Solar Electric Fundamentals

Photovoltaics (PV) or Solar Electric

- Direct conversion of sunlight into dc electricity.
- Solid-state electronics, no-moving parts.
- High reliability, warranties of 20 years or more.
- PV modules are series- and parallel-interconnected to meet the voltage and current requirements.
- Energy storage (battery) is needed for nighttime operation.

Basic Electricity Terms

- **Ampere** (Amp, A) – Basic unit of electric current, like the flow of water in a pipe.
- **Volt** (V) – Basic unit of electric voltage (potential), like the pressure of water in a pipe.
- **Watt** (W) – Basic unit of electric power.

  1 Volt X 1 Amp = 1 Watt
- **Watt-Hour** – Basic unit of electric energy.

  1 Watt for 1 hour = 1 Watt-hour (Wh)

  100 Watts for 10 hours = 1 kiloWatt-hour (kWh)

Outline

- Solar Industry Status
- Solar Electric – Systems View
- Solar PV Technology
- Stand-alone Off-grid Applications
- Grid-connected Applications
- Intro to Hybrid Systems
- Solar System Analysis Tools

Outline

- **Solar Industry Status**
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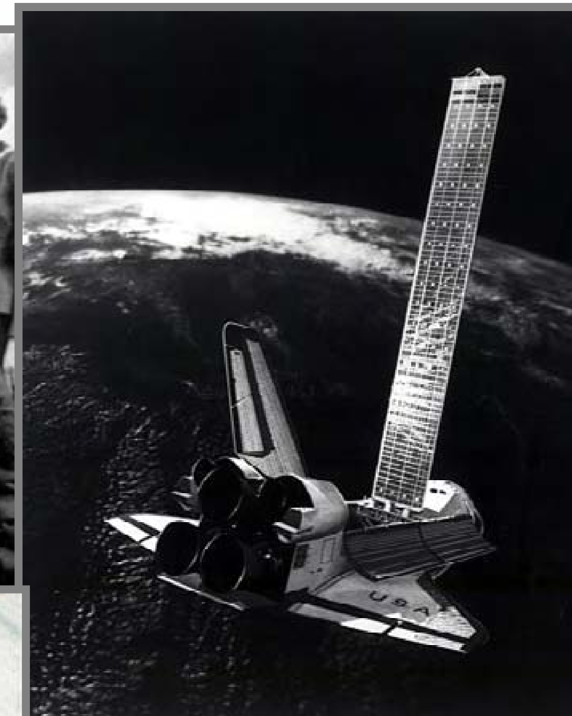
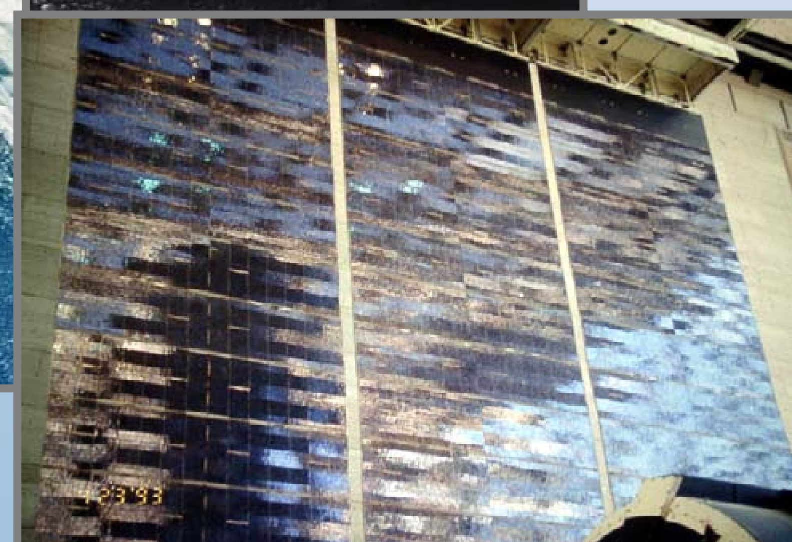
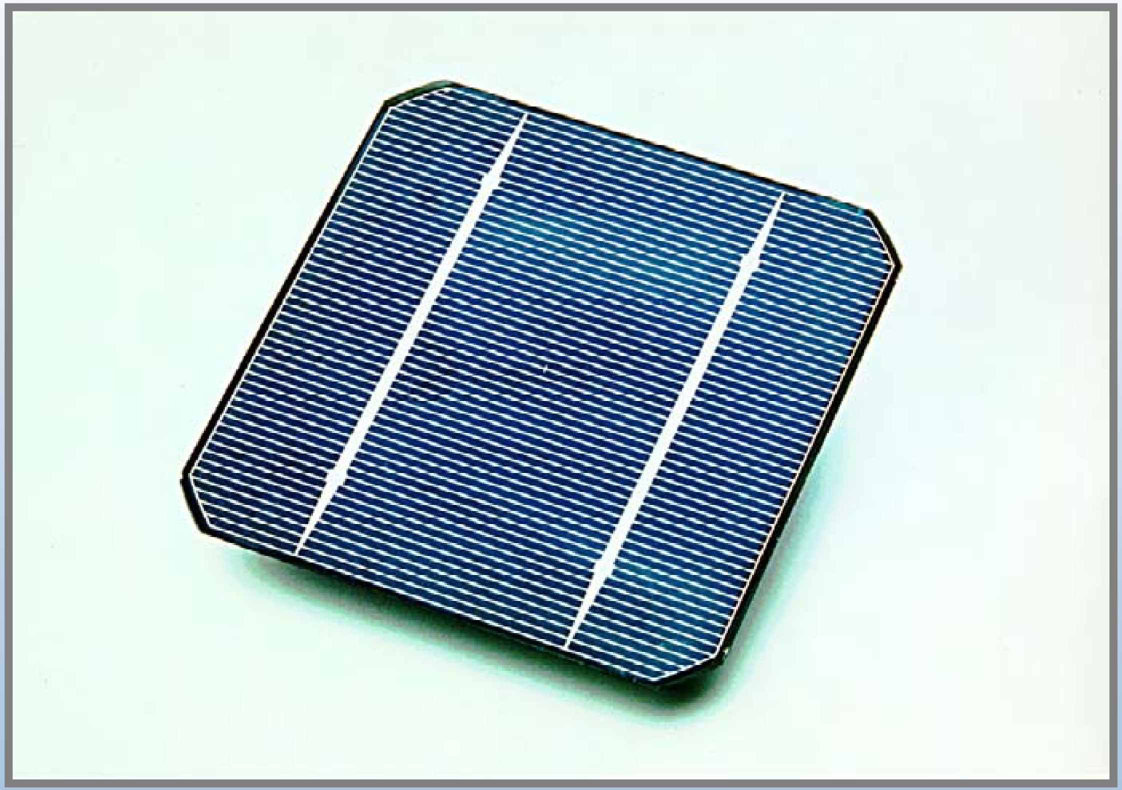
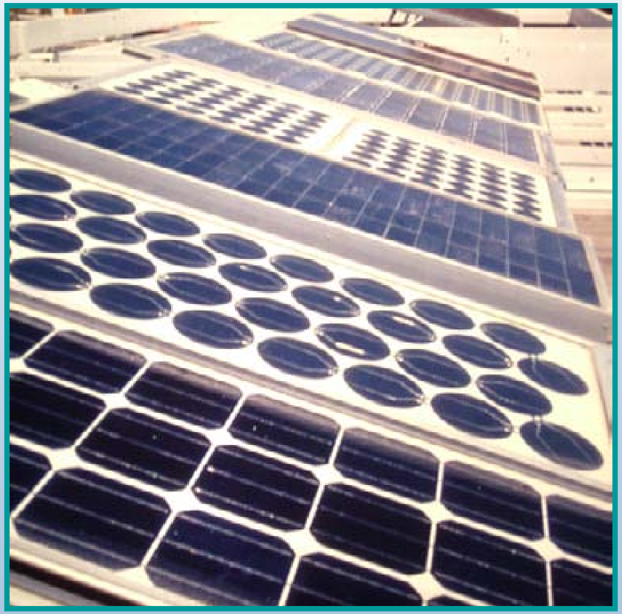

USA

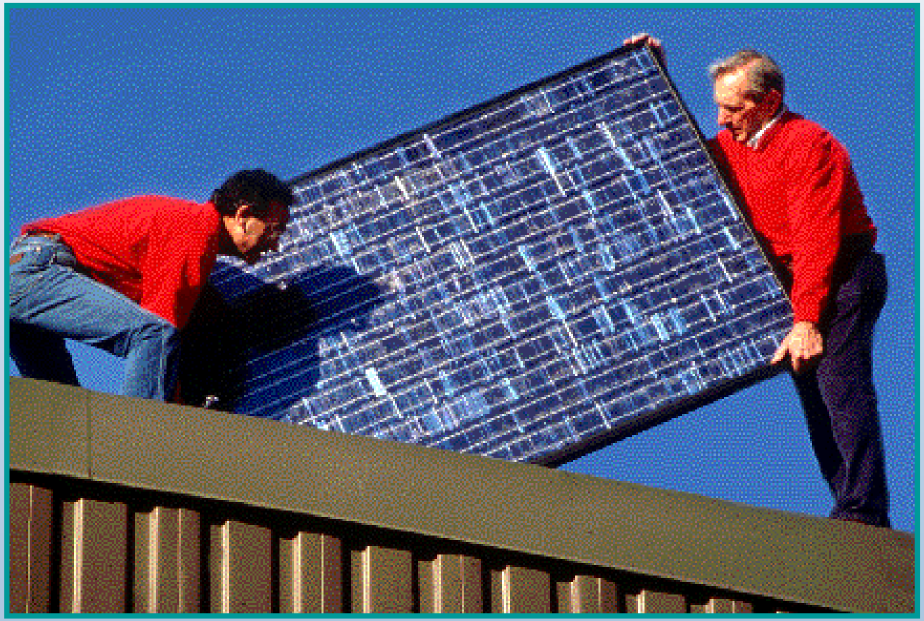


A typical solar cell (10cm x 10cm) generates about 1W at about 0.5V.

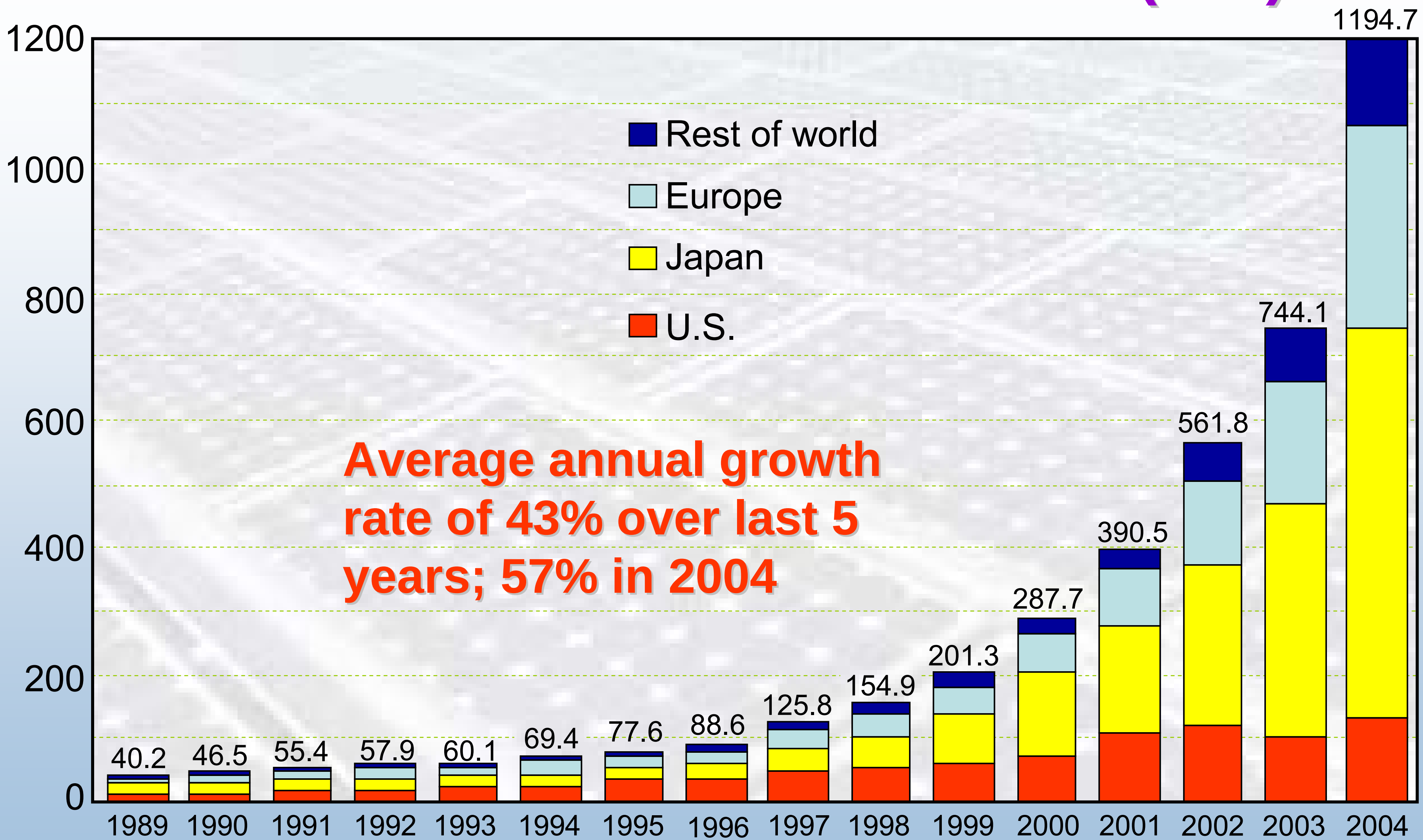


Individual cells are connected in series (increases the voltage) and in parallel (increases the current) into a module.





World PV Cell/Module Production (MW)



Source: Paul Maycock, *PV News*, February 2005

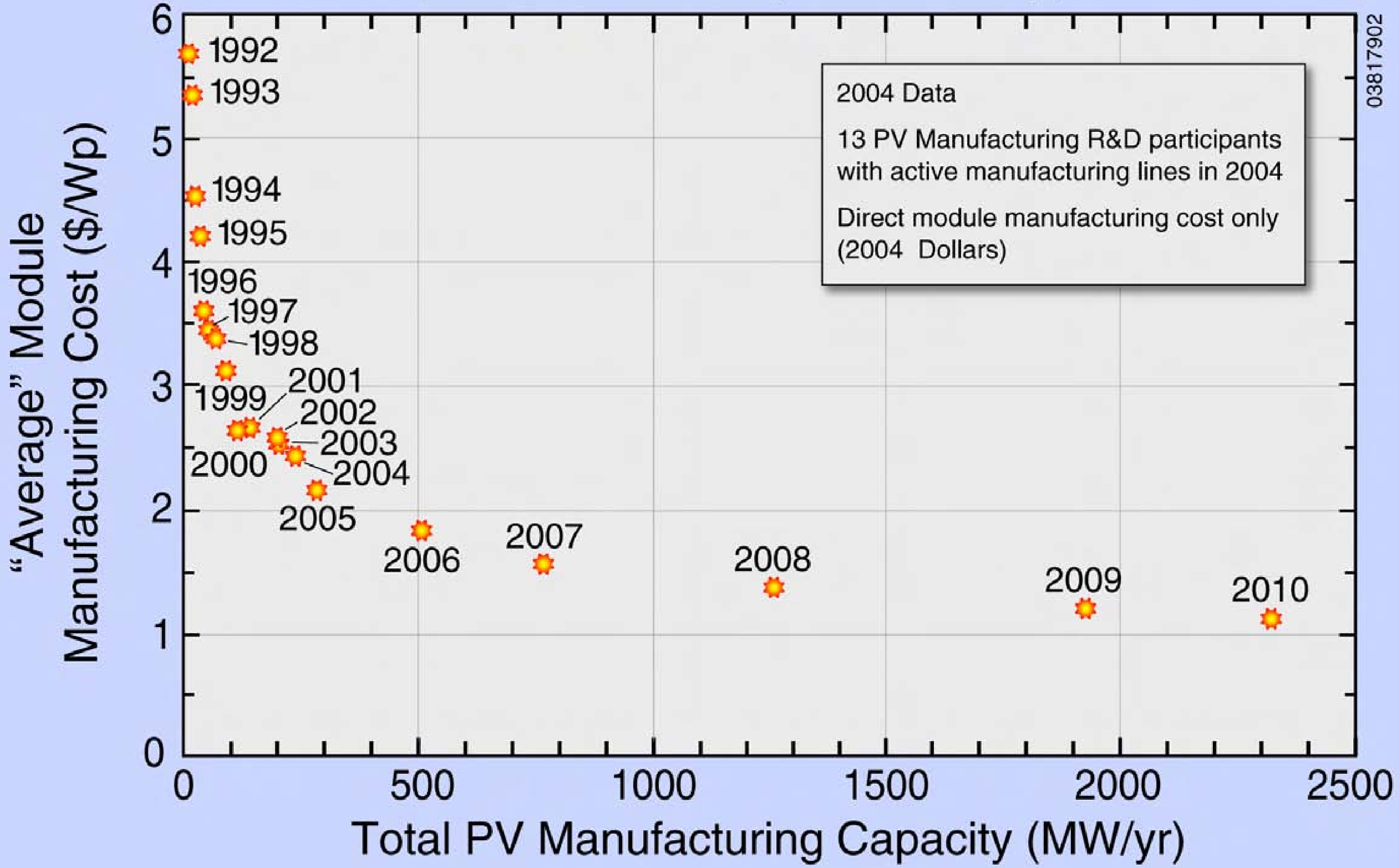
026587210

NREL National Renewable Energy Laboratory

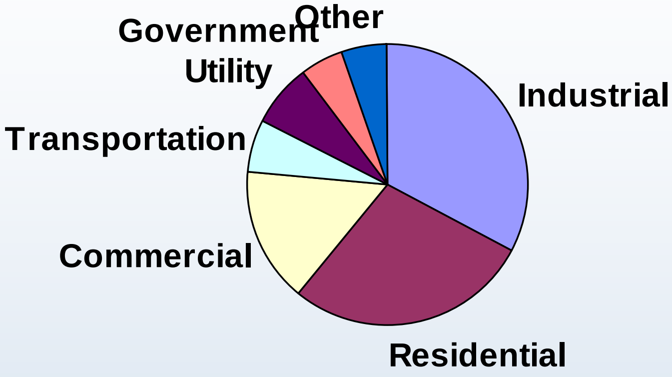
Crystalline Silicon, Thin-Films, and Concentrators

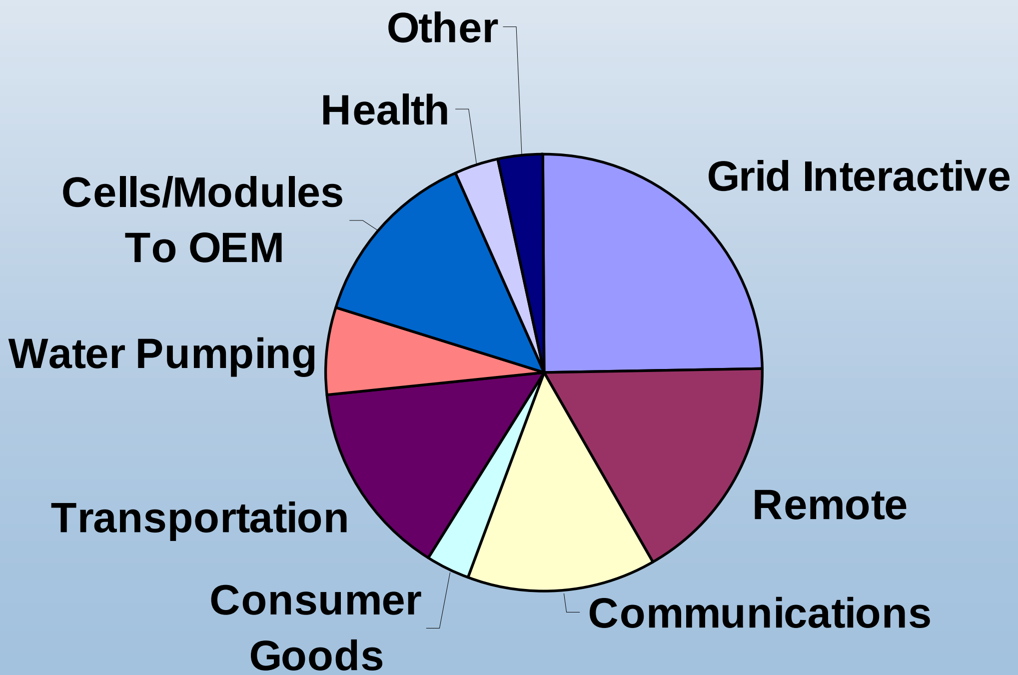
PV Industry Cost/Capacity

(DOE/US Industry Partnership)



PV Markets





- Most Cost Effective:
  - Small Loads
    - Emergency Call Boxes
    - Irrigation Controls
    - Sign lighting
  - Avoided Line Extensions ($20k to $100k/mile)
    - Water Pumping
    - Residential
  - Remote Diesel Generators ($0.19 to $1.68/kWh)

2001 EIA data

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Simple Direct Drive PV System

What determines the system design?

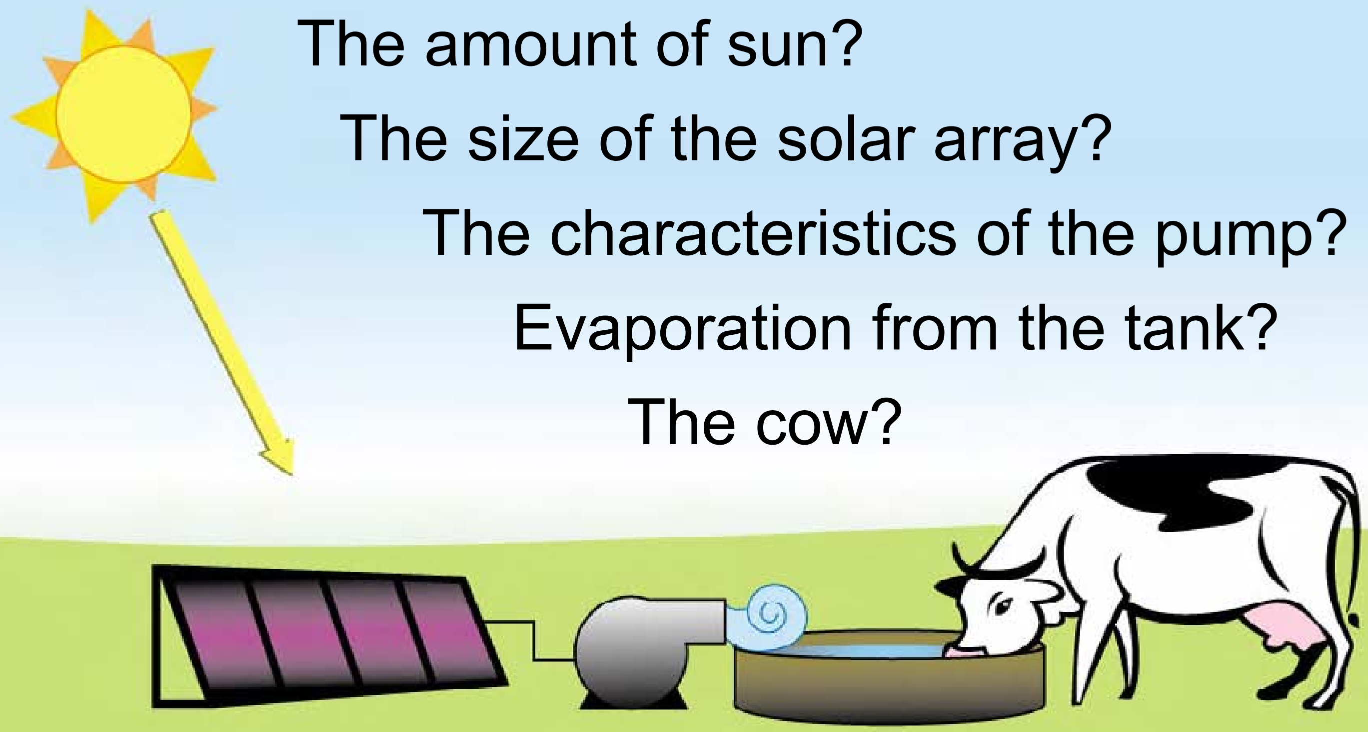
The amount of sun?

The size of the solar array?

The characteristics of the pump?

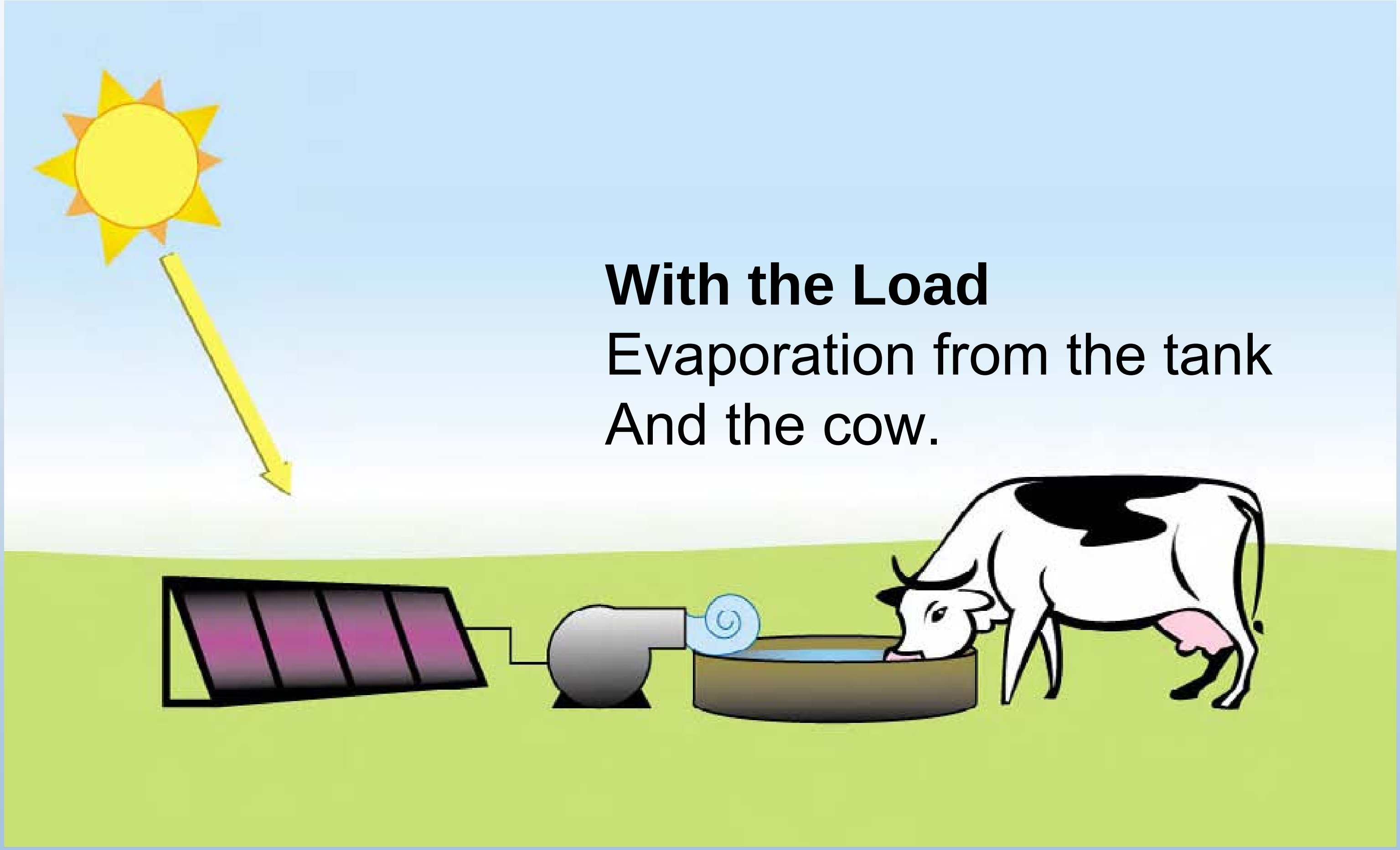
Evaporation from the tank?

The cow?



Simple Direct Drive PV System

Where do you start in a system design?



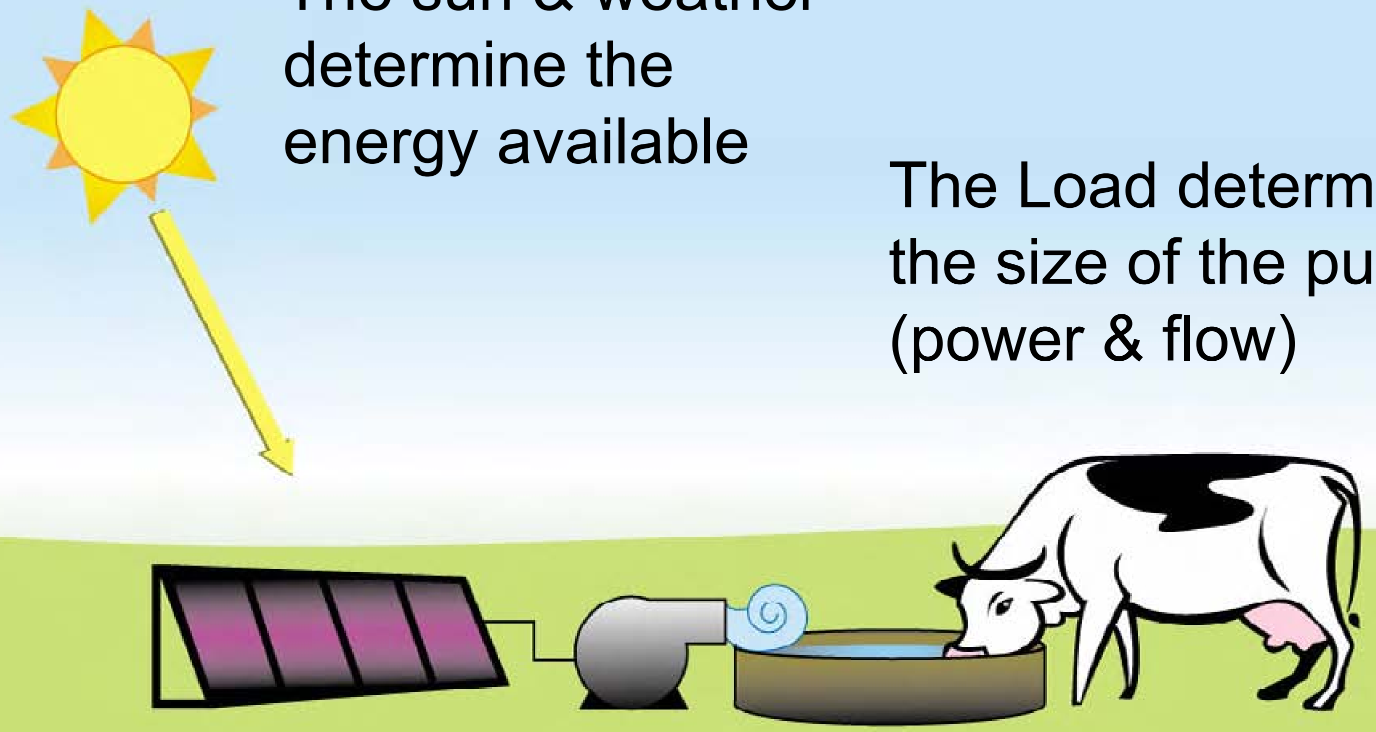
With the Load
Evaporation from the tank
And the cow.

Simple Direct Drive PV System

Simplified Design Process

The sun & weather determine the energy available

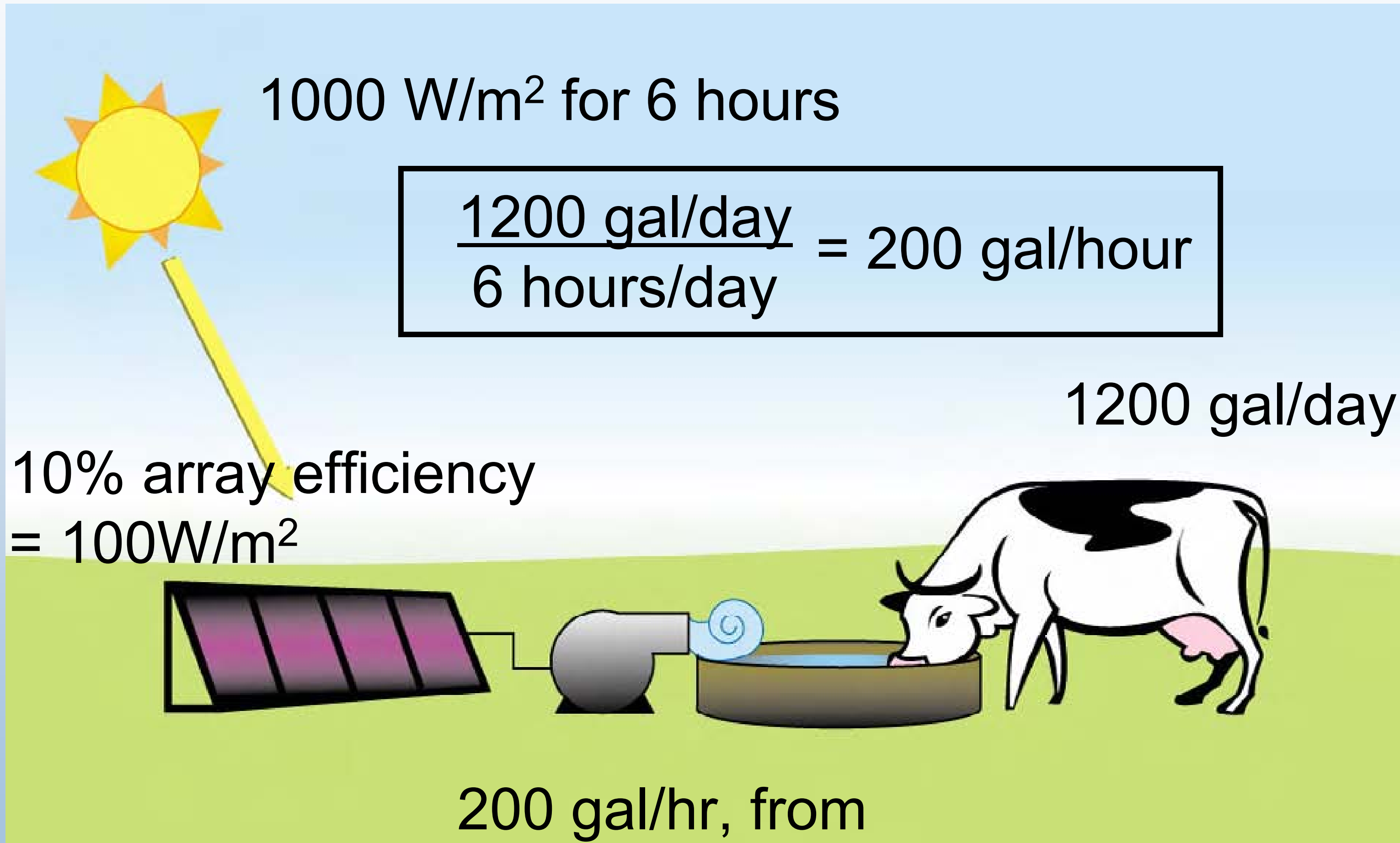
The Load determines the size of the pump (power & flow)



The solar array is sized to deliver the needed energy in the time available.

Simple Direct Drive PV System

What is the PV array size?



Load Determination 1st Step in Dedicated System Design

- Identify all energy needs, then diversify
- Chose high efficiency appliances
- Add up all power and calculate energy needed per day
- Determine what loads are right for Solar
- Chose structures and enclosures
- Use maximum power to size wire, switchgear, & inverter
- Use energy requirements and environment to size batteries
- Use distances & specific appliances to determine phase & voltage

Design Basics

- dc motors make simplest systems; PV modules heart of the system.
- Non-grid remote systems like lights, communications, etc. require energy storage (batteries); batteries are the heart of the system.
- Complex loads like remote homes may require other generators and inverter; inverter is the heart of the system.
- All designs start with the electrical (load) requirements.

Design Basics

- Total daily (use cycle) energy must be known or best estimate in kWh/cycle.
- Largest power level must be known to determine wire size, safety gear, inverter specifications, etc.
- Required system availability must be established.
- Site specific resources must be determined.......resource maps and the like are not usable for design.

Design Procedure

- Determine loads—both kWh and ac or dc kW
- Determine energy storage requirements
- Set System availability
- Size PV and other generation to meet load directly or charge the energy storage subsystem
- Chose voltage, wiring, inverter, controls to match ampacity (Max current plus)

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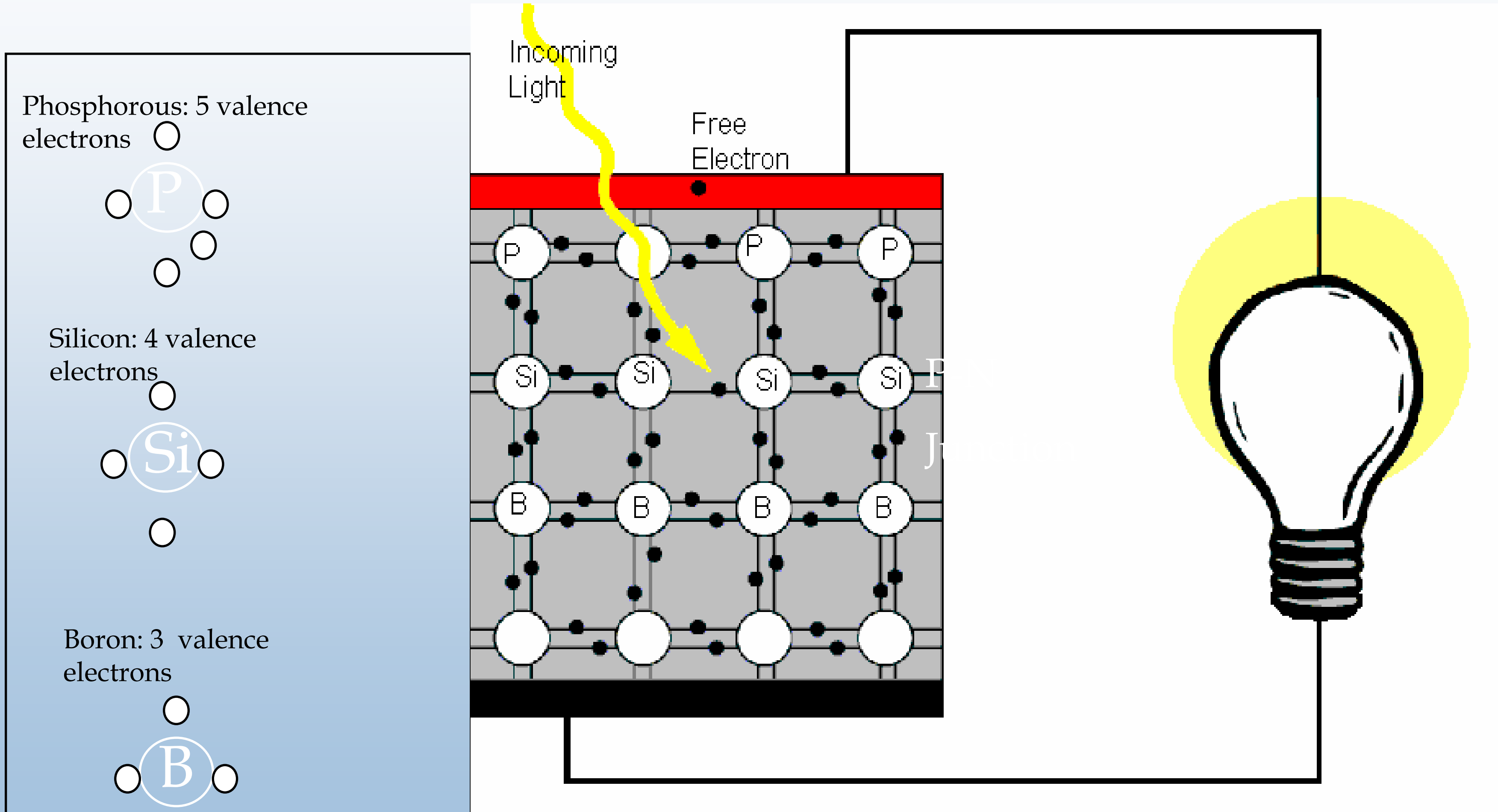
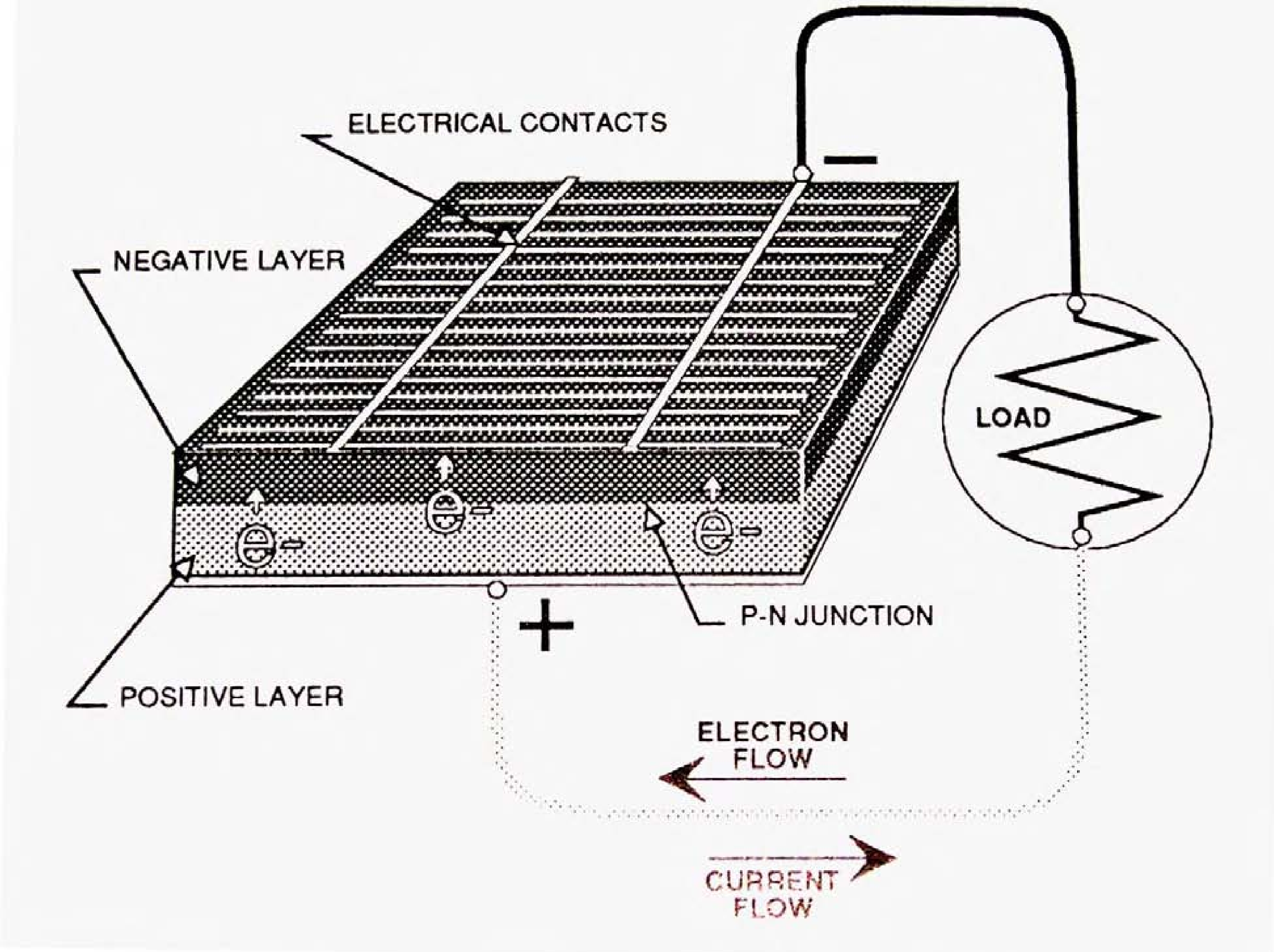
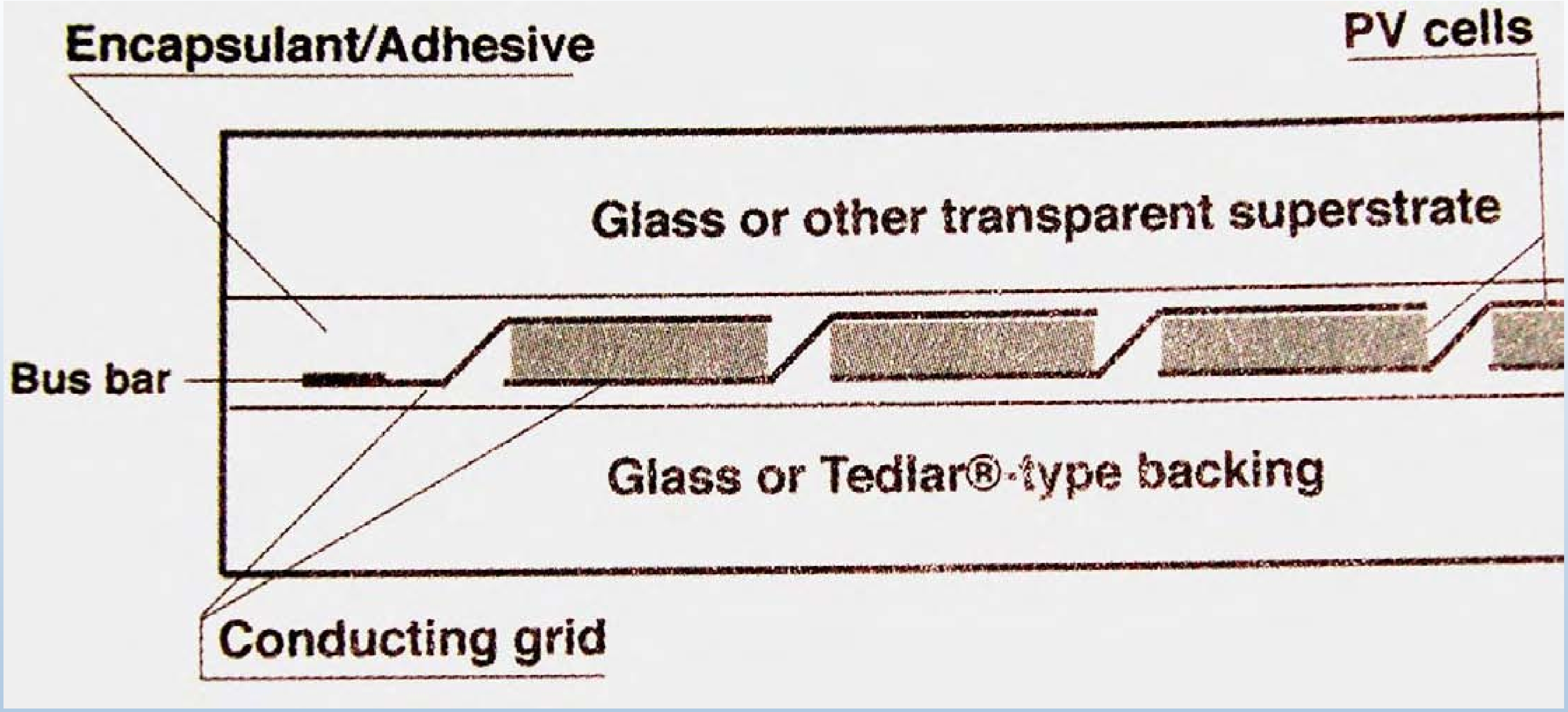
The Photovoltaic Effect



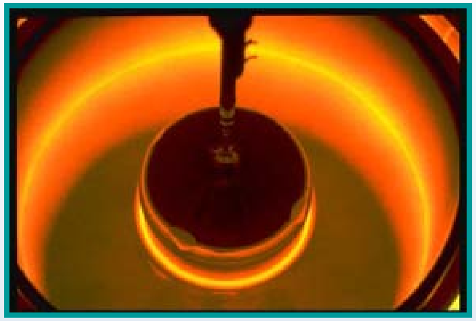
No material is consumed and the process could continue indefinitely

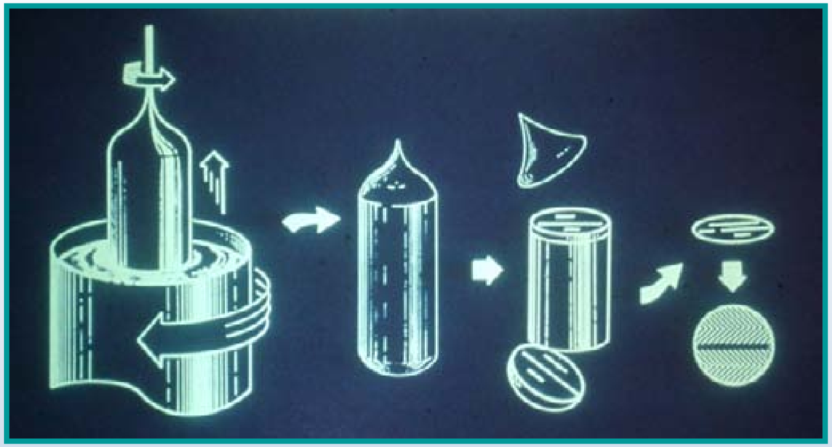

ELECTRICAL CONTACTS
NEGATIVE LAYER
POSITIVE LAYER
P-N JUNCTION
LOAD
ELECTRON
FLOW
CURRENT
FLOW

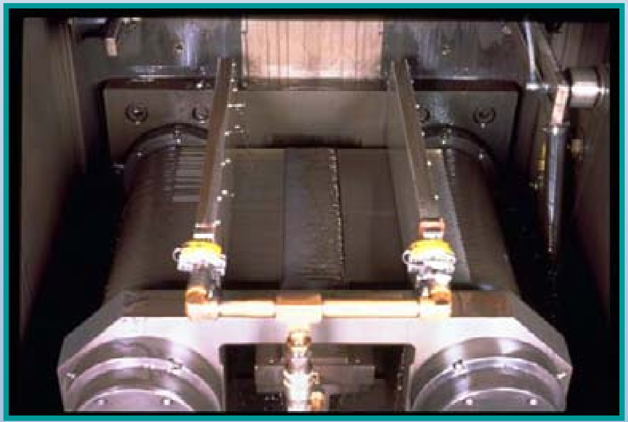


Encapsulant/Adhesive
PV cells
Glass or other transparent superstrate
Bus bar
Glass or Tedlar®-type backing
Conducting grid

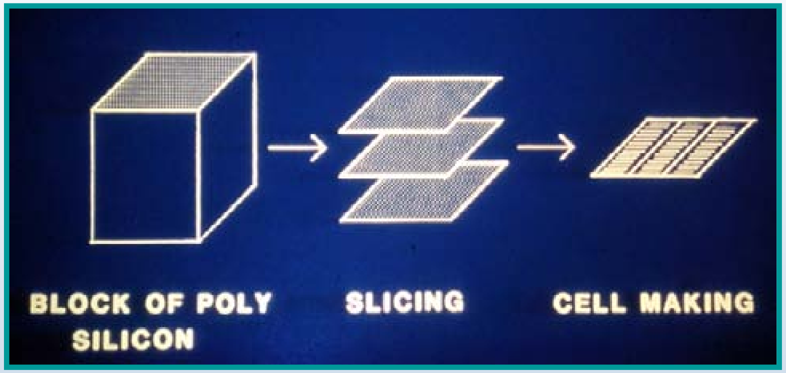
“Czochralski” Technology

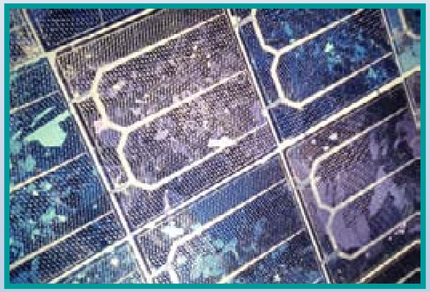


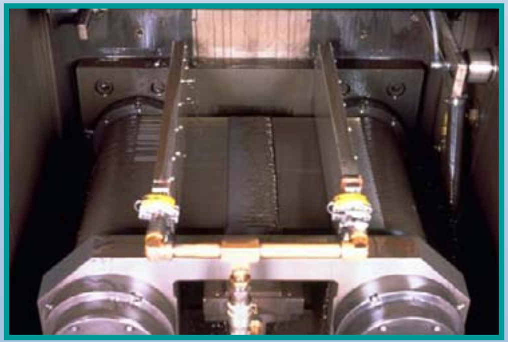




Cast Polycrystalline Technology



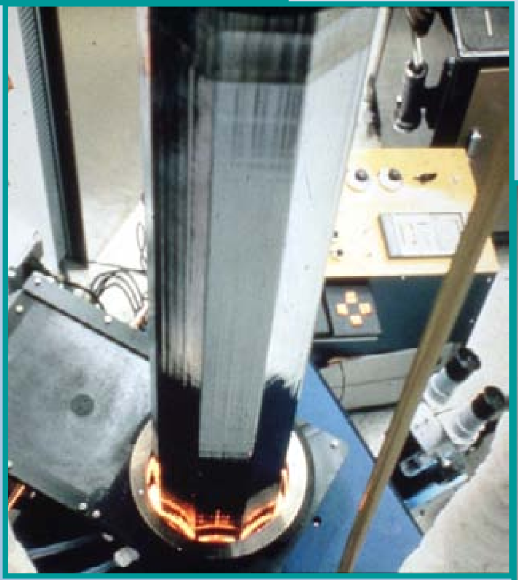


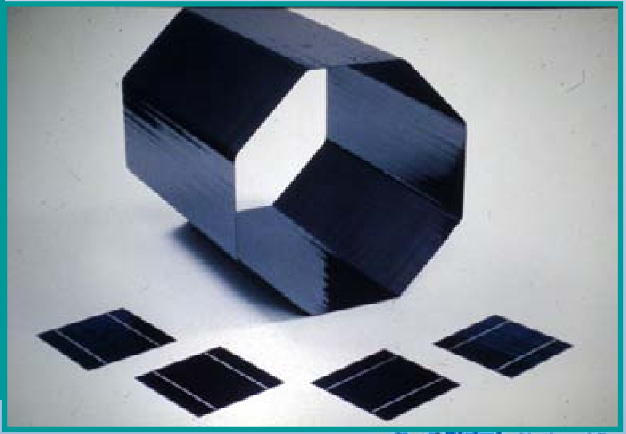


“Sheet” Technologies

“Thin film” Silicon

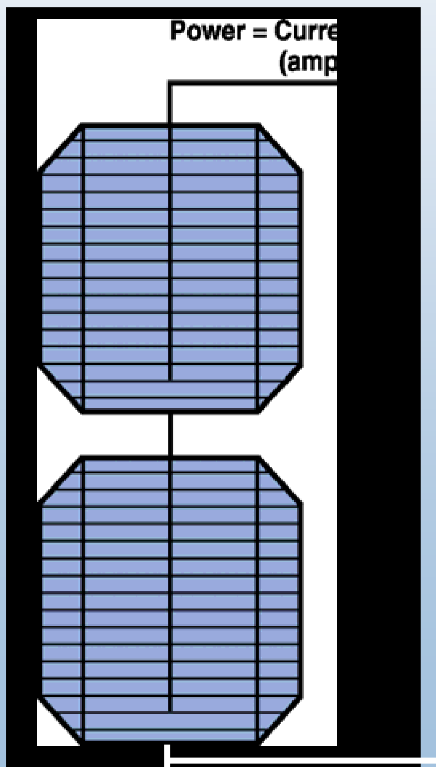
Edge-defined
Film-fed
Growth
(EFG)



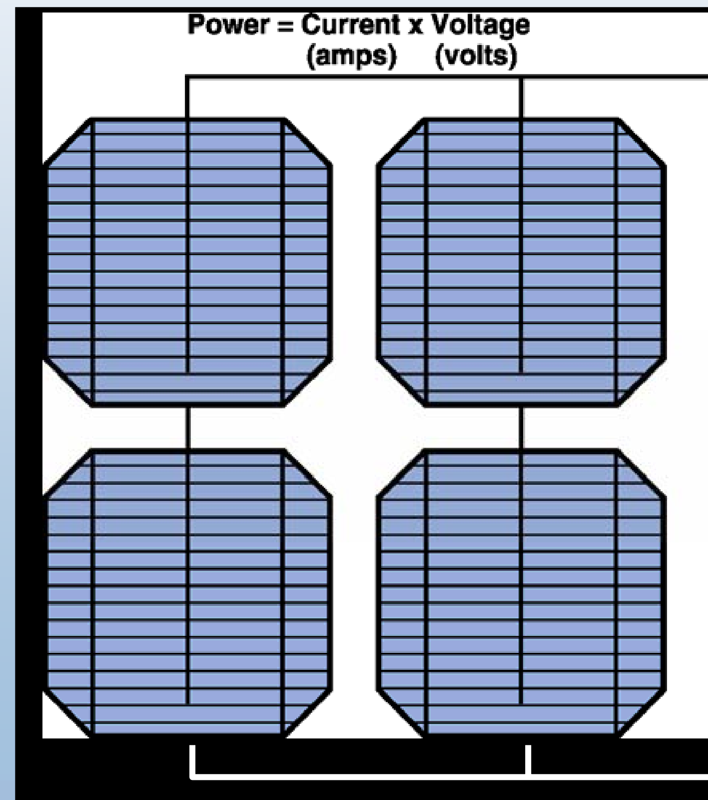


PV Cells

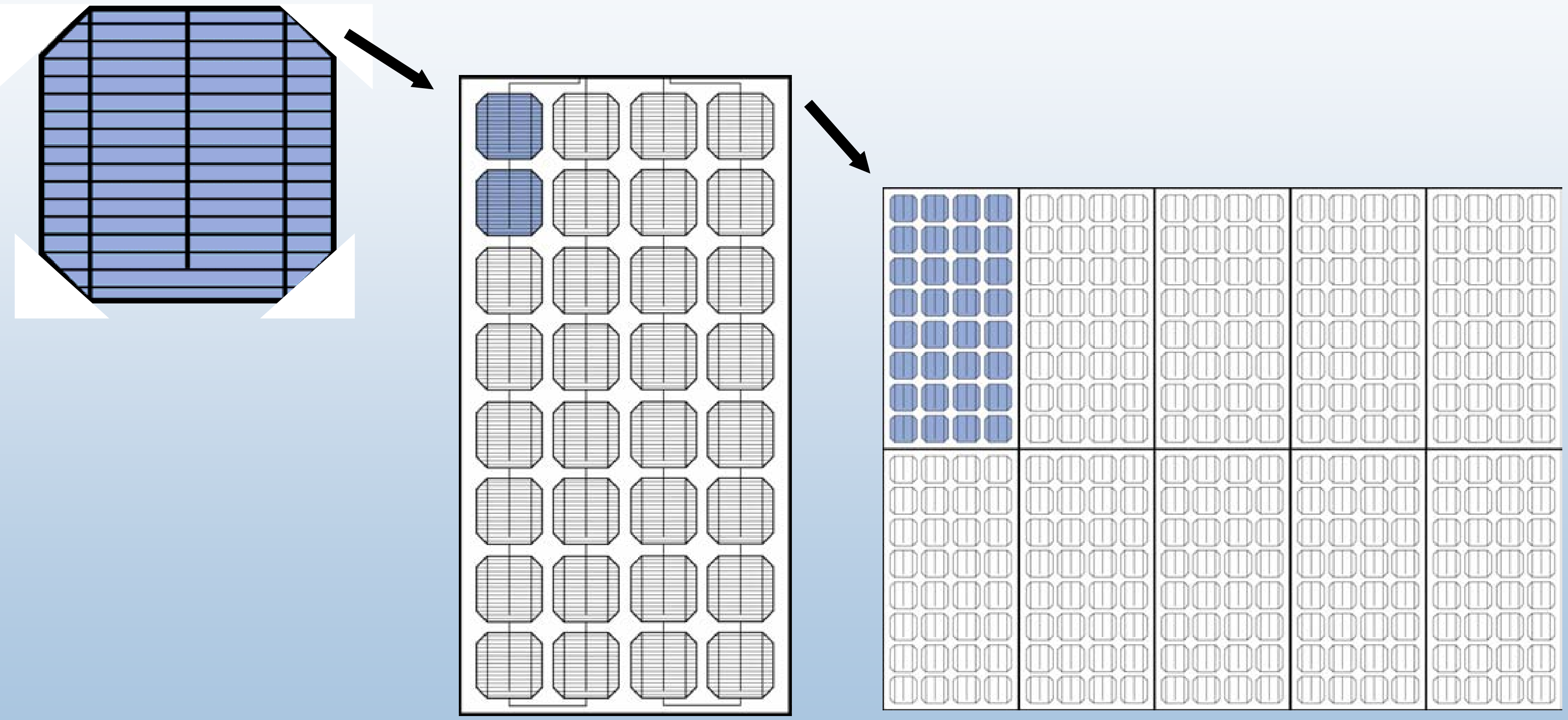
PV Cells are wired in series to increase voltage...



and in parallel to increase current

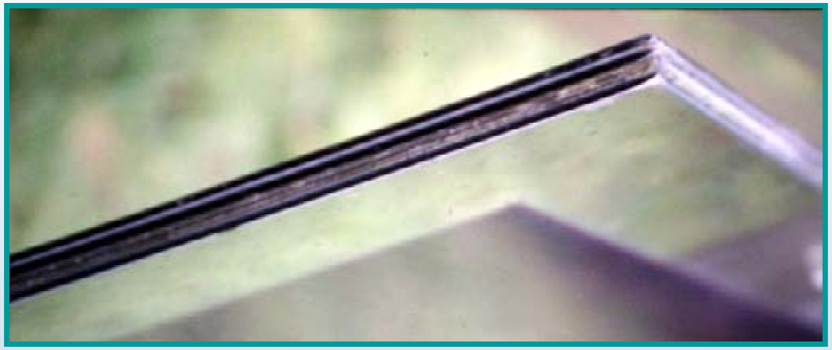


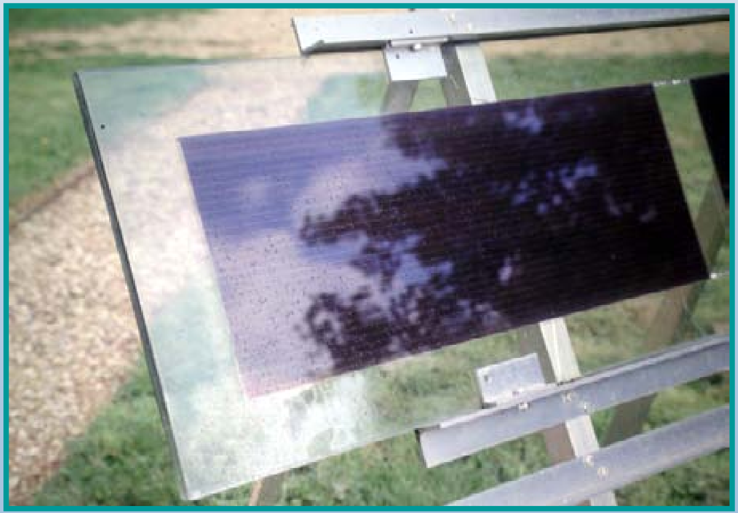
PV is Modular



Cells are assembled into modules, and modules into arrays.

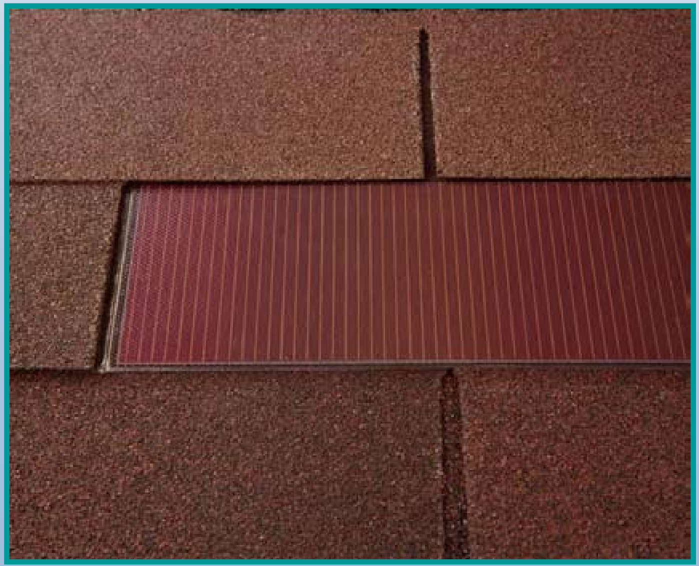
Thin Film Technologies On Glass



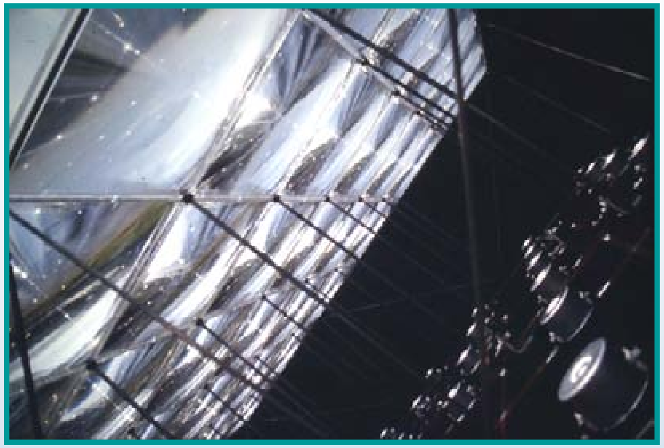


Thin Film Technologies On Flexible Substrates

Building-Integrated PV (BIPV)



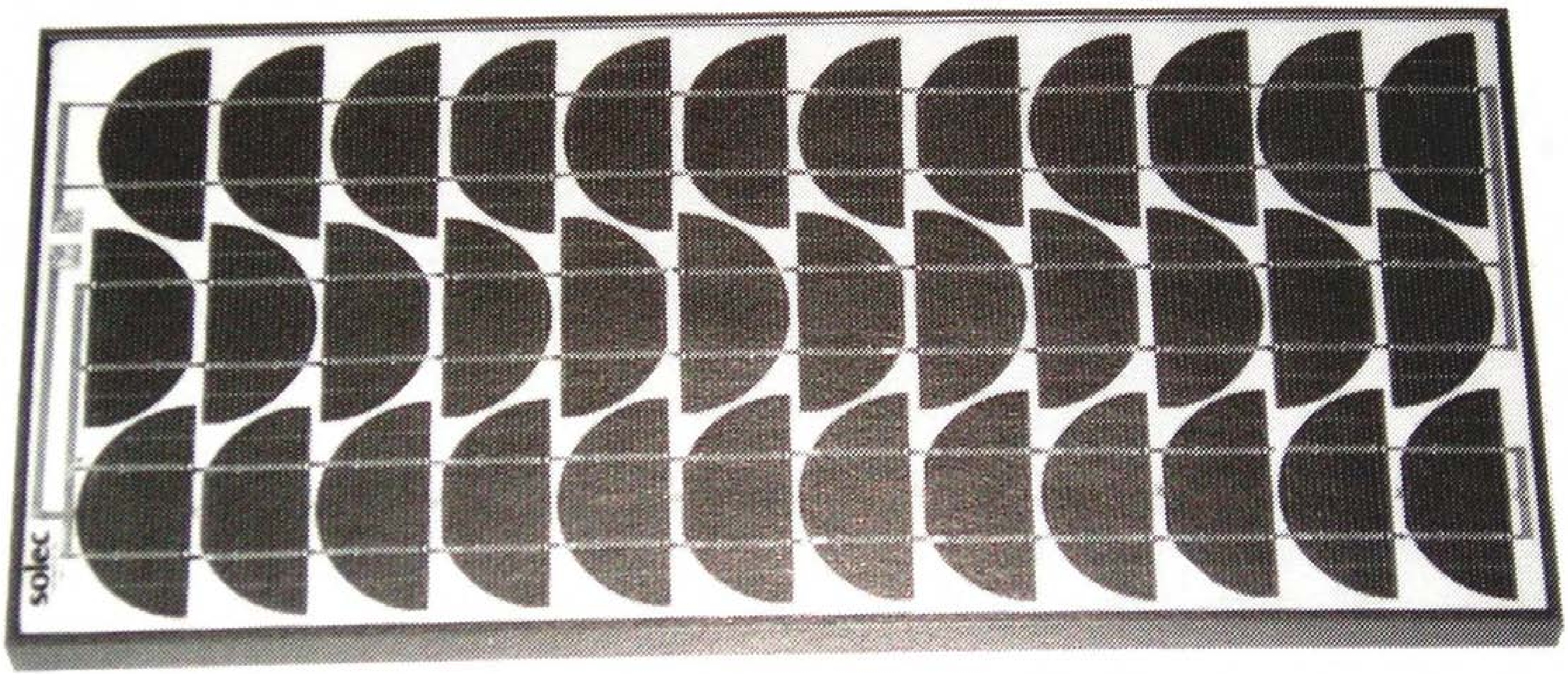
Concentrating PV Systems



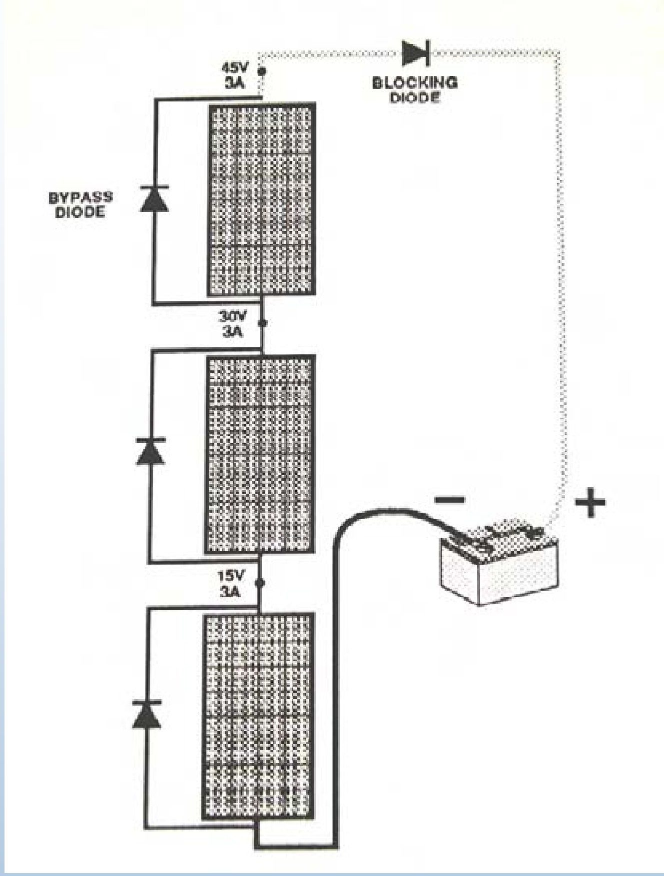
Point
Focus
100-1000X

Line
Focus
30-50X

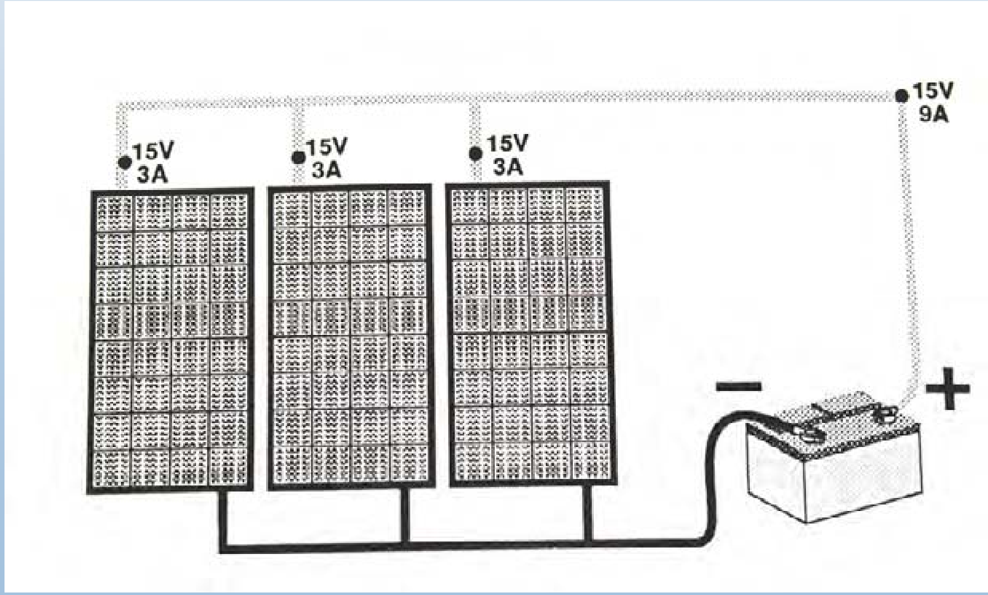
36 cells in Series → About 18 Volts



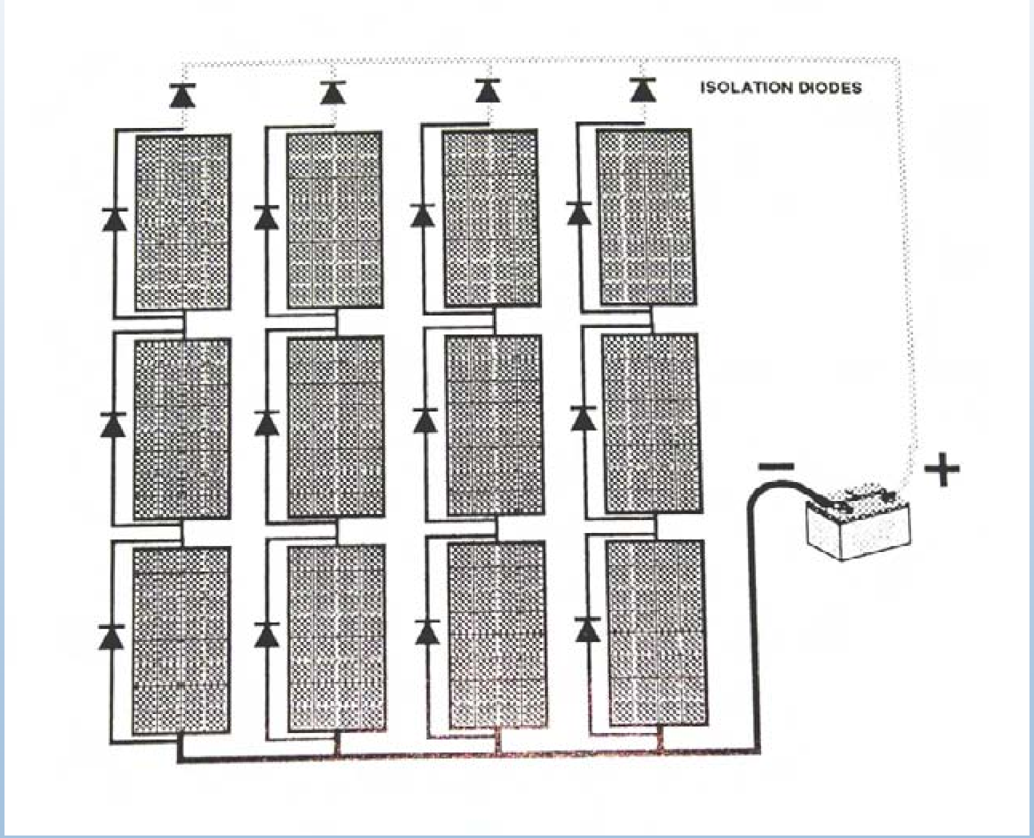
Series connection increases voltage



Parallel connection increases current



Modules are connected in series and parallel to achieve the voltage and current needed for the system



Collector Technology Considerations

- Flat plate, single crystal and polycrystalline Si most common and high acceptance
- Higher efficiencies usually mean less cost for wiring and structure
- Tracking can provide more power and energy in less space but fixed costs must be compared
- Long term performance essential.

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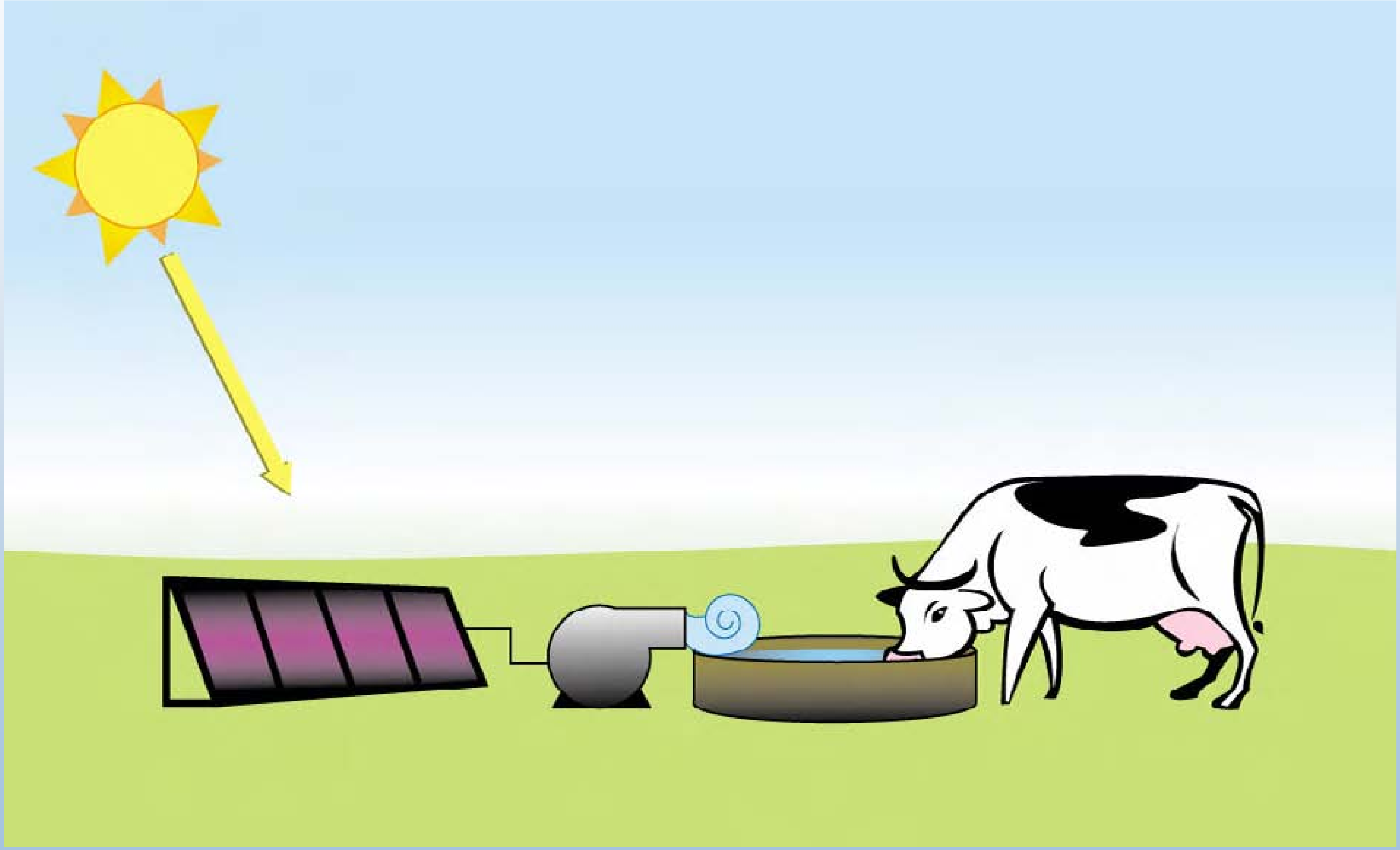
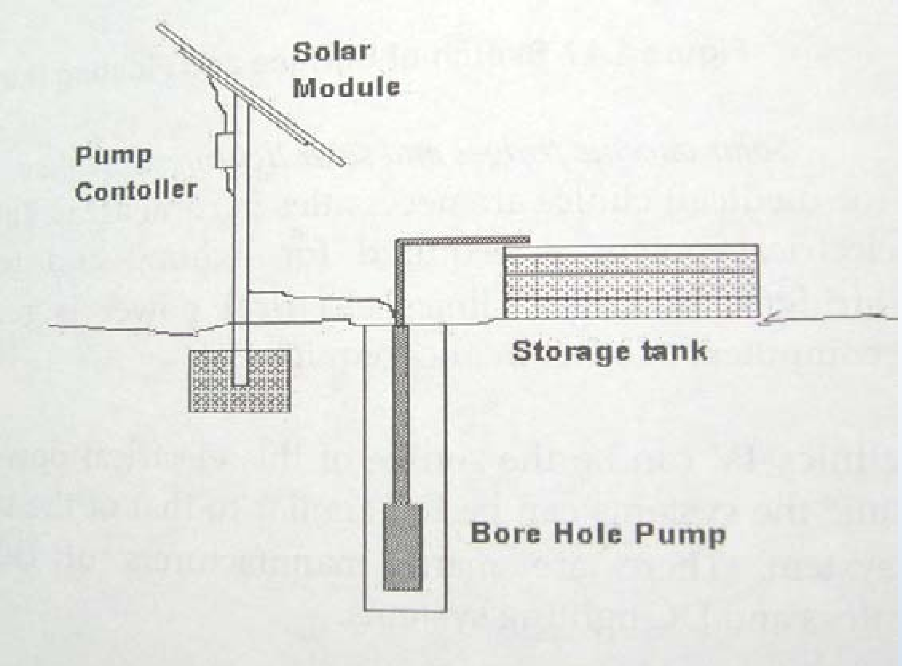
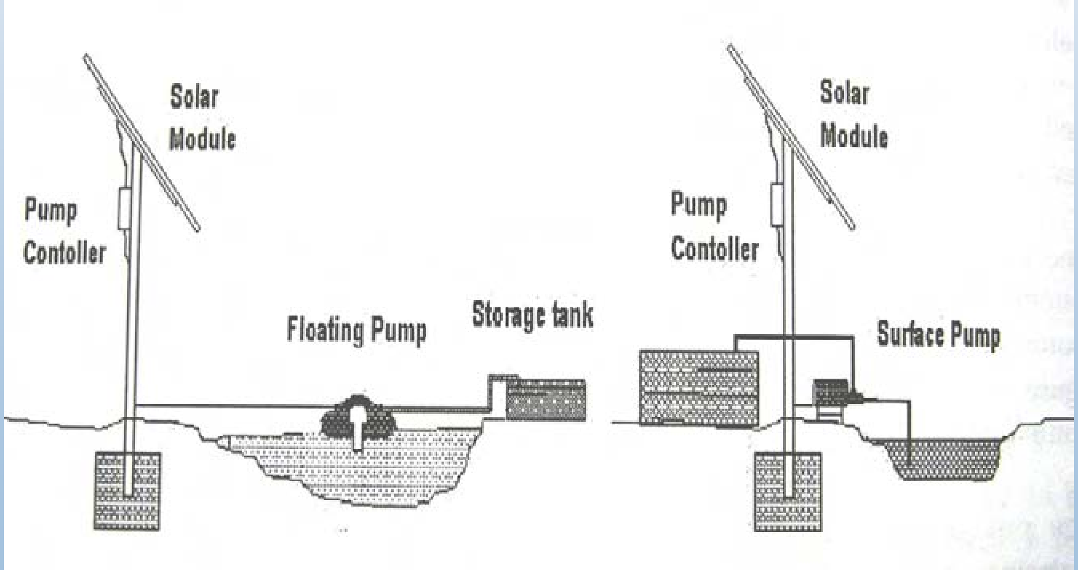




Water Pumping Designs



Rural Electrification: Classics

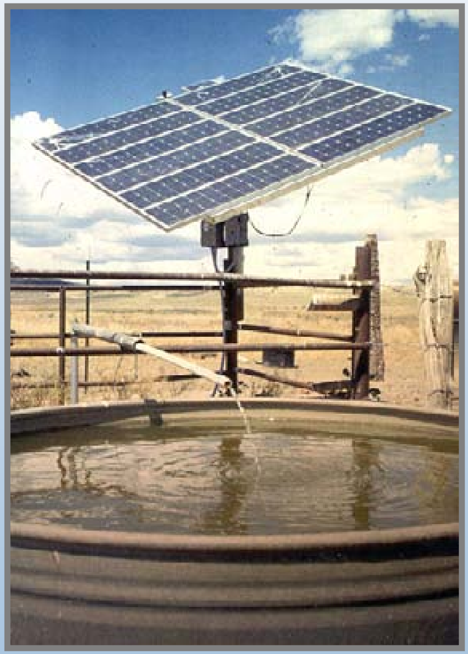
Historically, the primary means of providing power have been through grid extension and diesel generators.

- **Grid Extension:** Very high initial cost, poor cost recovery, time intensive (generation, transmission, distribution) and usually must be subsidized. Most often used.
- **Diesel Generators:** Inexpensive installation but expensive to operate, environmental damage/pollution, and subject to volatile fuel costs and availability.

Solar Water Pumping

Ute Mt. Ute Tribe , CO

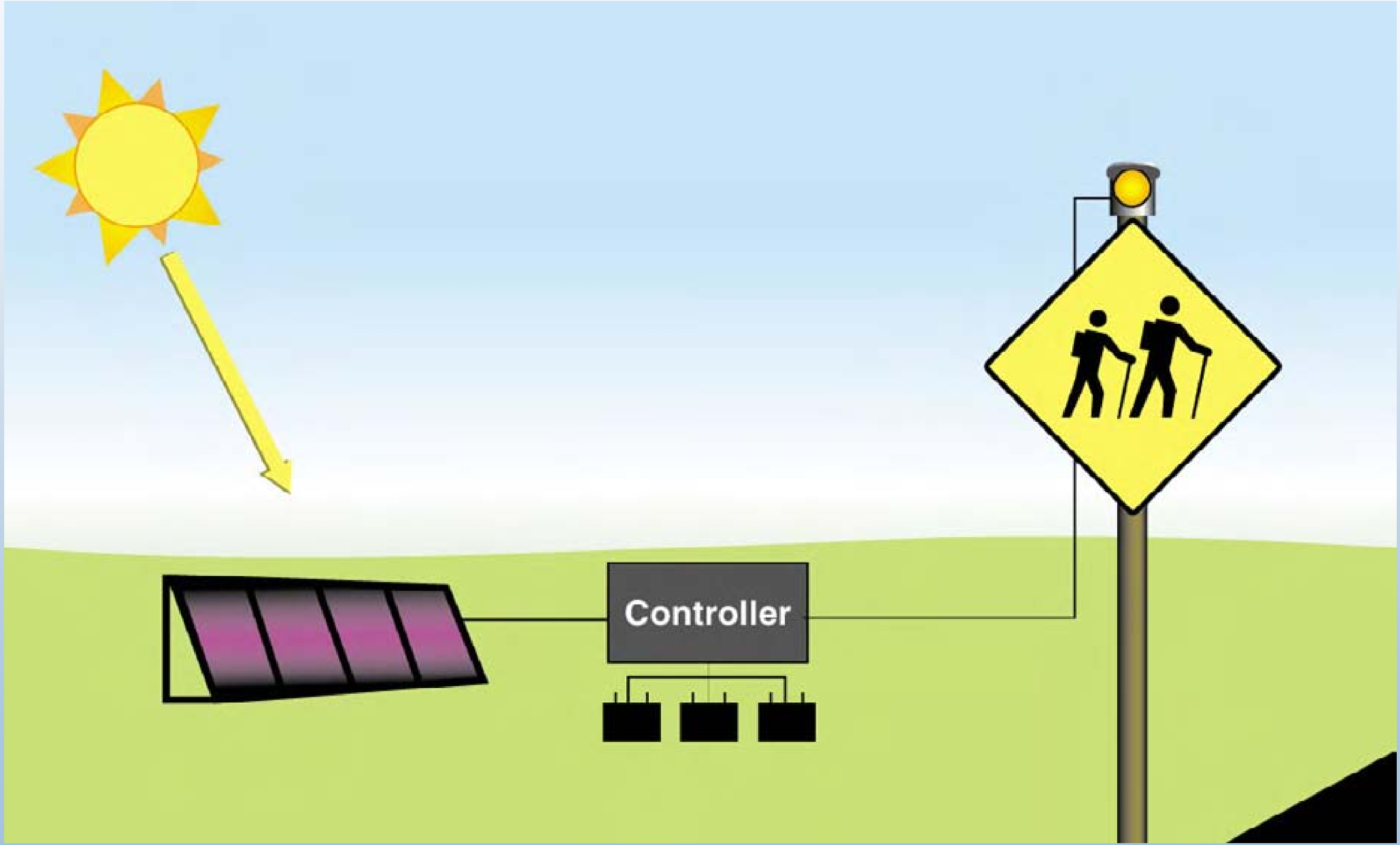
Inadequate Wind & High Maintenance Costs



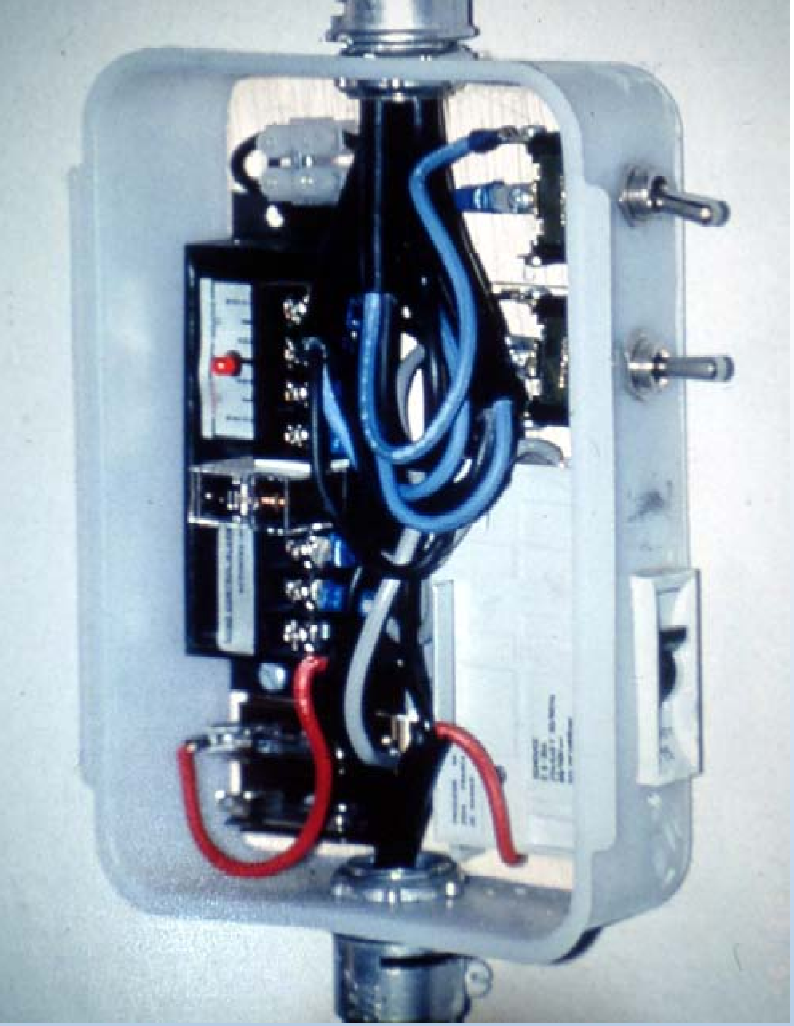
Applications of PV Systems Without Electrical Storage

	Homes / Farms / Ranches	Commercial / Industrial	Public Services: parks, restrooms, bus shelters	Transportation: rail, highway, bus, marine, air	Buildings: offices, schools, apartments	Utilities: electric, gas, water	Communication: radio, TV, telephone, ham radio	Rural Communications: domestic/ international
Pump water to reservoir	⚡	⚡	⚡			⚡		⚡
Pump water from flooded fields	⚡		⚡					⚡
Circulation pumps for de-icing	⚡		⚡					⚡
Water purification	⚡	⚡	⚡					⚡
Evaporative cooling	⚡	⚡	⚡	⚡	⚡	⚡	⚡	⚡
Ventilation fans	⚡	⚡	⚡	⚡	⚡	⚡	⚡	⚡
Aerate pond water	⚡	⚡	⚡					⚡

Simple DC PV System with Battery Storage




امريكانا
30
دجاج كنتاكي
KFC
PICO
بيكو

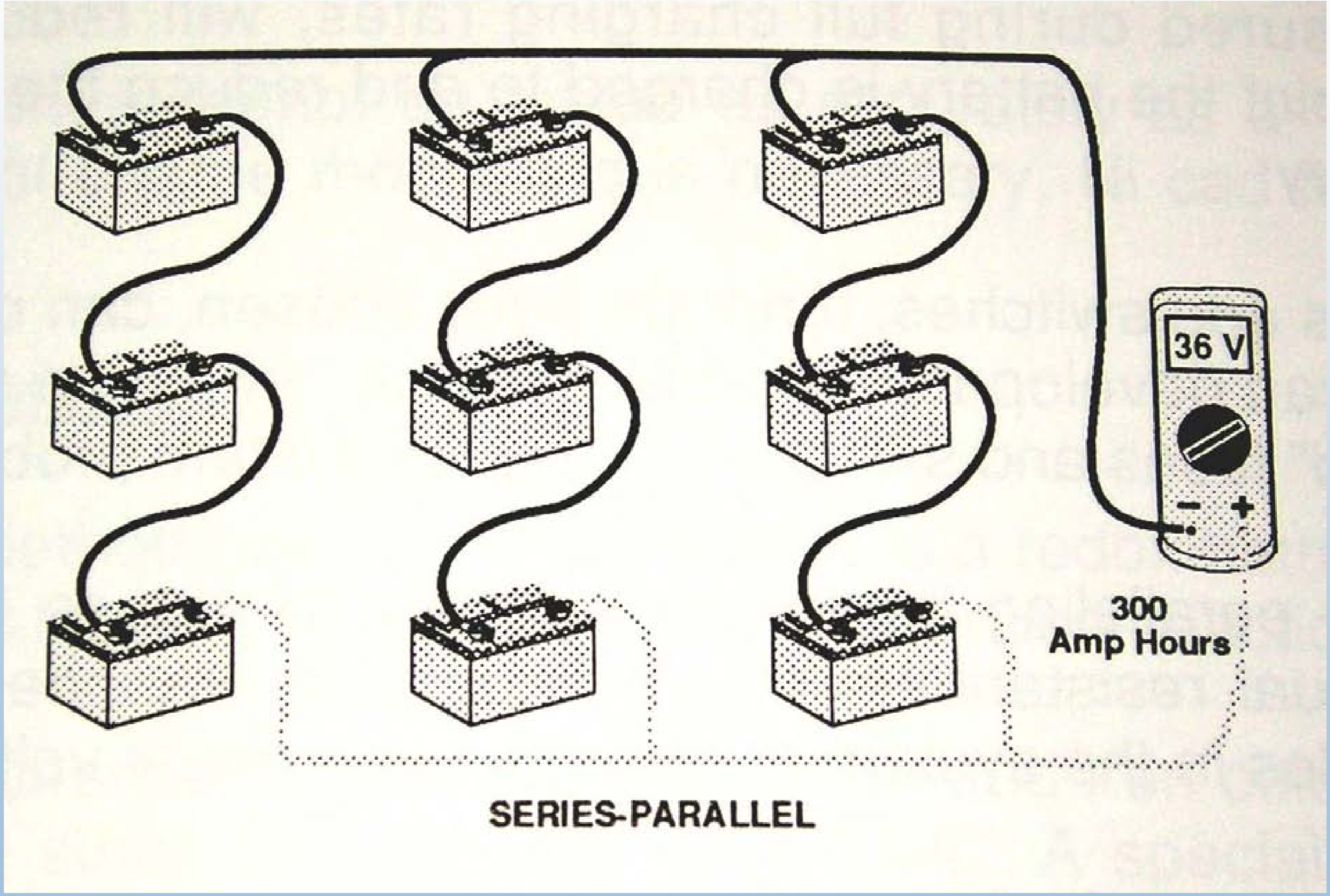


Charge Controller protects the Batteries From: Overcharge, Over-Discharge

Energy Storage

- Deep cycle storage batteries are common
- Batteries require a temperature moderated enclosure and maintenance
- Storage size tied to electrical usage
- Technical issues are temperature, temperature, and temperature-I'll explain
- Most systems with batteries use a charge control device

Just like solar cells, batteries are connected in series and parallel to achieve the storage requirements



12 volt PV-Battery System

Typical PV - Battery Systems

DC PV System Example: PJKK Federal Building, HI

- 2 solar panels per lamp with peak output of 96 watts
- 39 Watt fluorescent lamps, 2500 lumens
- 90 amp-hour battery powers 12 hours per night
- ~$2500 per light

Department of Interior

National Park Service

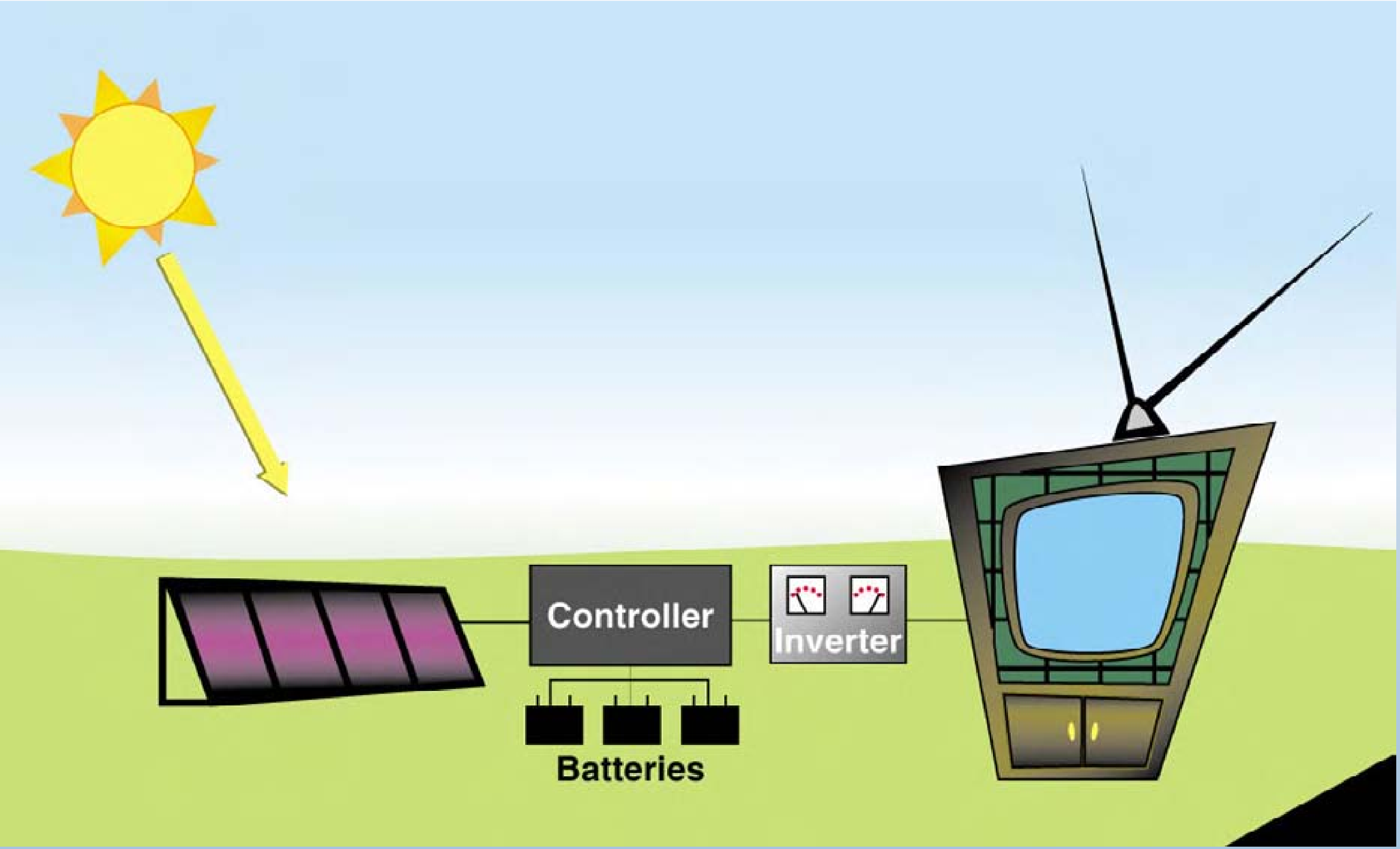
Military Field Applications

USDA Forest Service

Wedding Day!!!

In Xinjiang, China, the groom bought 2-40 watt PV panels for the bride as a wedding present.

AC PV System with Inverter



Inverter
5kW

Converts Direct Current (DC) to Alternating Current (AC)

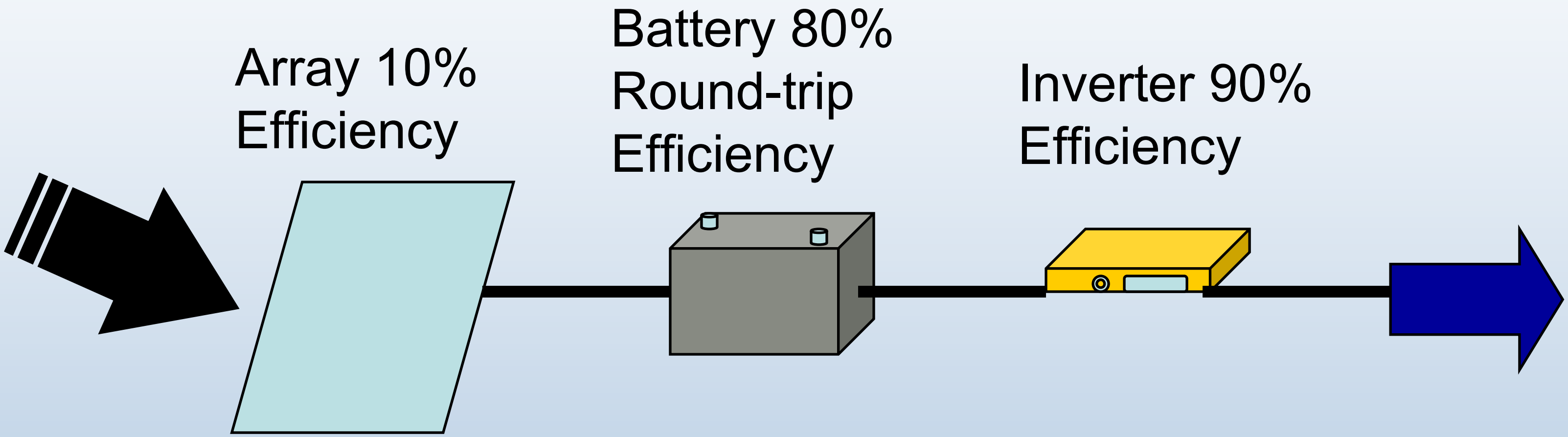
50 kW Inverter

AC System Controls

- Inverters convert dc to ac
- Inverters require an enclosure and may be placed with switchgear and controllers
- Inverters are matched to system voltage and maximum aggregate load
- System controls represent the least reliable components in a PV system

System Efficiency

Efficiency = power out / power in



100 Watts from sun > 10 Watts >8 Watts > 7.2 AC Watts to load

Overall system efficiency is product of component efficiencies.
Example 0.10*0.80*0.90=0.072

...exacerbated by “mismatch” losses, typical system efficiency = 0.06

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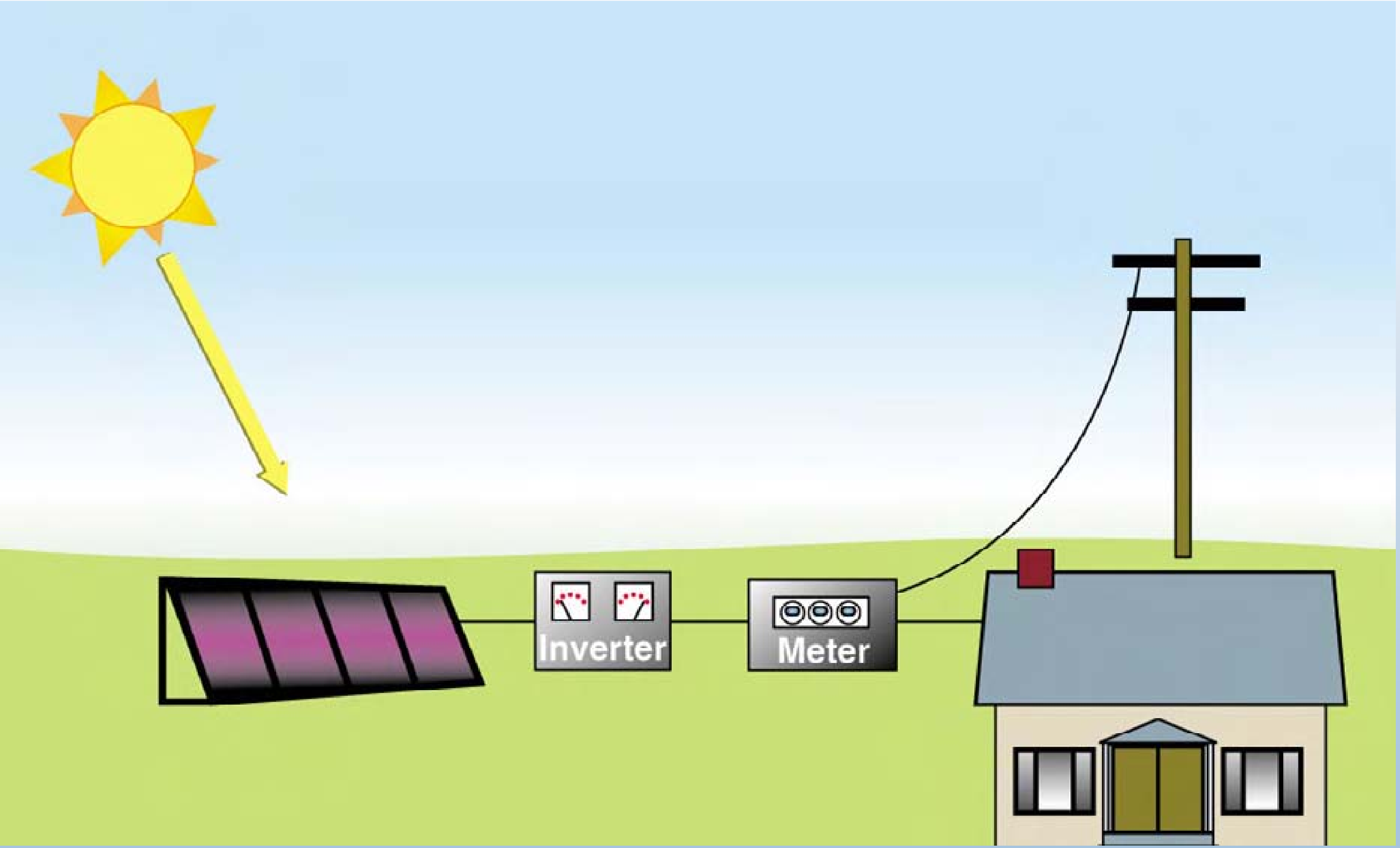
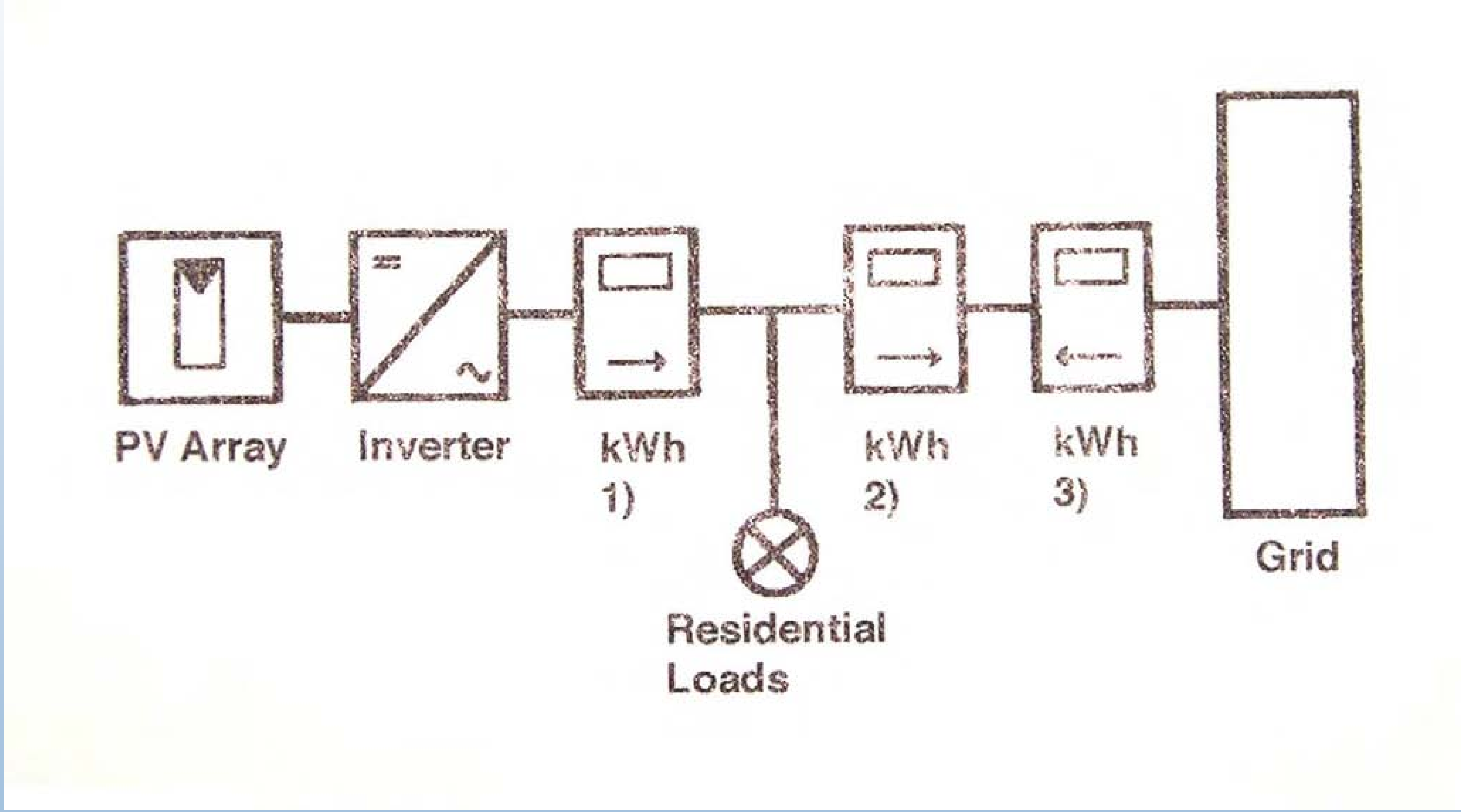
Utility-Connected (Line-Tie) PV System

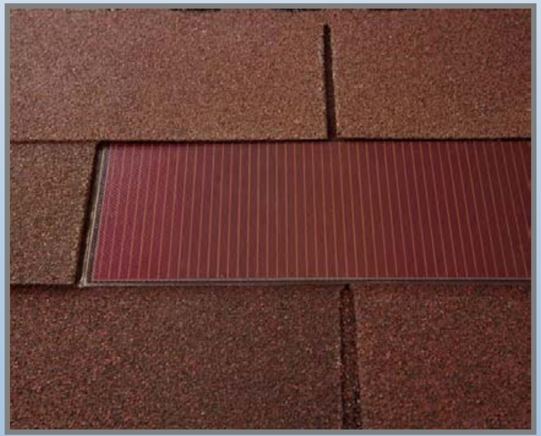


Grid-connected Metering Requirements Depend on the Local Electric Utility



Jicarilla, Apache, AZ
2.4 kW Grid Connected
Dulce High School

Building-Integrated PV (BIPV)



Utility-Connected PV Example: Presidio Thoreau Center

- Building-Integrated Photovoltaics
- 1.25 kW PV Array
- Spacing between cells admits daylight into entry atrium below

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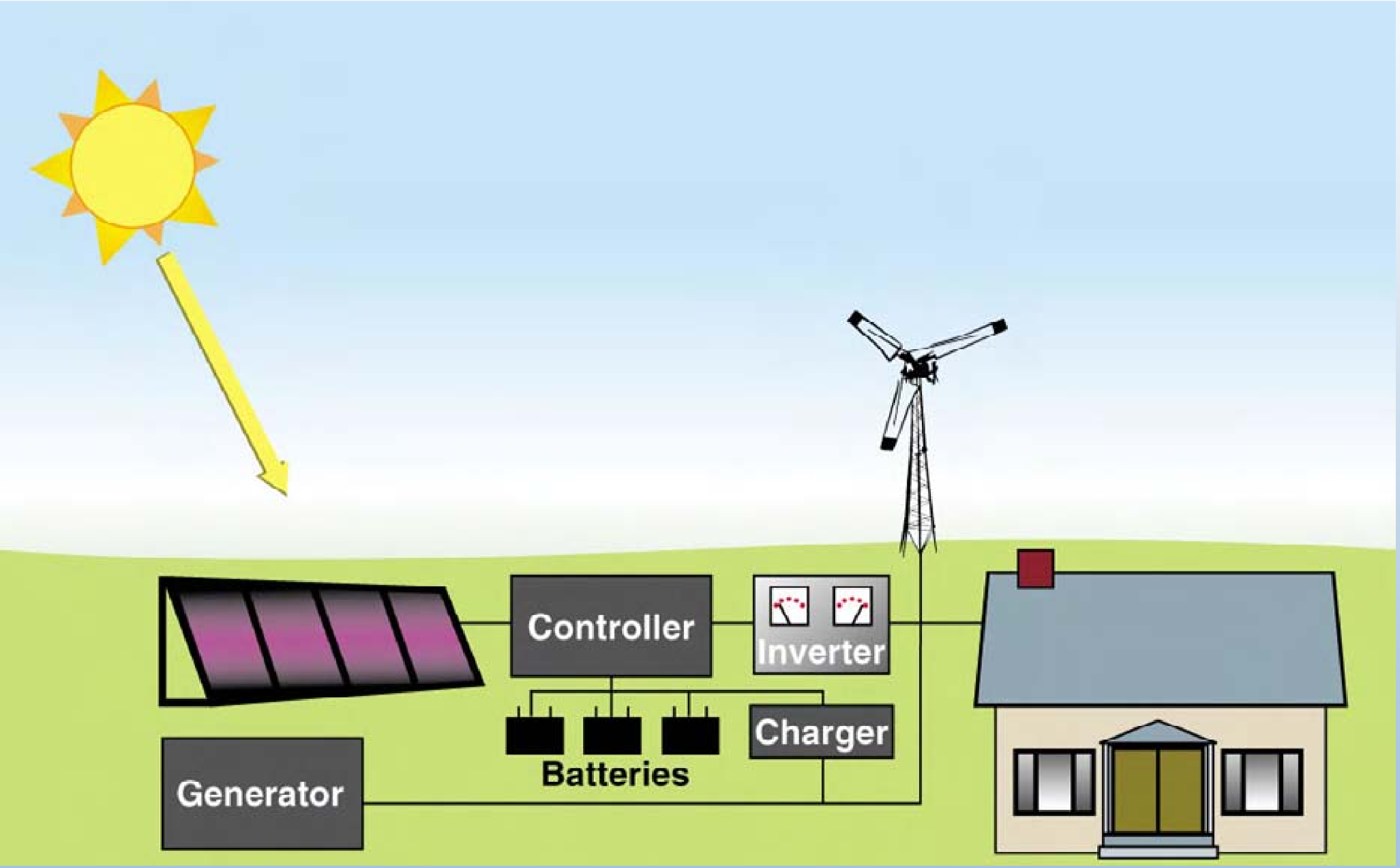
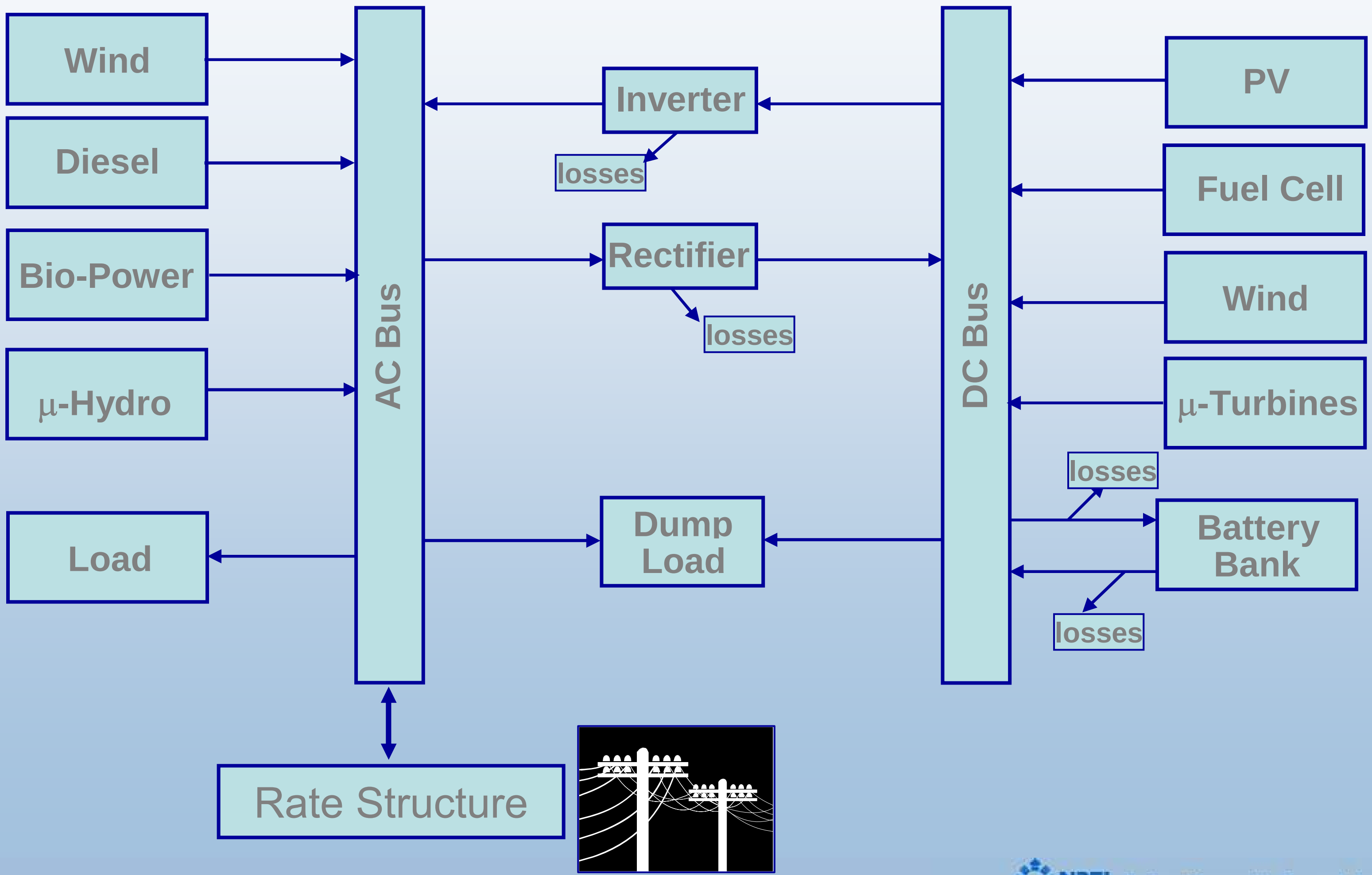
Hybrid PV/Generator System



Hybrid Power System Examples: “Communications”

Village Power Hybrids
Simulation Models for Options Analysis



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PV Design Tools

- System Sizing
- System Configuration
- On grid vs. Off grid
- Est. Power Output
- Building Simulations
- Shading
- Temperature & Thermal Performance
- Economic Analysis
- Avoided Emissions
- Building Energy Load Analysis
- Meteorological Data
- Library of Modules, Batteries & Inverters

Available Software

- PVSYST
- PV DESIGN PRO
- WATSUN PV
- PV CAD
- PV FORM
- BLCC
- HOMER
- ENERGY-10
- AWNSHADE

PV Design Tools

- **PV Watts**
  http://rredc.nrel.gov/solar/codes_algs/PVWATTS/
  - **Google: PVWATTS**
- **RETScreen – PV**
  - **Google: RETScreen**
- **HOMER Distributed System Hybrid Optimization Model**
  - **www.nrel.gov/homer**