ENERGY

itp CAMP

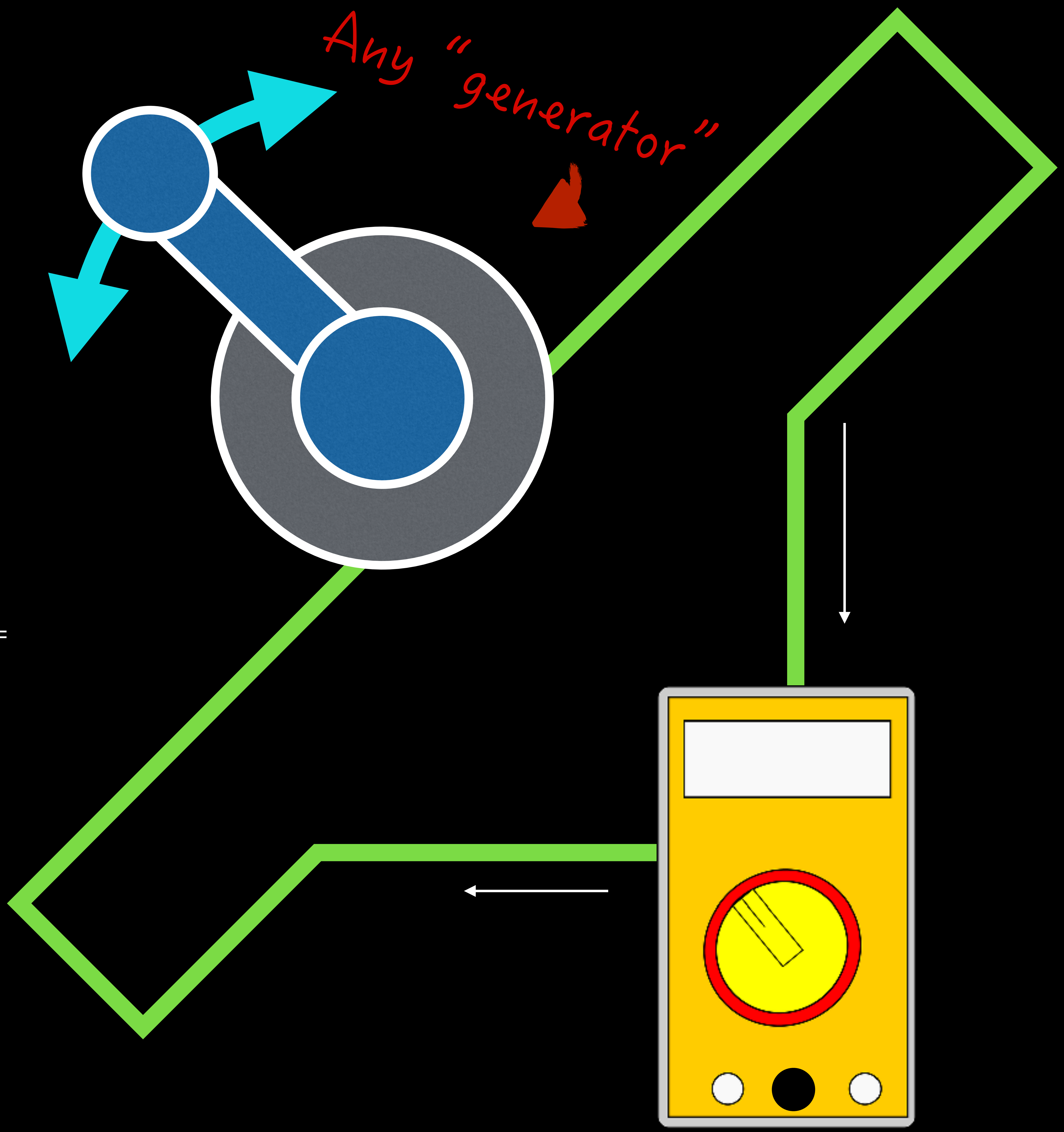
14 week course notes:
fddrsn.net/teaching/energy

Review

Conclusions:

- Energy (joule or watt-hour) is important, but surprisingly tricky to pin down in everyday terms.
- Power (watt) is the rate of energy conversion *(informally: "consumption")*.
- Power is more familiar from every day life, especially electronics.
- Power = Energy/Time, and
- Energy = Power x Time

Review



Human
2000 kilocalories / 1 day =
~100 Watts

1W (electric) =
1V * 1A

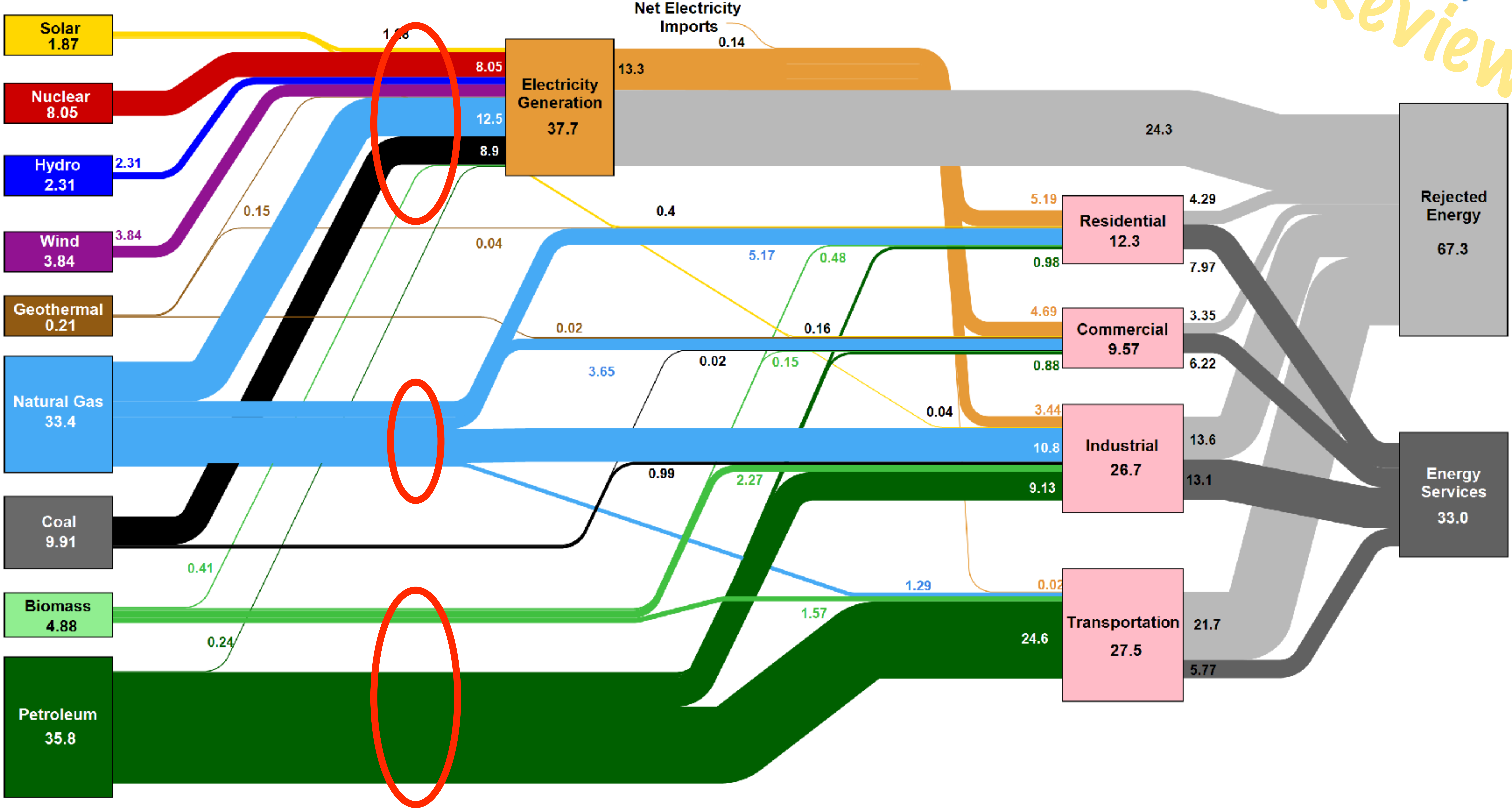
We can measure

Open Circuit Voltage

and

Short Circuit Current

Estimated U.S. Energy Consumption in 2022: 100.3 Quads



Source: LLNL July, 2023. Data is based on DOE/EIA SEDS (2021). 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 consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity 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 0.65% for the residential sector, 0.65% for the commercial sector, 0.49% for the industrial sector, and 0.21% for the transportation sector. Totals may not equal sum of components due to independent Rounding. LLNL-MI-410527


Energy directly from the sun, powering a
GLOBAL TRANSFORMATION
happening right now

~1GW TOTAL GLOBAL INSTALLED SOLAR IN 2000

~1GW OF NEW SOLAR INSTALLED EVERY 3 DAYS IN 2019

"Solar additions totaled 119 gigawatts globally in 2019" - Bloomberg Green

~1GW OF NEW SOLAR PROJECTED EVERY 1.8 DAYS IN 2022

Solar additions projected to exceed 200GW in 2022*

*Reports list 220 - 260GW for 2022

SHOULD EXCEED 1TW SOON

*1TW global capacity achieved in April 2022

https://www.bloomberg.com/news/articles/2020-09-01/the-world-added-more-solar-wind-than-anything-else-last-year

https://www.solarpowereurope.org/insights/market-outlooks/global-market-outlook-for-solar-power-2022

https://www.pv-magazine.com/2022/12/23/global-solar-capacity-additions-hit-268-gw-in-2022-says-bnef/

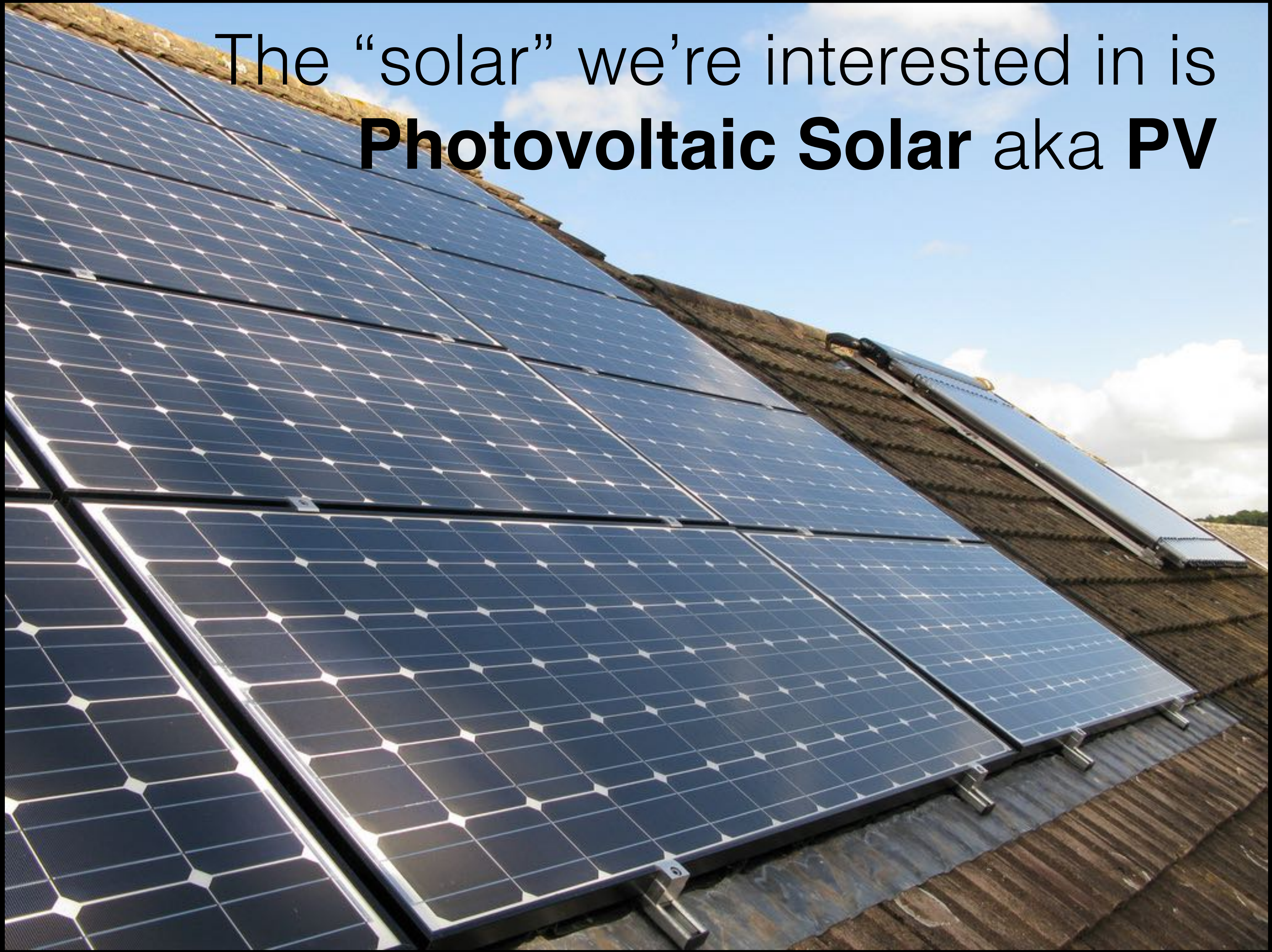
"THE FIRST TERAWATT OF SOLAR TOOK 70 YEARS. THE NEXT WILL TAKE 3."

Global total: 1.6TW 2023

https://iea-pvps.org/snapshot-reports/snapshot-2024/

- Pierre Verlinden, solar pioneer and former chief scientist at Trina Solar

https://www.pv-magazine.com/


The “solar” we’re interested in is
Photovoltaic Solar aka **PV**

(Not “Concentrating Solar Power”, “Solar Thermal”, etc…)

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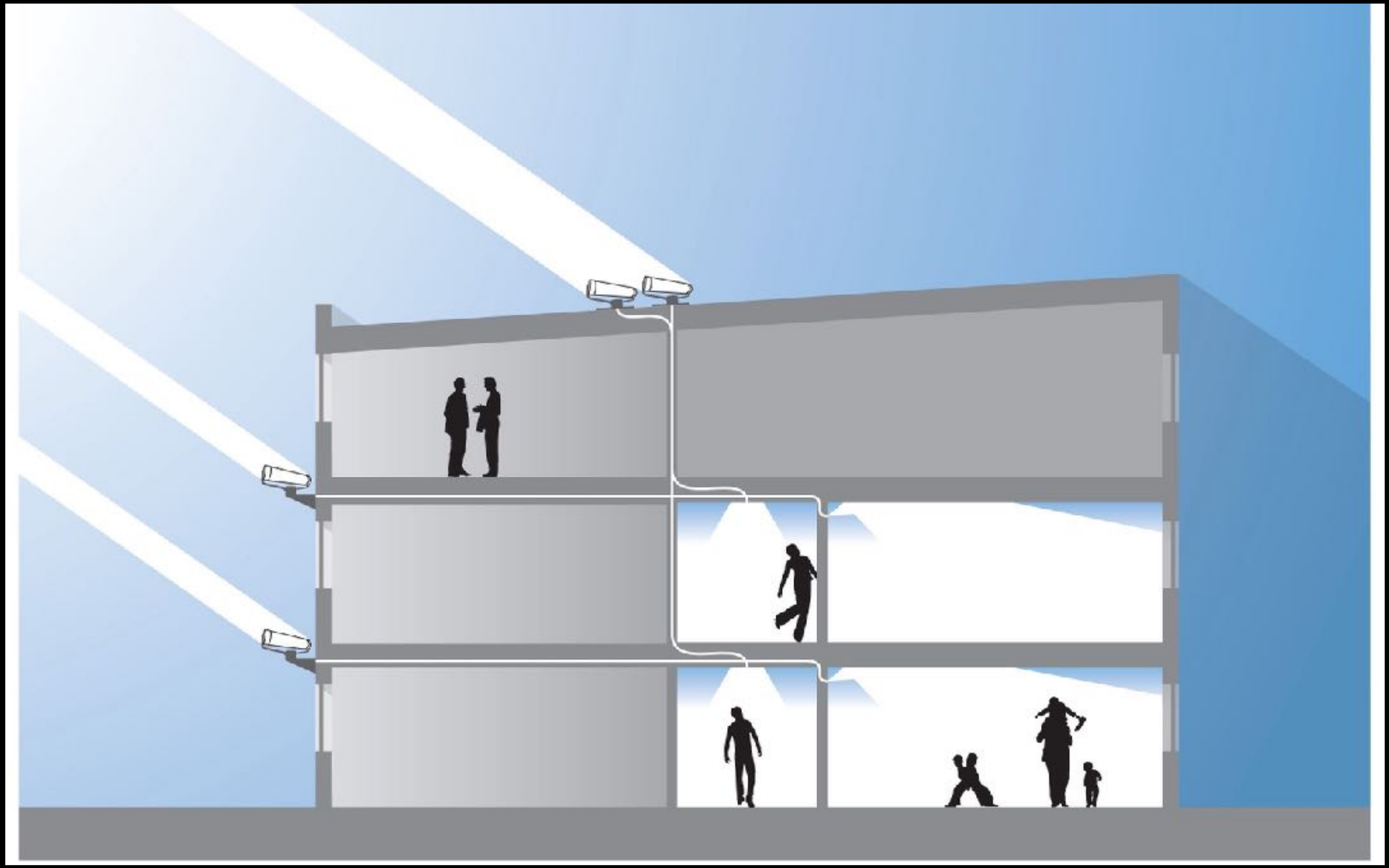
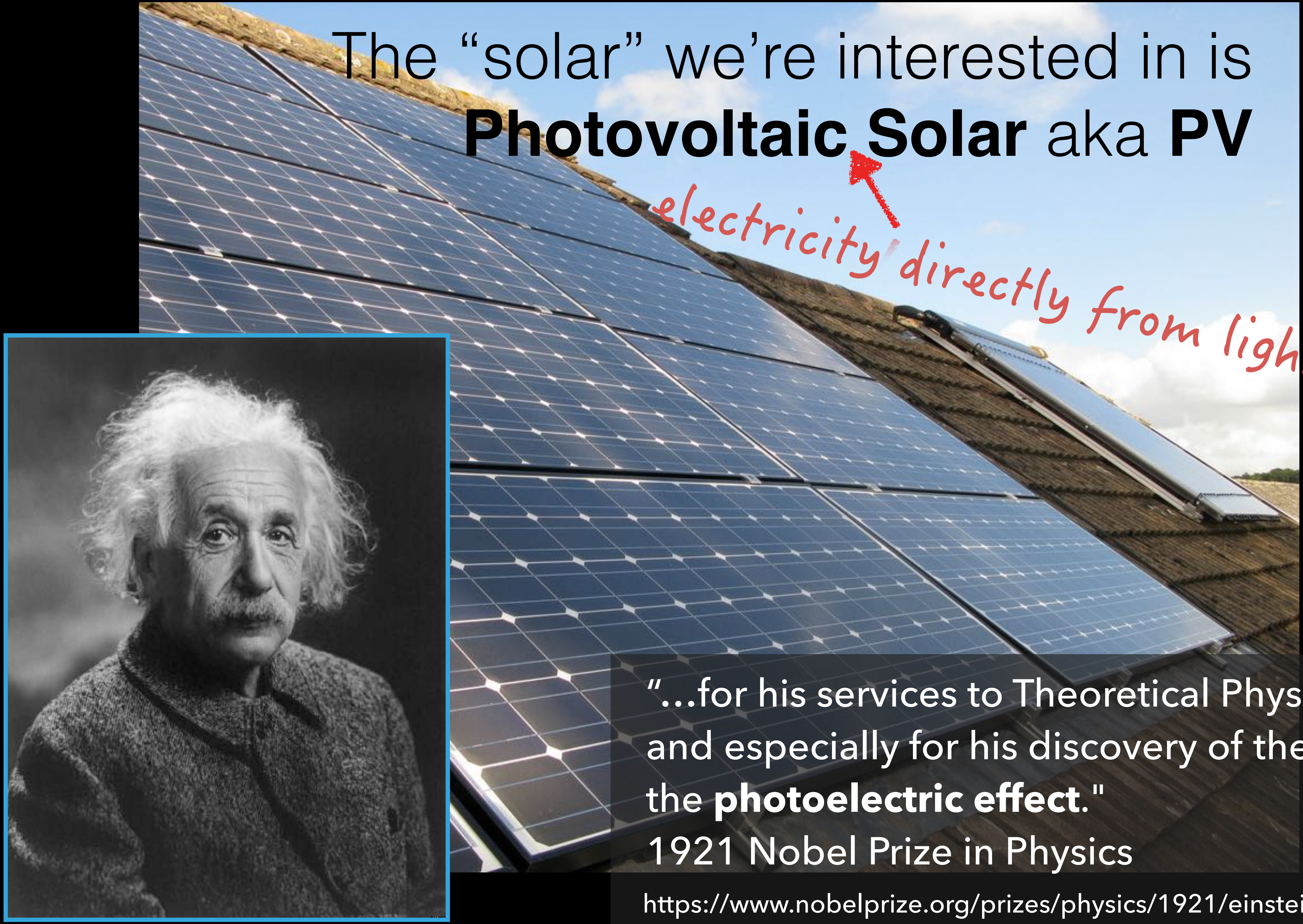


Parans

(Not indirect solar lighting, heliostats, etc…)

The "solar" we're interested in is
Photovoltaic Solar aka **PV**

electricity directly from light



"…for his services to Theoretical Physics, and especially for his discovery of the law of the **photoelectric effect**."
1921 Nobel Prize in Physics

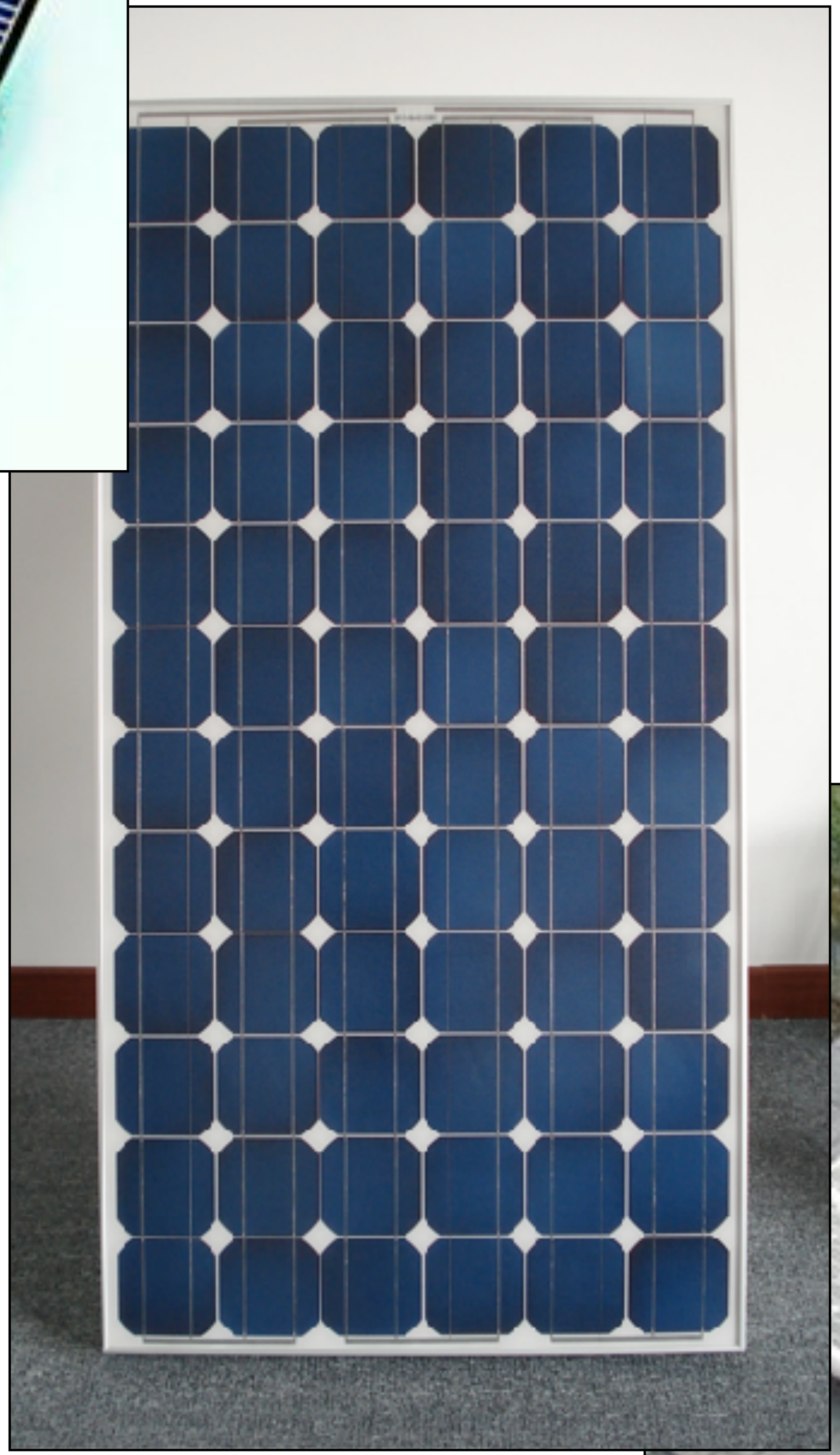
https://www.nobelprize.org/prizes/physics/1921/einstein/facts/

THE SAME STUFF!!!

Small and large commercial applications

Cell



Module: group of cells

Array: group of modules

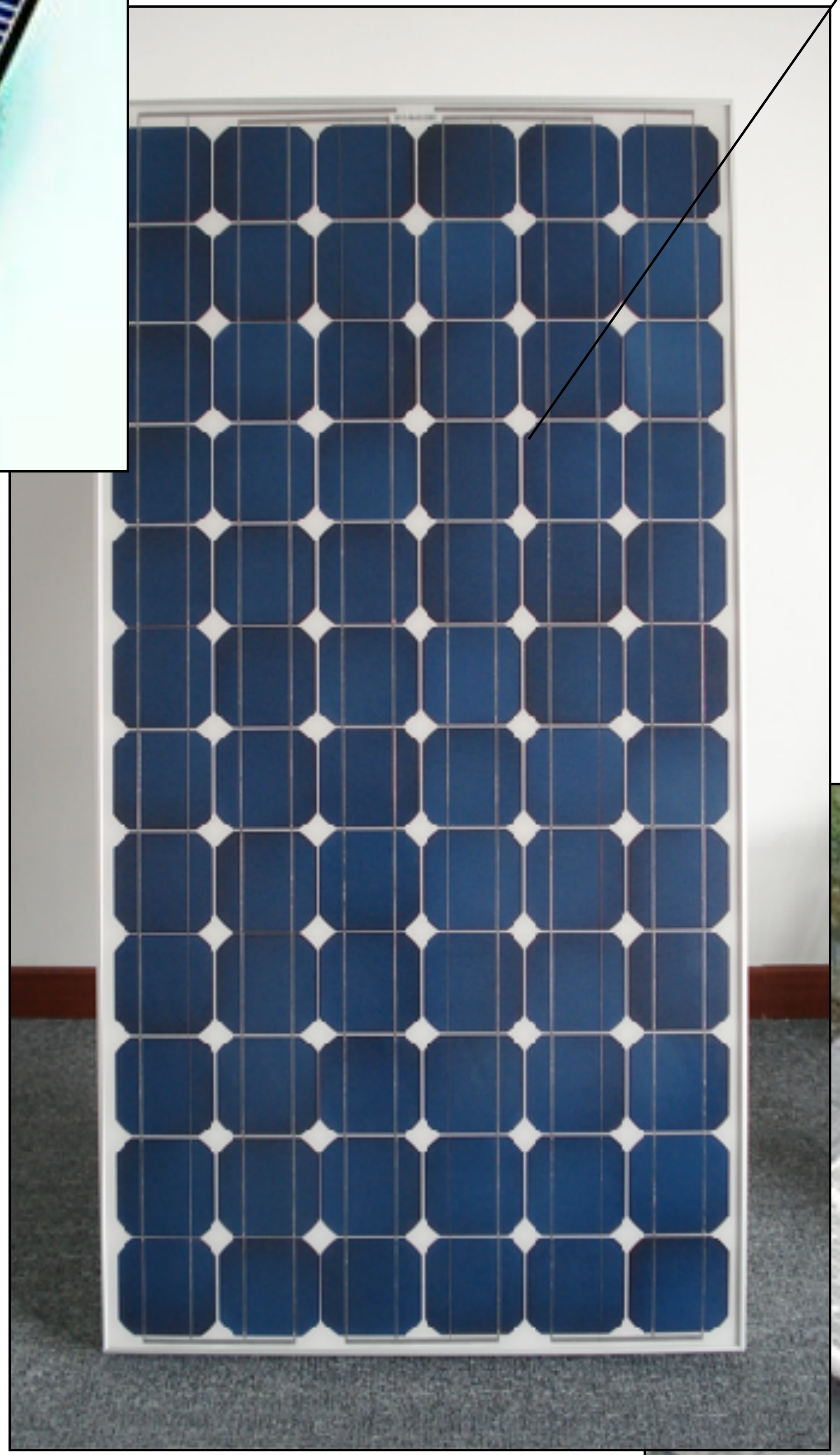
Cell:
Single piece of PV material.

Voltage dependent on semiconductor type

Current dependent on surface area.

Basics

Cell



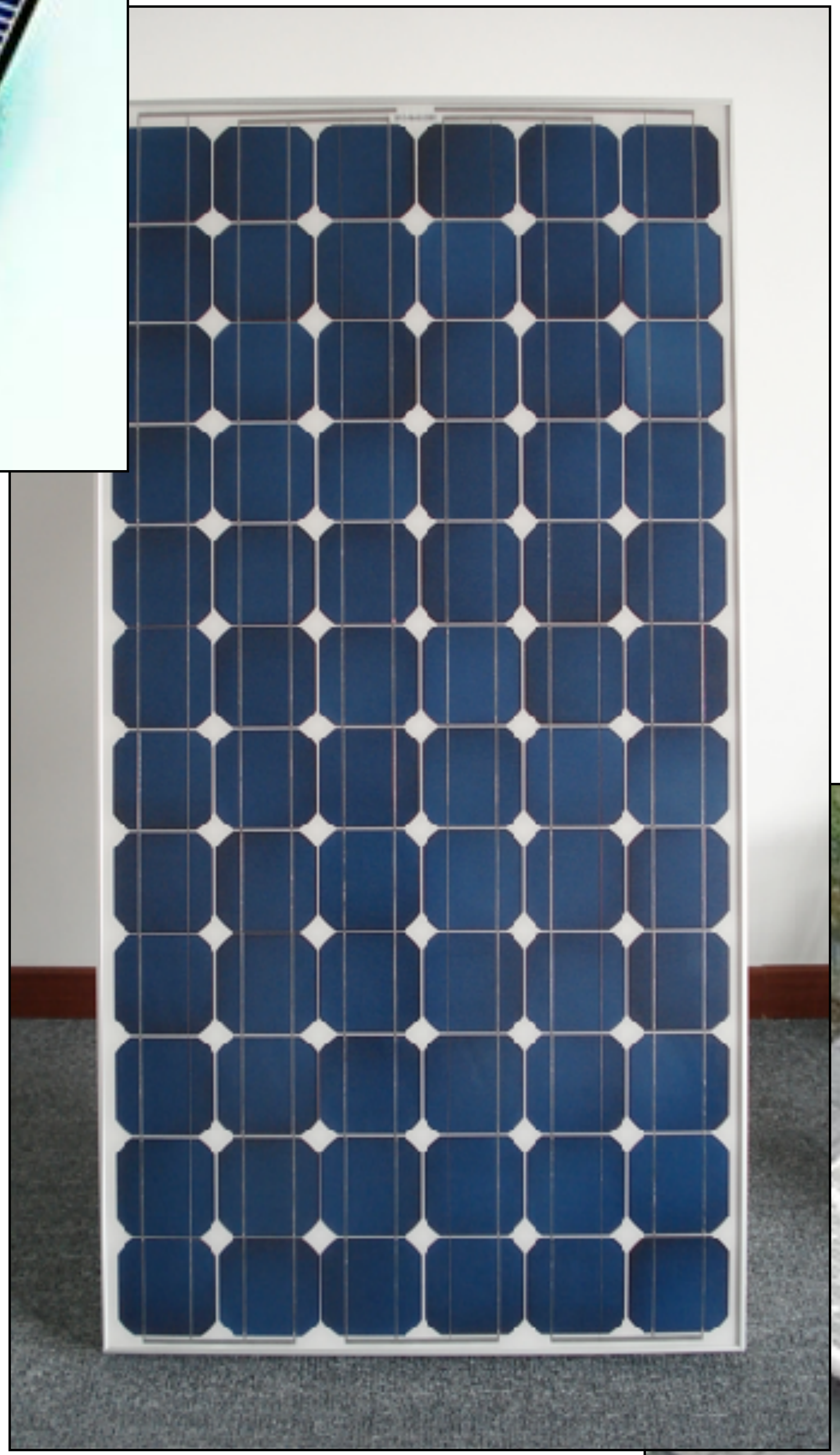
Module: group of cells

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

Array: group of modules

Basics

Cell



Module: group of cells

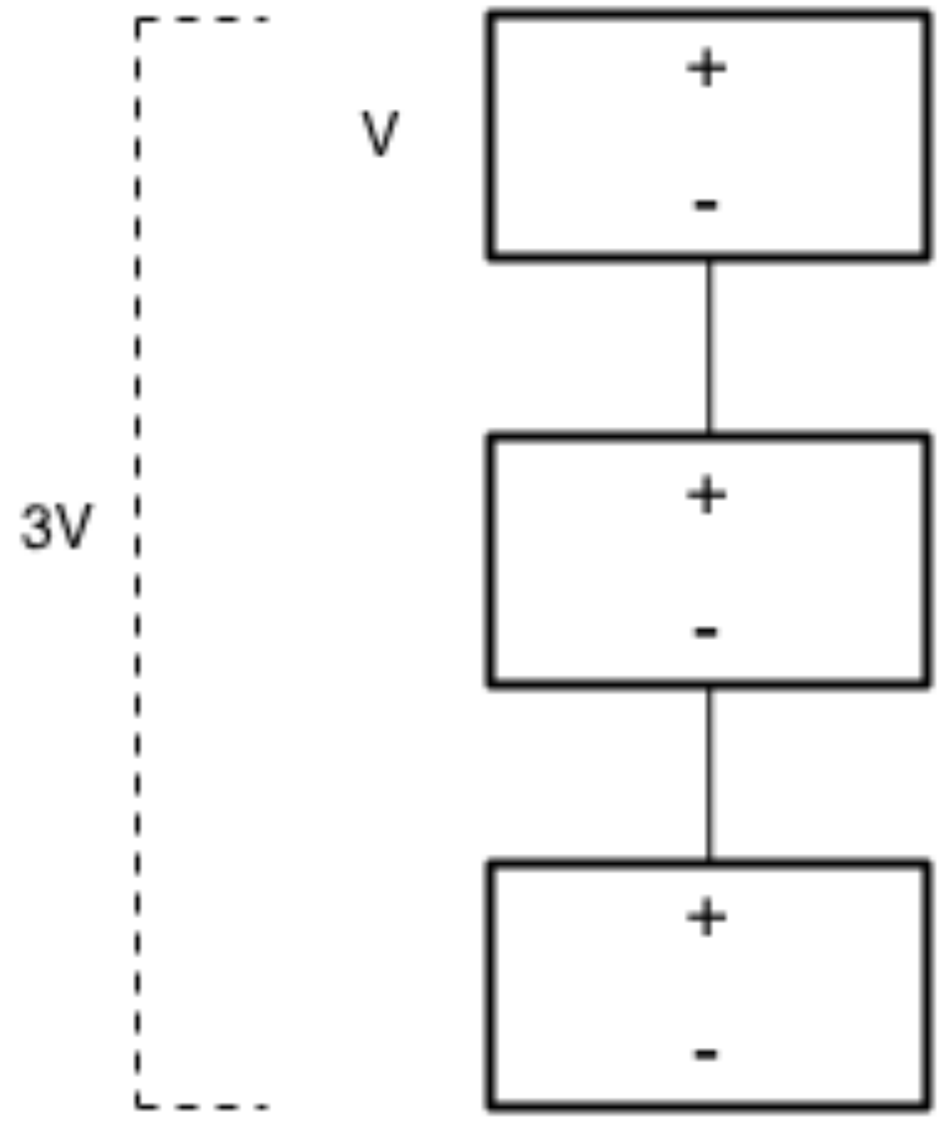
Array:
Multiple modules arranged in series and parallel groups to achieve desired voltage and current.

Array: group of modules

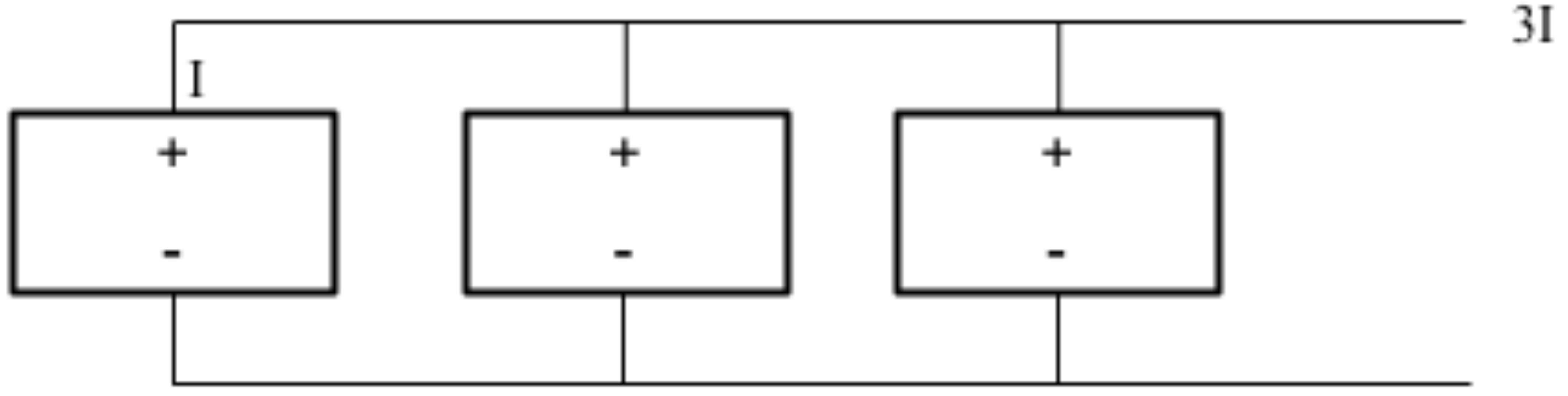
Basics

(Cell or module)

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



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



Basics

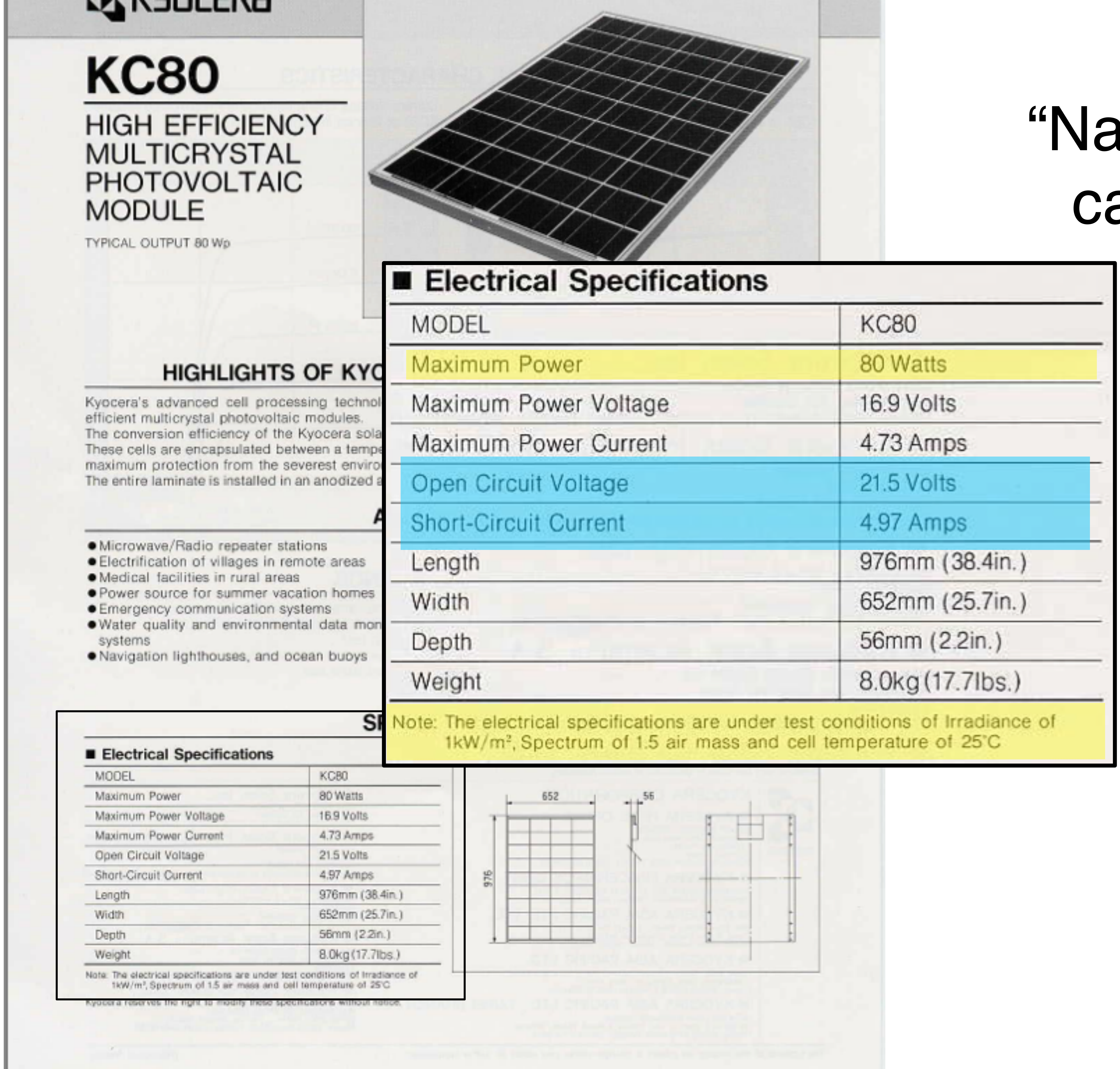
Metrics we care about are:

Rated performance
- “Watts-peak” under standardized conditions (AM1.5 1000W/m^2)

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

Short Circuit (SC) Current
- current through short circuit

And of course, cost:
Cost / Watt



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

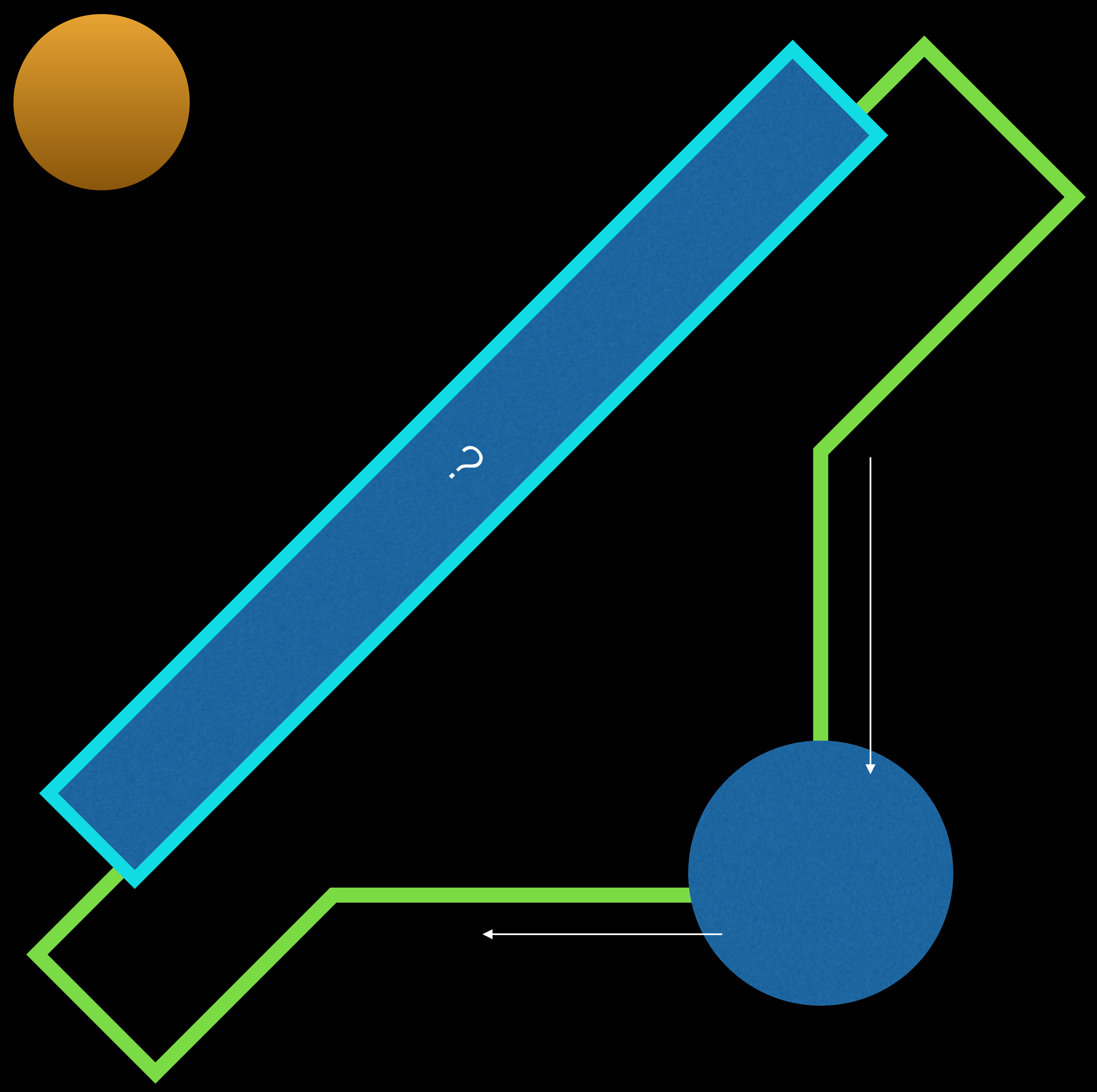
- Microwave/Radio repeater stations
- Electrification of villages in remote areas
- Medical facilities in rural areas
- Power source for summer vacation homes
- Emergency communication systems
- Water quality and environmental data mon systems
- Navigation lighthouses, and ocean buoys

■ Electrical Specifications

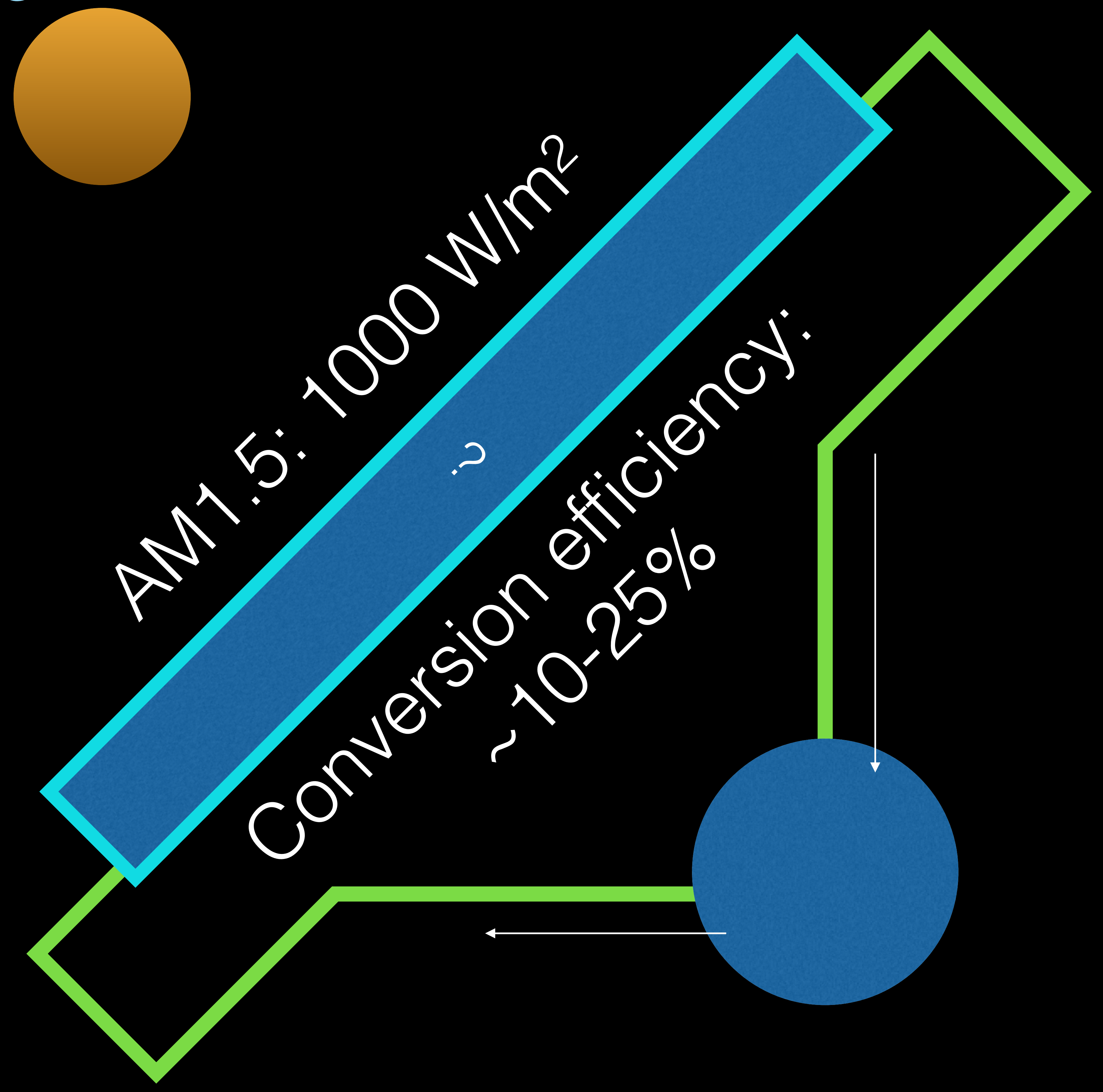
MODEL	KC80
Maximum Power	80 Watts
Maximum Power Voltage	16.9 Volts
Maximum Power Current	4.73 Amps
Open Circuit Voltage	21.5 Volts
Short-Circuit Current	4.97 Amps
Length	976mm (38.4in.)
Width	652mm (25.7in.)
Depth	56mm (2.2in.)
Weight	8.0kg (17.7lbs.)

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

“Nameplate capacity” = 80W



Solar constant at Earth orbit:
1367 W/m^2



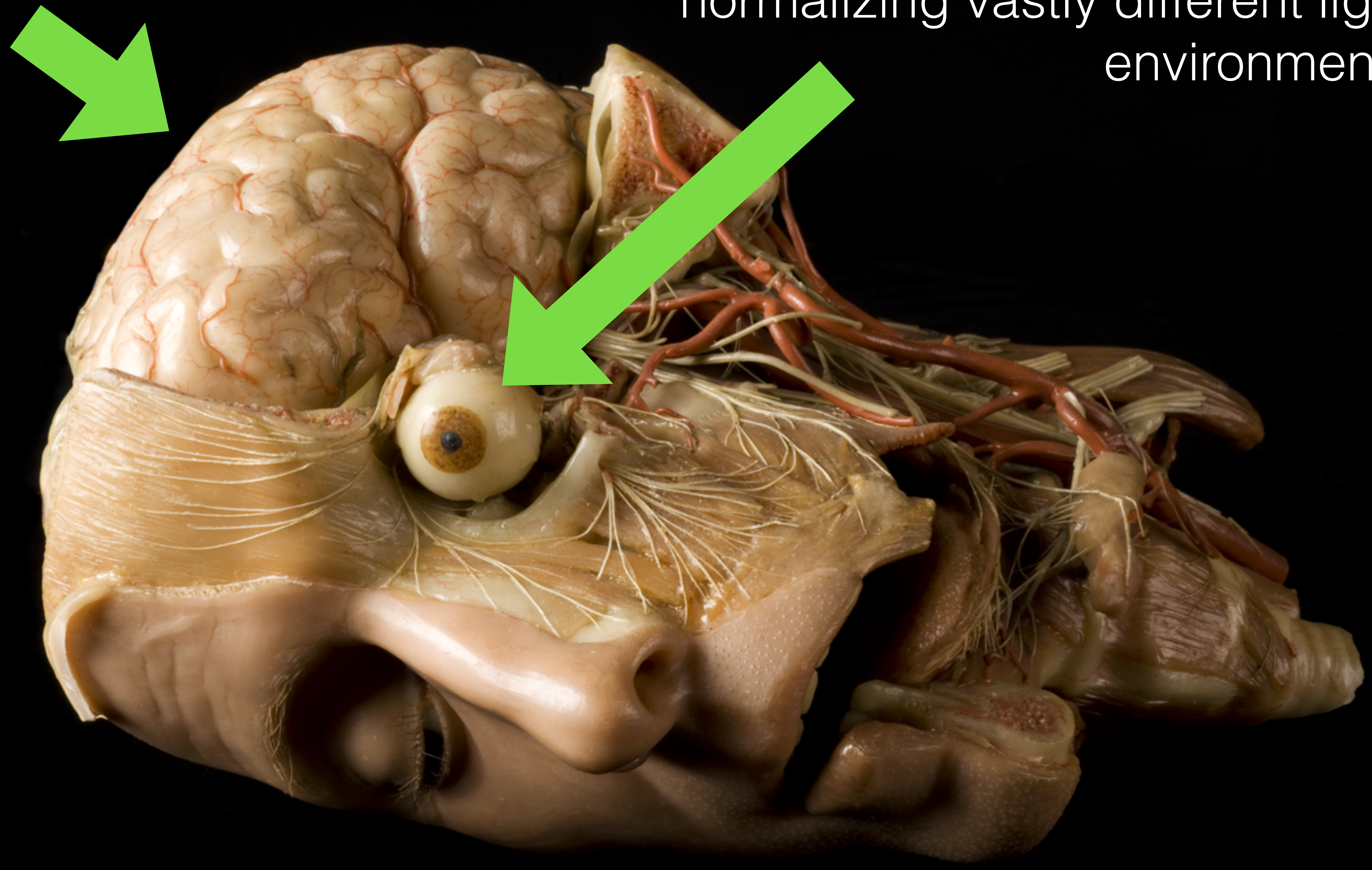
DC electricity
Voltage depends on number of cells in series.
Current proportional to area and light intensity

Remember:
Watt is SI unit of power

1W = 1J/s

1W (electric) = 1V * 1A

These are deceptively amazing at normalizing vastly different light environments



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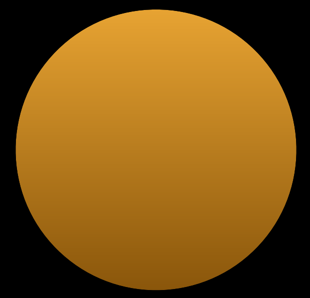


AM1.5: **1000 W/m²**

Average solar radiation for a location on the northern hemisphere with a latitude angle of 47° - 55°.

sunny, clear sky
summer: 600 - 1000 W/m²
winter: 300 - 500 W/m²

sunny, scattered clouds or partly cloudy
summer: 300 - 600 W/m²
winter: 150 - 300 W/m²

cloudy, fog
summer: 100 - 300 W/m²
winter: 50 - 150 W/m²

Typical indoor lighting:
1-2 W/m²

MOVA Globes are wild!

http://www.renewable-energy-concepts.com/solarenergy/solar-basics/insolation-weather.html

For later:

Local solar potential
Balance of system
Tracking methods
Concentrating systems
Solar lighting
Solar thermal

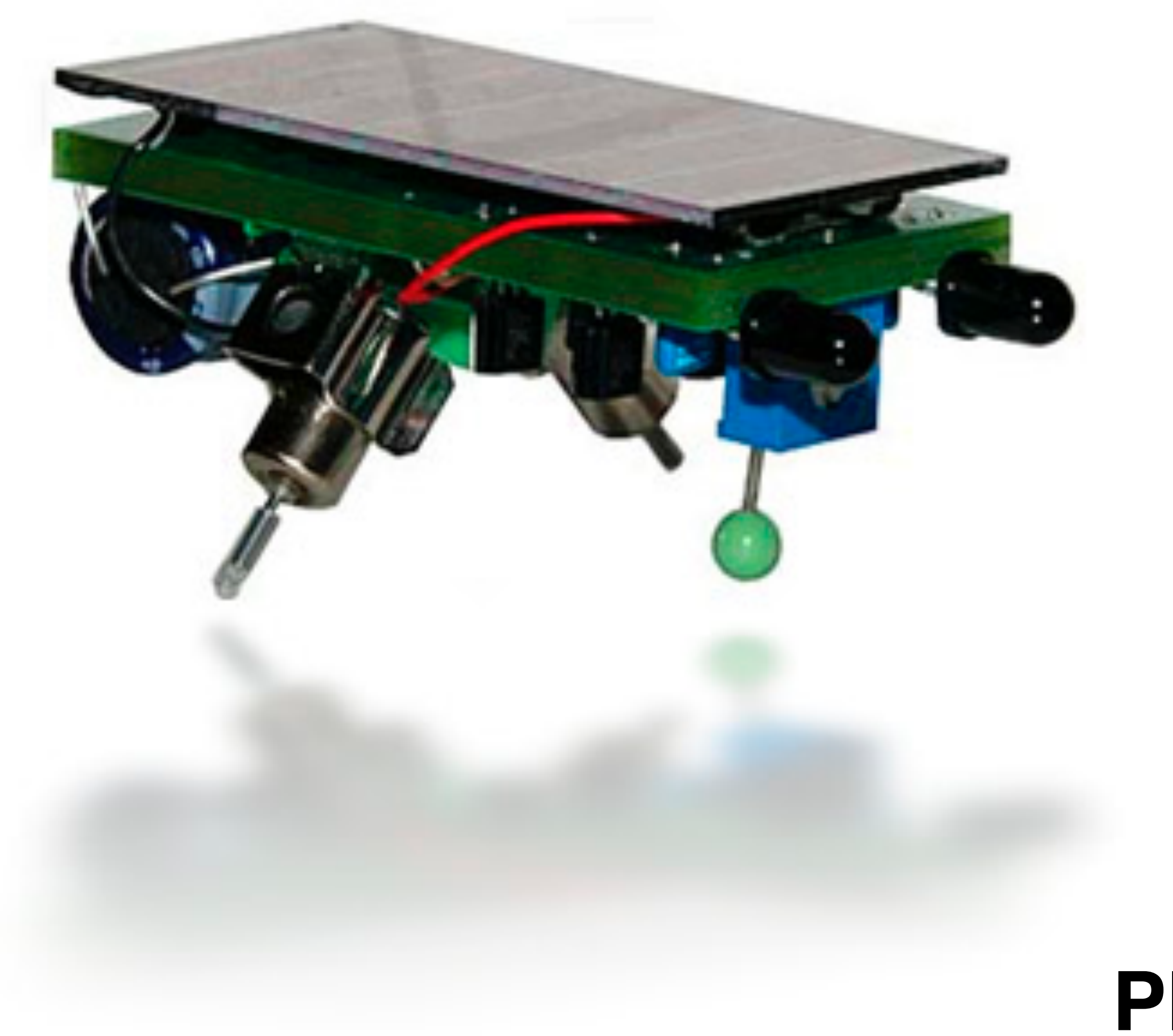
also:
Kardashev scale
Space based solar power
Dyson swarms

For now:

Preview: Planning a solar powered project
Different sizes of solar (1/10/100W)

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.

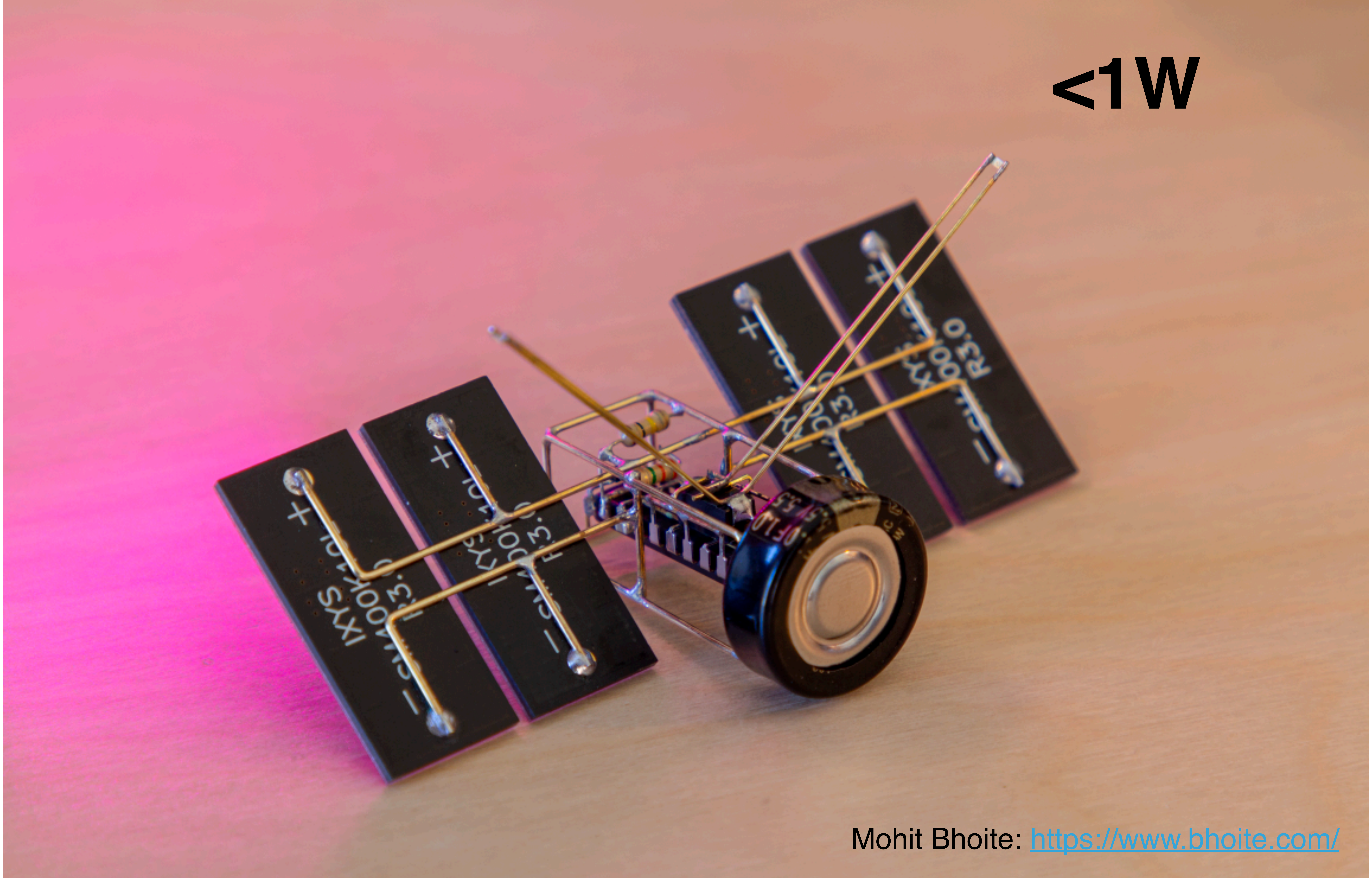


Solarbotics

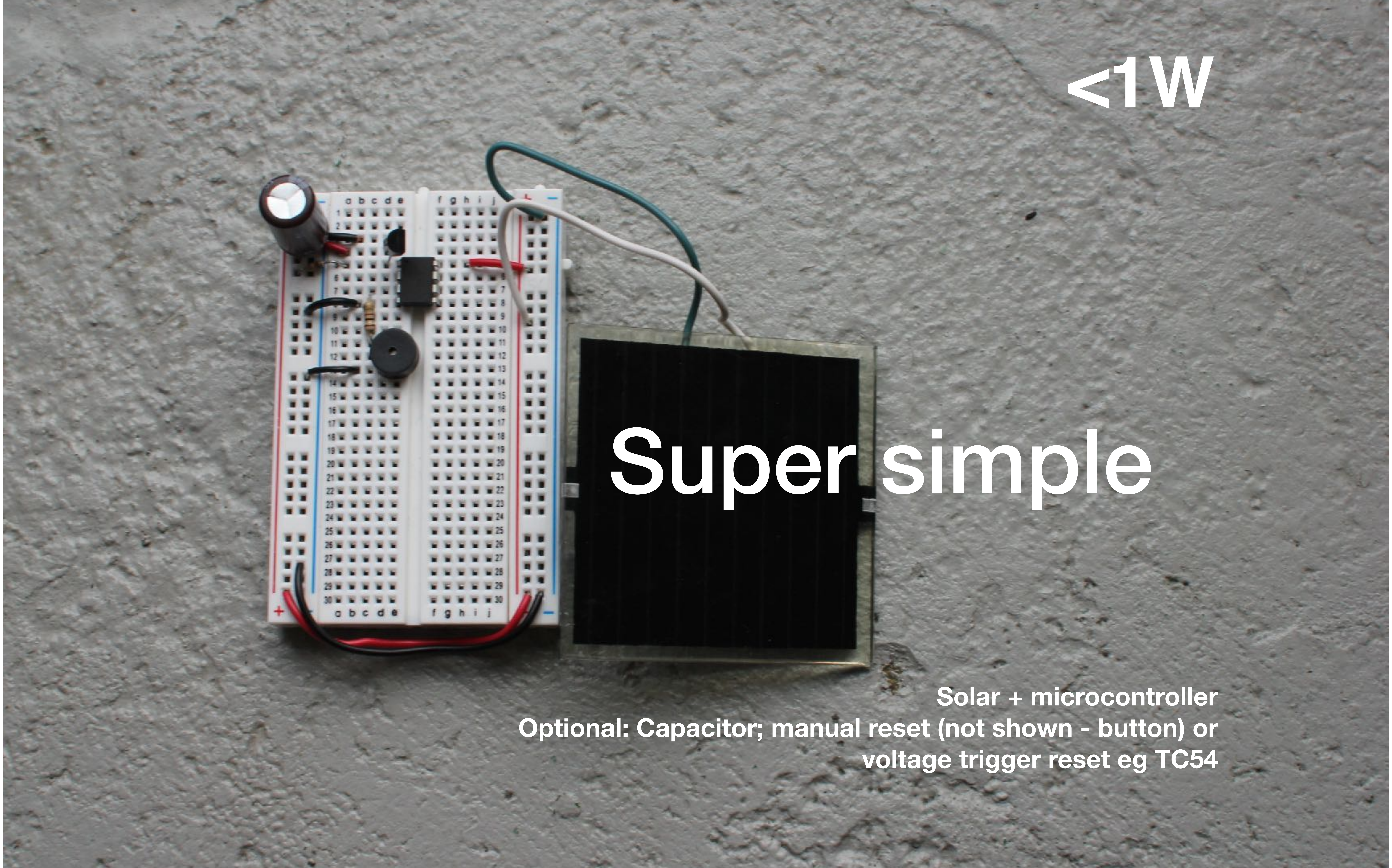
Feddersen

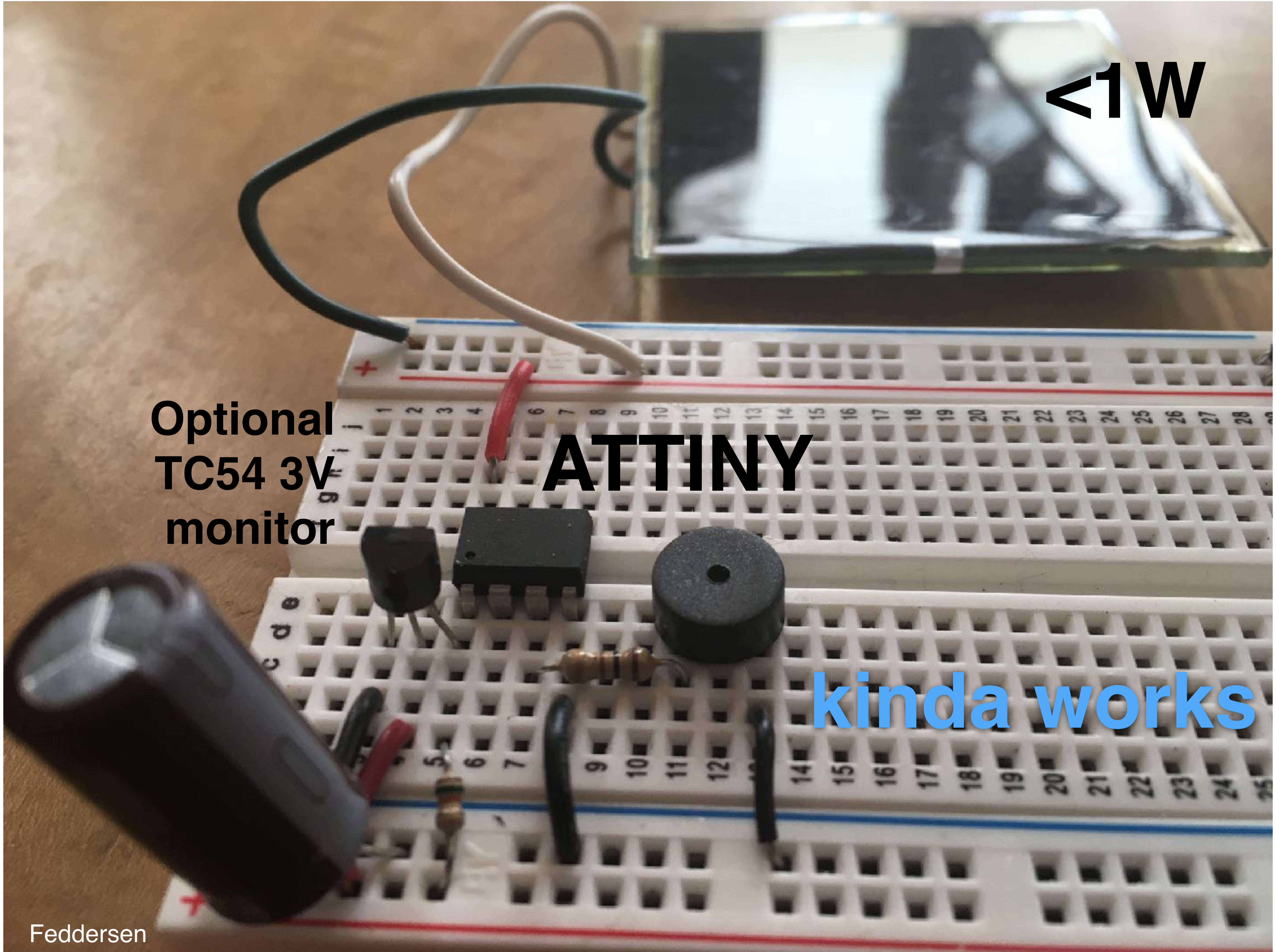
B.E.A.M.

“Trimet Solar Engine” type



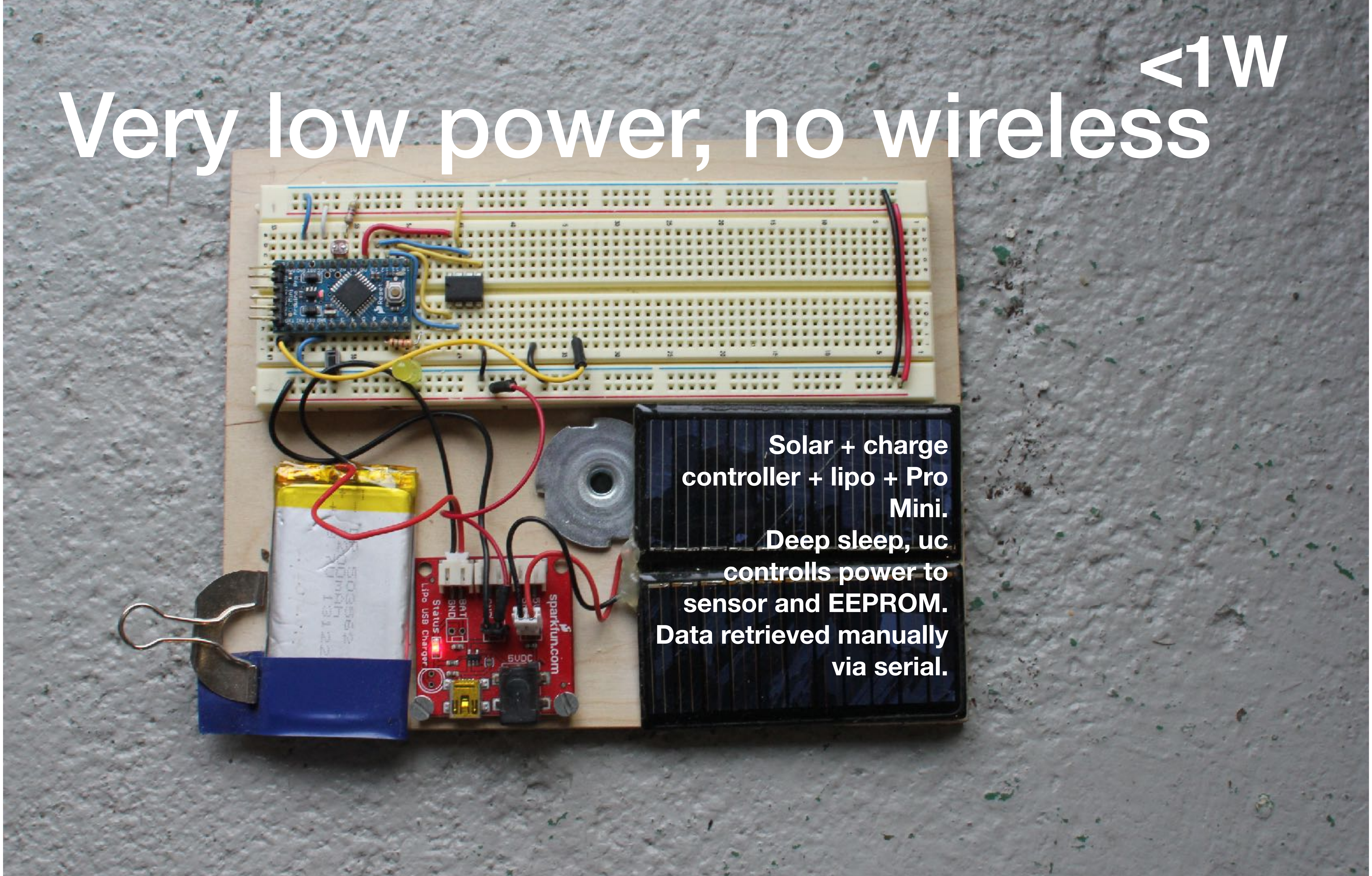
<1W
Mohit Bhoite: https://www.bhoite.com/


<1W
Super simple
Solar + microcontroller
Optional: Capacitor; manual reset (not shown - button) or
voltage trigger reset eg TC54

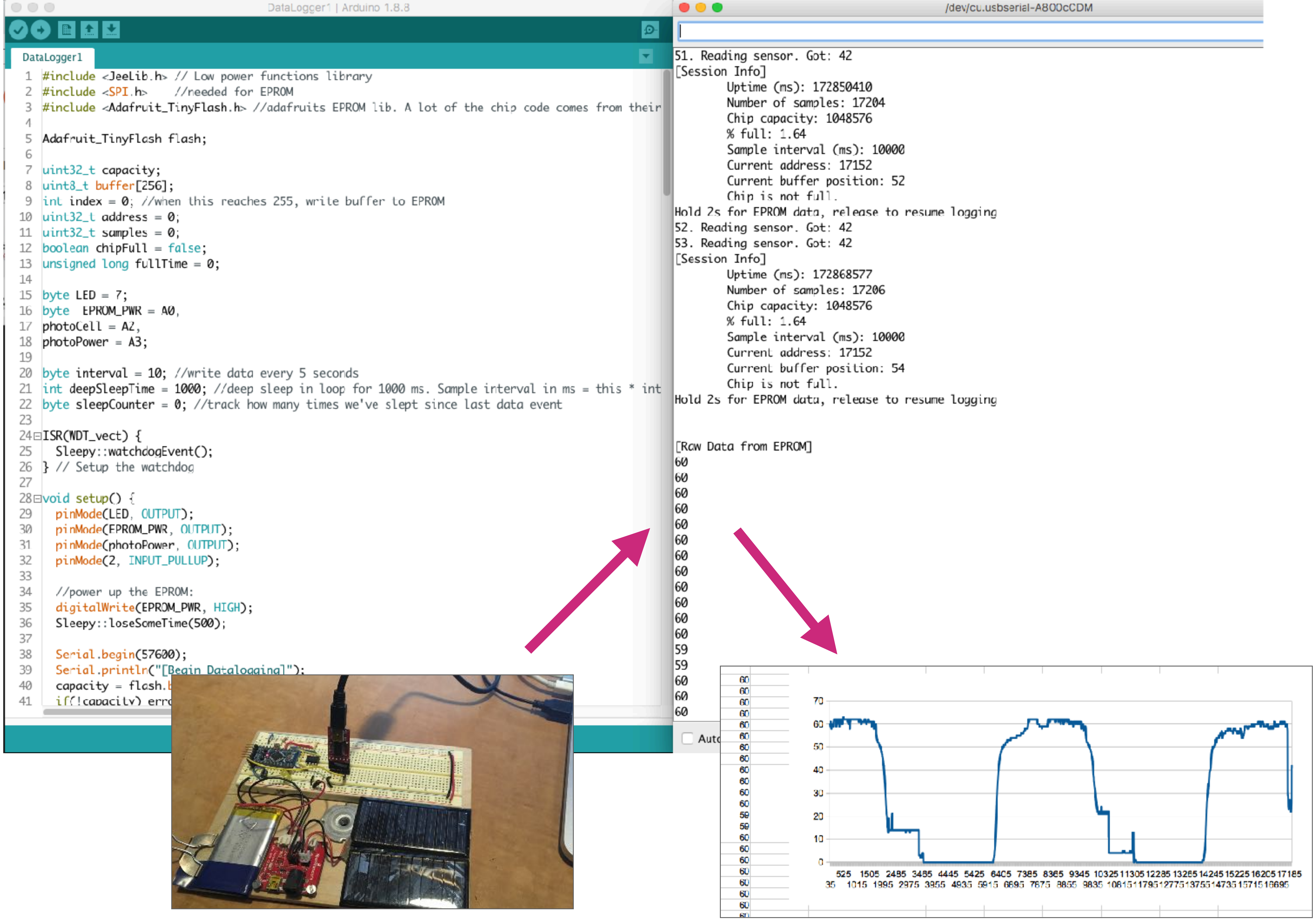

<1W
Optional
TC54 3V
monitor
ATTINY
kinda works
Feddersen

Very low power, no wireless

<1W



Solar + charge controller + lipo + Pro Mini.
Deep sleep, uc controlls power to sensor and EEPROM.
Data retrieved manually via serial.



DataLogger1 | Arduino 1.8.8
DataLogger1
#include <JeeLib.h> // Low power functions library
#include <SPI.h> //needed for EPROM
#include <Adafruit_TinyFlash.h> //adafruits EPROM lib. A lot of the chip code comes from their
Adafruit_TinyFlash flash;
uint32_t capacity;
uint8_t buffer[256];
int index = 0; //when this reaches 255, write buffer to EPROM
uint32_t address = 0;
uint32_t samples = 0;
boolean chipFull = false;
unsigned long fullTime = 0;
byte LED = 7;
byte EPROM_PWR = A0,
photoCell = A2,
photoPower = A3;
byte interval = 10; //write data every 5 seconds
int deepSleepTime = 1000; //deep sleep in loop for 1000 ms. Sample interval in ms = this * int
byte sleepCounter = 0; //track how many times we've slept since last data event
ISR(WDT_vect) {
Sleepy::watchdogEvent();
} // Setup the watchdog
void setup() {
pinMode(LED, OUTPUT);
pinMode(EPROM_PWR, OUTPUT);
pinMode(photoPower, OUTPUT);
pinMode(2, INPUT_PULLUP);
//power up the EPROM:
digitalWrite(EPROM_PWR, HIGH);
Sleepy::loseSomeTime(500);
Serial.begin(57600);
Serial.println("[Begin Datalogging]");
/dev/cu.usbserial-A800cCDM
51. Reading sensor. Got: 42
[Session Info]
Uptime (ms): 172850410
Number of samples: 17204
Chip capacity: 1048576
% full: 1.64
Sample interval (ms): 10000
Current address: 17152
Current buffer position: 52
Chip is not full.
Hold 2s for EPROM data, release to resume logging
52. Reading sensor. Got: 42
53. Reading sensor. Got: 42
[Session Info]
Uptime (ms): 172868577
Number of samples: 17206
Chip capacity: 1048576
% full: 1.64
Sample interval (ms): 10000
Current address: 17152
Current buffer position: 54
Chip is not full.
Hold 2s for EPROM data, release to resume logging
[Raw Data from EPROM]
60
60
60
60
60
60
60
60
60
60
60
60
59
59
60
60
60
70
60
50
40
30
20
10
0

1-10W

Size: Small to Medium

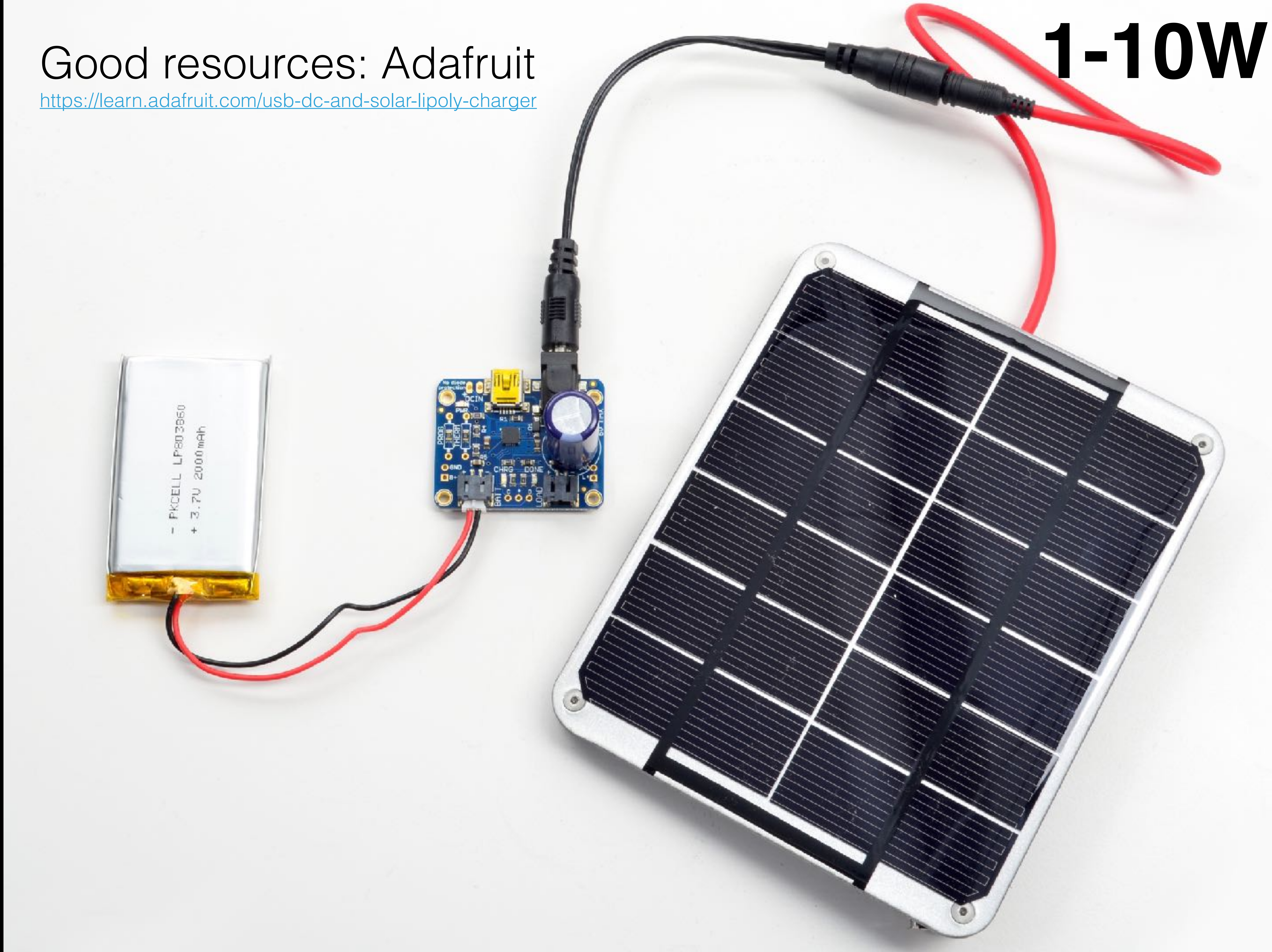
Can you directly power what you want? See SolaSystem amplifier from class notes.

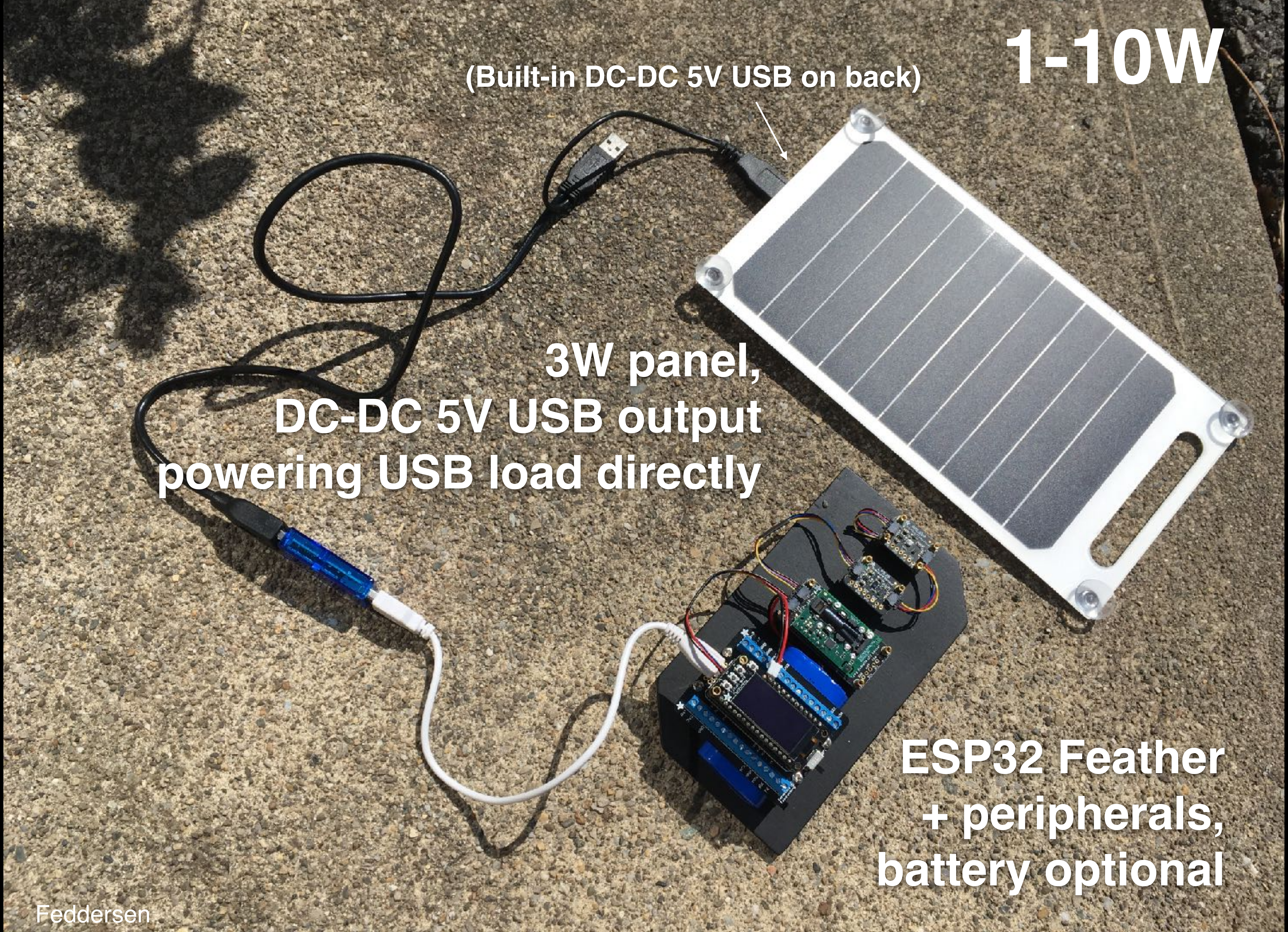
If not, and you need to store energy, use consumer small-scale charge controllers and batteries sized to your energy and power budget. Farad-class ultra capacitors are also an option. Consider direct DC-DC converters for loads. See ITP portable solar kits or Solio chargers for examples.

Good resources: Adafruit

https://learn.adafruit.com/usb-dc-and-solar-lipoly-charger

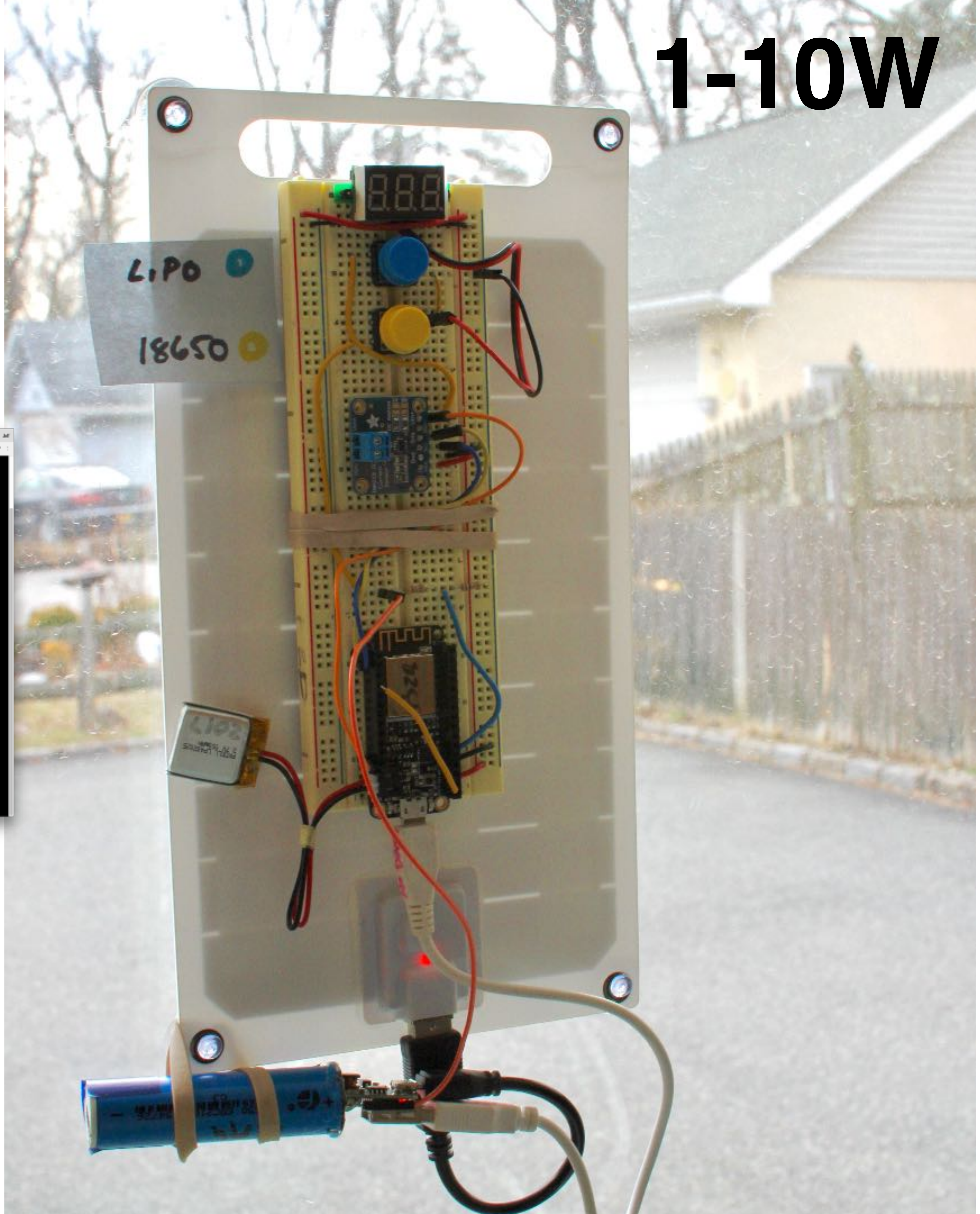
1-10W




1-10W
(Built-in DC-DC 5V USB on back)
3W panel,
DC-DC 5V USB output
powering USB load directly
ESP32 Feather
+ peripherals,
battery optional
Feddersen

Off-the-shelf

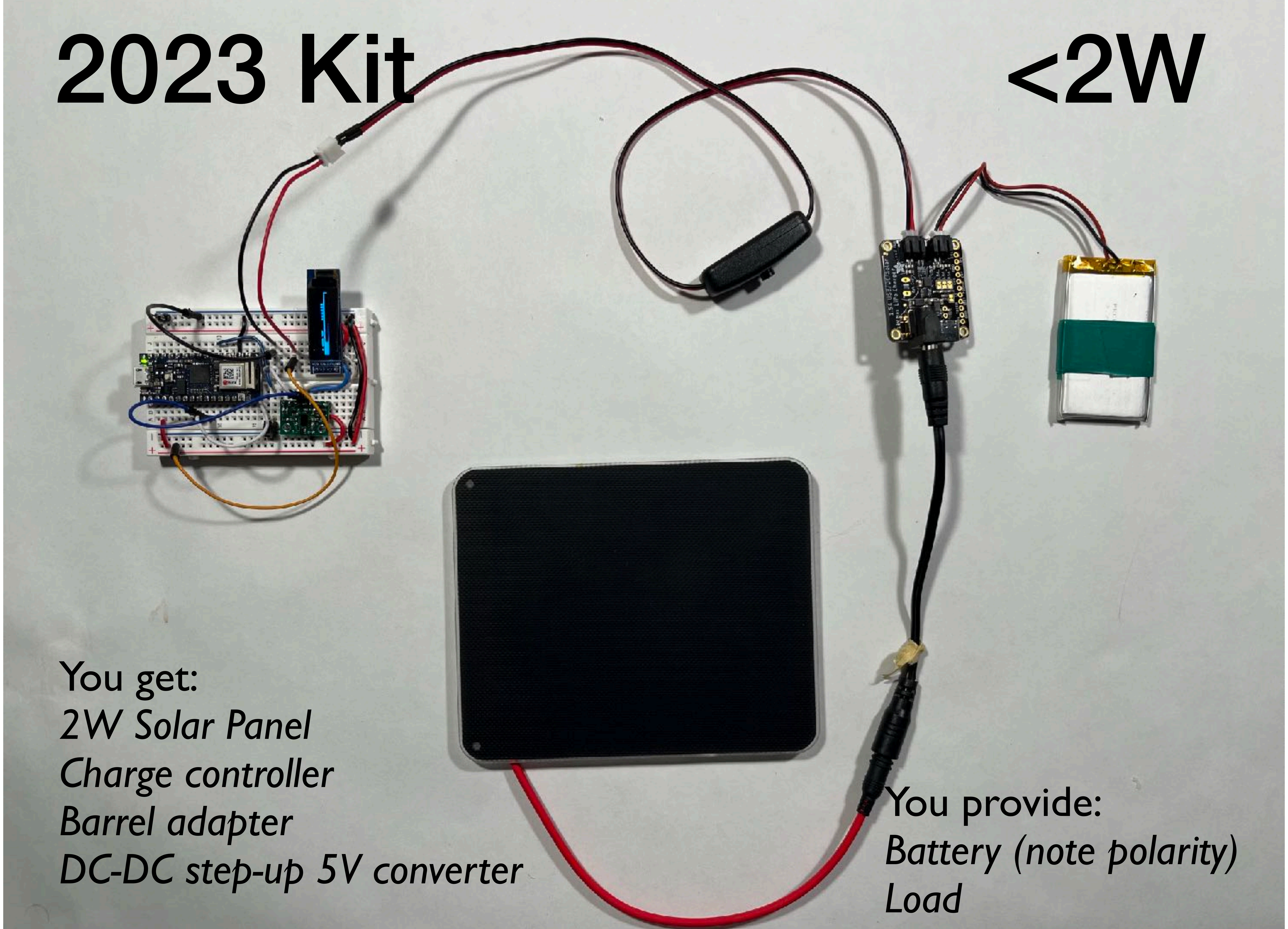
1-10W



USB Solar panel + USB battery
ESP8266, deep sleep
I2C sensor
Data via MQTT to io.adafruit.com
Manual voltage monitoring with push buttons

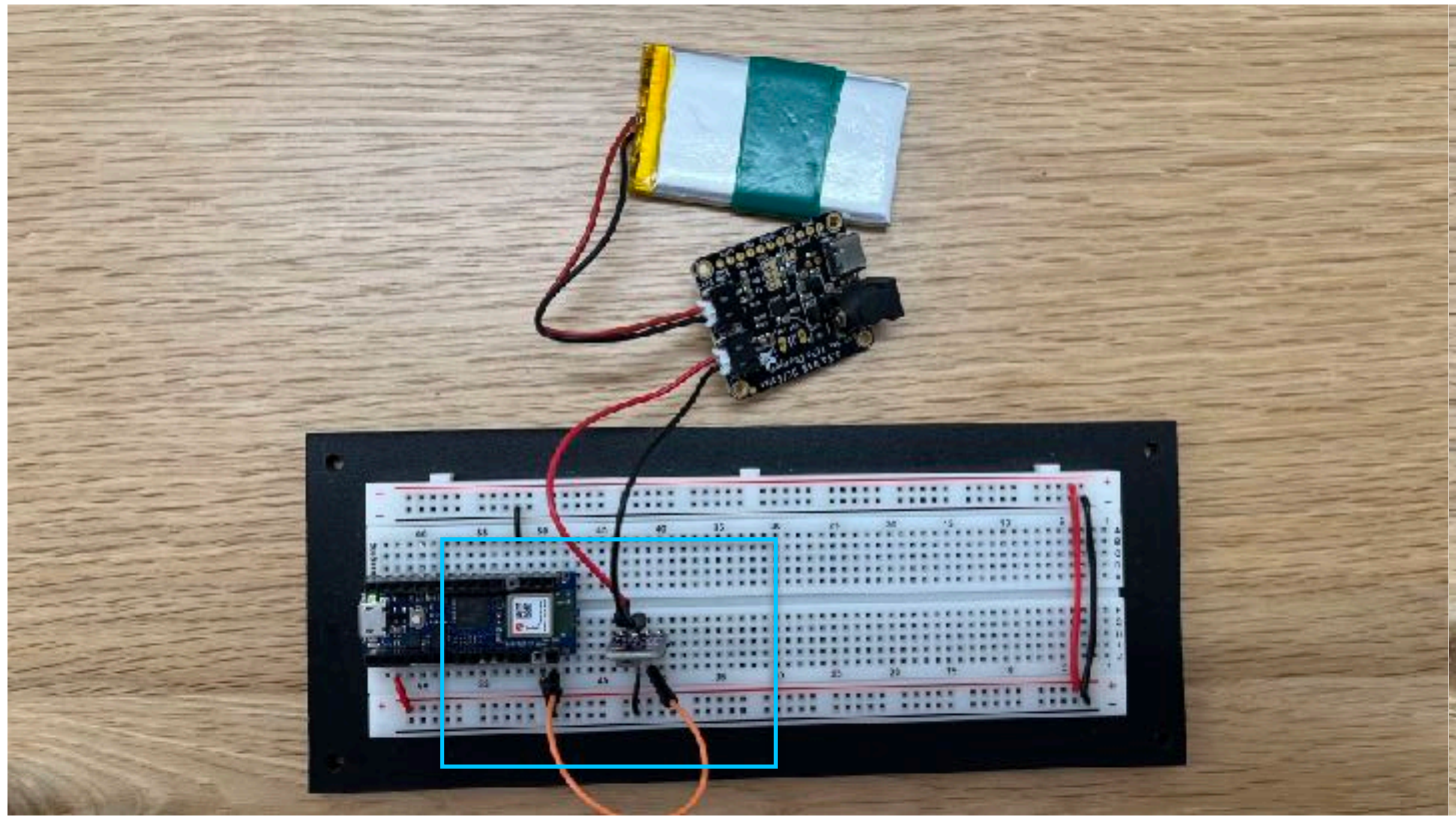
2023 Kit

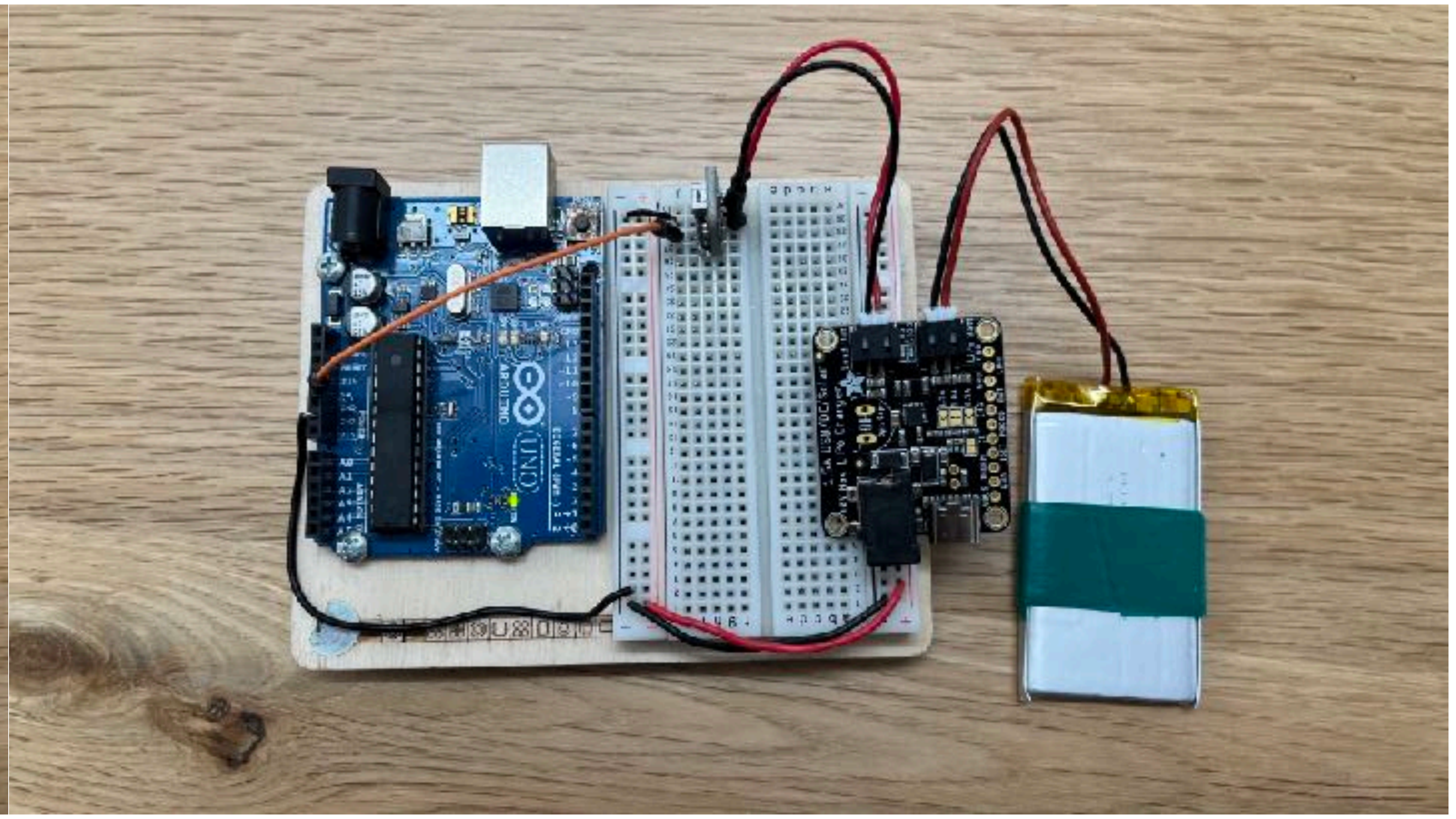
<2W



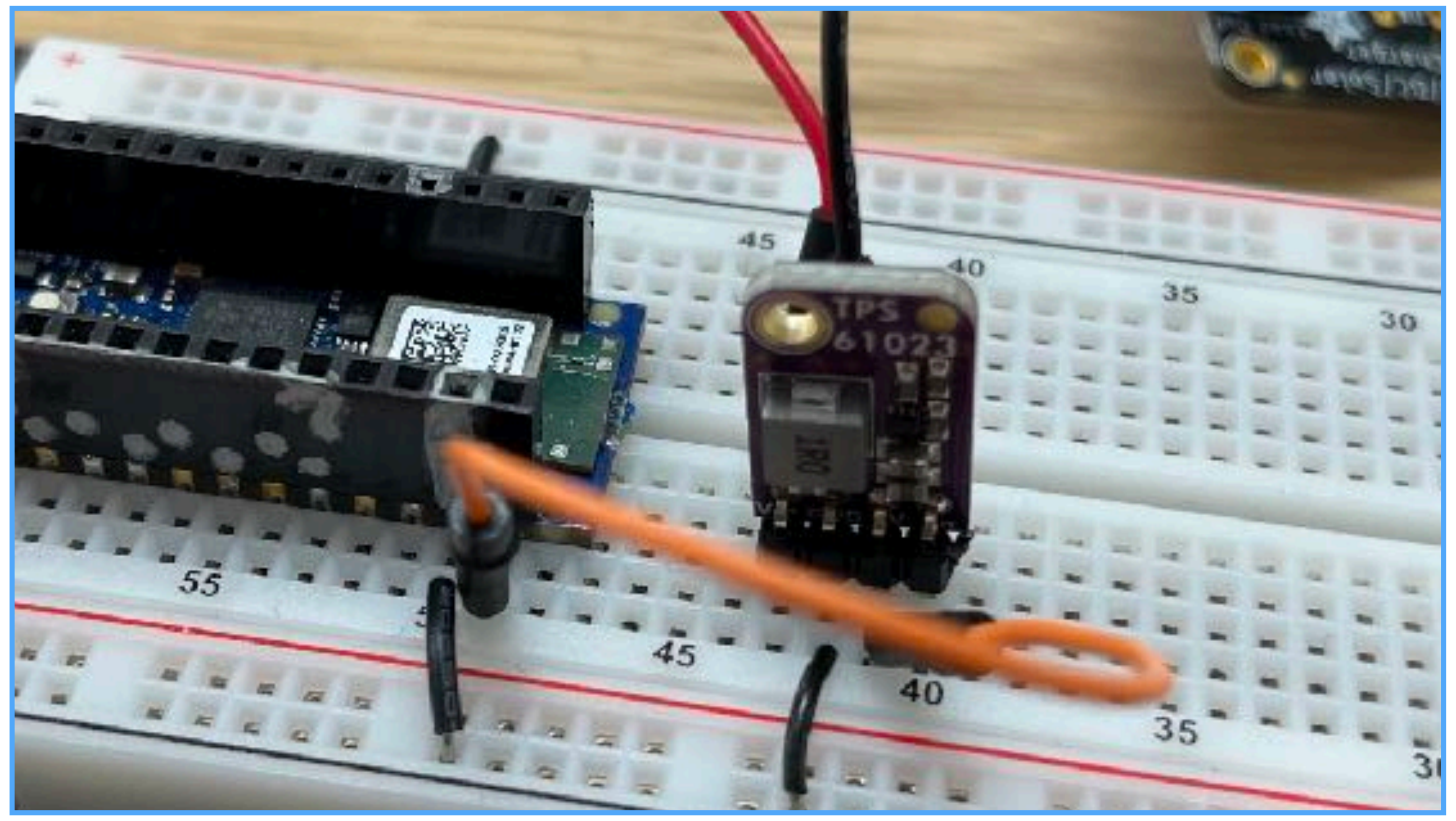
You get:
2W Solar Panel
Charge controller
Barrel adapter
DC-DC step-up 5V converter

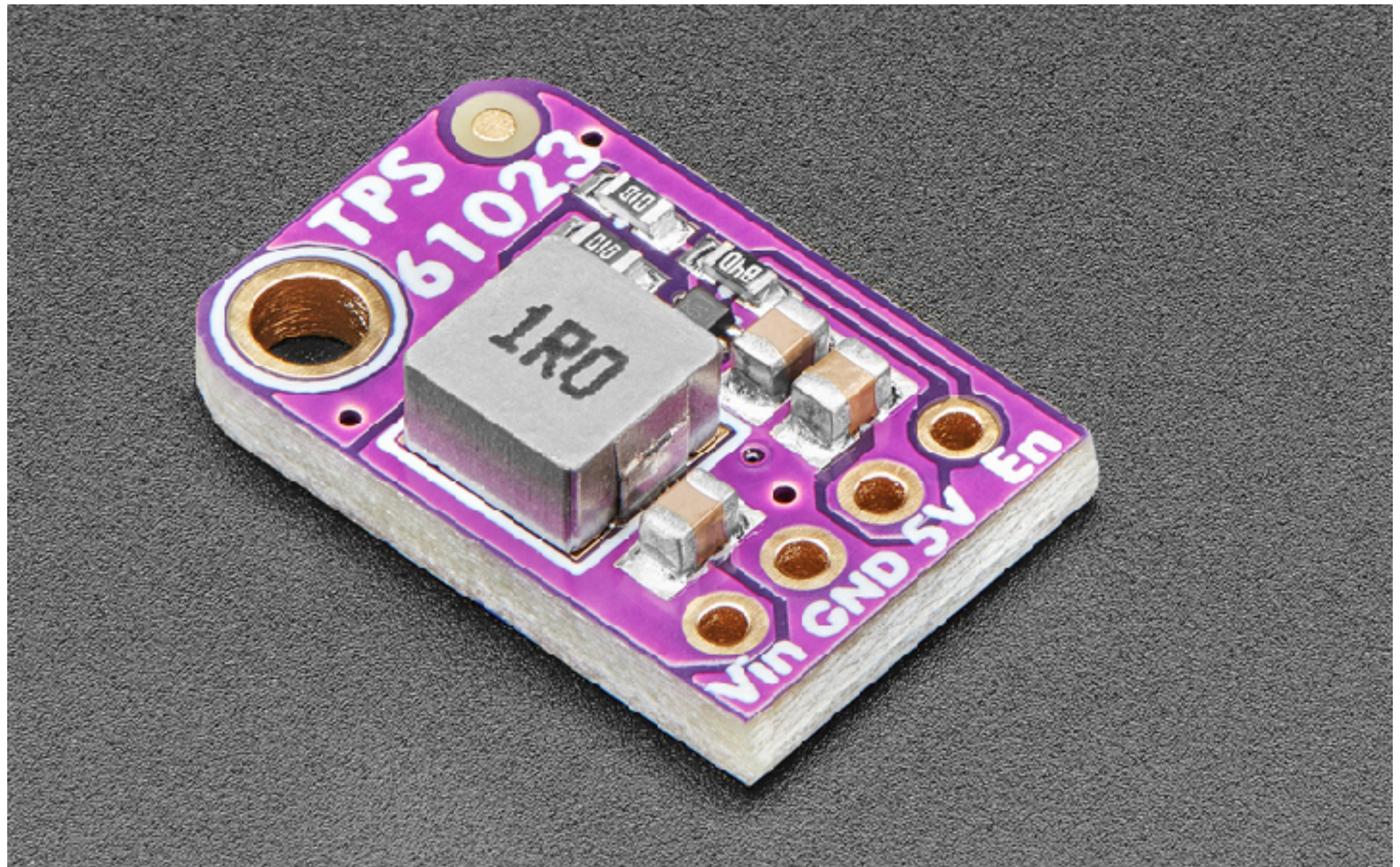
You provide:
Battery (note polarity)
Load

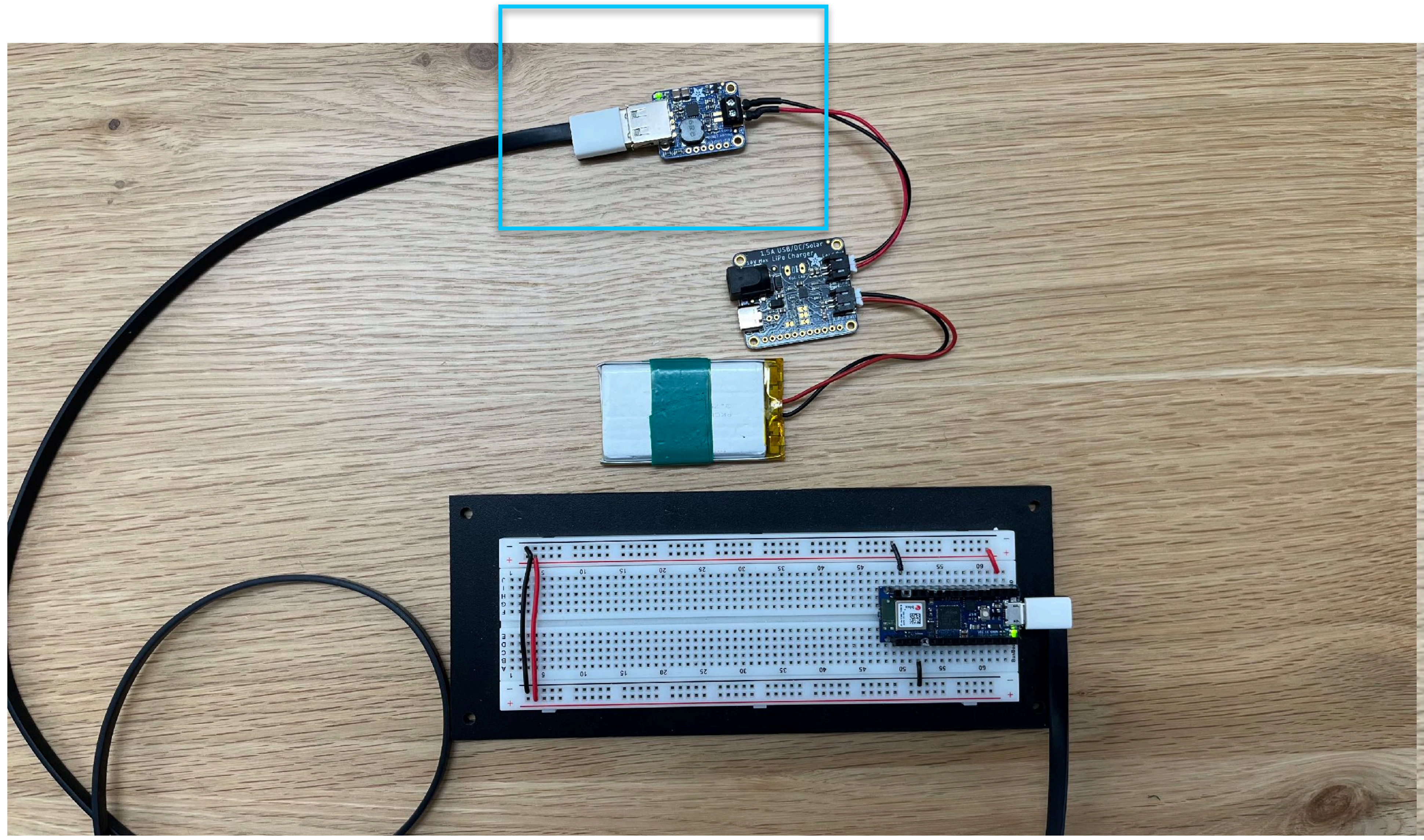


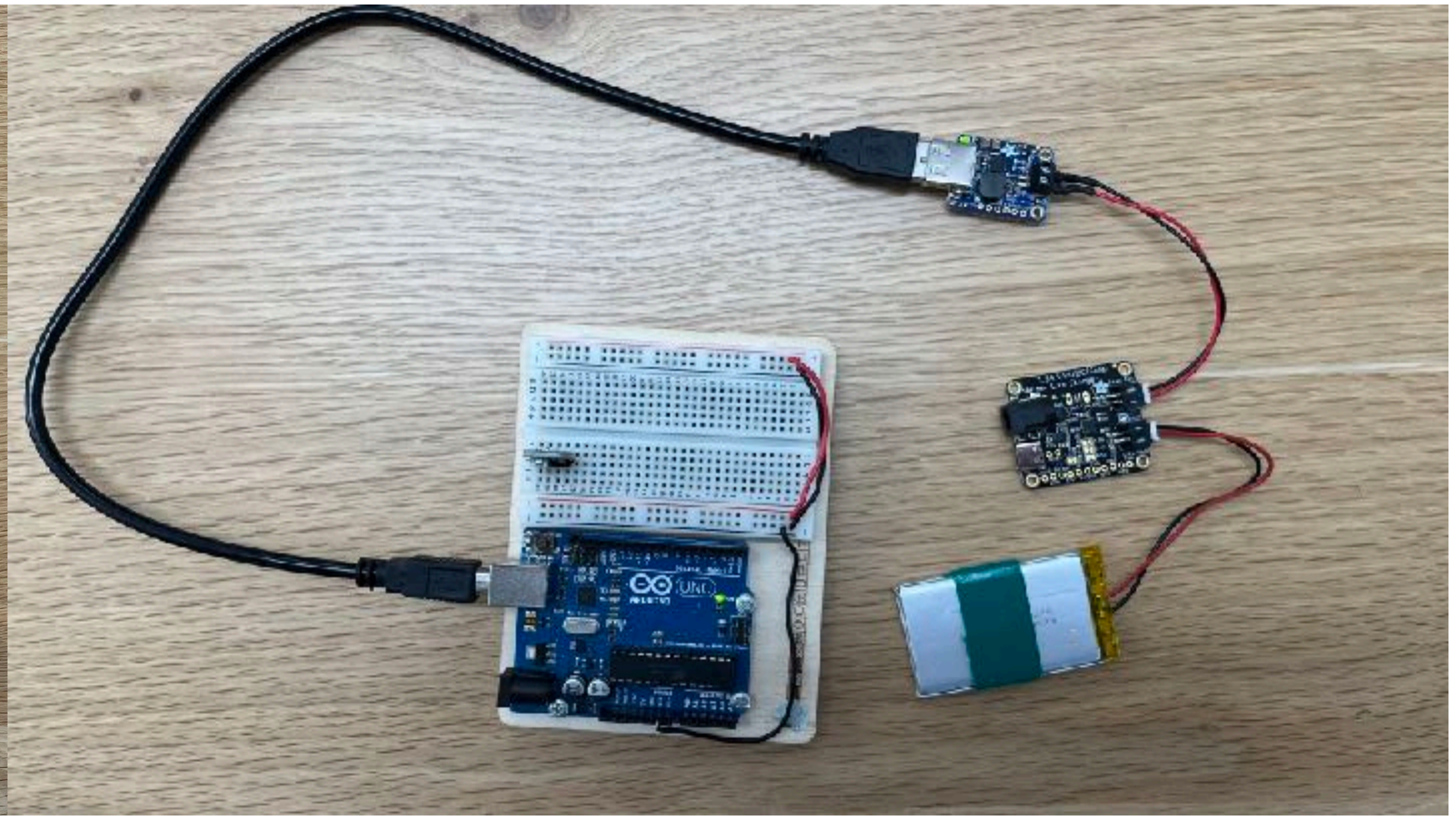


With MiniBoost 5V, 2-5V to 5V@1000mA output

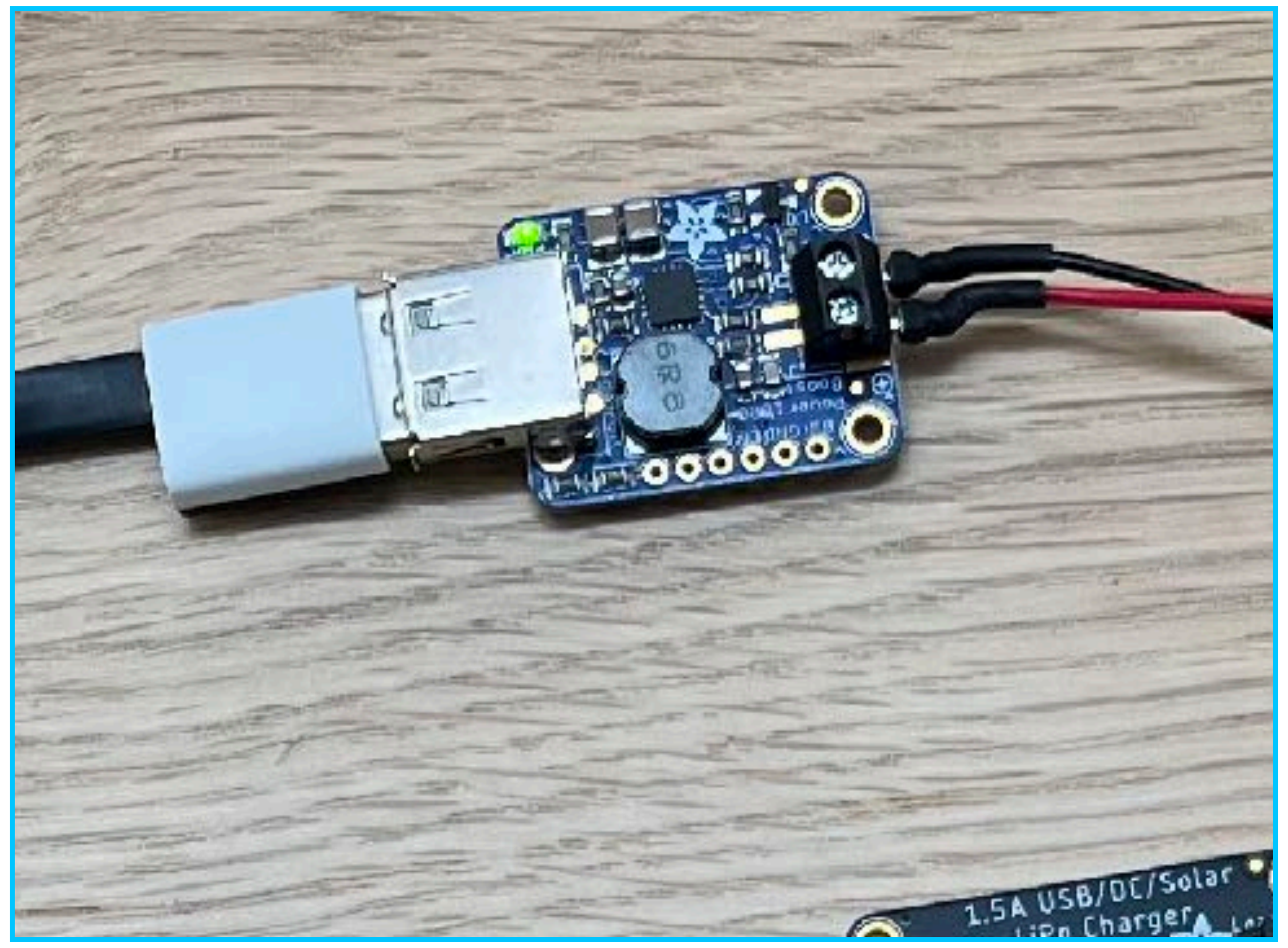


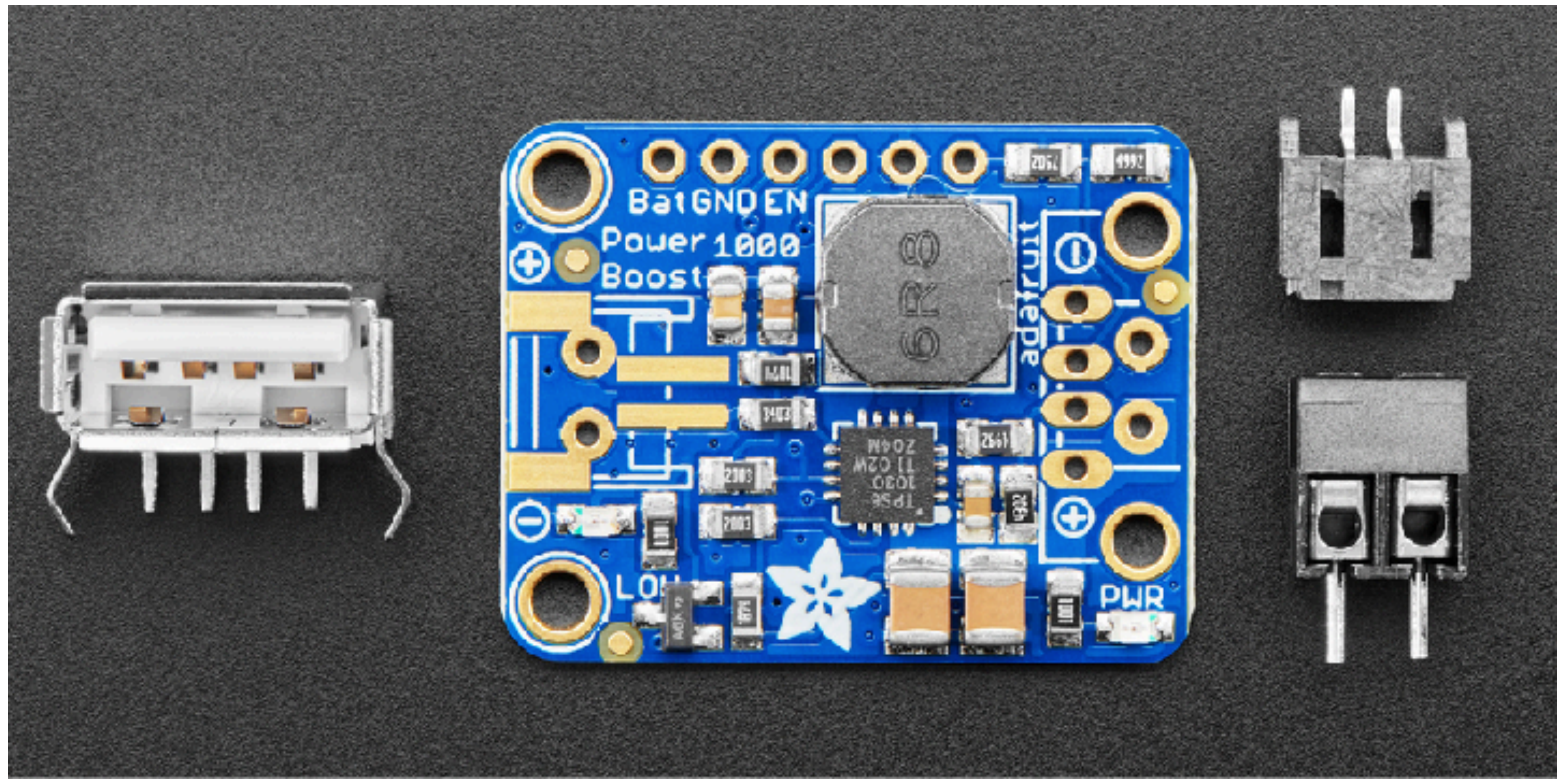






With PowerBoost 1000, 1.8-4V to 5V@1000mA output

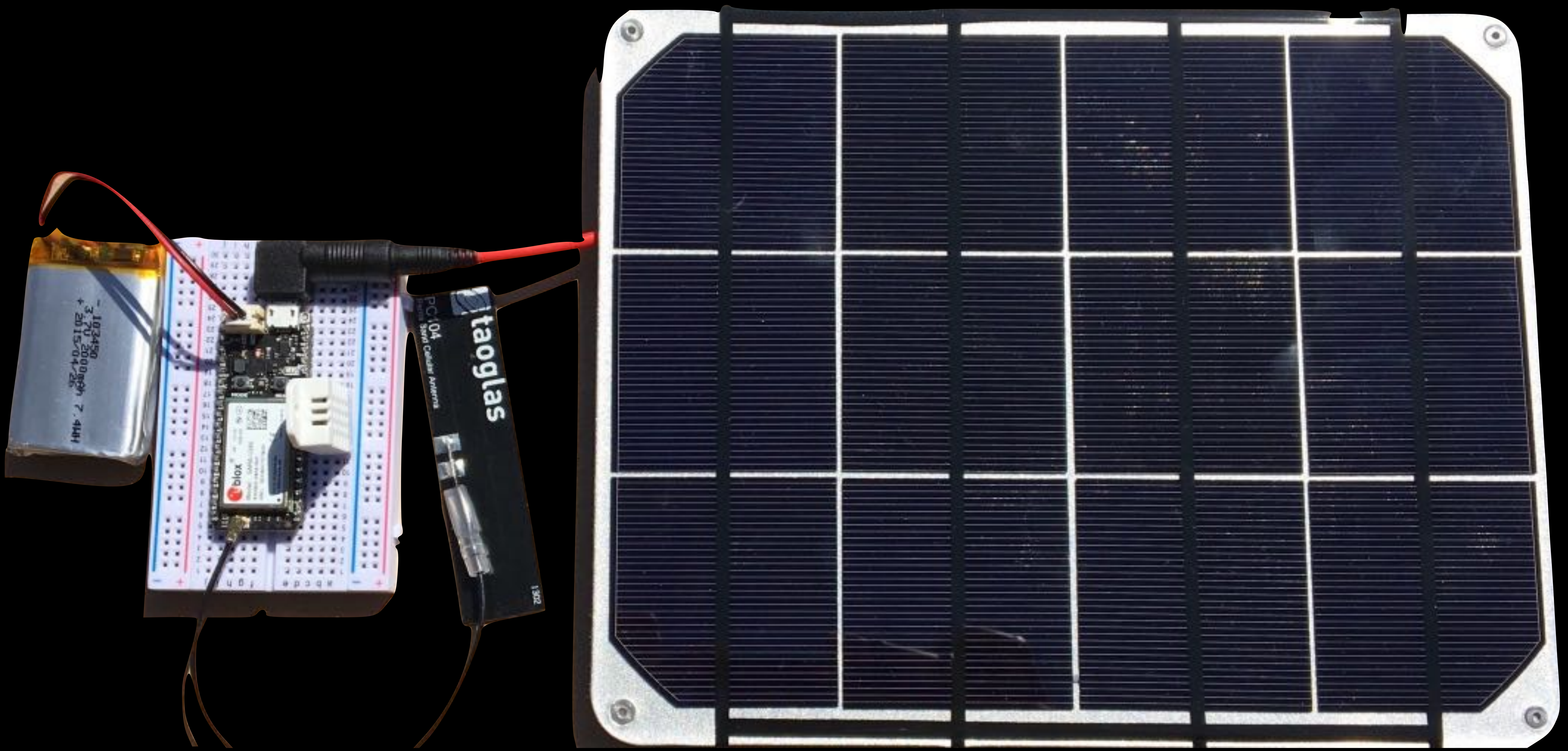




Good resources: Voltaic

http://www.voltaicsystems.com/blog/

1-10W



1-10W

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.

Feddersen

Planning

>50W


SolarSaga 60
Jackery
Jackery
INPUT:
OUTPUT:
DISPLAY
Jackery

Markus Kayser “Solar Sinter” 2011

Alternate pathway: no-logic system, activity follows available light

Patrick Marold, "Solar Drones", 2016

https://patrickmarold.com/solar-drones-national-music-centre

SOLAR DO-NOTHING MACHINE, 1957

Charles and Ray Eames

https://www.eamesoffice.com/the-work/solar-do-nothing-machine/

ROUTLEDGE ADVANCES IN ART AND VISUAL STUDIES

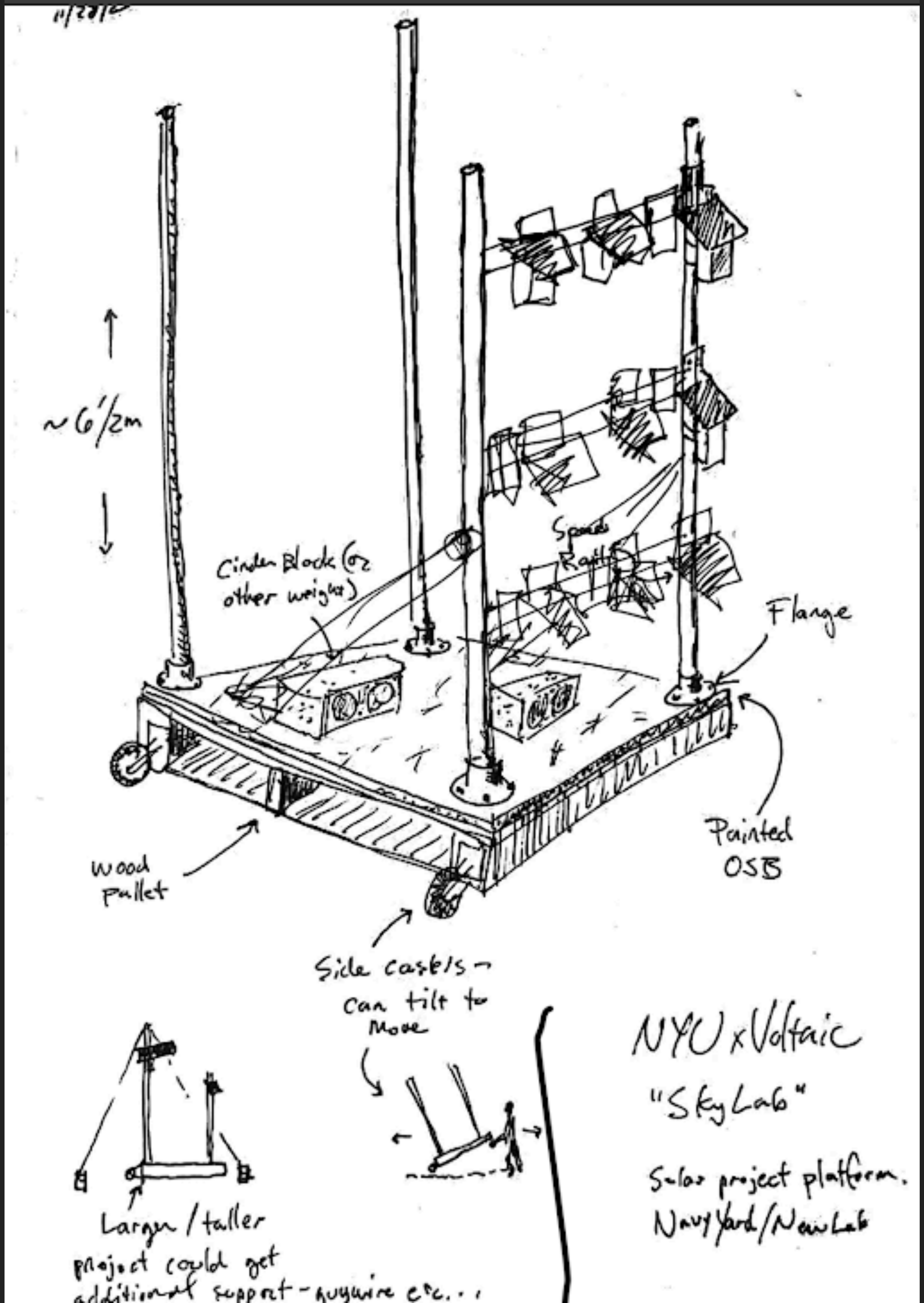
A HISTORY OF SOLAR POWER ART AND DESIGN

ALEX NATHANSON

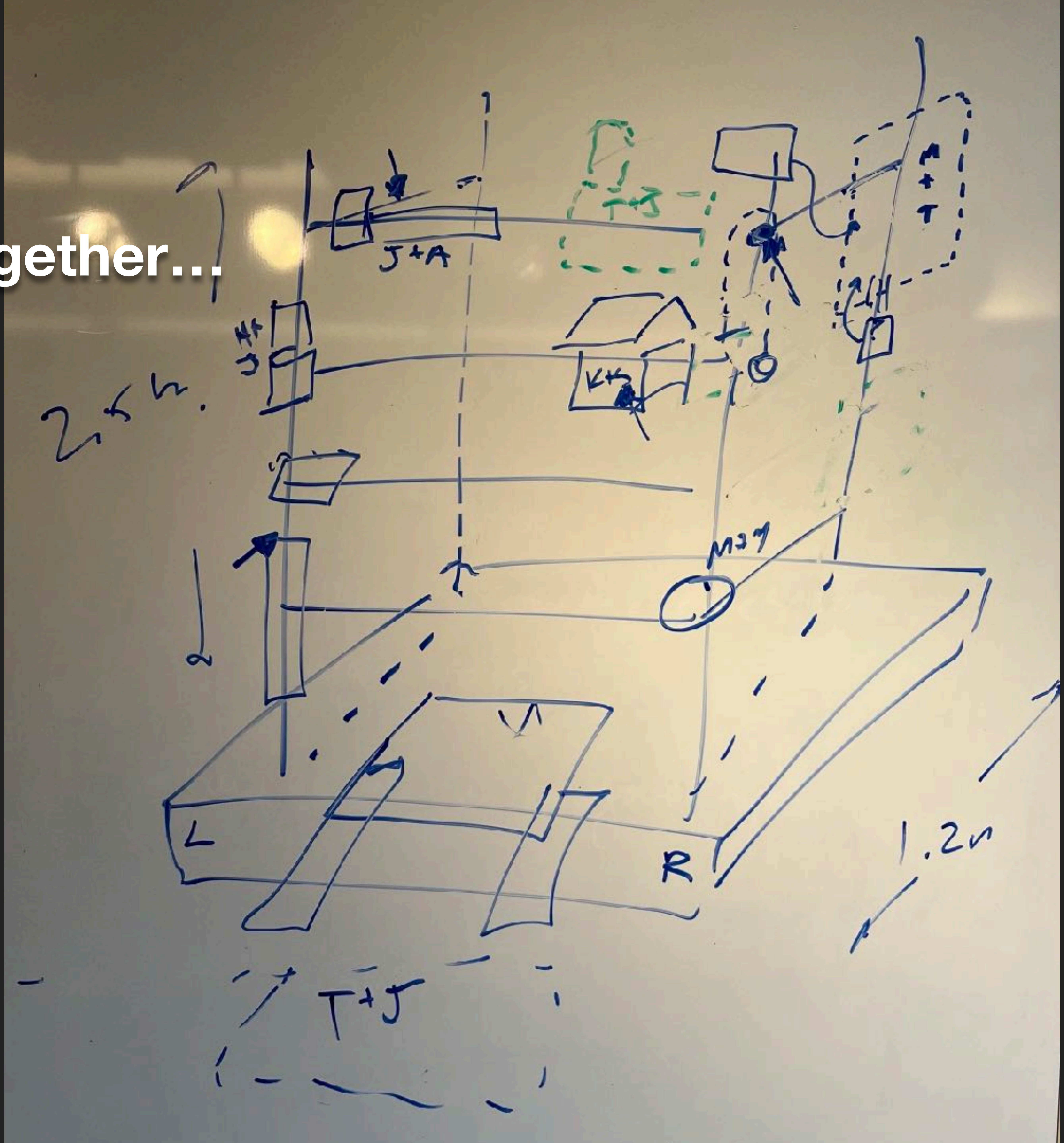
ROUTLEDGE

ITP 2024 ENERGY CLASS!

Concept in 2023…



Plan coming together…



Reality! 4/2024

Installation...

Success!


LIGHTROOM
& Tom Xia
This solar-powered


RAINSHINE
Anvay Kantak
& Jo Suk
A sound sculpture that
channels the energy of
the sun into the sound
of rain.


Total Energy Collected: 159.47 Joules
Total Flied Distance: 610.65 Meters


SUNWATCHER
Zongze Chen
& Henrique Stockler
SunWatcher 1 is a
robot that reports
weather data from
eerie depths of
parking lot at the
Brooklyn Navy Yard
ITP Floor. It
constantly
the environmental
conditions of the
world, especially
it's a beautiful
day. But does it
hear back from us?


Skylab
HS-318