Framework for the design of regenerative product systems

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Outline

- Introduction
- Definitions
- Product systems
- Ecosystems
- The Regeneration Factor
- A framework for regenerative systems
- Conclusions & Discussion

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Definitions

- Impact – an effect on the environment
- Sustainability – meeting the needs of the present without compromising the ability of future generations to meet their own needs – Brundtland Commission
- Restoration – return of a damaged system to a prior functional state –
- Regeneration – autonomous return of a damaged system to a prior functional state
- Evolution – gradual, progressive change usually making systems more diverse & resilient

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Definitions

- System - a set of objects and processes that together perform a function not obtainable by the objects and processes alone
  - Closed system - a system whose elements, including all mass and energy flows, lie within a boundary
  - Open system - a system whose elements lie within a boundary that allows mass and energy flows across the boundary
- Product - a substance or article that is grown, processed, or manufactured to serve a purpose
- Product system – a set of objects and processes that together function to produce a product or service

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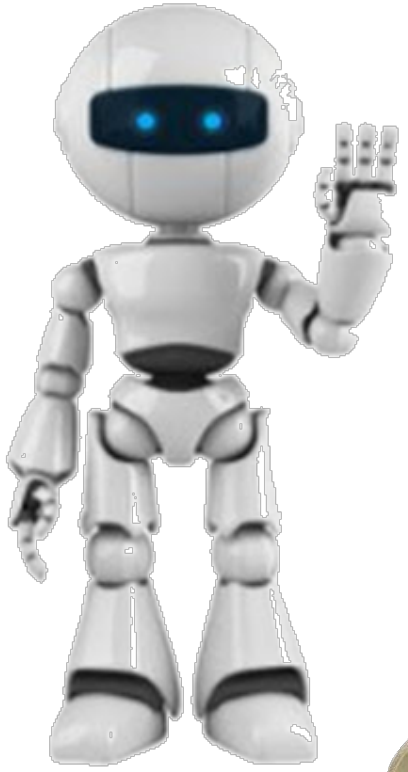
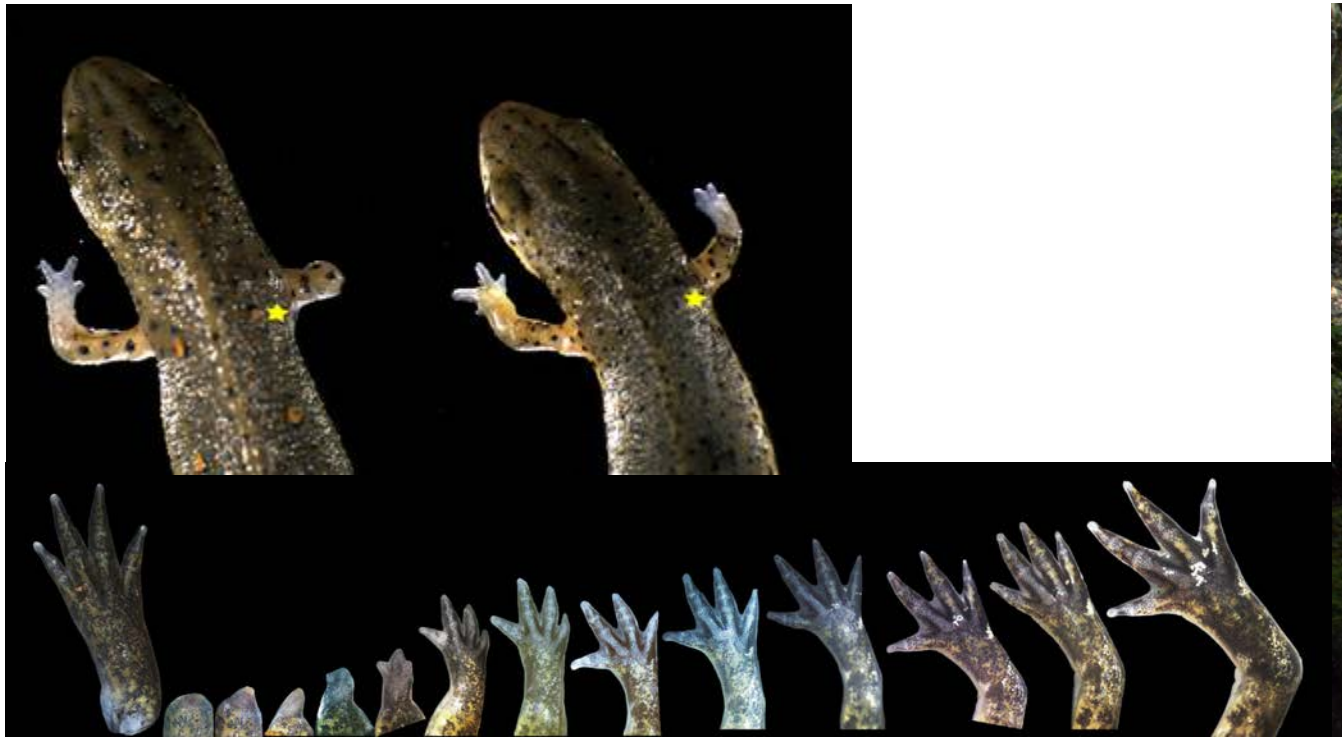
Can A Product Be Regenerative?

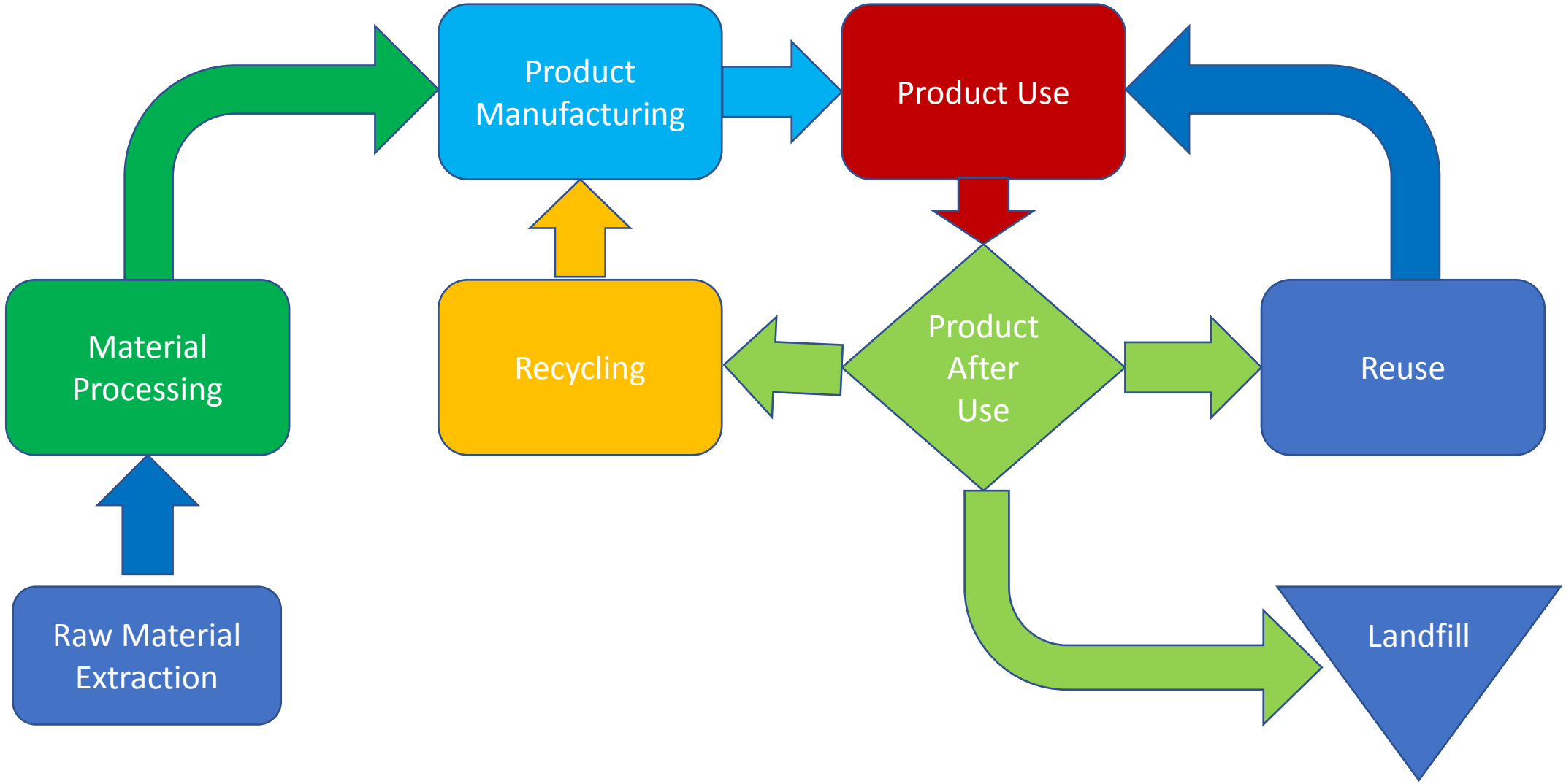


Can a Product System Be Regenerative?

- Living systems can be Regenerative.
- By incorporating a living system a product system can be Regenerative (but usually isn’t)



Product System



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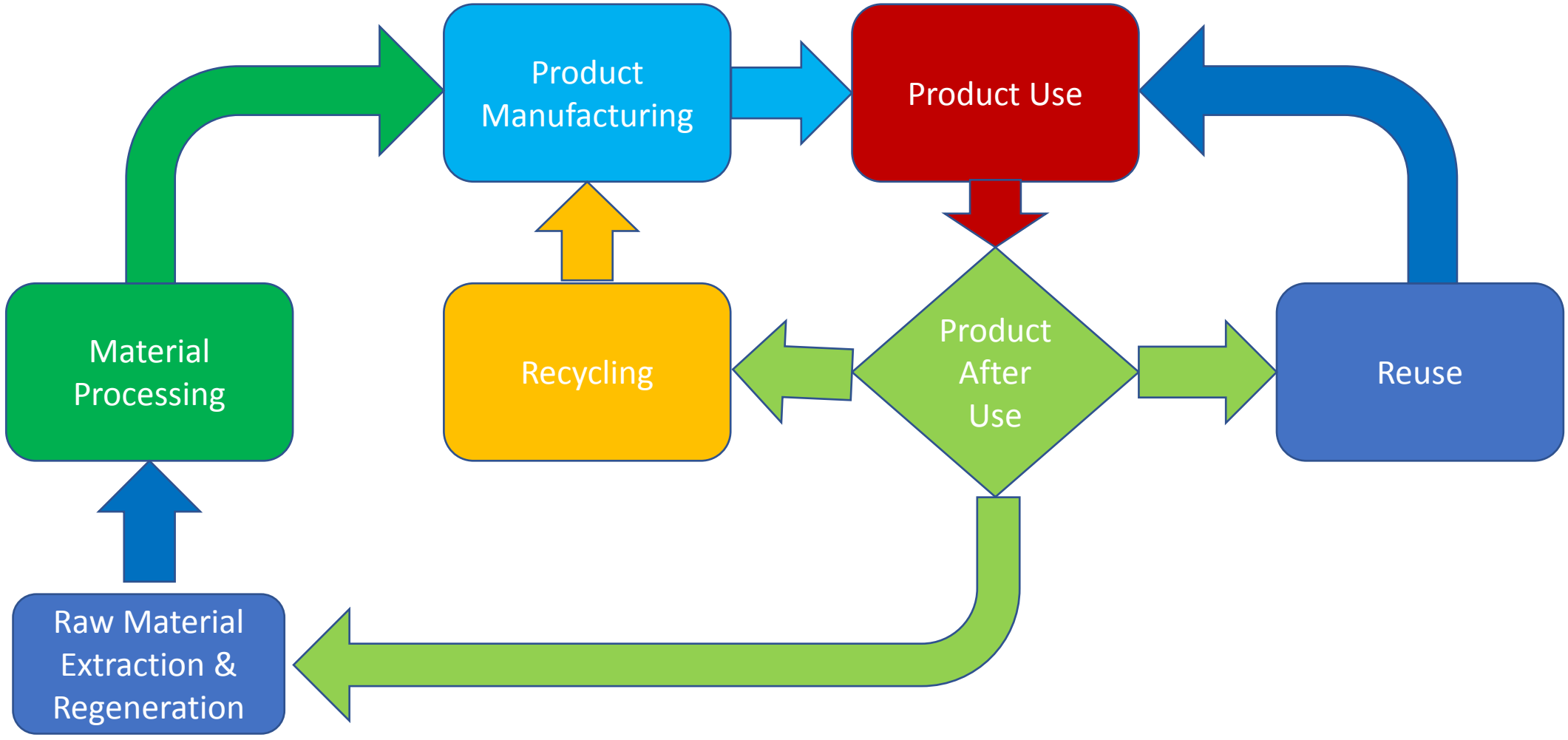
Product System – Zero Waste & Regeneration



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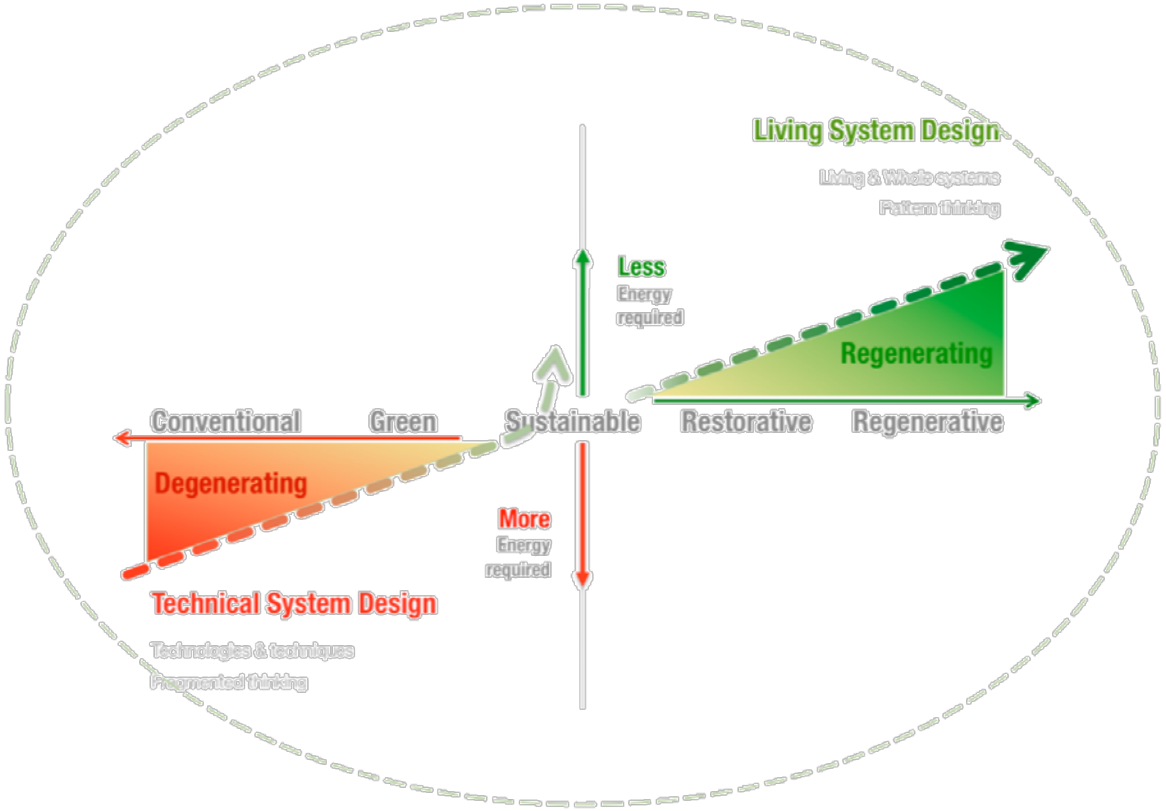
Attributes of a Regenerative Ecosystem

- Abiotic resource depletion
- Biodiversity
- Carbon sequestration
- Hydrogeology
- Land Use
- Connectivity



McKay S. K., I. Linkov, J. C. Fischenich, S. J. Miller, and J. Valverde 2012. *Ecosystem restoration objectives and metrics*. EBA Technical Notes Collection. ERDC TN-EMRRP-EBA-12-16. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://cw-environment.usace.army.mil/eba/*

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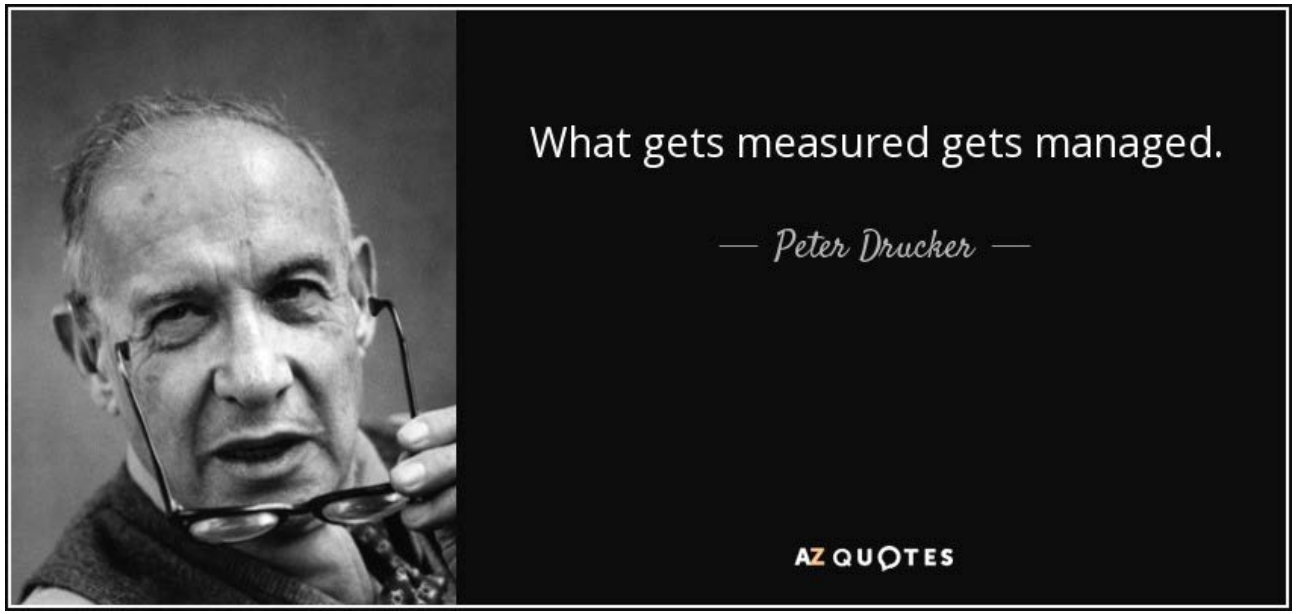
Metrics for Attributes of a Regenerative Ecosystem

ELEMENT	METRIC
Abiotic Resource Depletion	MJ (fossil fuel eq.) [1]
Biodiversity	Species per hectare (micro and macro flora and fauna) relative to undisturbed area [2]
Carbon Sequestration	Kg CO_2 eq. [3]
Hydrogeology	Water surface area and flow relative to undisturbed area [4]
Land Use	Percent (fraction) undisturbed area [5]
Connectivity	Buffer radius and incidence function [6]

Developing a Relative Metric

Objectives:

- Consider each attribute for a regenerative system
- Emphasize criteria that are not regenerative so they receive greater attention



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Developing a Relative Metric

For attributes whose value increases with increasingly adverse impact, such as global warming,

measure the value for a reference system, v_r, and for the subject system, v_s. The relative attribute is then,

$$x_i = \frac{v_s}{v_r}$$

For positive v_s and v_r, $0 \leq X_i \leq 1$

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Developing a Relative Metric

For each attribute whose value increases with increasingly favorable outcomes, such as biodiversity,

measure the value for the reference system, v_r, and for the subject system, v_s. The relative attribute is then,

$$x_i = \frac{v_r - v_s}{v_r}$$

For positive v_s and v_r, $0 \leq X_i \leq 1$

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Calculating a Regeneration Factor

Using The Harmonic Mean

- Given the set of n factors, x_1, x_2,…x_n, with weights w_1, w_2,…w_n, respectively, the Regeneration Factor, RF_w, is calculated as:

$$RF_w = 1 - \frac{w_1 + w_2 + \cdots + wn}{\frac{w_1}{x_1} + \frac{w_2}{x_2} + \cdots + \frac{w_n}{x_n}}$$

- where the factors, x_1, x_2,…x_n, are the impacts that must be corrected to restore the system:

  x_1 = First impact factor, e.g., GHG emissions (kg CO2eq)

  x_2 = Second impact factor, e.g., fossil feedstock depletion (kg petroleum)

  x_n = n^{th} impact factor

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Metric: The Regeneration Factor

- Defined by a Regeneration Factor (RF)
- RF = 1 + “Quality” Factor

RF < 1
System is being harmed by factors inhibiting full regeneration

RF = 1
System that is perfectly balanced

RF > 1
System is evolving

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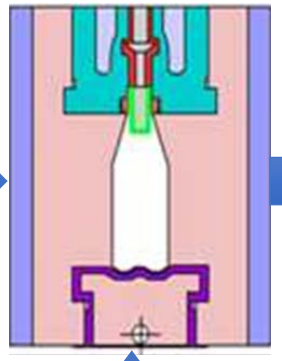
Examples

- Regeneration Factor of a petrochemical HDPE resin system
- Regeneration Factor of a recycled HDPE resin system
- Regeneration Factor of a biobased HDPE resin system

Case Study: Plastic Bottles

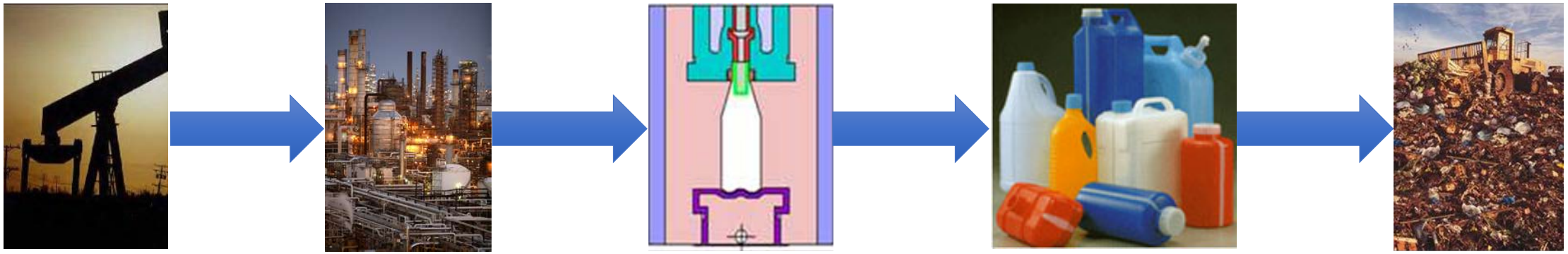


Petrochemical-based

Bio-based

Recycled

Regeneration Factor of Petrochemical HDPE Bottle System (No energy or material recovery)



Impact Category	Impact	Impact (Normalized)	Ref
Global Warming Potential (kg/kg)	1.89	1.0	[7]
Fossil Resource Depletion (MJ/kg)	75.3	1.0	[7]

RF = 1 - (1+1)/(1/1 + 1/1)

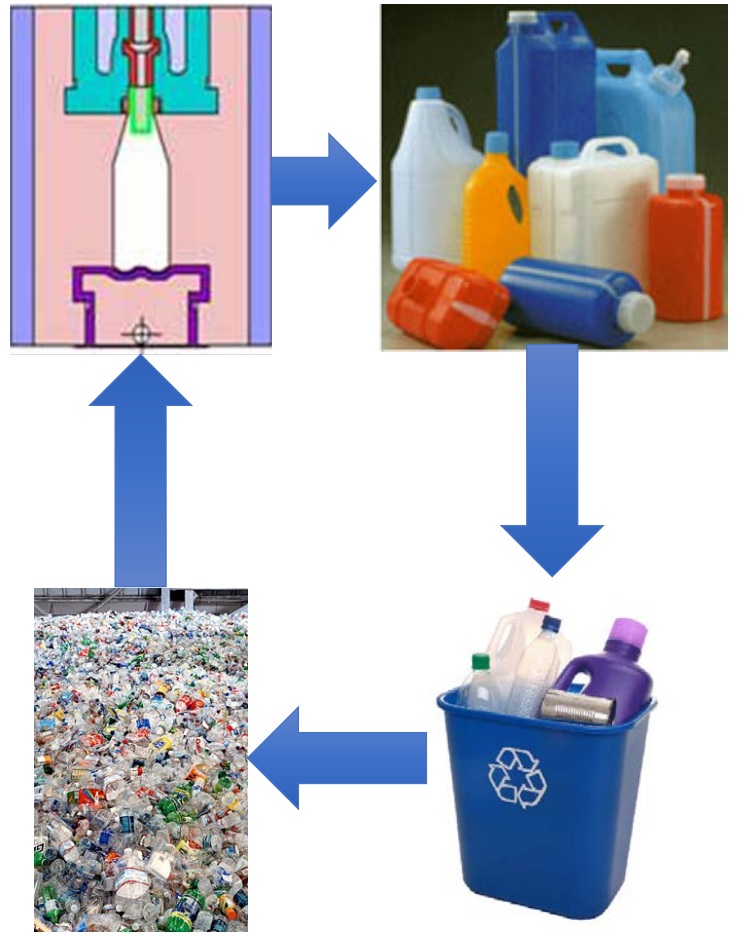
= 1 – 2/2

= 0.00

Regeneration Factor of Recycled HDPE Bottle System

Impact Category	Impact	Impact (Normalized)	Ref
Global Warming Potential (kg/kg)	0.56	0.56/1.89 = 0.30	[7]
Fossil Resource Depletion (MJ/kg)	8.69	8.69/75.3 = 0.12	[7]

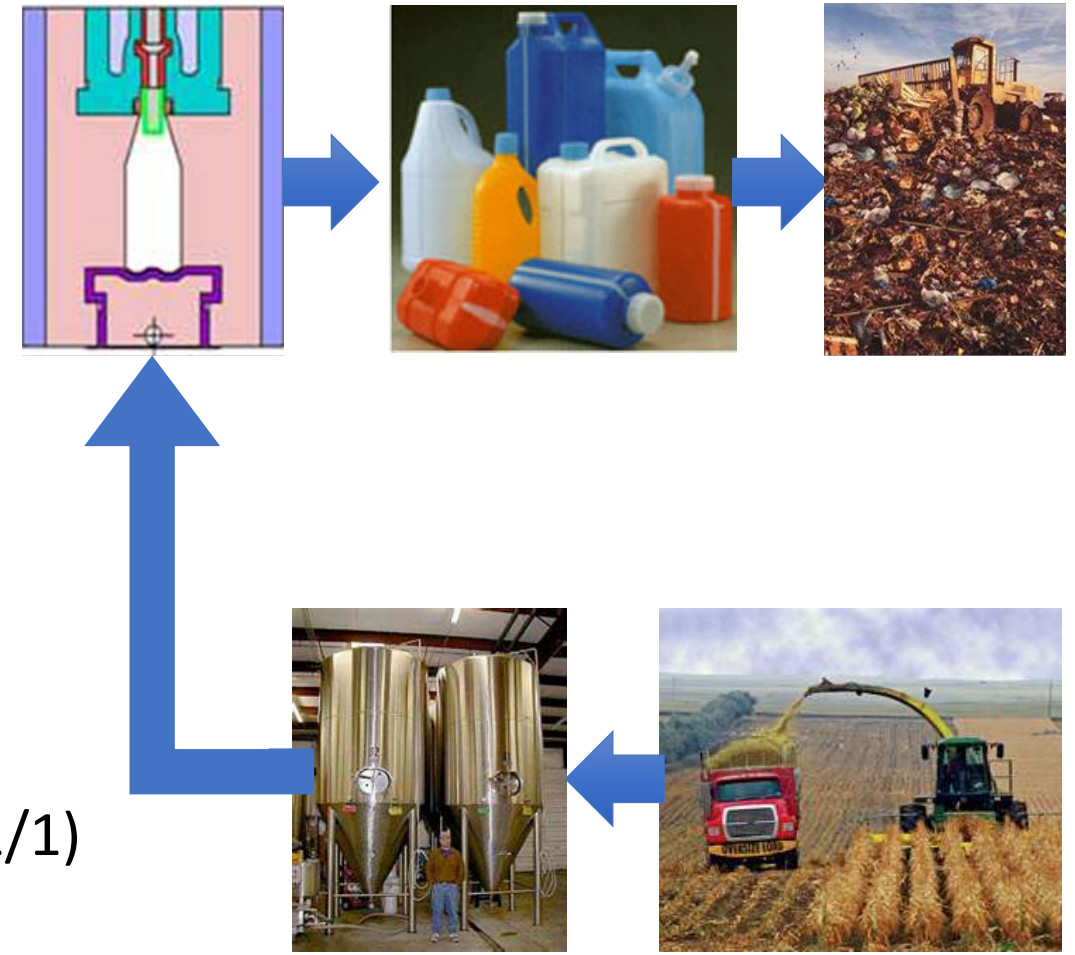
$$RF = 1 - (1+1)/(1/0.30 + 1/0.12)$$
$$= 1 - 2/(3.3 + 8.3)$$
$$= 1 - 2/11.6$$
$$= 0.83$$



Recycled

Regeneration Factor of Biobased HDPE Bottle System

Impact Category	Impact	Impact (Normalized)
Global Warming (kg/kg)	-2.1	-2.1/1.89 = -1.1
Fossil Resource (MJ/kg)	18.0	18.0/75.3 = 0.24
Non-regenerative Agriculture	--	1.0



Bio-based

RF = 1 - (1+1+1)/(1/(-1.1) + 1/0. 24) + 1/1)
= 1 – 3/(-0.9 + 4.6 + 1)
= 1 – 3/(4.7)
= 0.36

Thank you!

Questions?

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