ENERGY

The ability to cause work

Since all energy can be converted 100% to heat, it is convenient to express energy in heat units

Not all forms of energy are equivalent...

Energy Quality

related to concentration

flexibility

ease of transportation

convertibility

Every process is dependent upon many different input forms, from energy, to materials to information.

What is needed is the ability to evaluate all forms of energy, materials, and information on a common basis by converting them into equivalents of one form of energy, a measure of the past and present support to any process occurring in the biosphere.

EMERGY

EMERGY (from EMbodied enERGY)

Available energy of one kind that is used up in transformations directly and indirectly to make a product or service

EMERGY (EMbodied enERGY)

The foundations of the Emergy analysis are the main outcome of the work by Howard T. Odum, one of the most creative and productive scholars in the field of system analysis

Emergy is an expression of all the energy used in the work processes that generate a product or service *in units of one type of energy*

A scientific measure of the overall investment that has been necessary to obtain the service or product at issue, in terms of all the resources now virtually embodied in it

The idea of including all the "expenses", also including the indirect environmental support embodied in human labor and services, shifts the attention from the user-side perspective to the donor-side one

- Expressed in energy of the same FORM … usually solar energy
- Sometimes called Energy Memory = Emergy
- Units = solar emergy Joules = sej

Unit Emergy Values (UEVs)

The amount of emergy required to produce a unit of a product

→ *Transformity, defined as the emergy input per unit of available energy output. For example, if 40,000 solar emjoules are required to generate a joule of wood, then the solar transformity of that wood is 40,000 solar emjoules per joule (abbreviated sej/J)*

	sej/J
Sunlight	1
Wood	36.000
Coal	97.000
Oil	148.000

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→ *Specific emergy, defined as the emergy per unit mass output, and usually expressed as solar emergy per gram (sej/g). Because available energy is required to concentrate materials, the UEV of any substance increases with concentration. Elements and compounds not abundant in the environment therefore have higher emergy/mass ratios when found in concentrated form since more environmental work was required to concentrate them, both spatially and chemically*

	sej/J
Sunlight	1
Wood	36.000
Coal	97.000
Oil	148.000

Energy Transformation Hierarchy

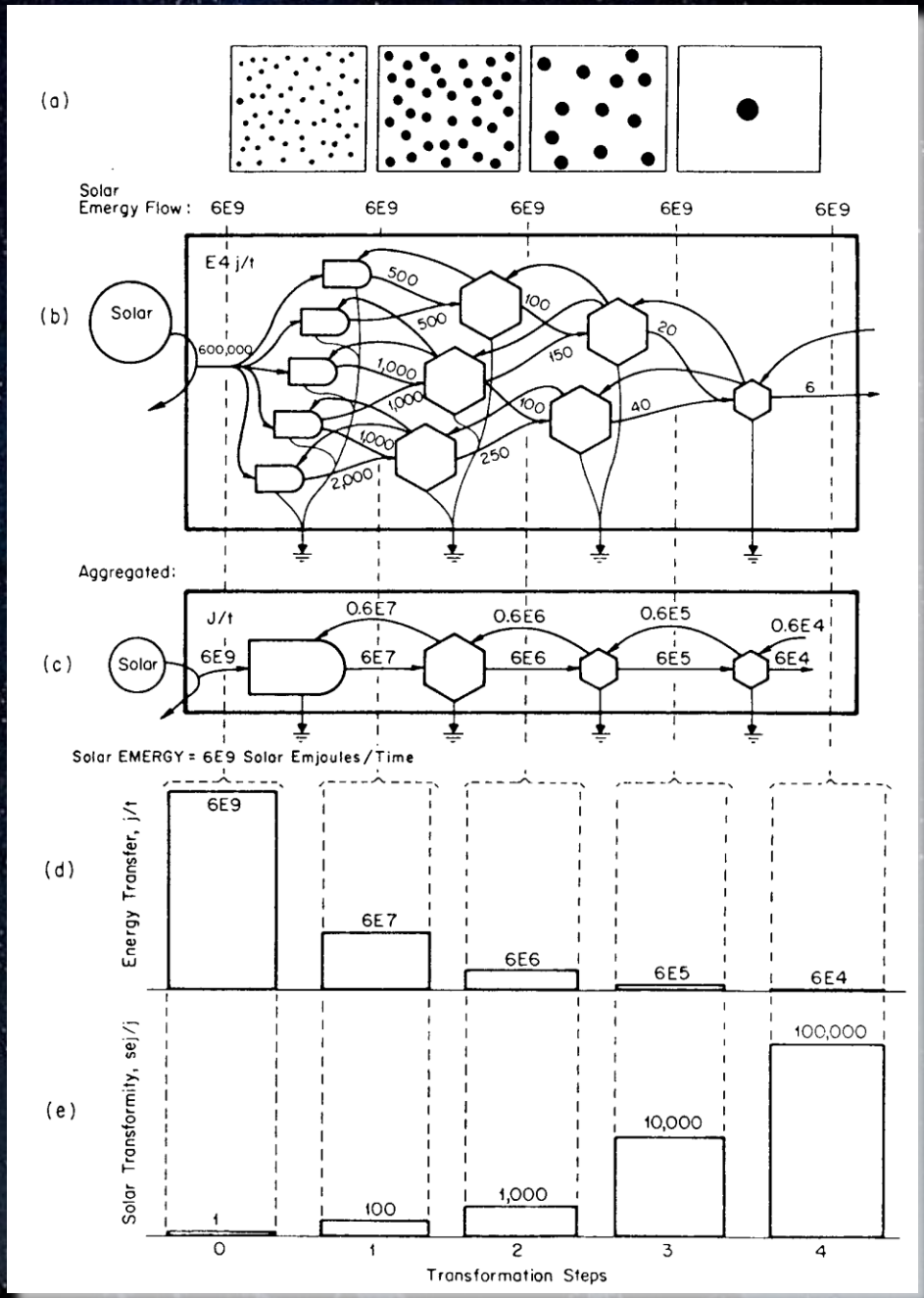
Spatial view of units and their territories

Energy networks including transformation and feedbacks

Aggregation of energy network into an energy chain

Bar graph of the energy flows for the levels in the energy hierarchy

Bar graph of solar transformities



Emergy concept is a manifold tool for

- accounting
- describing
- explaining
- understanding

1) An ST diagram is drawn

2) A table of the actual flows of resources, labor and energy is set up from the diagram and all flows are evaluated in terms of emergy

3) Quantitative results are interpreted

4) ST Equations are setup

5) A dynamic simulator is built and validated

Emergy indicators

Emergy accounting
(STATIC ANALYSIS)

Simulator

Emergy analysis
(DYNAMIC ANALYSIS)

EMERGY ALGEBRA

Rule 1: Emergy is the available energy (exergy) of one kind that is used up in transformations directly and indirectly to make a product or service.

Rule 2: In processes having one output, all independent emergy inputs are assigned to the processes' output.

Rule 3: When a pathway splits, the emergy is assigned to each branch of the split based.

Rule 4: In processes having two or more co-products, all independent input emergy is assigned to each co-product.

Rule 5: Within a system, emergy cannot be counted twice:

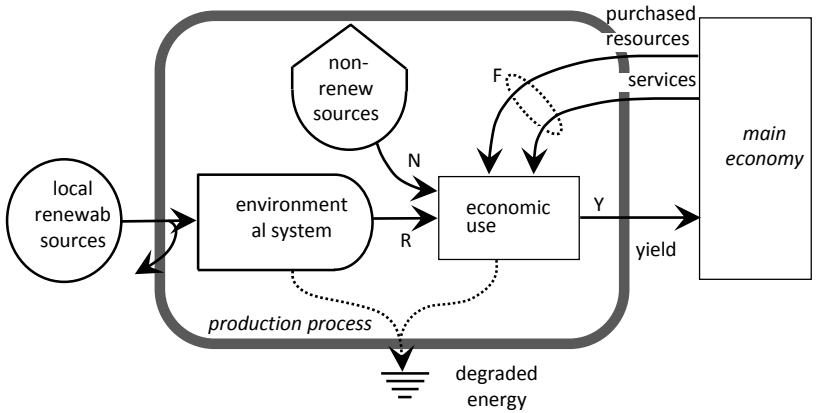
a) emergy in feedbacks cannot be double counted

b) co-products, when reunited cannot be added to equal a sum greater than the source of emergy from which they were derived

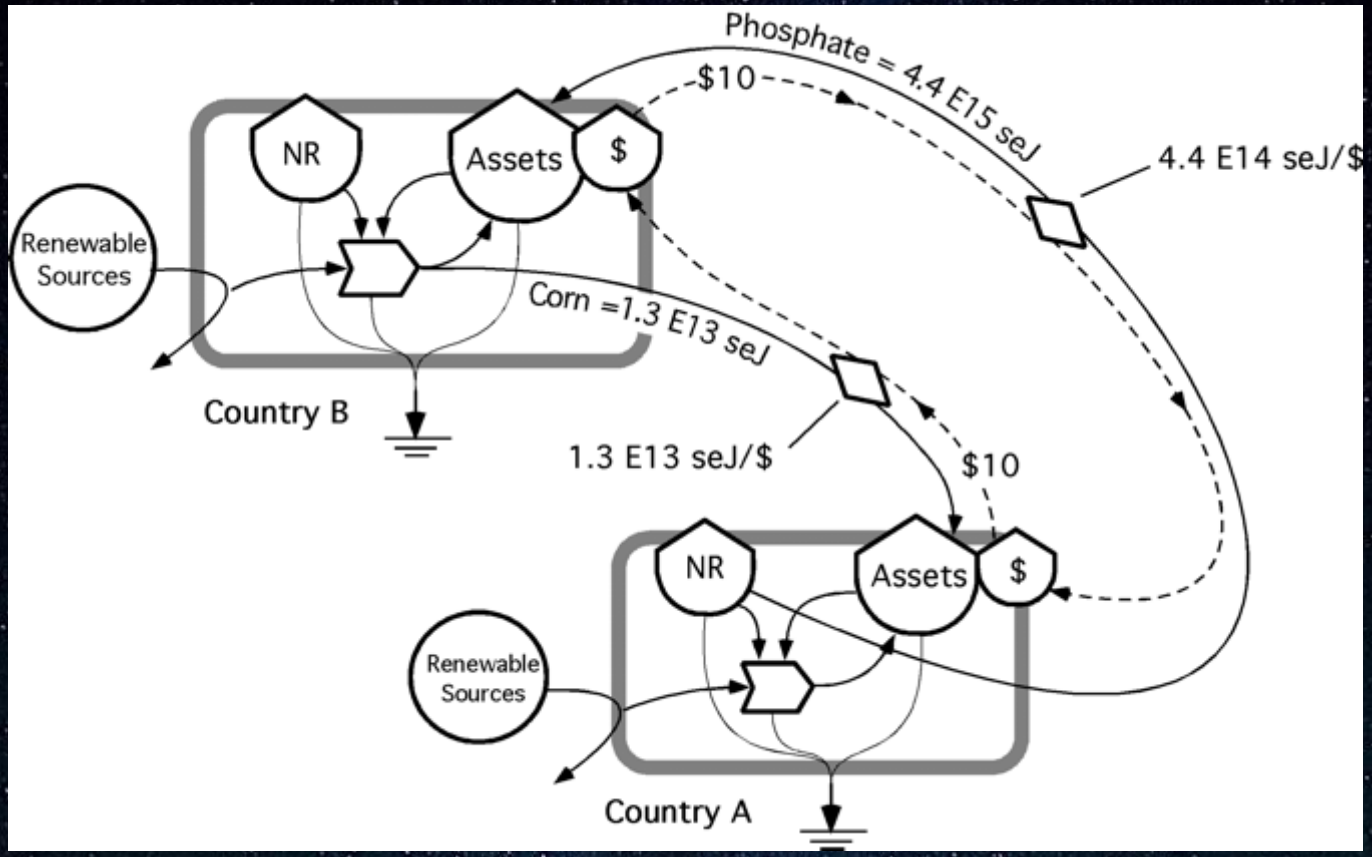
c) only those emergy flows which make up inputs $Em(u_1)$, $Em(u_2)$, and $Em(u_3)$ that are distinct and independent are included in the output, $Em(y_j)$

Emergy indicators

Inputs and services	Expression	Meaning
Total emergy (Y)	$Y = I + F$	Emergy of total outputs
Nature's contribution (I)	$R + N$	Emergy of renewable and non-renewable resources
Renewable natural resources (R)		These could include rain, materials and services, nutrients from soil, minerals and air
Non-renewable natural resources (N)		These could include soil or biodiversity, but not people
Feedback from economy (F)	$F = M + S$	Total inputs originating from the economy and feeding back into the system
Materials (M): Renewable (Mr) and non-renewable (Mn) materials and energy	$M = Mr + Mn$	Renewable materials of natural origin. Non-renewable materials include minerals, chemicals, steels, fuel etc.
Services (S): Renewable (Sr) and non-renewable (Sn) services and externalities (Sa)	$S = Sr + Sn + Sa$	Renewable services include human labour supported by renewable sources, which can be local (Srl) and external (Sre). Non-renewable services include external services, taxes, insurance etc. Externalities include effluents, medical costs, job losses etc.



Emergy indicators		
Solar transformity (Tr)	$\frac{Y}{\sum Ep}$	Ratio of the output divided by the energy of the products
Renewability (%R)	$\frac{100x(R + Mr + Sr)}{Y}$	Ratio of renewable inputs divided by the total emergy of the system
Emergy yield ratio (EYR)	$\frac{Y}{Mn + Sn}$	Ratio of total emergy used divided by the emergy of non-renewable inputs from the economy
Emergy investment ratio (EIR)	$\frac{Mn + Sn}{R + Mr + Sr + N}$	Ratio of emergy of non-renewable economic inputs divided by the emergy of natural investments (natural inputs plus renewable inputs from the economy)
Environmental loading ratio (ELR)	$\frac{N + Mn + Sn}{R + Mr + Sr}$	Ratio of non-rewenwable emergy to renewable inputs.
Emergy exchange ratio (EER)	$\frac{Y}{\left[(\$)x\left(\frac{sej}{\$}\right)\right]}$	Ratio of emergy delivered by the producer to the economy divided by the emergy received from the sale of items produced
Emergy self-support ratio (ESR)	$\frac{R + N}{Y}$	Ratio of the emergy inputs to the total emergy
Emergy matching (EM)	$\frac{Subsystem}{Subsystem}$	Ratio that measures how well co-existent subsystems within an area balance one another in terms of their emergy values.
Emergy investment (EI)	$\frac{F}{(R + N)}$	Ratio between the emergy sources from the economy and free renewable sources
Environmental sustainability index (ESI)	$\frac{EYR}{ELR}$	Indicator of the sustainability of a system
Emergy flow density (ED)	$\frac{Y}{Area}$	Ratio of the emergy flow that is supporting a system divided by its area.
Social emergy indicators		
Labour services ratio (LSR)	$\frac{Sr}{S}$	This ratio represents human labour supported by renewable resources divided by the total value of services, including renewable and non-renewable services and externalities.
Labour empower ratio (LER)	$\frac{Sr}{Y}$	This ratio is defined as human labour supported by renewable resources divided by total emergy.
Labour work ratio (LWR)	$\frac{Srl}{S}$	The local human labour supported by renewable resources divided by the total value of services, including renewable and non-renewable services and externalities.
Externalities empower ratio (EER)	$\left(\frac{Sn}{Y}\right)$	The ratio is given by dividing the non-renewable services with the total emergy.



Trade of commodities between two countries. Country A exports phosphate mineral to Country B, while Country B exports corn to Country A. The dollar terms of trade balance ($10), however the emergy terms of trade are decidedly in favor of Country B who **imports 4.4 E15 sej and exports only 1.3 E15 sej**

courtesy by M.T. Brown

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Explanations of ecological relationships with energy systems concepts

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Emergy and exergy stored in genetic information

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Energy hierarchy and transformity in the universe

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MODELING FOR ALL SCALES

An Introduction to System Simulation

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A conceptual framework and interpretation of emergy algebra

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Emergy and Network Analysis

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A Rigourous Mathematical Framework for Computing a Sustainability Ratio: the Emergy

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Emergy paths computation from interconnected energy system diagram

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