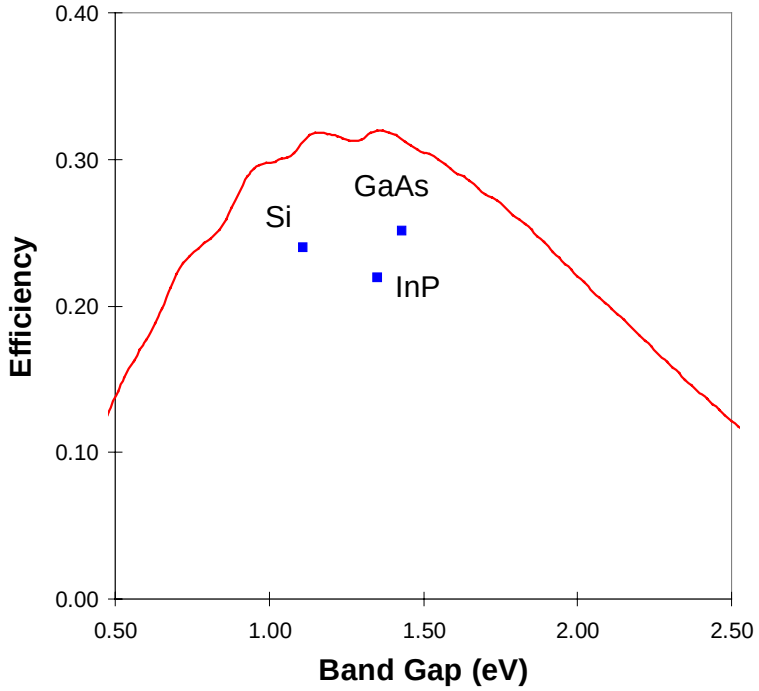
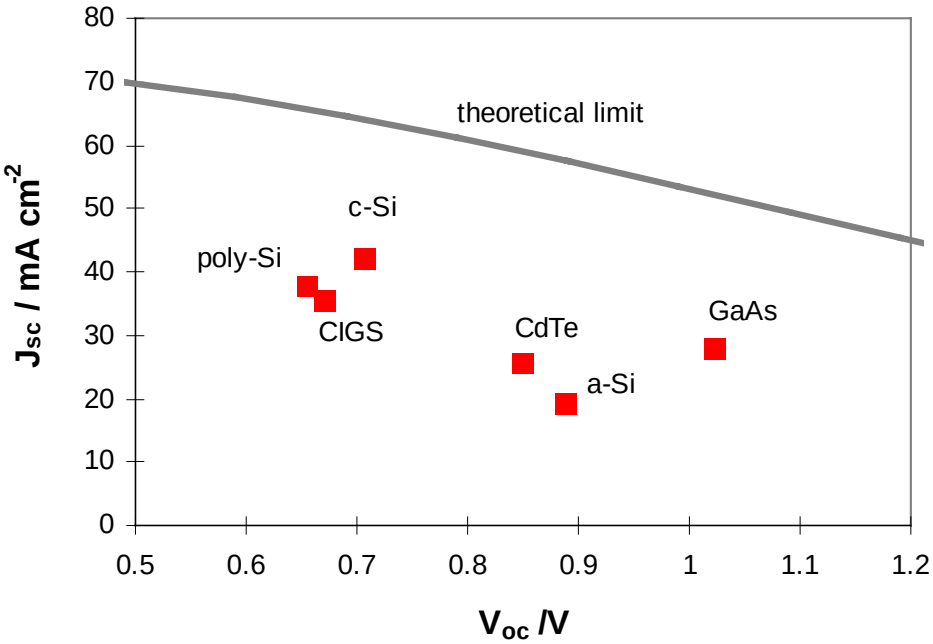
Actual versus ideal PV performance





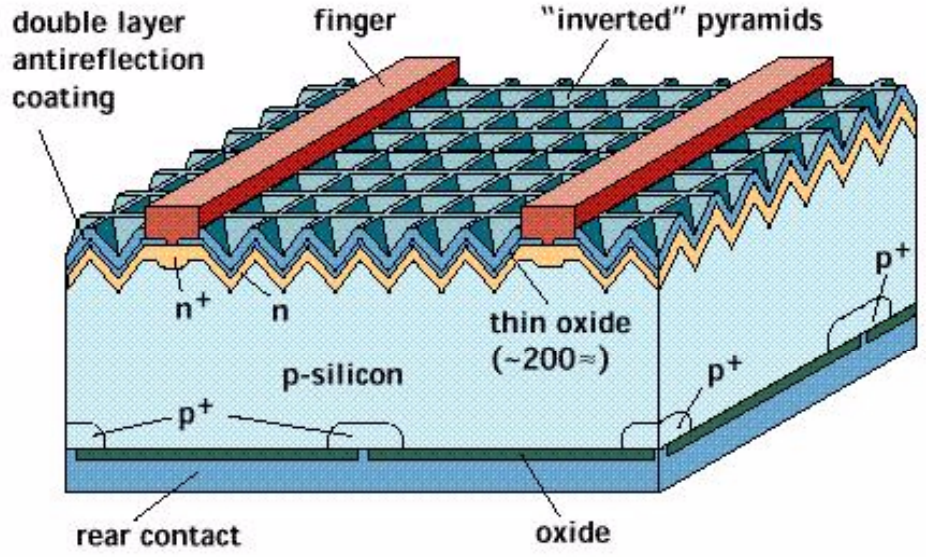
Sources of loss

- Unavoidable
  - Photons with E < Eg not absorbed
  - Electrons excited by photons with E > Eg lose some energy to heat
  - Some electrons recombine to emit light (required for equilibrium in dark)

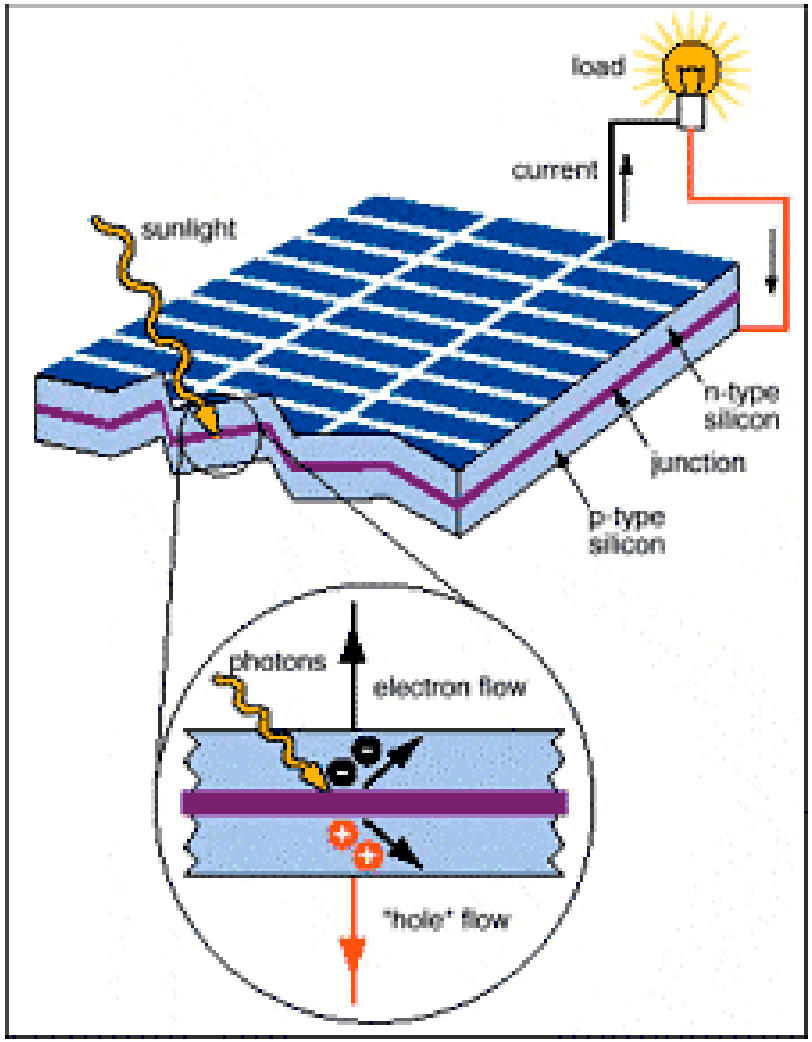
- Avoidable

Problem	***Solution***
Reflection by surface and contacts	Antireflection coat, narrow metal fingers
Incomplete of light absorption	Textured surfaces, thick active layer
Non-radiative charge recombination	High purity crystal, low doping in bulk of cell, surface passivation
Resistive losses	High doping near contacts, deep metal fingers

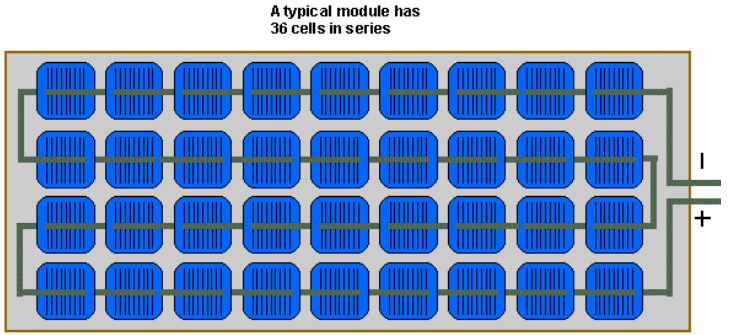
25% efficient PERL cell



From cells to systems

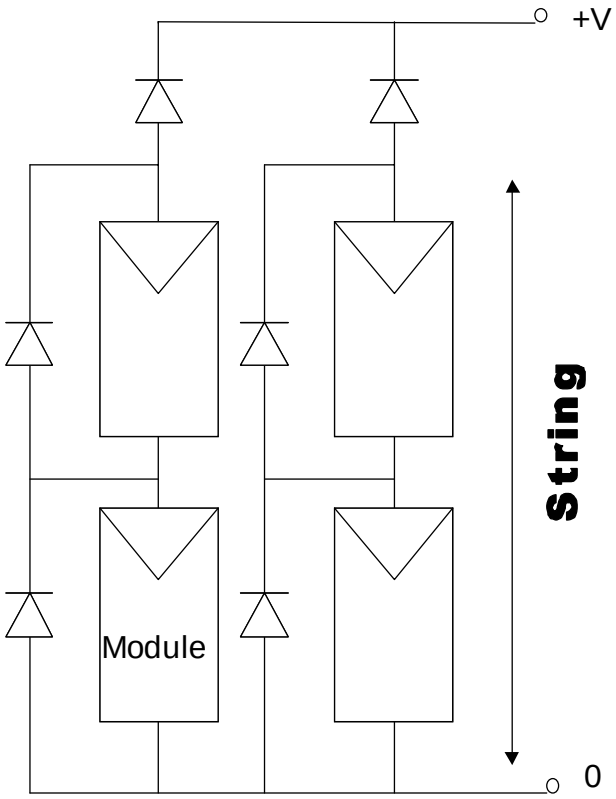


Light to power efficiency of best silicon solar cell ~ 25%

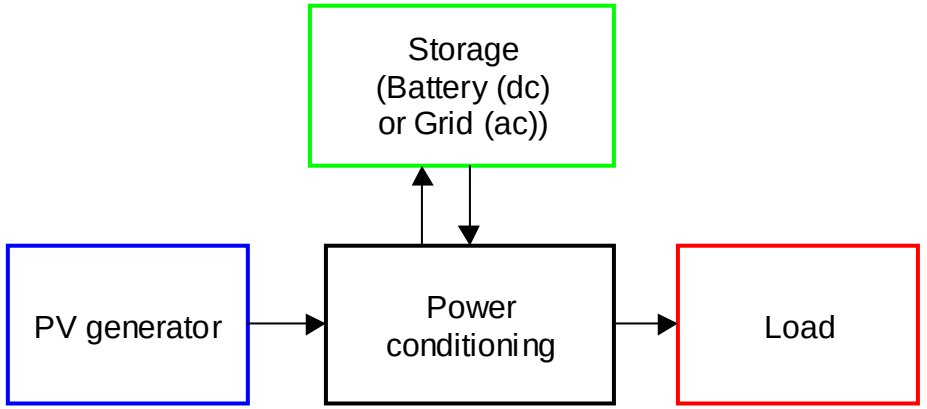


C-Si module efficiencies typically ~ 15%

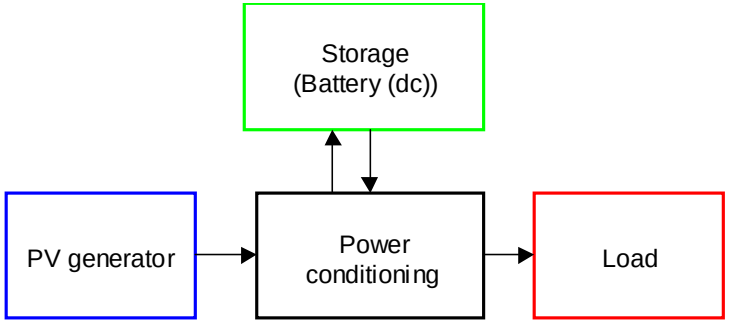
From cells to systems

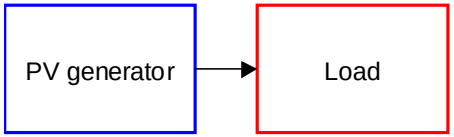


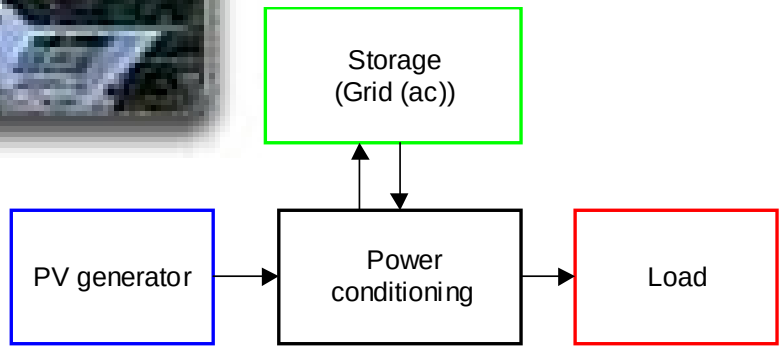
Array of modules



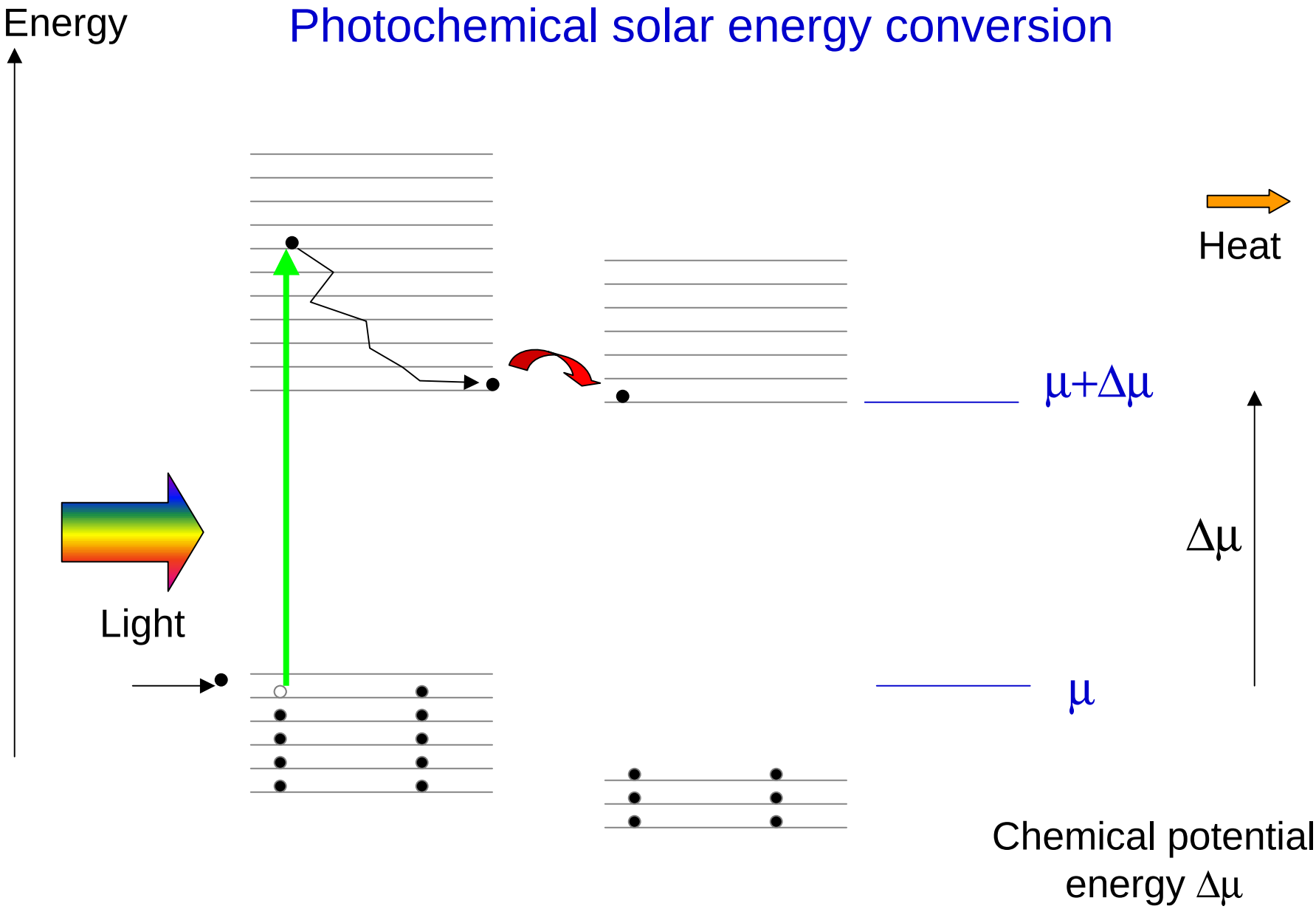
Components of a PV system

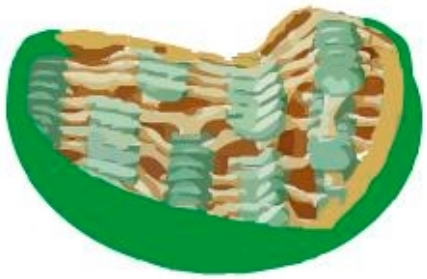

Storage
(Battery (dc))
PV generator
Power
conditioning
Load


PV generator
Load

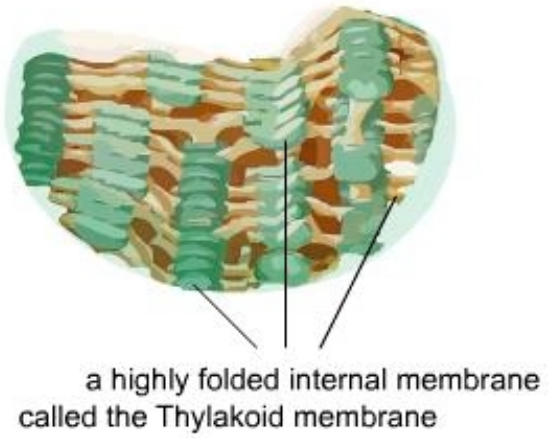

Storage
(Grid (ac))
PV generator
Power
conditioning
Load

Photochemical solar energy conversion

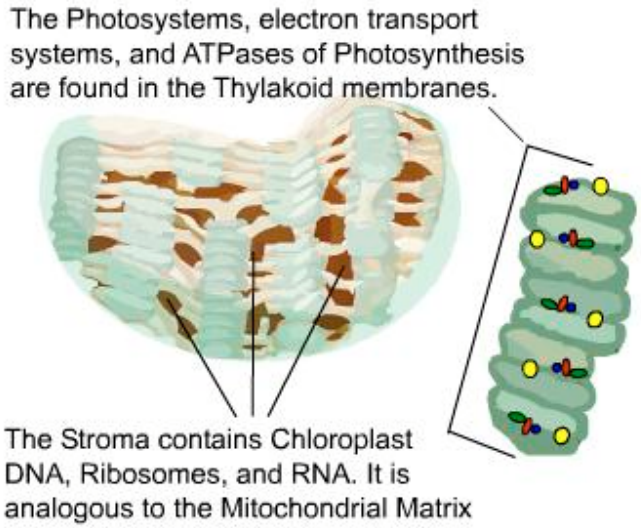




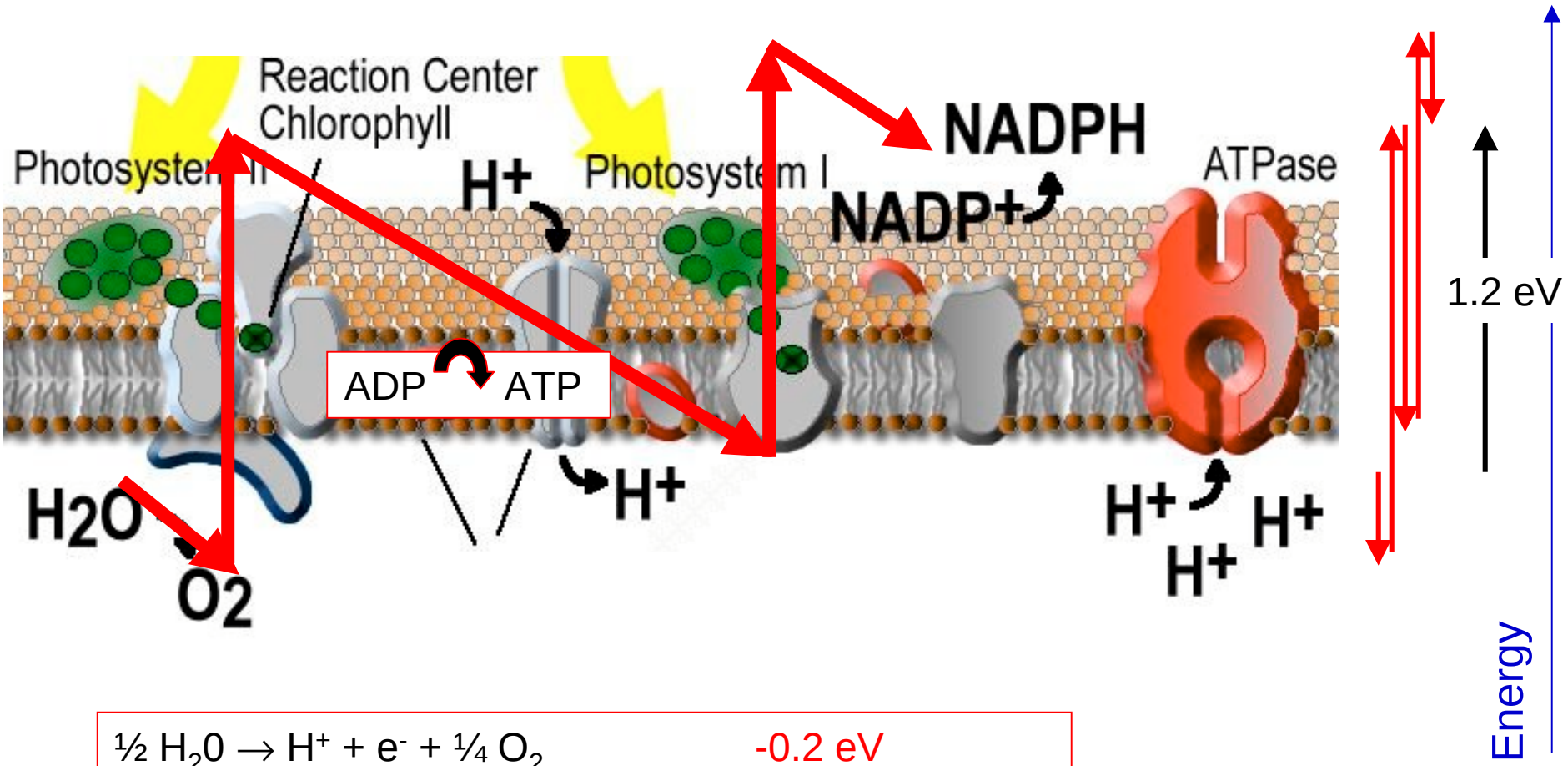
Chloroplast



Thylakoid membrane



Light harvesting complex



½ $H_20 \rightarrow H^+ + e^- + ¼\ O_2$	-0.2 eV
absorption by PS2	+1.1 eV
ATP formation	-0.5 eV
absorption by PS1	+1.0 eV
½ $NADP^+ + H \rightarrow$ ½ NADPH + ½ H^+	-0.2 eV

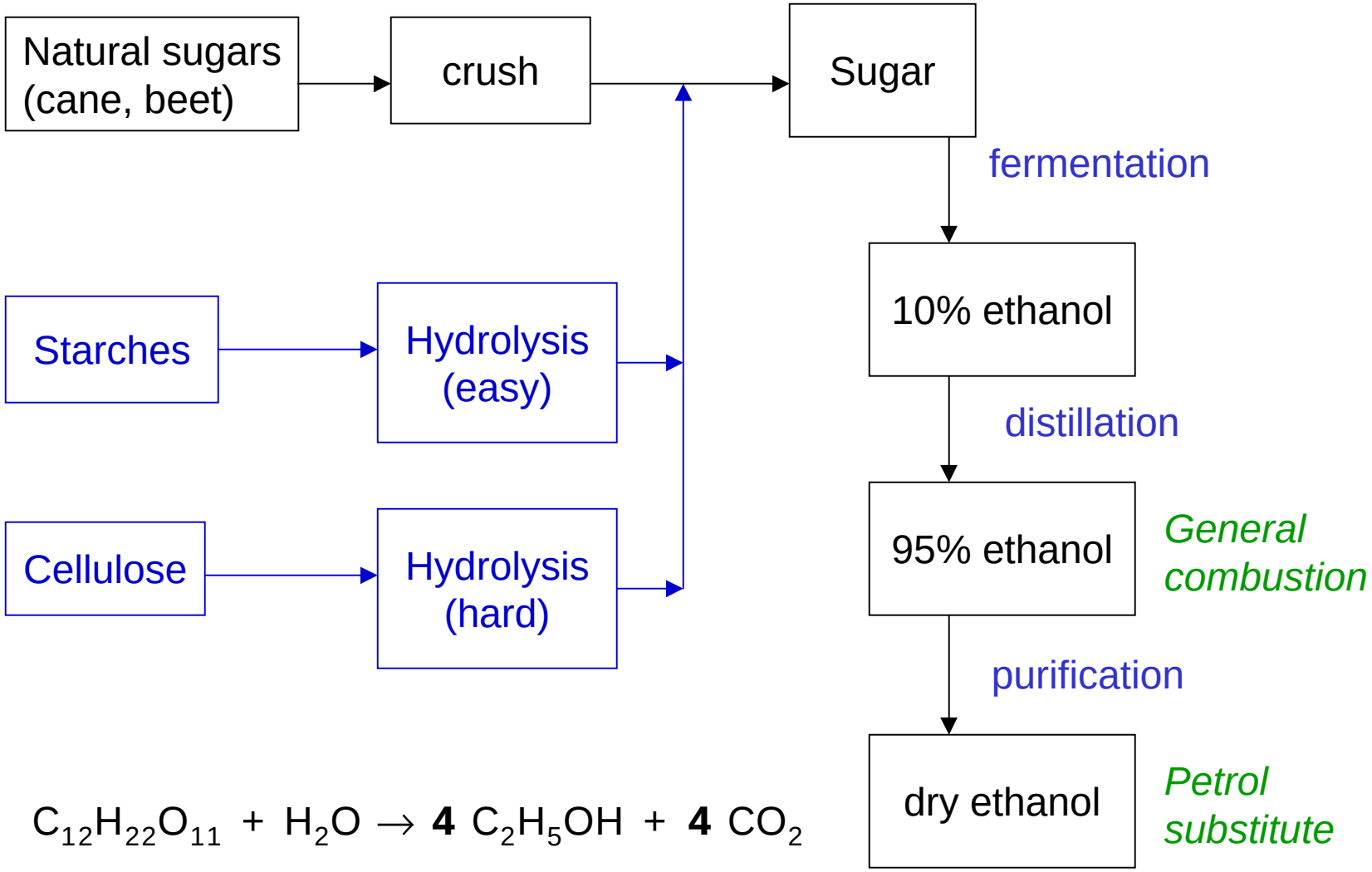
Conditions	**Photosynthetic efficiency [%]**
Including plant respiration:	
Whole earth	0.1
Grassland	1
Continuing crop	2
Lab conditions	5
Theoretical maximum Filtered light, excluding respiration, initial photosynthetic process only	33

Crop	Biomass yield (dry) [kg ha^{-1} $year^{-1}$]	Energy density [MJ kg^{-1} (dry)]	'Power' density [W m^{-2}]	Efficiency [%] for 200 Wm^{-2} mean irradiance
Temperate forest	7,000	18	0.4	0.2
Tropical forest	11,000	18		
Sorghum	50,000	17		
Maize	25,000	18		
Sugarcane	30,000	18		
Eucalyptus	20,000	19		
Kelp	54,000	21		
Ethanol		27		
Gasoline		36		
Coal		~ 24		

NB: I hectare = 10^4 m^2

Biomass has reasonable energy density, but low energy conversion rate

Ethanol production



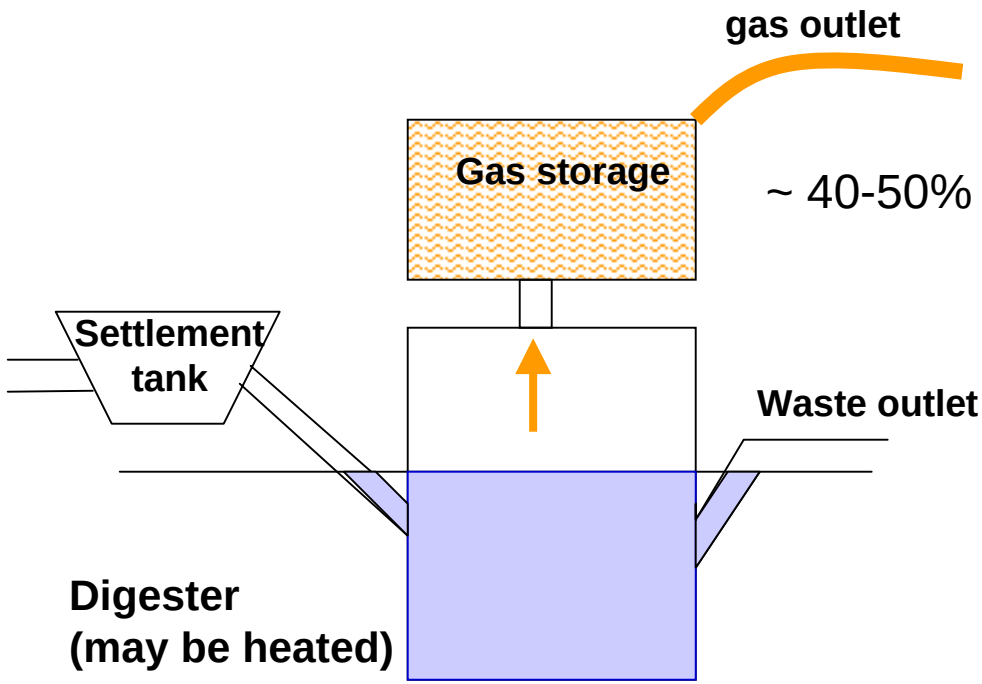
$C_{12}H_{22}O_{11} + H_2O \rightarrow \mathbf{4}\ C_2H_5OH + \mathbf{4}\ CO_2$

~ 80% of initial enthalpy in product

Biogas production

Anaerobic bacteria

$$[CH_2O] + H_2O \rightarrow CH_4 + CO_2$$



~ 40-50% of initial enthalpy in product

Sewage, landfill, waste

http://www.holsworthy-biogas.co.uk/

Summary of Lecture 23

- Photosynthesis is the light-driven conversion of solar energy into chemical potential energy. $CO_2 + 2H_2O + h\nu \rightarrow [CH_2O] + O_2 + H_2O$
- Products contain ΔH = 4.8 eV per carbon atom more energy than reactants
  ΔH is released as heat in the combustion of biomass.
- Efficiency of solar to chemical energy conversion: typically 1-3%
- Energy density in dry biomass: typically 15 - 20 MJ kg^{-1}
- Solid biomass converted to liquid or gaseous fuels *e.g.* ethanol or methane for ease of transport and higher E density.
- Solar fuels represent a very stable form of E storage!