OSU~EmEa - 7

# Emergy Evaluation Procedure

Evaluation procedure: systems diagram, evaluation table, footnotes, summary diagram, and emergy indices

# Emergy Evaluation Procedure…

- Emergy accounting uses the thermodynamic basis of all forms of energy, materials and human services, but converts them into equivalents of one form of energy.

- Emergy accounting is organized as a top down approach where first a system diagram of the process is drawn to organize the evaluation and account for all inputs and outflows.

- Tables of the actual flows of materials, labor and energy are constructed from the diagram and all flows are evaluated.

- The final step of an emergy evaluation involves interpreting the quantitative results.

# Emergy Evaluation Procedure…

## Evaluating Alternatives…

- In some cases, the evaluation is done to determine fitness of a development proposal.

- In others, it may be a question of comparing different alternatives, or

- the evaluation may be seeking the best use of resources to maximize economic vitality.

So the final step in the evaluation is to calculate several emergy indices that relate emergy flows of the system being evaluated to predict economic viability, carrying capacity, or fitness.

# Emergy Evaluation Procedure…

## Emergy Synthesis/Analysis

- Emergy evaluations are both synthetic and analytic.
- Analysis is the process of breaking a complex topic or substance into smaller parts to gain a better understanding. Synthesis is the act of combining elements into coherent wholes. emergy synthesis strives for understanding by grasping the parts as well as the wholeness of systems.
- By evaluating complex systems using emergy methods, the major inputs from the human economy and those coming “free” from the environment can be integrated to analyze questions of public policy and environmental management holistically

# Emergy Evaluation Procedure…

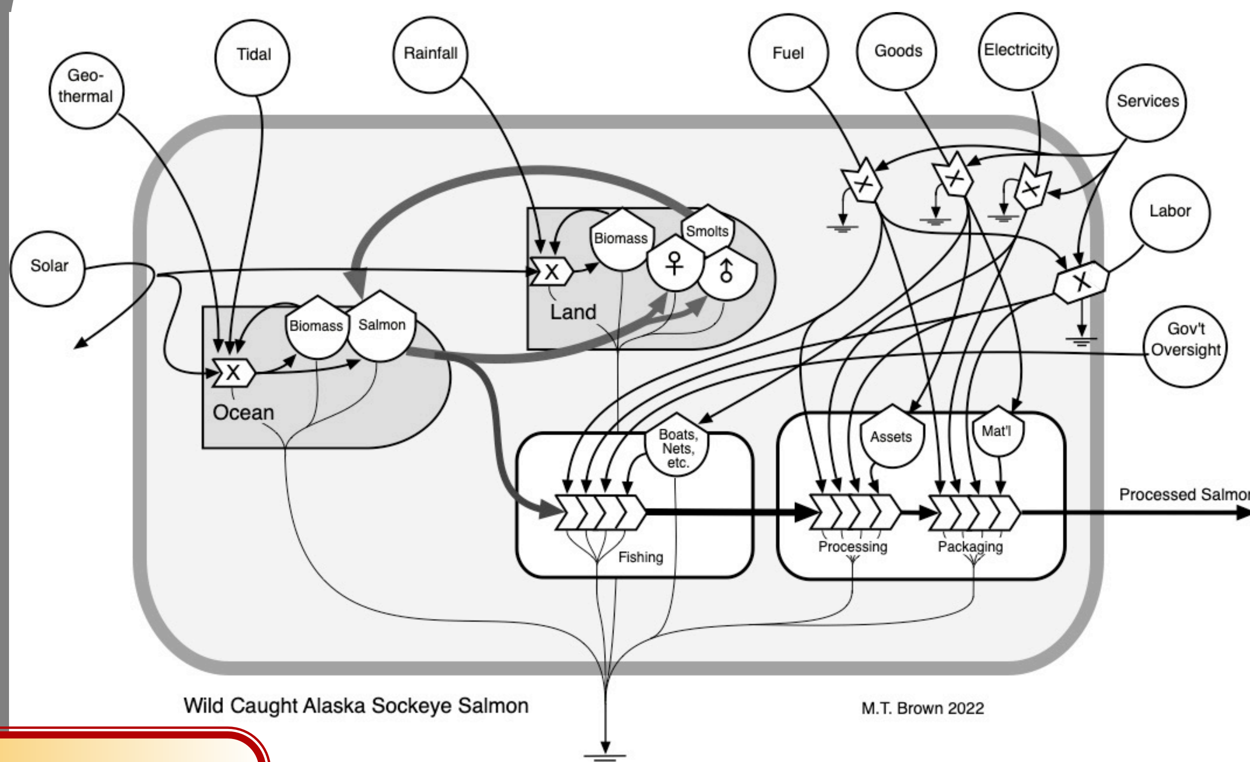
## 1. Left-right Energy Systems Diagram

Systems diagrams are used to show the inputs that are evaluated and summed to obtain the emergy of a resulting flow or storage.

The purpose of the system diagram is to conduct a critical inventory of processes, storages and flows that are important to the system under consideration and are therefore necessary to evaluate.

# Emergy Evaluation Procedure…

Example systems diagram…




System diagram of the process is drawn to organize the evaluation and account for all inputs and outflows.

# Emergy Evaluation Procedure…

## 2. Preparation of an Emergy Evaluation Table

- Tables of the actual flows of materials, labor and energy are constructed from the diagram.
- Raw data on flows and storage reserves are converted into emergy units, and then summed for a total emergy flow to the system.

# Emergy Evaluation Procedure…

Example emergy evaluation table…

Note footnote numbers.

Table 2. Emergy of inputs to produce 1 kg of sockeye salmon at each phase

| | Item | Units | Quantity | UEV (sej/unit) | Emergy (E12 sej) |
|---|---|---|---|---|---|
| Fishing phase | | | | | |
| 1 | Environmental Support (land) | J | 2.3E+09 | 1.20E+04 | 27.96 |
| 2 | Environmental Support (ocean) | m2 | 1.28E+03 | 2.71E+10 | 34.68 |
| 3 | Monitoring Activities (diesel) | kg | 4.69E-03 | 7.26E+12 | 0.03 |
| 4 | Drift Net & Tender Vessels | kg | 1.68E-02 | 2.40E+13 | 0.40 |
| 5 | Diesel Fuel | kg | 1.66E-01 | 7.26E+12 | 1.21 |
| 6 | Labor (Air transport-jet fuel) | kg | 1.25E-02 | 7.40E+12 | 0.09 |
| 7 | Labor | (p*hrs) | 6.36E-02 | 1.00E+14 | 6.36 |
| 8 | Output (salmon, live weight) | kg | 1.0 | 7.07E+13 | 70.74 |
| | Transformity | J | 1.0 | 6.76E+06 | |
| | | | | | |
| Processing phase | | | | | |
| 9 | Landed sockeye salmon | kg | 1.72 | 7.07E+13 | 121.67 |
| 10 | Building (Steel & Concrete) | m2 | 9.61E-05 | 1.4E+16 | 1.35 |
| 11 | Machinery | kg | 1.25E-03 | 2.39E+13 | 0.03 |
| 12 | Water | m3 | 1.82E-02 | 6.61E+11 | 0.01 |
| 13 | Diesel | kg | 1.30E-01 | 7.26E+12 | 0.94 |
| 14 | Electricity (USA) | kWh | 1.20E-01 | 1.80E+12 | 0.22 |
| 15 | Labor (Air transport-jet fuel) | p*km | 1.87E-03 | 7.40E+12 | 0.01 |
| 16 | Labor | p*hrs | 6.69E-02 | 1.00E+14 | 6.69 |
| 17 | Output processed product | kg | 1 | 1.31E+14 | 130.92 |
| | Transformity | J | 1.0 | 1.25E+07 | |
| | | | | | |
| Packaging phase | | | | | |
| 18 | Average salmon product | kg | 1.00E+00 | 1.31E+14 | 130.92 |
| 19 | Ship transport | ton*km | 2.85E-01 | 1.20E+10 | 0.00 |
| 20 | Plastic | kg | 1.12E-02 | 9.66E+12 | 0.11 |
| 21 | Cardboard | kg | 2.30E-02 | 7.00E+12 | 0.16 |
| 22 | Metal sheet for cans | kg | 1.10E-01 | 6.90E+13 | 7.59 |
| 23 | Pallets (Wood) | kg | 2.94E-02 | 2.89E+11 | 0.01 |
| 24 | Output Salmon product | kg | 1.00E+00 | 1.39E+14 | 138.79 |
| | Transformity | J | 1.0 | 1.33E+07 | |

# Emergy Evaluation Procedure...

| Notes to Table 2 | | | | |
|---|---|---|---|---|
| 1 | Environmental support (land) | | | |
| | Rainfall | 800 | mm | USEPA, 2014 |
| | Watershed area | 1.16E+11 | $m^2$ | USEPA, 2015 |
| | Density water | 1000 | kg $m^{-3}$ | |
| | Gibbs energy of rain | 4.72E+03 | J/kg | |
| | Time rearing | 2 | yrs | USEPA, 2014 |
| | Number of smolt = | 1.88E+08 | ind | |
| | Energy = | 0.8m rainfall * 1.16e11 $m^2$ *1000 kg $m^{-3}$* 4.72 E3 J $kg^{-1}$ * 2yrs / 1.88E8 ind | | |
| | = | 2.33E+09 | J | |
| | Solar transformity rainfall = | 1.20E+04 | sej/J | Brown and Ulgiati, 2016 |
| 2 | Environmental Support (ocean) | | | |
| | Energy input to ocean | | | |
| | Sunlight = | 7.42E+13 | J/ha | Lee and Brown, 2021 |
| | Geothermal = | 2.057E+10 | J/ha | Lee and Brown, 2021 |
| | Tidal = | 3.104E+09 | J/ha | Lee and Brown, 2021 |
| | Solar transformities ocean inputs | | | |
| | Sunlight = | 1 | seJ/J | Brown et al. ,2016 |
| | Geothermal = | 4900 | seJ/J | Brown et al. ,2016 |
| | Tidal = | 30900 | seJ/J | Brown et al. ,2016 |
| | Emergy input to ocean = | Sunlight * solar Tr + Geothermal energy * geothermal Tr + Tidal energy * tidal Tr | | |
| | = | (7.35 E13 J $ha^{-1}$ *1.0 seJ $J^{-1}$ + 2.06 E10 J $ha^{-1}$ * 4900 seJ $J^{-1}$+ 3.1 E09 J $ha^{-1}$ * 30900 seJ J-$^{1}$) / 10,000 $m^2$ $ha^{-1}$ | | |
| | = | 2.71E+10 | seJ $m^{-2}$ | |
| | Artic ocean NPP = | 214 | mg C $m^{-2}$ $day^{-1}$ | Westbury, 2015 |
| | = | 78.11 | g C $m^{-2}$ $yr^{-1}$ | |
| | Average salmon mass = | 1.0 | kg C | half of landed mass |
| | Trophic efficiency | 1.0% | | estimate |
| | NPP required to support 1 kgC fish = | 1000gC fish / 1.0% efficiency | | |
| | = | 1.00E+05 | gC $yr^{-1}$ | |
| | Ocean area required = | NPP required/Artic Ocean NPP | | |
| | = | 1.00 E5 gC $yr^{-1}$ / 78.11 gC $m^{-2}$ $yr^{-1}$ | | |
| | = | 1.28E+03 | $m^2$ | |
| 3 | Monitoring Activities (Diesel) | | | |
| | Diesel fuel = | 4.69E-03 | kg | Table 1 |
| | Specific Emergy= | 7.26E+12 | sej $kg^{-1}$ | Brown and Ulgiati, 2011 |
| 4 | Drift Net & Tender Vessels | | | |
| | Quantity of boats & gear = | 1.68E-02 | kg | Table 1 |

Every line item has a note to calculations and data sources

# Emergy Evaluation Procedure…

| | | | | |
|---|---|---|---|---|
| | Specific Emergy= | 2.40E+13 | sej $kg^{-1}$ | See supplemental material |
| 5 | Diesel Fuel | 1.66E-01 | kg | Table 1 |
| | Specific Emergy= | 7.26E+12 | sej $kg^{-1}$ | Brown and Ulgiati, 2011 |
| 6 | Labor (Air transport-jet fuel) | | | |
| | passenger * km = | 4.48E-01 | p *km | Table 1 |
| | Fuel use= | 0.035 | l $p*km^{-1}$ | EcoInvent |
| | density jet fuel = | 0.8 | kg $l^{-1}$ | |
| | energy intensity jet fuel = | 4.82E+07 | J $kg^{-1}$ | |
| | = | 4.48e-01 p $km^{-1}$ * 0.035l p km* 0.8kg $l^{-1}$ | | |
| | = | 1.25E-02 | kg | |
| | Unit emergy value = | 7.40E+12 | sej $kg^{-1}$ | Brown and Ulgiati, 2011 |
| 7 | Labor | 6.36E-02 | p*hrs | Table 1 |
| | Unit Emergy Value (UEV)= | 1.00E+14 | sej $p*h^{r-1}$ | See supplemental material |
| 8 | Output (Sockeye salmon, live weight) | 1.0 | kg | |
| | Specific Emergy = | 7.07E+13 | sej $kg^{-1}$ sum of emergy inputs to fishing phase | |
| | Transformity = | 7.07 E13 sej $kg^{-1}$ * 1000g $kg^{-1}$ * 2.5 Cal $g^{-1}$ * 4186 J $Cal^{-1}$ | | |
| | = | 6.76E+06 | sej/J | |
| 9 | Landed sockeye salmon | 1.72 | kg | 1 kg of finished product requires 1.72 kg of landed salmon |
| | Specific Emergy = | 7.07E+13 | sej $kg^{-1}$ | Item 8 |
| 10 | Building (Steel & Concrete) | 9.61E-05 | $m^2$ | Table 1 |
| | Unit emergy value = | 1.4E+16 | sej $m^{-2}$ | See supplemental material |
| 11 | Machinery | 1.25E-03 | kg | Table 1 |
| | Specific Emergy = | 2.39E+13 | sej $kg^{-1}$ | See supplemental material |
| 12 | Water | 1.82E-02 | $m^3$ | Table 1 |
| | Unit emergy value = | 6.61E+11 | sej $m^{-3}$ | Brown and Ulgiati, 2016 |
| 13 | Diesel | 1.73E-01 | kg | Table 1 |
| | Specific Emergy = | 7.26E+12 | sej $kg^{-1}$ | Brown and Ulgiati, 2011 |
| 14 | Electricity (USA) | 3.51E-01 | kWh | Table 1 |
| | Unit emergy value = | 1.80E+12 | sej $kWh^{-1}$ | See supplemental material |
| 15 | Labor (Air transport-jet fuel) | | | |
| | passenger * km = | 6.69E-02 | p*km | Table 1 |
| | Fuel use= | 0.035 | l $p*km^{-1}$ | EcoInvent |
| | density jet fuel = | 0.8 | kg $l^{-1}$ | |
| | energy = | 6.69 E-02 p*km * 0.035 l $p*km^{-1}$* 0.8 kg $l^{-1}$ | | |
| | = | 1.87E-03 | J | |
| | Specific Emergy = | 7.40E+12 | sej $kg^{-1}$ | Brown and Ulgiati, 2011 |
| 16 | Labor | 6.69E-02 | p*hrs | Table 1 |
| | Unit Emergy Value (UEV)= | 1.00E+14 | sej $p*h^{r-1}$ | See supplemental material |
| 17 | Output processed product (average) | 1.00 | kg | |
| | Specific Emergy = | 1.31E+14 | sej $kg^{-1}$ sum of emergy inputs to proc. phase | |

# Emergy Evaluation Procedure...

| | | | | | |
|---|---|---|---|---|---|
| | Transformity = | 1.31 E14 sej $kg^{-1}$ * 1000g $kg^{-1}$ * 2.5 Cal $g^{-1}$ * 4186 J $Cal^{-1}$ | | | |
| | = | 1.25E+07 | sej/J | | |
| 18 | Average Salmon Product (kg) | 1.00 | kg | | |
| | Specific Emergy = | 1.31E+14 | sej $kg^{-1}$ | Item 17 | |
| 19 | Ship transport (Packaging) | 2.85E-01 | ton*km | Table 1 | |
| | Unit Emergy Value (UEV)= | 1.20E+10 | sej t*$km^{-1}$ | See supplemental material | |
| 20 | Plastic | 1.12E-02 | kg | Table 1 | |
| | Specific emergy = | 9.66E+12 | sej $kg^{-1}$ | See supplemental material | |
| 21 | Cardboard | 2.43E-02 | kg | Table 1 | |
| | Specific emergy = | 7.00E+12 | sej $kg^{-1}$ | See supplemental material | |
| 22 | Metal sheet for cans | 0.11 | kg | Table 1 | |
| | Specific emergy = | 6.90E+13 | sej $kg^{-1}$ | See supplemental material | |
| 23 | Pallets (Wood) | 2.94E-02 | kg | Table 1 | |
| | Specific emergy = | 2.89E+11 | sej $kg^{-1}$ | See supplemental material | |
| 24 | Average Salmon Product (kg) | 1.00 | kg | | |
| | Specific emergy = | 1.39E+14 | sej $kg^{-1}$ sum of emergy inputs to packaging phase | | |
| | Transformity = | 1.39E14 sej $kg^{-1}$ * 1000g $kg^{-1}$ * 2.5 Cal $g^{-1}$ * 4186 J $Cal^{-1}$ | | | |
| | = | 1.33E+07 | sej/J | | |

# Emergy Evaluation Procedure…

## 3. Emergy of Storages

- When calculating the emergy of stored quantities (storages), it is necessary to sum the emergy of each of the inputs for the time of its contribution.
- Input emergy inflows are multiplied by the time it takes to accumulate the storage.

# Emergy Evaluation Procedure…

## 4. Evaluations Based on Averaged Inputs

- All systems pulse… with time intervals and pulse strength that increase with scale.
- To evaluate a process on one scale of time and space usually means using averages for each of the inputs from smaller scales where pulses are of high frequency.
- For example, for an evaluation of phenomena on the scale of human economy, yearly averages are often appropriate.

# Emergy Evaluation Procedure…

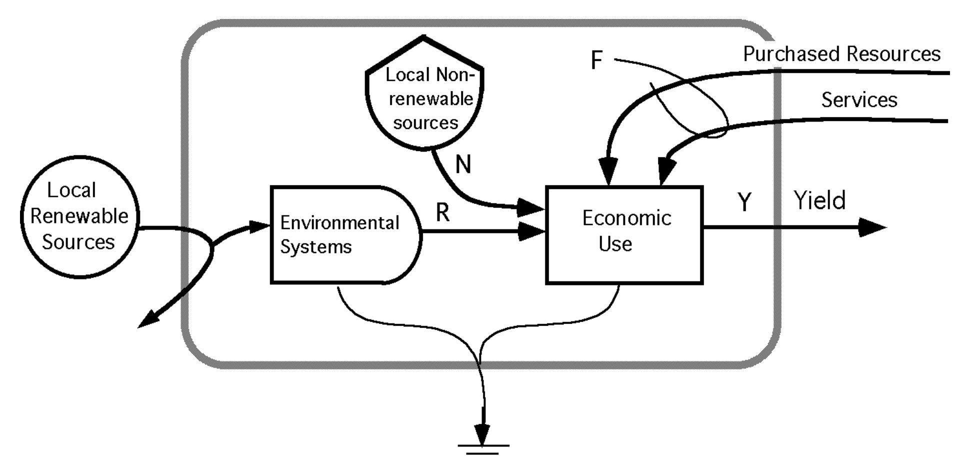
## 5. Calculating Unit Emergy Values (UEVs)

- After an evaluation table is prepared, UEVs of products can be calculated.
- The output or product is evaluated first in units of energy or mass...
- Then the input emergy in the last column is summed and the UEV for the product is calculated by dividing the emergy by the units of the output.
- The UEV that results is useful for other emergy evaluations.

# Emergy Evaluation Procedure…

## 6. Performance Indicators

The systems diagram below shows non-renewable environmental contributions (N) as an emergy storage of materials, renewable environmental inputs (R), and inputs from the economy as purchased (F) goods and services.

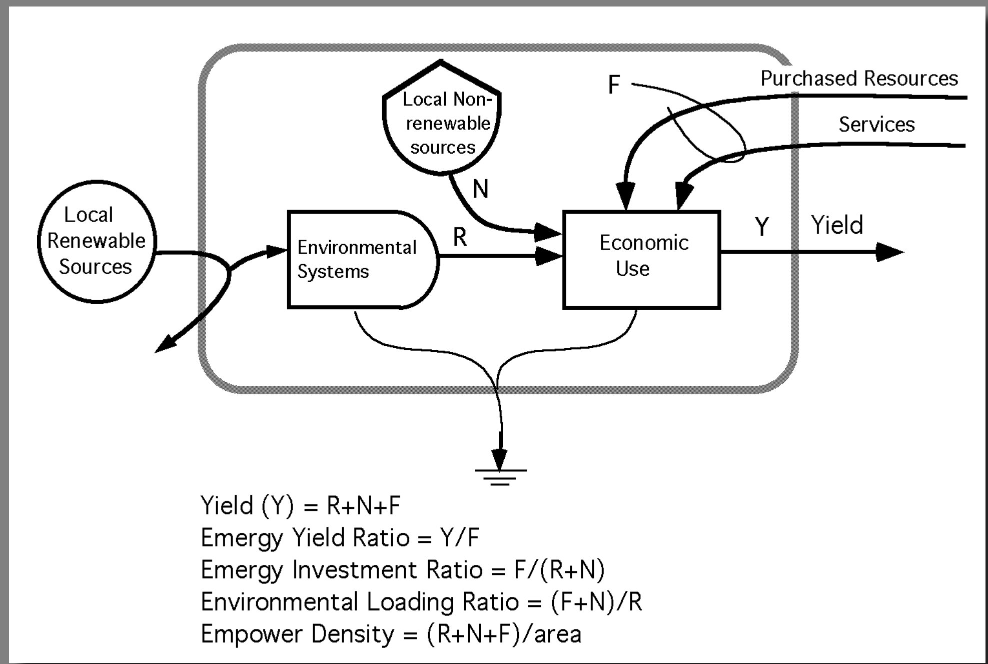



Yield (Y) = R+N+F
Emergy Yield Ratio = Y/F
Emergy Investment Ratio = F/(R+N)
Environmental Loading Ratio = (F+N)/R
Empower Density = (R+N+F)/area

# Emergy Evaluation Procedure…

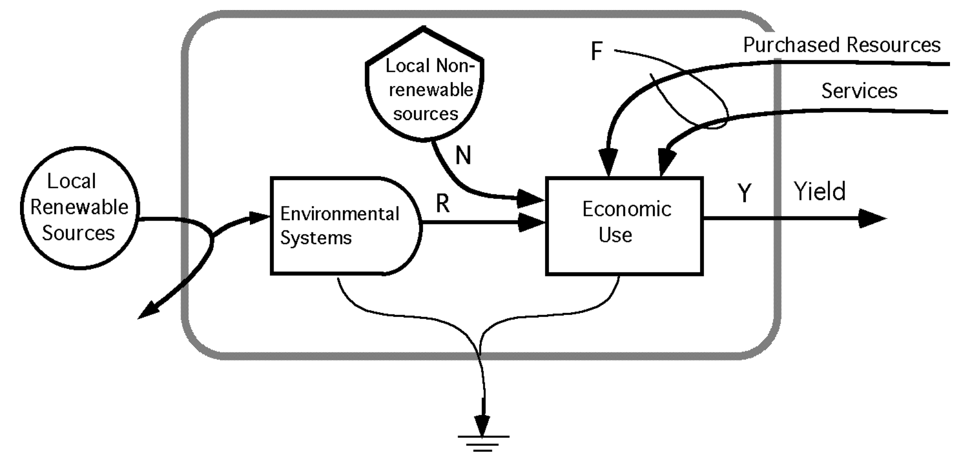
Several ratios, or indices are given in the figure that are used to evaluate the global performance of a process as follows:

Emergy yield ratio. The ratio of the emergy yield from a process to the emergy costs. The ratio is a measure of how much emergy is provided by a process  for a given emergy expenditure.



# Emergy Evaluation Procedure...

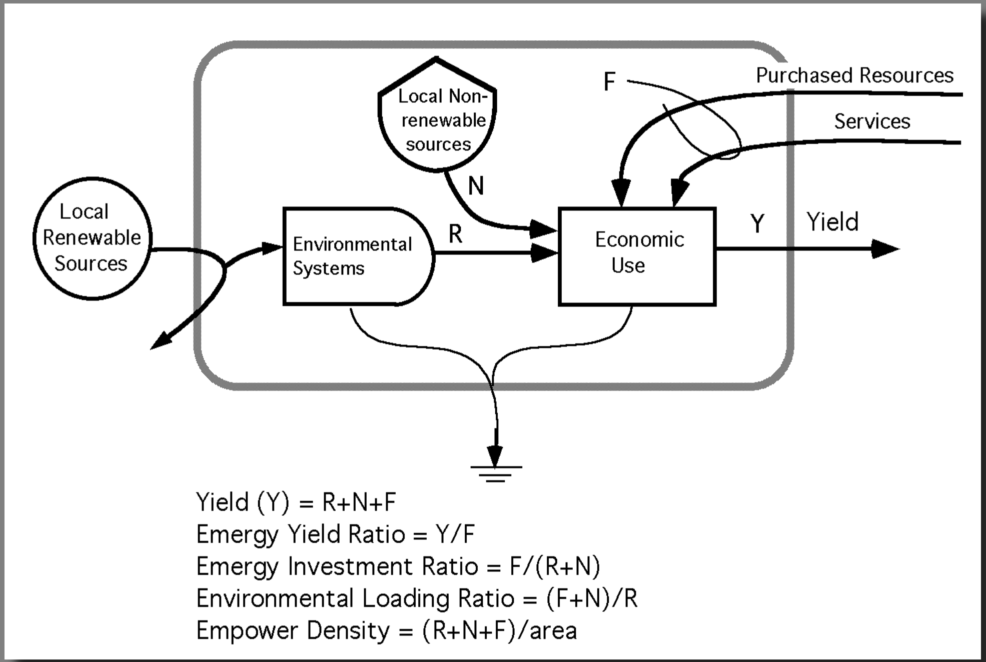
Environmental loading ratio. The ratio of nonrenewable and imported emergy use to renewable emergy use. It is and indicator of the pressure of a transformation process on the environment and can be considered a measure of ecosystem stress due to a production (transformation activity.




Yield (Y) = R+N+F
Emergy Yield Ratio = Y/F
Emergy Investment Ratio = F/(R+N)
Environmental Loading Ratio = (F+N)/R
Empower Density = (R+N+F)/area

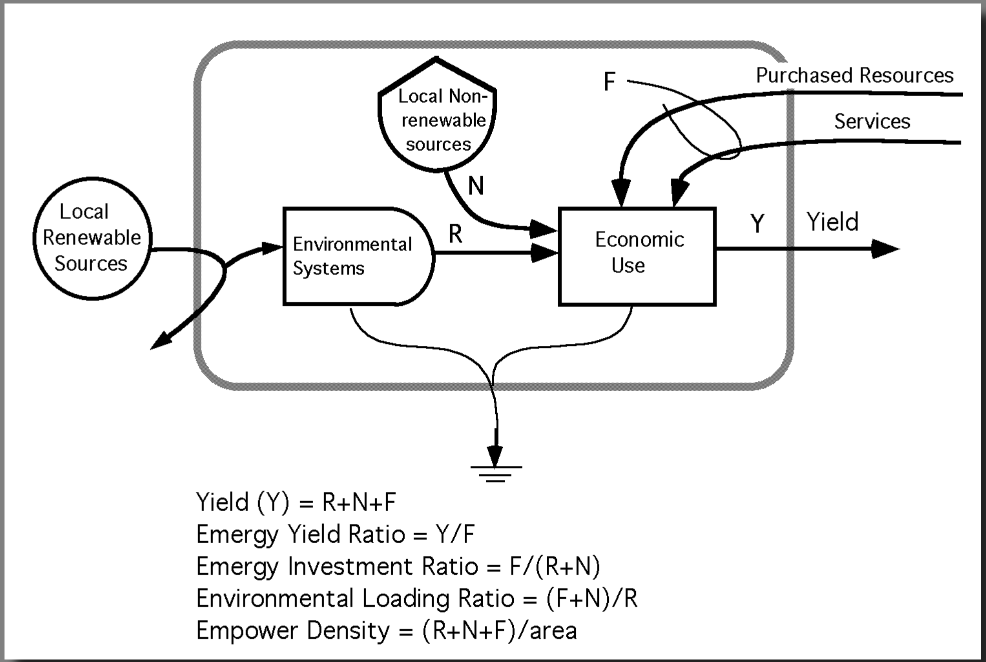
# Emergy Evaluation Procedure…

Emergy Sustainability Index. The ratio of the Emergy Yield Ratio to the Environmental Loading Ratio. It measures the contribution of a resource or process to the economy per unit of environmental loading.



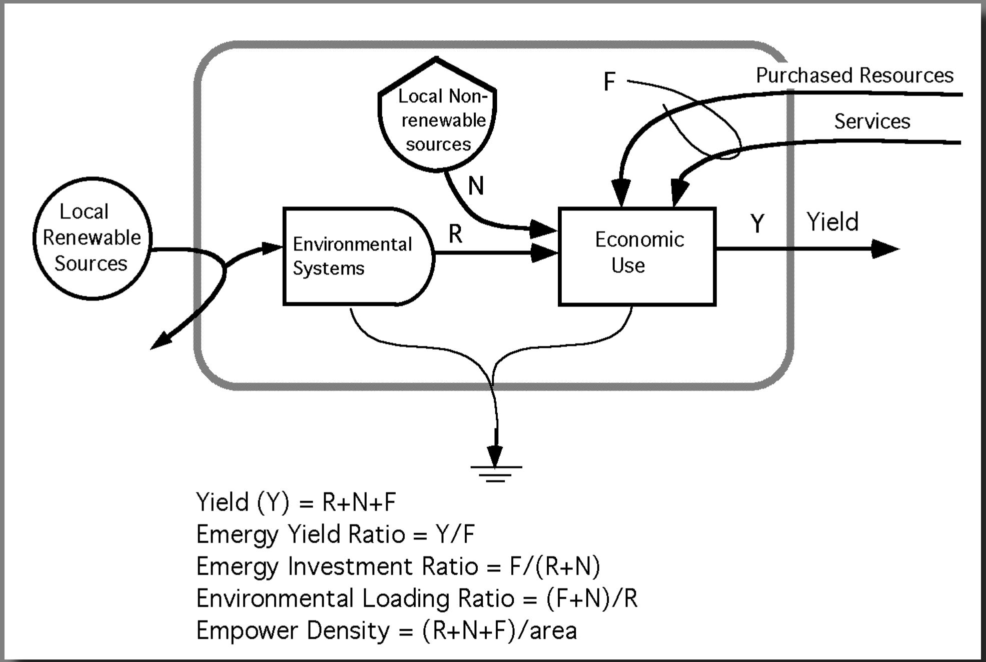
# Emergy Evaluation Procedure...

Emergy Investment ratio. The ratio of emergy fed back from outside a system to the indigenous emergy inputs (both renewable and non-renewable). It evaluates if a process is a good user of the emergy that is invested, in comparison with alternatives.



# Emergy Evaluation Procedure...

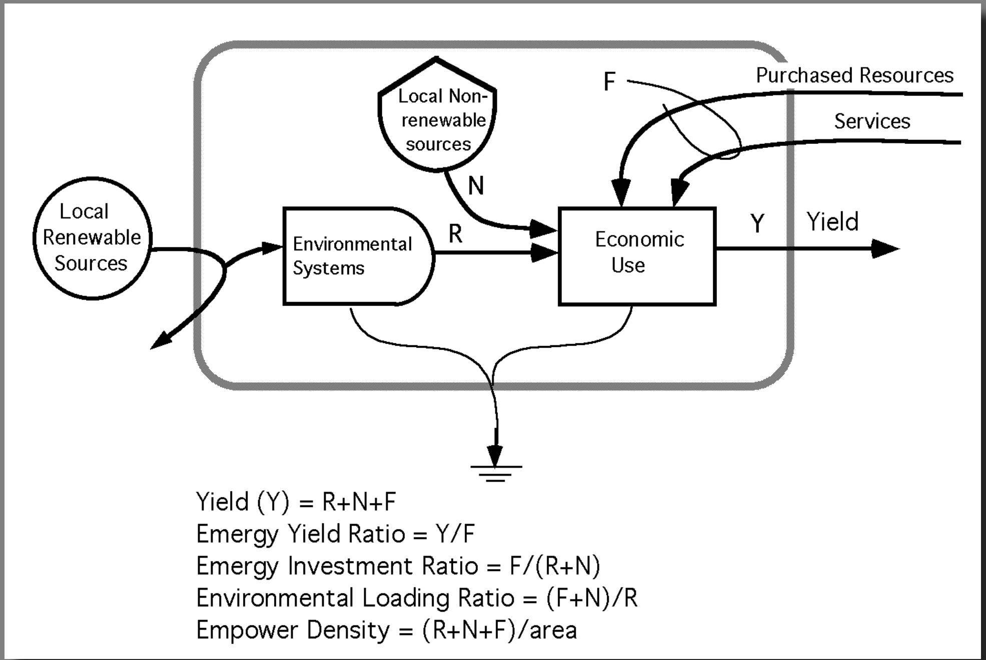
Empower density. The ratio of total emergy use in the economy of a region or nation to the total area of the region or nation. Renewable and nonrenewable emergy density are also calculated separately by dividing the total renewable emergy by area and the total nonrenewable emergy by area, respectively.



# Emergy Evaluation Procedure…

Several other ratios are sometimes calculated depending on the type and scale of the system being evaluated…

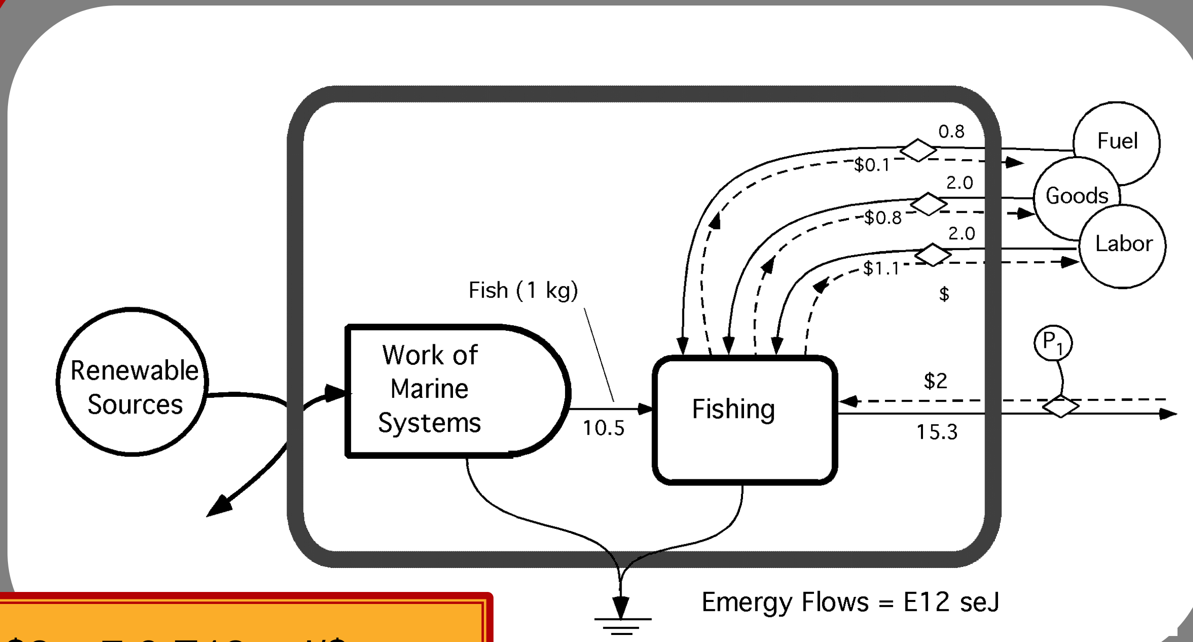
Percent renewable emergy (%Ren). The ratio of renewable emergy to total emergy use. In the long run, only processes with high %Ren are sustainable.



# Emergy Evaluation Procedure...

Emprice. The emprice of a commodity is the emergy one receives for the money spent.

Its units are sej/currency.




Emprice = 15.3 E12 sej/ $2 = 7.6 E12 sej/$

Questions…