Systems, life cycles and the circular economy: Identifying sustainable solutions

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IChemE webinar

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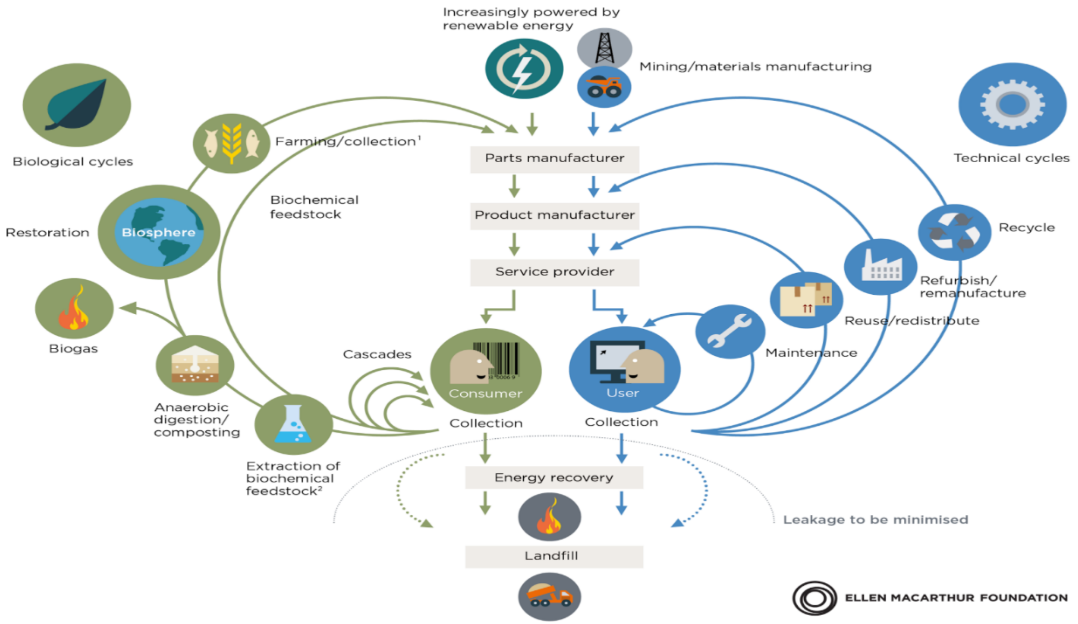
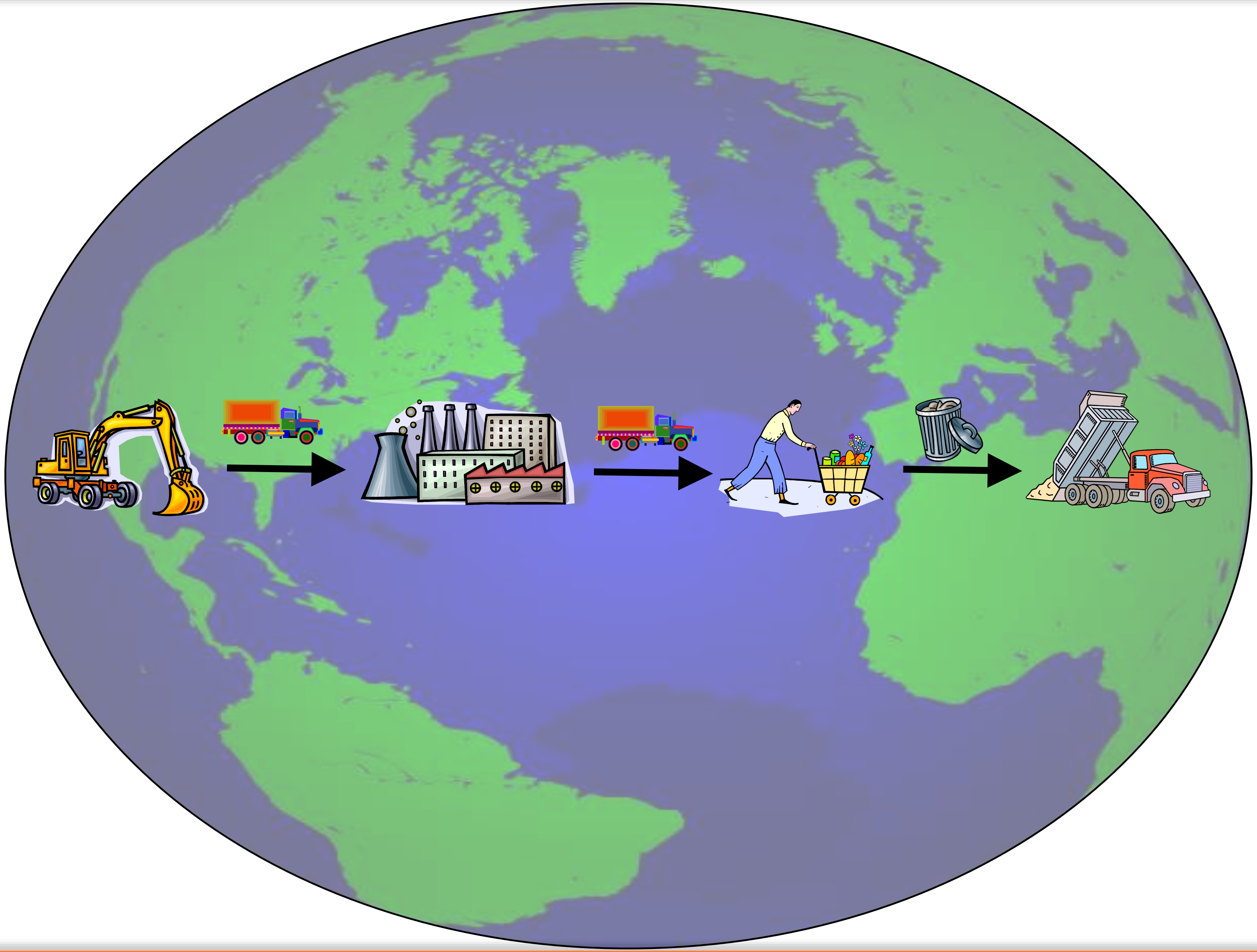
Sustainable Industrial Systems

Overview

- Linear vs circular economy
- Systems approach and life cycle thinking
- “Circularity” vs “sustainability”
- Understanding the complexity
- Illustrative examples
  - Single vs reusable plastics
  - Food waste and energy
  - Plastics recycling
- Conclusions
- Q&A



Linear economy

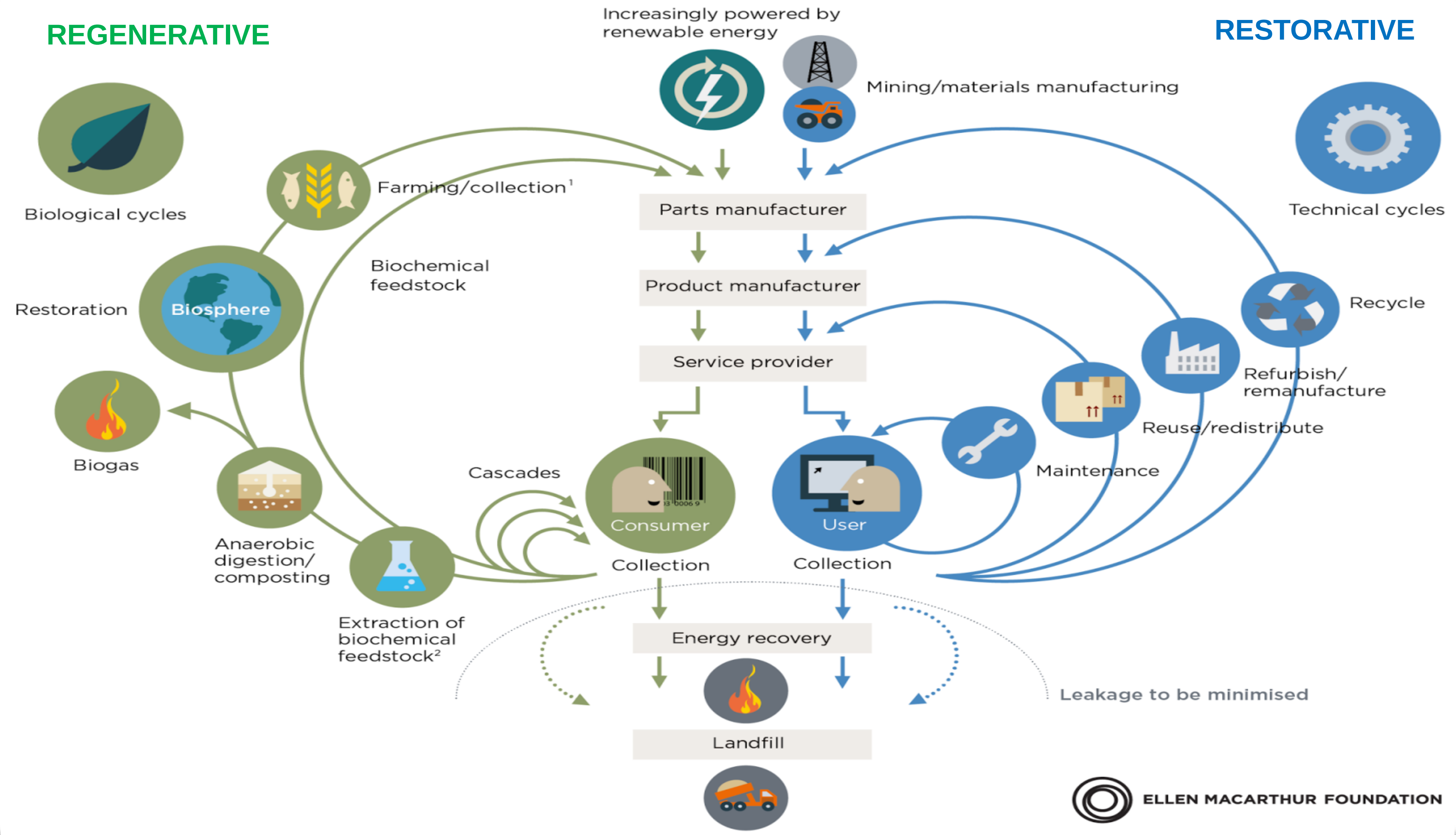


From linear to circular economy

Circular economy concept

- Regenerative and restorative by design
- Keep products and resources in use as long as possible
- Extract the maximum value while in use
- Recover and regenerate products and resources at the end of life

Circular economy concept



Systems approach and life cycle thinking

Integrating life cycle thinking and the circular economy concept

- Regenerative and restorative by design
- Keep products in use as long as possible
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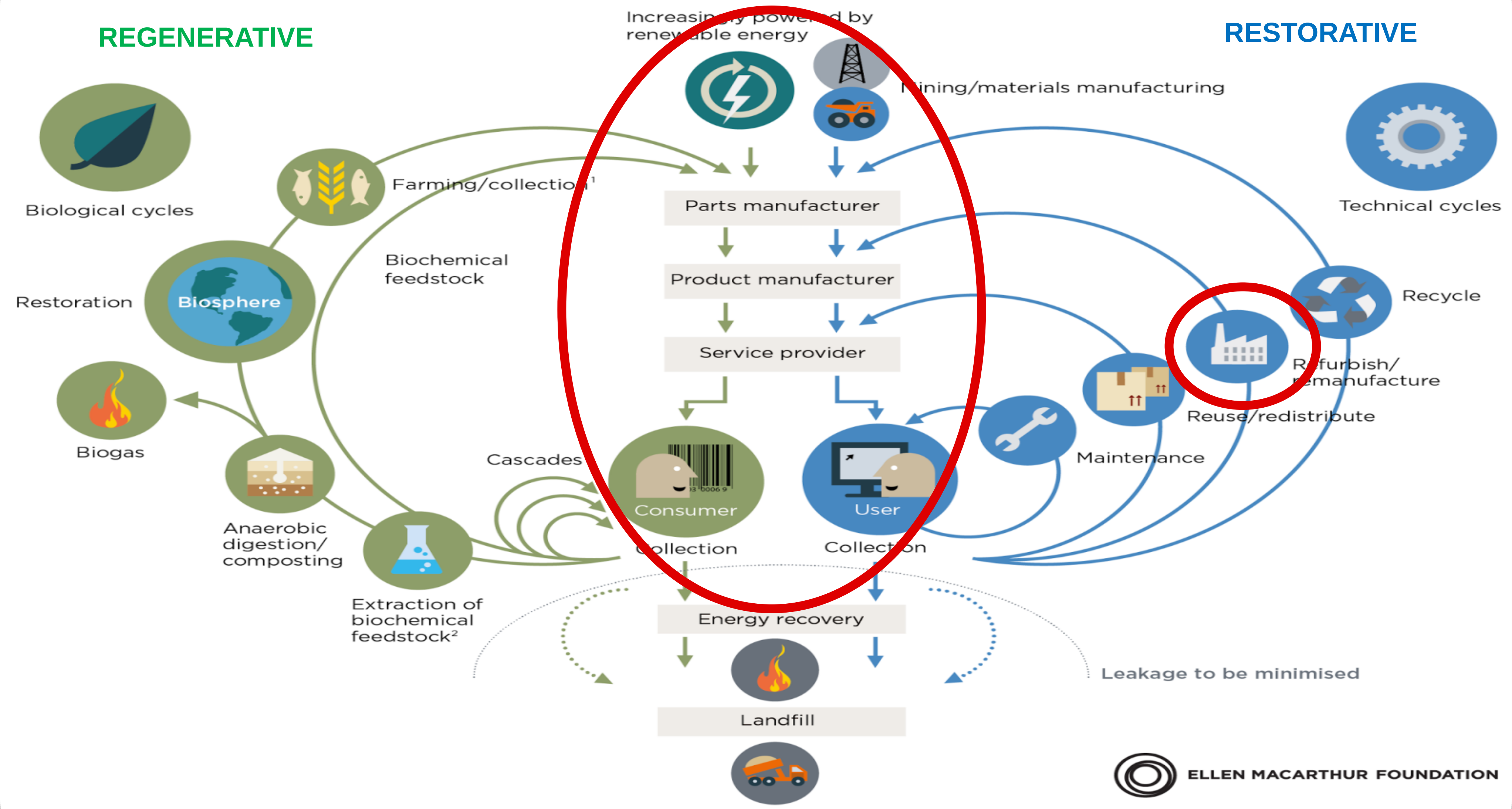
Circular economy concept



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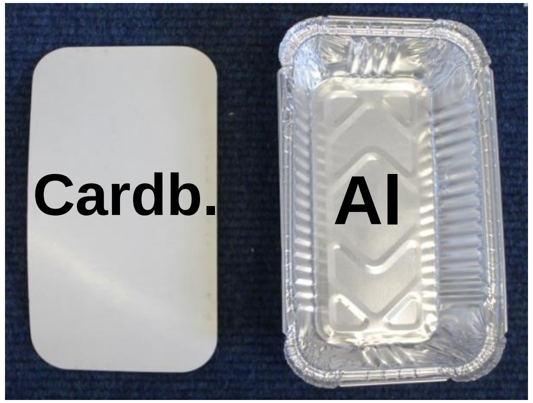
Illustrative example #1

Single-use plastics:

To ban or not to ban?

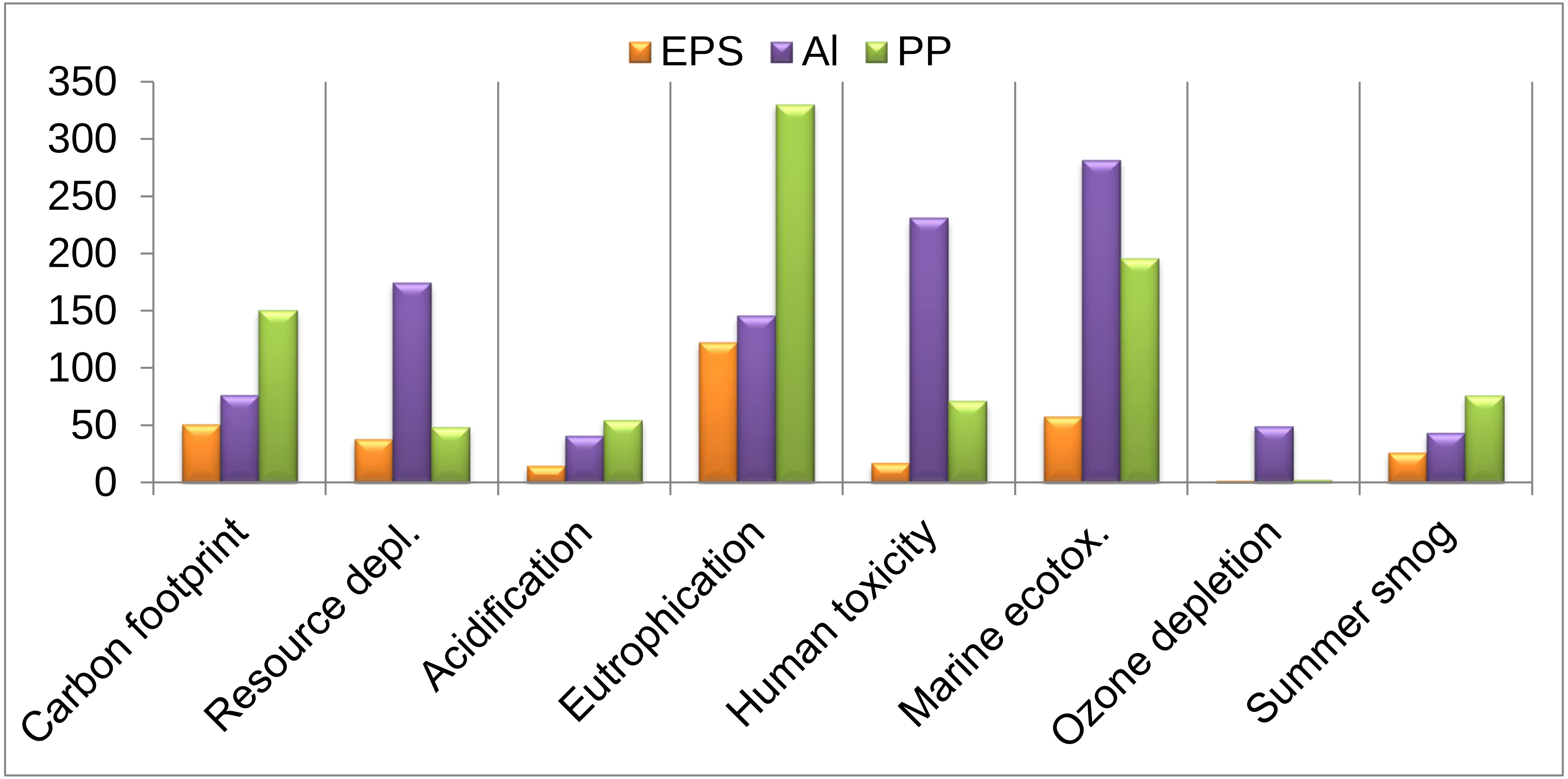
Takeaway-food containers: Single-use vs reusable



End-of-life management (European Union)

- Polypropylene
  - 11% recycled, 44% incinerated and 45% landfilled
- Aluminium
  - 54% recycled and 46% landfilled
- Extruded polystyrene
  - 50% landfilled and 50% incinerated

Life cycle impacts of single-use containers



Not to scale

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Life cycle impacts of single-use containers

- EPS
  - 7% to 28 times lower impacts than aluminium
  - 25% to six times lower than polypropylene

- Less EPS needed than PP and less energy used than for aluminium



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Single-use vs reusable container

Number of uses of reusable PP containers needed to equal the impacts of single-use containers

Impact	 vs 	 vs 
Carbon footprint	18	11
Resource depl.	208	3
Acidification	29	8
Eutrophication	18	14
Human toxicity	37	2
Marine ecotox.	24	4
Ozone depletion	27	1
Summer smog	16	9

Gallego-Schmid et al. J. Cleaner Prod. (2018) 211 417-427

Summary

- Single-use, non-recyclable EPS has the lowest life cycle environmental impacts
- Single-use polypropylene container is the worst option for most impacts
- Reusable PP container needs to be reused 16-208 times to match the single-use EPS container
- Recycling of EPS is technically possible but costly
- In this case, "circular" does not translate into "environmentally sustainable"

Integrating life cycle thinking and the circular economy concept

- Regenerative and restorative by design
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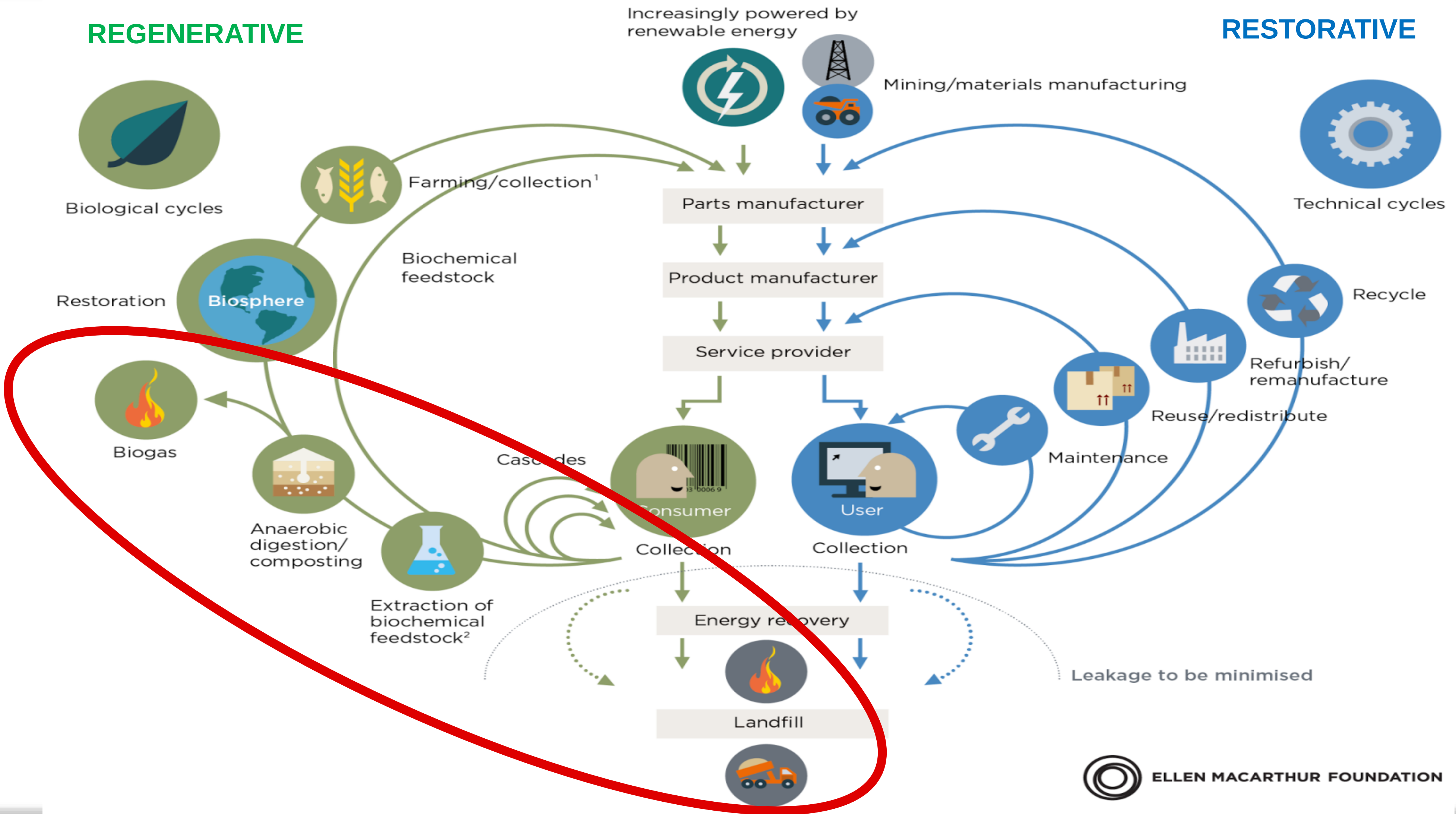
Circular economy concept

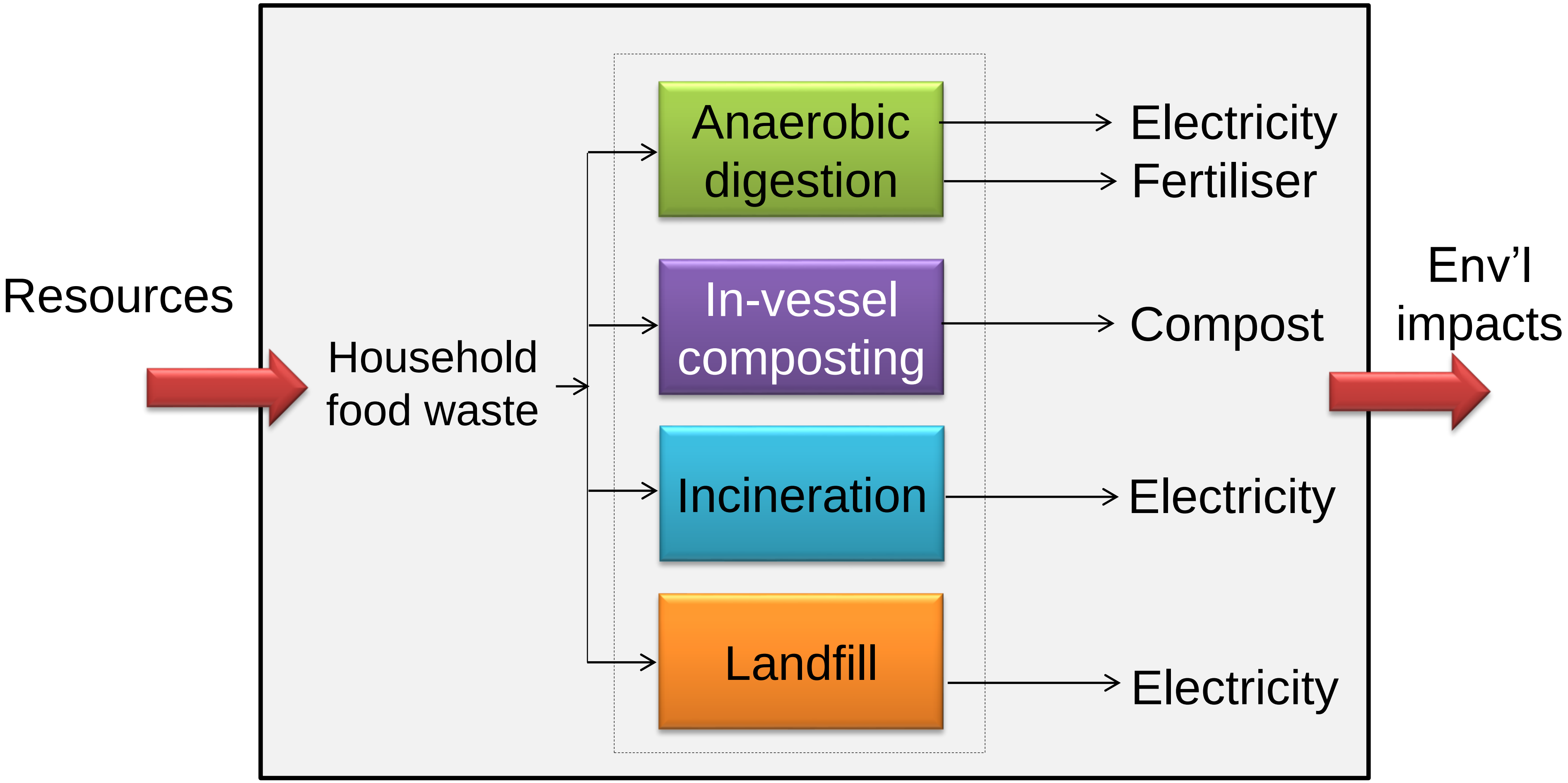


Illustrative example #2

Food waste and energy

To digest, compost, burn or bury?

Resource recovery from food waste



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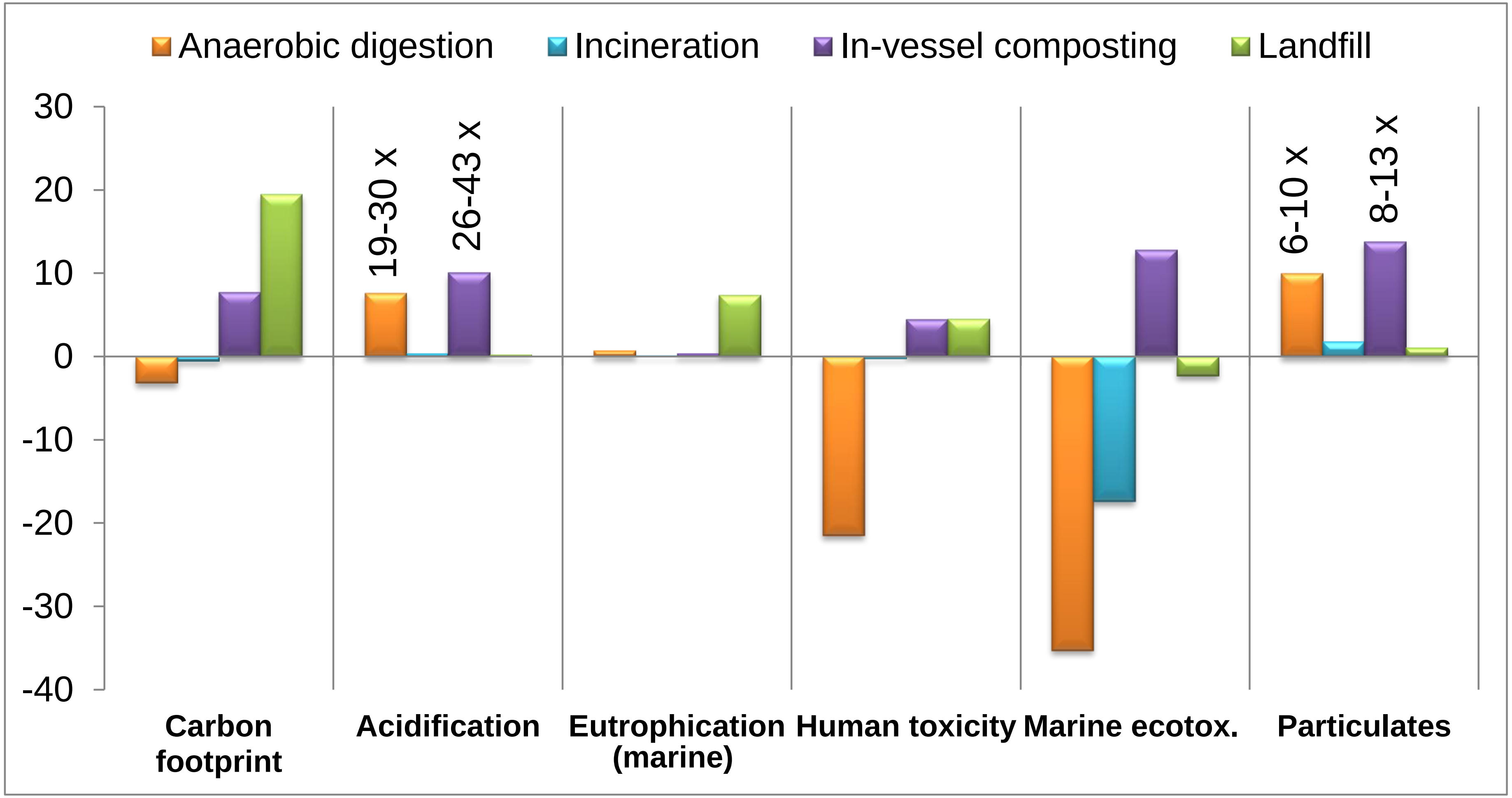
Environmental impacts (per tonne waste)



Not to scale

Summary

- In-vessel composting is the worst option for most impacts
  - In this case “circular” does not translate into “environmentally sustainable”
- Anaerobic digestion is the best option for the carbon footprint and most other impacts
- However, it has much higher acidification and particulates (PM10)
- Much greater benefits would be achieved through waste prevention (several orders of magnitude)

Integrating life cycle thinking and the circular economy concept

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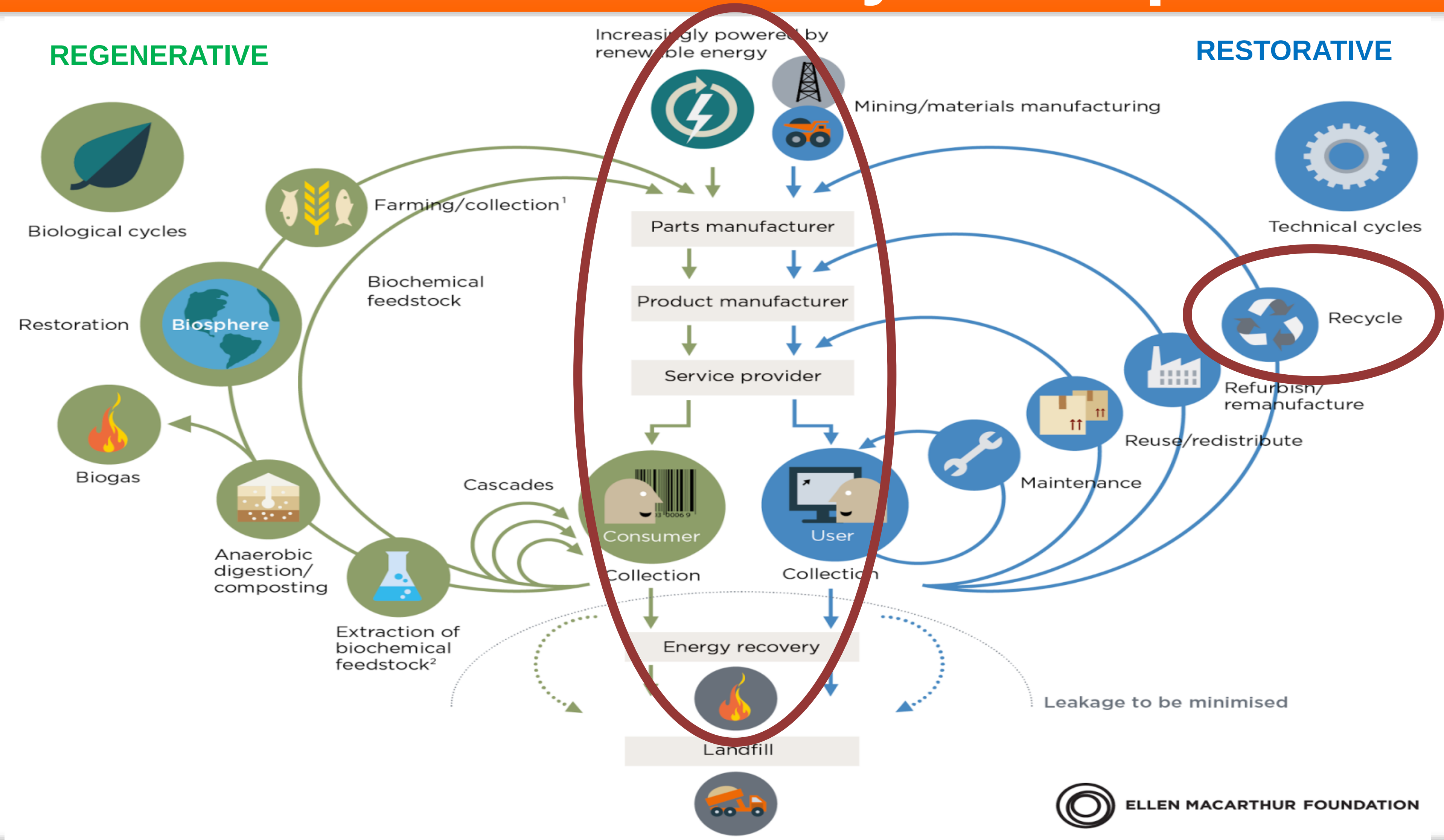
Circular economy concept



Illustrative example #3

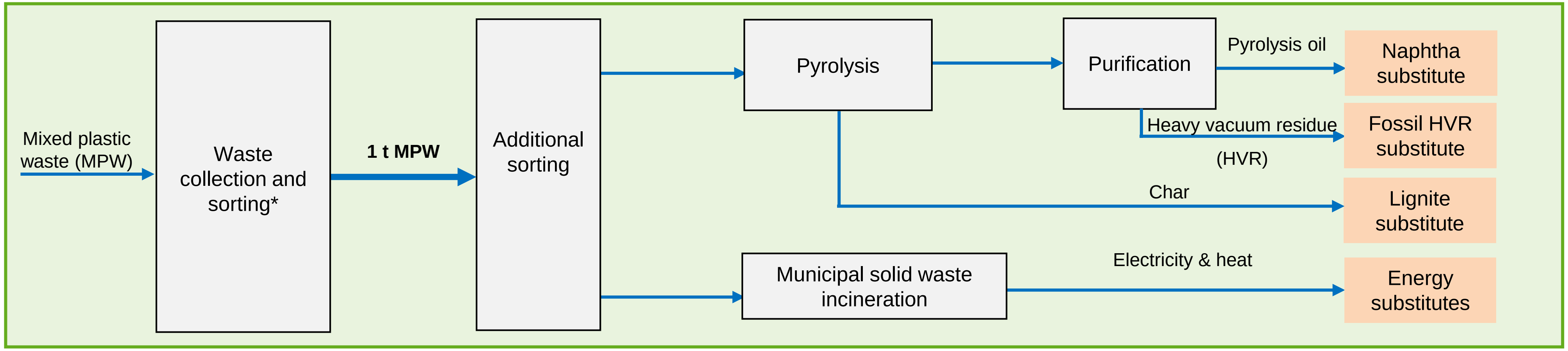
Plastics recycling:

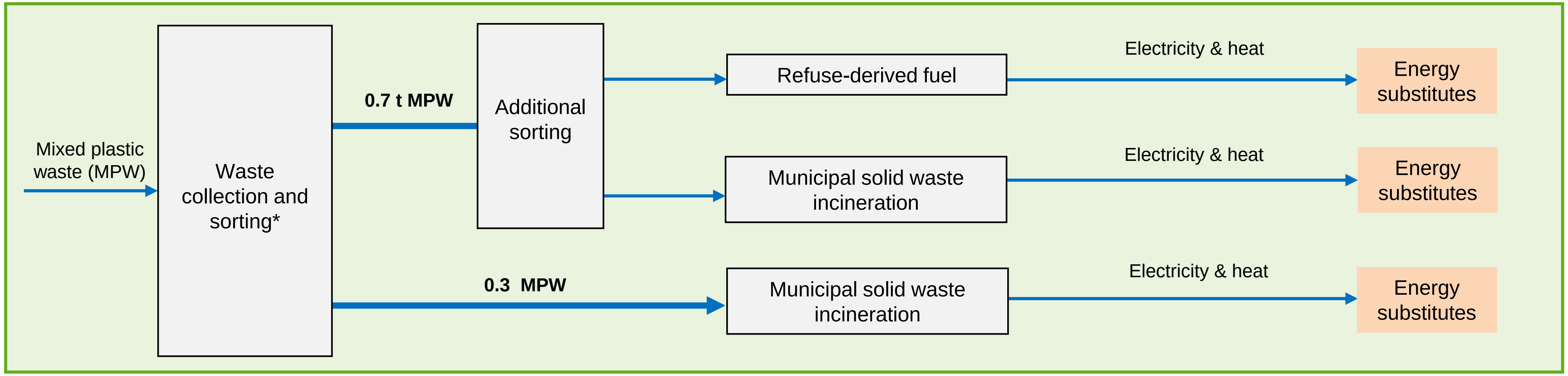
To recycle, burn or use virgin plastics?

Systems and functions

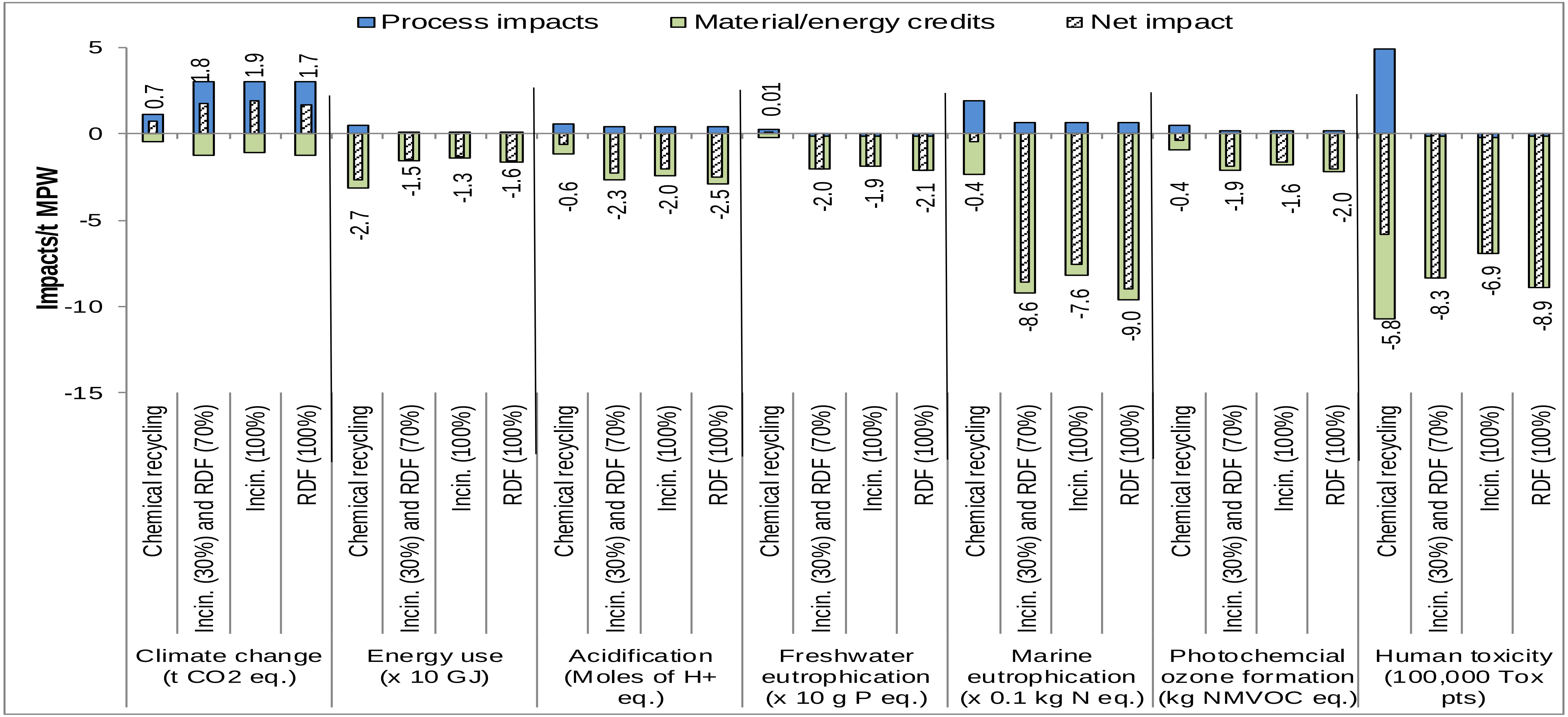
- Waste treatment
- Production of plastics
- Waste treatment and production of plastics

System definition: waste treatment





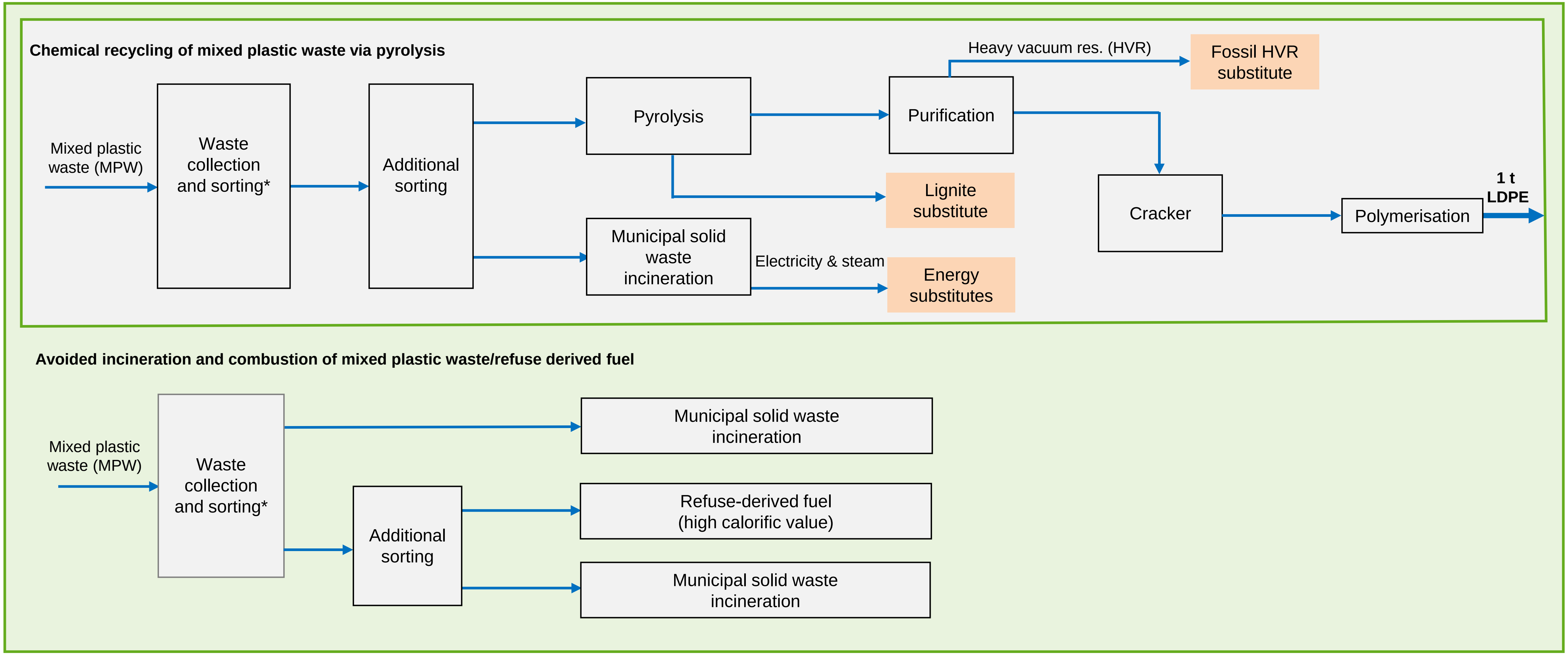
Chemical recycling of plastics vs energy recovery



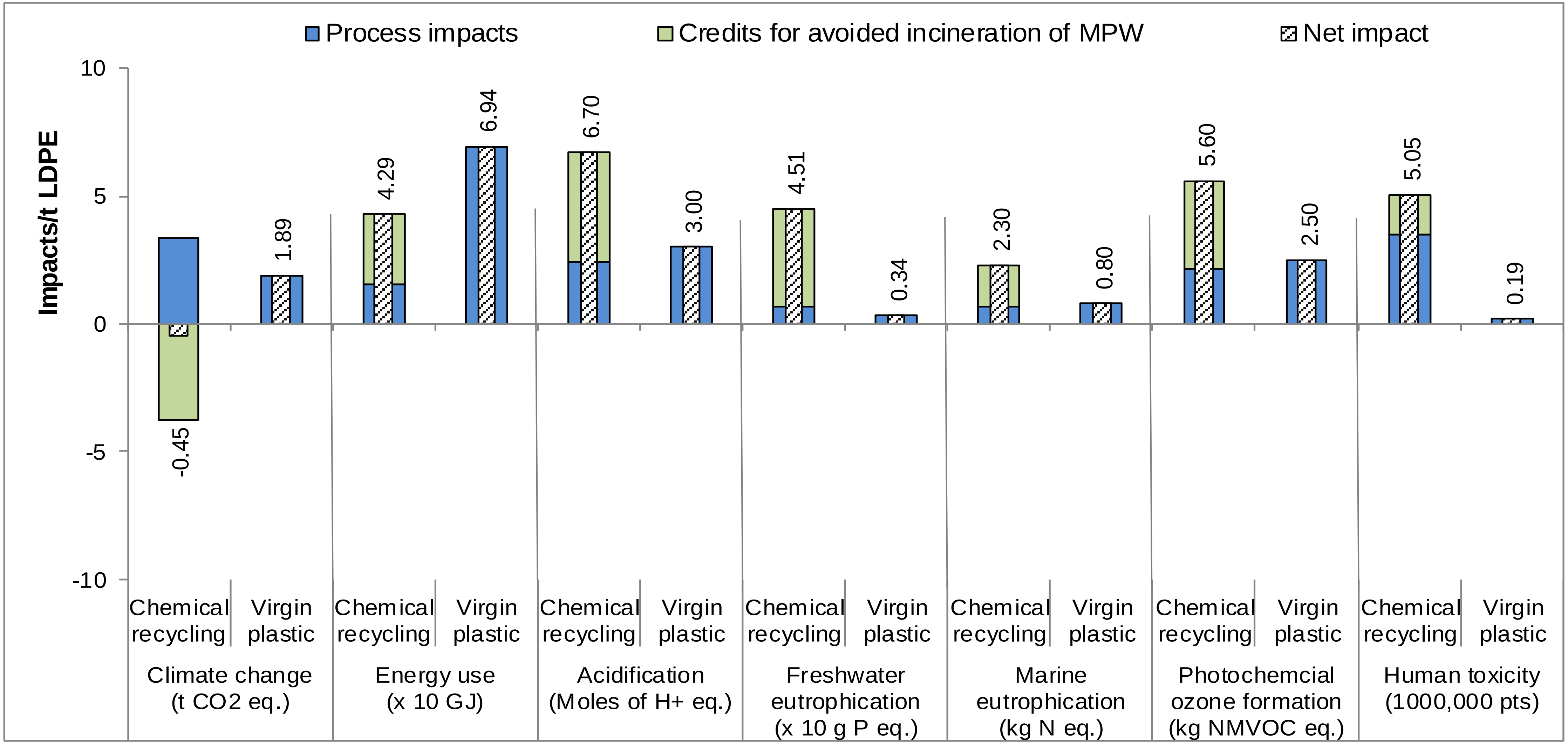
Summary

- Chemical recycling is a better option than energy recovery for climate change
- Chemical recycling also has the lowest life cycle energy use
- However, energy recovery is a better option for all other impacts
- Therefore, "circular" does not mean "environmentally sustainable" for all impacts
  - Trade-offs are necessary, noting that most impacts for all options are net-negative (=savings)

System definition: production of plastics



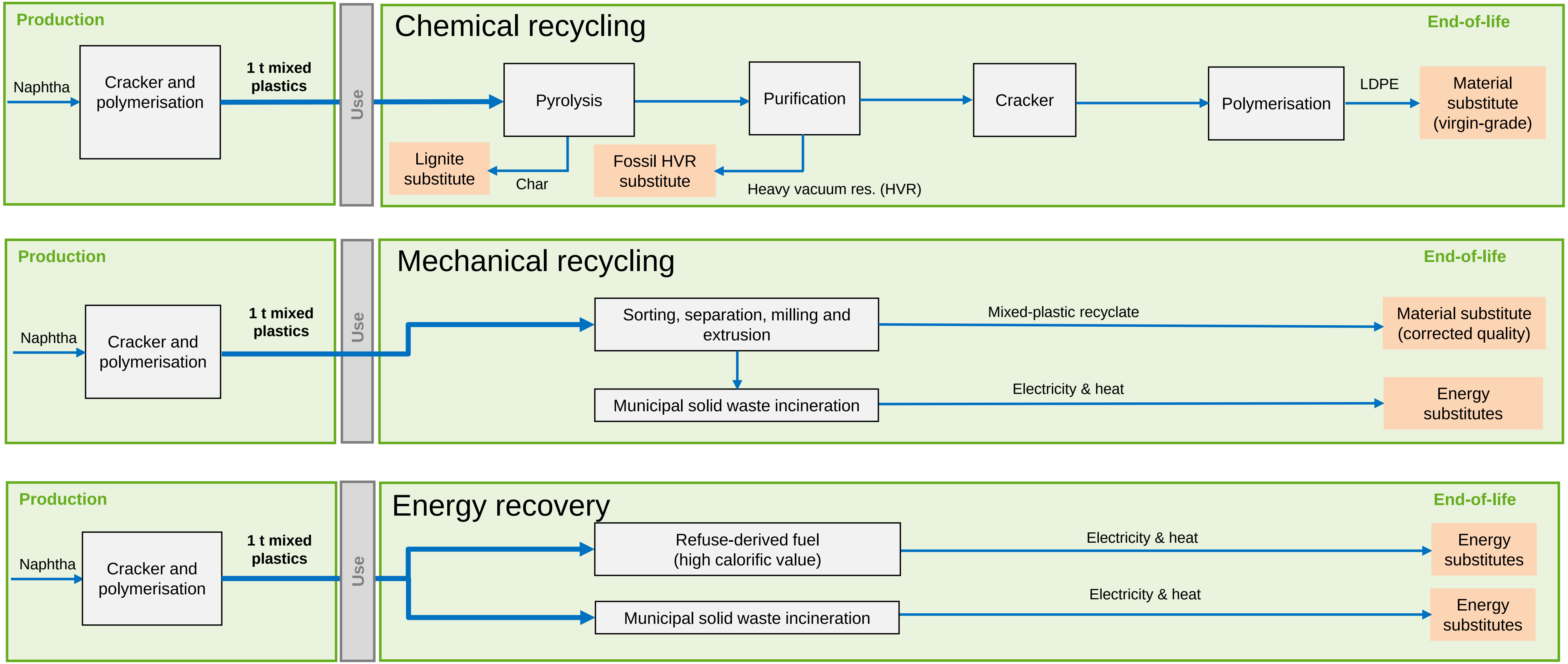
Production of plastics: Chemical recycling vs virgin plastics



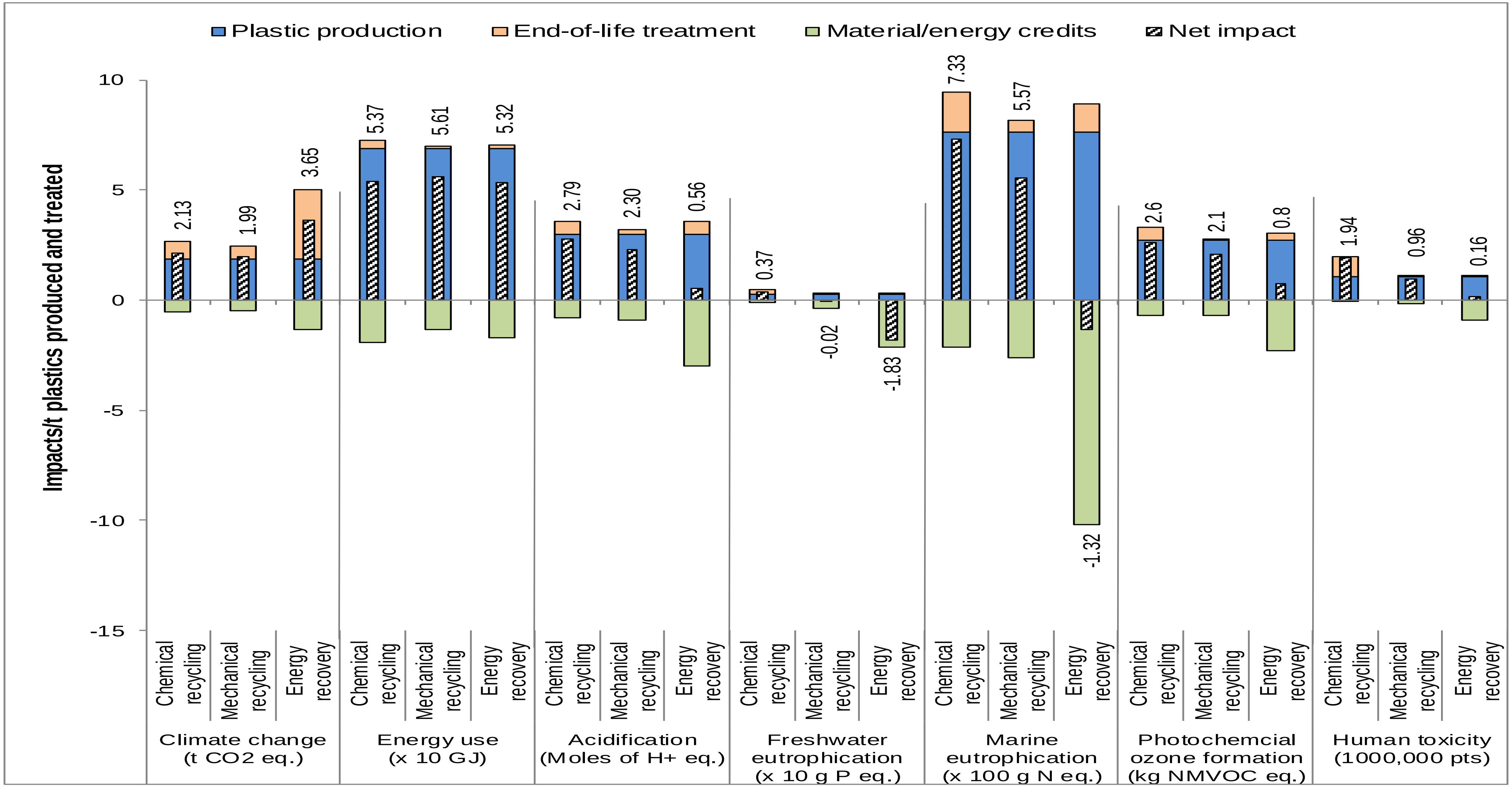
Summary

- Chemically-recycled LDPE has lower climate change impact and energy use than virgin LDPE
- However, most of its other impacts are significantly higher than of the virgin plastic, e.g.:
  - Eutrophication and human toxicity are 13 and 26 times greater
  - Acidification, marine eutrophication and photochemical ozone formation are >2 as high
- Therefore, “circular” does not mean “environmentally sustainable” for all impacts
  - Some trade-offs are necessary

System definition: waste treatment and production of plastics



Chemical vs mechanical recycling vs energy recovery



Summary

- Mechanical recycling has lower impacts (6-105%) than chemical recycling in all impact categories
- Energy recovery has the highest climate change impact
- However, it outperforms both the chemical and mechanical recycling for most other impacts
- Again, “circular” does not mean “environmentally sustainable” for all impacts
  - Some trade-offs are necessary

Conclusions

- Most products and services are not designed for a circular economy
- We still need to understand better when “circular” is “sustainable”
- The systems and life cycle approaches are essential
- Implementation of a circular economy will be challenging but is achievable
    - Drivers are increasing
    - Methods and evaluation tools are available
    - Technologies are developing (slowly)
- More success stories are needed to stimulate the uptake
- Legislation will need to get tougher
- Much greater benefits can be achieved through sustainable consumption…

References (for the illustrative examples)

1. Gallego-Schmid A., J. M. F. Mendoza and A. Azapagic (2019). Environmental impacts of takeaway food containers. *Journal of Cleaner Production* 211 417-427.

2. Slorach, P. C., H. K. Jeswani, R. Cuéllar-Franca and A. Azapagic (2019). Environmental and economic implications of recovering resources from food waste in a circular economy. *Science of the Total Environment* 693 133516 1-18.

3. Jeswani, H., C. Krüger, M. Russ, M. Horlacher, F. Antony, S. Hann and A. Azapagic (2021). Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery. *Science of the Total Environment* 769 144483 1-15.