



D-Lab: Energy

Week 4: Solar

Estimation

How big a solar panel do you need to power a 100W incandescent light bulb?

Solar Rules of Thumb

solar flux: 1 kW/m^2

PV efficiency (best case): 10-20%

➠ 100 W/m^2

Solar Options

SODIS: water disinfection

Solar Thermal

- cooking/drying
- water heating
- generating electricity

PV: generating electricity

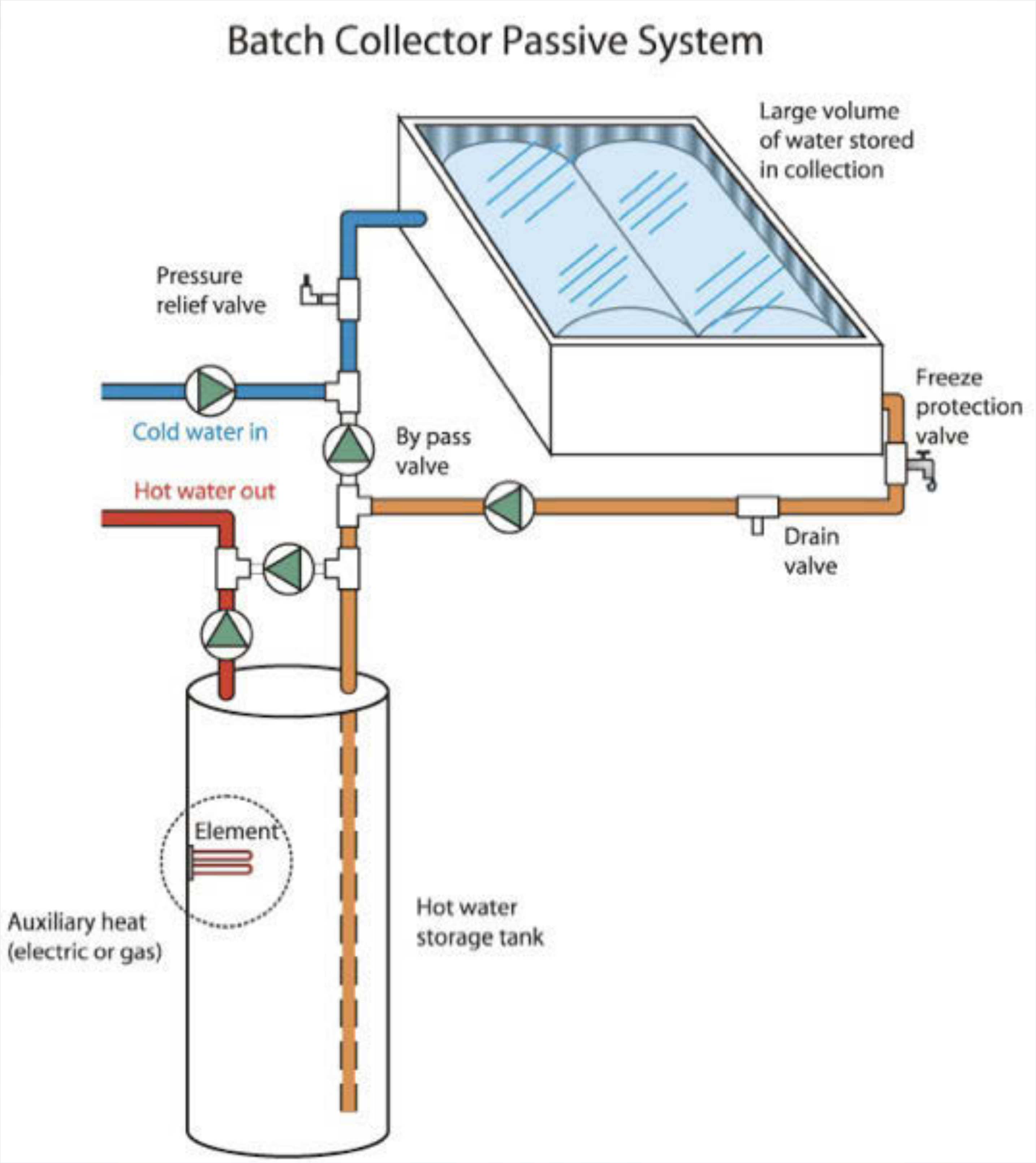
Solar drying

Fruits of the Nile - Uganda

http://www.fullwellmill.co.uk/partners/fon.htm

Solar Thermal Panels

for water heating



Courtesy of Southface Energy Institute. Used with permission.
Source: http://www.southface.org/learning-center/library/solar-resources/how-solar-thermal-works.

Luz Project in Mojave Desert, CA

largest solar thermal-electric installation in the world
350MW peak output

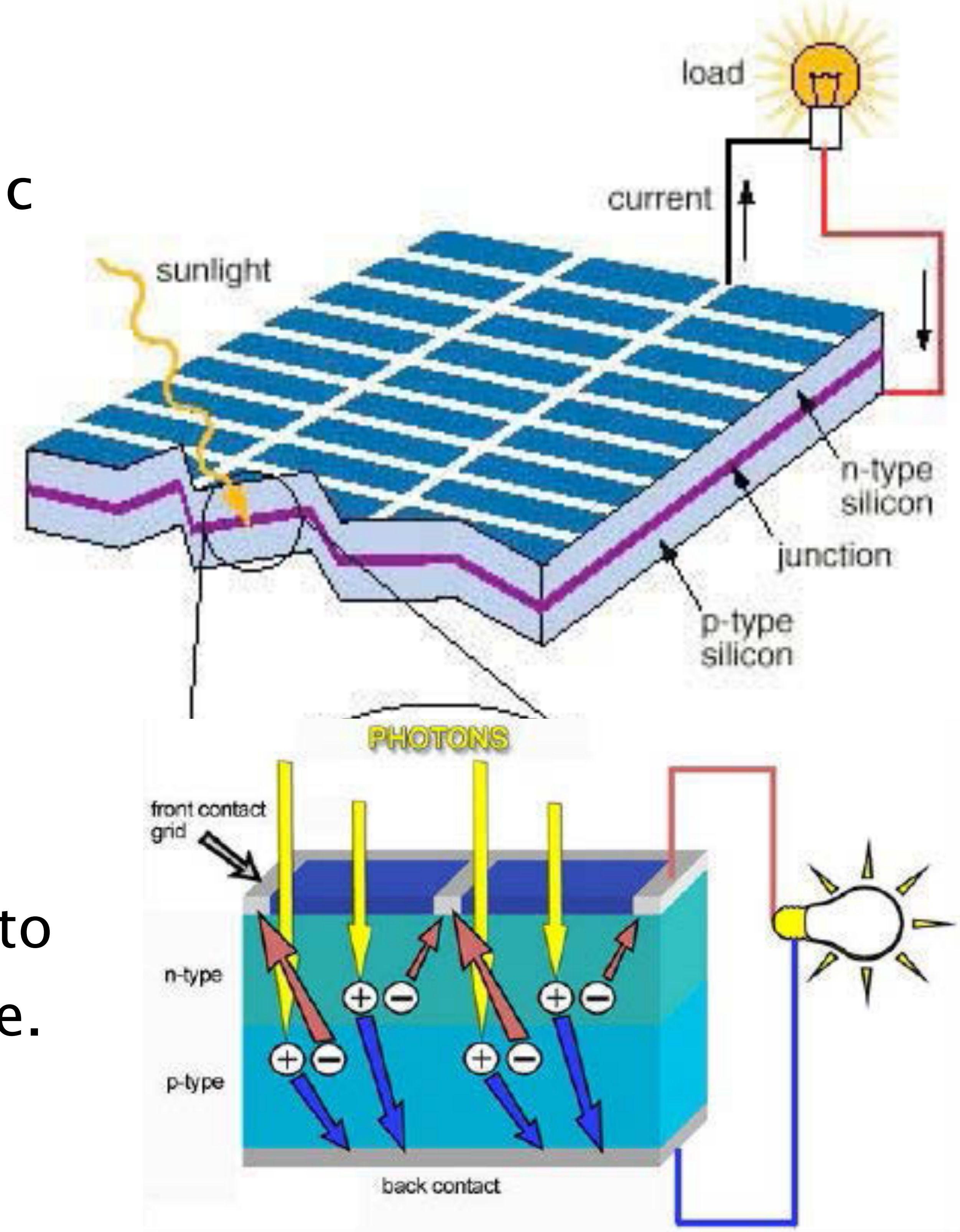
generates high-temperature steam using arrays of concentrating mirrors. steam powers a turbine that drives a generator to produce electricity

Overview of Photovoltaics

Matthew Seitzler, M.S., E.I.T.
www.SRE-Engineering.com

How do photovoltaics work?

- Light is converted to electricity via photovoltaic effect in silicon.
- Materials have difference eff. and costs.
- 3-25% of light is converted directly into electricity.
- Dependent on the intensity of light normal to the surface of the module.



Many photovoltaic materials, all wil pros and cons

- crystalline silicon
  - monocrystalline
  - polycrystalline
  - multicrystalline
  - ribbon silicon
- amorphous silicon
- cadmium telluride
- copper indium selenide/sulfide
- organic cells

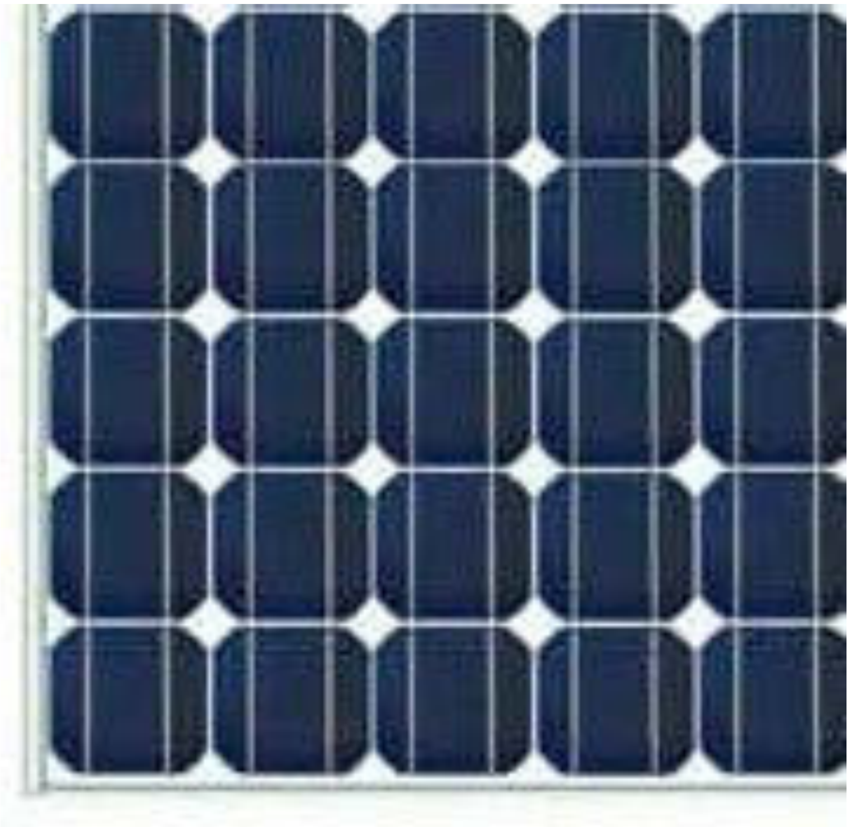
How do photovoltaics work?

Solar cells (~0.5V) are wired together to obtain module (panel) voltage (5-31V).

Modules are wired together depending on solar electric system type to form array (15-1000V).

Module power values include efficiencies.

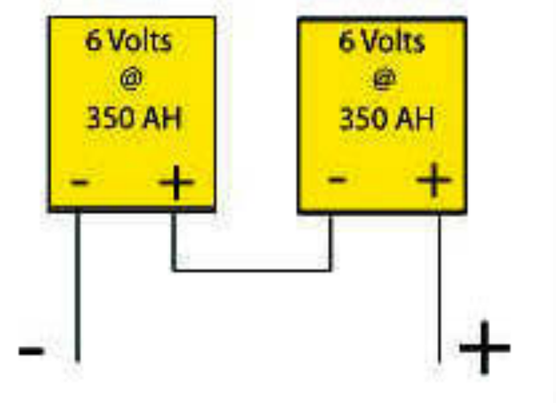
Sensitive to temperature.



Section of 200 W Solar Module

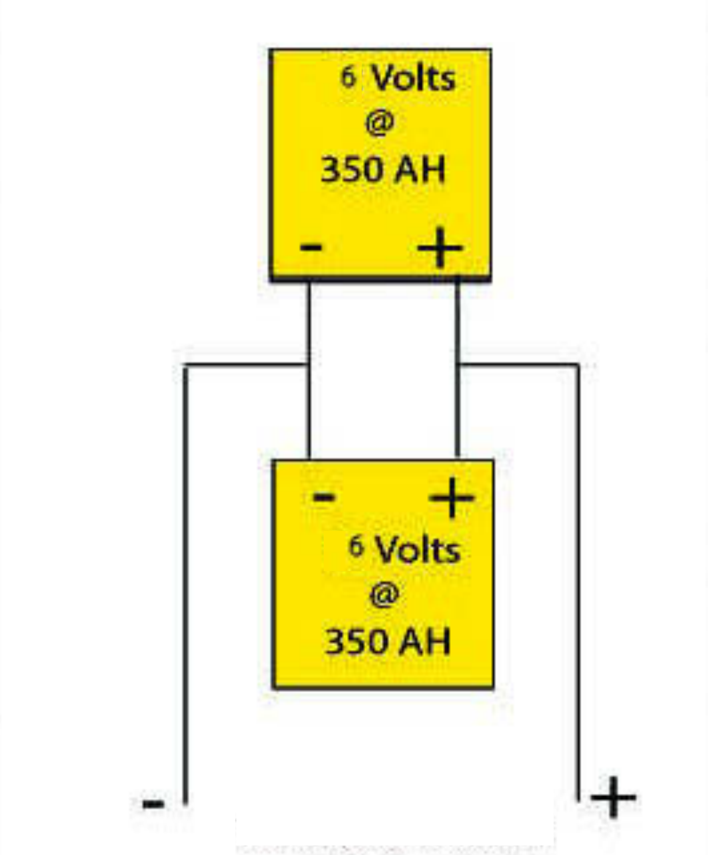
Series vs. Parallel Wiring

SERIES



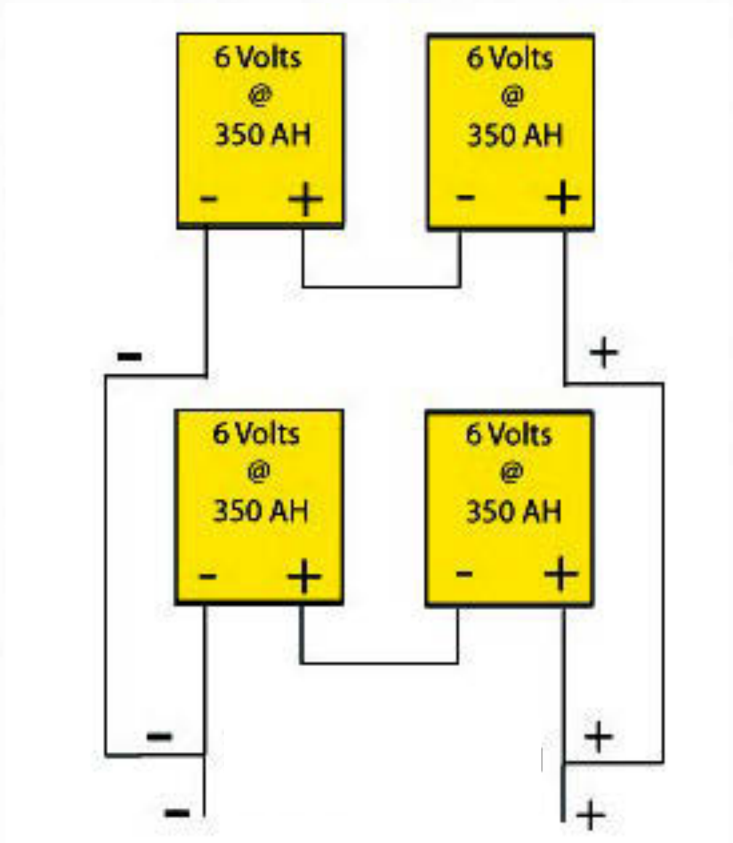
12 Volts @ 350 Amp hours.

PARALLEL



6 Volts @ 700 Amp hours.

SERIES/PARALLEL



12 Volts @ 700 Amp hours.

Solar Electric System Components

Typical Components:

- Solar Panel or Module (3–20%)
- Solar Regulator or Charge Controller (90–95%)
- Battery (80%)
- Power Inverter (90–97%)
- DC Disconnect
- Fuses

Stand-alone PV system components

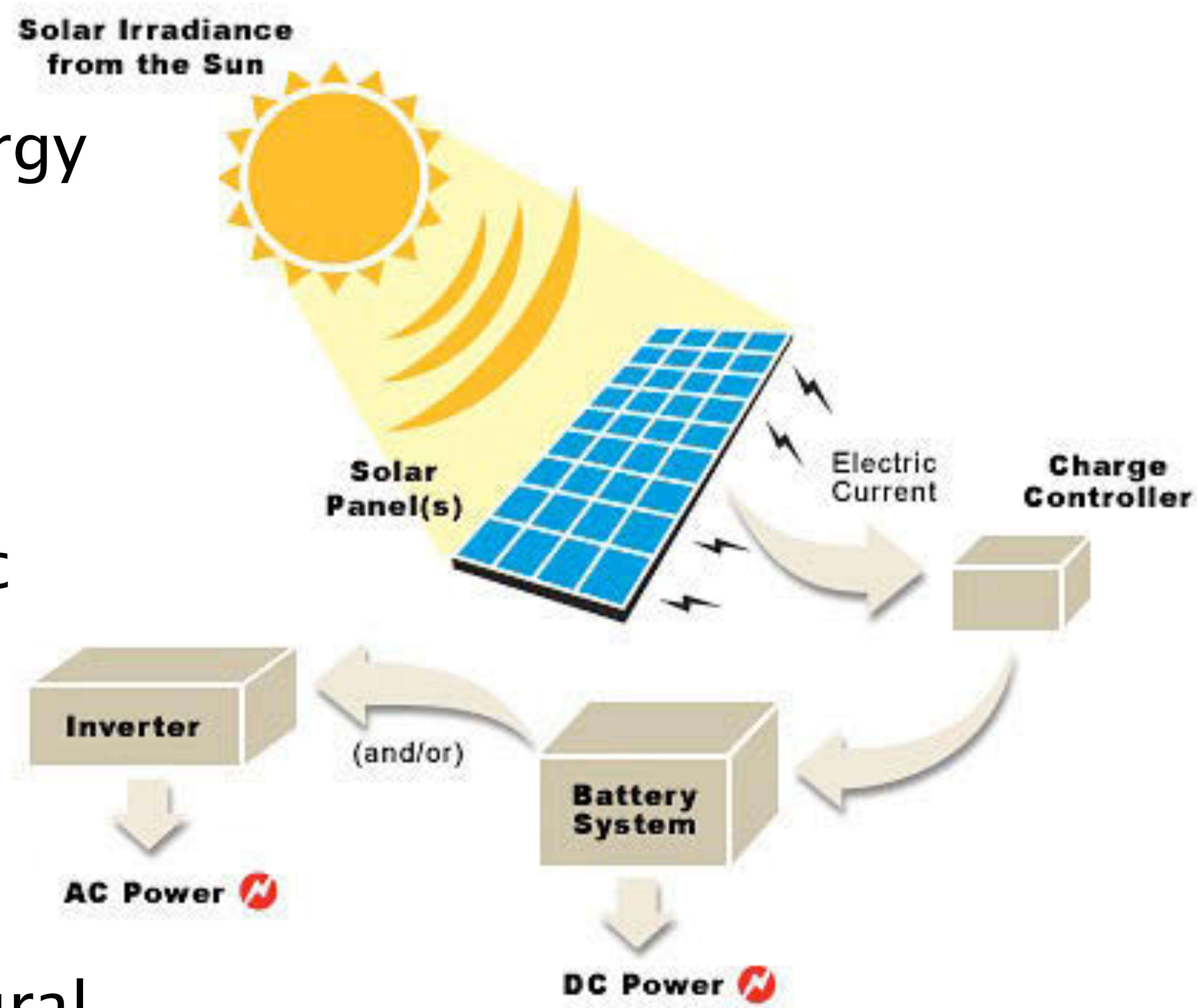
Common PV system types

- Grid-tied PV systems
- Stand alone or autonomous systems
- Hybrid PV

Common PV system types

Stand alone systems

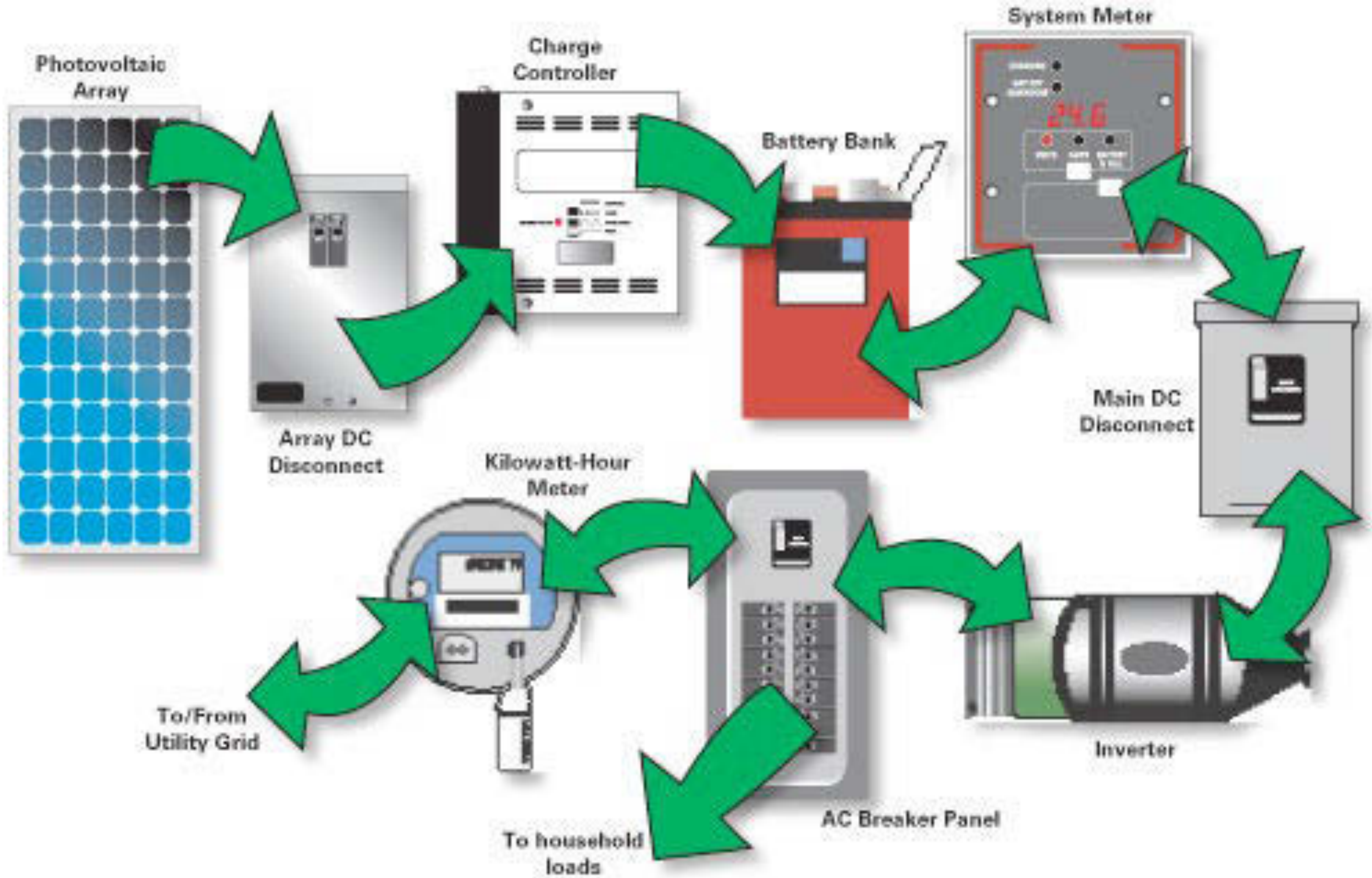
- Direct or stored PV energy possible
- System is completely autonomous i.e. not connected to an electric grid
- Like a mini-grid
- Lower system voltages
- Typically deployed in rural



Common PV system types

Islanding (Hybrid) systems

- Connected to the utility grid
- Battery bank used to store energy
- Energy from battery bank fed to grid
- Uses lower array voltages



PV System Examples

Bangladesh stand-alone PV system

Masdar 10 MW Solar array

Load and Energy Use Estimation

Incandescent lights	60 - 150 W (per bulb)
Fluorescent lights	15 W (per tube)
Laptop com-puter	20 - 40 W
Desktop com-puter	150 - 200 W
Stereo system	20 - 50 W
Washing machine	600 - 1,000 W (includes heating the water)
Dryer	4,000 - 6,000 W
Air conditioner	4,000 - 6,000 W
Oven	8,000 - 12,000 W
Microwave	750 - 1200 W
Refrigerator	500 W
Telephone	2 - 5 W
Television	80 - 100 W
VCR	20 - 50 W
Hair dryer	1000 - 1500 W

Design Application

Problem:

- Can I power my small 110 volt AC 75 watt refrigerator for three hours during a day with 5 sun hours using a 12 volt, 100 amp hour battery and a 100 watt solar module?
- To prevent destroying the battery I do not want to go lower than 70% discharge.
- Assume system efficiencies of 80% for the battery conversion, 95% charge controller, 95% for the inverter.

What type of system is this?

Design Application

Tools:

- Ohm's Law:
  - Voltage (V) = Current (I)*Resistance (R)
- Electrical Power Equation:
  - Power (P) = Current (I)*Voltage(V)
- Solar Energy International PV Design Manual
- Friends in PV.

Design Application

I. Resource Estimation

Known:

100 watt[1] module, 5 sun hours per day

Calculate Resource:

Energy = 100 W*5 hrs/day =500 Whrs/day

Include Charge Controller Eff.:

Energy = 500 Whrs/day*0.95 = <u>475 Whrs/day</u>

1. Nominal value (P_{nom}) from manufacturer for standard testing conditions.

Design Application

II. Load Determination

Known:

75 W frig, 3 hours per day

Calculate Load:

Load = 75 W*3 hrs/day =225 Whrs/day

Calculate Load with inverter eff.:

Load = 225 Whrs/day/0.95 [2] = 236 Whrs/day

Note: Inverter size should be 1.25 times surge load for frig.

2. Eff. in devisor because of load or demand side computation.

Design Application

III. Energy Storage

Known:

100 Amp*hr battery, 80% eff., with 70% allowable discharge

Calculate Storage Capacity:

1. Convert to kWhrs

   100 Amp*hrs*12 Volts =1200 Whrs

2. Include eff. & allowable discharge

   1200 Whrs*0.70*0.80 = 672 Whrs*

*Estimated value not including battery degradation overtime.

Design Application

IV. Energy Balance

Known:

Resource = 475 Whrs/day

Load = 236 Whrs/day

Resource side:

- Resource > Load ? Yes, Load is only ~50% of Resource

Storage side:

- Storage > Load ? Yes, Load is only ~35% of Resource

Design Application

IV. Limit Calculations

Days of Autonomy (D_{auto}):

- D_{auto} = Storage/Load

  D_{auto}= 672 Whr/ 236 Whr/day =~ 2.8 days

Days to charge battery (D_{bat}):

- D_{bat} = Storage/Resource

  D_{bat} = 672 Whr/472 Whr/day =~1.4 = 2 days

- Actual values depend on load and resource timing.

Design Application

Conclusion

- Can provide energy to load based upon solar resource.
- Energy surplus per day predicted.
- System can run off battery for at least a day if needed.
- System needs at least two days (without load) to fully recharge.

Resources:

Hypothetical US grid PV: PVWATTS

http://www.nrel.gov/rredc/pvwatts/

~Natural Resources of Canada, RETSCREEN

Solar Energy International, PV Design and Installation Manual.

Surface meteorology and Solar Energy

A renewable energy resource web site (release 6.0)
sponsored by NASA's Earth Science Enterprise Program

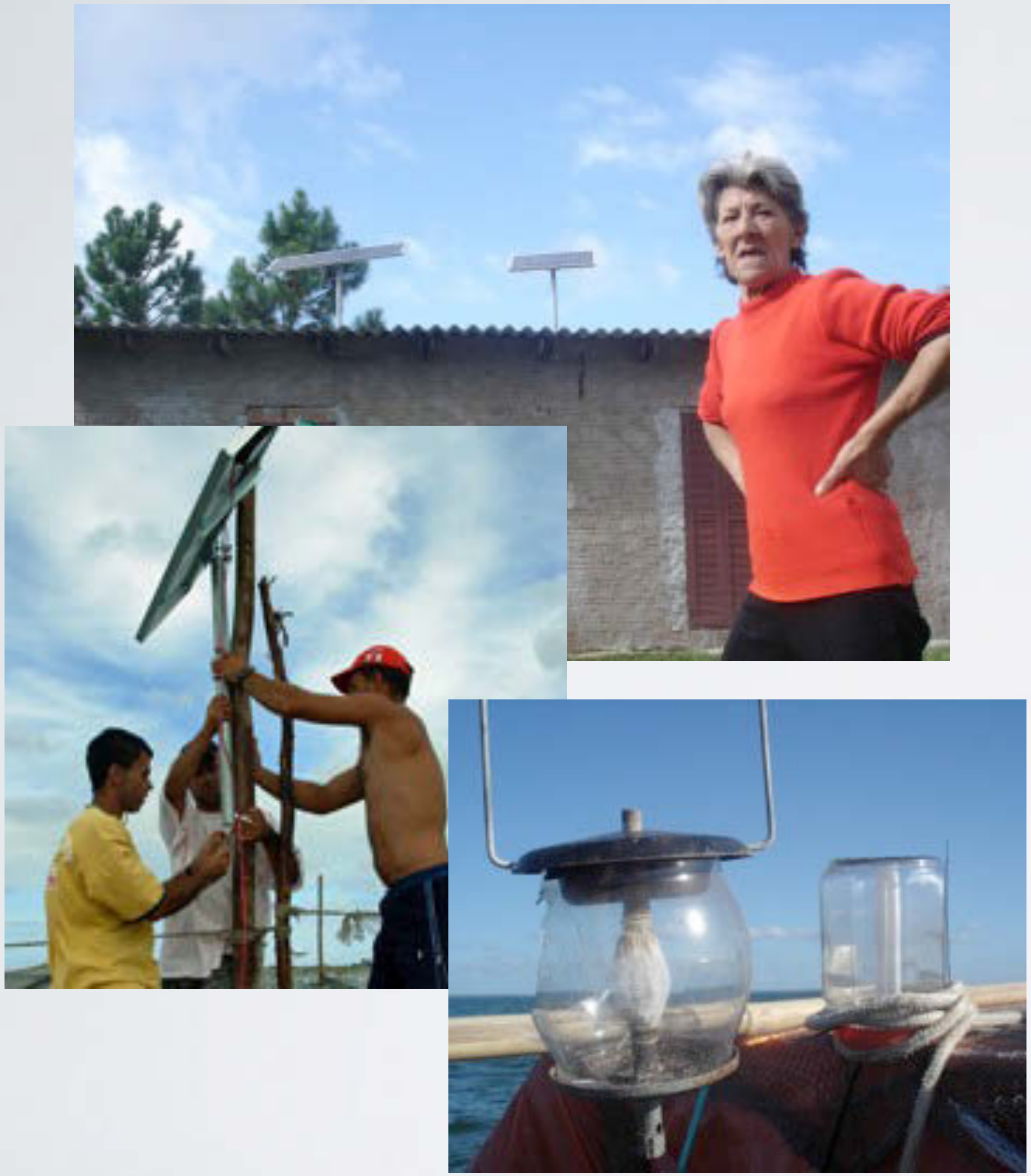
http://eosweb.larc.nasa.gov/sse/

Developing World Applications

Grameen Shakti

Tea shop, woman technicians and mobile phone shop (www.gshakti.org)

IDEAAS - Brazil



Courtesy of Francisco Noguera. Used with permission.

- Fee for service
  - Company responsible for care of battery
- Flexible payment system
  - Customer determines timing/ size of payment
- User education
  - Tools for teaching illiterate customers to care for own systems

Solar customer, installation, and lights for shrimp boats

SELCO - India

Lighting for a temple, silk cocoon sorting, and solar installation www.selco-india.com

Courtesy of SELCO Solar Pvt. Ltd. Used with permission.

D.Light Design

www.dlightdesign.com

Courtesy of STG International. Used with permission.

STG

Focused on Lesotho, MIT project, solar-thermal power technology solution: parabolic troughs, the organic Rankine cycle (ORC) engine, and the electrical control system

EC.711 D-Lab: Energy
Spring 2011