Solar Power

for Wireless Sensor Networks

March 2015

ICTP Workshop on Scientific Applications for the Internet of Things (IoT)

Sebastian Büttrich

sebastian@nsrc.org

UNIVERSITY OF OREGON

NSRC
Network Startup Resource Center

MANA project

Greenland

http://itu.dk/mana

Solar power

May refer to thermal, electric and other forms of powering
Here, we talk about

photovoltaic power

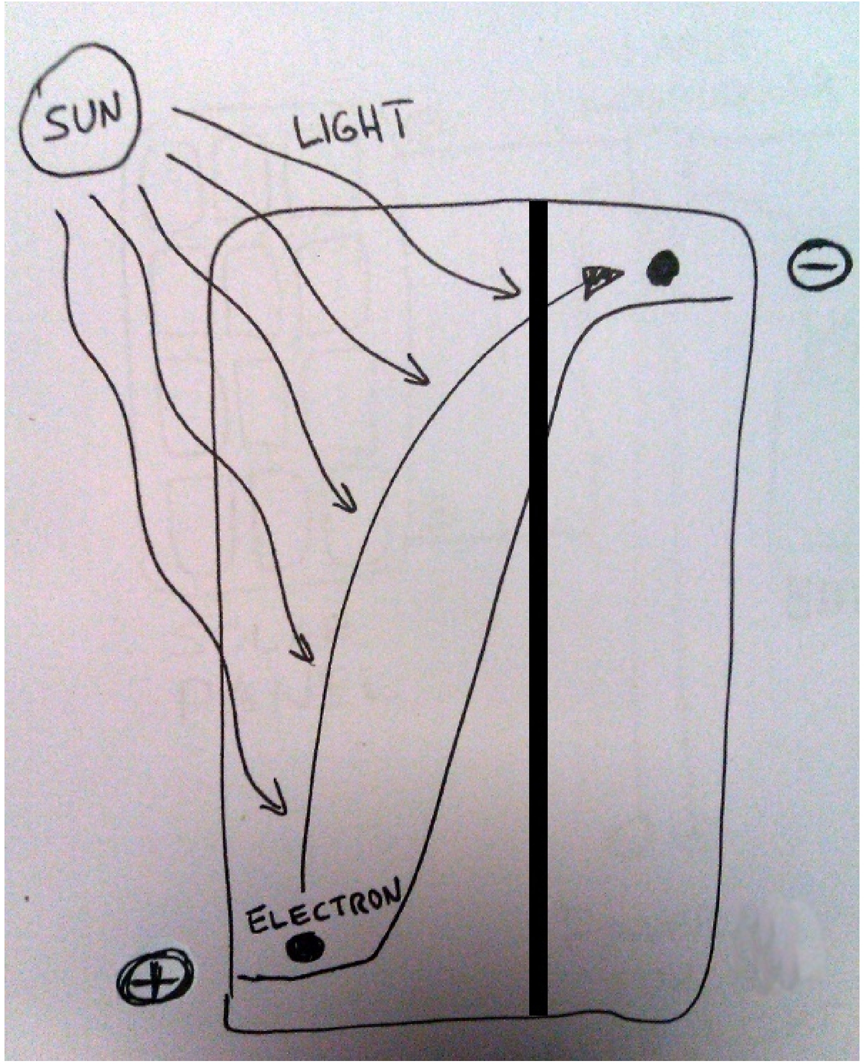
the production of electric energy by means of photovoltaic panels.

Principle

Photovoltaic panels

Generate electric power (DC)
through the separation
of electric charges
in a pn junction
in semiconductor materials,
mostly Silicon based,
but also other materials.

Note: there are other types of solar panels too –
see slide on research!



Types of solar power deployments

On grid

May deliver energy back to the grid

AC, inverters needed for AC/DC conversion

Off grid

Autonomous systems,

may or may not need AC.

In the case of WSN, we typically look at these **autonomous systems**

Elements of pv setup

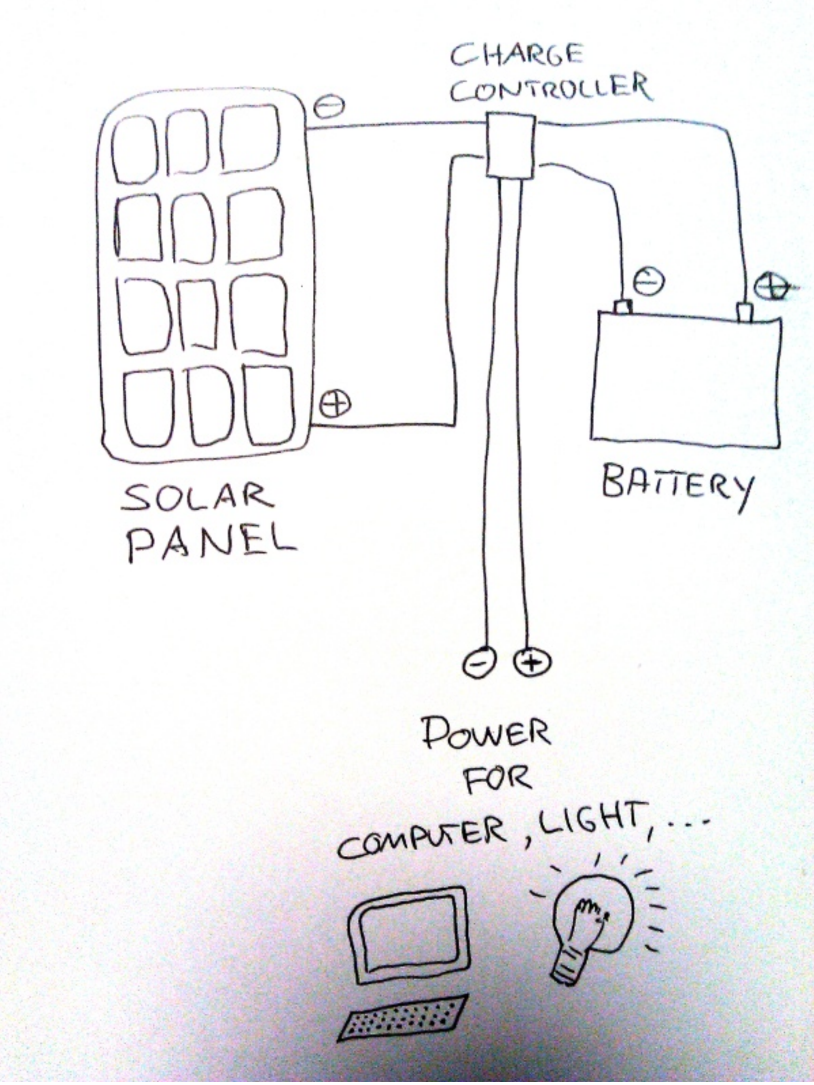
Photovoltaic panel

Charge controller

Battery

Load / Consumer

Optionally: Inverter (AC)

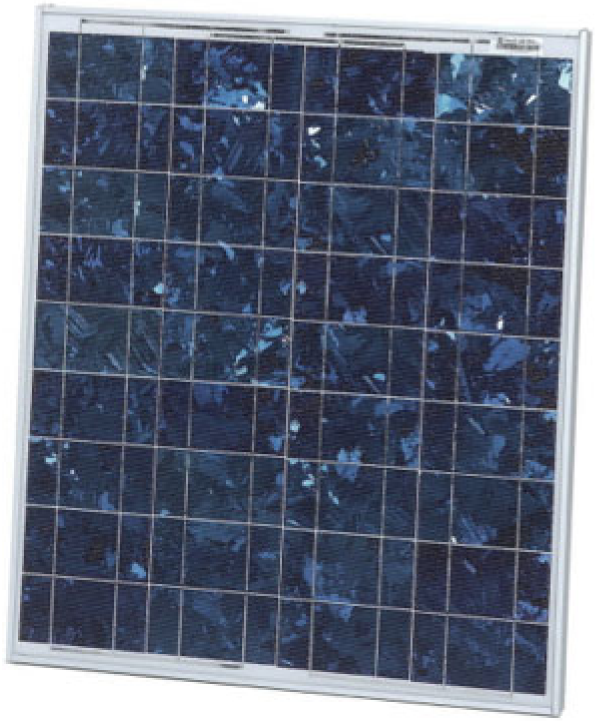


Types of solar cells

Monochrystalline

Types of solar cells

Polychrystalline

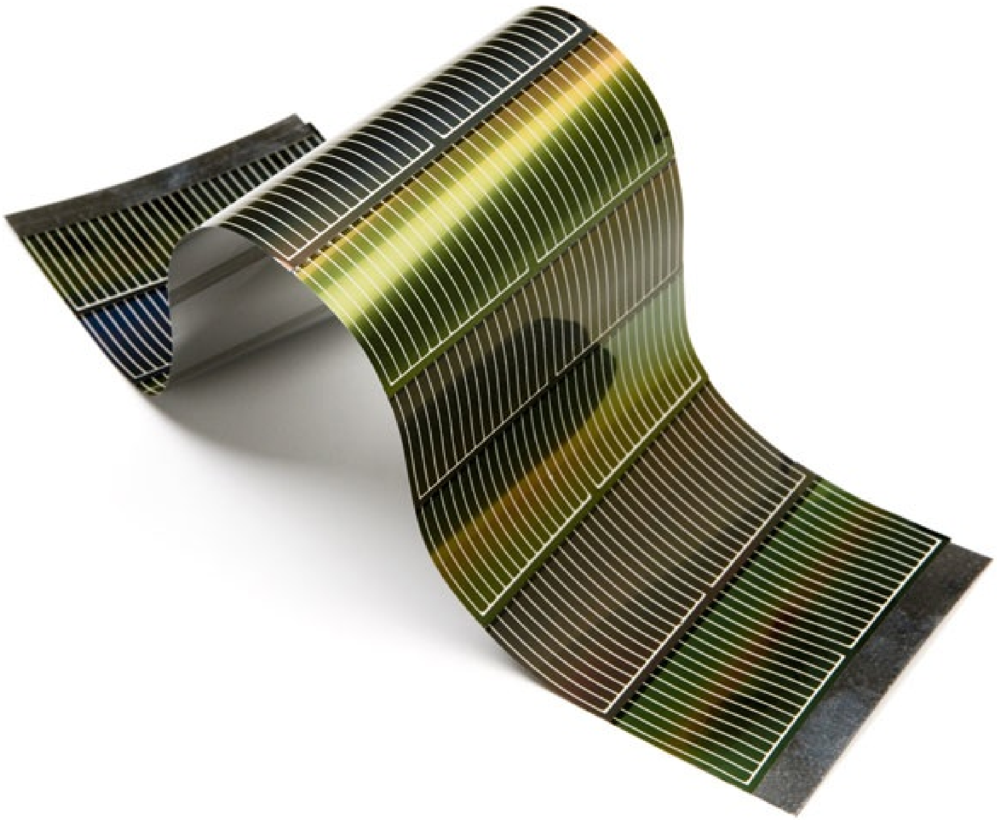


Types of solar cells

Thin Film, flexible

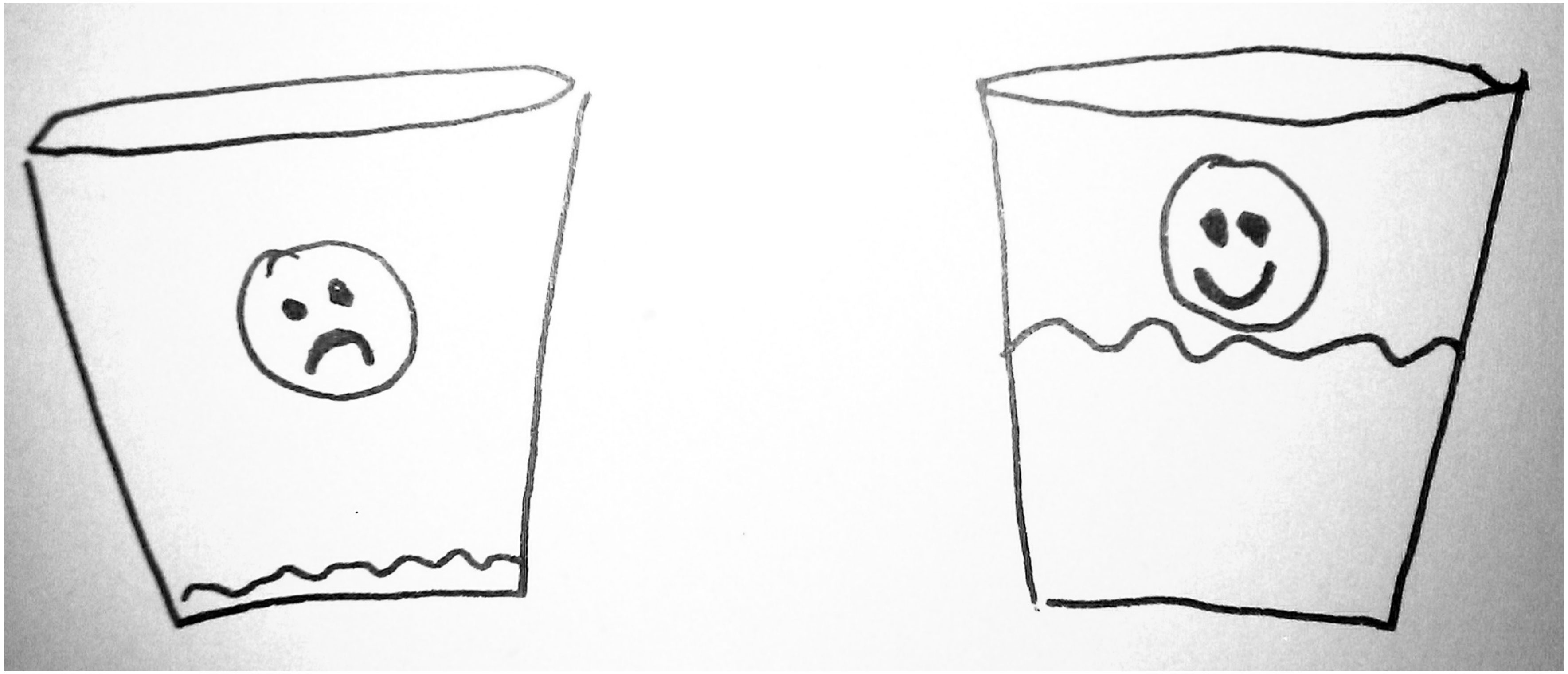
e.g. CIGS

Copper indium gallium selenide (CuInxGa(1-x)Se2)



Batteries

- Need to be suitable type for solar charging cycles: deep cycle batteries, optimized for many rounds of charge and discharge
- Often of type GEL battery (closed Lead Acid)
- Should never be depleted completely
- Battery capacity is measured in Ah (Amperehours) or Wh (Watthours)



- WSN sensor boards might have special

types of batteries –
we might look at
systems with
huge battery banks of 1000s Ah
or
just a tiny Li battery that is being trickle
charged.

Alternative to Batteries

- Supercaps

Def. Farad F = A x s / V

1 F at 12 Volts:

1F x 12V = 12 As

100 F ==> 1200 As = 1/3 Ah

600 F ==> 1.8 Ah

1000 F ==> 3 Ah

biggest supercaps: ~ 5000 F / 15 Ah

in normal shops: 200 ... 600 F

- temporary storage in mechanical or thermal systems

  Discuss!

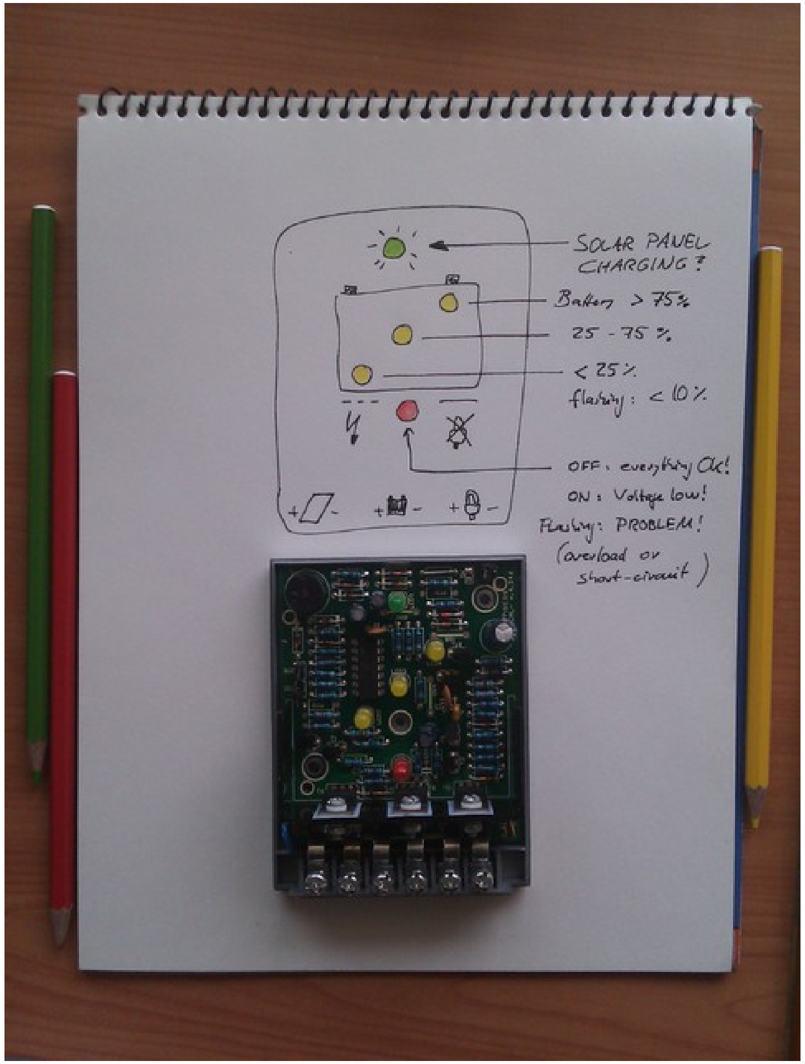
Example: 2 x 200Ah batteries

Charge Controller

Intelligent control of charging process

Capacity control

Power conditioning


SOLAR PANEL CHARGING ?
Battery > 75%
25 - 75 %
< 25%
flashing : < 10%
OFF : everything Ok!
ON : Voltage low!
Flashing: PROBLEM!
(overload or short-circuit)

Photovoltaic systems in all sizes

pv integrated in sensor node: Memsic Eko

Characteristics of a solar panel

- operating voltage
- peak power
- open circuit voltage
- short circuit current
- maximum current at nominal voltage
  --> power

Reminders ...

Voltage	U
Current	I
Power	P
Resistance	R

$P = U \times I$

$U = R \times I$

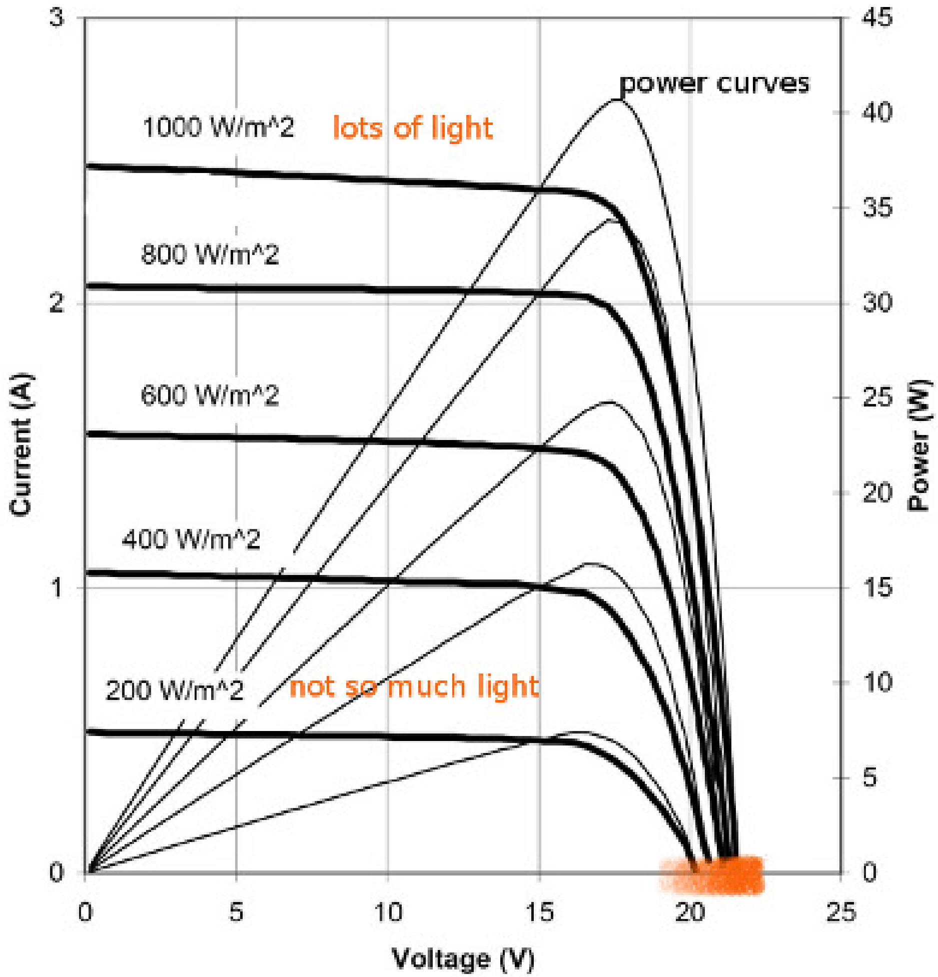
Example: open circuit voltage of a 12 volt panel

Characteristics of a solar panel

IV – curves:
voltage and current

P = I x U

MPP
Maximum Power Point



How much power can be generated?

2 main factors:

- Insolation – how much light we have
- Efficiency of conversion

Insolation maps

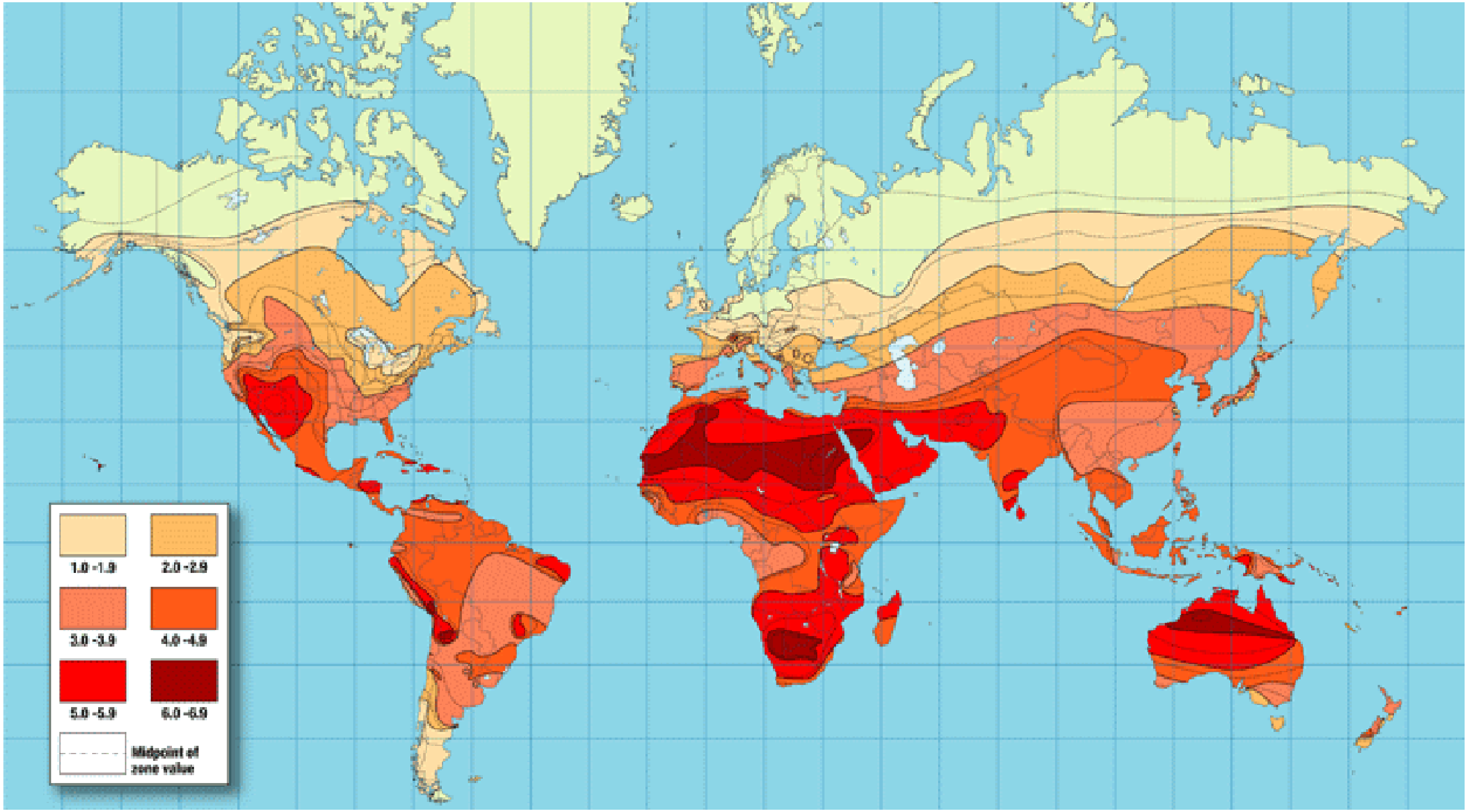
map influx of solar radiation energy,

e.g.

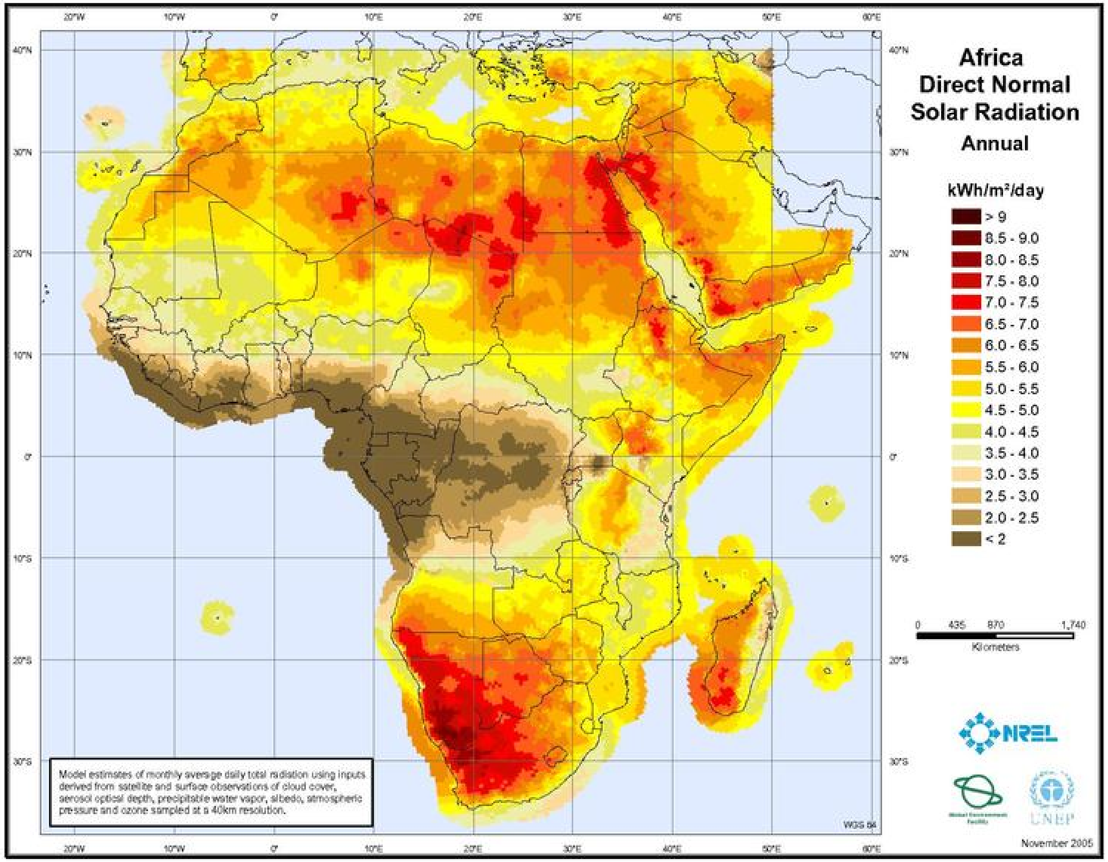
kW per square meter

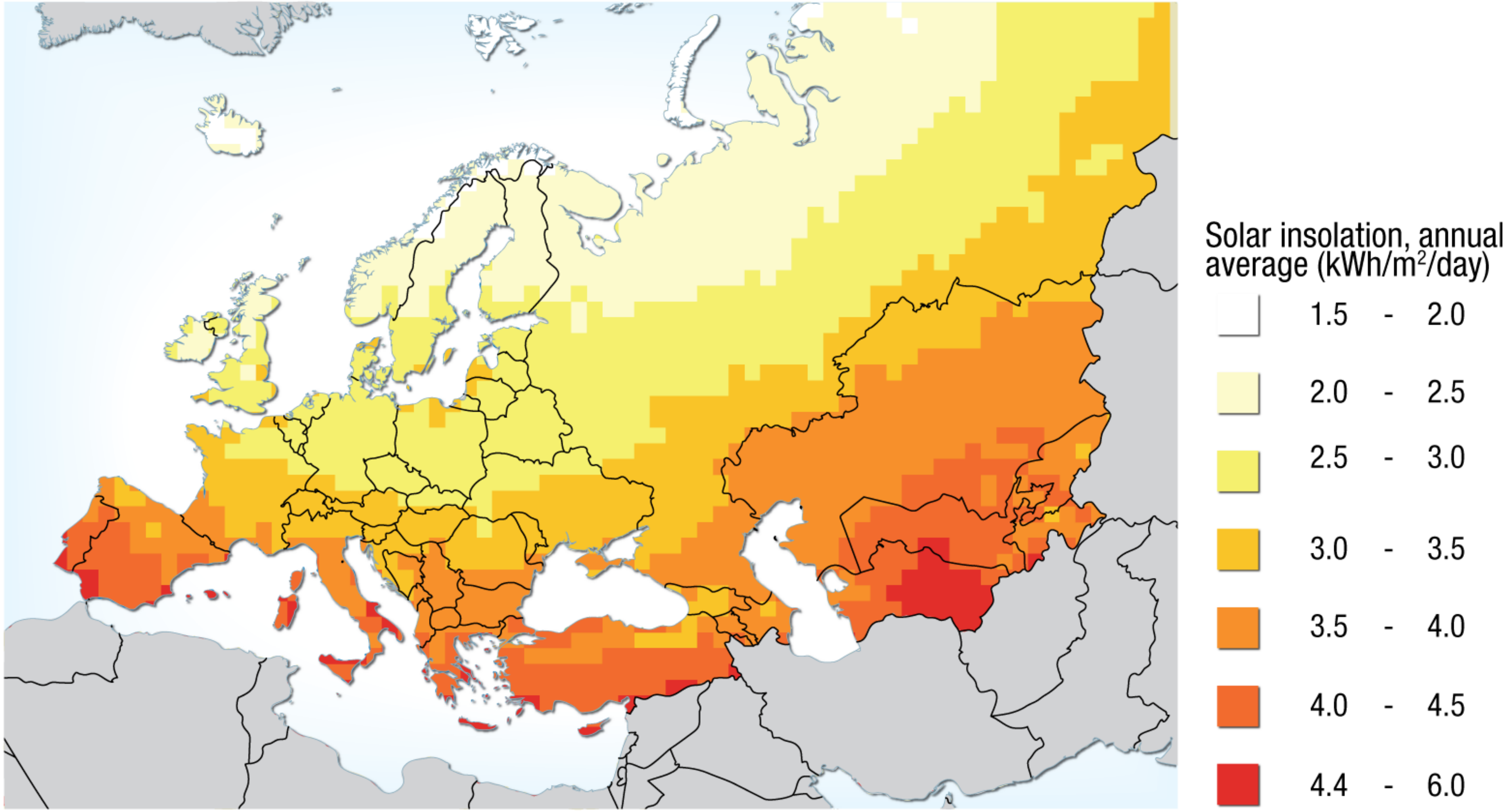
or

kWh per square meter and time


1.0 -1.9
2.0 -2.9
3.0 -3.9
4.0 -4.9
5.0 -5.9
6.0 -6.9
Midpoint of zone value

Artists view of Desertec plans


Africa
Direct Normal
Solar Radiation
Annual
kWh/m²/day
> 9
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2
0 435 870 1,740
Kilometers
Model estimates of monthly average daily total radiation using inputs derived from satellite and surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone sampled at a 40km resolution.
WGS 84
NREL
UNEP
November 2005


Solar insolation, annual average (kWh/m²/day)
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.0
4.0 - 4.5
4.4 - 6.0

Efficiency of solar cells

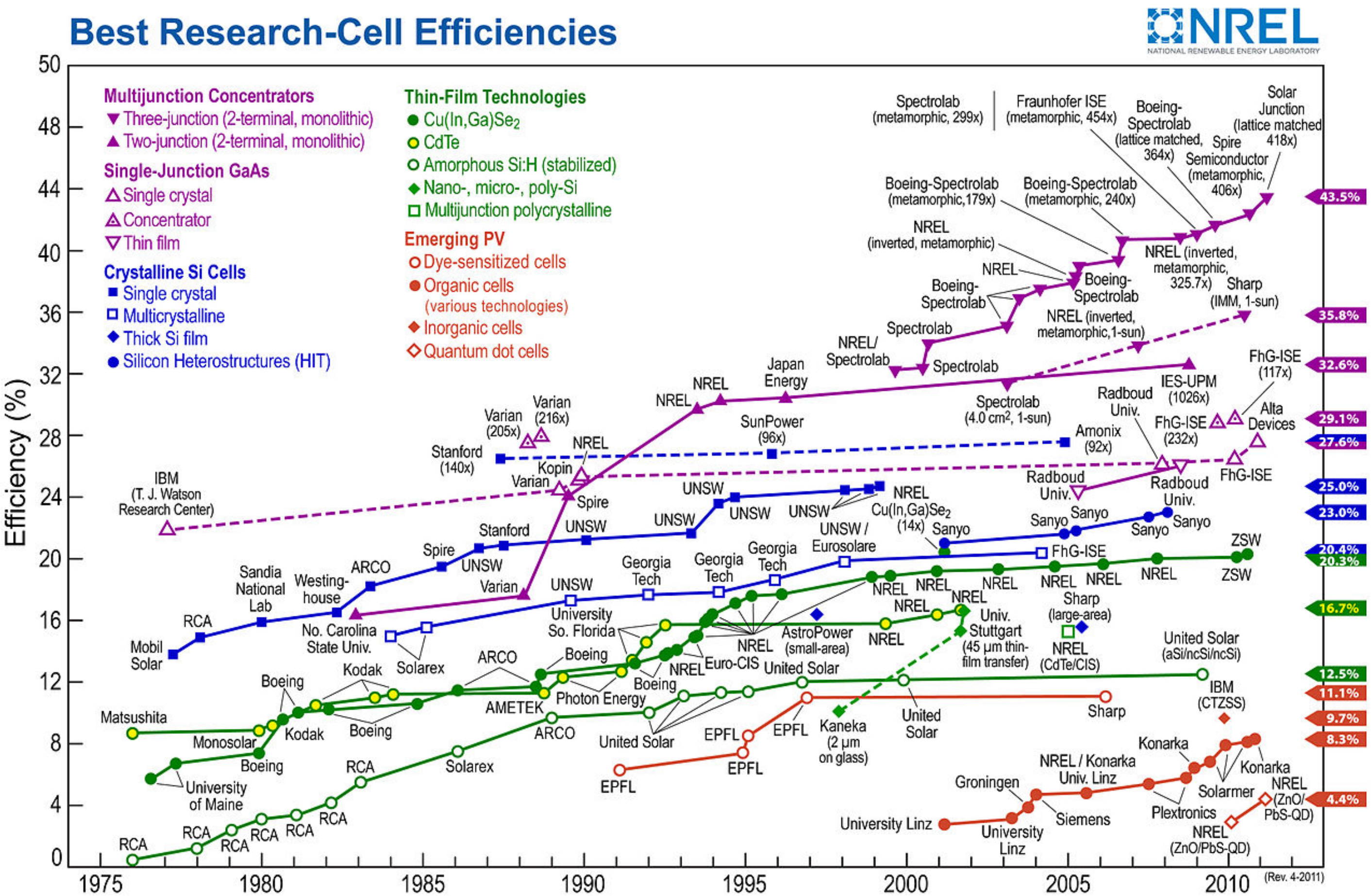
Cells currently available typically have
< 20 % conversion efficiency

Realistic values of monochrystalline cells:
approx. 15 %

Intense research to improve efficiency

Example: Measured Efficiency of commercial panels

Manufacturer Name	Module Model Number	PTC	Area (sqft)	PTC/ Sqft	Description
SunPower Corporation	SPR-230-WHT-U	209.5	13.395	15.64	230W Monocrystalline Module, White Backsheet
SunPower Corporation	SPR-225-BLK-U	201.9	13.395	15.073	225W Monocrystalline Module, Black Backsheet
Sanyo Electric Co. Ltd.	HIP-215NKHA1	199.6	13.486	14.801	215W HIT Power N Hybrid Amorphous/Monocrystalline
SunPower Corporation	SPR-220-WHT-U	198.2	13.395	14.797	220W Monocrystalline Module, White Backsheet
SunPower Corporation	SPR-220-BLK-U	197.3	13.395	14.729	220W Monocrystalline Module, Black Backsheet
Sanyo Electric Co. Ltd.	HIP-210NKHA1	194.9	13.486	14.452	210W HIT Power N Hybrid Amorphous/Monocrystalline
SunPower Corporation	SPR-215-WHT-U	193.5	13.395	14.446	215W Monocrystalline Module, White Backsheet
Sanyo Electric Co. Ltd.	HIP-205BA19	190.7	13.486	14.141	HIT Power 205W - Hybrid Amorphous/Monocrystalline
SunPower Corporation	SPR-210-WHT-U	189	13.395	14.11	210W Monocrystalline Module, White Backsheet
Sanyo Electric Co. Ltd.	HIP-205NKHA1	190.2	13.486	14.104	205W HIT Power N Hybrid Amorphous/Monocrystalline
SunPower Corporation	SPR-210-BLK-U	188.1	13.395	14.043	210W Monocrystalline Module, Black Backsheet
SunPower Corporation	SPR-205-BLK-U	183.6	13.395	13.707	205W Monocrystalline Module, Black Backsheet
Schuco USA LP	SPV 210 SMAU-1	192.1	15.766	12.184	210W Monocrystalline Module, Black Frame
Siliken California Corp	SLK60P6L 235 Wp	210.7	17.476	12.056	235W Polycrystalline Module
Siliken California Corp	SLK60P6L 230 Wp	206.1	17.476	11.793	230W Polycrystalline Module
REC ScanModule AB	REC230AE-US (BLK)	200.7	17.025	11.789	230W Polycrystalline Module, High Performance
Solon Ag Fuer Solartechnik	P220/6+/01 235Wp	208	17.653	11.783	235W Polycrystalline Module
Suntech Power Co.	STP280-24/Vb-1	246	20.908	11.766	280W Polycrystalline Module, MC Connectors
ET Solar Industry, Ltd	ET-P672270	241.8	20.908	11.565	270W Polycrystalline Module
aleo solar AG	S18.230	204.5	17.689	11.561	230W Polycrystalline Module
REC ScanModule AB	SCM225	196.5	17.025	11.542	225W Polycrystalline Module
Siliken California Corp	SLK60P6L 225 Wp	201.5	17.476	11.53	225W Polycrystalline Module
Solon Ag Fuer Solartechnik	P220/6+/01 230Wp	203.4	17.653	11.522	230W Polycrystalline Module
ET Solar Industry, Ltd	ET-P672265	237.1	20.908	11.34	265W Polycrystalline Module
Suntech Power Co.	STP270-24/Vb-1	236.9	20.908	11.331	270W Polycrystalline Module, MC Connectors
aleo solar AG	S18.225	199.9	17.689	11.301	225W Polycrystalline Module
Sharp Corporation	ND-U230C1	198	17.541	11.288	230W Polycrystalline Module, Locking Connector
Solartech Power Inc.	SPM230P	197.9	17.541	11.282	230W Polycrystalline Module
REC ScanModule AB	SCM220	192	17.025	11.278	220W Polycrystalline Module
Siliken California Corp	SLK60P6L 220 Wp	197	17.476	11.272	220W Polycrystalline Module


Best Research-Cell Efficiencies
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Efficiency (%)
Multijunction Concentrators
Three-junction (2-terminal, monolithic)
Two-junction (2-terminal, monolithic)
Single-Junction GaAs
Single crystal
Concentrator
Thin film
Crystalline Si Cells
Single crystal
Multicrystalline
Thick Si film
Silicon Heterostructures (HIT)
Thin-Film Technologies
Cu(In,Ga)Se2
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Multijunction polycrystalline
Emerging PV
Dye-sensitized cells
Organic cells
(various technologies)
Inorganic cells
Quantum dot cells
43.5%
35.8%
32.6%
29.1%
27.6%
25.0%
23.0%
20.4%
20.3%
16.7%
12.5%
11.1%
9.7%
8.3%
4.4%
(Rev. 4-2011)
1975
1980
1985
1990
1995
2000
2005
2010

Prices

World market prices have just reached
< \$ 1 / Watt
for midsize panels (approx 100 Watt) -
realistically, you will pay \$ 2 ... 5 / Watt

However, for WSN we are mostly looking at smaller panels, with higher price per Watt

Example:
small panels for
e.g. Arduino

	0.5w Solar Panel 55x70	$2.00
	1.5W Solar Panel 81X137	$6.99
	1w Solar Panel 75X100	$3.50
	2.5W Solar Panel 116X160	$12.90
	2w Solar Panel 80X180	$9.90
	3W Solar Panel 138X160	$14.90
	B-Squares (SOLAR-SQUARE)	$22.50

Dimensioning a pv system

First rule: **minimize load!**

Collect realistic data for
insolation, load, time characteristics, etc

Conservative approach to dimensioning

- Know your load
- Decide how much uptime without recharge you need (longest dark period)
- ==> Battery Capacity
- Decide how long it may take to recharge the battery
- ==> Solar panel size

Appendix: Dimensioning exercise

Dimensioning a photovoltaic system: First approximation

You could call this the "battery approach" - we start with

- looking at the total load of consuming devices
- how long we need to keep them running without sun -
- then we calculate the battery capacity and everything else from there.

All numbers here are of course just examples – total load, insolation hours and other factors will be different from case to case!

To start, we need to know two things:

Total Load at 12 Volts [W]: e.g. 20 Watt (==> 1.7 A)

Days of Autonomy, that means: how long we can run without sun:

we will say 3 days a 8 hours a day ==> 24 hours.

These two lead us to ...

*Total Battery Capacity needed [Ah]: 40 = 24 h * 1.7 A*

However, no battery should be discharged completely ever - the maximum discharge depends on the type of battery. Read your data sheet!

What is the maximum discharge level of the batteries? e.g. 50%: 50%

With this correction, we get …

Total Battery Capacity needed [Ah]: 80

Now that we know the battery capacity, we need to know how many days we allow for full recharging, once the sun is shining

Maximum time for recharging [days]: 1

How many hours of sun on an average day? 5

This gives us the total power of the solar panels needed – we will need to have 40/5 A flowing into the battery

We need this many Watts from the 12 Volts panels: 60 Watt!

60 Watt of panels to power 20 Watt of consumer devices, for some of the time.

And we are only using it 8 hours a day, and have not been demanding a long autonomy phase.

For nonstop operations, it would be approximately 200 Watts!

Let us look at the same system from a different angle.

Dimensioning a photovoltaic system: Second approximation

This is the "worst month approach", simplified. That means, we will

- calculate how much energy (power x time) we need per month
- take the month with the least sun
- see how many solar panels we need to generate the needed energy in that worst month

Again , we need to know the ...

Total Load at 12 Volts [W]: 20

How many hours per day do we need our devices running? 8

this tells us, how many AmpHours will be needed:

[redacted]

*Total AmpHours per month: 400 (30 days * 8 hours * 1.7 A)*

What are the average sunshine hours in the worst (darkest) month of the year?

150 (i.e. 5 hours a day ... a sunny climate)

These hours will have to be enough to generate the same amount of AmpHours we found above – this tells us how many watts of solar power we need:

Total Watts of 12 V Solar Panels: 32 Watt

Now we still need to know our battery capacity – again based on:

Days of Autonomy, that means: how long we can run without sun: 3

and

The maximum discharge level of the batteries? 50

This results in

Total Battery Capacity 50 Ah

This second approach leads to a far more optimistic result - only 1/2 of the solar panel power needed.

Discuss!

Why is this the case?

What does the "worst month model" neglect?