Circular economy: Some notes on closing the loop

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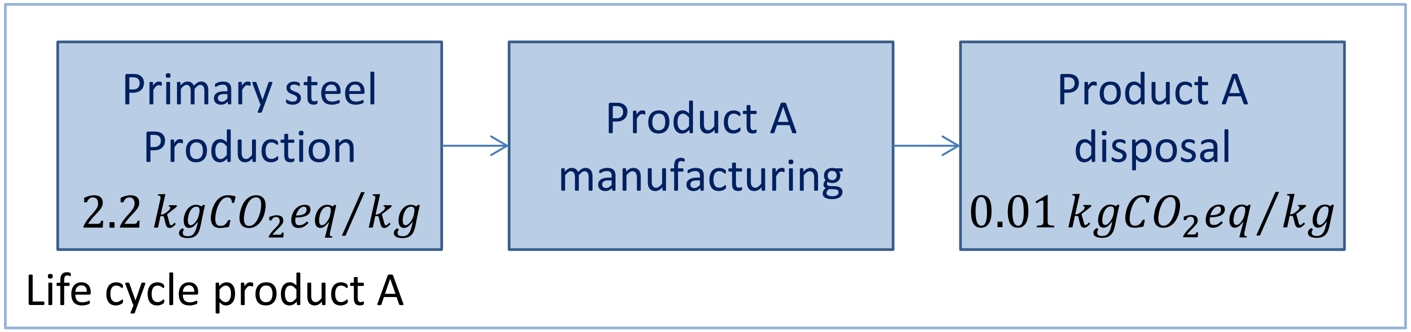
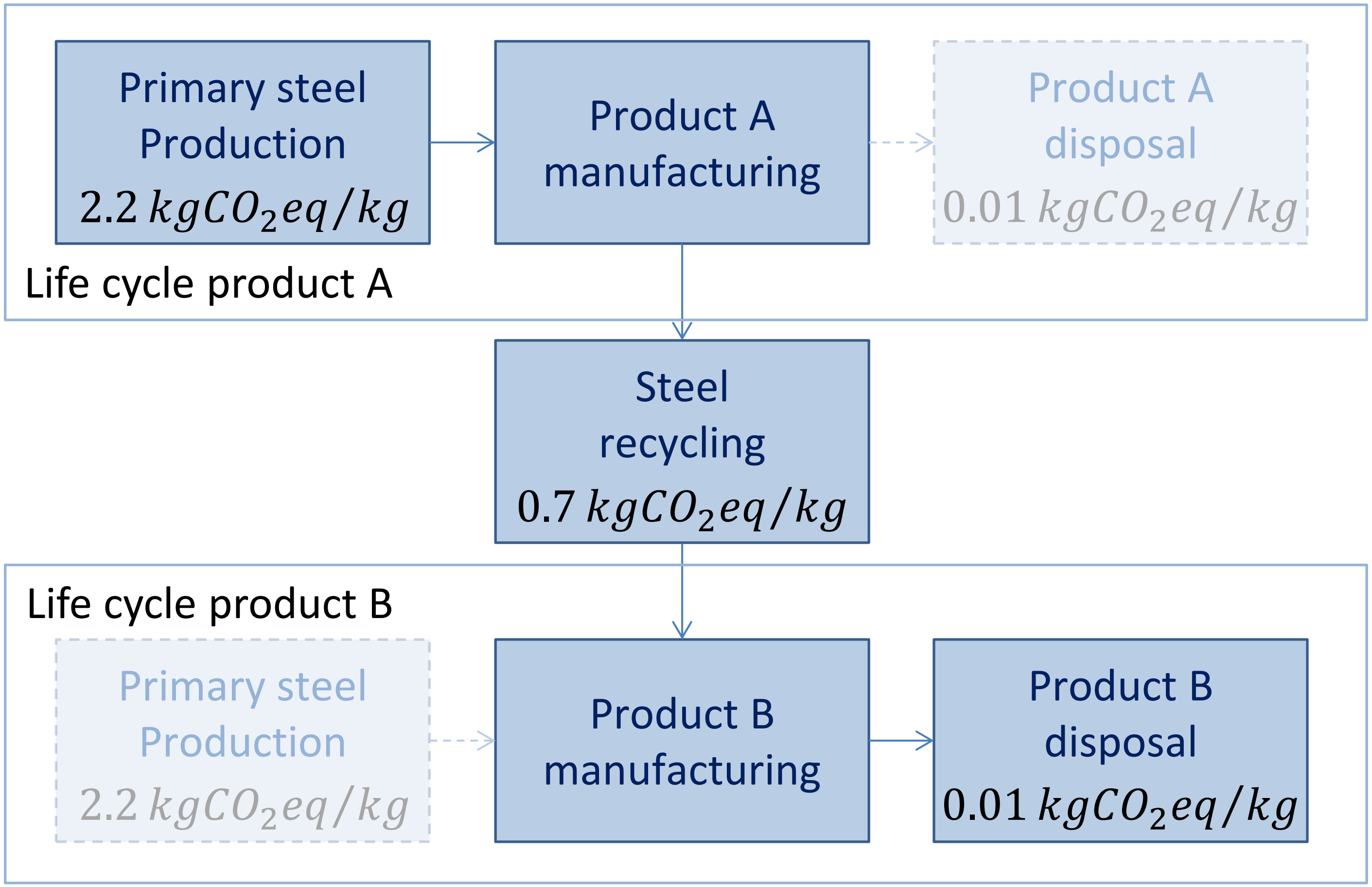
Why do we reuse or recycle?



Total GHGs: $4.4\ kgCO_2eq$

GHG intensity: $2.2\ kgCO_2eq/kg$

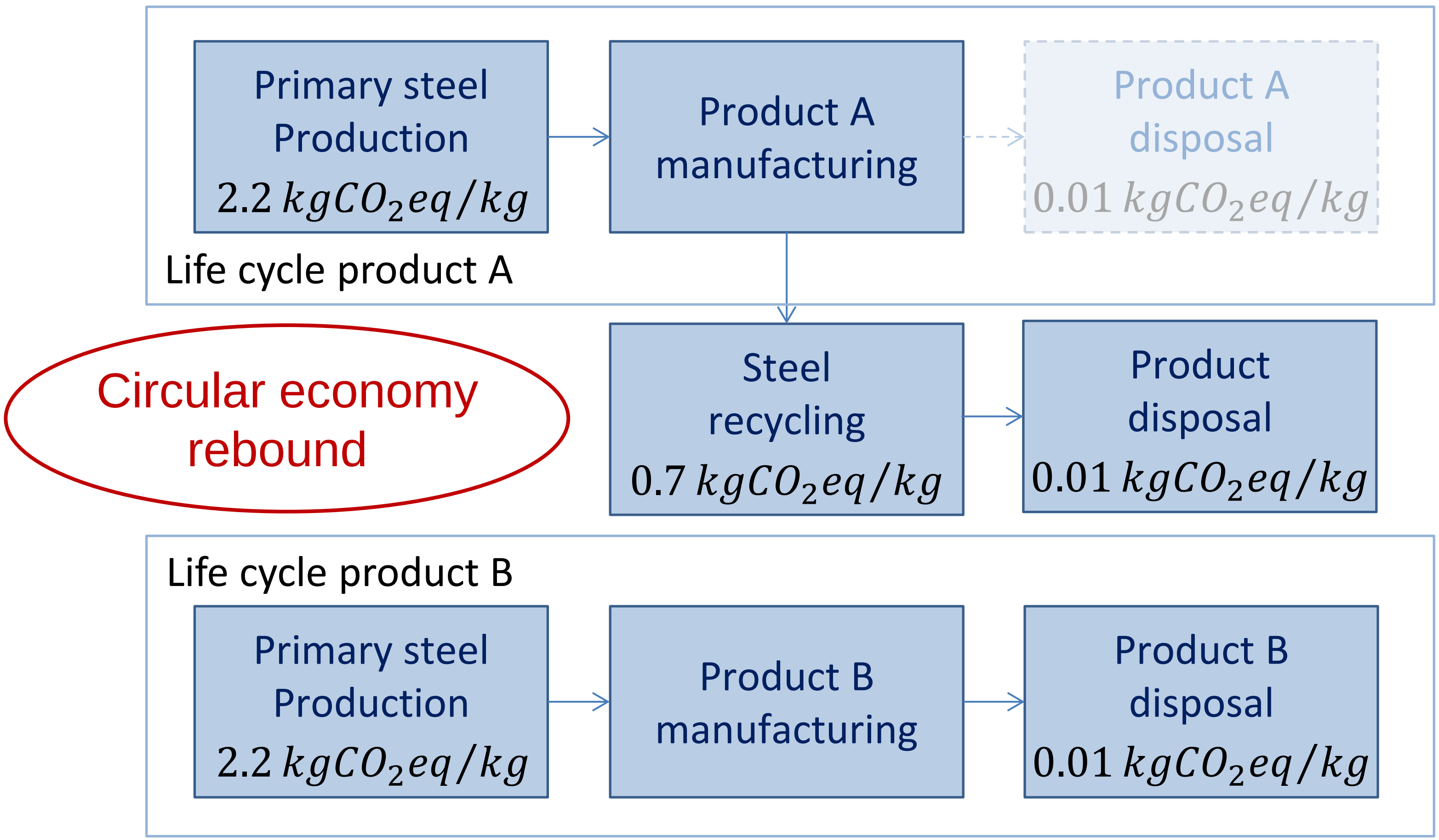
Because it can avoid primary production and disposal processes!



Total GHGs: $2.9\ kgCO_2eq$ (34% reduction)

GHG intensity: $1.45\ kgCO_2eq/kg$ (34% reduction)

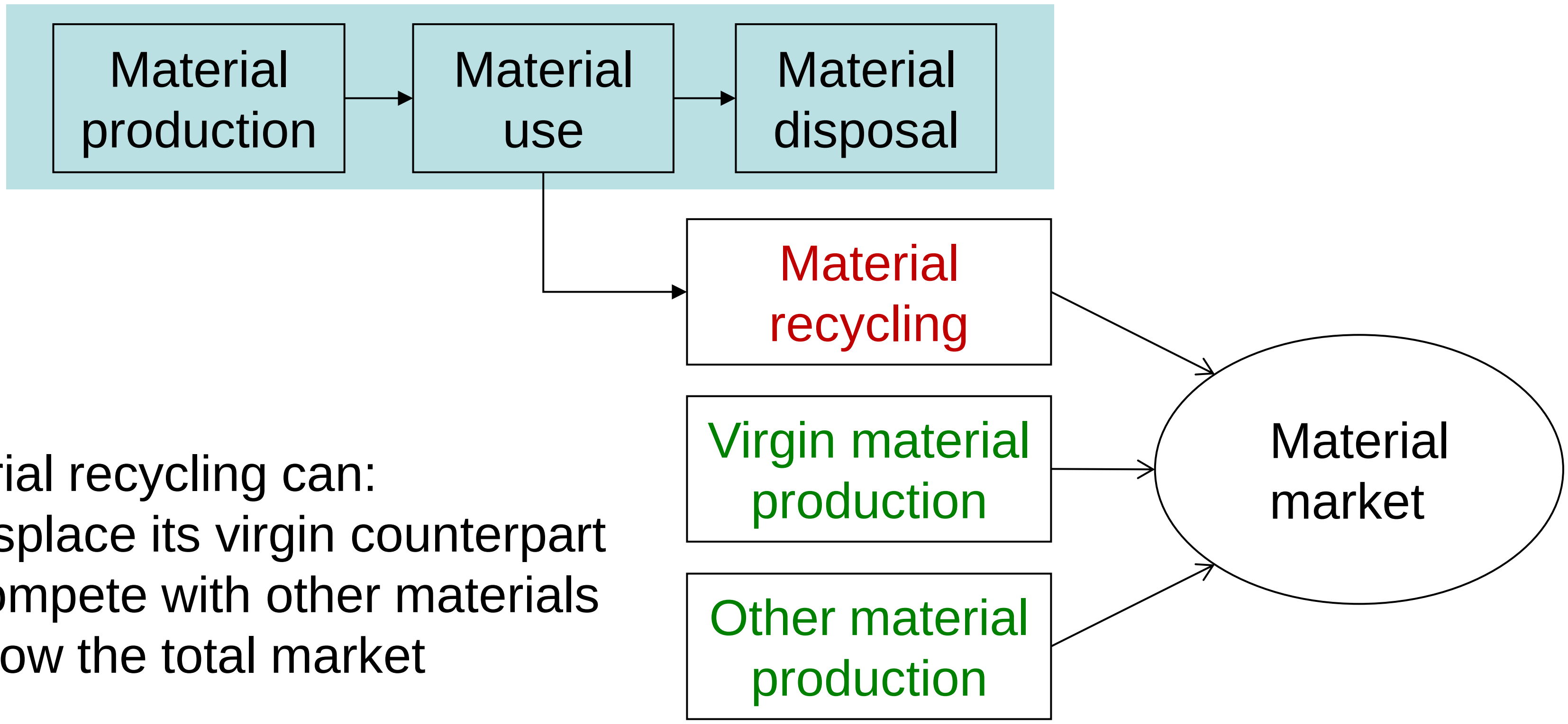
Without displaced primary production, recycling increases total impacts!



Total GHGs: 5.1 $kgCO_2eq$
(16% increase)

GHG intensity: 1.7 $kgCO_2eq/kg$
(23% reduction)

Displaced primary production is market-mediated!



Material recycling can:

- Displace its virgin counterpart
- Compete with other materials
- Grow the total market

It is frequently assumed that closed-loop recycling is intrinsically preferable to open-loop recycling…

What is closed-loop recycling? The typical definition is:
"Material from a product system is recycled in the ***same*** product system"

"Same" has two meanings:
- The very one previously referred to
- Similar in kind, quality, quantity, or degree

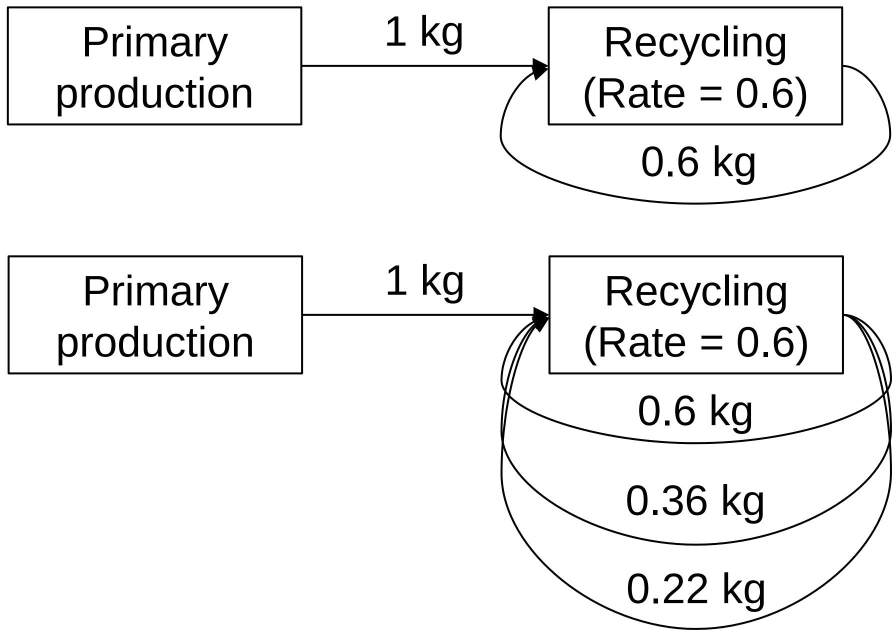
There are 3 misconceptions about closed-loop recycling:

1. Quantity argument: It generates more secondary resource from each unit of primary resource.
2. Quality argument: Even per recycled unit, it is environmental preferable to open-loop recycling.
3. The distinction between closed and open loops is useful.

Misconception 1: Closed loops generate more secondary resource

1 loop

3 loops



What's wrong with this perspective?

n loops

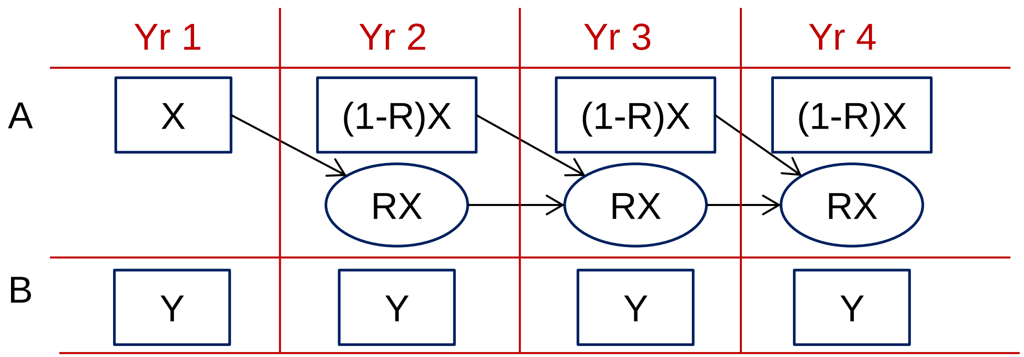
$$S = P + PR + PR^2 + PR^3 + \cdots + PR^n = P\frac{(R - R^{n+1})}{(1 - R)}$$

$$n \to \infty \Rightarrow S = P\frac{R}{1 - R}$$

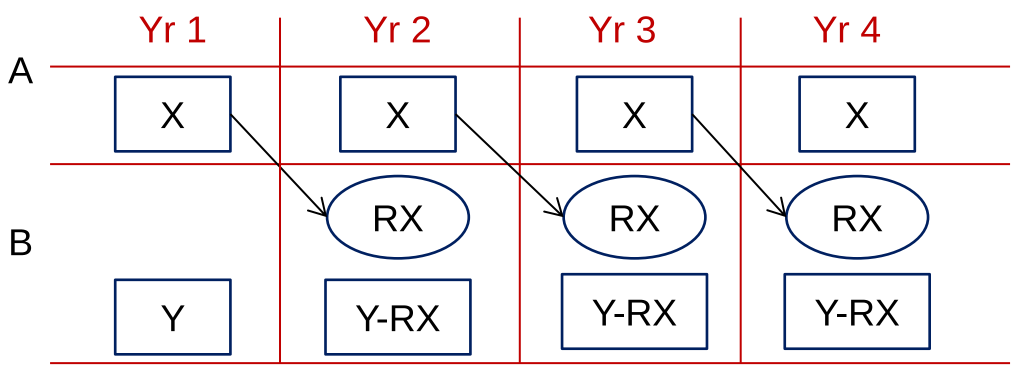
P: Amount of primary material
S: Amount of secondary material obtained from P
R: Recycling rate
n: Number of recycling cycles

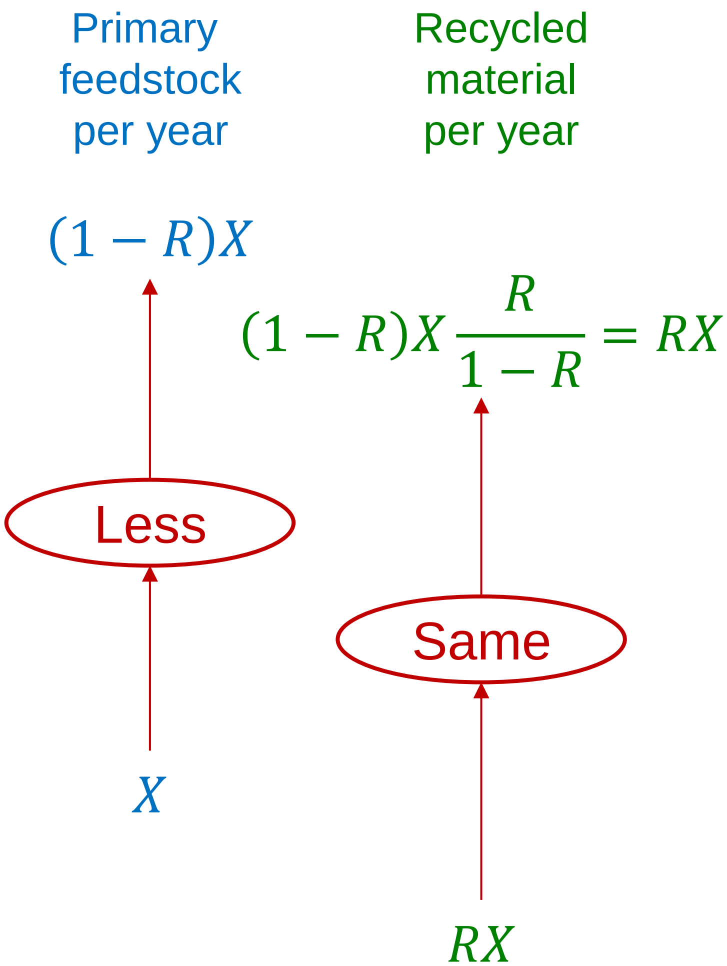
Closed-loop recycling also reduces the amount of primary material available for recycling!

Closed-loop Recycling



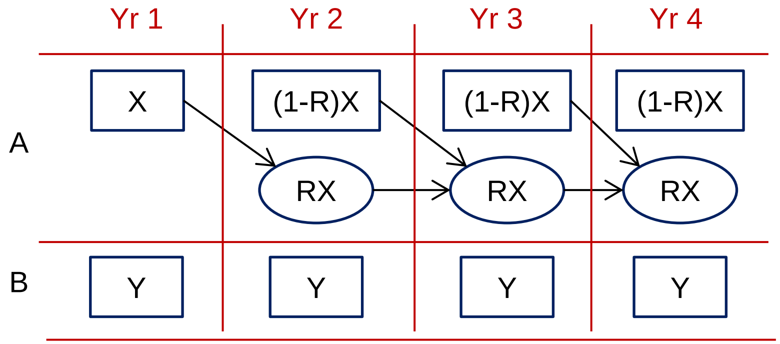
Open-loop Recycling





Misconception 2: Closed-loop recycling is environmentally preferable

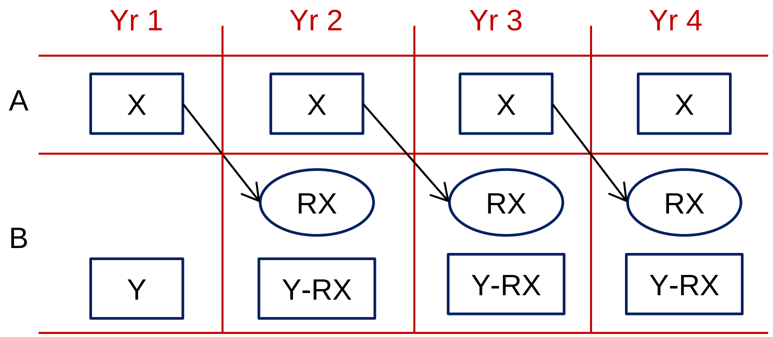
Closed-loop Recycling



Annual Environmental Benefits

$$RX(E_{prim_A} + E_{landfill_A} - E_{repro_{AA}})$$

Open-loop Recycling



$$RX(E_{prim_B} + E_{landfill_A} - E_{repro_{AB}})$$

The closed-loop scenario has higher environmental benefits than the open-loop scenario if

$$(E_{prim_A} - E_{repro_{AA}}) > (E_{prim_B} - E_{repro_{AB}})$$

The only thing that matters is the difference between avoided burden and reprocessing burden

Example: Recycling 1kg of used lubricant oil (UO)

Closed-loop: Re-refining 1kg of UO into 650g base oil (and some co-products)

$$E_{ReRe} - E_{prim_{ReRe}} = (0.4 - 0.9)\frac{kgCO_2e}{kg\ UO} = \mathbf{0.5}\,\frac{\mathbf{kgCO_2e}}{\mathbf{kg\ UO}}$$

Open-loop: Energy recovery by recycling 1kg UO into 910g recycled fuel oil (RFO)

Scenario: RFO displaces only heavy fuel oil

$$E_{RFO} - E_{prim_{HFO}} = (2.8 - 3.4)\frac{kgCO_2e}{kg\ UO} = \mathbf{0.6}\,\frac{\mathbf{kgCO_2e}}{\mathbf{kg\ UO}}$$

Scenario 2: RFO displaces heavy fuel oil and natural gas

$$E_{RFO} - E_{prim_{HFO\,\&\,nat\,gas}} = (2.8 - 3.1)\frac{kgCO_2e}{kg\ UO} = \mathbf{0.3}\,\frac{\mathbf{kgCO_2e}}{\mathbf{kg\ UO}}$$

Misconception 3: Closed-loop recycling is a meaningful concept

Definition:
"Material from a product system is recycled in the ***same*** product system"

Problem 1:
What kind of similarity is required for a loop to be closed?
Problem 2:
How similar do the supplying and receiving product systems need to be for the loop to be closed?

Example 1:
Is bottle-to-bottle recycling closed loop?

Example 2:
Is automotive aluminum recycling closed-loop?

Conclusions

Circular economy policy should ***not*** be guided by

- Number of loops
- Aiming for closed-loop recycling

Instead, it should be guided by the following questions:

- What and how much primary product, material, or fuel does a circular economy activity *displace*?
- Which circular economy activities have the highest *displacement potential*, measured in total net environmental impact that can be avoided?

Ongoing Research Grant:

Displaced Production Due to Reuse and Recycling: Theory Development and Case Studies National Science Foundation CBET #1335478 Roland Geyer, Richard Startz, Trevor Zink

Further Reading:

Zink et al. (2015) A Market-Based Framework for Quantifying Displaced Production from Recycling or Reuse, Journal of Industrial Ecology, published online, DOI: 10.1111/jiec.12317

Geyer et al. (2015) Common Misconceptions about Recycling, Journal of Industrial Ecology, published online, DOI: 10.1111/jiec.12355

Geyer et al. (2015) Assessing the Greenhouse Gas Savings Potential of Extended Producer Responsibility for Mattresses and Boxsprings in the United States, Journal of Industrial Ecology, published online, DOI: 10.1111/jiec.12313

Geyer et al. (2013) Life Cycle Assessment of Used Oil Management in California - Pursuant to Senate Bill 546 (Lowenthal), CalRecycle Report DRRR-2013-01465, http://www.calrecycle.ca.gov/Publications/Detail.aspx?PublicationID=1465