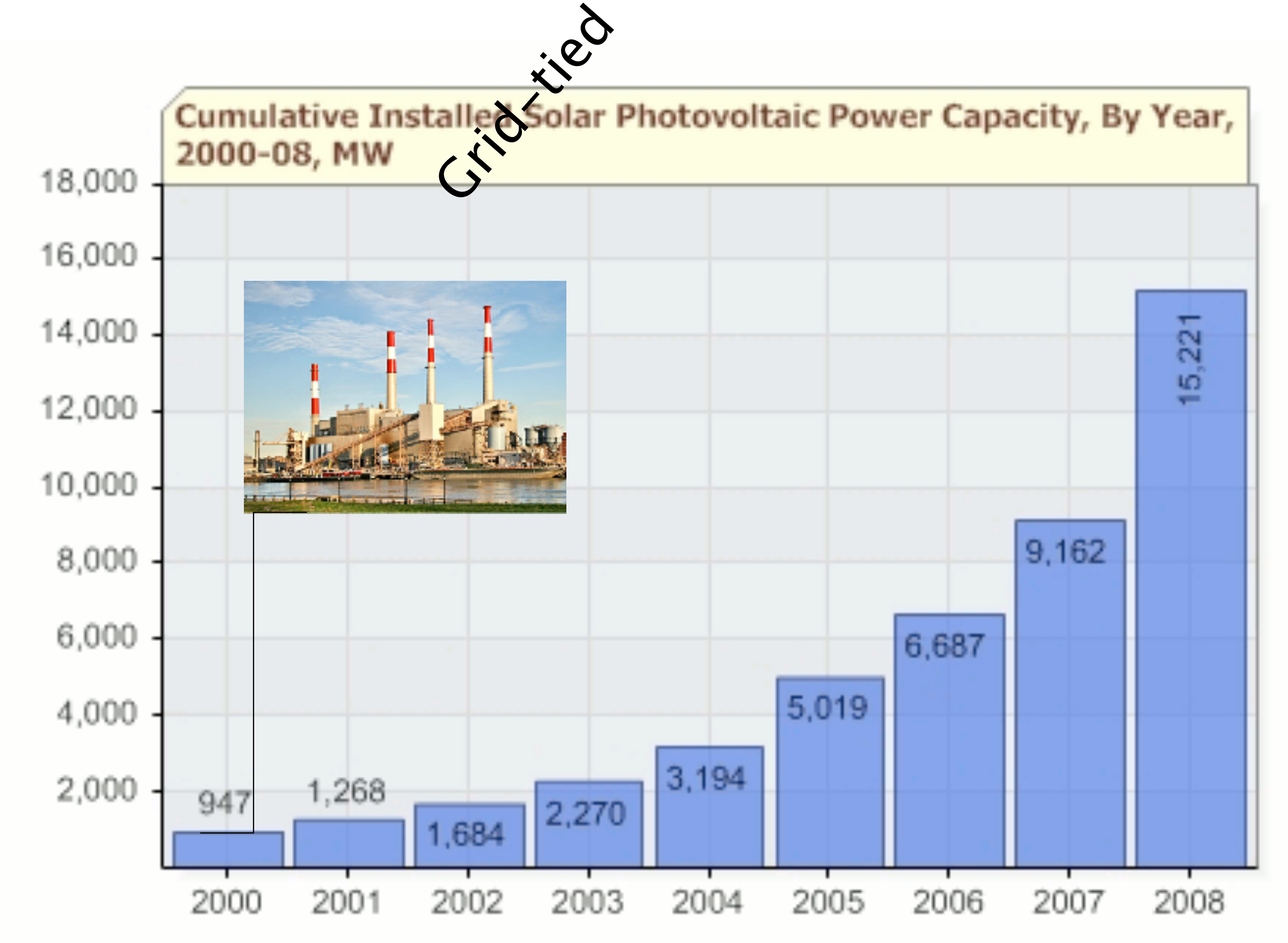
Photovoltaics

Conversion of light to electricity

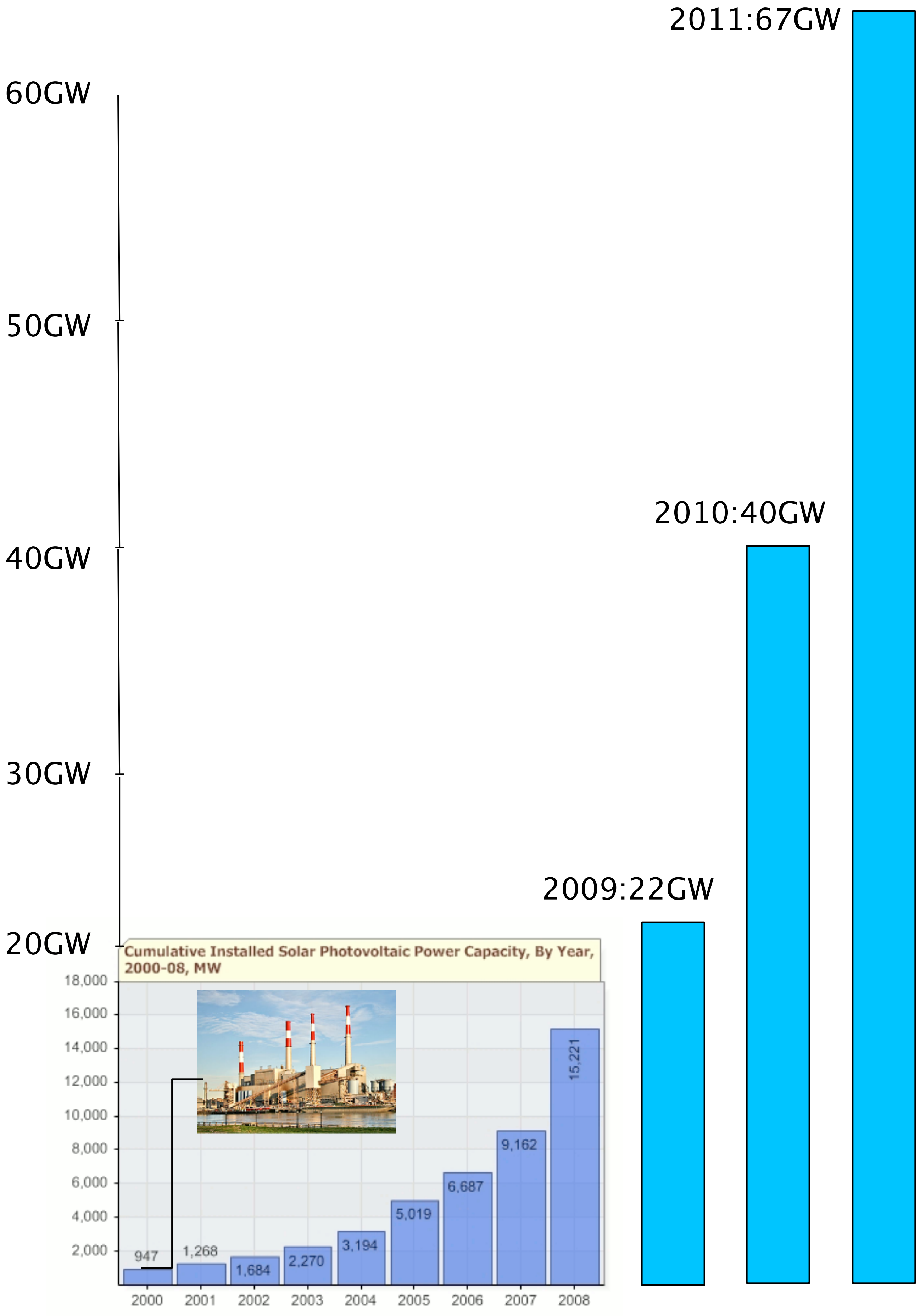
Energy
ITP / NYU / Feddersen

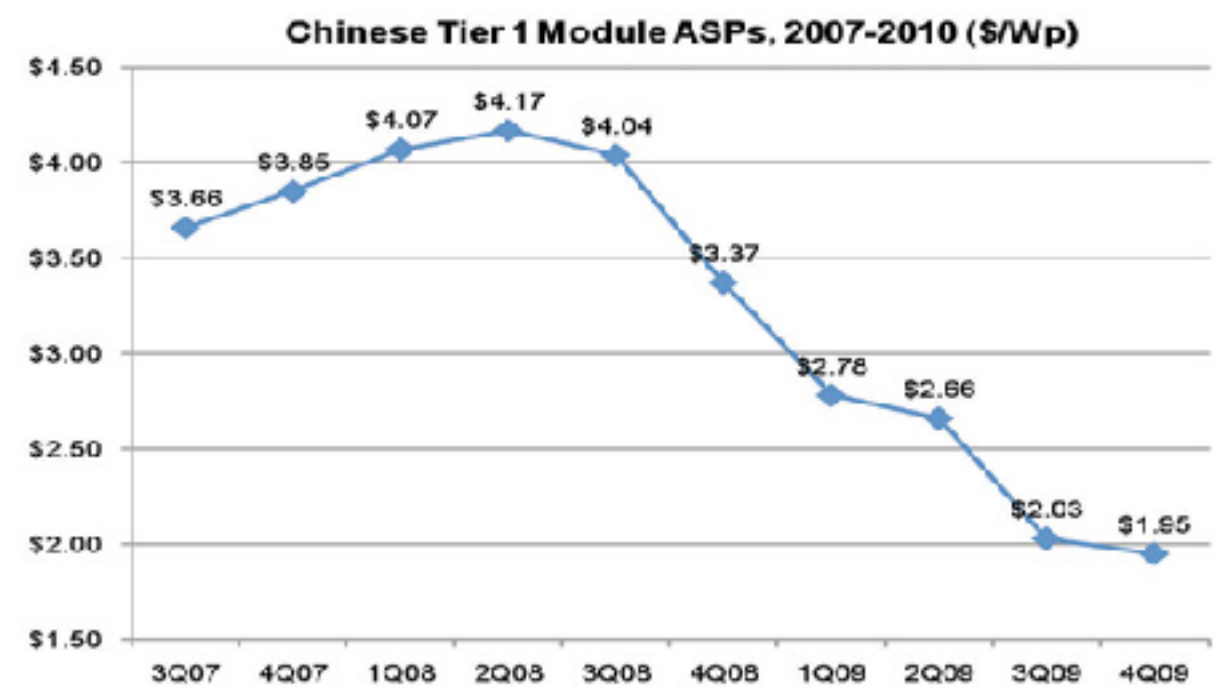
GLOBAL TRANSFORMATION



Source: http://www.energyandcapital.com/
Inset: Big Allis, first 1GW generator, in Queens.

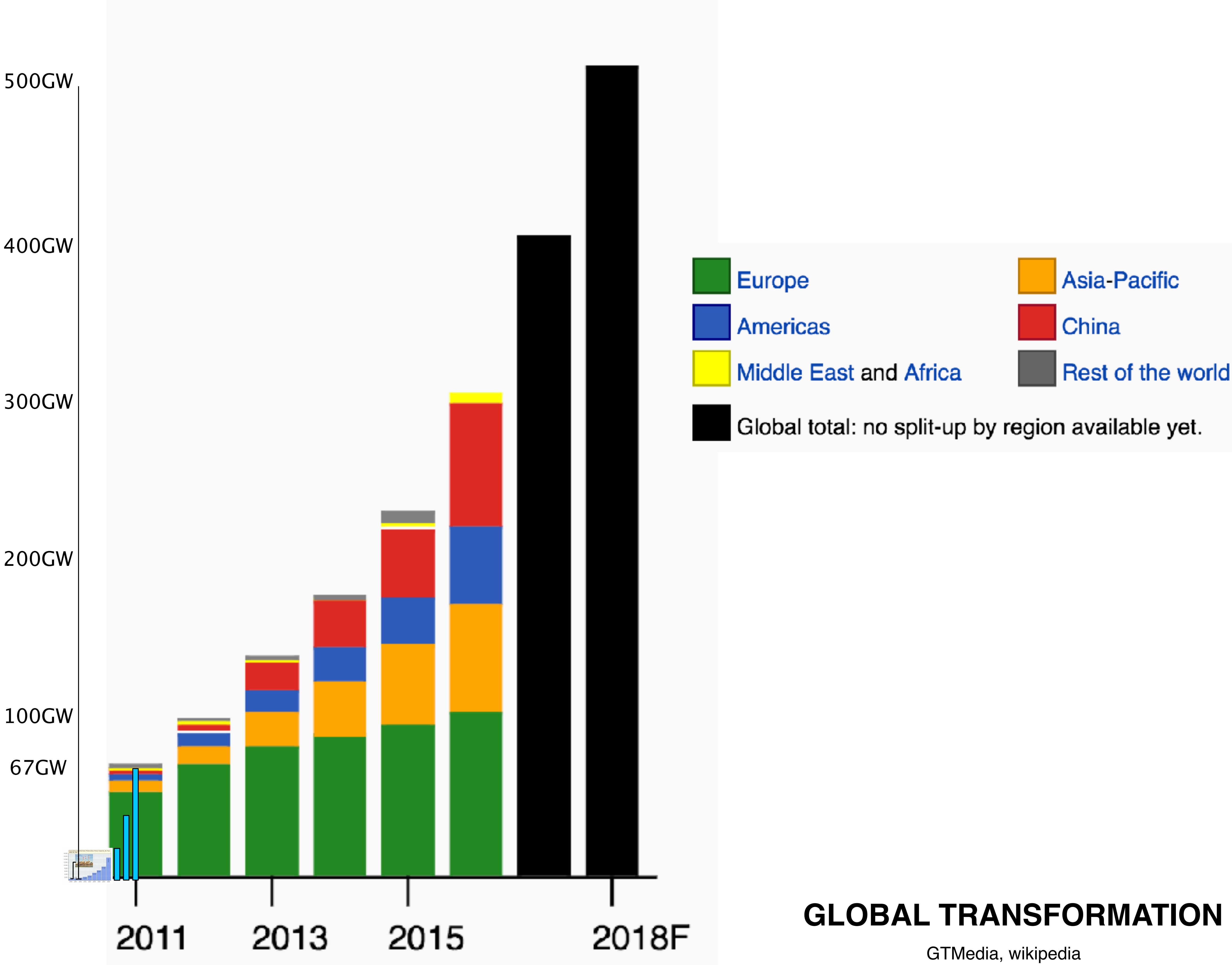
GLOBAL TRANSFORMATION





GTMedia, wikipedia

GLOBAL TRANSFORMATION



GLOBAL TRANSFORMATION

GTMedia, wikipedia

2015

THE BILLIONS IN CHANGE SOLUTION

Hans Free Electric™

The Hans Free Electric™ bike enables people to generate their own
electricity. Here's how it works: A person pedals the hybrid bicycle, which
drives a flywheel system, which turns a generator, which charges a
batte… for … hour yields a day's worth of electricity for an
av… …It's electricity on demand. There's no utility bill, no
n… …wait for the sun to shine or the wind to blow,
a…

https://web.archive.org/web/20161116093435/http://billionsinchange.com:80/solutions/free-electric

GLOBAL TRANSFORMATION

2018

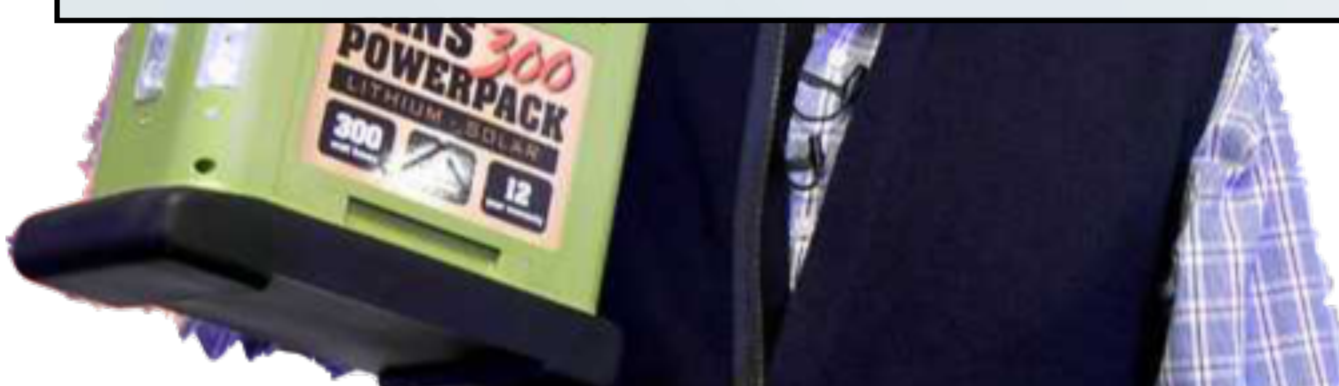
HANS™ SOLAR BRIEFCASE

A Look Back At How We Arrived Here

It started with the goal to bring free electrical power to the billions of people worldwide who have little-to-no access to electricity. How? Provide a way for people to generate their own energy, store it, and use it for simple, yet life-changing, applications, such as light, communication, and education. The first solution created by Stage 2 was the HANS™ Free Electric bike.

However, after multiple field tests showed that the bike needed modifications, as did the battery, Stage 2 went back to the drawing board. Through the process of making these improvements, two completely new inventions emerged. The HANS™ PowerPack and HANS™ Solar BriefCase quickly leapfrogged the bike in terms of usability, affordability, and scalability.

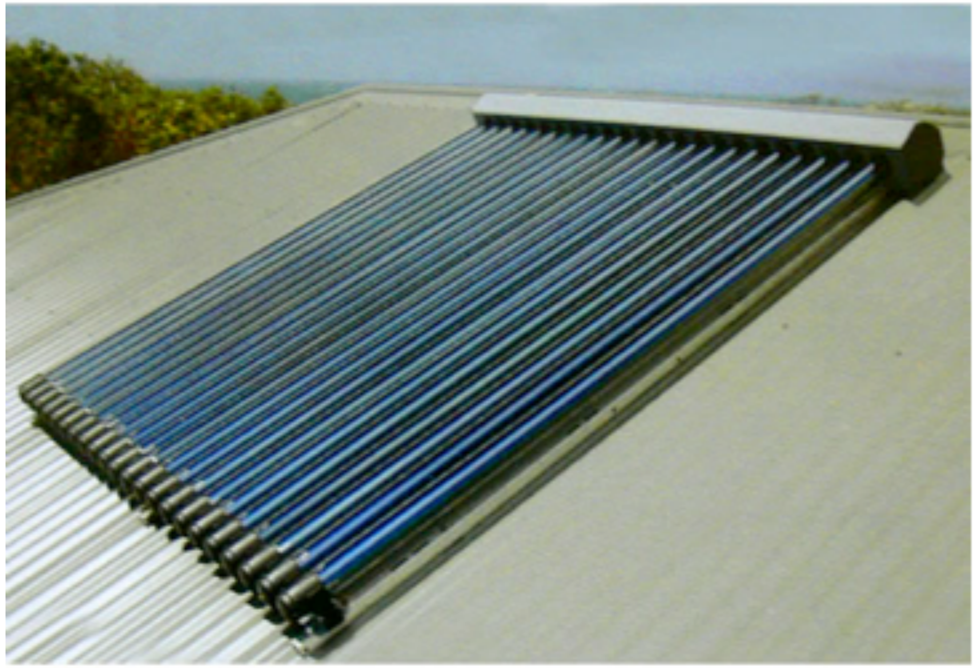
The current plan for the HANS™ Free Electric bike is to produce it on a limited basis for India only. There are no longer plans to make the bike available to the US market, and the existing US inventory of a few dozen bikes will be donated to the Billions in Change Foundation for charitable and fundraising purposes.



GLOBAL TRANSFORMATION

SOLAR TWO - MOJAVE DESERT, CALIFORNIA

Not to be confused with solar thermal applications



More solar thermal

Sterling engine

Sunlight Direct HSL-3000

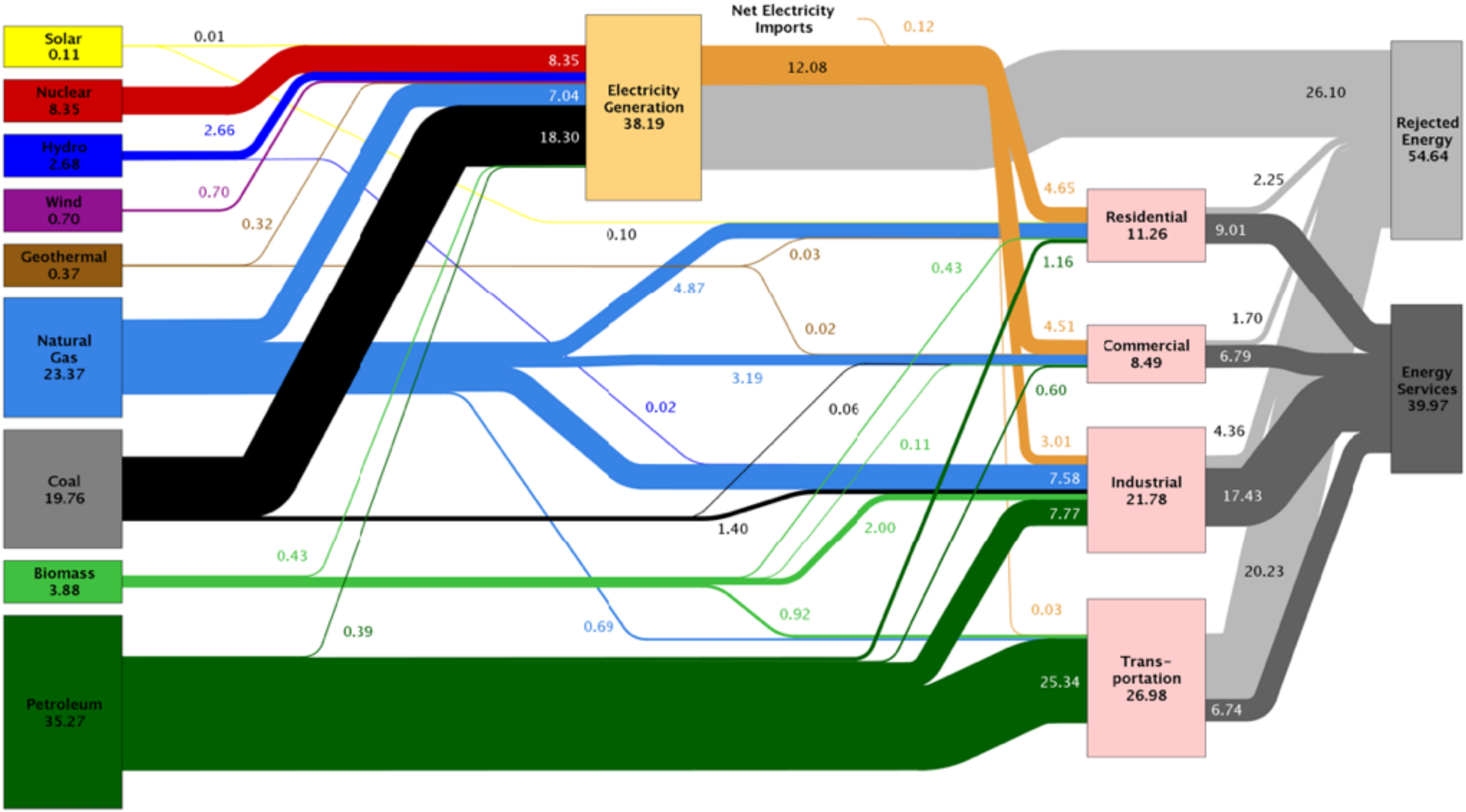
Parans SkyPort with custom fixture

Also not to be confused with direct use of sunlight for illumination.

REVIEW

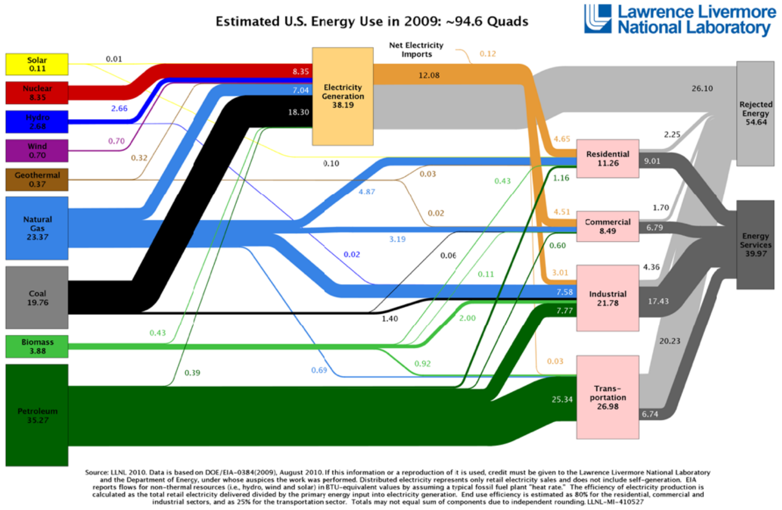
Estimated U.S. Energy Use in 2009: ~94.6 Quads

Lawrence Livermore National Laboratory



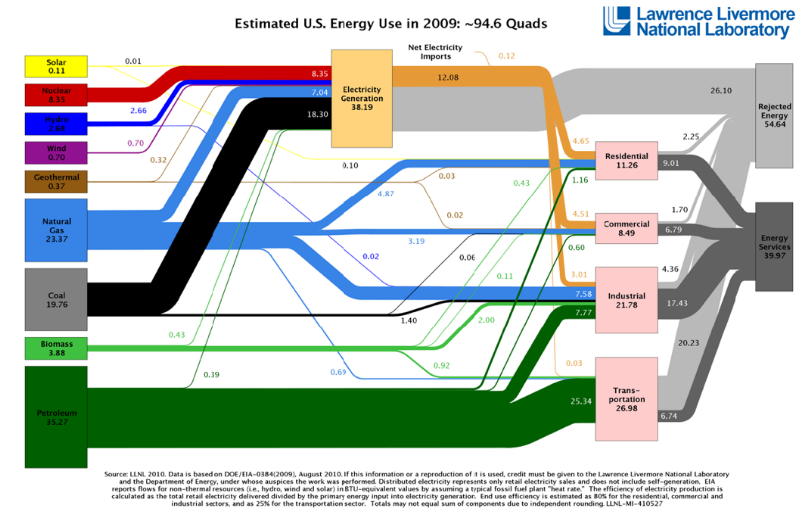
Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

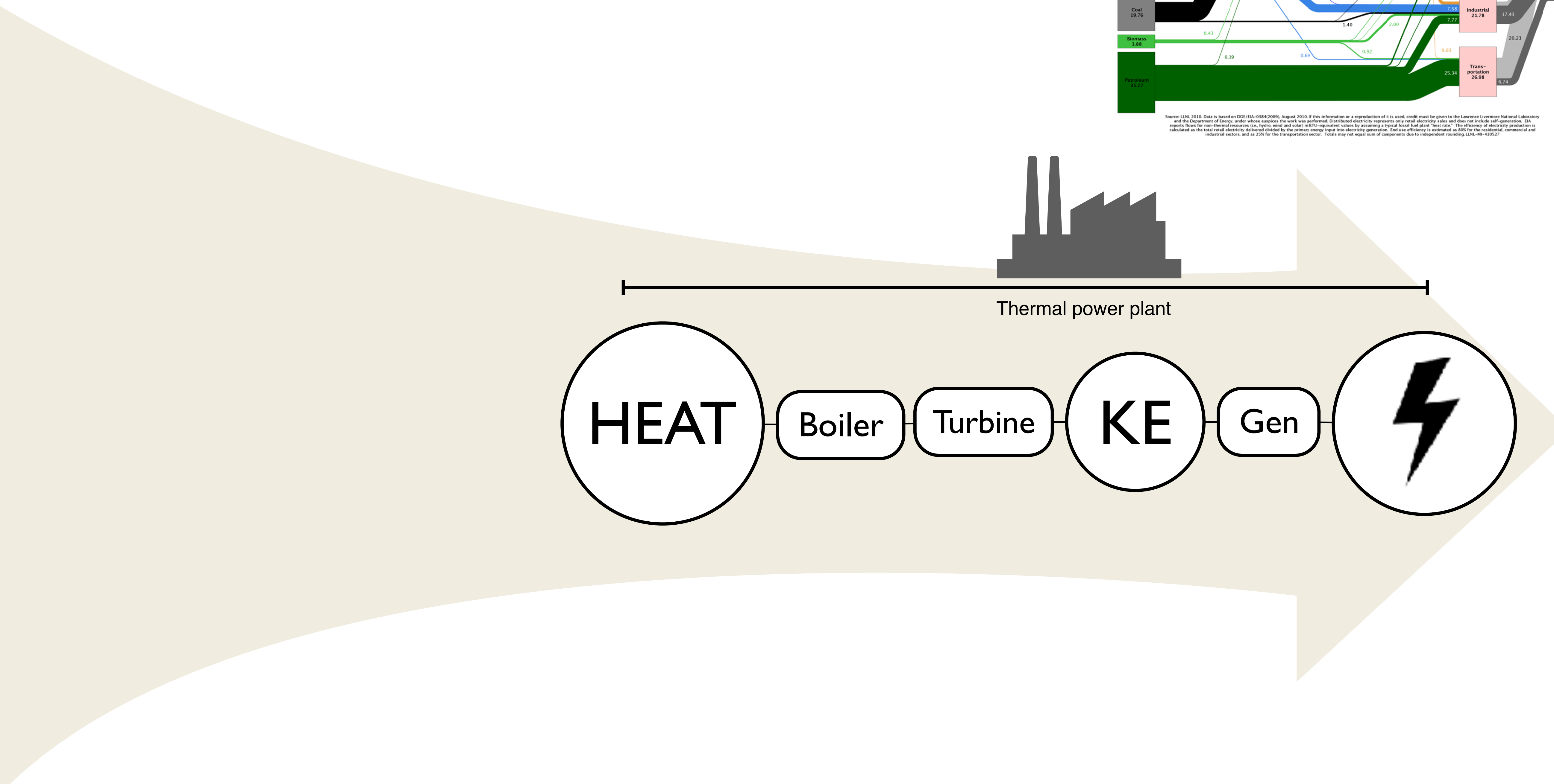
Review



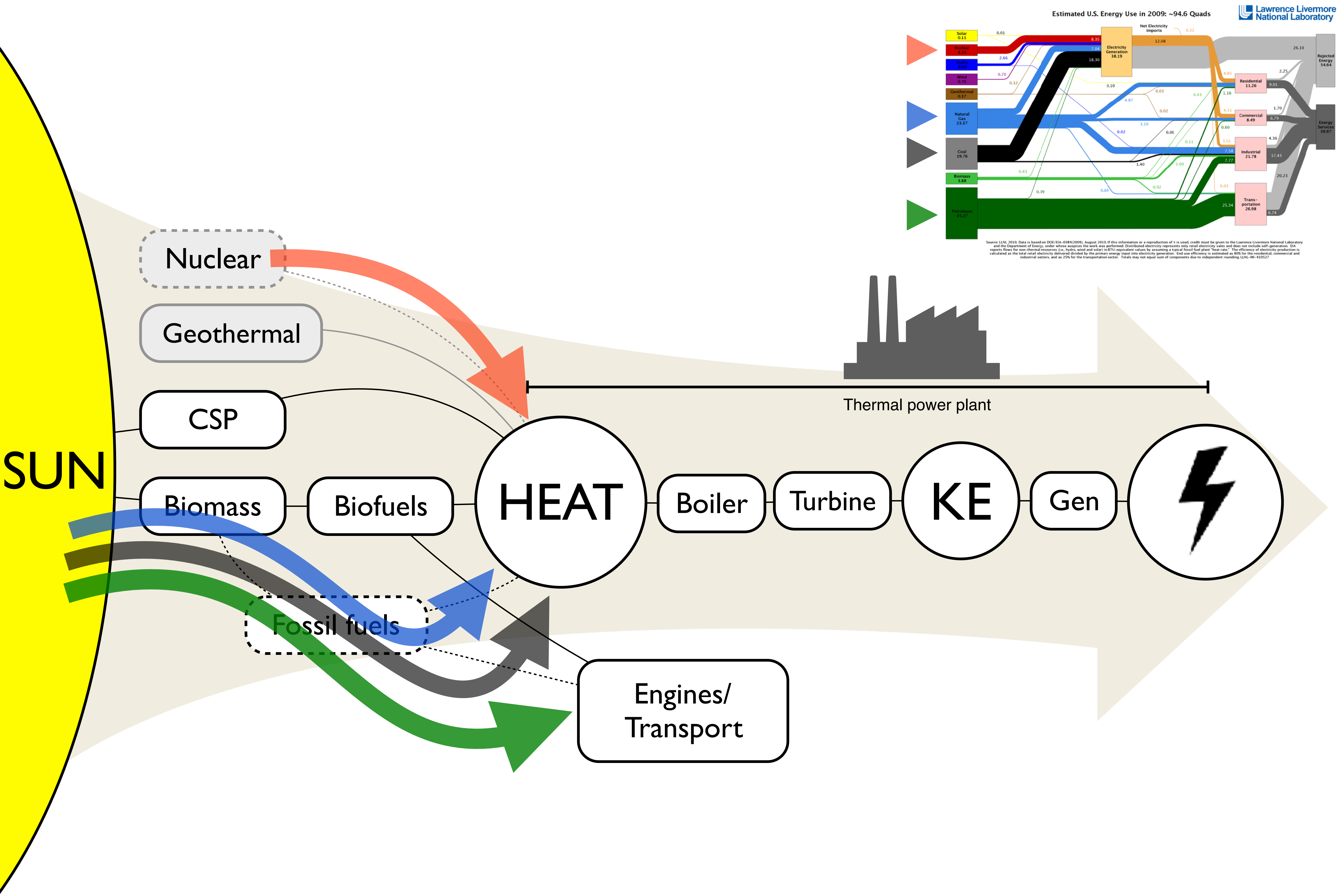
Estimated U.S. Energy Use in 2009: ~94.6 Quads
Lawrence Livermore National Laboratory
Solar 0.11
Nuclear 8.35
Hydro 2.68
Wind 0.70
Geothermal 0.37
Natural Gas 23.37
Coal 19.76
Biomass 3.88
Petroleum 35.27
Net Electricity Imports
0.12
Electricity Generation 38.19
12.08
Residential 11.26
Commercial 8.49
Industrial 21.78
Trans-portation 26.98
Rejected Energy 54.64
Energy Services 39.97
0.01
8.35
2.66
7.04
18.30
0.70
0.32
0.10
0.03
4.87
0.02
3.19
0.02
0.06
1.40
0.43
0.39
0.69
0.92
0.43
1.16
0.60
0.11
2.00
7.58
7.77
25.34
4.65
4.51
3.01
0.03
26.10
2.25
9.01
1.70
6.79
4.36
17.43
20.23
6.74
Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Review

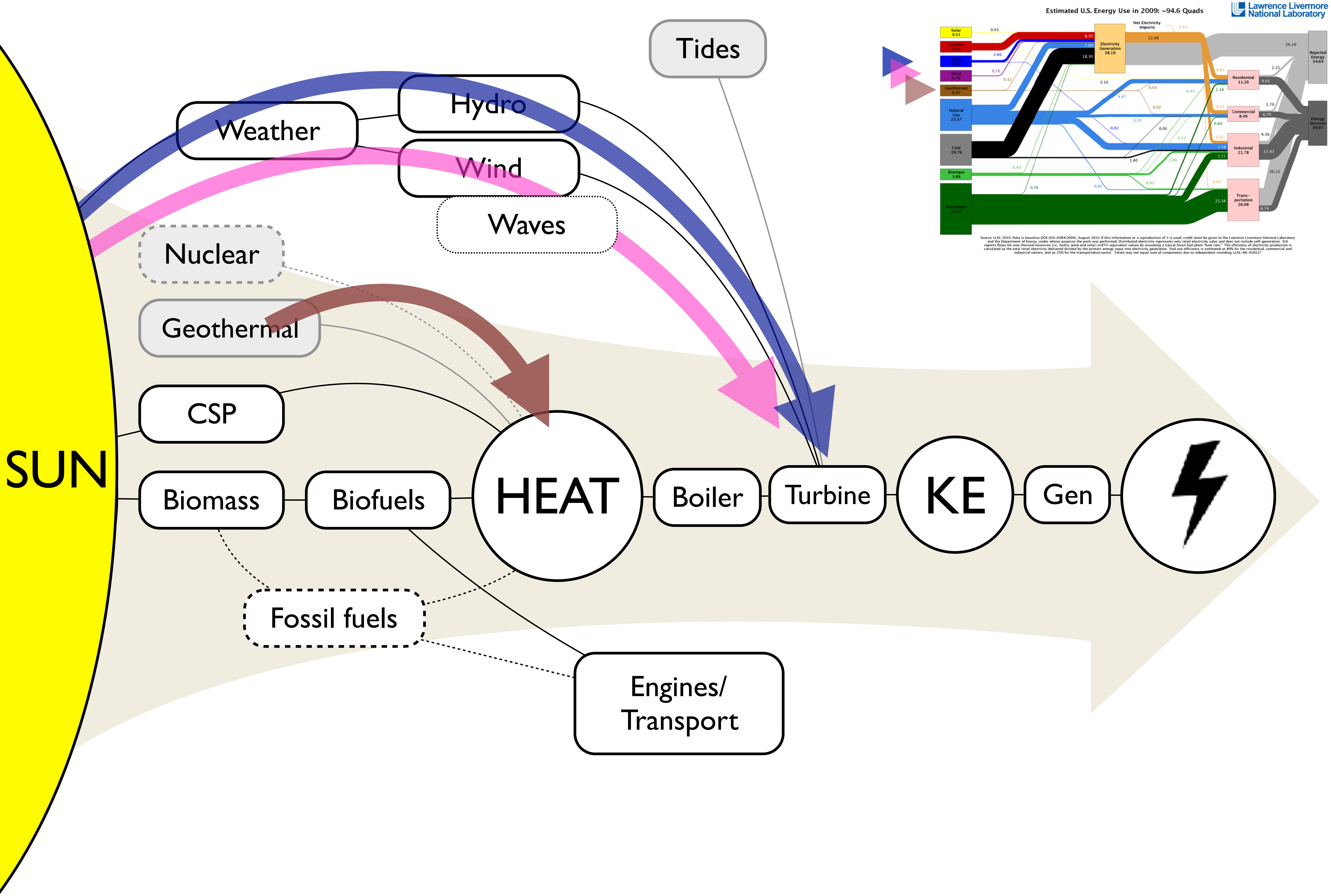

Estimated U.S. Energy Use in 2009: ~94.6 Quads
Lawrence Livermore National Laboratory


Thermal power plant
HEAT
Boiler
Turbine
KE
Gen

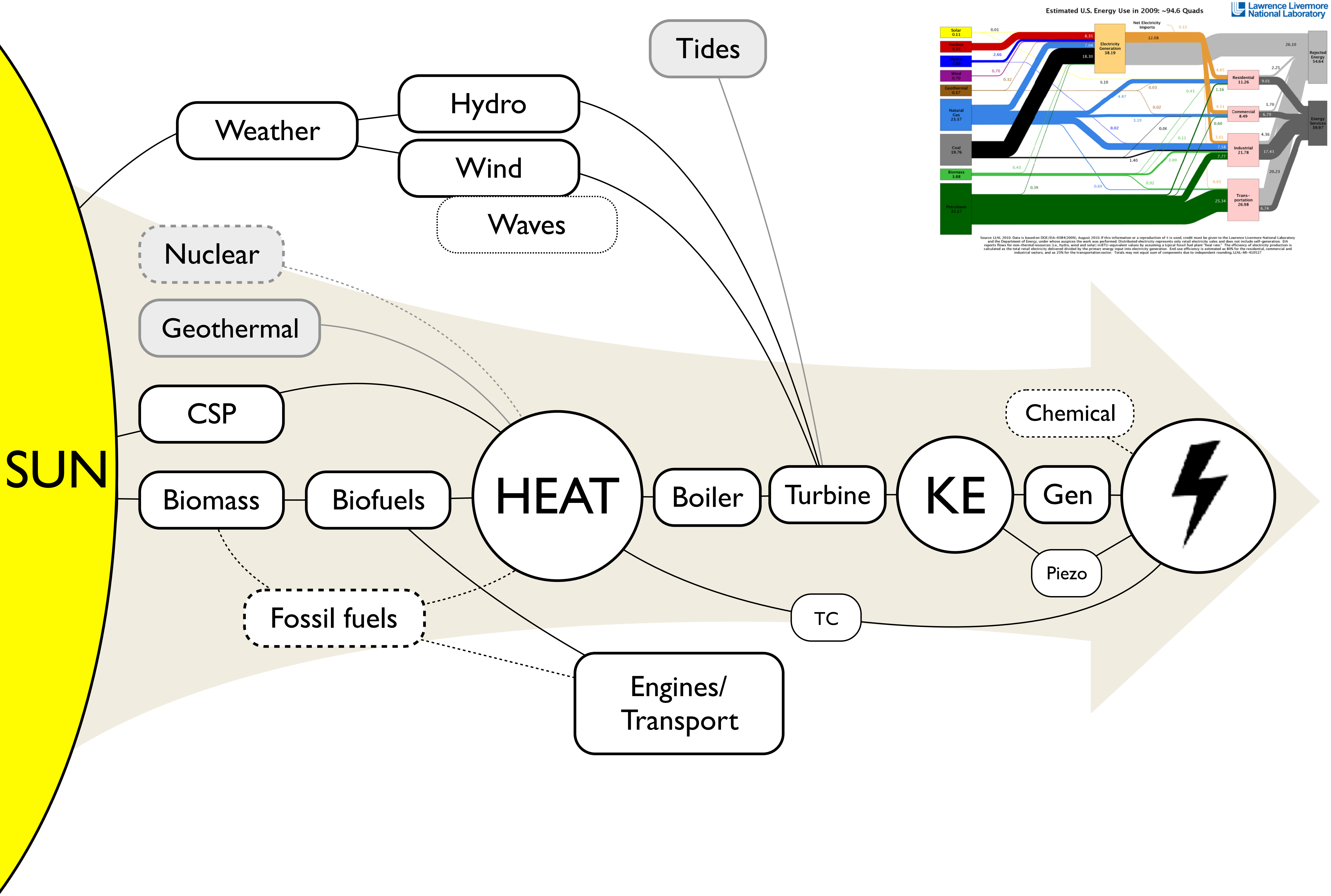
Review


Estimated U.S. Energy Use in 2009: ~94.6 Quads
Lawrence Livermore National Laboratory
Nuclear
Geothermal
CSP
SUN
Biomass
Biofuels
HEAT
Boiler
Turbine
KE
Gen
Fossil fuels
Engines/ Transport
Thermal power plant

Review

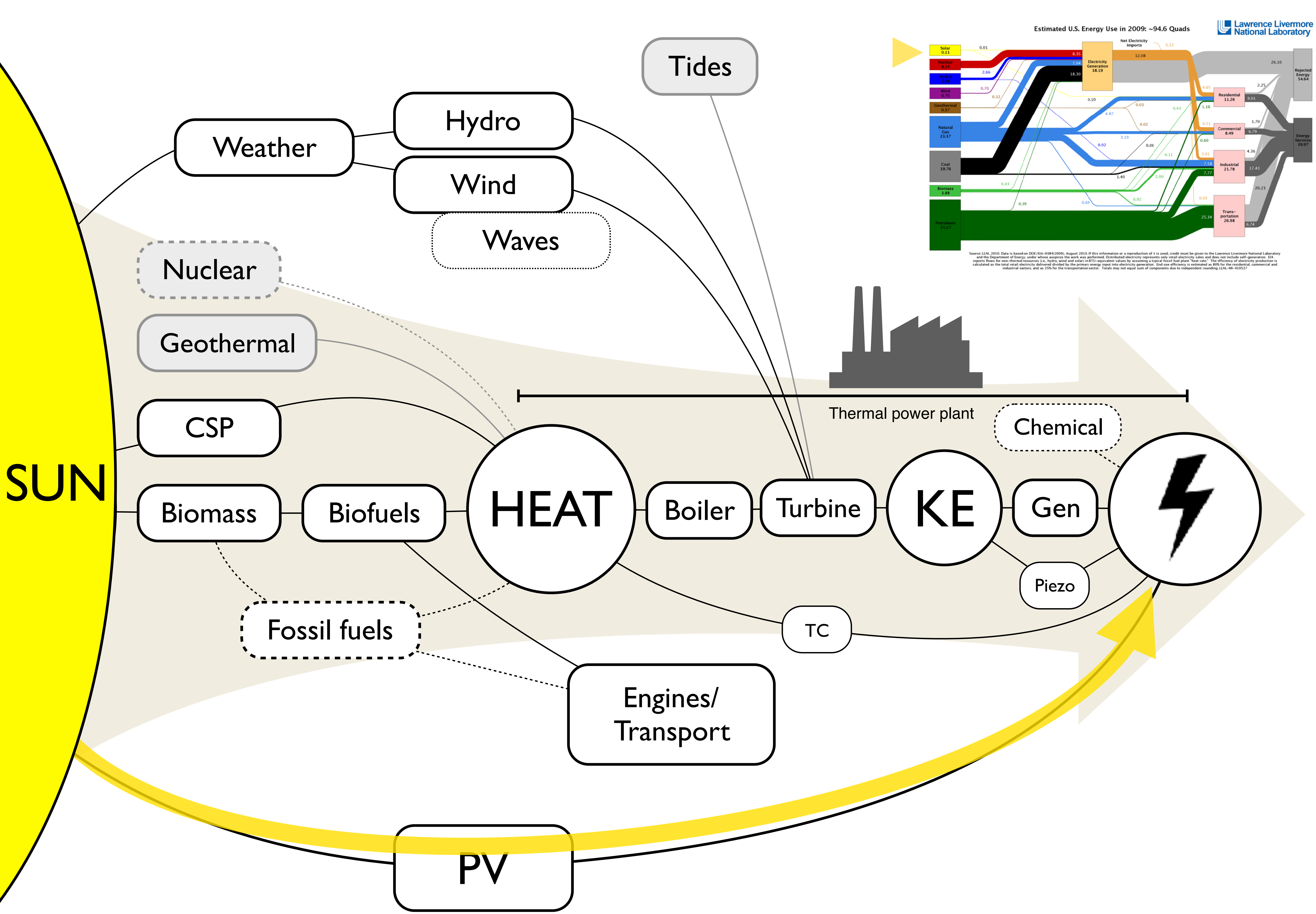

Estimated U.S. Energy Use in 2009: ~94.6 Quads
Lawrence Livermore National Laboratory
Tides
Hydro
Weather
Wind
Waves
Nuclear
Geothermal
CSP
SUN
Biomass
Biofuels
HEAT
Boiler
Turbine
KE
Gen
Fossil fuels
Engines/
Transport

Review



SUN
Weather
Hydro
Wind
Waves
Tides
Nuclear
Geothermal
CSP
Biomass
Biofuels
Fossil fuels
HEAT
Boiler
Turbine
KE
Gen
Chemical
Piezo
TC
Engines/
Transport
Estimated U.S. Energy Use in 2009: ~94.6 Quads
Lawrence Livermore National Laboratory

Review



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Lawrence Livermore National Laboratory
Tides
Hydro
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HEAT
Boiler
Turbine
KE
Gen
Thermal power plant
Chemical
Piezo
TC
Fossil fuels
Engines/
Transport
PV

Review

OVERVIEW

4.2 billion kg of H -> Energy / second
so 3.85×10^{26} Watts (385 yottawatts!)

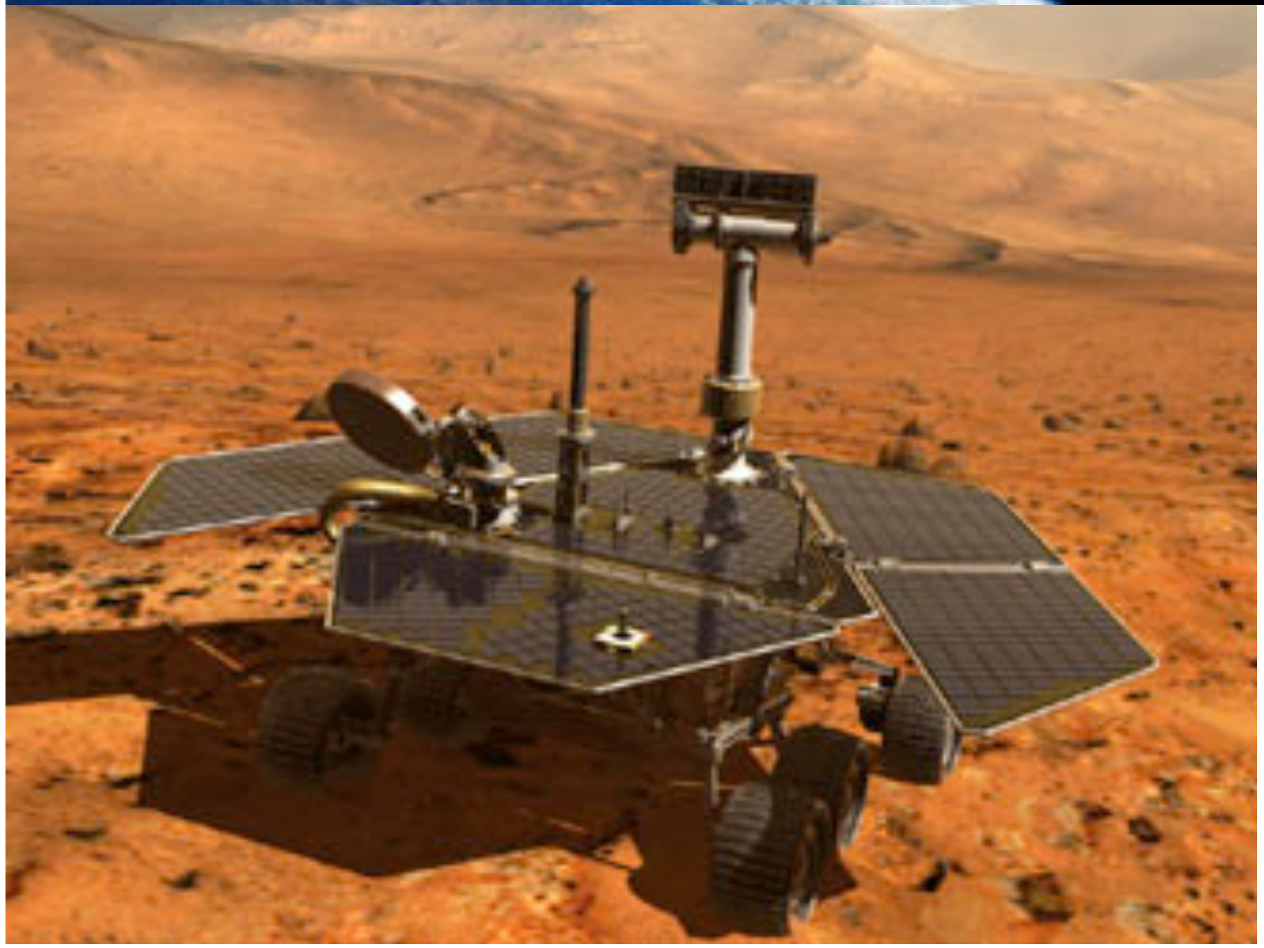
Solar constant in space at Earth locale:
$1368\ W/m^2$

Distributed over Earth's sphere:
$342\ W/m^2$

Average insolation (after reflection and absorption):
$170\ W/m^2$

Global solar power:
87 PW (~7000x fossil fuel use)

source: Smil



PV works!
Enabling technology for telecom and space exploration

MER originally planned for ~90 sols, have operated for over 2000.
140W GaAs/Ge cells

Terrestrial applications

Overview

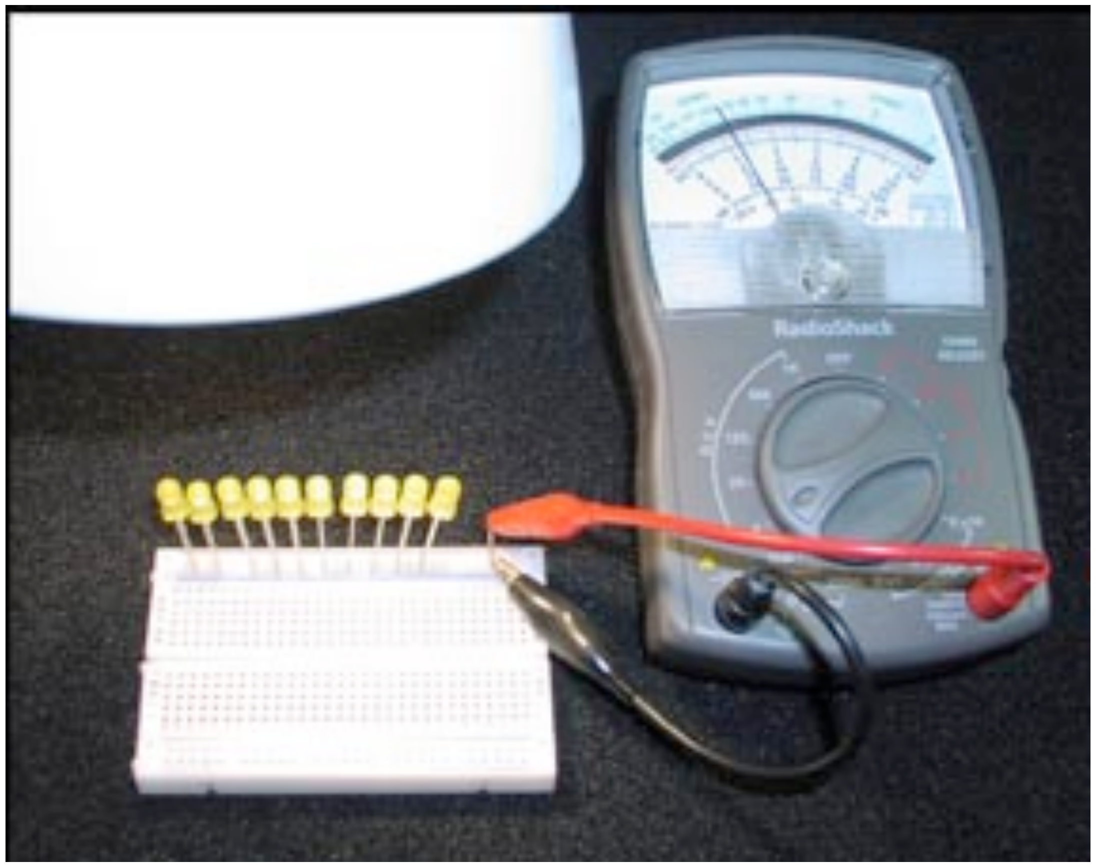
Fishermen in Kenya attracting shrimp w/ solar-charged lights (photo:Siemens)

Small and large commercial applications

Overview

BASICS

All PV is similar in that:

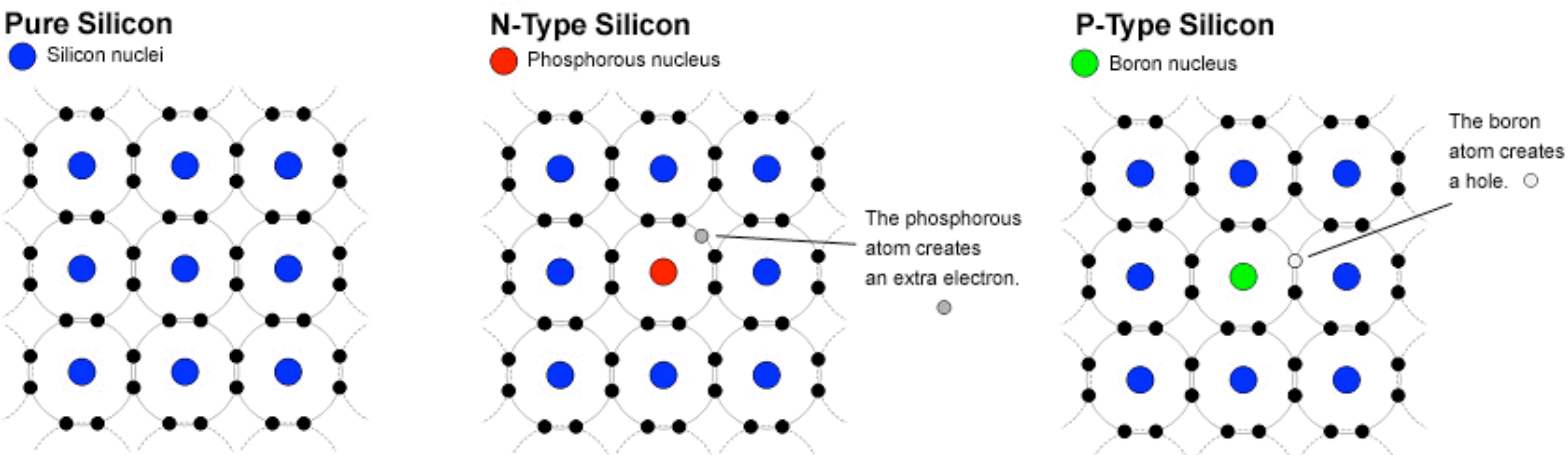


Photovoltaic materials directly convert light into electricity.

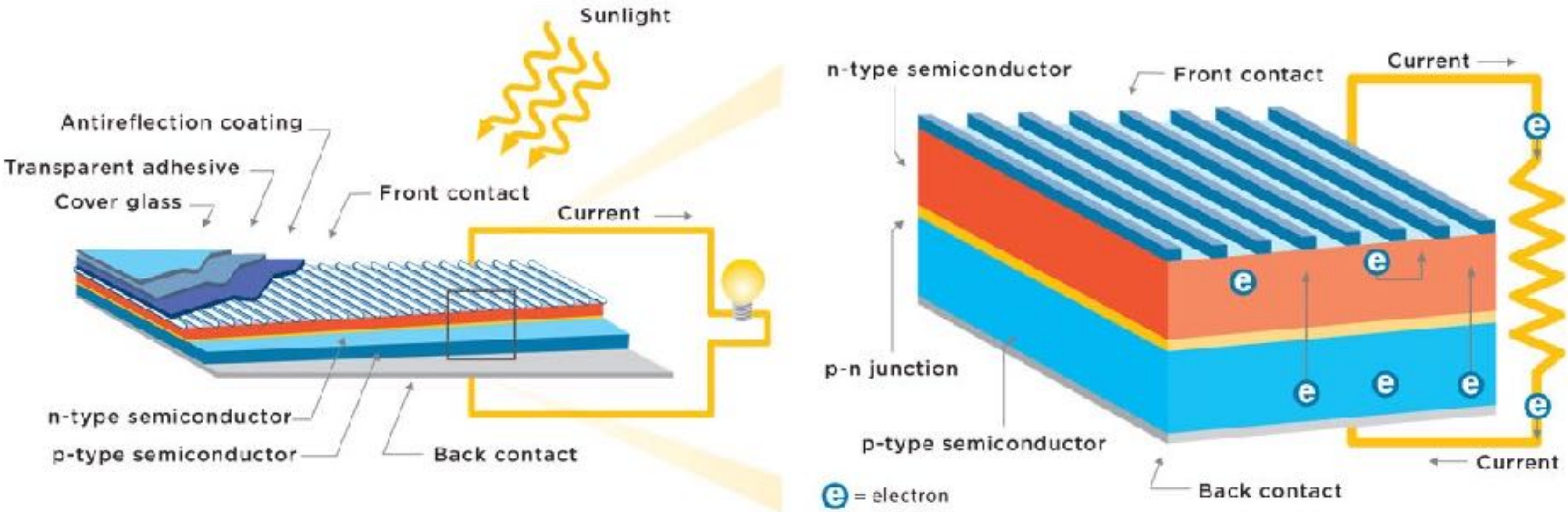
Most semiconductors (including LEDs) do this to some extent.

Source: http://www.imagesco.com/

A junction of P- and N-type materials forms a diode optimized to separate charge carriers when exposed to light



Source: http://www.techbites.com/



Solar cells are composed of two layers of semiconductor material with opposite charges. Sunlight hitting the surface of a cell knocks electrons loose, which then travel through a circuit from one layer to the other, providing a flow of electricity.

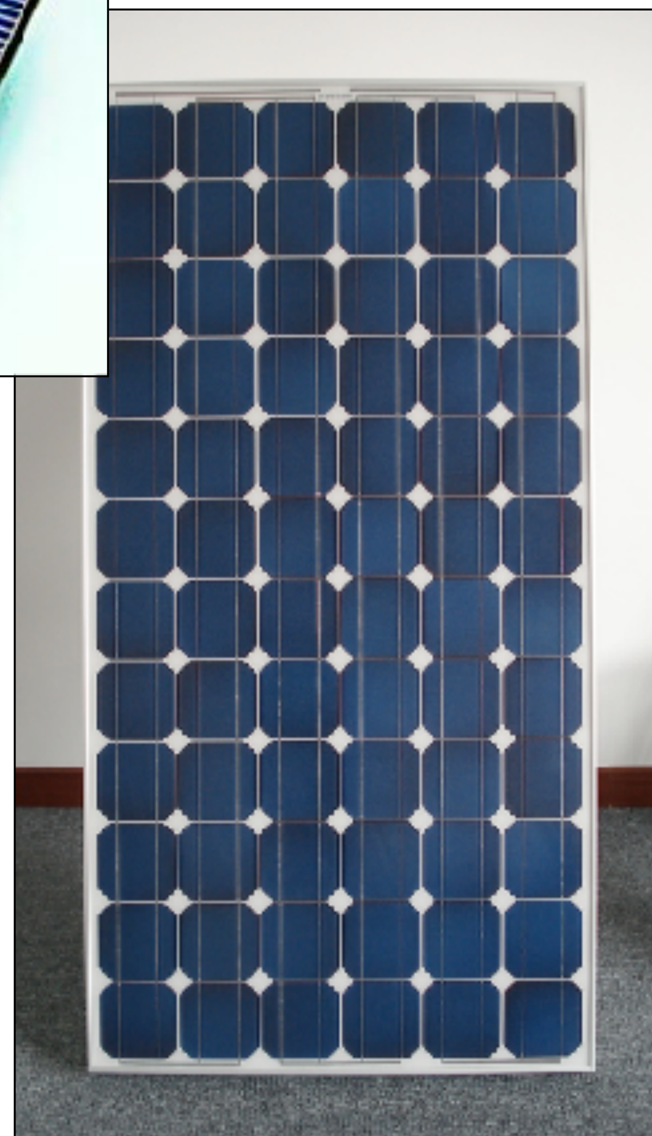
Source: Union of Concerned Scientists

Basics

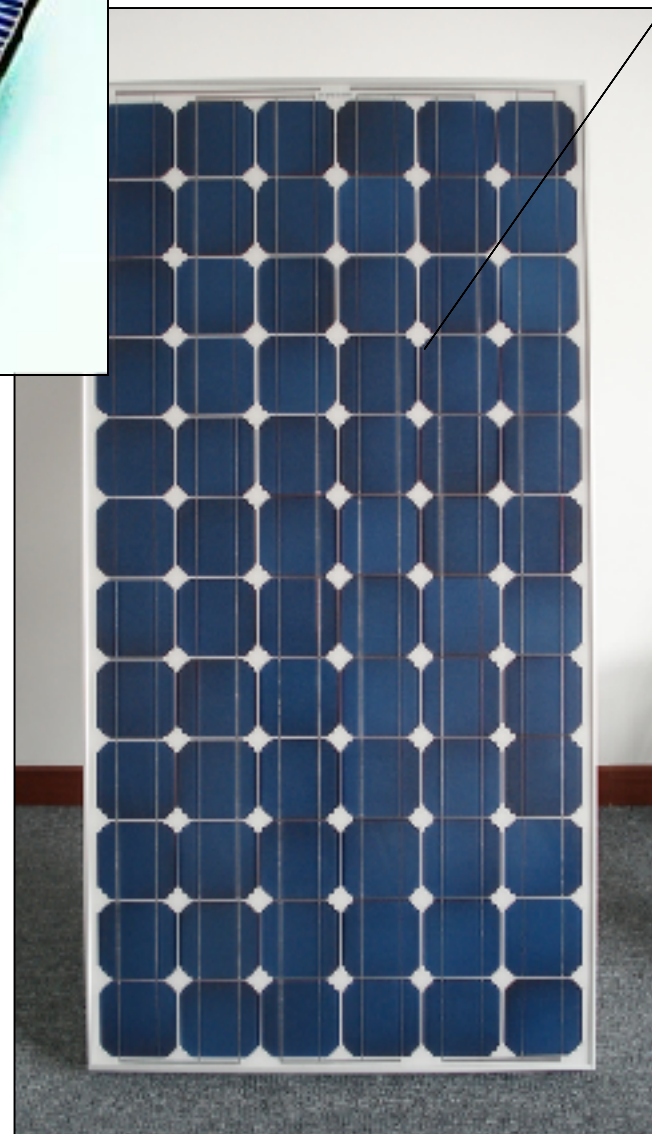
Cell:
Single piece of PV material.

Voltage dependent on semiconductor type

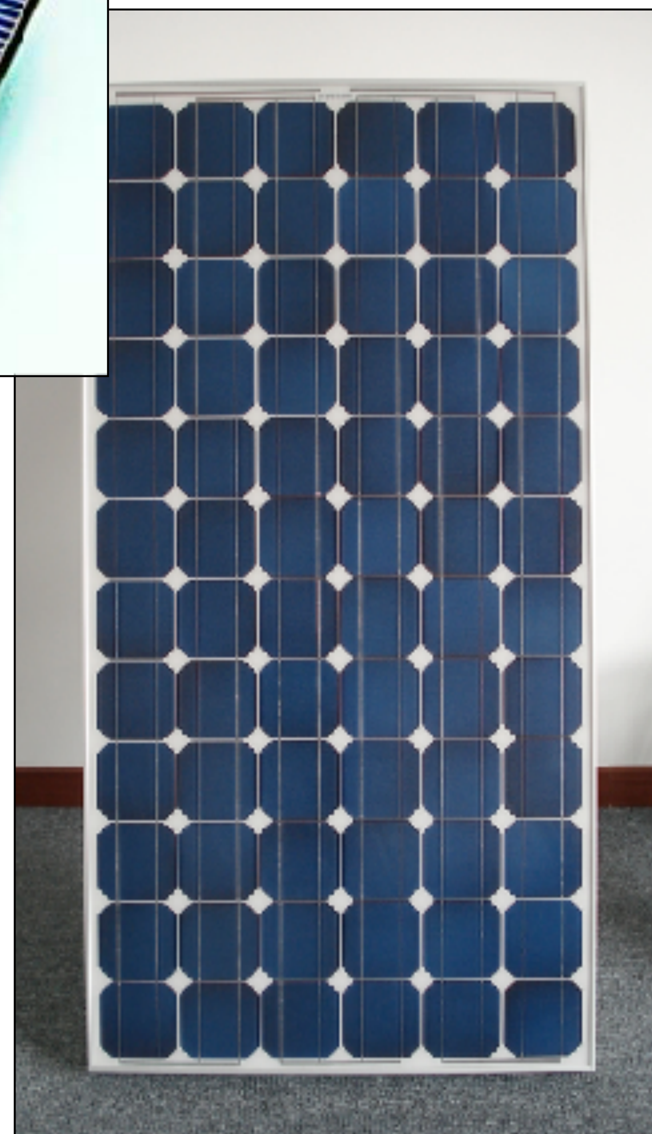
Current dependent on surface area.



Basics



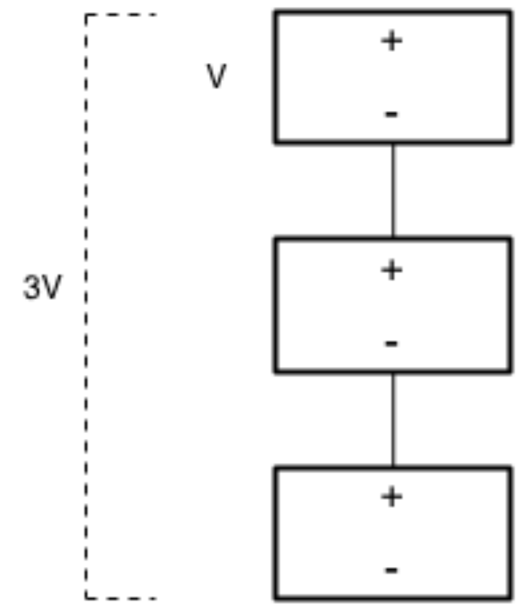
Module:
Multiple cells arranged in series and parallel groups to achieve desired voltage and current.



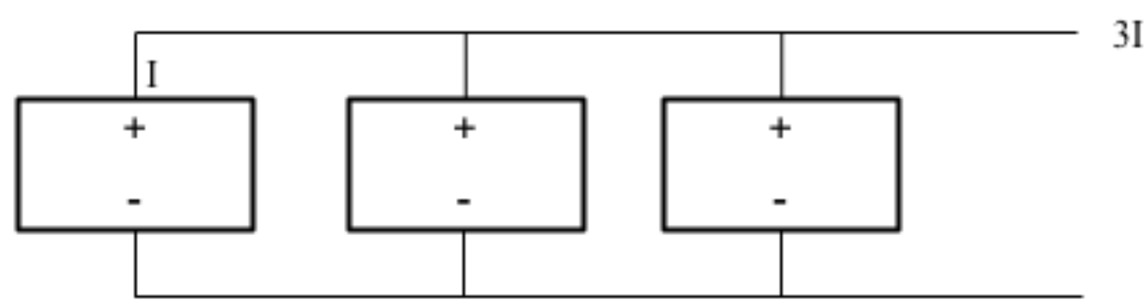
Array:
Multiple modules arranged in series and parallel groups to achieve desired voltage and current.

Basics

In ***series***: Voltage sums, current remains the same



In ***parallel***: Voltage stays the same, current sums



Basics

Metrics we care about are:

Rated performance
- “Watts-peak” under standardized conditions

Open Circuit (OC) Voltage
- voltage measured with no load

Short Circuit (SC) Current
- current through short circuit

And of course, cost...

KC80

HIGH EFFICIENCY MULTICRYSTAL PHOTOVOLTAIC MODULE

TYPICAL OUTPUT 80 Wp

■ Electrical Specifications

MODEL	KC80
Maximum Power	80 Watts
Maximum Power Voltage	16.9 Volts
Maximum Power Current	4.73 Amps
Open Circuit Voltage	21.5 Volts
Short-Circuit Current	4.97 Amps
Length	976mm (38.4in.)
Width	652mm (25.7in.)
Depth	56mm (2.2in.)
Weight	8.0kg (17.7lbs.)

Note: The electrical specifications are under test conditions of Irradiance of 1kW/m², Spectrum of 1.5 air mass and cell temperature of 25°C

HIGHLIGHTS OF KYO

Kyocera's advanced cell processing technol efficient multicrystal photovoltaic modules.
The conversion efficiency of the Kyocera sola
These cells are encapsulated between a tempe maximum protection from the severest enviro
The entire laminate is installed in an anodized a

- Microwave/Radio repeater stations
- Electrification of villages in remote areas
- Medical facilities in rural areas
- Power source for summer vacation homes
- Emergency communication systems
- Water quality and environmental data mon systems
- Navigation lighthouses, and ocean buoys

■ Electrical Specifications

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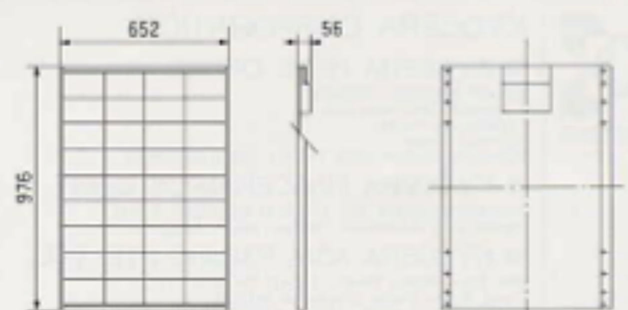


"Nameplate capacity" = 80W

DIFFERENCES

Different types of PV are distinguished by:

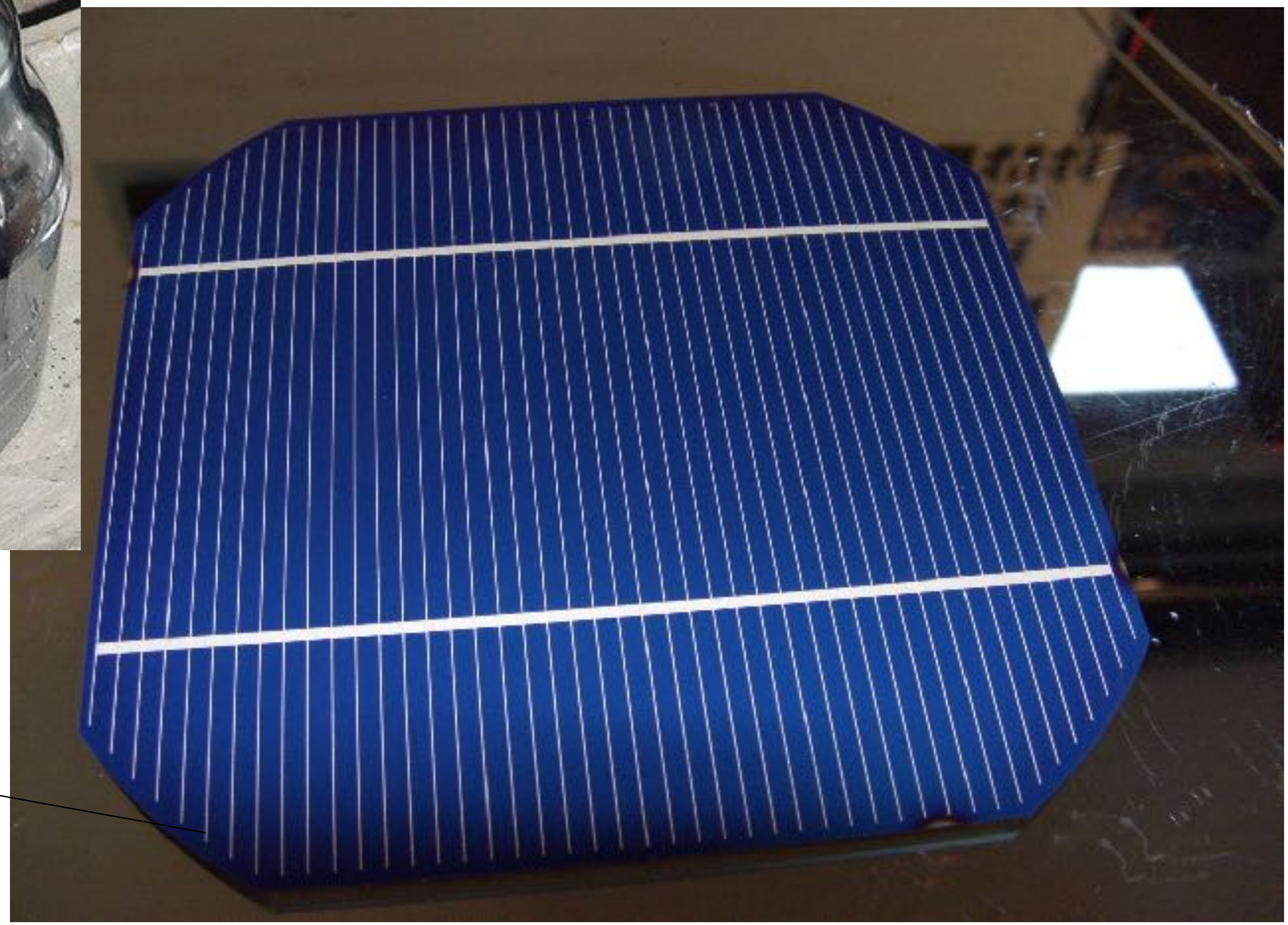
- Form of material (e.g. crystalline or thin film)

- Type of material (Si vs. CIGS vs...)

- Number of layers ("junctions")

Different types will have varying **efficiencies** under different **conditions**, and widely-ranging associated **costs**.

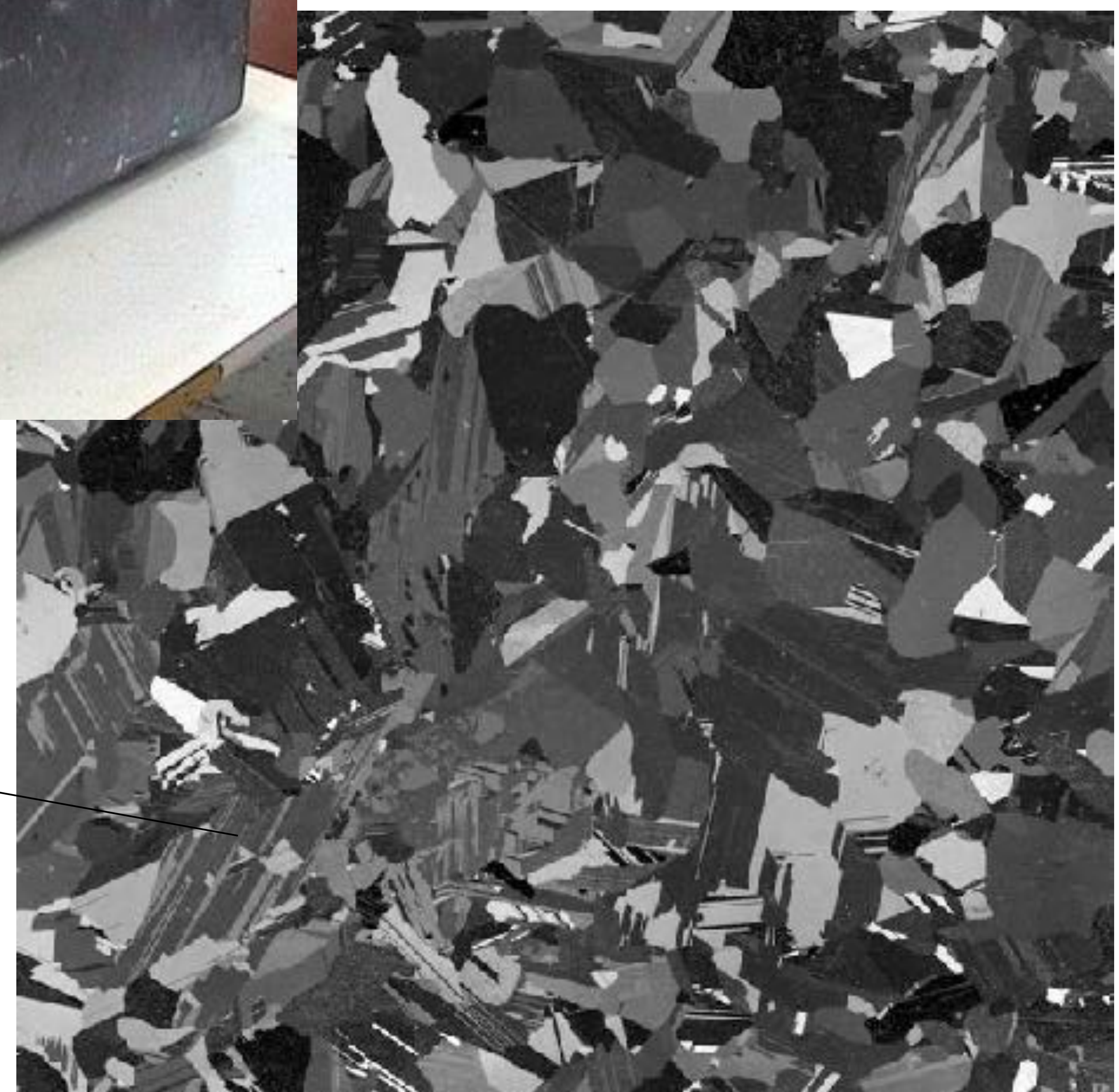
Mono-crystalline Si ingot and cell



Circa 300 um thick
Si layer

Differences

Polycrystalline Si
ingot and cell



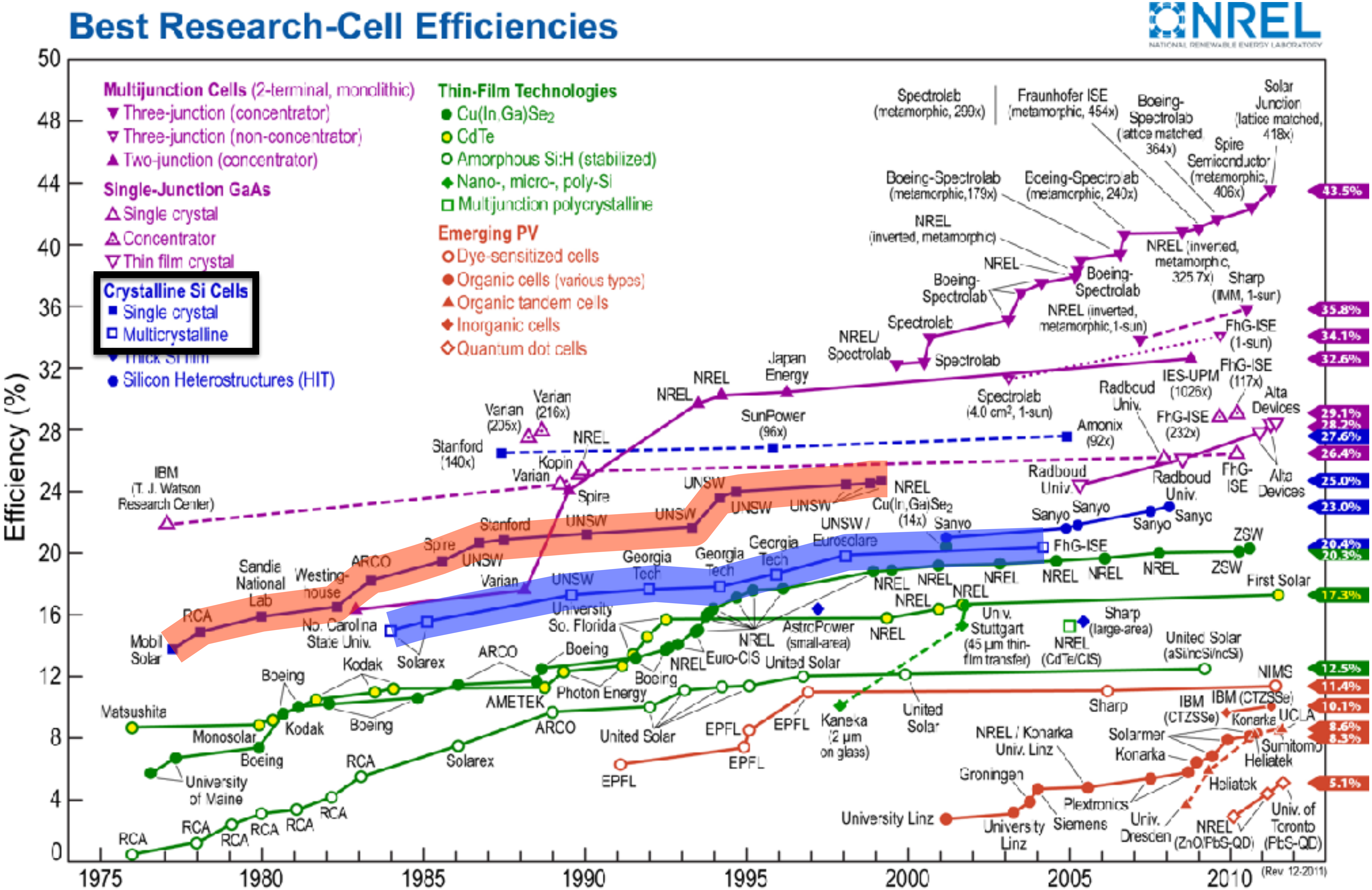
Circa 300 um thick
Si layer

Differences

Amorphous or thin film PV

Circa 30 um thick
Si layer

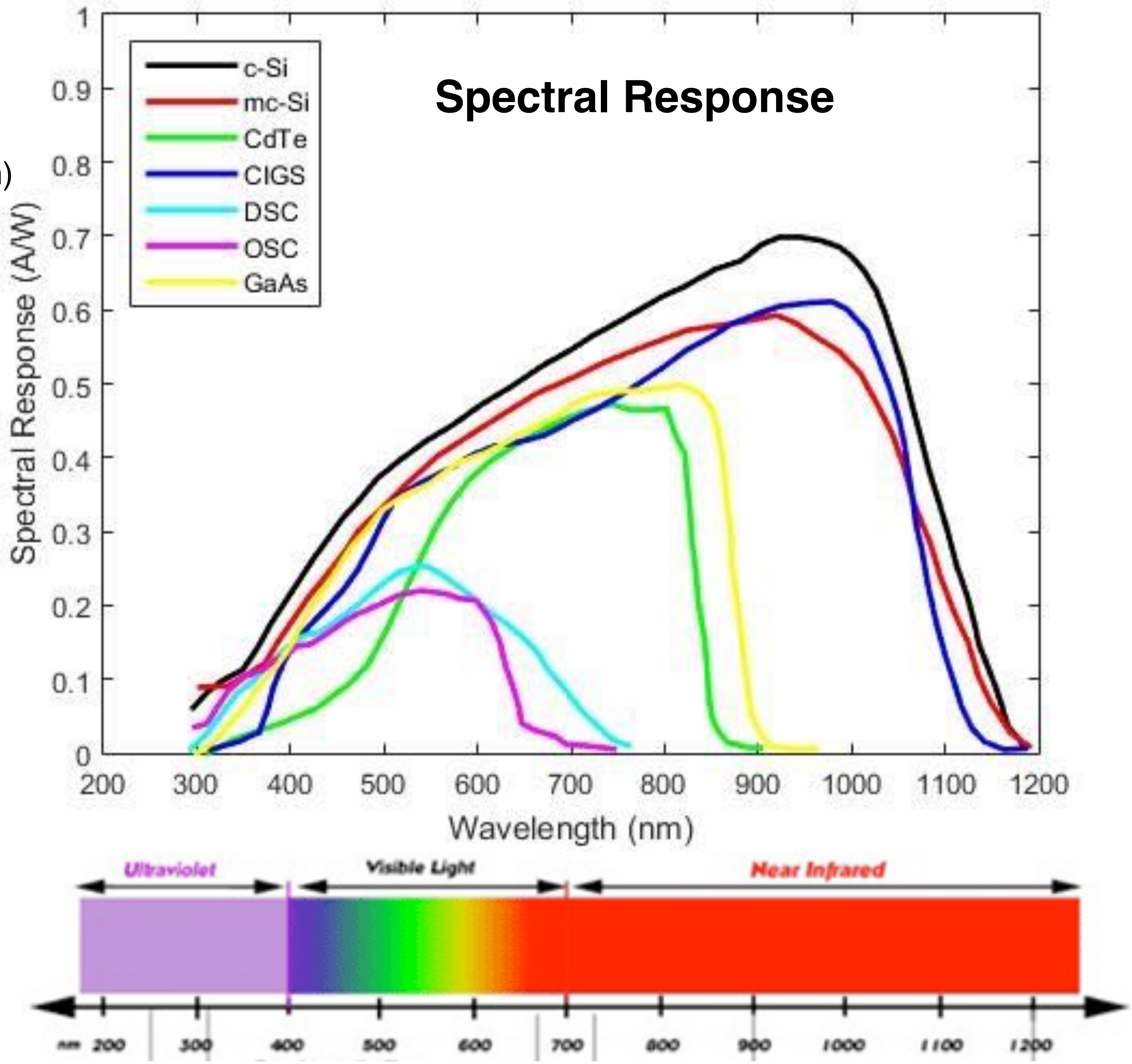
Differences



Source: DOE NREL

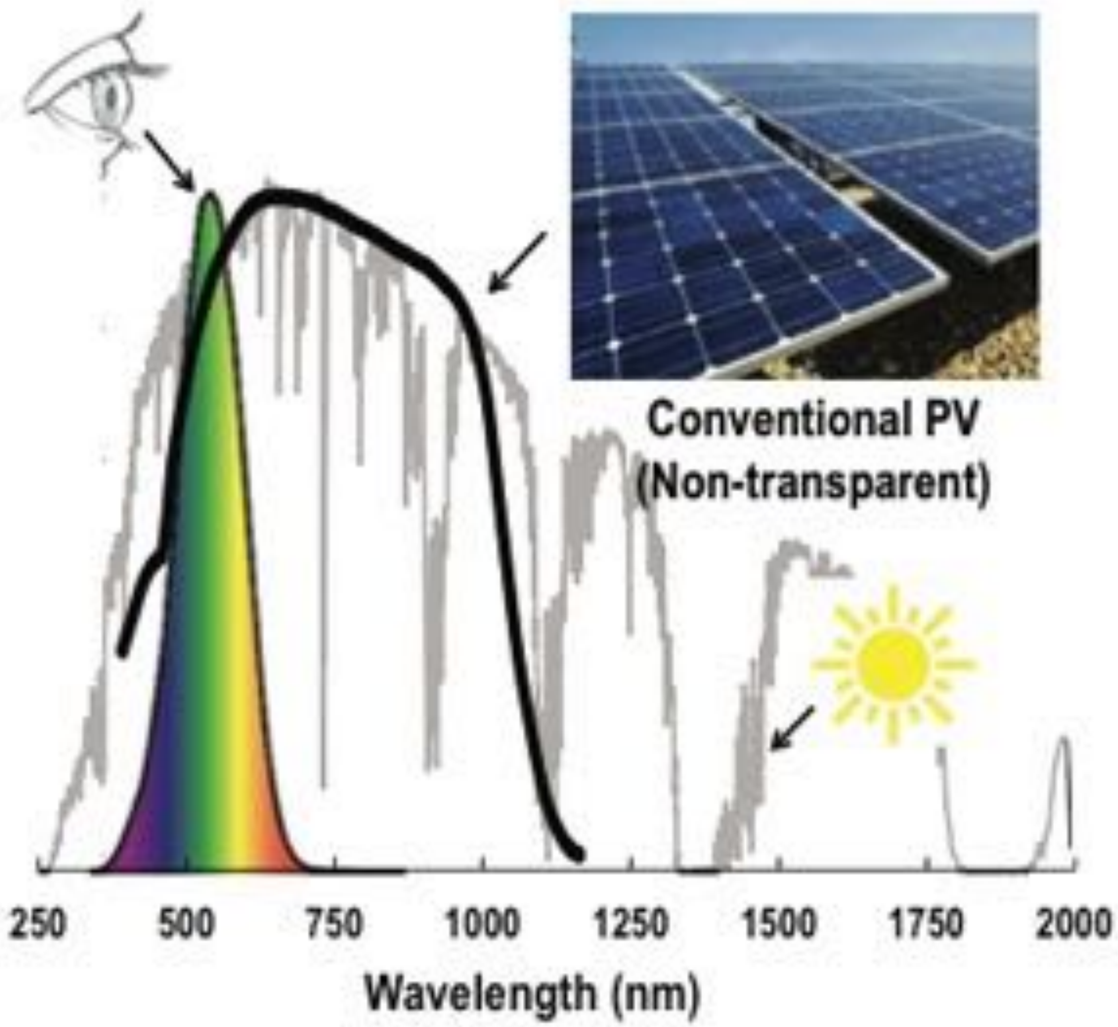
Differences

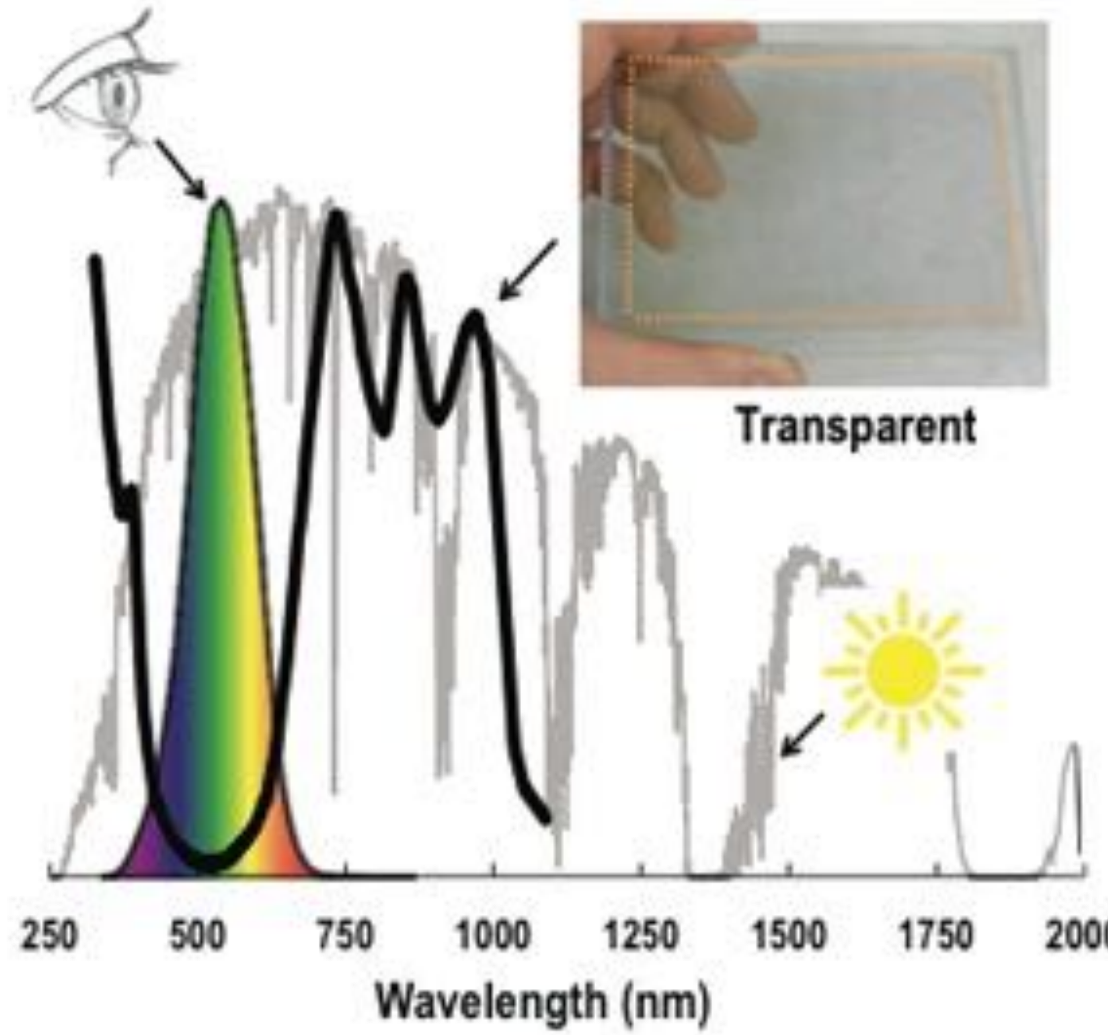
(Mono) Crystalline Si
Multi-crystalline Si
Cadmium Telluride (thin)
Copper-Indium-Gallium (thin)
Dye-Sensitized
Organic
Gallium Arsenide



Source: https://pvpmc.sandia.gov/modeling-steps/2-dc-module-iv/effective-irradiance/spectral-response/

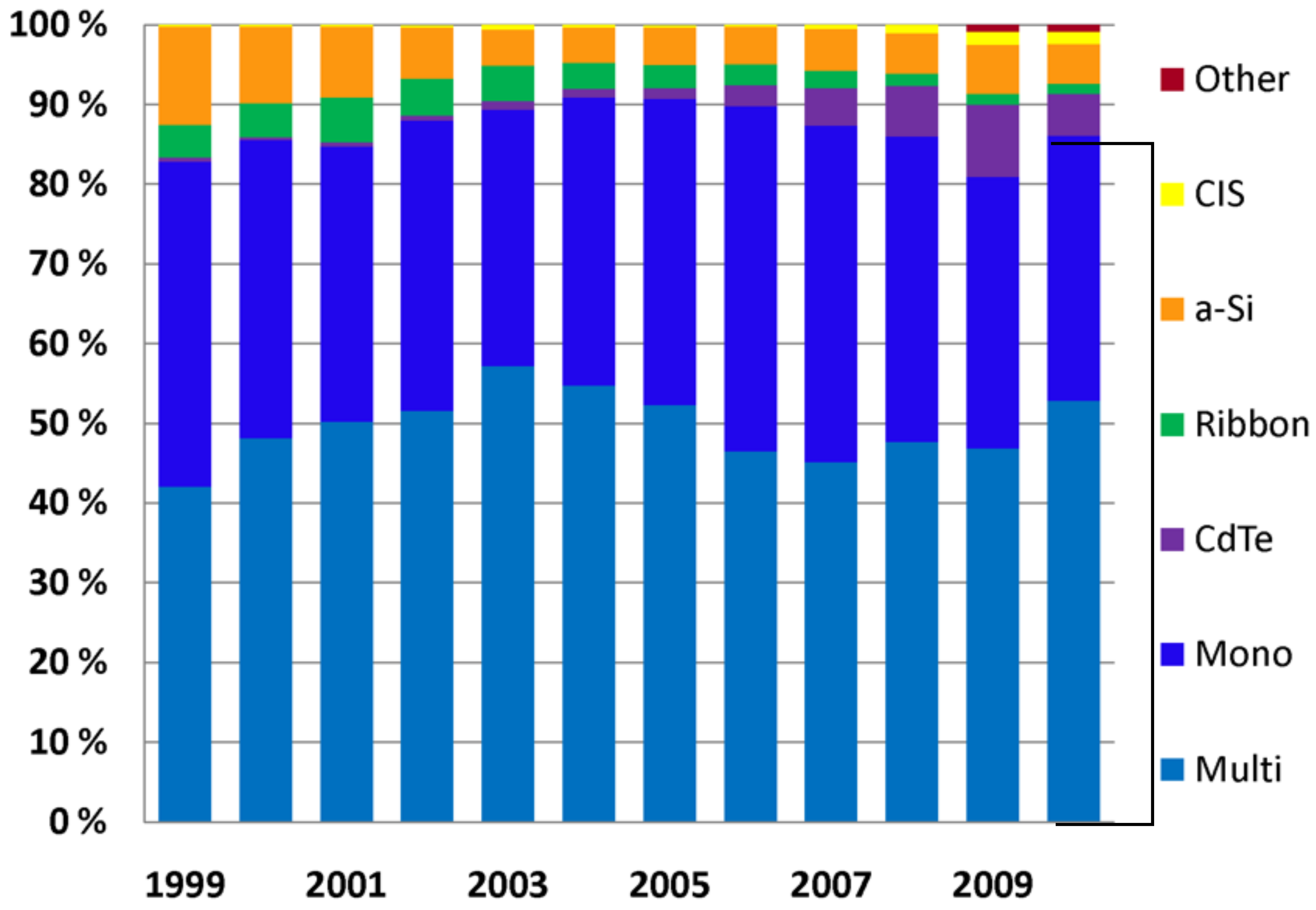
Differences





source: http://energy.mit.edu/news/transparent-solar-cells/

Differences



Source: Cleanenergy

Differences

For later:

Balance of system
Tracking methods
Concentrating systems
Solar lighting
Solar thermal

also:
Kardashev scale
Space based solar power
Dyson swarms

For now:

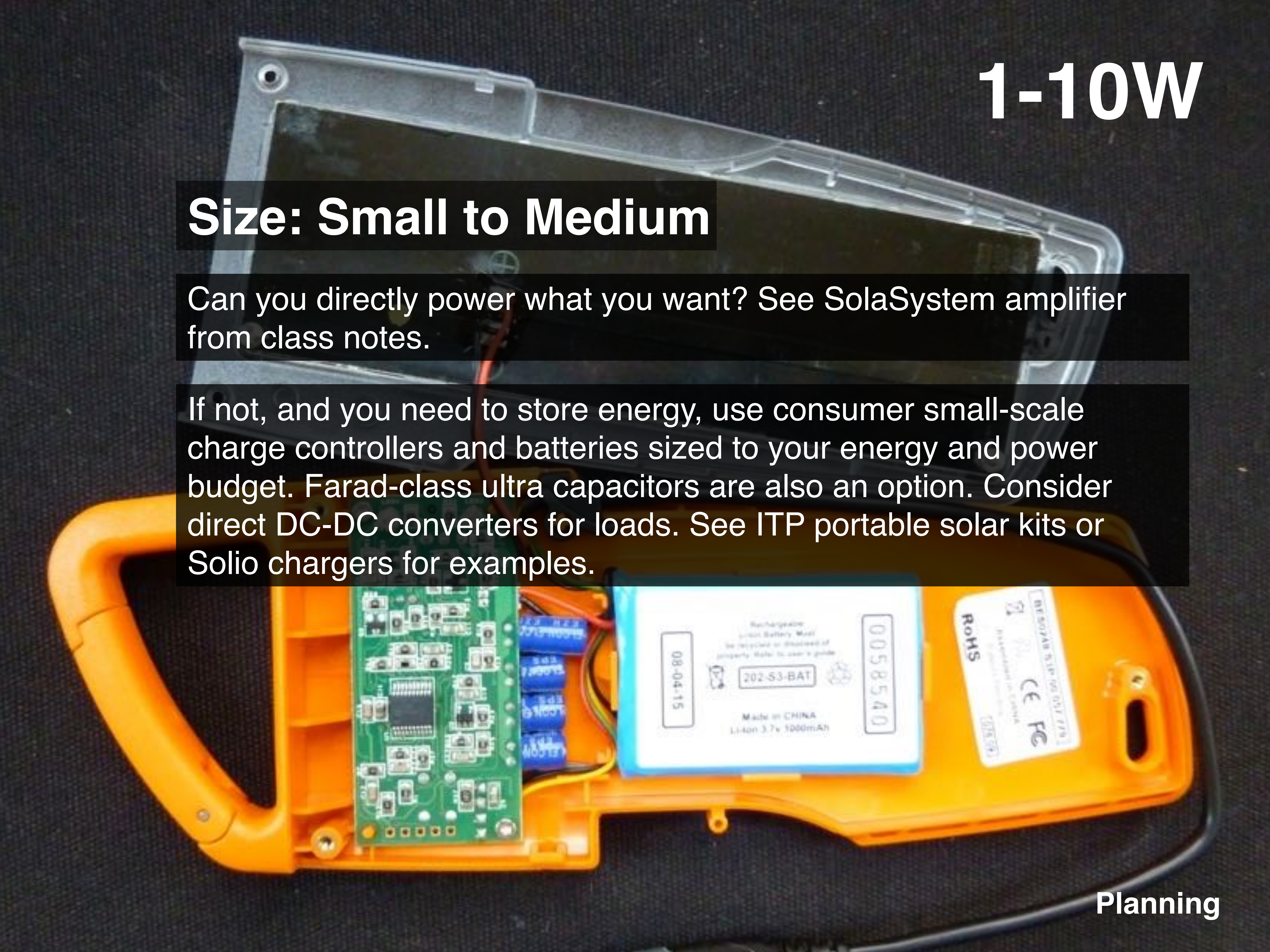
Planning a solar powered project

<1W

Size: Very Small

BEAM circuits. <1W PVs charge capacitors, discharged through resistive loads by voltage monitor ICs. Can be extended to power microcontrollers and other circuits.

Solarbotics

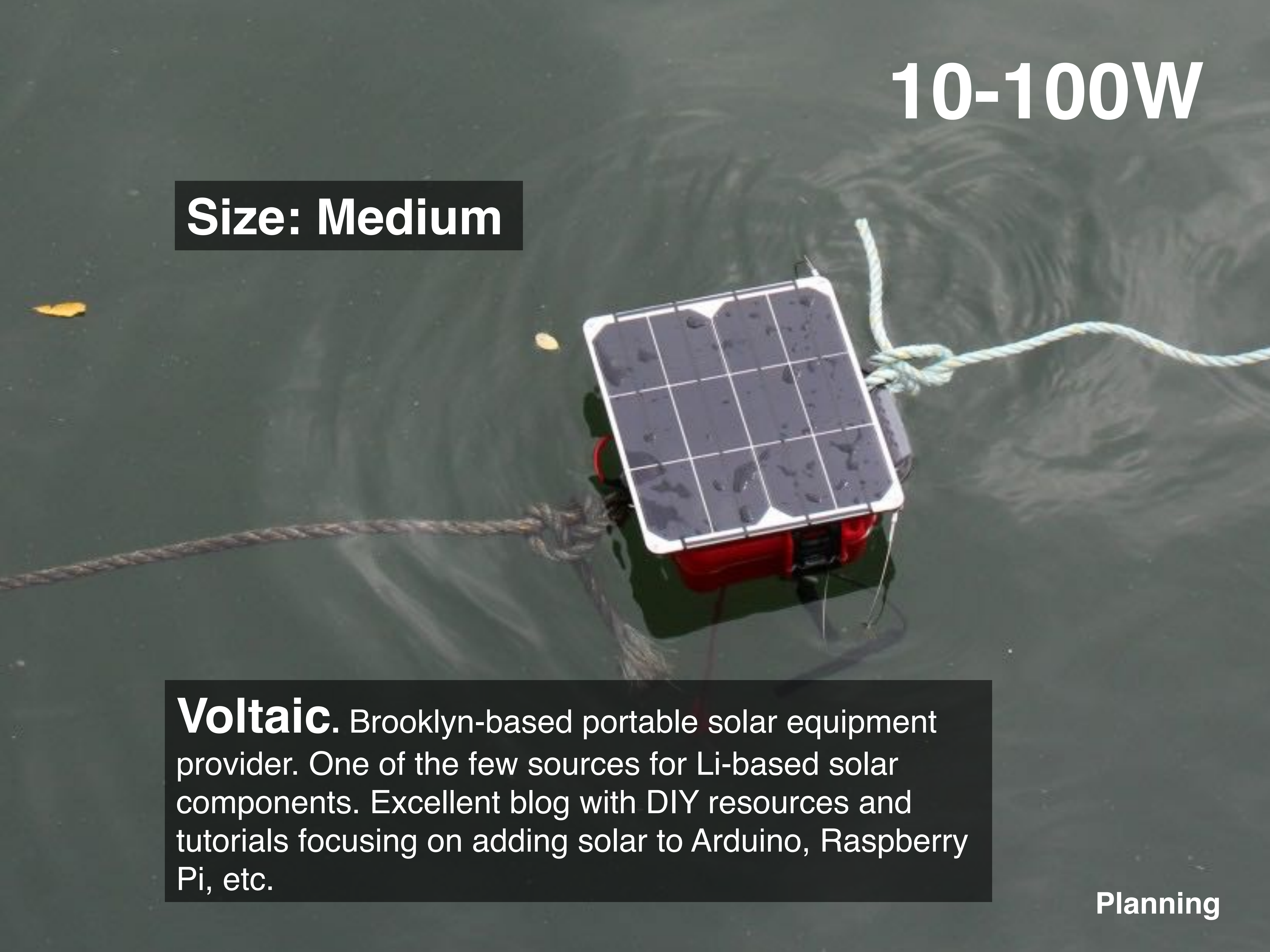


1-10W

Size: Small to Medium

Can you directly power what you want? See SolaSystem amplifier from class notes.

If not, and you need to store energy, use consumer small-scale charge controllers and batteries sized to your energy and power budget. Farad-class ultra capacitors are also an option. Consider direct DC-DC converters for loads. See ITP portable solar kits or Solio chargers for examples.



10-100W

Size: Medium

Voltaic. Brooklyn-based portable solar equipment provider. One of the few sources for Li-based solar components. Excellent blog with DIY resources and tutorials focusing on adding solar to Arduino, Raspberry Pi, etc.


>50W
Size: Medium to large
Use commercial grade modules, battery chargers and batteries. Mature products exist for off-grid markets. Use inverter as de facto common interface for AC loads.
Planning

CASE STUDY


Case study: Earth Speaker
Solar powered sound installation
Case Study

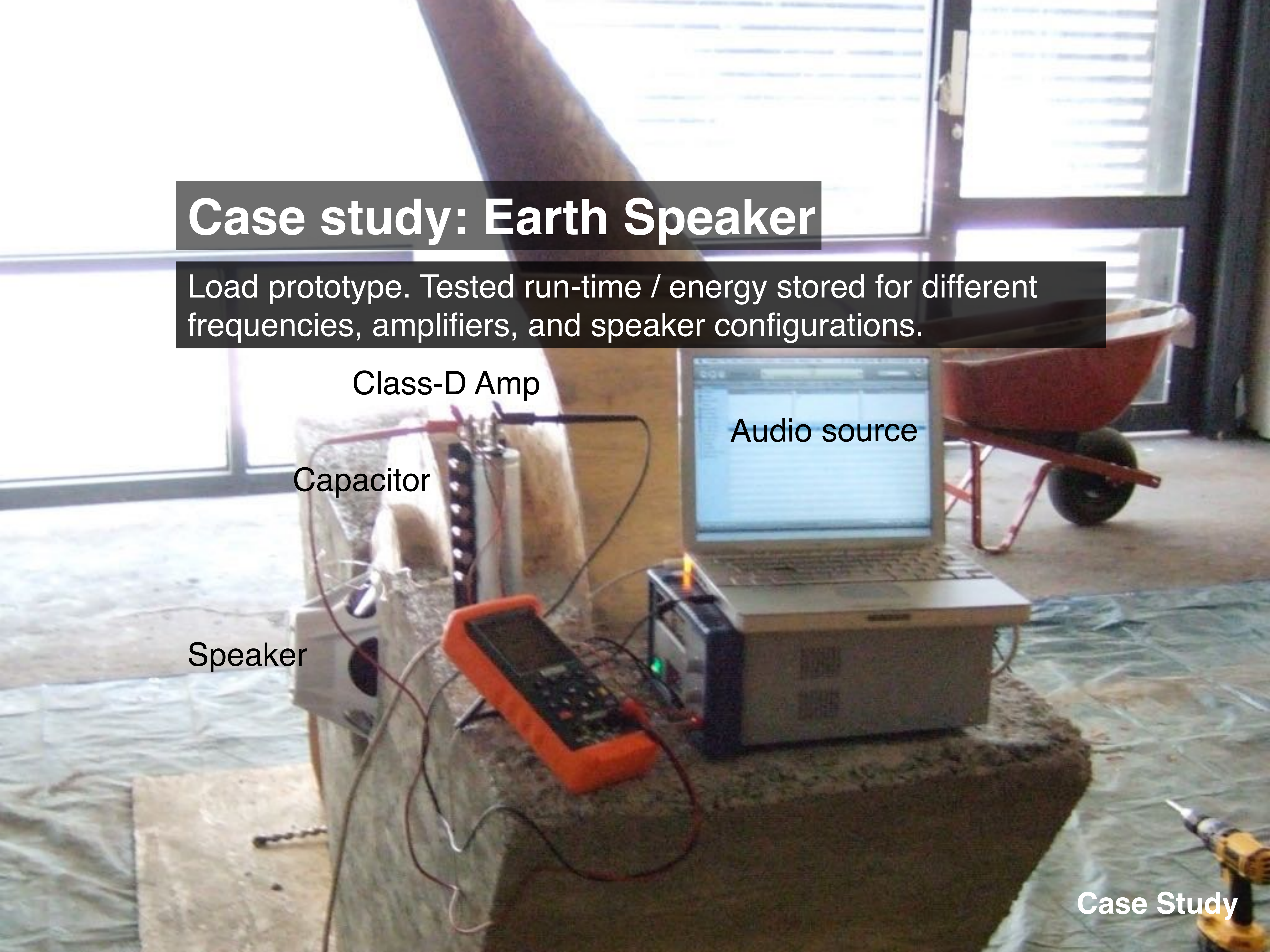
Case study: Earth Speaker

Power system prototype: 5x ~4.5V solar modules in series connected directly to a 12V 1.5 F capacitor.

Helped asses time required to charge at locale.

Case study: Earth Speaker

Load prototype. Tested run-time / energy stored for different frequencies, amplifiers, and speaker configurations.



Case study: Earth Speaker