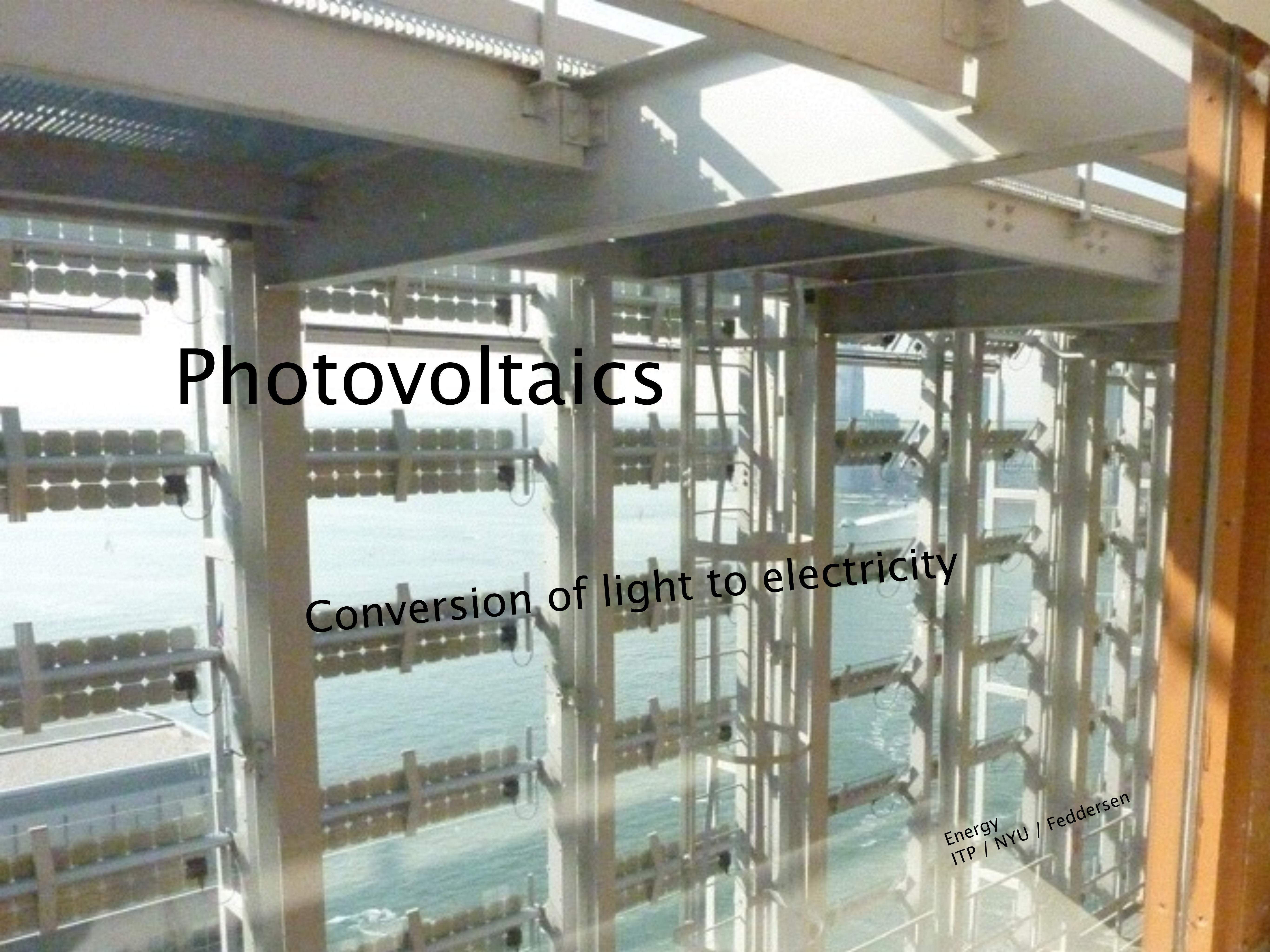


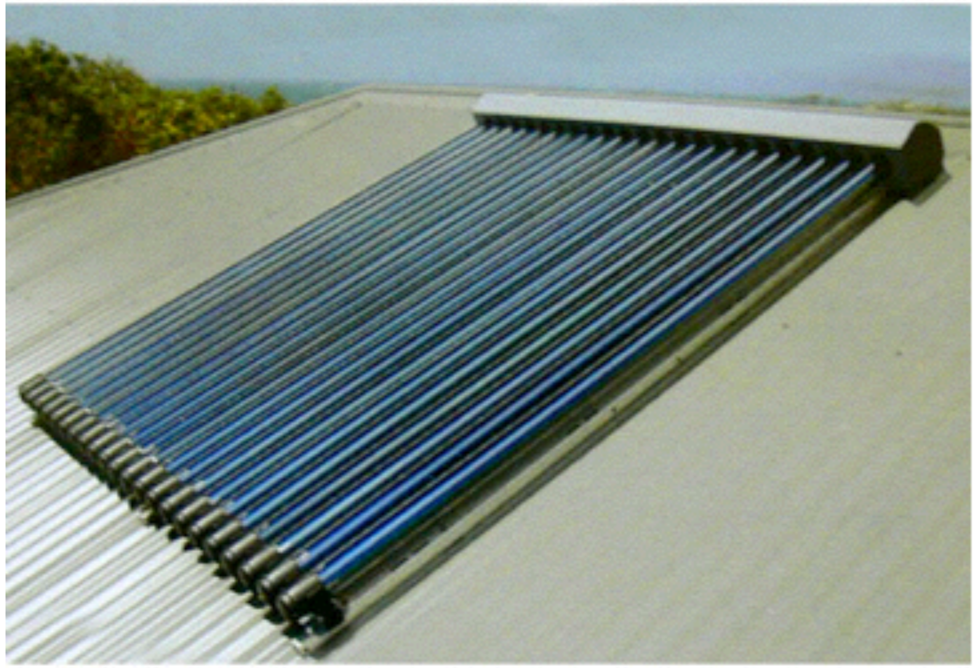
# Photovoltaics

Conversion of light to electricity

Energy
ITP / NYU / Feddersen

SOLAR TWO - MOJAVE DESERT, CALIFORNIA

Not to be confused with solar thermal applications



## More solar thermal

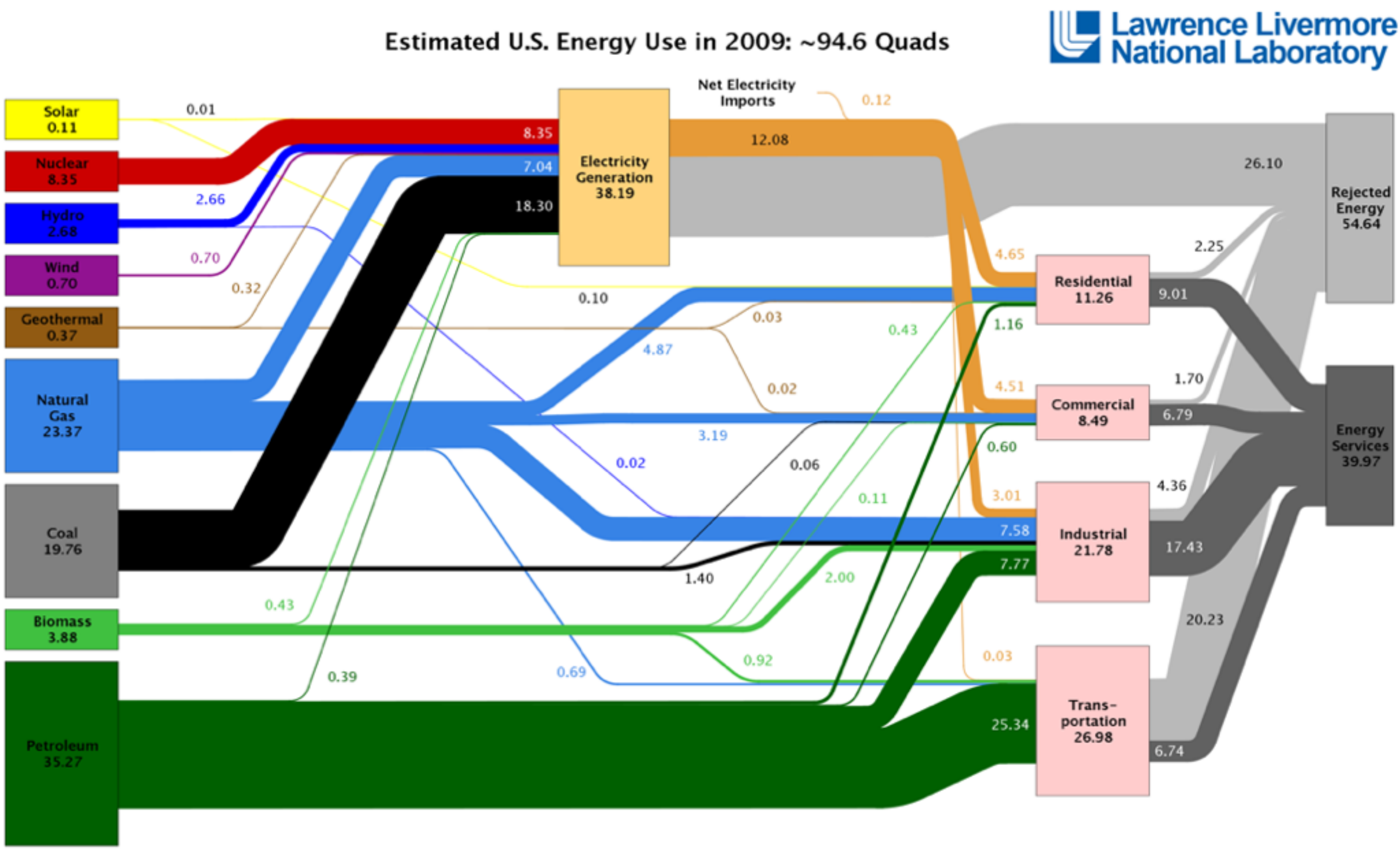
Sterling engine

Sunlight Direct HSL-3000

Parans SkyPort
with custom
fixture

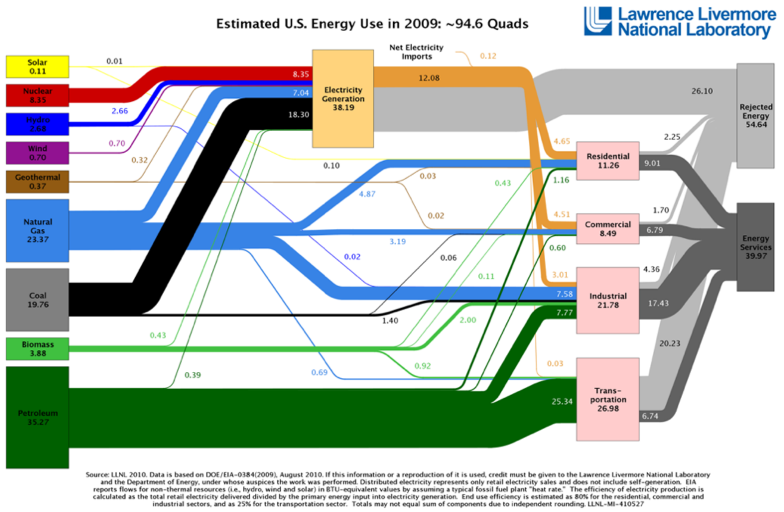
Also not to be confused
with direct use of sunlight
for illumination.

# REVIEW

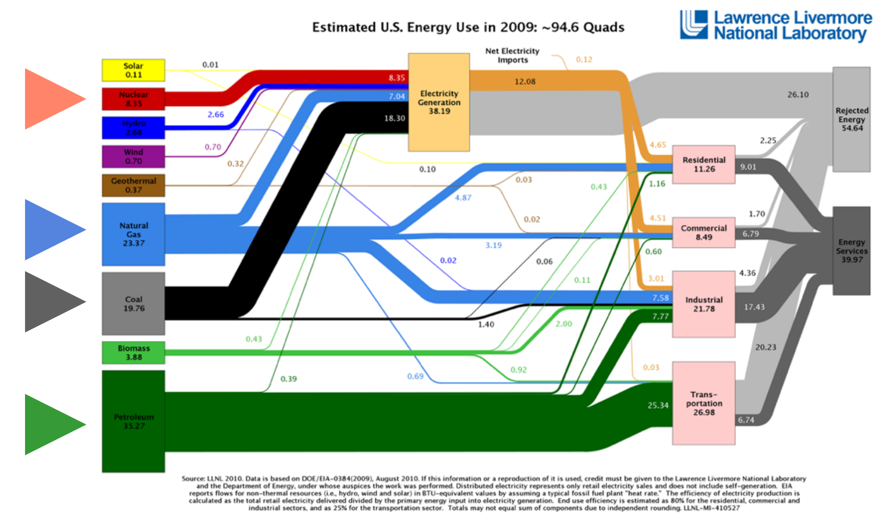


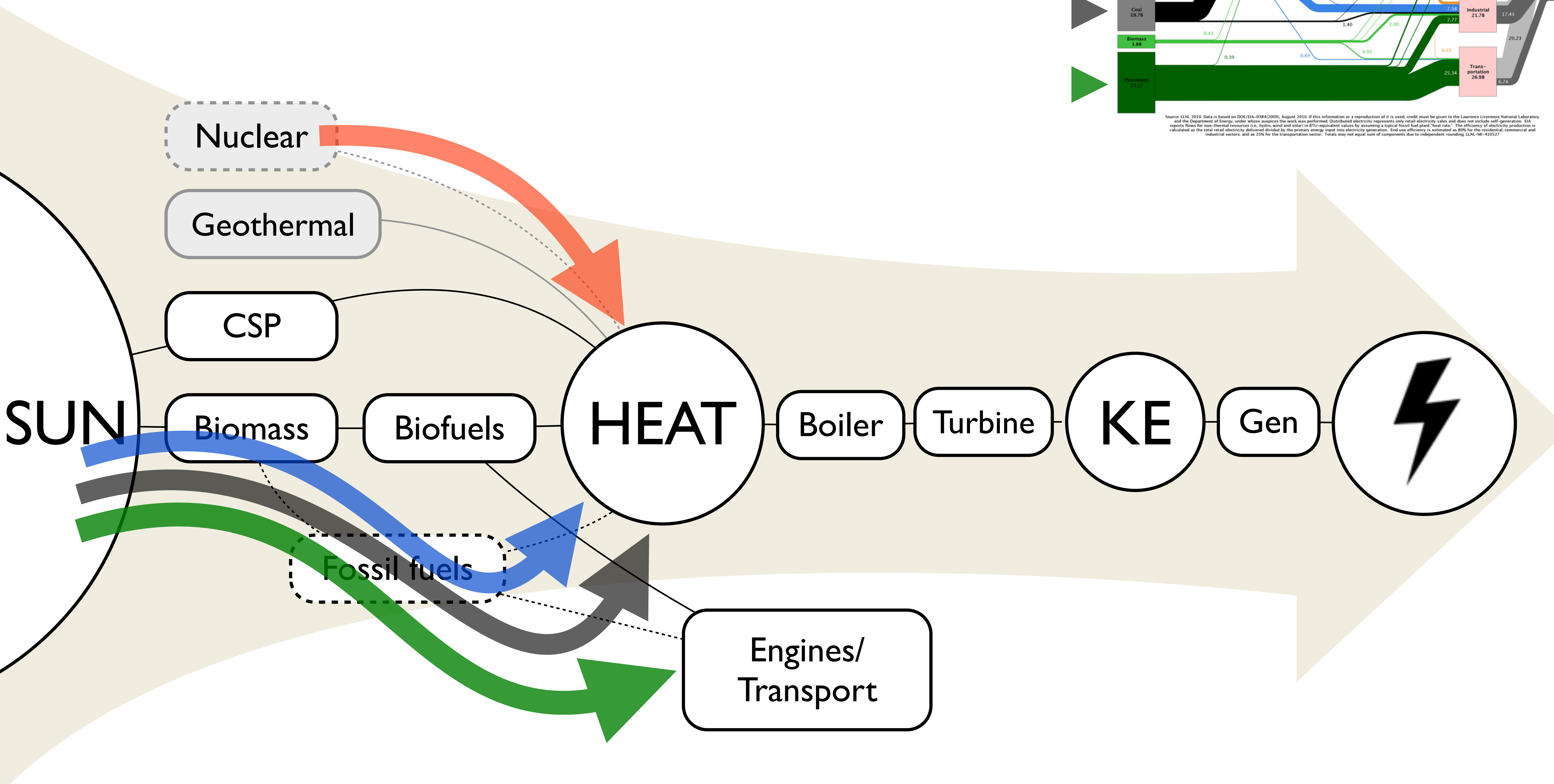

Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only 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**

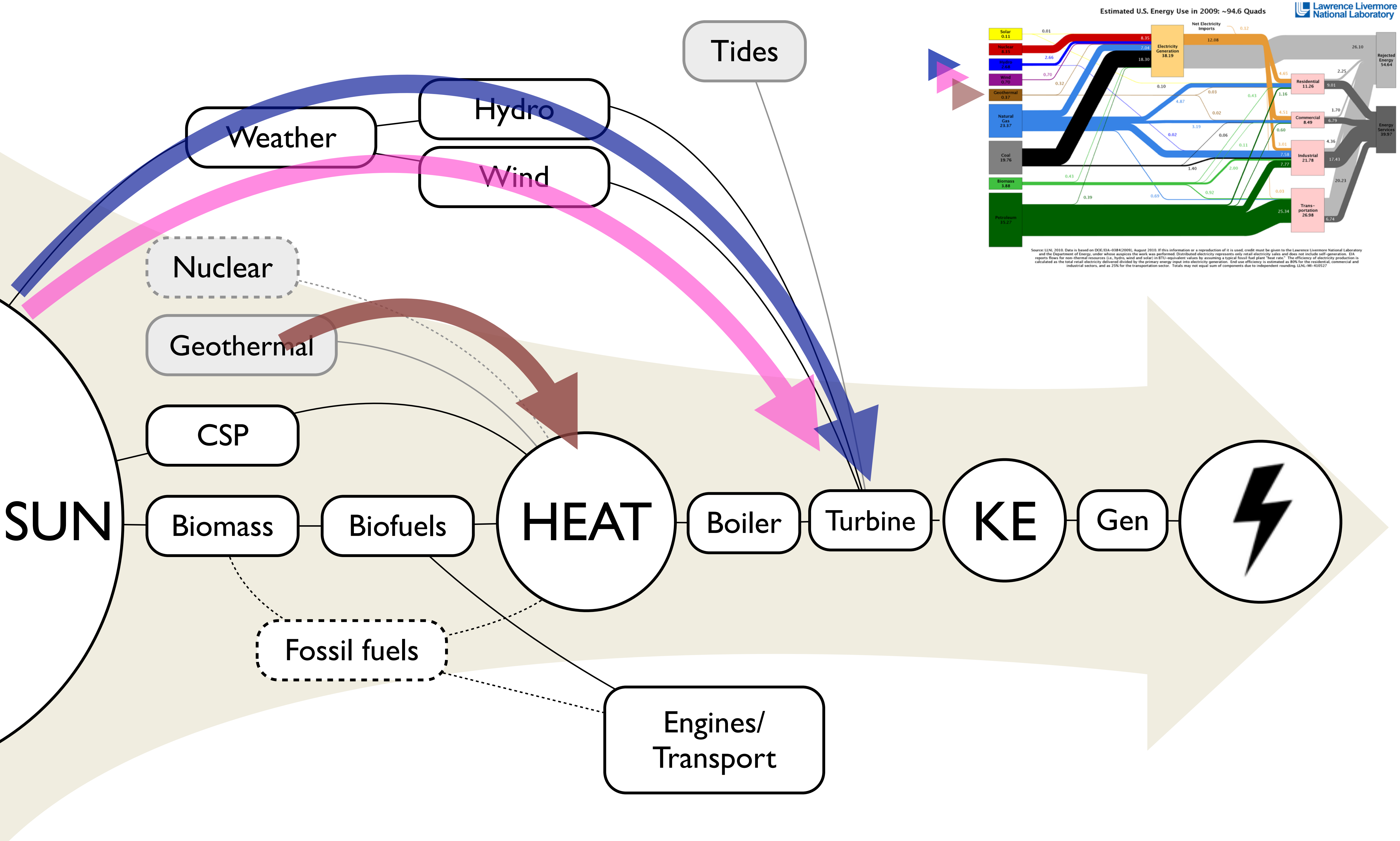

Estimated U.S. Energy Use in 2009: ~94.6 Quads
Lawrence Livermore National Laboratory
Solar 0.11
Nuclear 8.35
Hydro 2.68
Wind 0.70
Geothermal 0.37
Natural Gas 23.37
Coal 19.76
Biomass 3.88
Petroleum 35.27
Electricity Generation 38.19
Net Electricity Imports
Residential 11.26
Commercial 8.49
Industrial 21.78
Trans-portation 26.98
Rejected Energy 54.64
Energy Services 39.97
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


Nuclear
Geothermal
CSP
SUN
Biomass
Biofuels
HEAT
Boiler
Turbine
KE
Gen
Fossil fuels
Engines/
Transport

**Review**


Tides
Weather
Hydro
Wind
Nuclear
Geothermal
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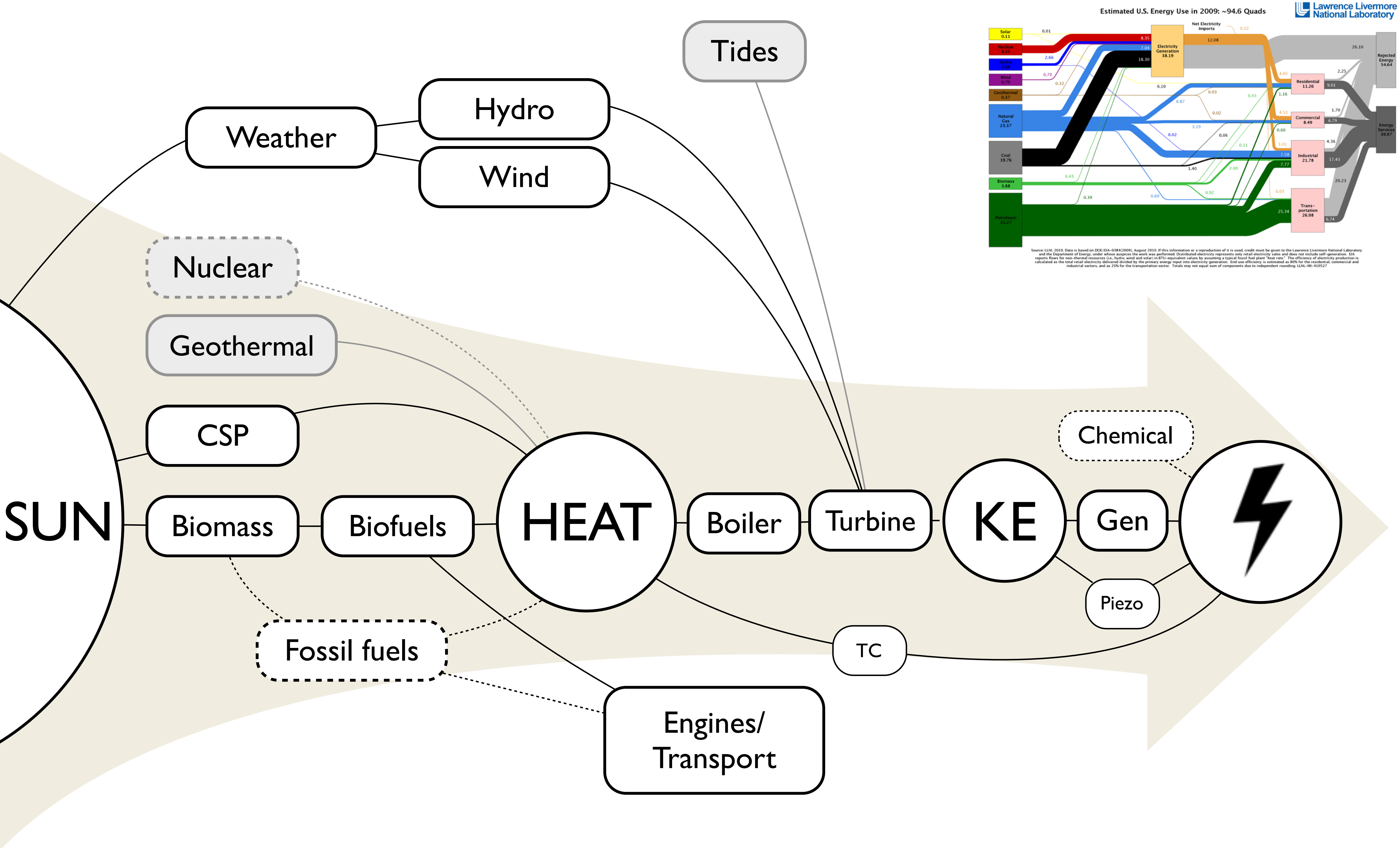
**Review**


Tides
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Chemical
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TC
Fossil fuels
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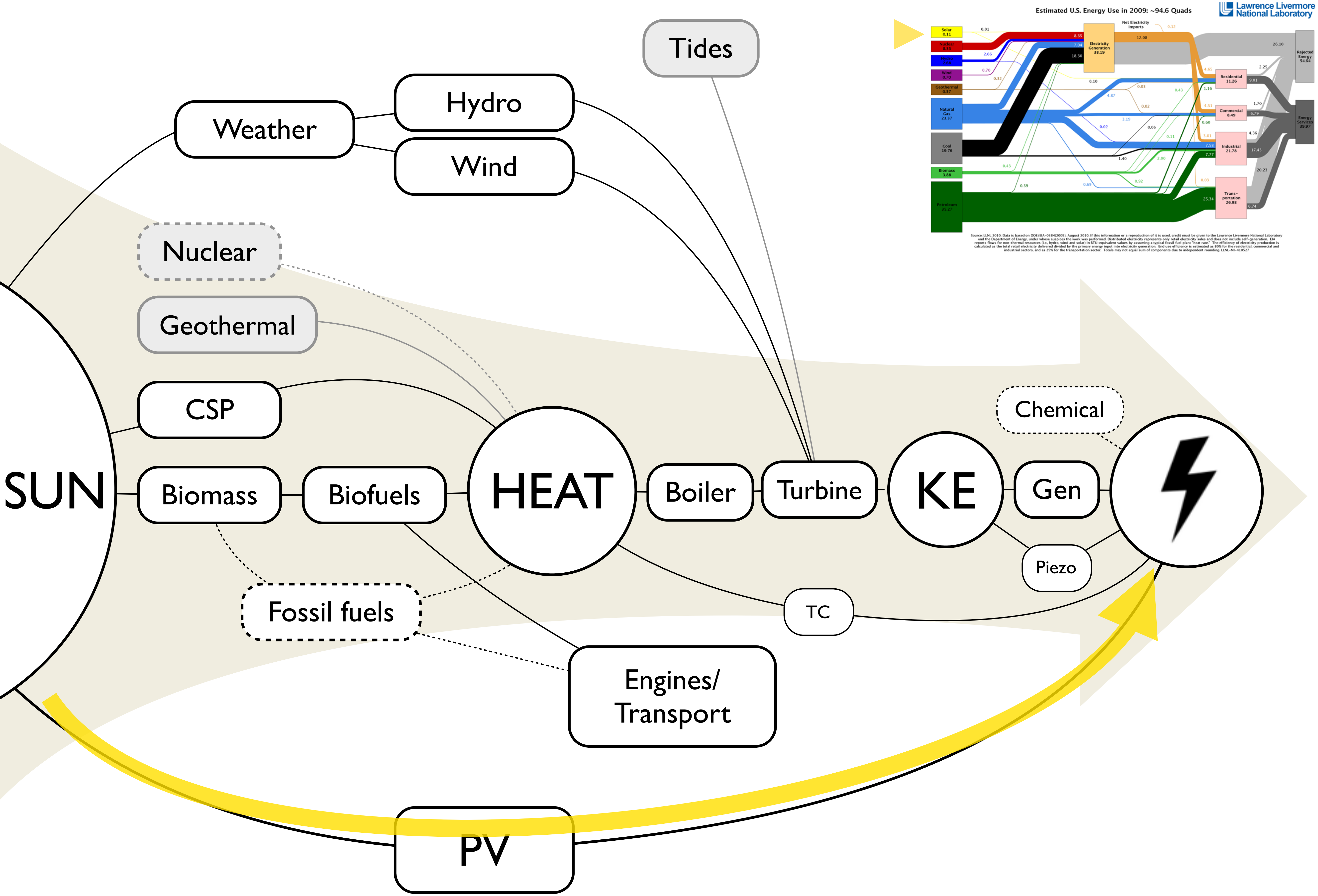
**Review**



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Tides
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Boiler
Turbine
KE
Gen
Chemical
Piezo
TC
Fossil fuels
Engines/ Transport
PV


**Review**

# OVERVIEW

4.2 billion kg of H -> Energy / second
so $3.85 \times 10^{26}$ 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 energy input:
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

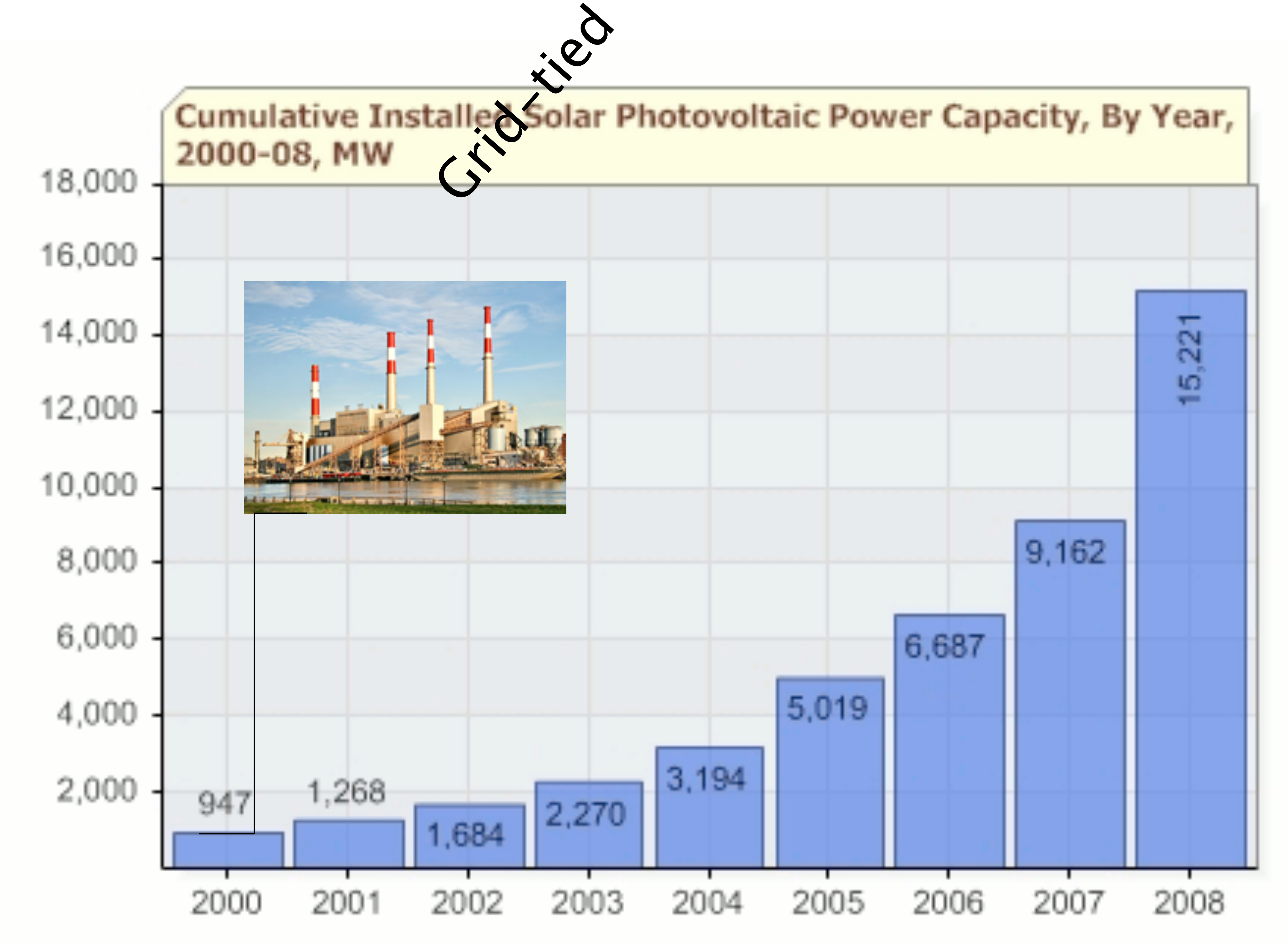



Terrestrial applications

**Overview**

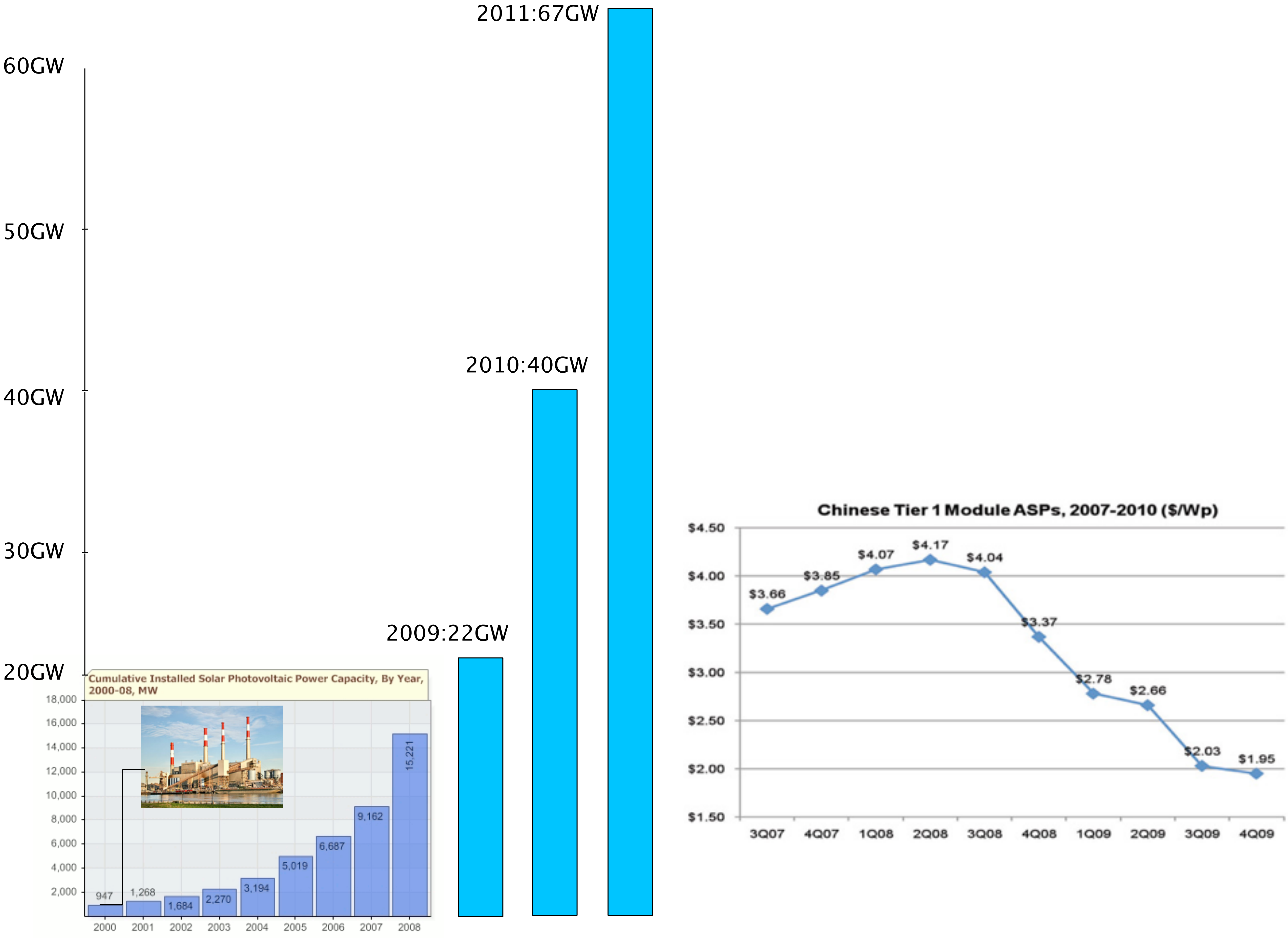
Fishermen in Kenya attracting shrimp w/ solar-charged lights (photo:Siemens)

Small and large commercial applications




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

**Overview**

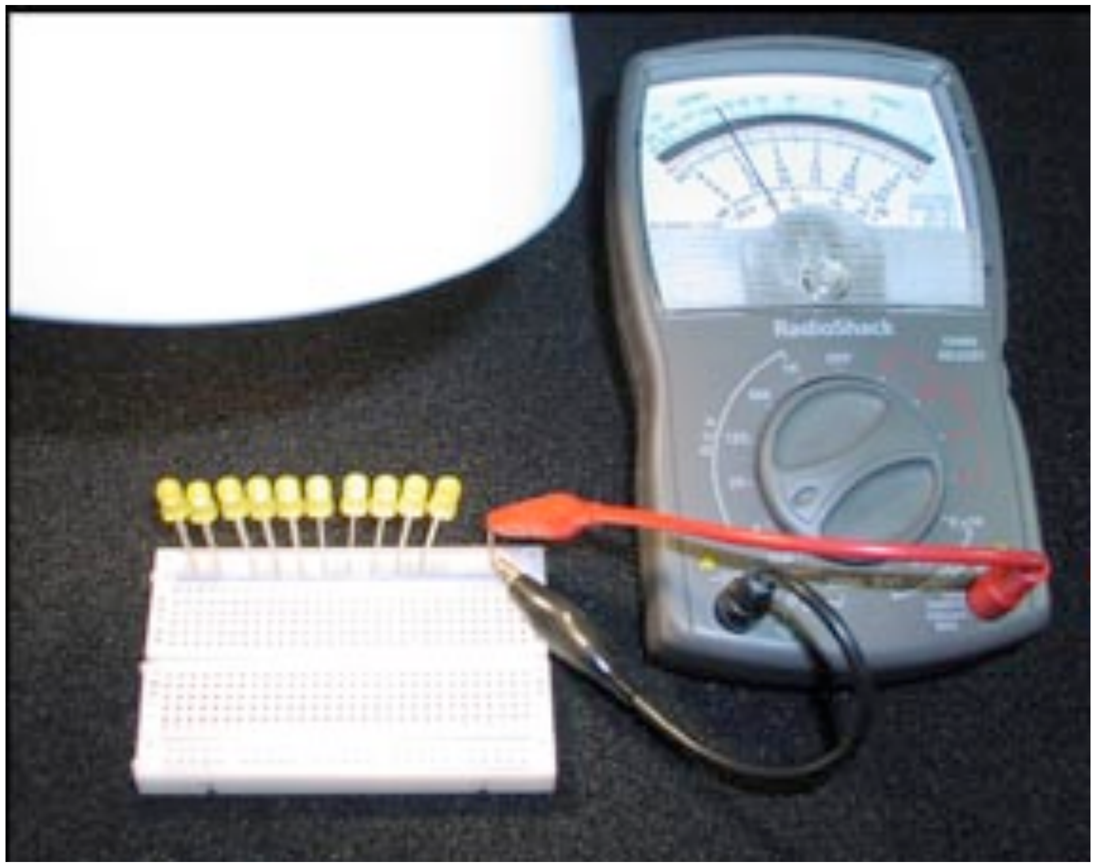



GTMedia, wikipedia

**Overview**

# BASICS

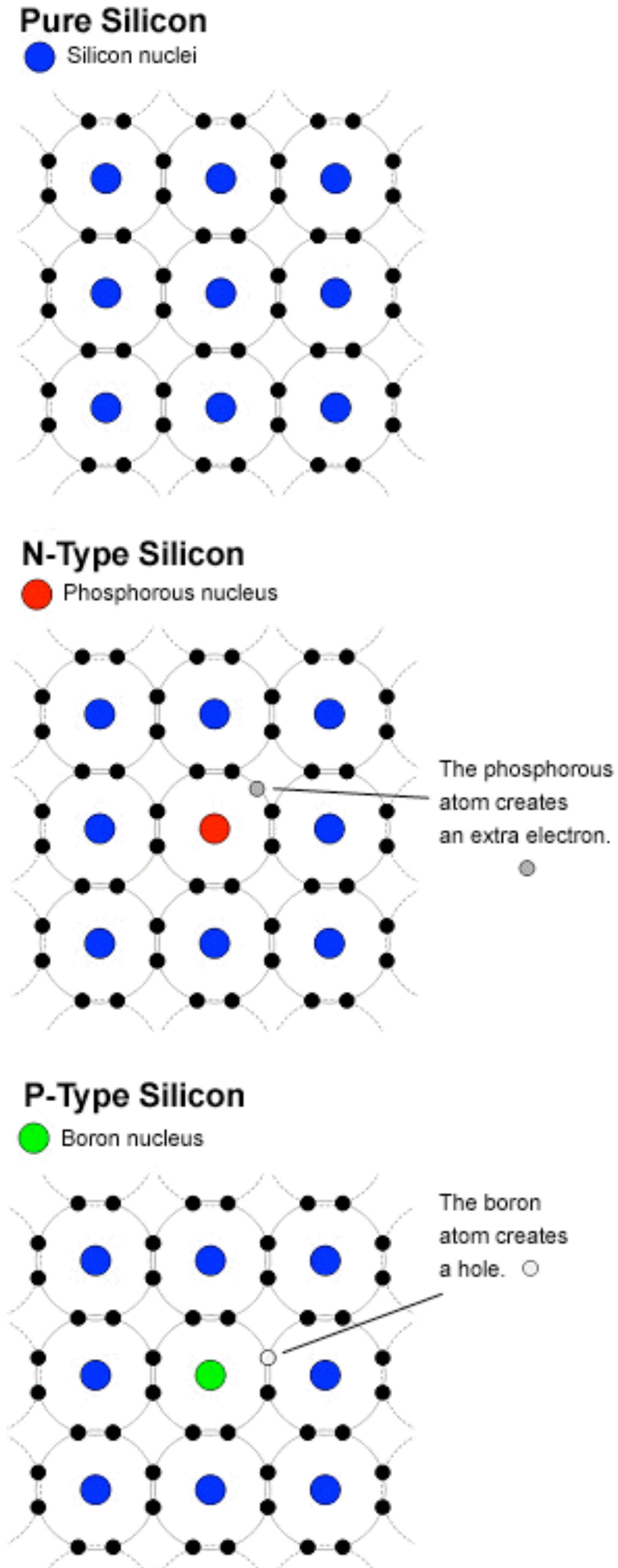
# All PV is similar in that:



Photovoltaic materials directly convert light into electricity.

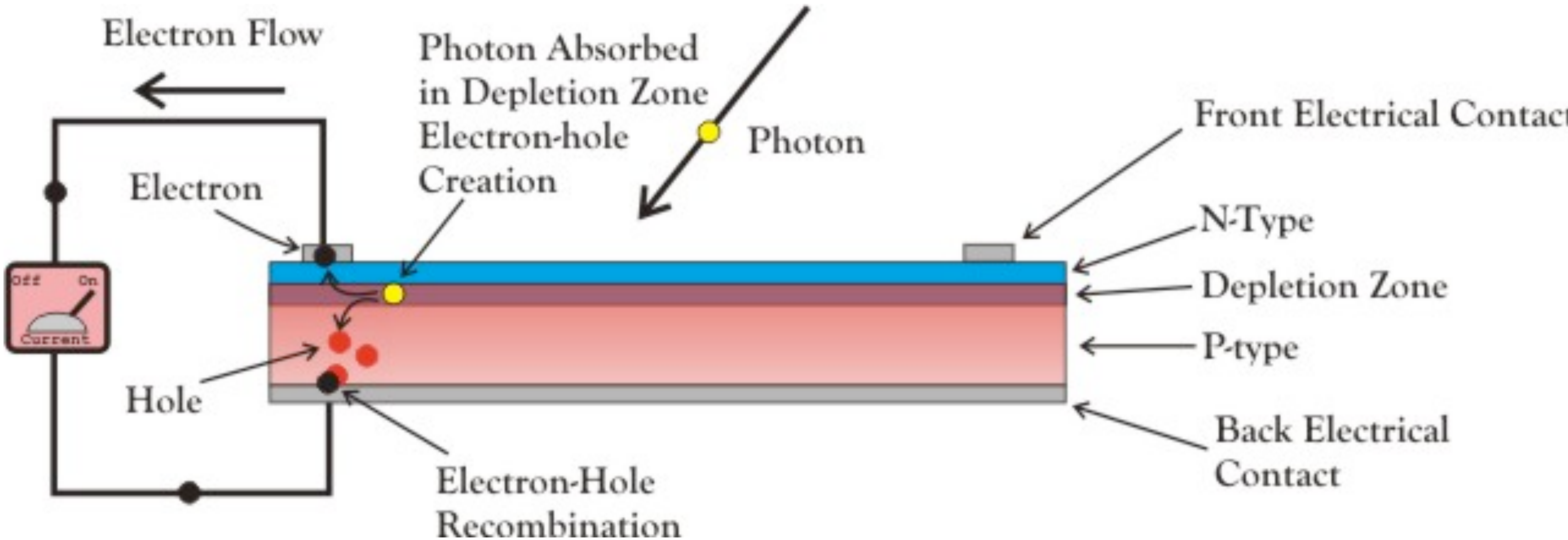
Most semiconductors (including LEDs) do this to some extent.

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




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

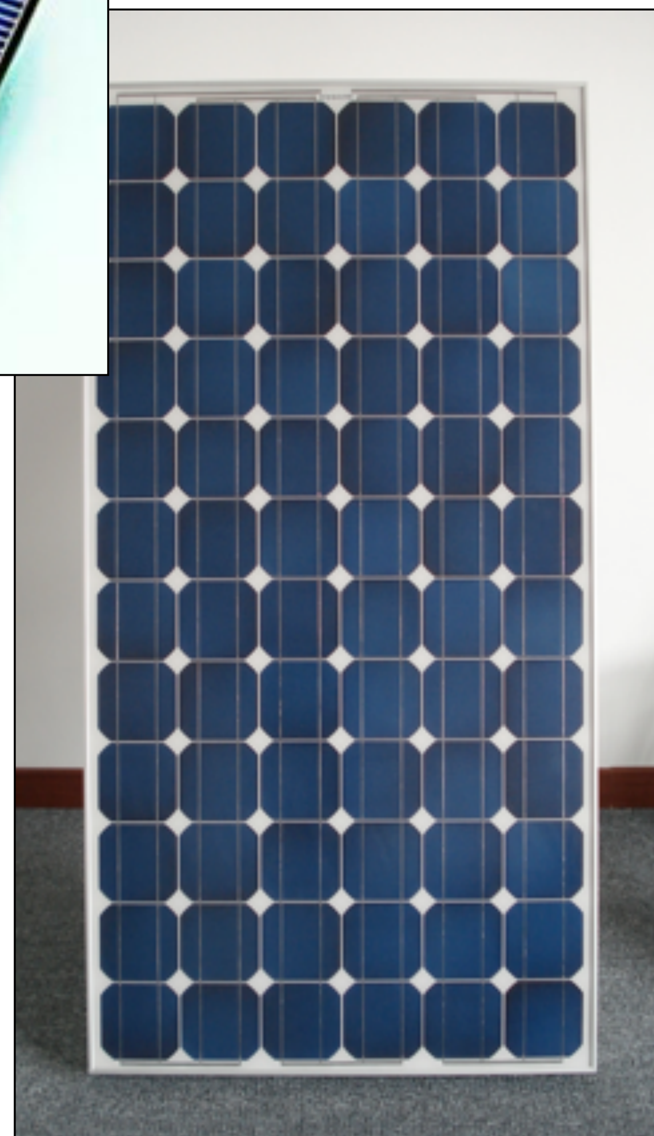
**Basics**



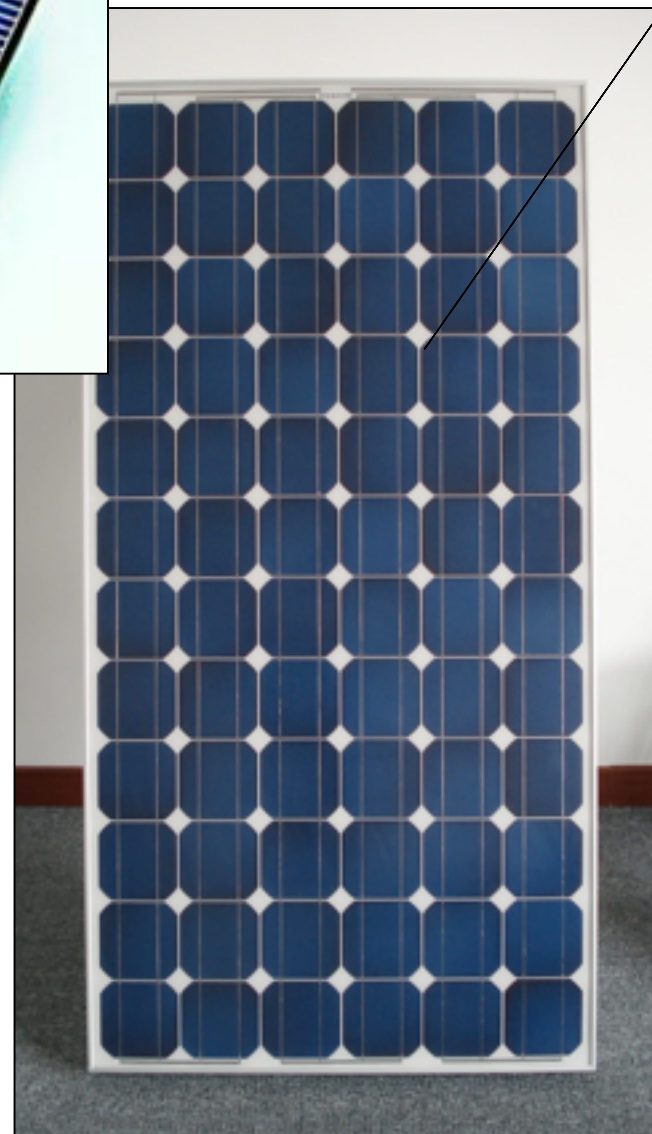

Source: http://www.imagesco.com/

**Basics**

**Cell:**
Single piece of PV material. Voltage dependent on semiconductor type, current on surface area.

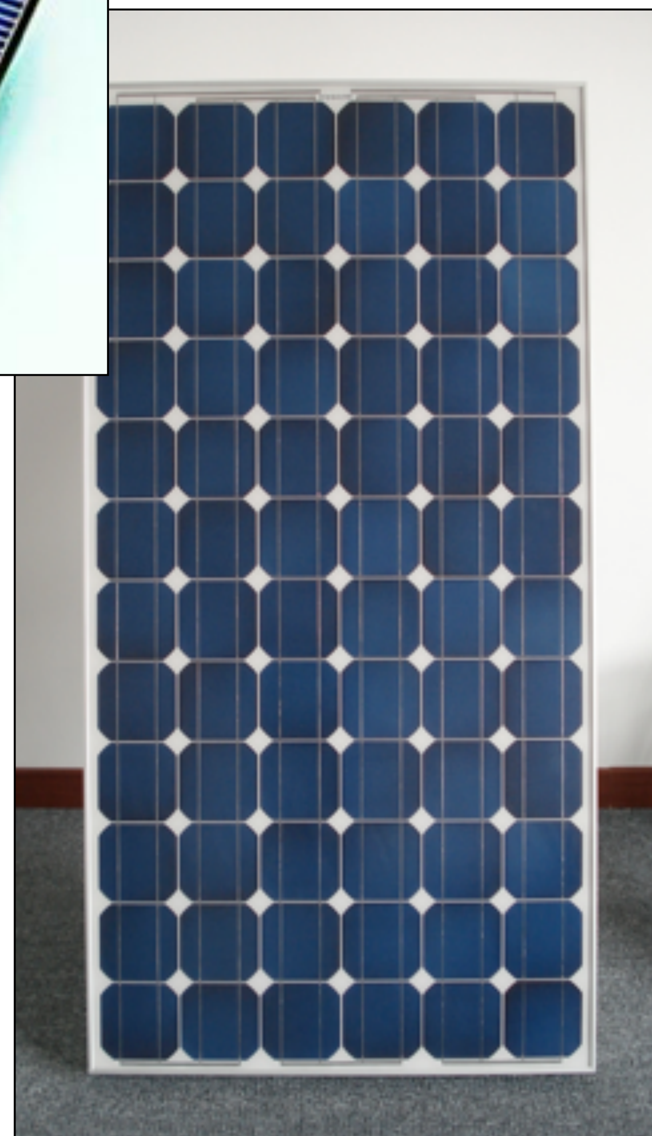


**Basics**



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

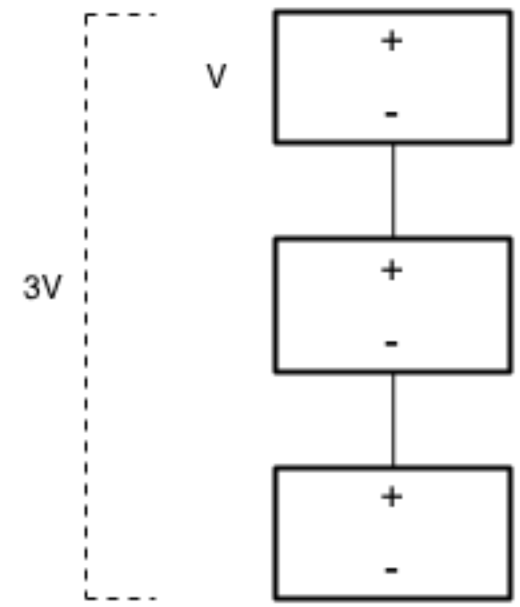
**Basics**



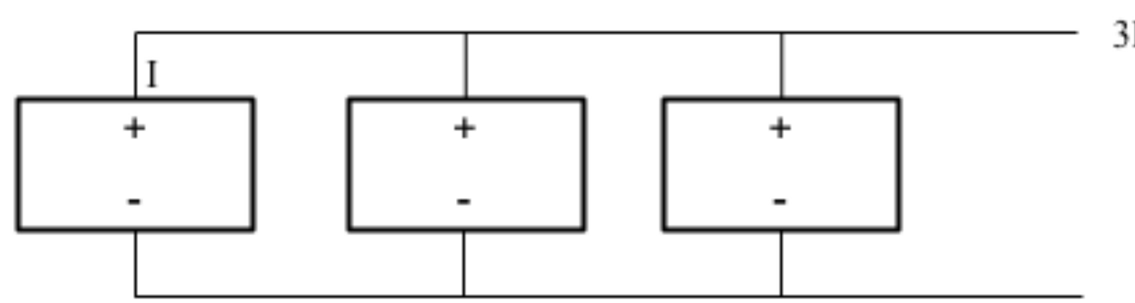
**Array:**
Multiple modules arranged in series and parallel groups to achieve desired voltage and current.

**Basics**

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




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



# 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

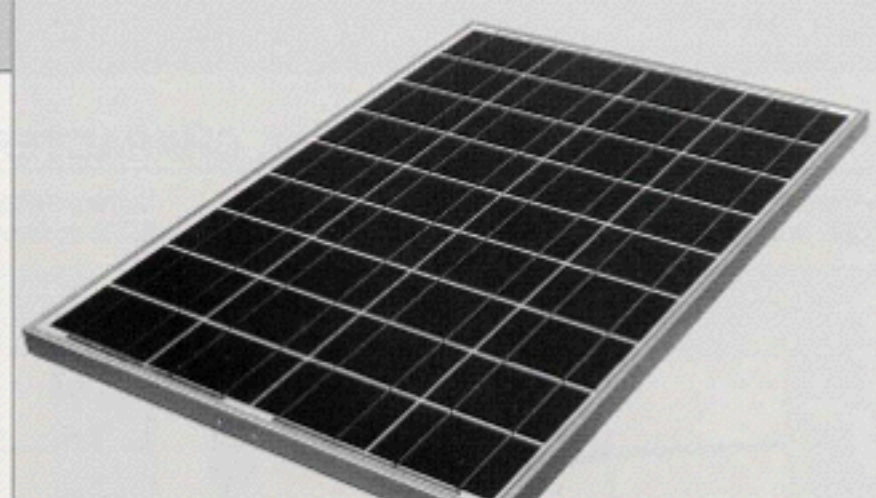
And of course, cost...

KYOCERA

# KC80

## HIGH EFFICIENCY MULTICRYSTAL PHOTOVOLTAIC MODULE

TYPICAL OUTPUT 80 Wp



### 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

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

| 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

SP

■ Electrical Specifications

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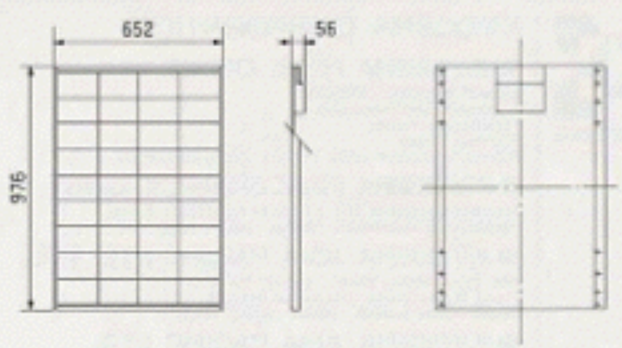



Basics

# DIFFERENCES

# Different types of PV are distinguished by:

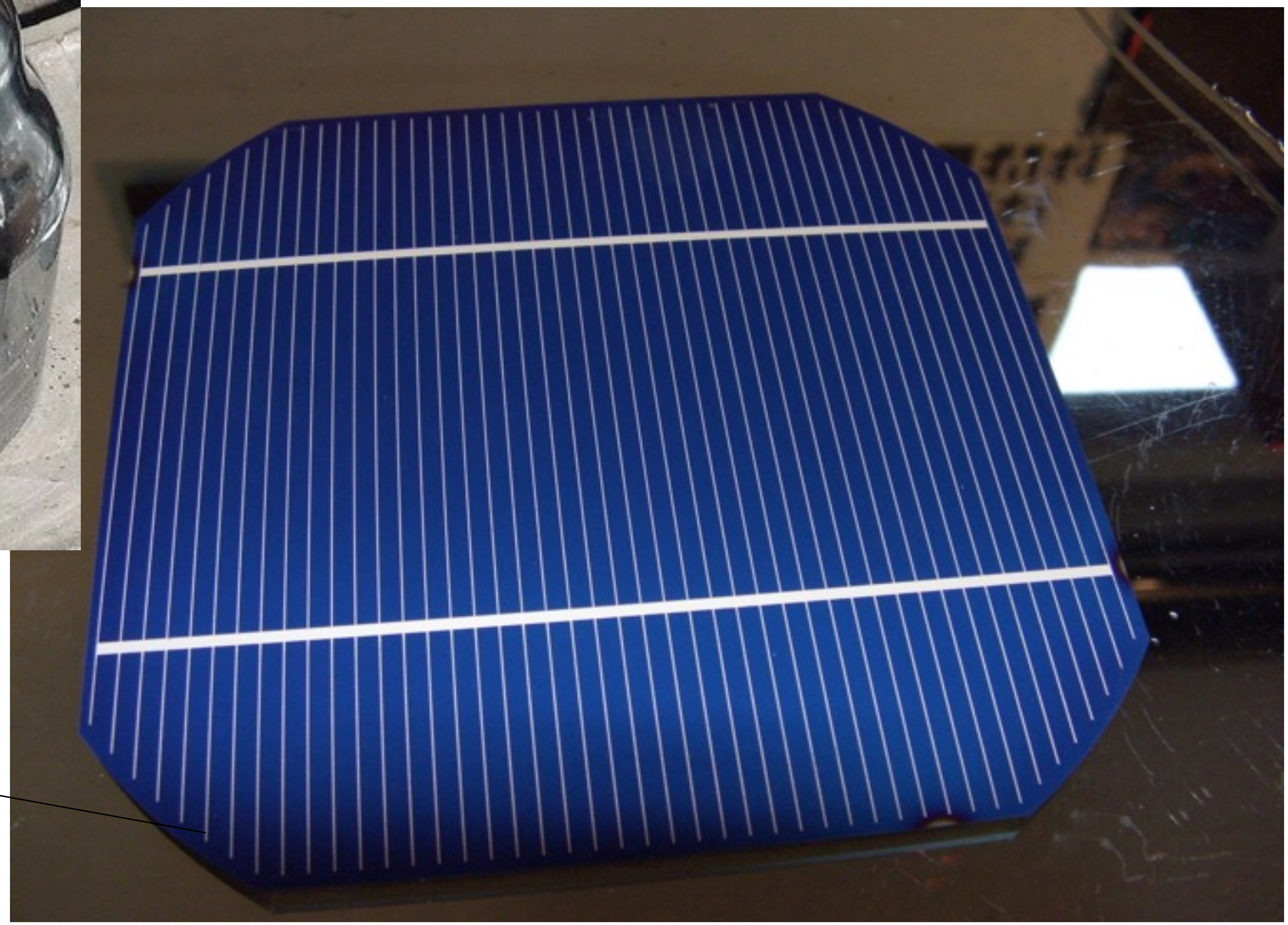
- Form of material (e.g. crystalline or thin film)

- 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**.

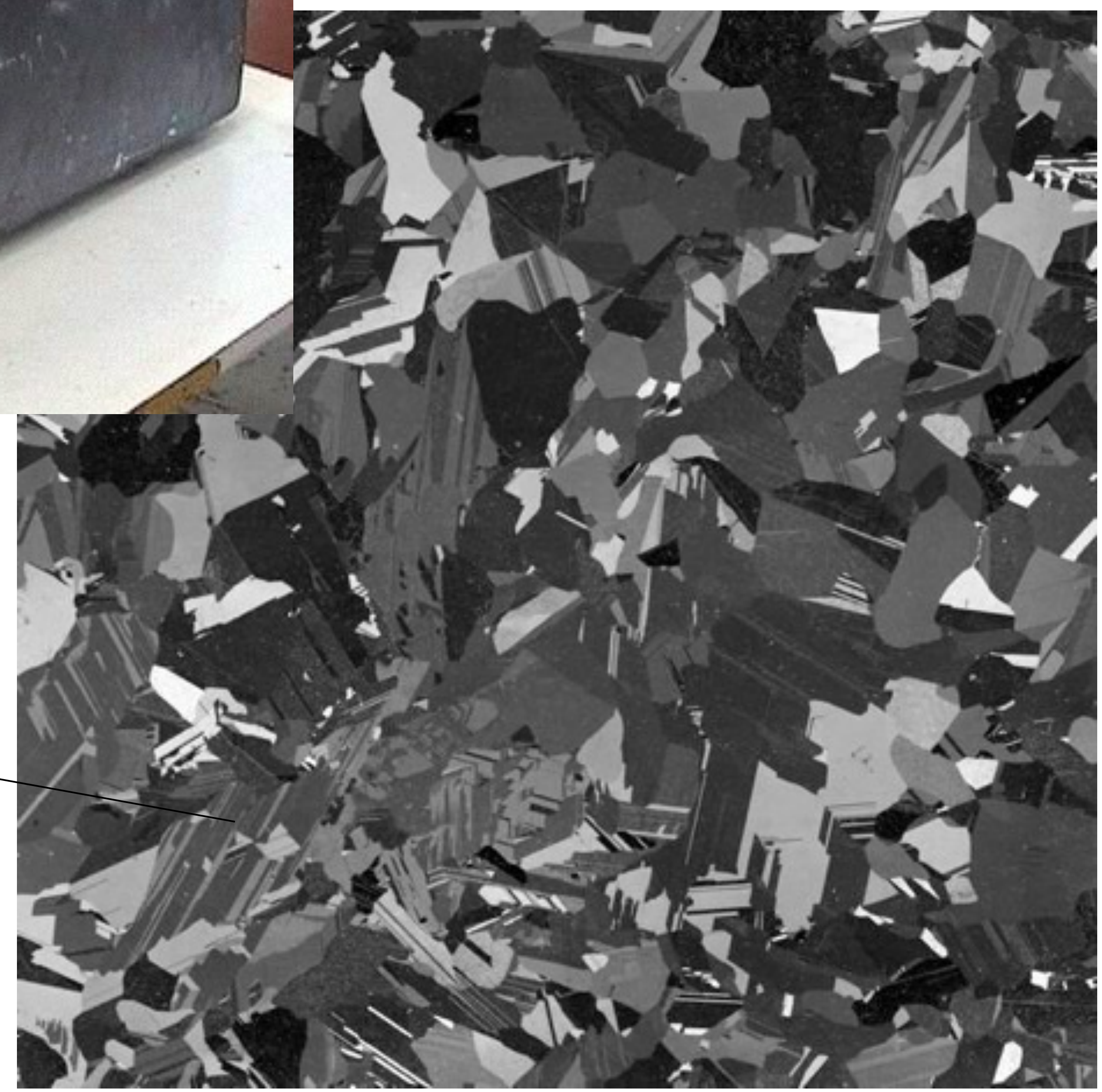
Monocrystalline Si ingot and cell



Circa 300 um thick
Si layer

**Differences**

Polycrystalline Si
ingot and cell



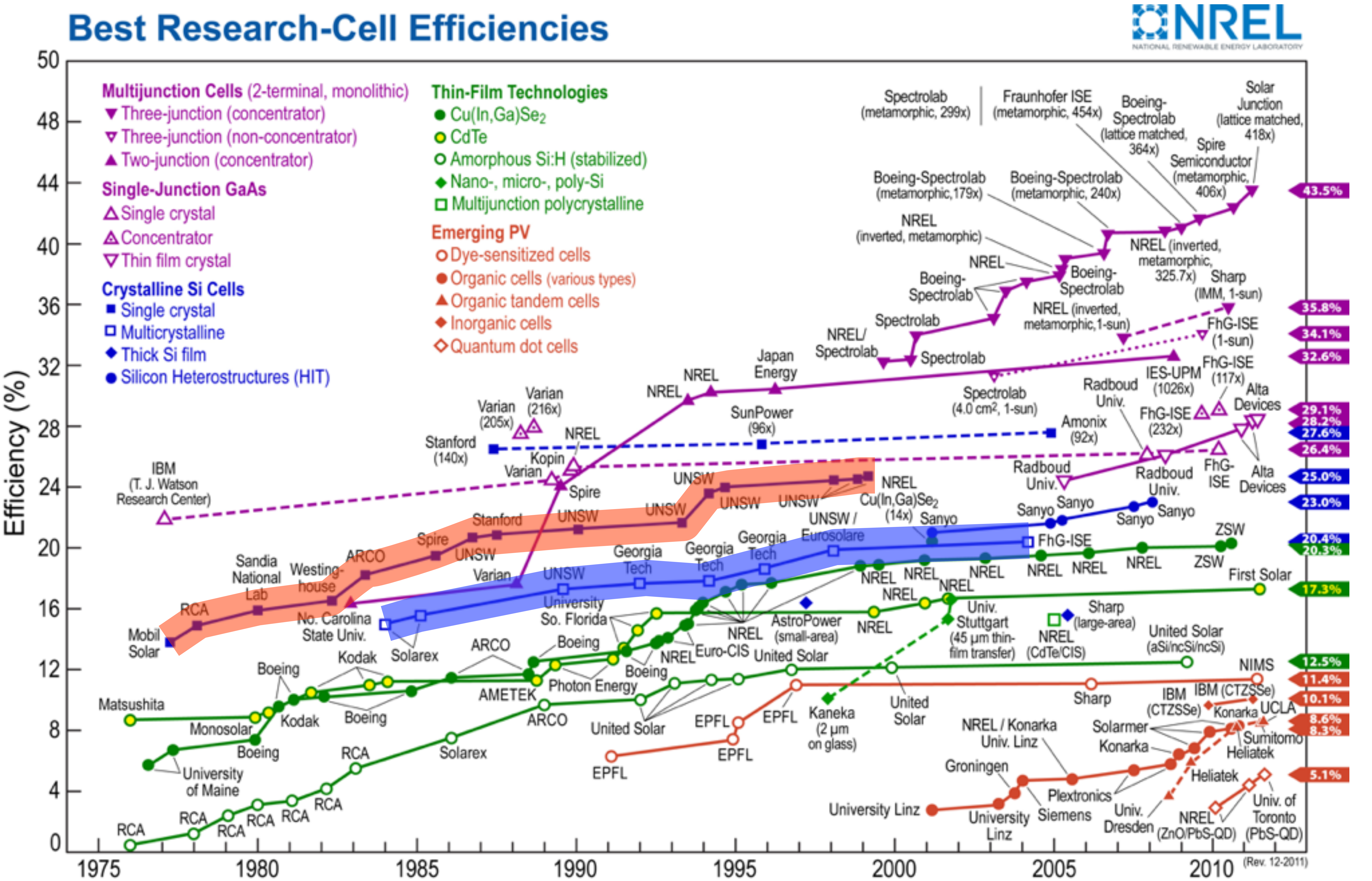
Circa 300 um thick
Si layer

**Differences**

Amorphous or thin film PV

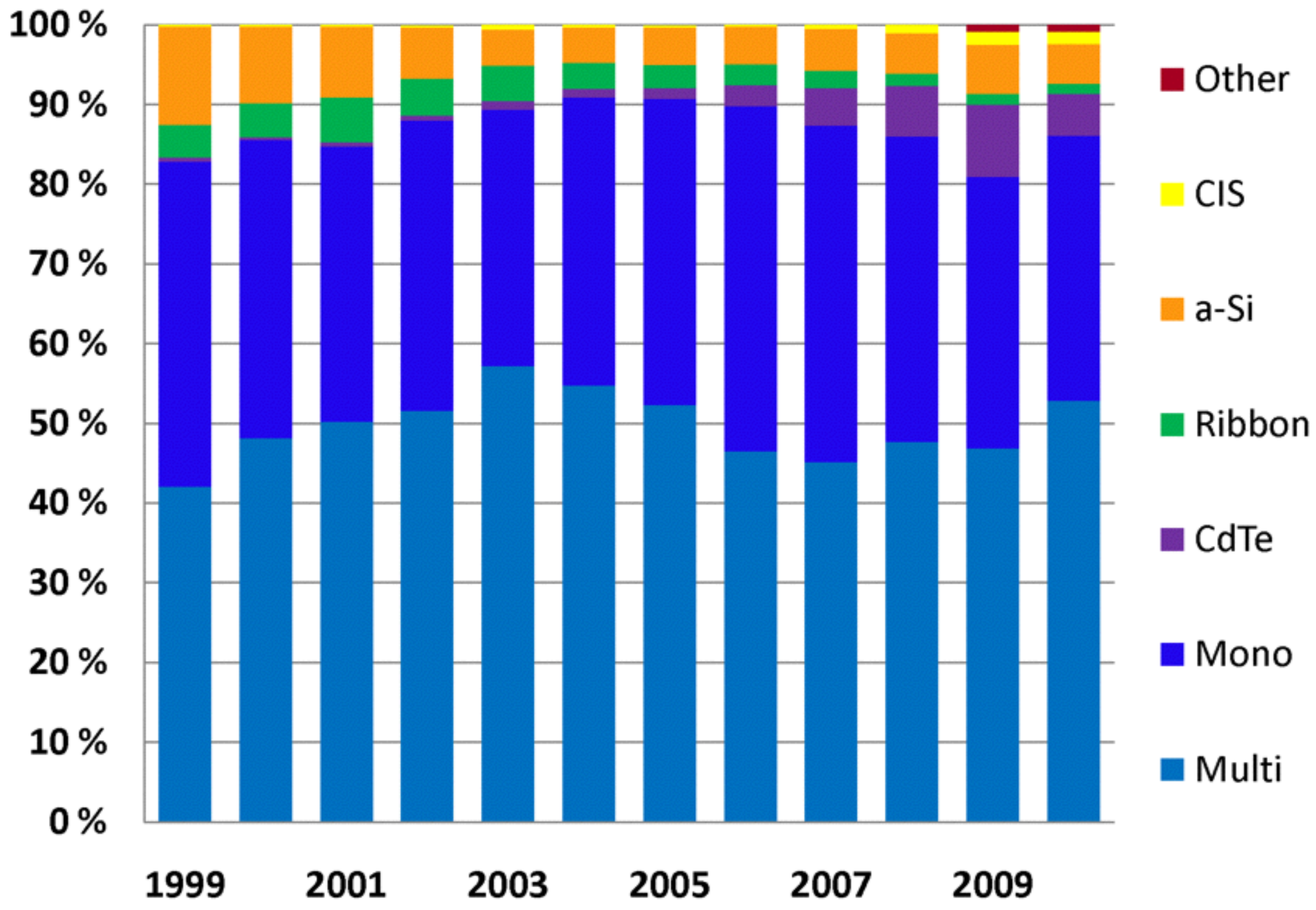
Circa 30 um thick
Si layer

**Differences**




Source: DOE NREL

**Differences**




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:

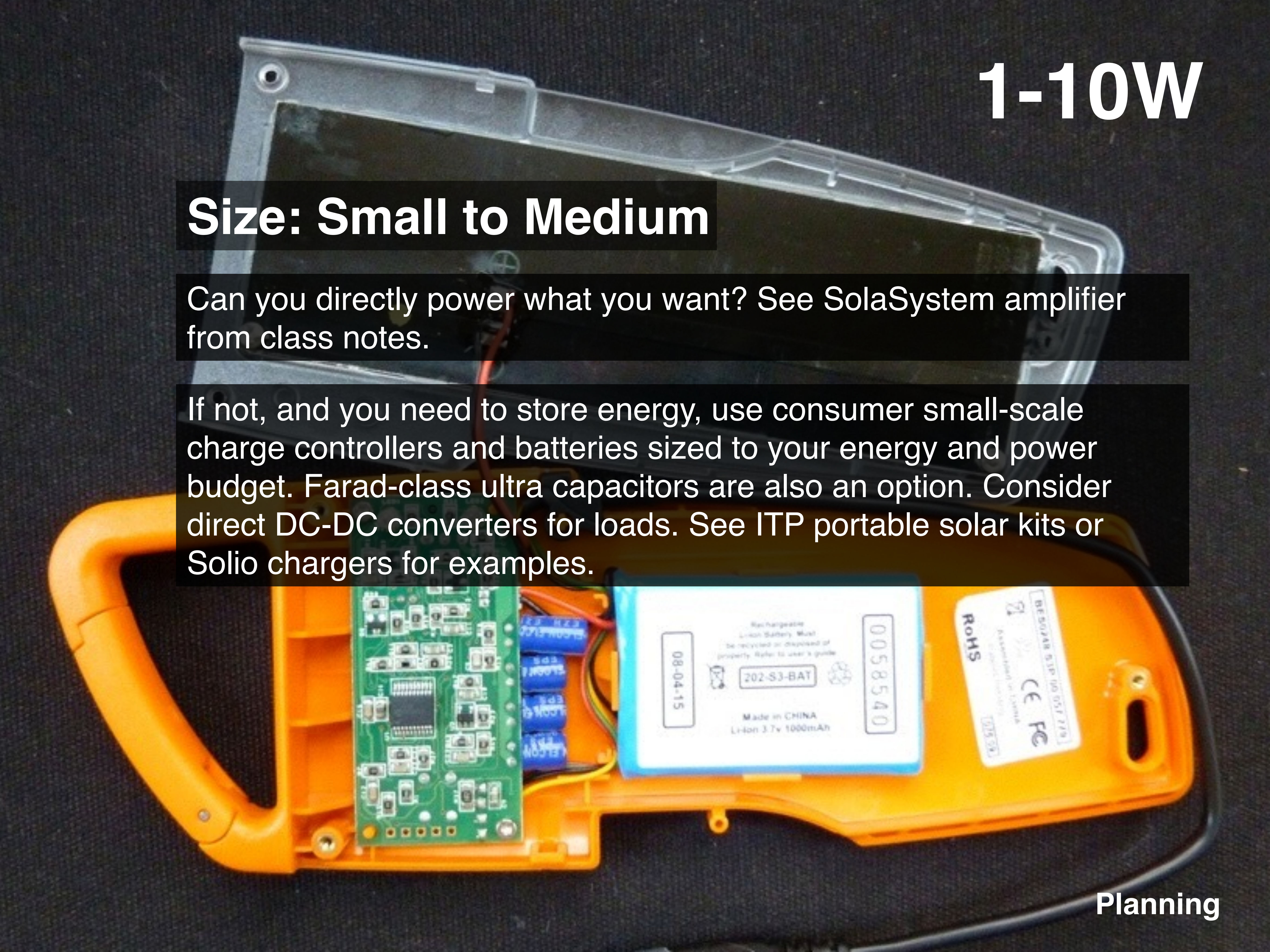
Planning a solar powered project

# <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.

# >10W

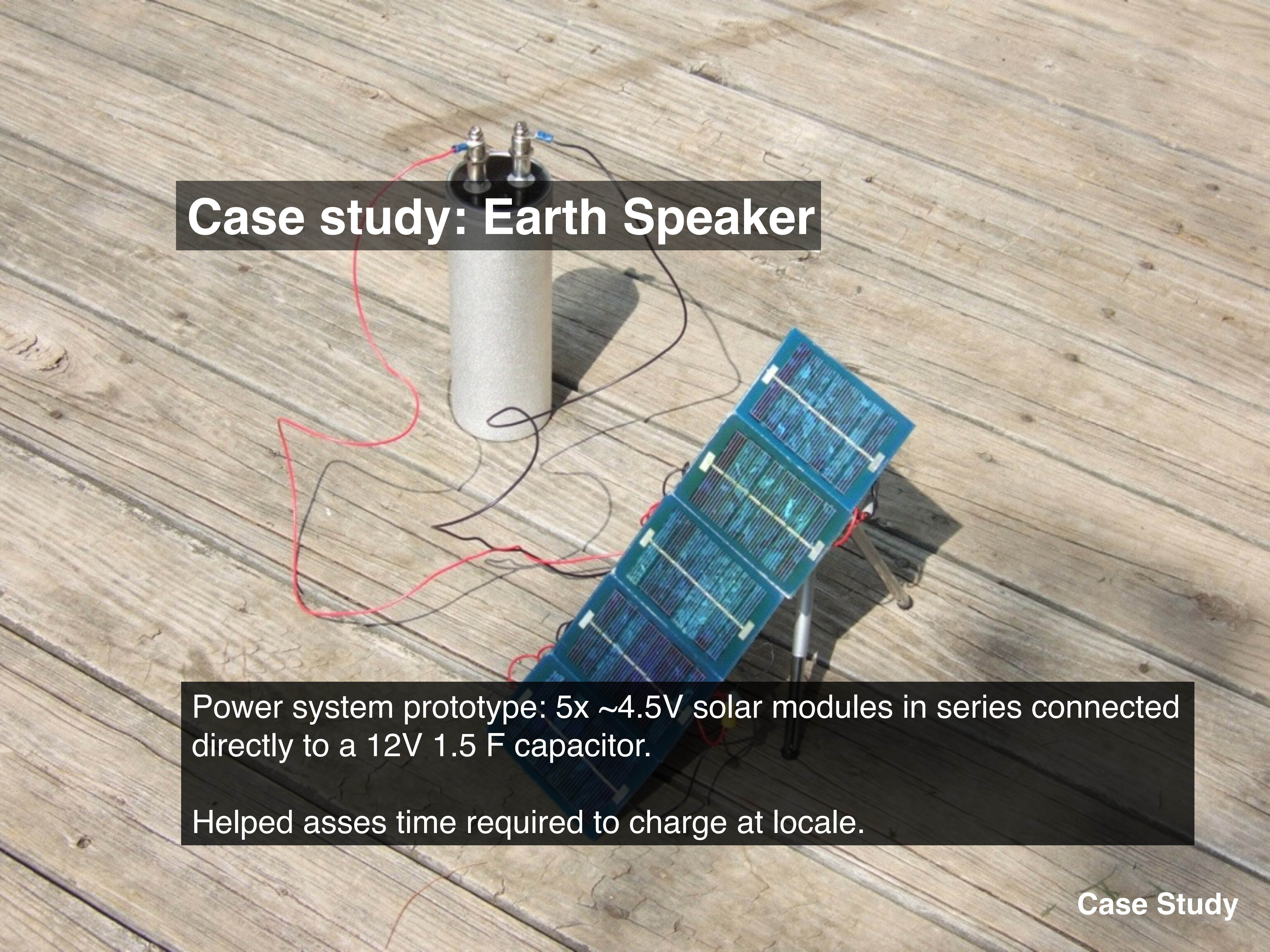
## Size: Medium to large

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.

# CASE STUDY

# Case study: Earth Speaker

Solar powered sound installation



# Case study: Earth Speaker

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

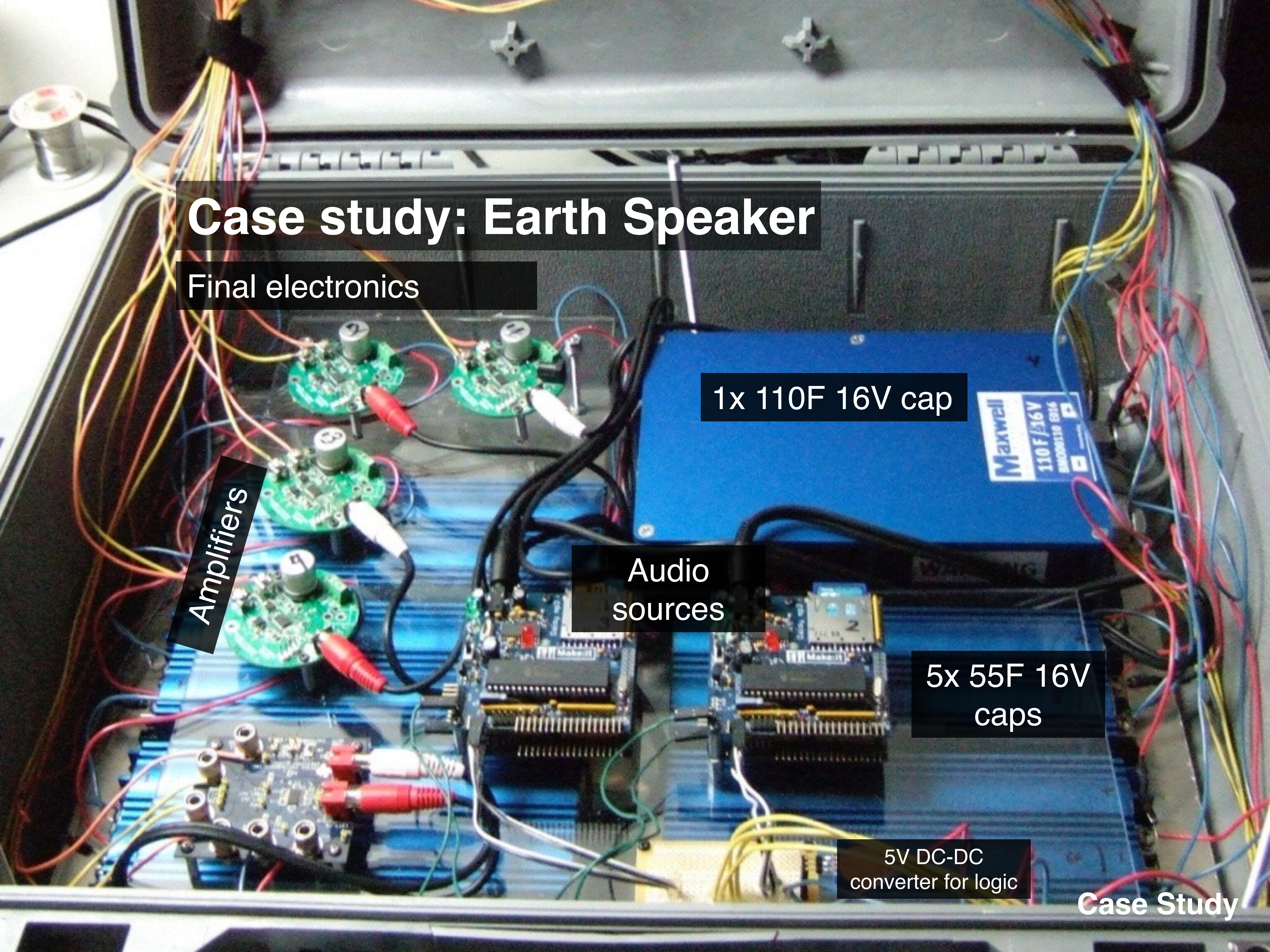
Helped asses time required to charge at locale.

# Case study: Earth Speaker

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

# Case study: Earth Speaker

Final electronics



What does this do to electricity use?