About the thermodynamics of ecosystems

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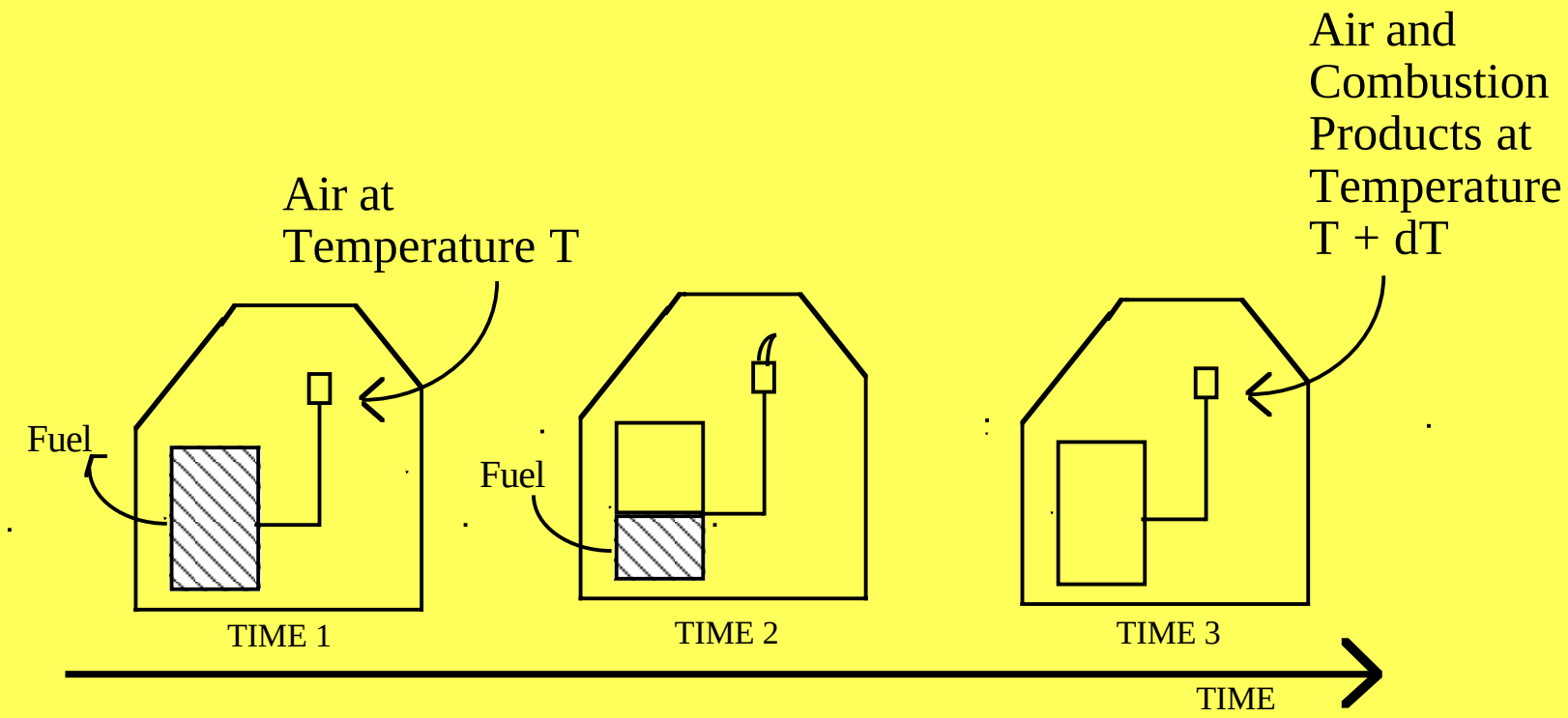
Exergy: The quality of energy

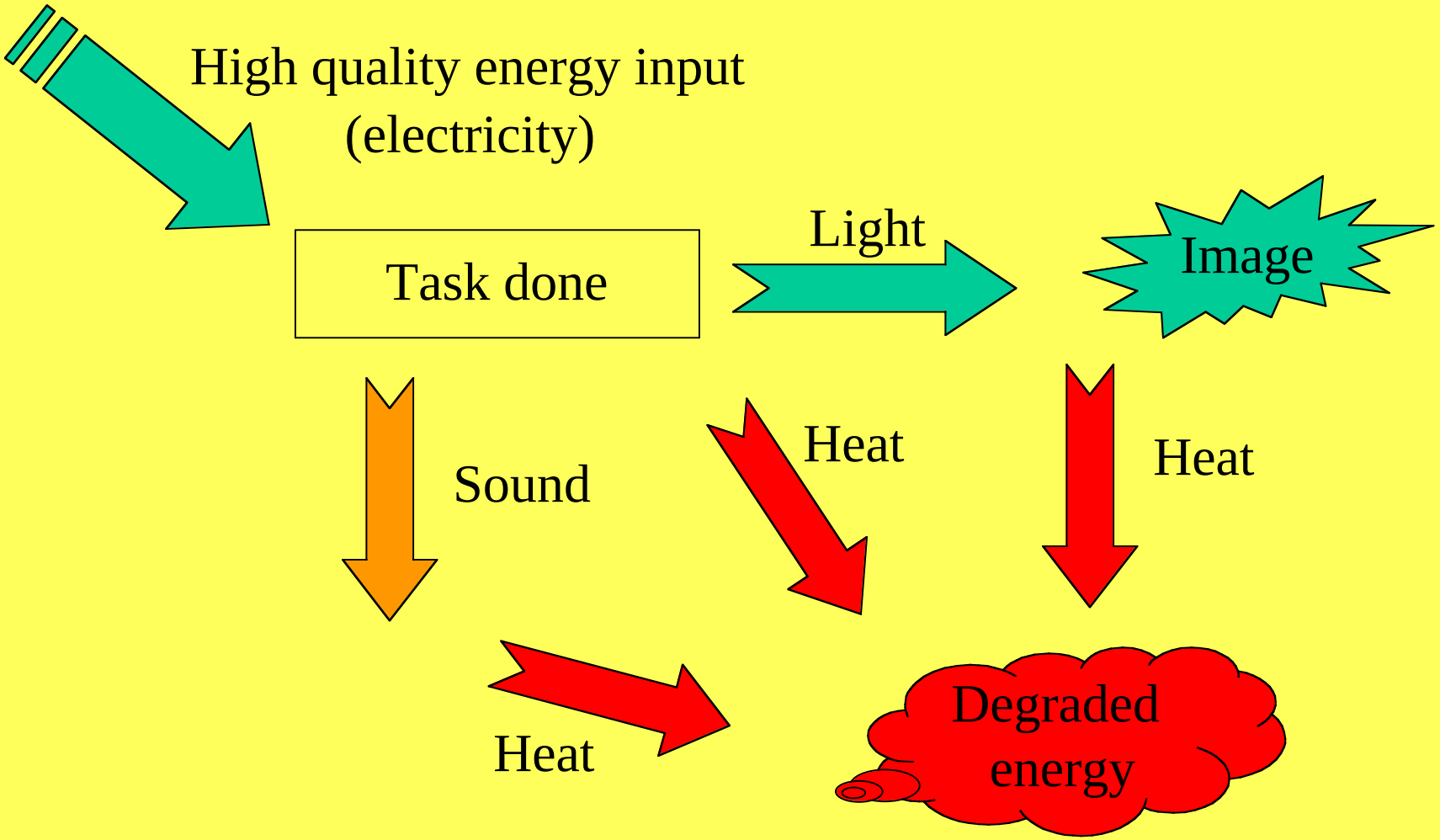


Energy Quantity in the container is constant.
Energy Quality (Exergy) in the container decreases.

(after Moran)

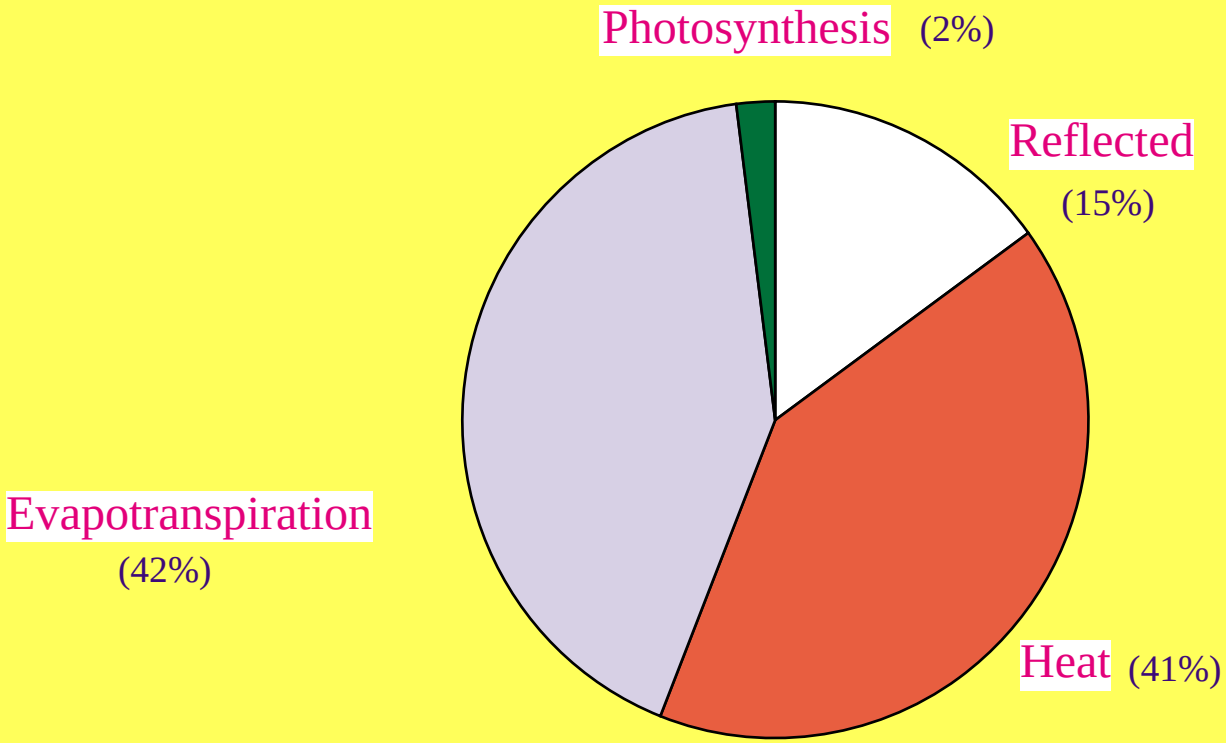
Energy IN = Energy OUT

Exergy IN »» Exergy OUT



The distribution of solar energy during the growing season in the Hubbard Brook Forested Ecosystem

(From Bormann and Likens, 1978)



Second law and ecosystems

What is the thermodynamic game?

Store energy

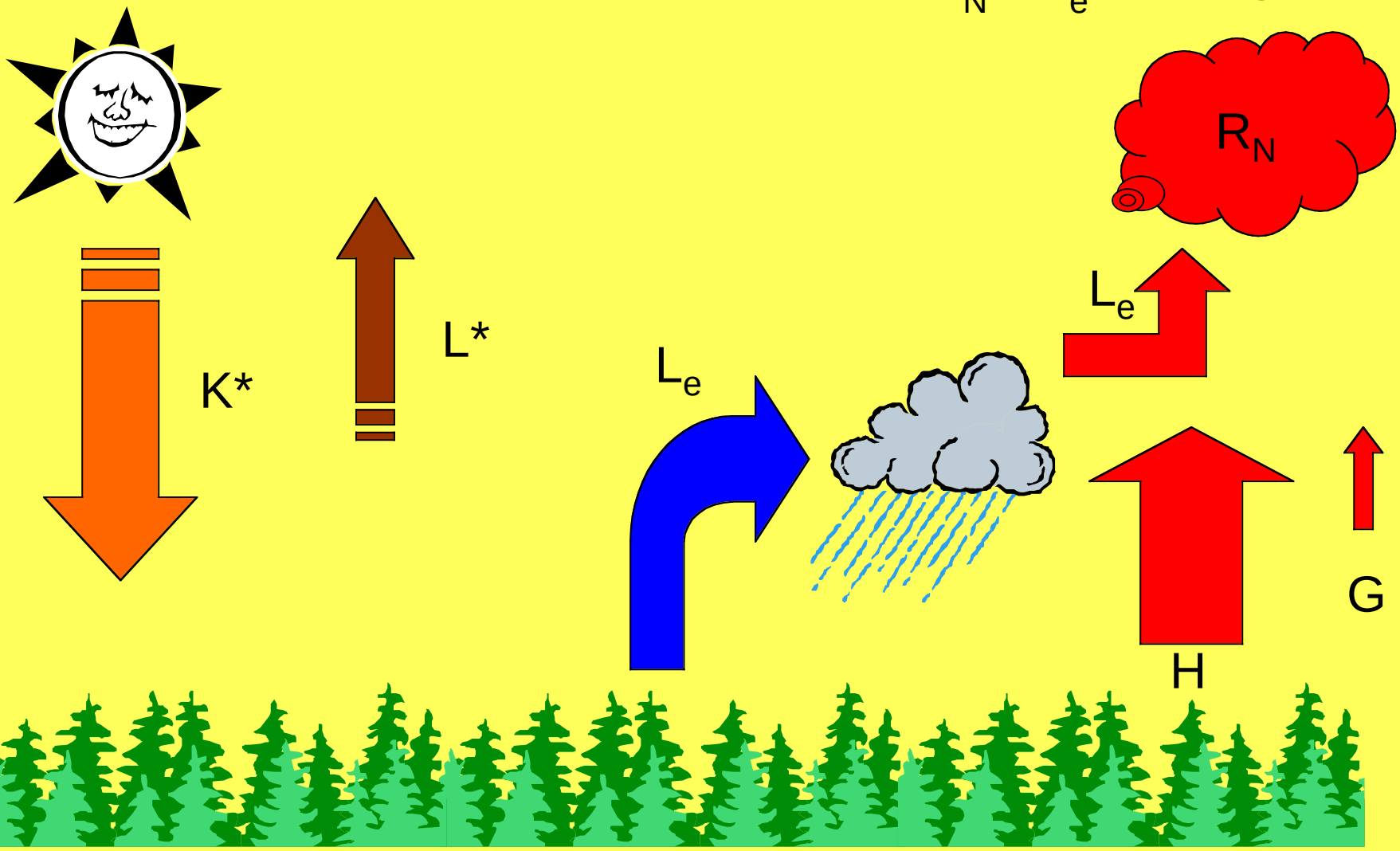
Increase Biomass

Make use of as much of the exergy as possible to perform tasks. Make the most effective use of the energy. Win! 

(H.T. Odum was right! If maximum work principle means extract the most available work from the energy source.)

$K^* = L^* + R_N$

$R_N = L_e + H + G$



The radiation equations

$$R_n = K^* - L^*$$

where K^* = Net flux of Solar Radiation (incoming), L^* = Net Flux of long wave radiation (outgoing), R_n = Net radiation flux absorbed at surface (all measured in watts / meter^2)

$$R_n = H + L_e + G$$

where H = sensible heat flux, L_e = latent heat flux, G= energy flux into the ground. R_n is the energy which is degraded from radiation into molecular motion.

$$L^* = \varepsilon [\sigma(T)^4]$$

where ε= emissivity, σ=Stefan-Boltzmann constant, T= surface temperature

If K^* is constant, the smaller T, the smaller L^* and hence the larger R_n and thus the larger the amount of energy degraded.

	Quarry	Clearcut	Douglas Fir Plantation	Natural Forest	400 year old Douglas Fir Forest
K* (w/m^2)	718	799	854	895	1005
L* (w/m^2)	273	281	124	124	95
R_n (w/m^2)	445	517	730	771	830
T (^oC)	50.7	51.8	29.9	29.4	24.7
R_n/K^* (%)	62	65	85	86	90

where

$$R_n = K^* - L^* \quad \text{and} \quad R_n = H + L_e + G$$

$$L^* = \varepsilon [\sigma (T)^4]$$

R_n is the energy which is degraded from radiation into molecular motion, that is captured by the ecosystem and utilized.

R_n/K^* = percent of net incoming solar radiation degraded into nonradiative processes, that is used by the ecosystem. This is a measure of second law effectiveness, a measure of the organizational state of an ecosystem.

	Quarry	Clearcut	Douglas Fir Plantation	Natural Forest	400 year old Douglas Fir Forest
T (^{O}C)	50.7	51.8	29.9	29.4	24.7
R_n/K* (%)	62	65	85	86	90
Beta Index	12.9	6.3	34.4	17.2	130.7
TRN	168	406	1631	788	1549

Beta Index: Spatial variability in the surface temperature

Thermal Response Number (TRN): For a given input of energy over a given time, the change in surface temperature. Temporal variability.

Both are measures of inertia, so bigger means less variability.

Nonequilibrium thermodynamic hypotheses concerning ecosystem development

- Exergy utilization will increase
  - Rn/K* will increase
  - Surface temperature will decrease
- Internal equilibrium will increase
  - Spatial variation in surface temperature will decrease (Beta index increases)
  - Temporal variation in surface temperature will decrease (TRN increases)

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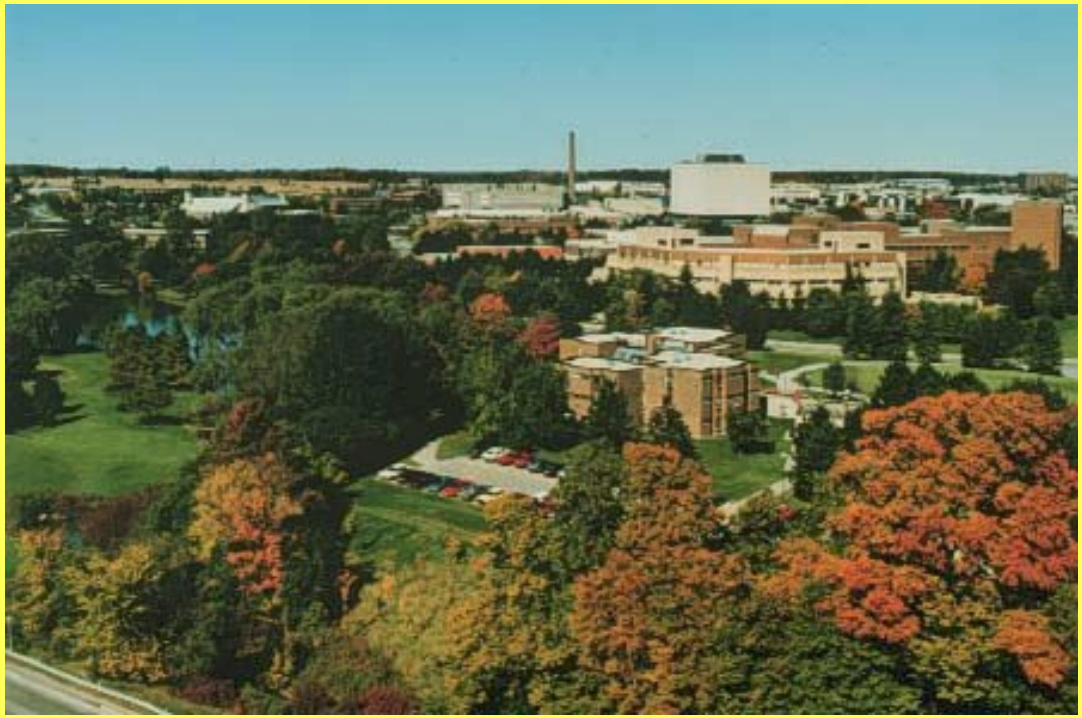

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