Lifecycle assessment and net energy analysis: *birds of a feather or uneasy bedfellows?*

…or Apples to apples: why net energy analysts community needs to adopt the LCA framework

Michael Carbajales-Dale, David Murphy

Wednesday, June 29 2016

BPE @ ISEE2016, Washington DC

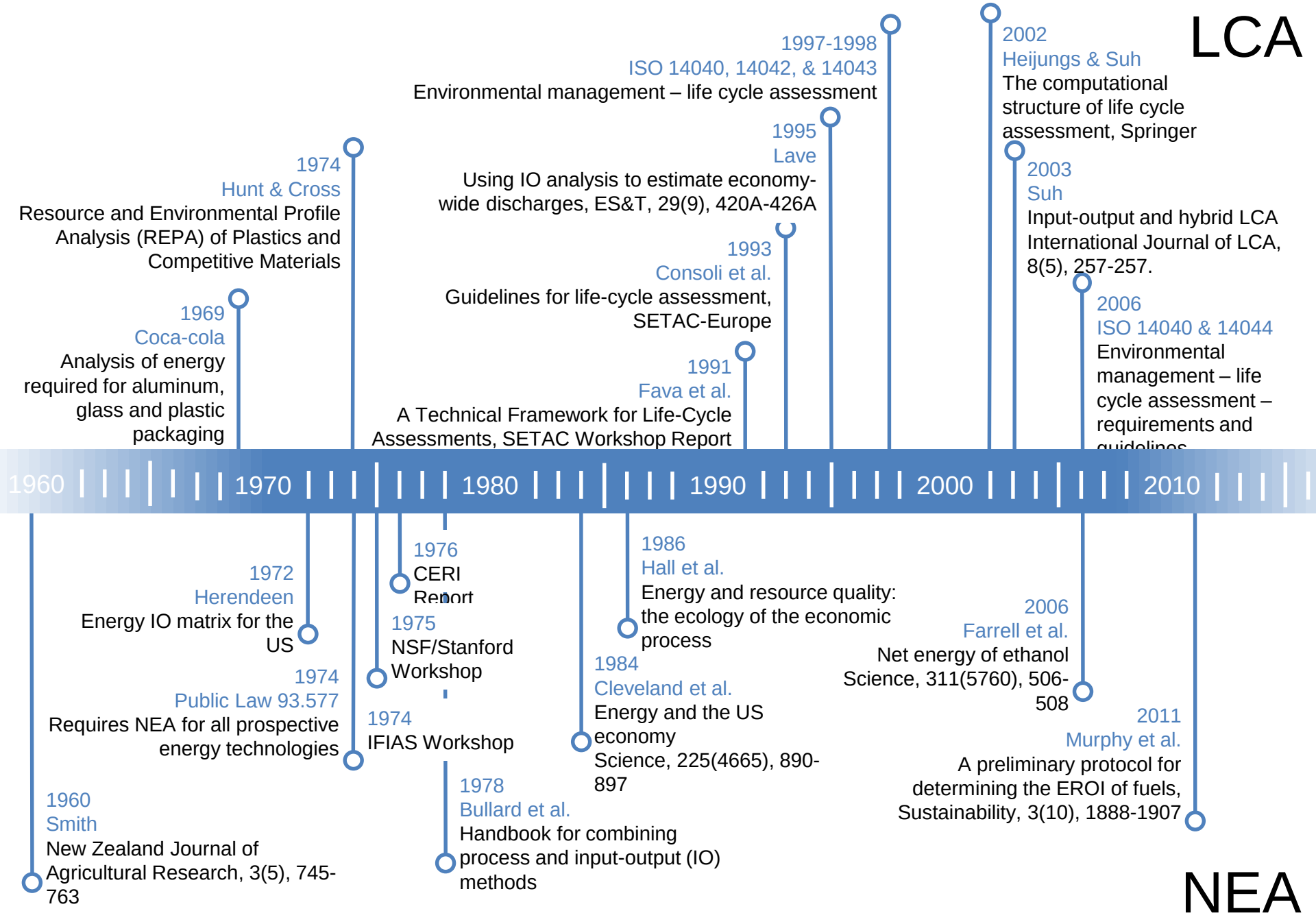
Abstract

Lifecycle assessment (LCA) and net energy analysis (NEA) are complementary approaches with a common historical basis but different underlying motivations and methodologies. As LCA practitioners move more and more beyond the bounds of attributional to consequential LCA the methodological concerns of NEA become more and more appropriate. As such, it is important to understand the large overlaps in method, but also the important distinctions between the two frameworks.

The hope is that NEA practitioners will appreciate more of the common elements between NEA and LCA adopt more of the methodological rigor of LCA and that practitioners of LCA will understand more of the underlying differences between the two frameworks and see insights and opportunities for developing consequential LCA.

Overview

- Historical development
- Goal (motivation and aim)
- Scope (system boundary & assumptions)
  - Functional unit
  - Project vs. industry scale
- NEA to-do list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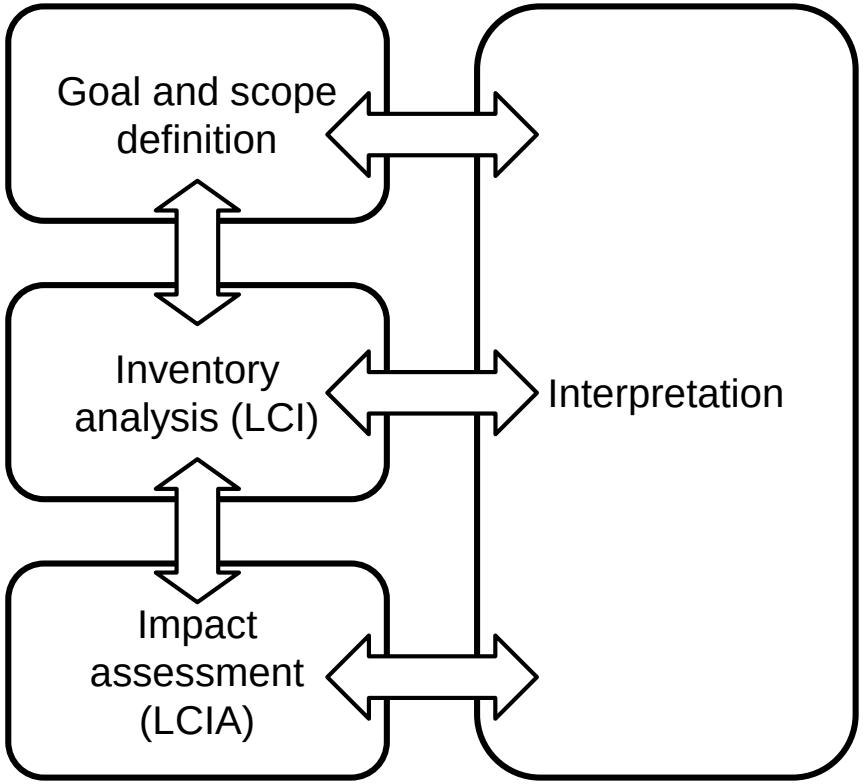
NEA

Overall steps in LCA

Life cycle assessment framework



- Based on ISO 14044: Standards for life cycle assessment

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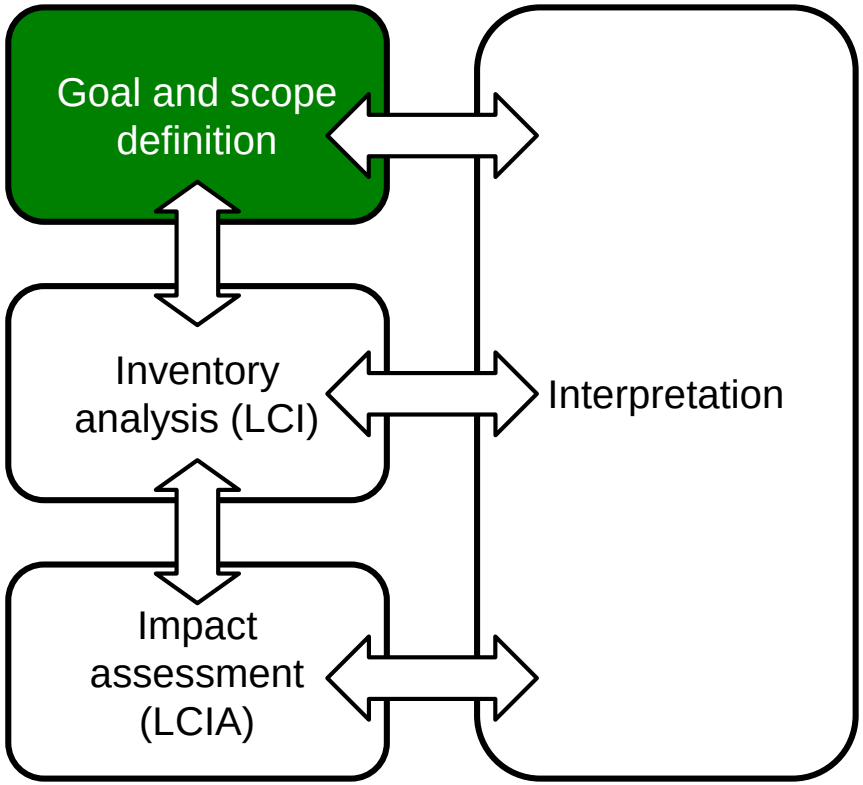

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According to ISO, goal definition shall "unambiguously state the intended application, the reason for carrying out the study and the intended audience"

Scope definition defines LCA purpose expected product, boundary conditions, functional unit and assumptions

Target audience and goal - LCA

Type: LCA Producer and User	Life cycle thinking	Stand-alone (descriptive)	Accounting (comparative & retrospective)	Change-oriented (comparative & prospective)
Policy makers	•Development of policies	•Producer take back schemes	•Procurement •Eco-labeling criteria	•Development of policies
Industry	•Supply chain management •Product development •Buildings	•Find "hot spots" •Product declarations	•Purchasing •Market communication •Methodological standards	•Product development •Buildings •Process choices & optimization
NGOs	•Campaign ideas	•Evaluation of strategies	•Eco-labeling criteria	•Evaluation of strategies
Consumers	•Life style choices		•Product choices	

Goals for NEA

A. descriptive assessment of the viability of a particular technology (e.g., solar satellite);
B. comparative assessment of alternative energy technologies;
C. calculation of the (minimum) EROI to support an industrial society, or alternatively assessing the feasibility of some technology to (single-handedly) support an industrial society

AND

D. calculation of net energy metrics for industry (e.g. oil and gas) and/or whole economy

Carbajales-Dale et al. (2015) Energy return on investment (EROI) of solar PV: an attempt at reconciliation, *IEEE Proceedings*.

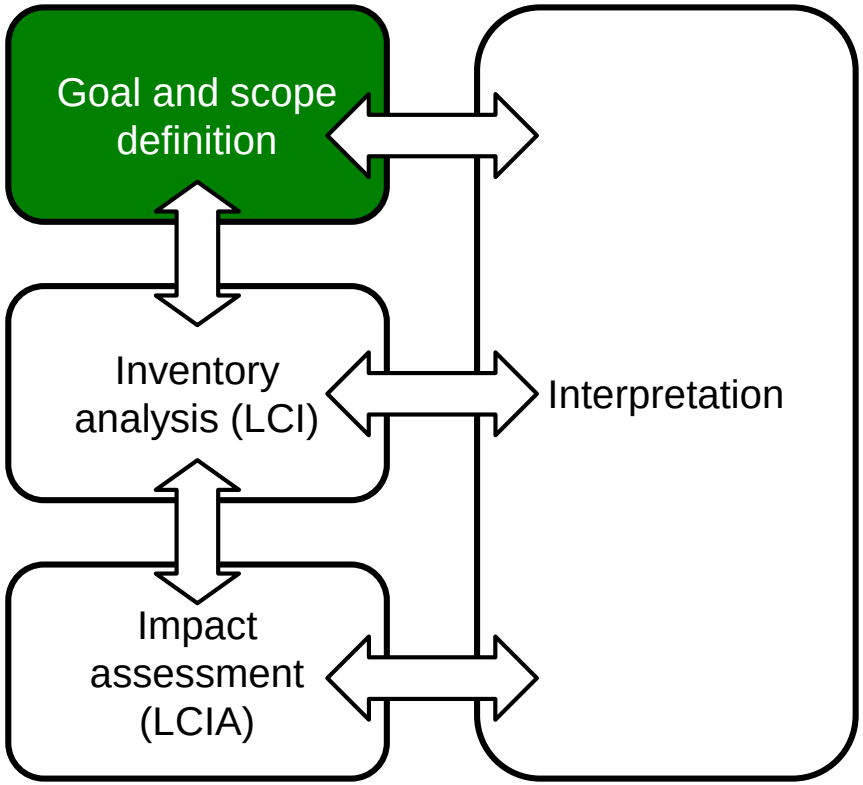
How can this issue play out

- Weißbach et al. (2013)
  - claimed goal: comparing EROI for ‘‘typical’’ power plants [p. 210]
  - solar and wind technologies require ten days of storage(!!) – far from “typical”

Weißbach, D., et al. "Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants." Energy 52 (2013): 210-221.

Overall steps in LCA

Life cycle assessment framework



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Scope definition must answer following:

- What materials, processes, or products are to be considered?
- What is their function? What is functional unit?
- What will be addressed?
- Who is performing LCA? Where are data from (industry or literature?)
- What are limitations of this LCA?
- What are the system boundaries?
- What stages are included?

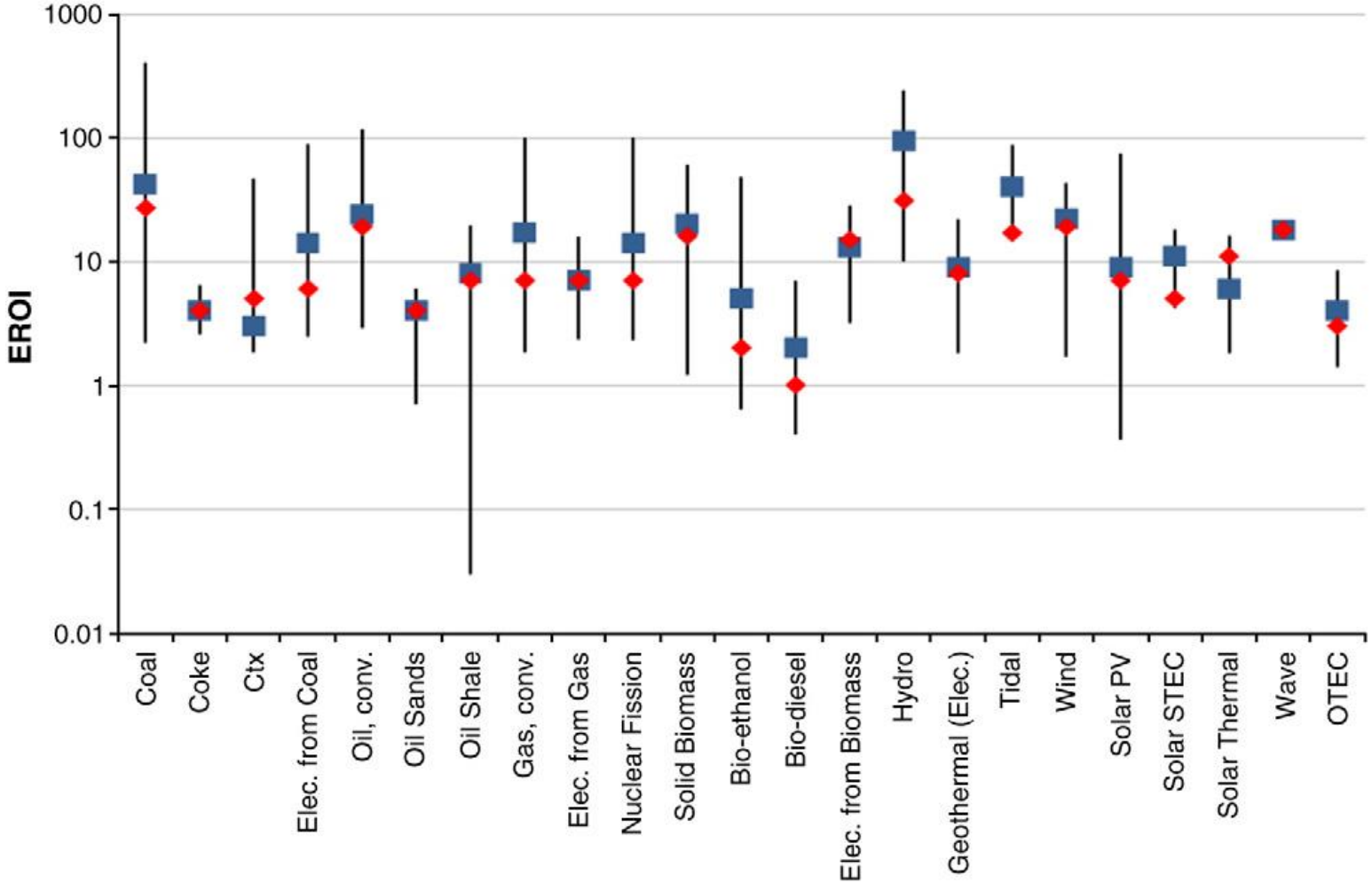
Functional unit

The functional unit (FU) provides a reference flow to which inventory data are normalized

Foam vs. ceramic cups

Inkjet vs. laser printer

What the functional unit!

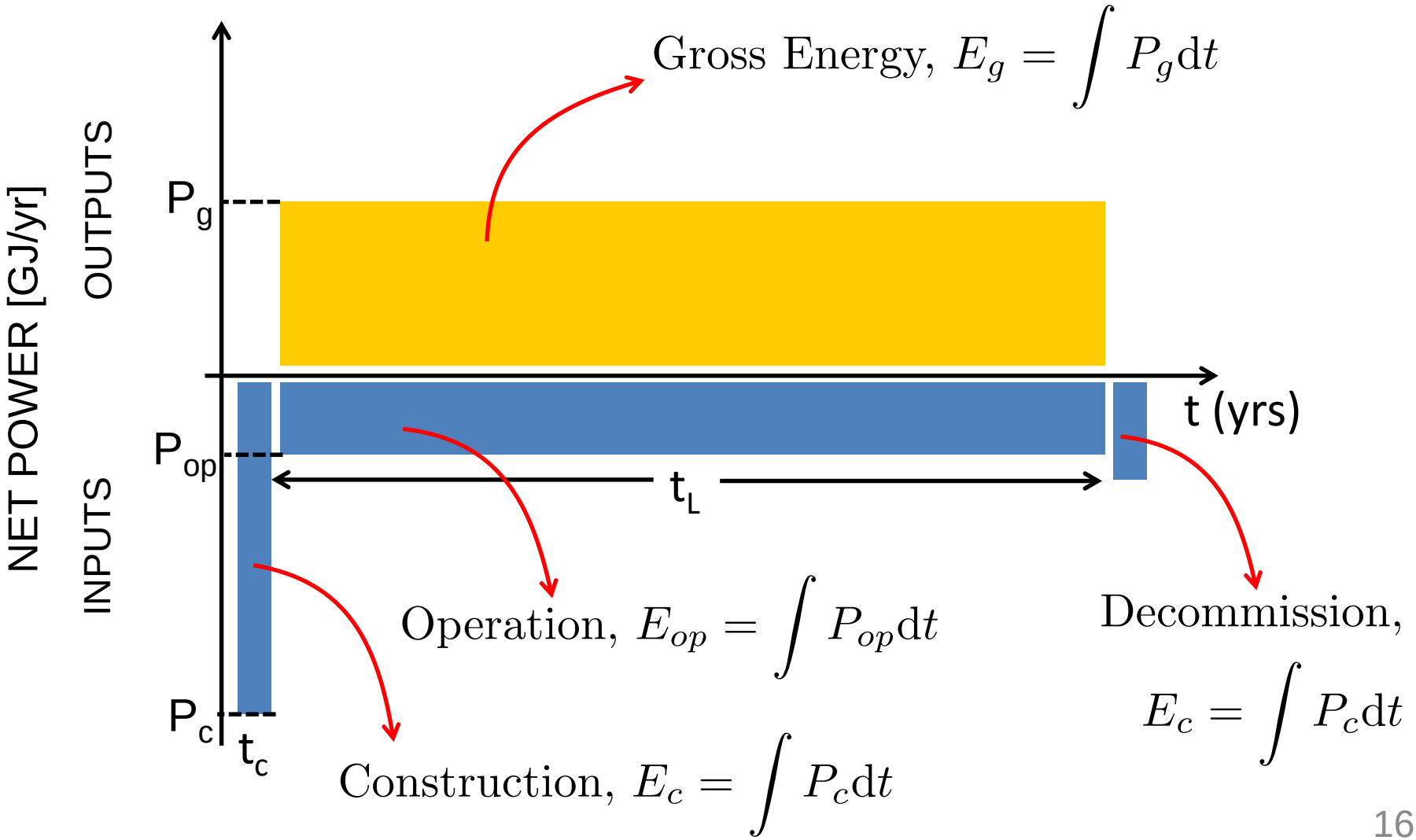


Dale, M., Krumdieck, S., & Bodger, P. (2012). Global energy modelling—A biophysical approach (GEMBA) Part 2: Methodology. Ecological Economics, 73, 158-167.

A financial interlude

- Cost-benefit ratio
  - ratio of present value of benefits ($) to present value of costs ($) for project
- Efficiency ratio
  - ratio of the expenditures ($/yr) to revenues ($/yr) in a given year

Power vs. energy return on investment



Power vs. energy return on investment

EROI

- defined at project level (e.g. oil well)
- defined over project lifetime (e.g. 5 years)

$$EROI = \frac{E_g}{E_c + E_{op} + E_d}$$

- Units $\left[\frac{J}{J}\right]$

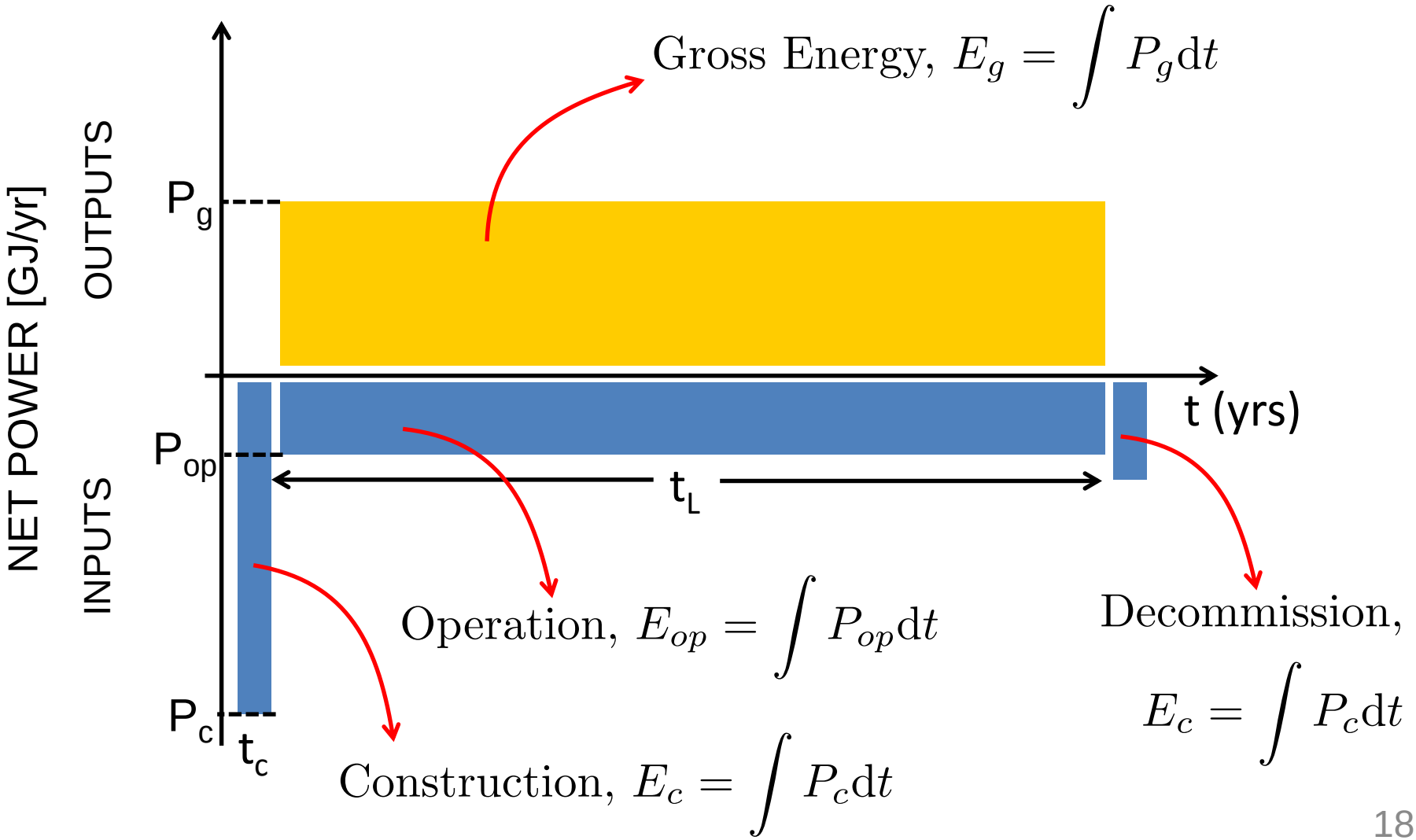
PROI

- defined at industry/economy scale
- defined over arbitrary timescale (e.g. 1 year)

$$PROI = \frac{P_g}{P_c + P_{op} + P_d}$$

- Units $\left[\frac{J/yr}{J/yr}\right]$

Power vs. energy return on investment



Power vs. energy return on investment

Energy flows for an industry growing at 100% per year

EROI = 15

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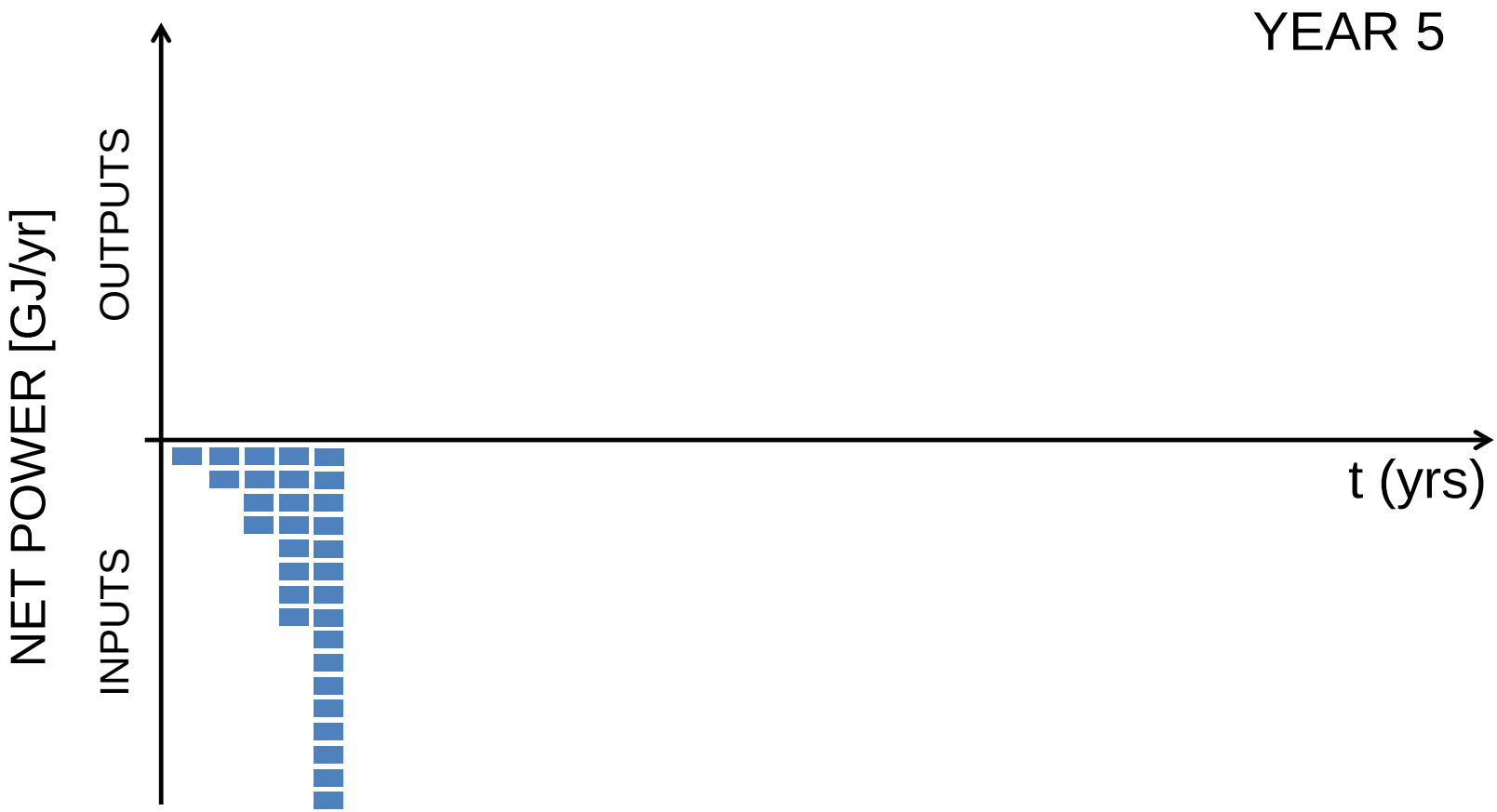
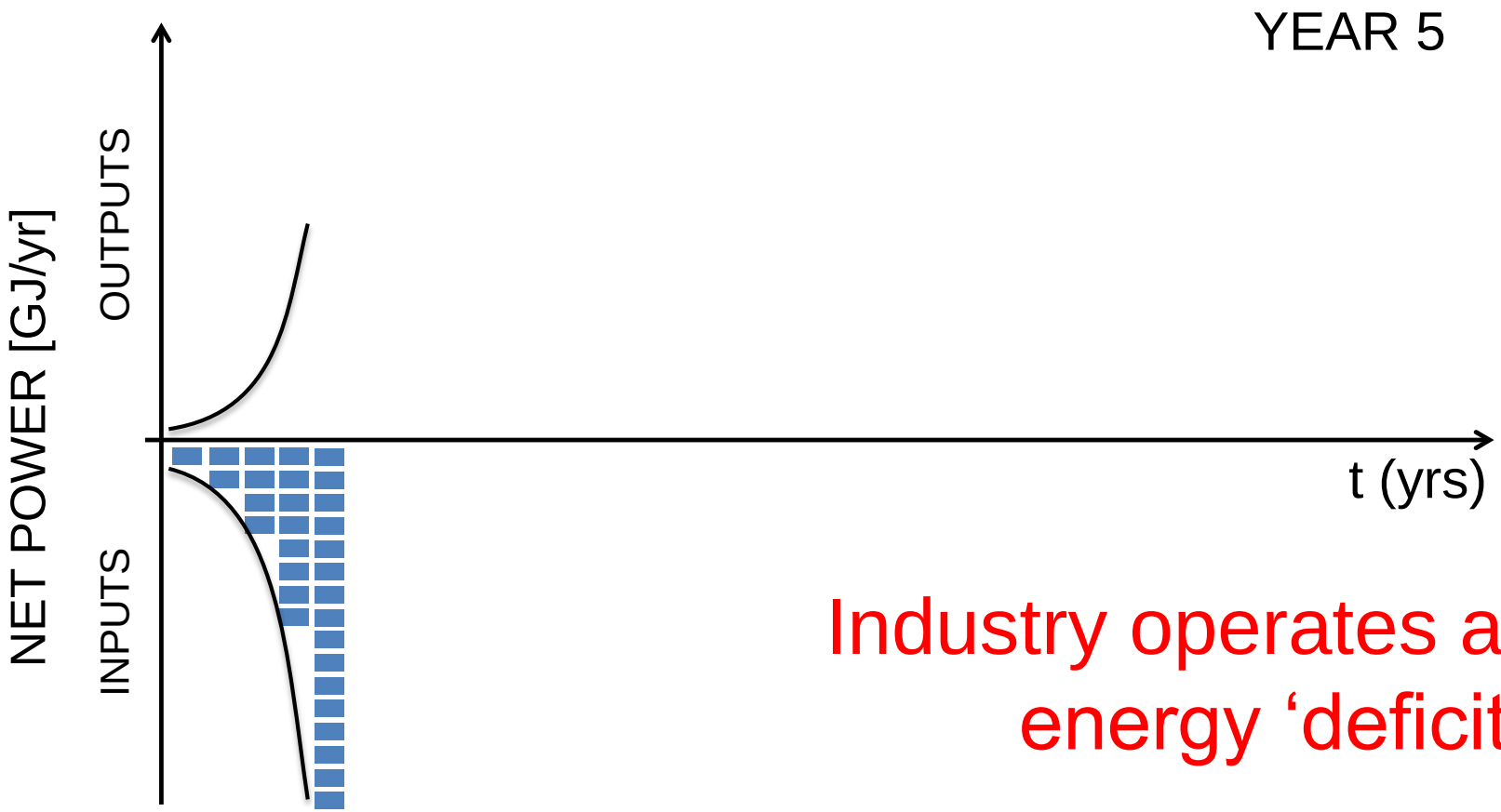


Power vs. energy return on investment

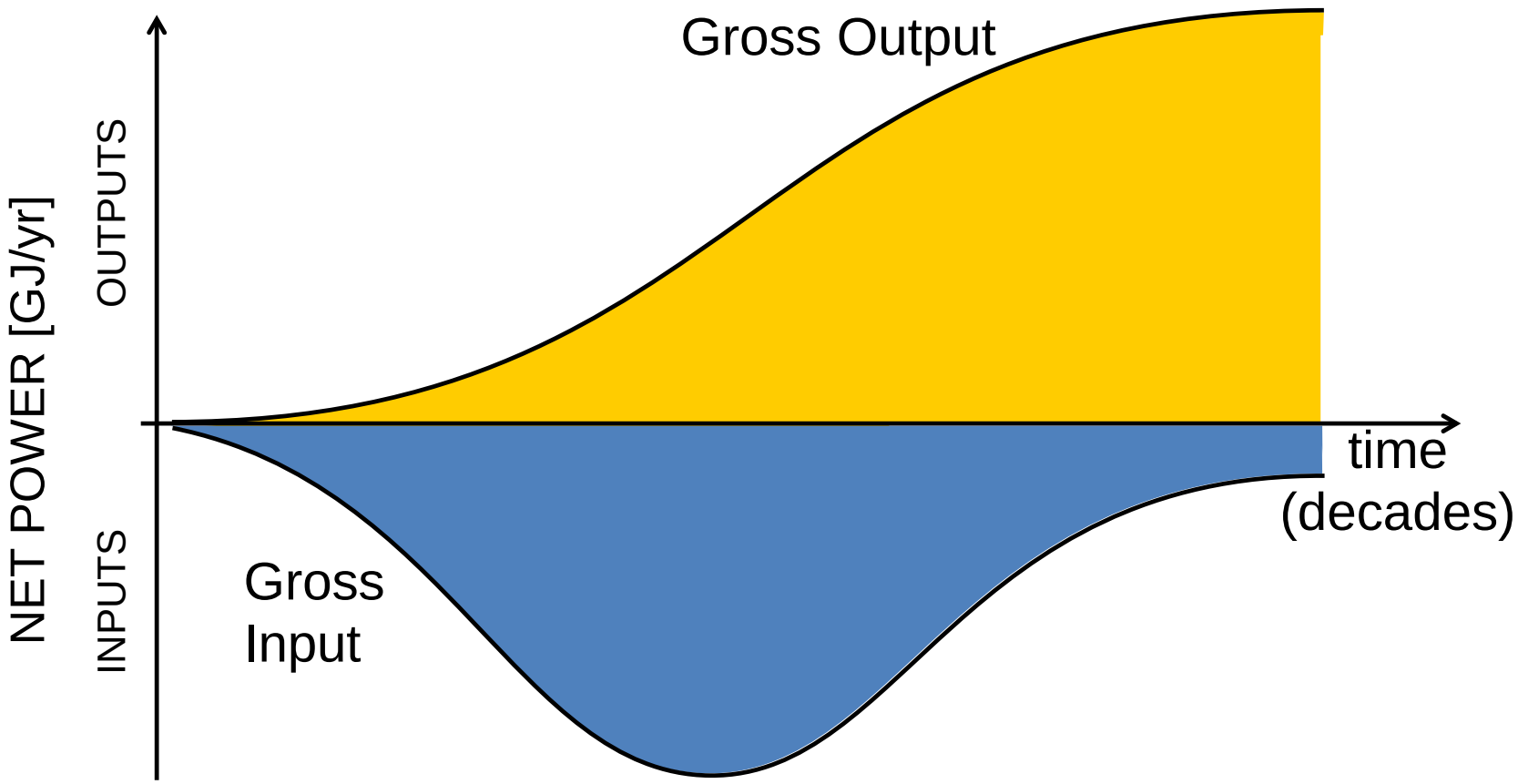
Energy flows for an industry growing at 100% per year

EROI = 15 → PROI = 0.5



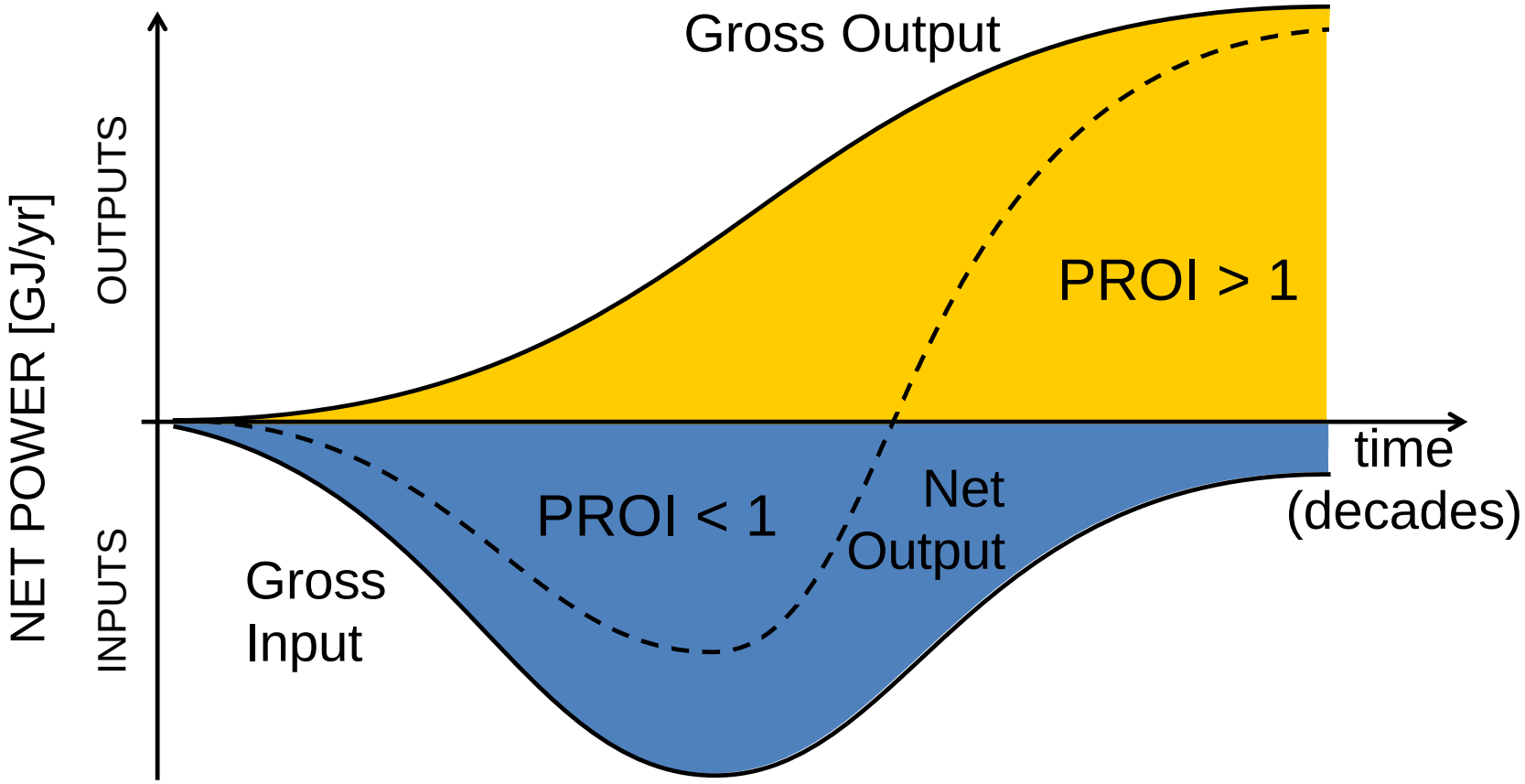
Industry operates at energy 'deficit'

Zooming out to longer time-scale



Zooming out to longer time-scale

- A fraction of gross output is re-invested for industry growth

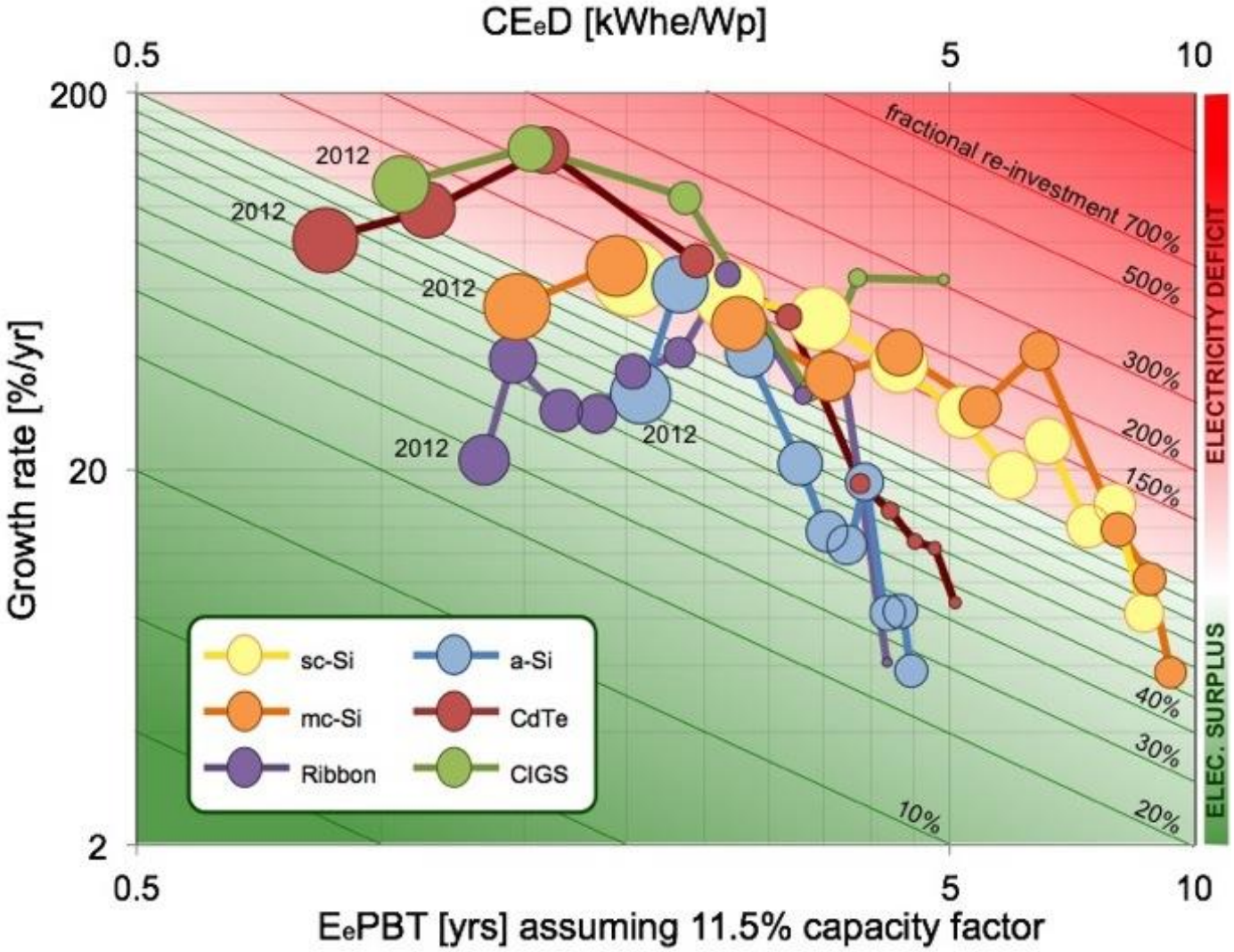


How can this play out?

- Prieto & Hall (2013)
  - “We employ five general methods in analyzing the energy contained/embodied or spent on the equipment, goods and services related to the solar PV plants in Spain… What follows is our estimate of each of the above five categories of energy inputs for Spain for the year 2009” [p.62]
- Clearly this is a PROI but is often compared directly with project-level estimates of EROI of PV.

Prieto, P. A., & Hall, C. A. (2013). Spain’s photovoltaic revolution: the energy return on investment. Springer Science & Business Media.

Net energy trajectories for all PV technologies



Technologies with lower CED can grow at a faster rate

Carbajales-Dale, Barnhart & Benson. *Energy & Environmental Science* 7(5) 1538-1544.

Net energy analysis to-do list:

1. Write a proper goal statement, including the following information:
   a. Intended application, i.e. is this a comparison study?
   b. Reasons for the research
   c. For whom the work is intended, i.e. the audience
2. Define the product system using a diagram with flows labeled
   a. Use the product flow diagram as a map when listing equations within the paper so that the reader is clear about which inputs are included and which are not
   b. Use this product flow diagram and labels when listing equations, so that the reader can clearly link calculations to the diagram and the boundaries used in the analysis
3. Clearly identify the functional unit of the analysis and make sure that this unit is the same as other units in the literature if the research is intended to be used comparatively.
4. Utilize process-level data when available and input-output level data as a backup/supplement
   a. Utilize EcoInvent (or other) major LCI database as a primary loci for data
   b. supplement these databases with other data (e.g. EIO-LCA) when needed, but only after these datasets have been utilized

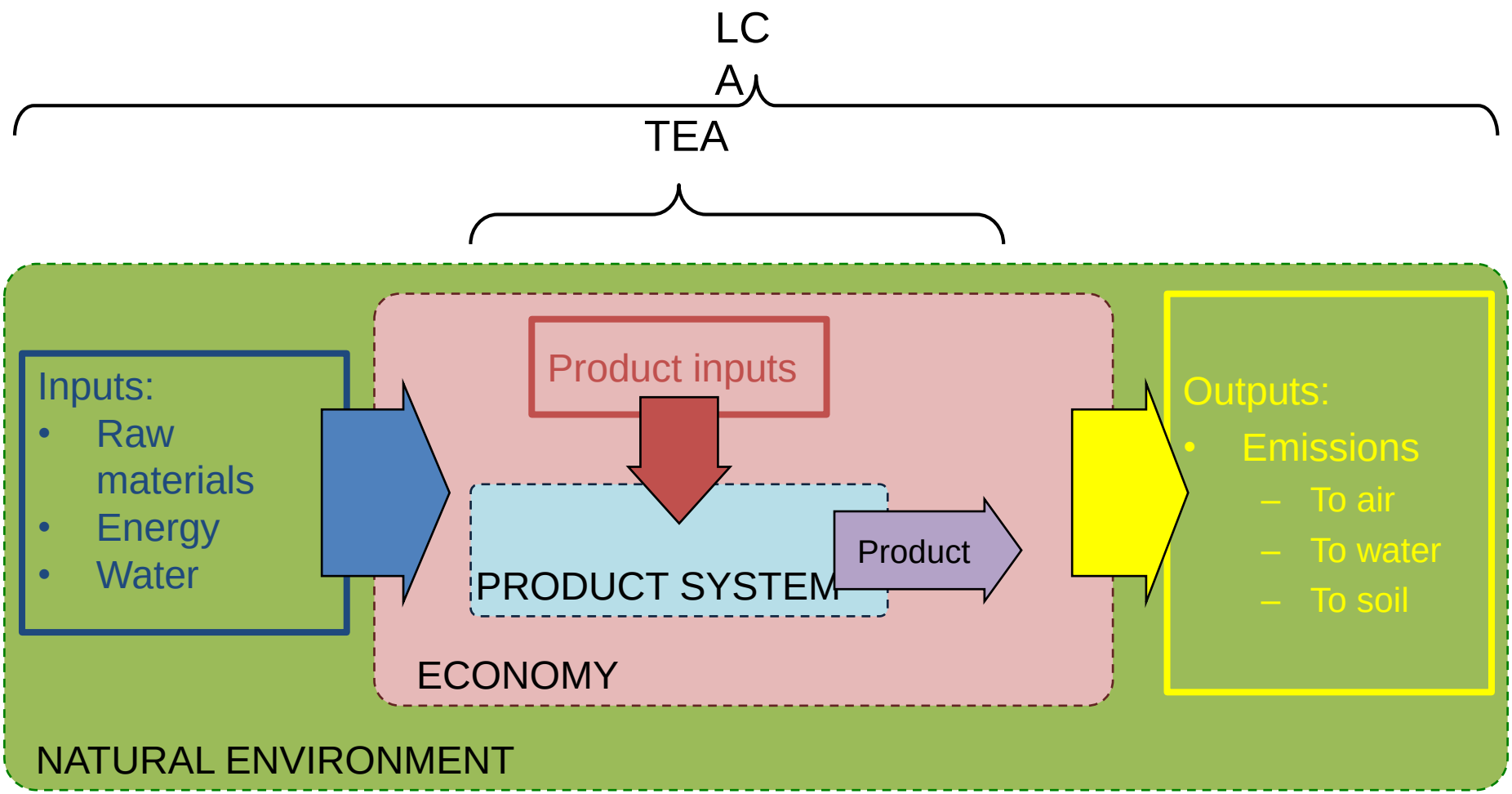
Murphy & Carbajales-Dale (2016) Comparing apples to apples, *Energies, IN REVIEW*, adapted from Hall & Day (2009) Revisiting the Limits to Growth after Peak Oil, *American Scientist*

Thanks for listening…

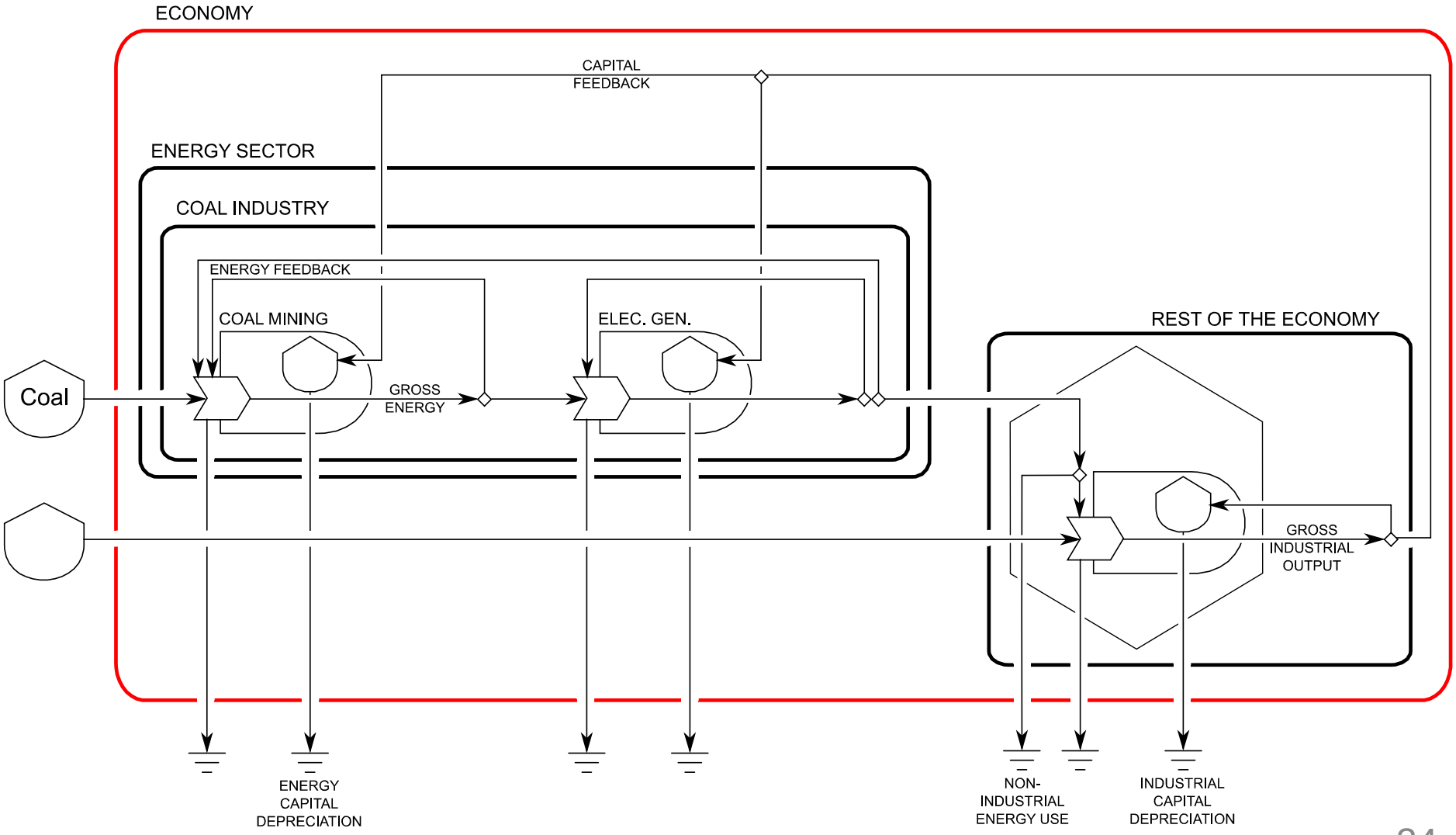
What about Ferroni & Hopkins

- Large storage requirement
  - again a ten-day storage is required
- Methodological flaws
  - The way in which labor and capital costs are included leads to double counting
- Non-standard parameters
  - Capacity factor of 7.5% because statistics not adjusted for growth - actual figure is closer to 10.5% (close to value for Germany of ~12%)
- Cherry-picking estimates for embodied energy in panels
- Harmonizing their values leads to an EROI of 12

Overview of LCA and TEA



Scope LCA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GROSS ENERGY
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ENERGY CAPITAL DEPRECIATION
NON-INDUSTRIAL ENERGY USE
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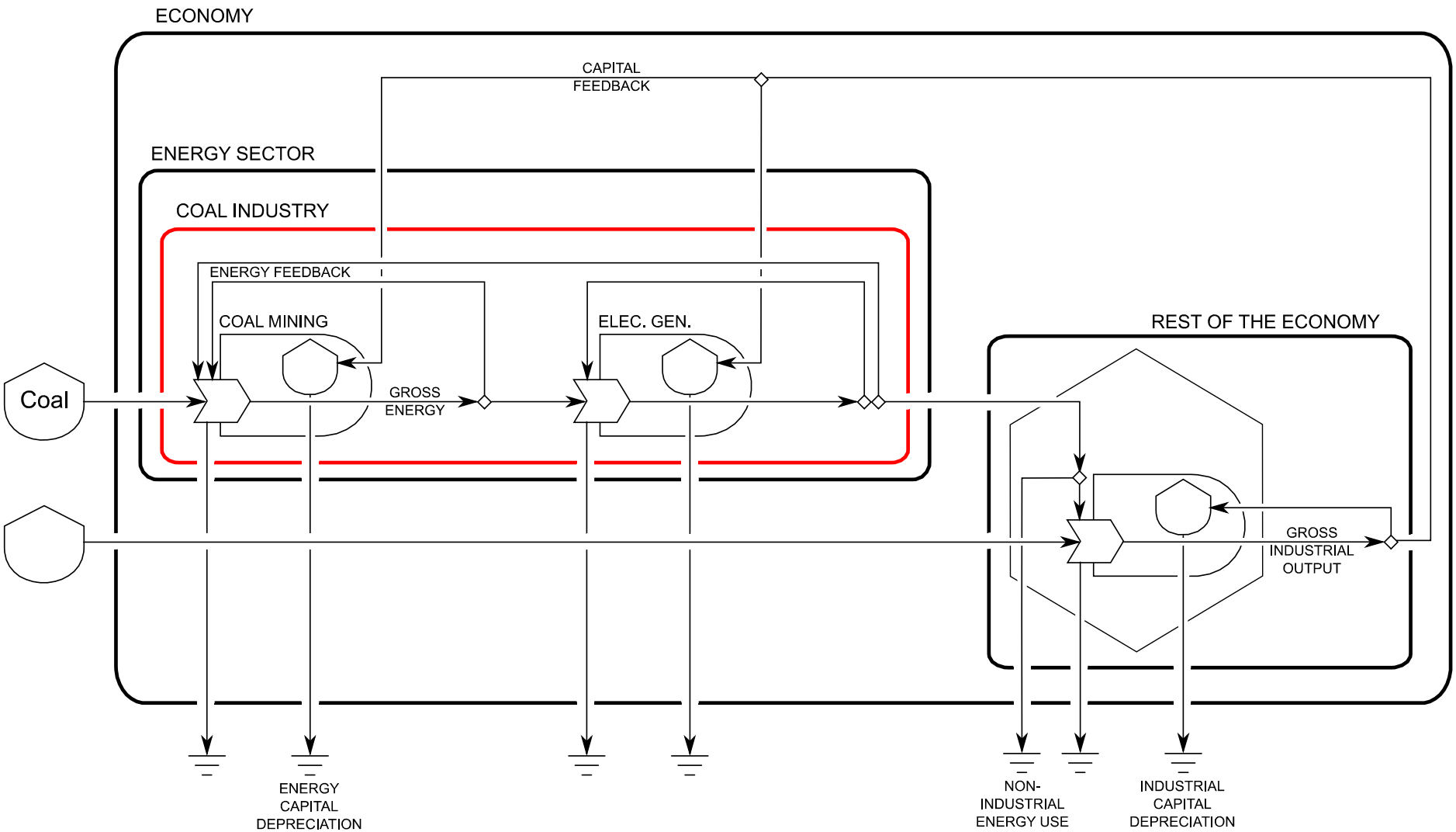
Attributional vs. consequential LCA

- Attributional LCA
  - calculates or compares environmental impacts at the product scale, e.g. GWP of corn-based ethanol

- Consequential LCA
  - calculates potential impacts of product change on larger system (industry or economy), e.g. climate impact of shift to 10% increase in corn-based ethanol

Scope NEA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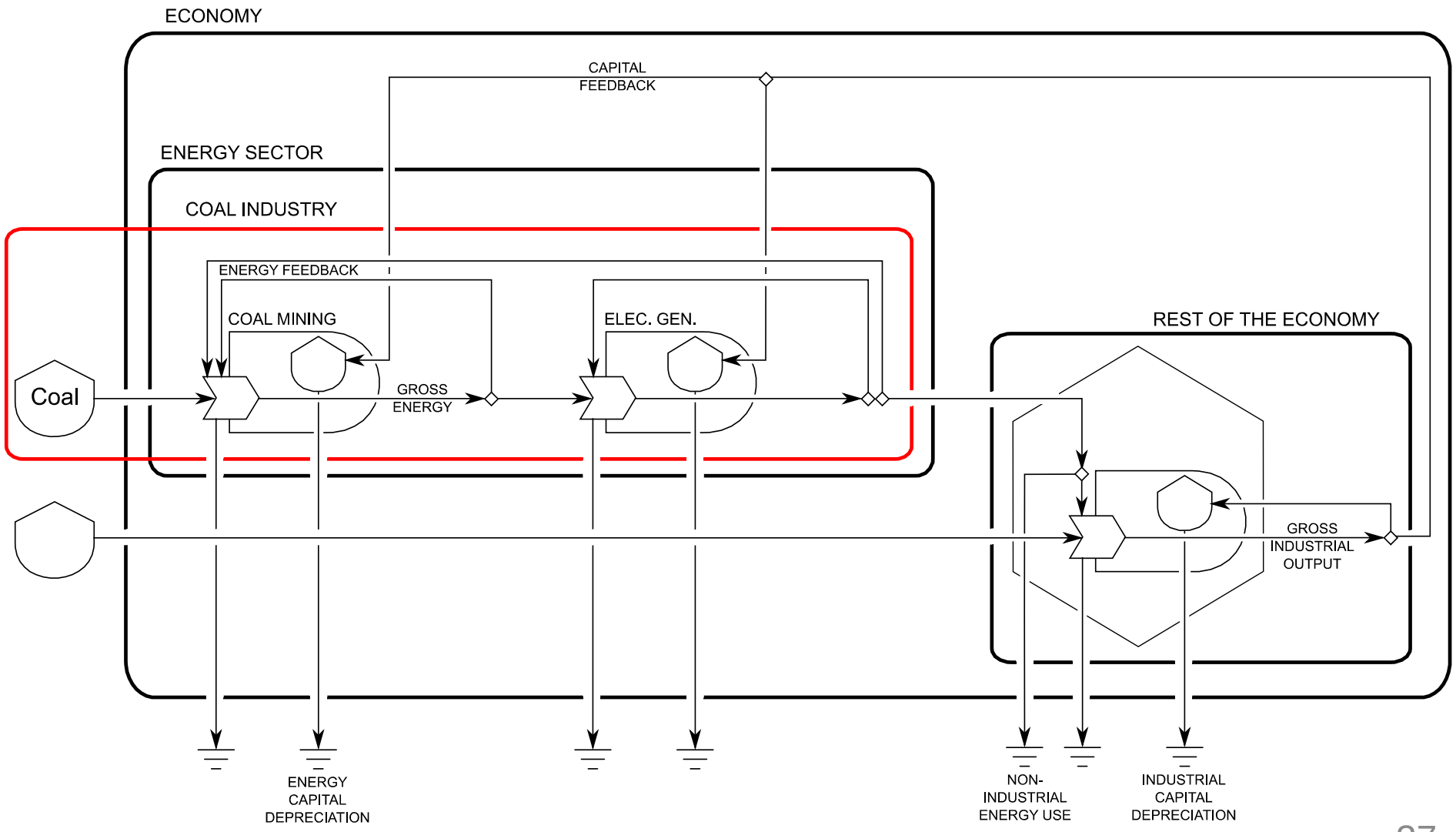
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Structure of LCA – Heijungs & Suh (2002)

- Determine bill of materials (direct inputs) over full lifecycle of product/service, *f*

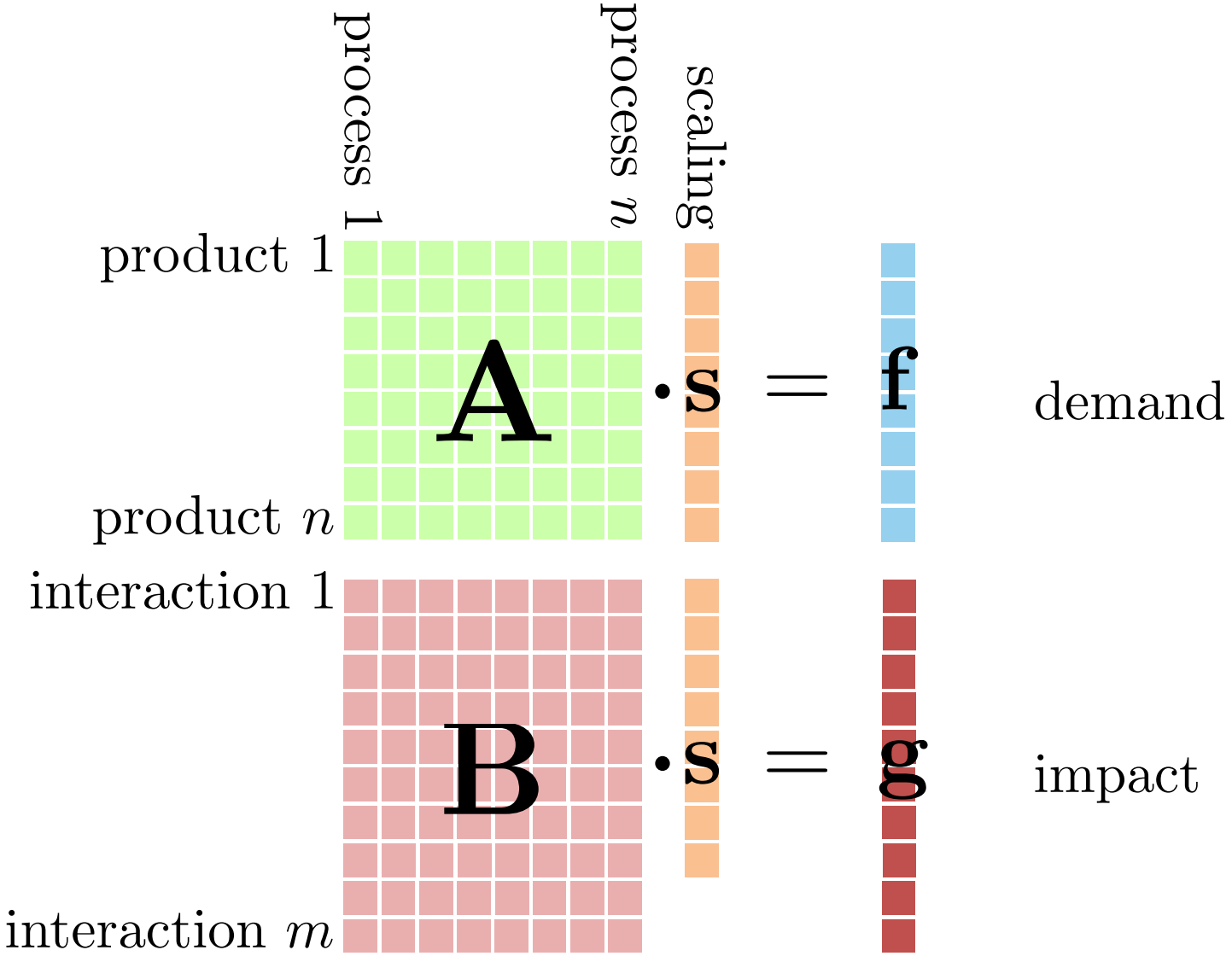
Structure of LCA – Heijungs & Suh (2002)

- Determine bill of materials (direct inputs) over full lifecycle of product/service, *f*

$$\mathbf{A} \cdot \mathbf{s} = \mathbf{f} \quad \text{demand}$$

$$\mathbf{B} \cdot \mathbf{s} = \mathbf{g} \quad \text{impact}$$

Structure of LCA – Heijungs & Suh (2002)

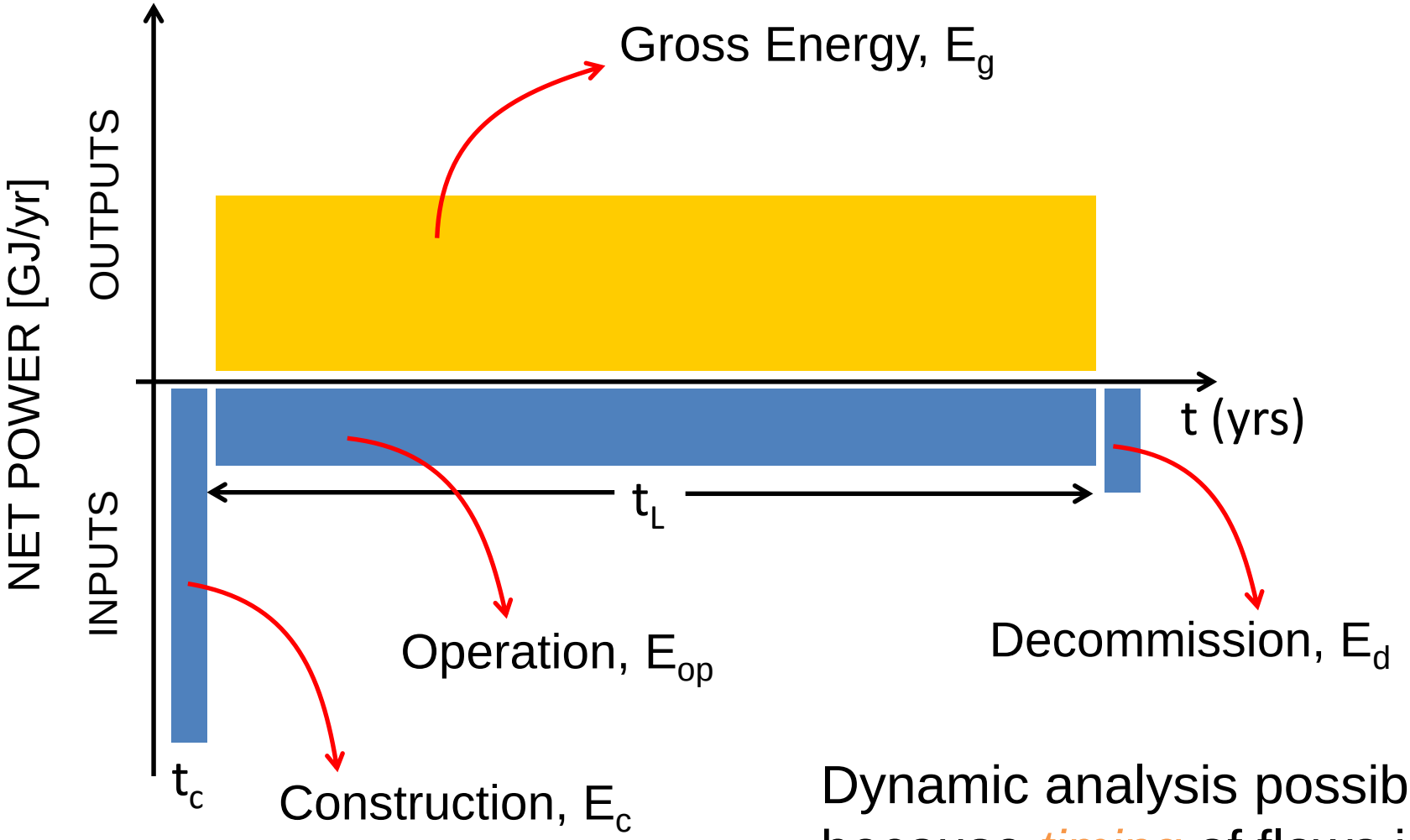


Structure of NEA

- *Process-based*, ‘bottom-up’ methods based on engineering-type models

- *Input-output*, ‘top-down’ methods based on economic (national accounts) methods

Process-based method



Dynamic analysis possible because *timing* of flows is known

Input-output method

- Uses environmentally-extended economic input-output models
- Financial flows (e.g. $/yr) used as a proxy for energy and material flows
- Resolution limited to scale of sector
- Steady-state assumption (no accumulation within sectors) inherent within national accounts

Common methodological issues

- Truncation issue (missing data)
- Co-product allocation
- Hybridization
- Aggregation
- Labor and services
- Indirect impacts (e.g. land-use change)
- Marginal vs. absolute impacts
- Linear model
- Inclusion of non-physical (e.g. social) impacts

Uncommon methodological issues

NEA:

- Production vs. investment
- Energy return ratios poorly defined
- Aggregation of different energy types

LCA:

- Weighting and aggregation of impact metrics
- Collapse of time dimension

Hybrid approaches

- Avoid truncation issue by combining process and input-output methods
  - process method is *transfer-based*
  - Input-output method is *flow-based*

- Must assume either
  - all input-output expenditures occur within a single year or
  - that the economy is not changing (steady-state)

Product scale vs. industry scale

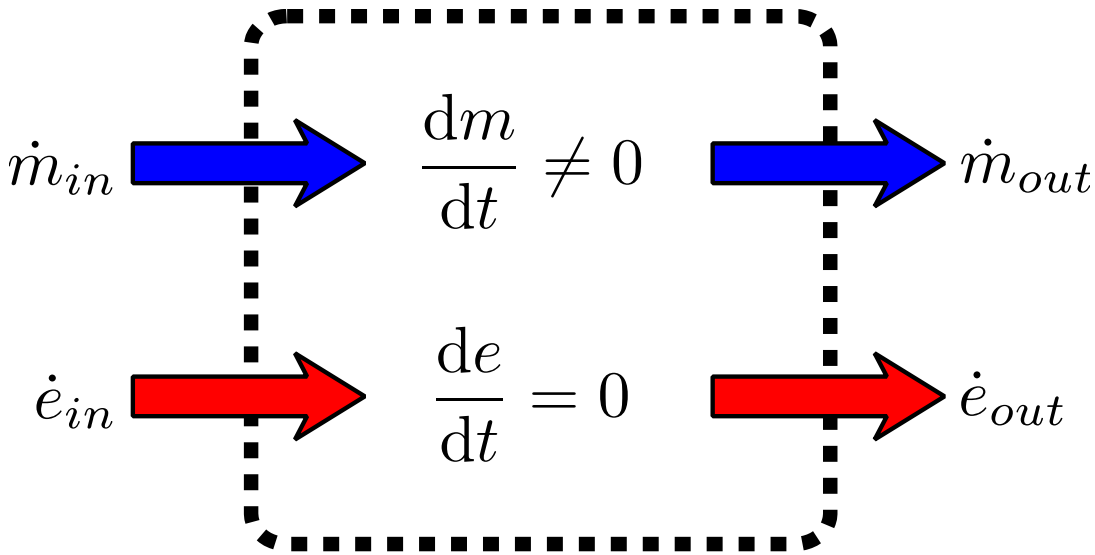
- Product scale
  - *transfer-based* assessment of impacts over full lifecycle which is well defined

- Industry scale
  - lifetime poorly (if at all) defined, often arbitrary
  - dynamic assessment necessary
  - *flow-based* analysis

Caveat emptor - whose lifetime?

Caveat scrutator - whose lifecycle?

Flows of mass and energy in and out of system need not balance in arbitrary time period



Caveat scrutator - whose lifecycle?

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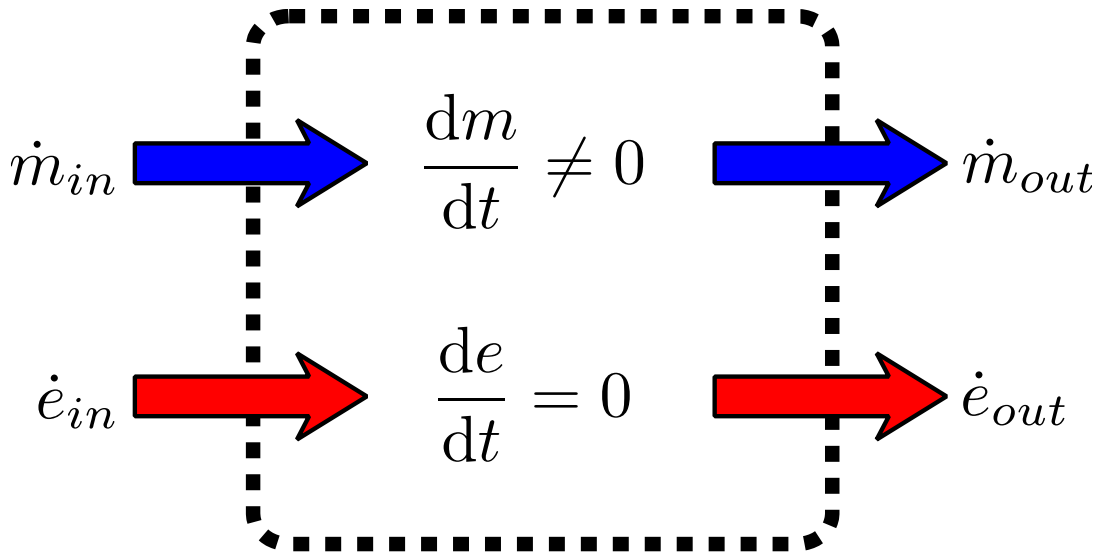
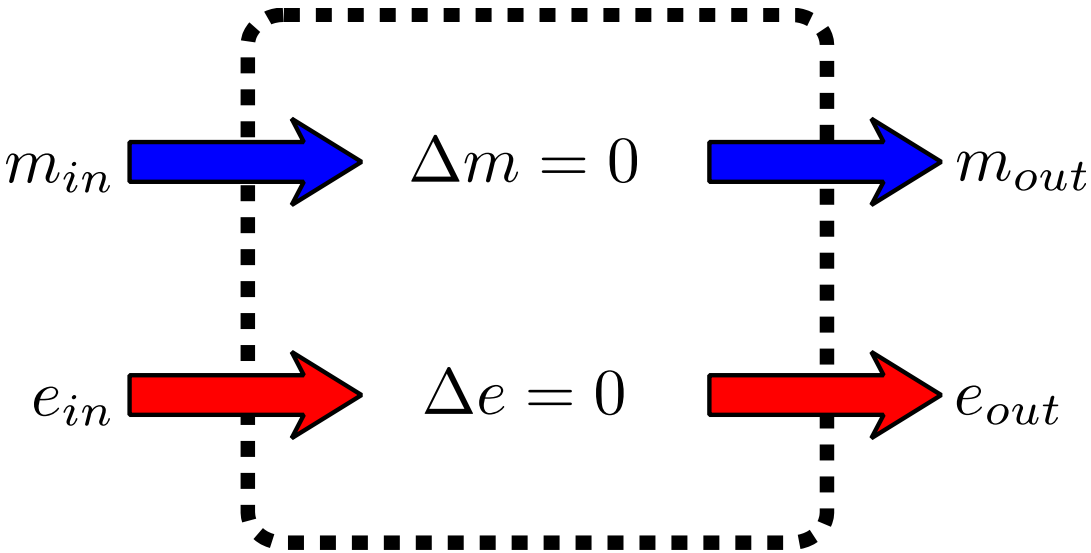
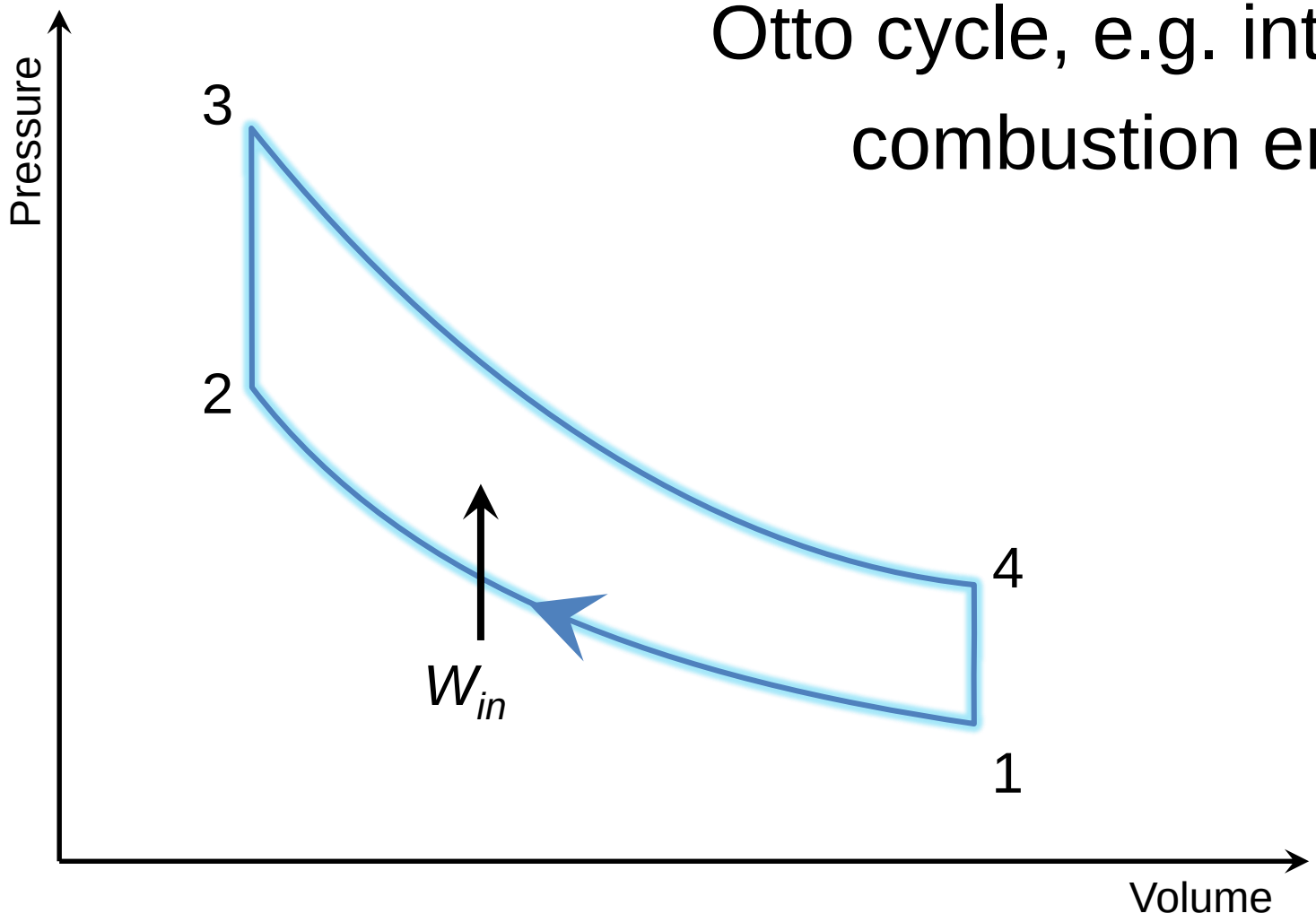




Transfers of mass and energy in and out of system must balance over full lifecycle

What do we mean by a ‘cycle’?

Otto cycle, e.g. internal combustion engine



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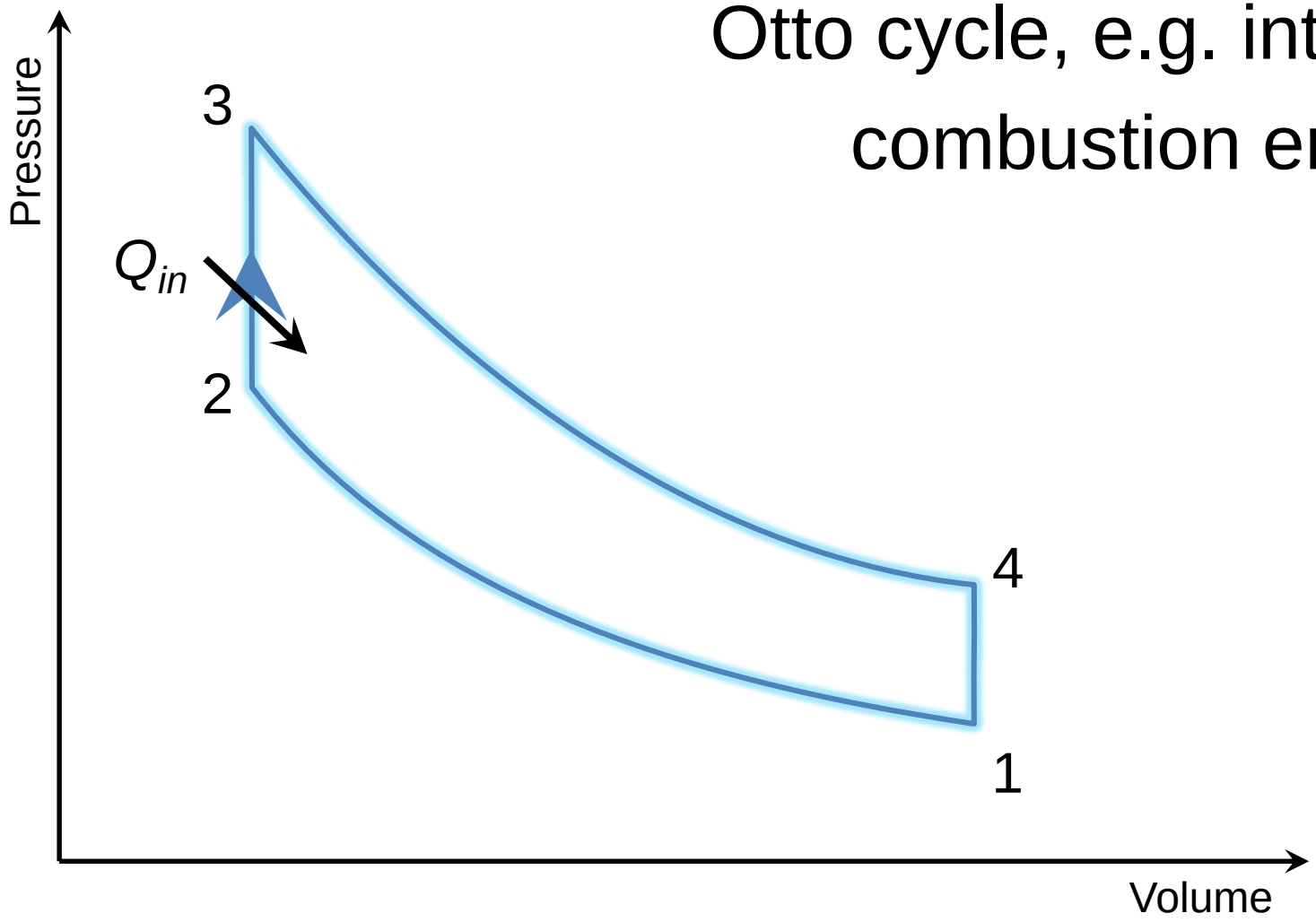

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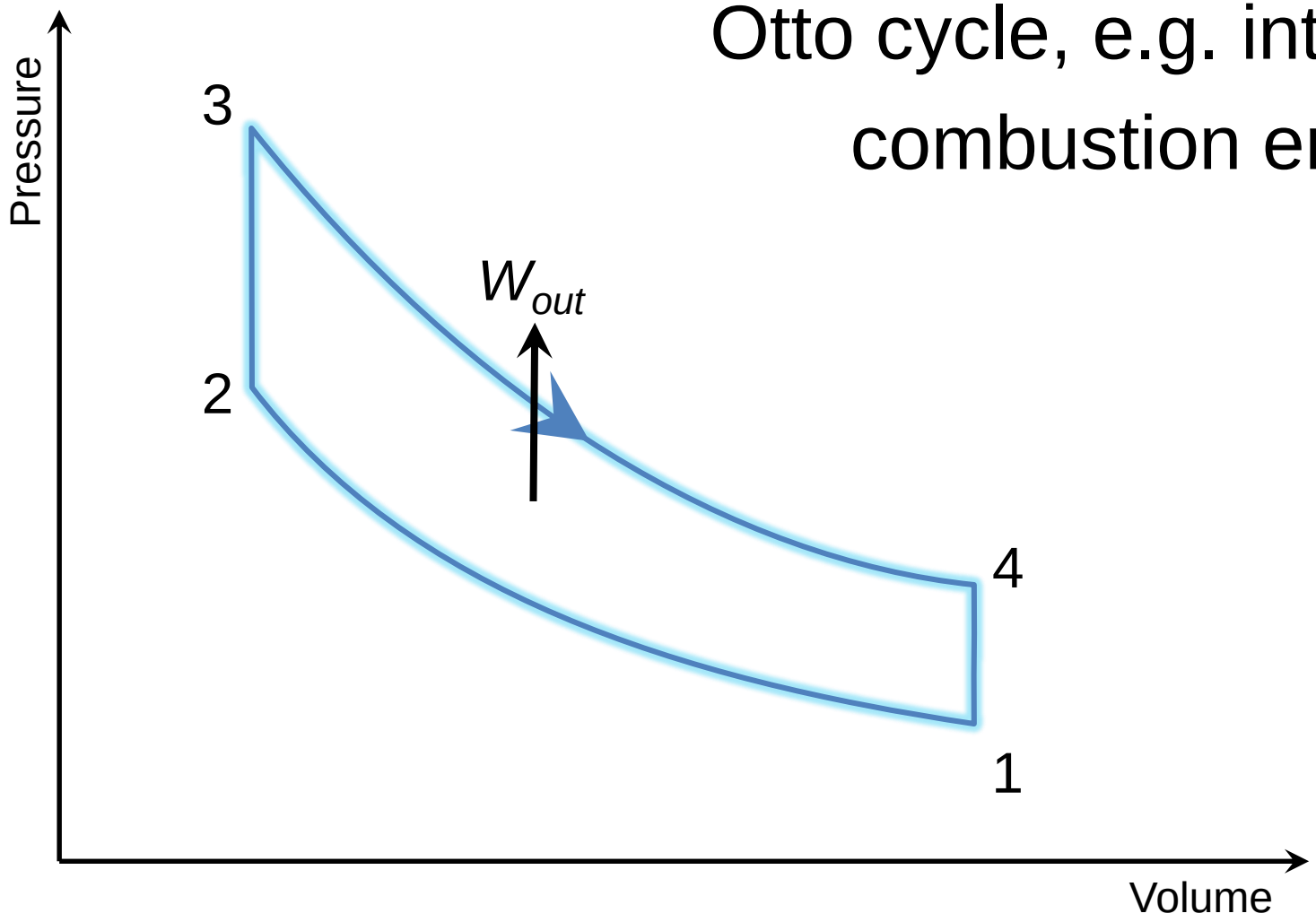

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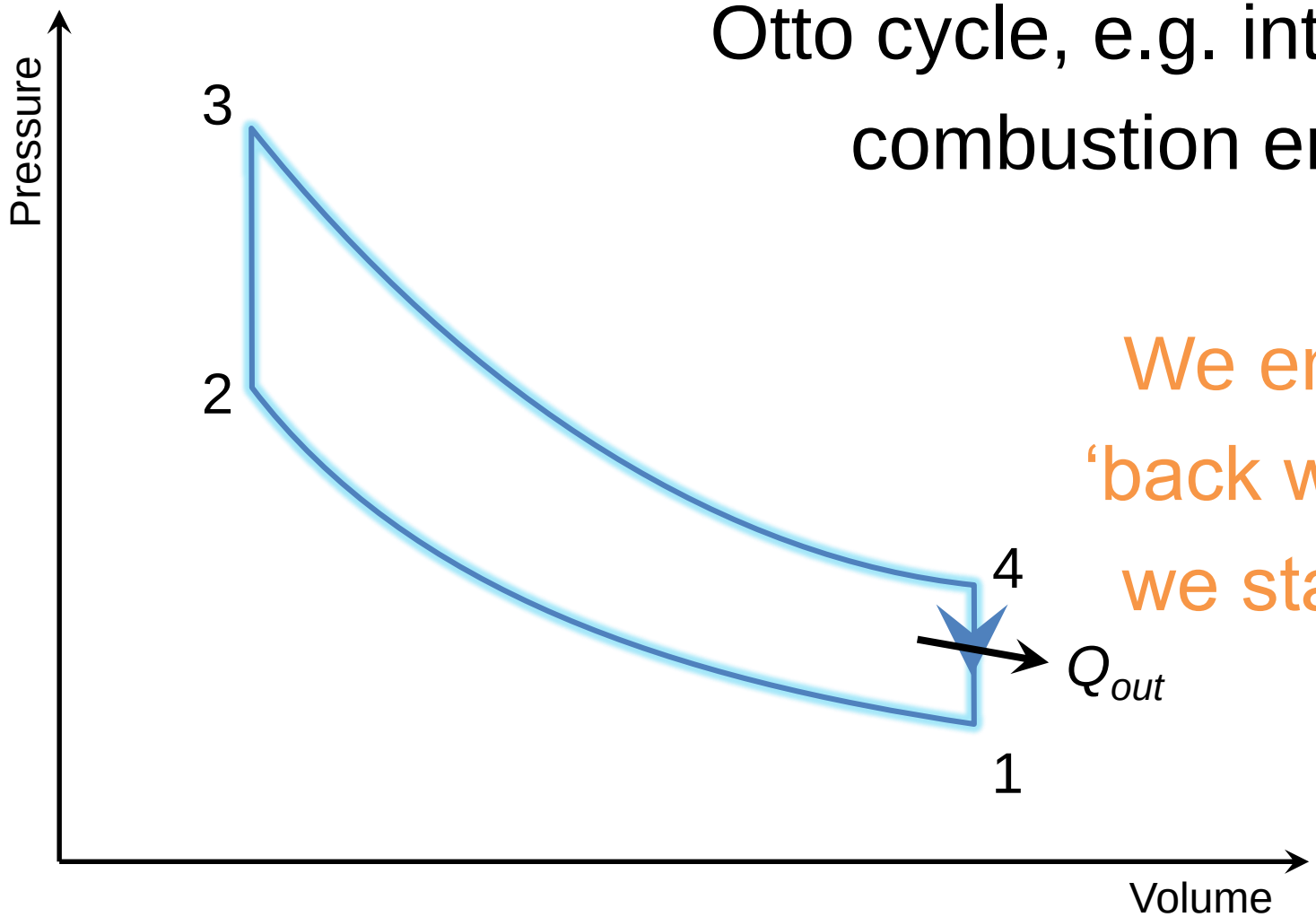
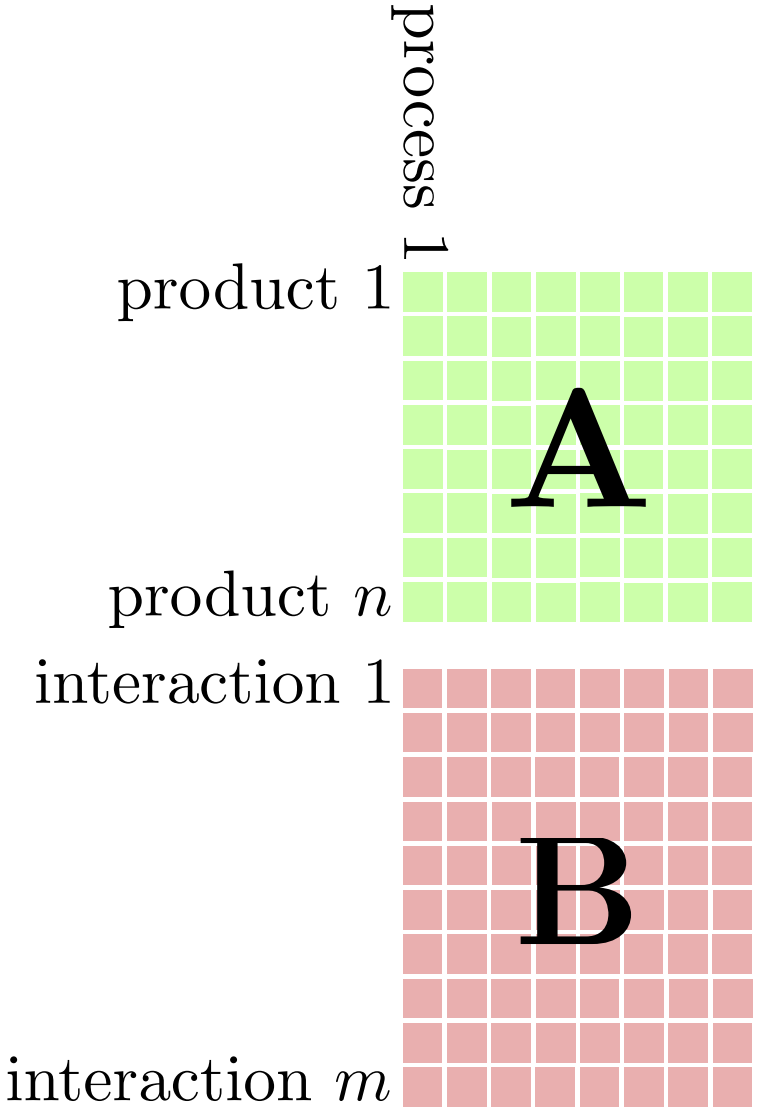


We end up ‘back where we started’

Do LCI processes ‘end up where they started’?



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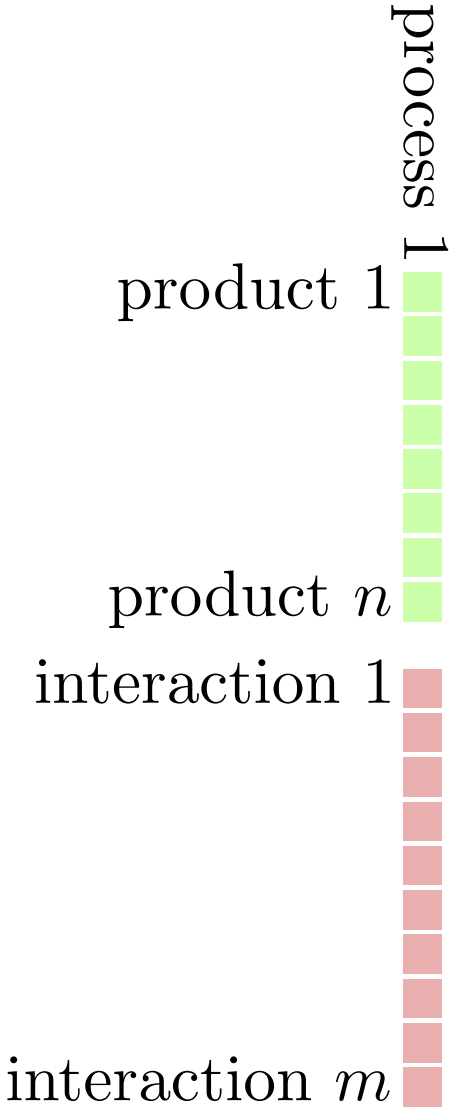

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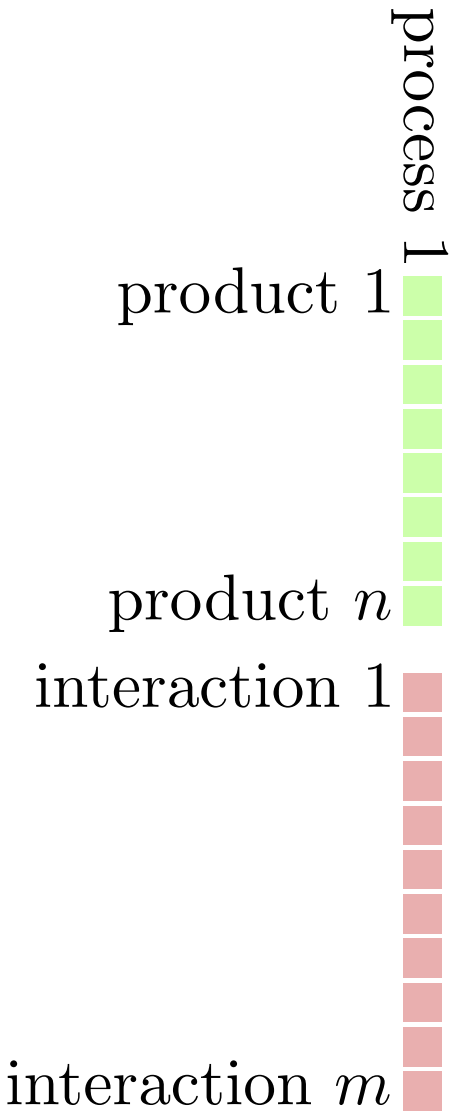

$$\sum_i \text{product}_i + \sum_j \text{interaction}_j = 0$$

Conclusions

- LCA and NEA share many common methodological similarities
  - NEA practitioners would benefit from the LCA framework (goal & scope, LCI, etc.)
- *Caveat scrutator*
  - Care must be taken when calculating NEA metrics from LCA data
  - LCA as is, not well suited to dynamic consequential analyses

Structure of LCA

Industrial processes

	Steel prod.	Elec.	Car man.	…
Industrial products: Steel	-1	0	0	…
Industrial products: Electricity	+1	-1	0	…
Industrial products: Car	0	+1	-1	…
Industrial products: …	…	…	…	…
Env. Extractions & emissions: Raw materials	+1	0	0	…
Env. Extractions & emissions: Emissions	0	0	0	-1
Env. Extractions & emissions: …	…	…	…	…

A

B

within economy

environmental transfers