Current, Best and Future Practice of LCA for CO_2 Utilization

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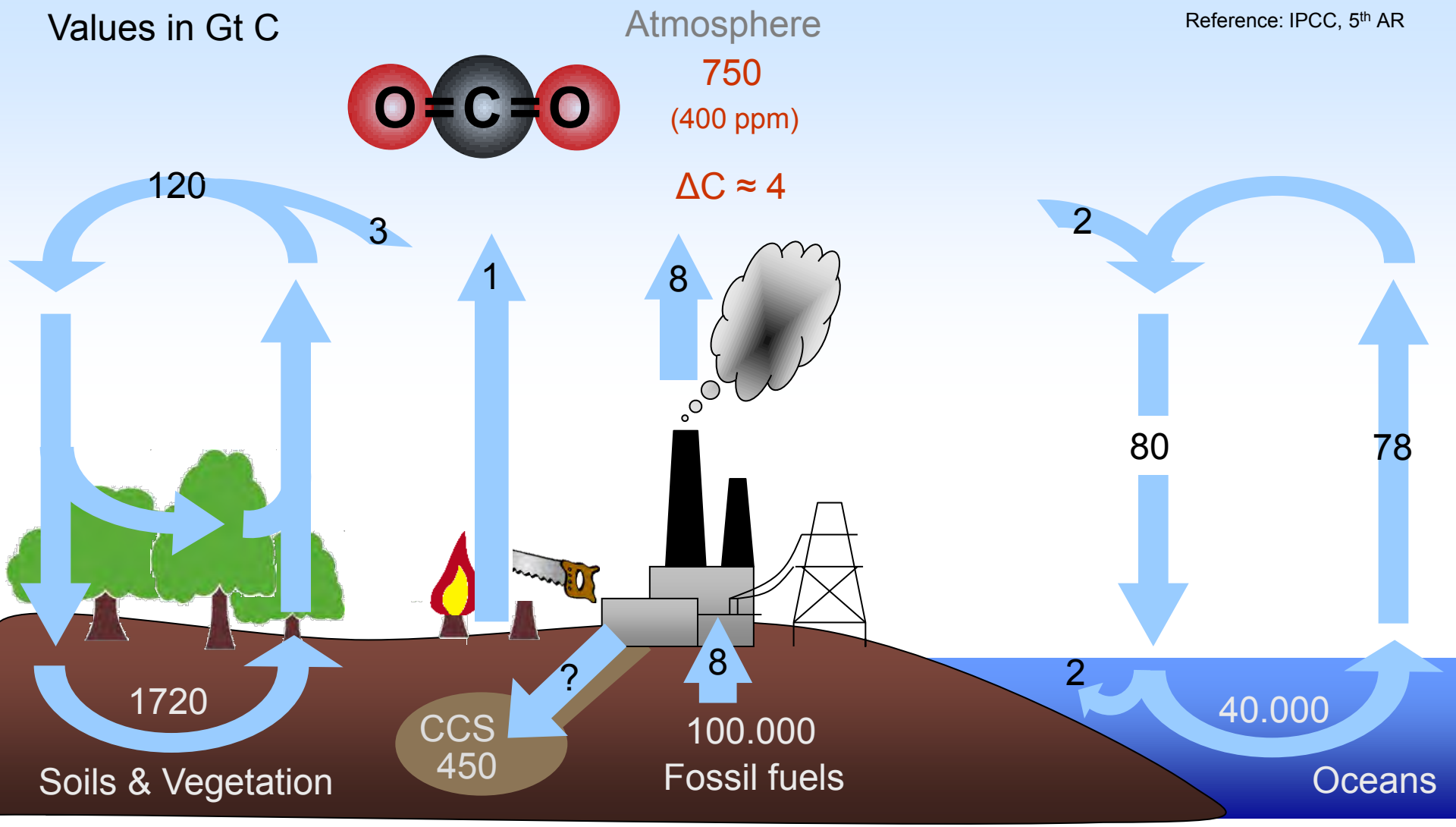
Workshop: Integrated life cycle approaches for understanding carbon dioxide utilization and sequestration pathways

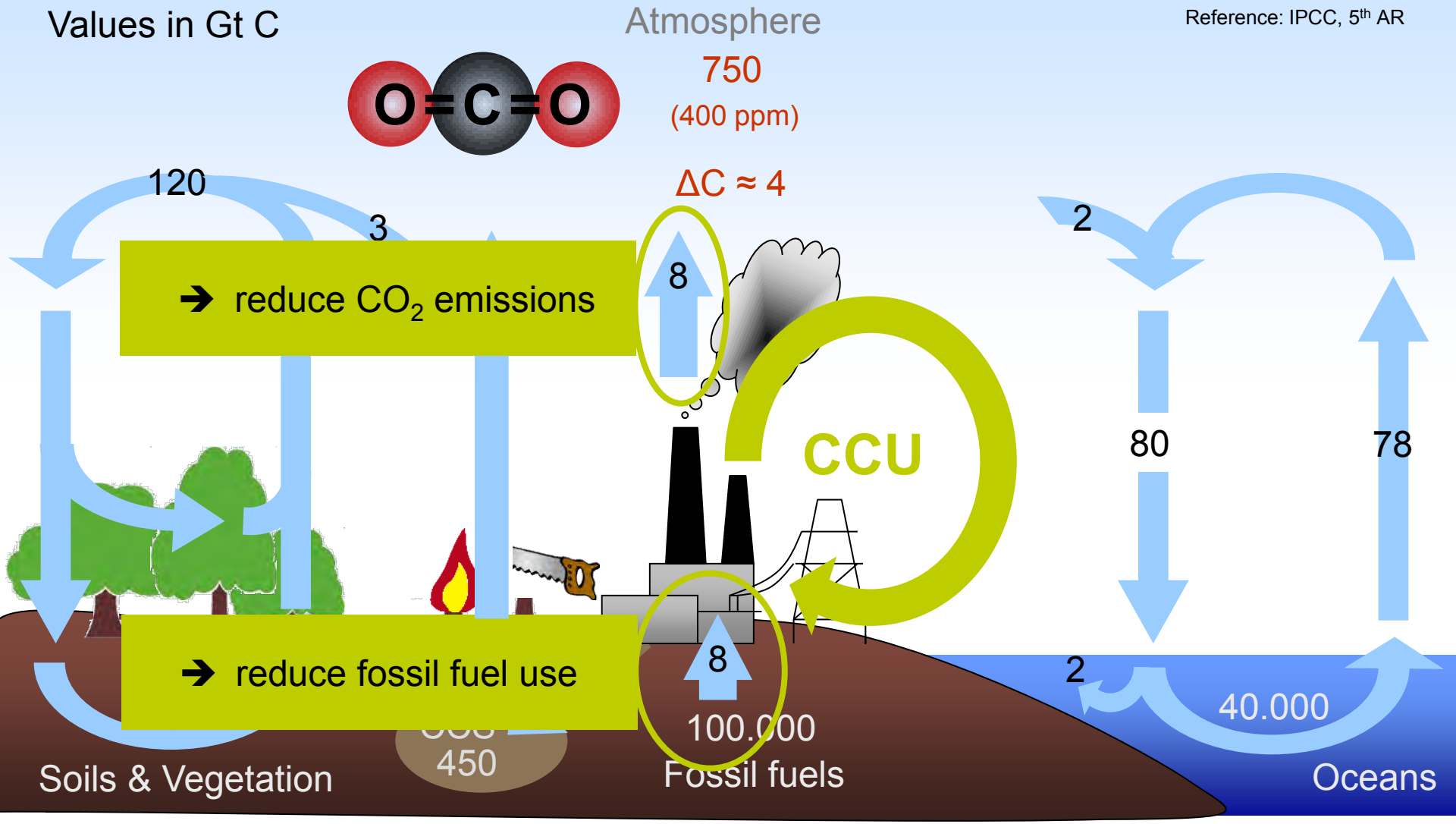
4 March 2015, Sheffield

LTT Lehrstuhl für Technische Thermodynamik | RWTH AACHEN UNIVERSITY

The Carbon Cycle – and CO_2 Capture and Utilization (CCU)

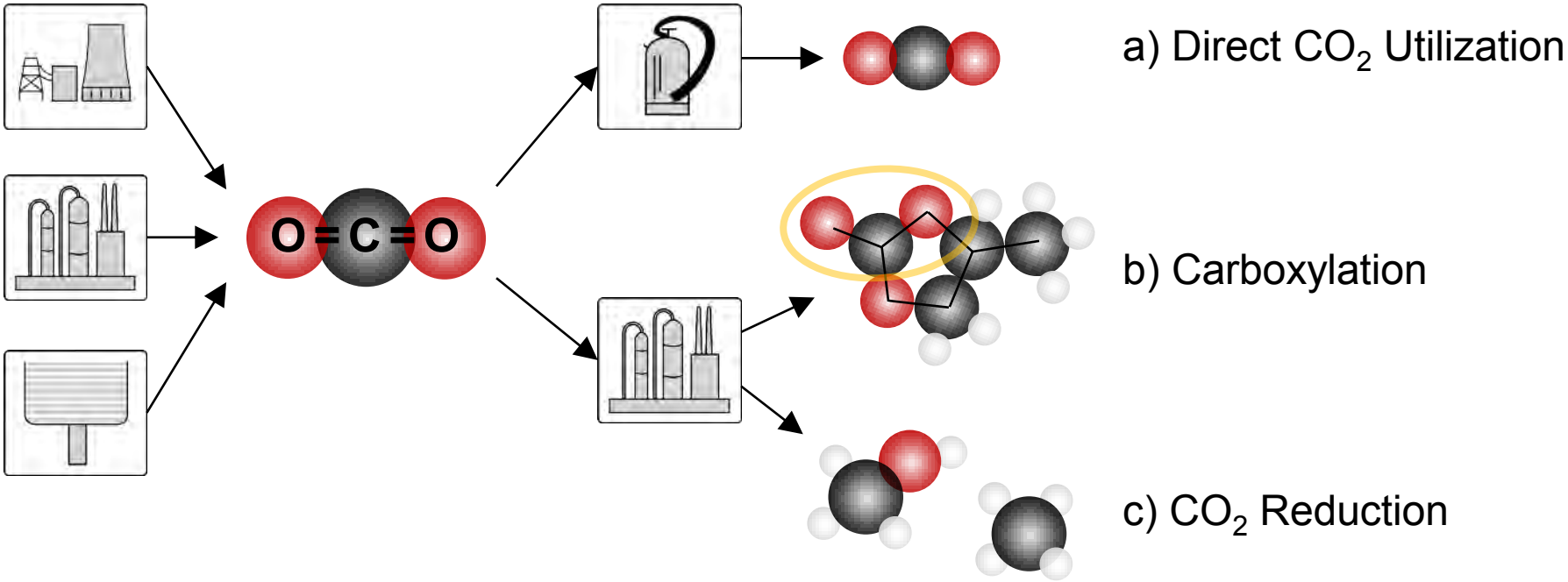


The Carbon Cycle – and CO_2 Capture and Utilization (CCU)



CO_2 Capture and Utilization (CCU) – Our Definition

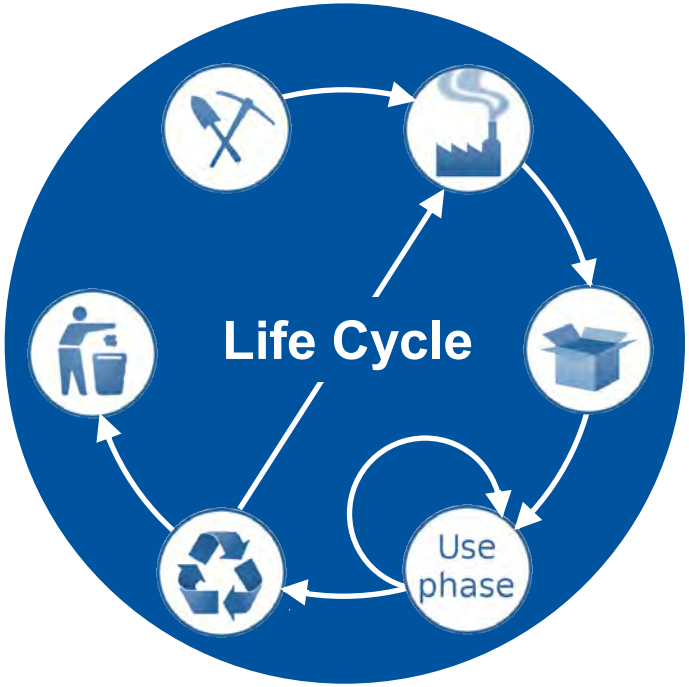
Industrial CO_2 capture & separate, **functional** utilization of CO_2



Reference: von der Assen et al., Energy Environ. Sci., 2013, 6, 2721

What is Life Cycle Assessment (LCA)?

Goal & scope definition



Inventory (LCI)

Flows from / to the environment

Inputs: resources
- … kg crude oil
- … kg coal
- …

Outputs: emissions
- … kg CO_2
- … kg NO_x
- …

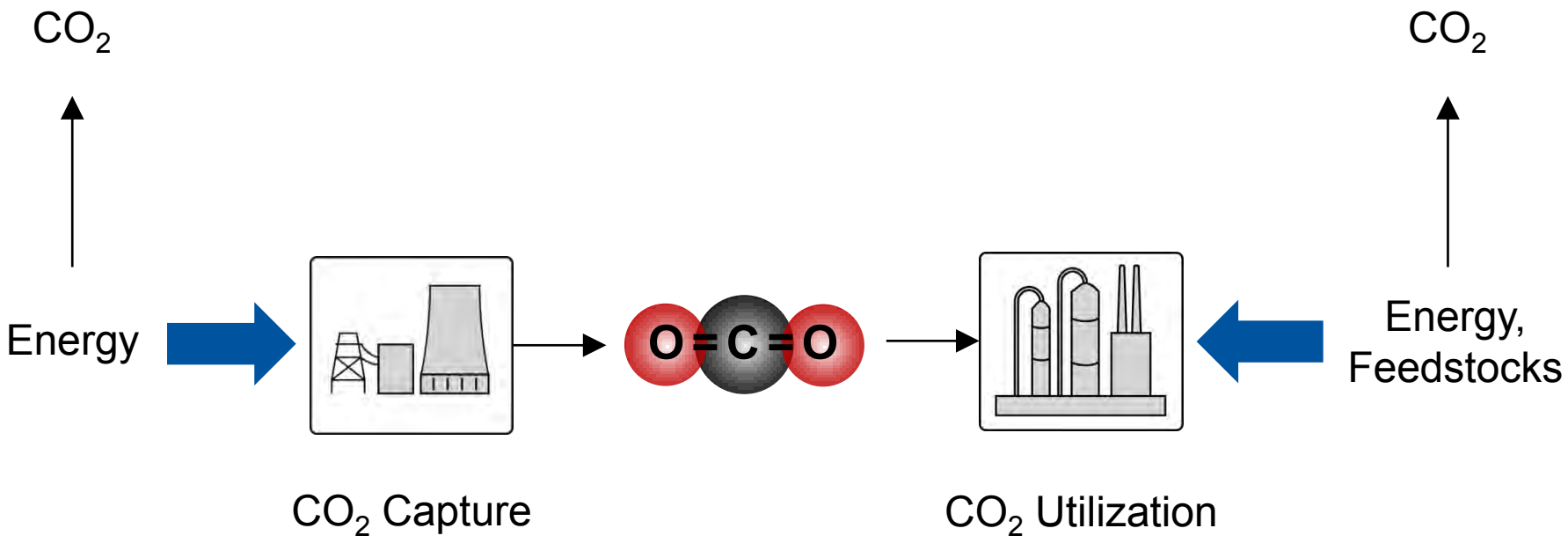
Impact Assessment (LCIA)

Environmental impacts

- fossil resource depletion
- water use
- global warming
- acidification
- others

Reference: von der Assen et al., Chem. Soc. Rev., 2014, 6, 2721

Why do we need LCA for CCU? (1/2)



➔ Environmental Benefits **not** guaranteed !

➔ Environmental Assessment / LCA required

Why do we need LCA for CCU? (2/2)

Current short-cut metrics in early development stages of CCU:

- Atom Economy
- E-factor
- Yield
- Amount CO_2 used [1]
- Share of CO_2 in reactants [2]
- Amount CO_2 fixed [1]
- CO_2 storage duration [1]

Environmental impacts of non-CO_2 reactants not considered ! (e.g. H_2, epoxides)

CO_2 source often neglected !

Separate, overrated metric ! (more later)

[1] Peters et al., ChemSusChem., 2011, 4(9), 1216
[2] Müller et al., Chem. Eng. Tech., 2014, 37(9), 1612

➔ Current short-cut metrics **not** reliable !

➔ Simplified LCA **is accessible** & **more reliable**

Research field *«CO_2 Utilization and Life Cycle Assessment»*

Our Team

Our Project Partners

BAYER

cat® Catalytic Center

IASS POTSDAM

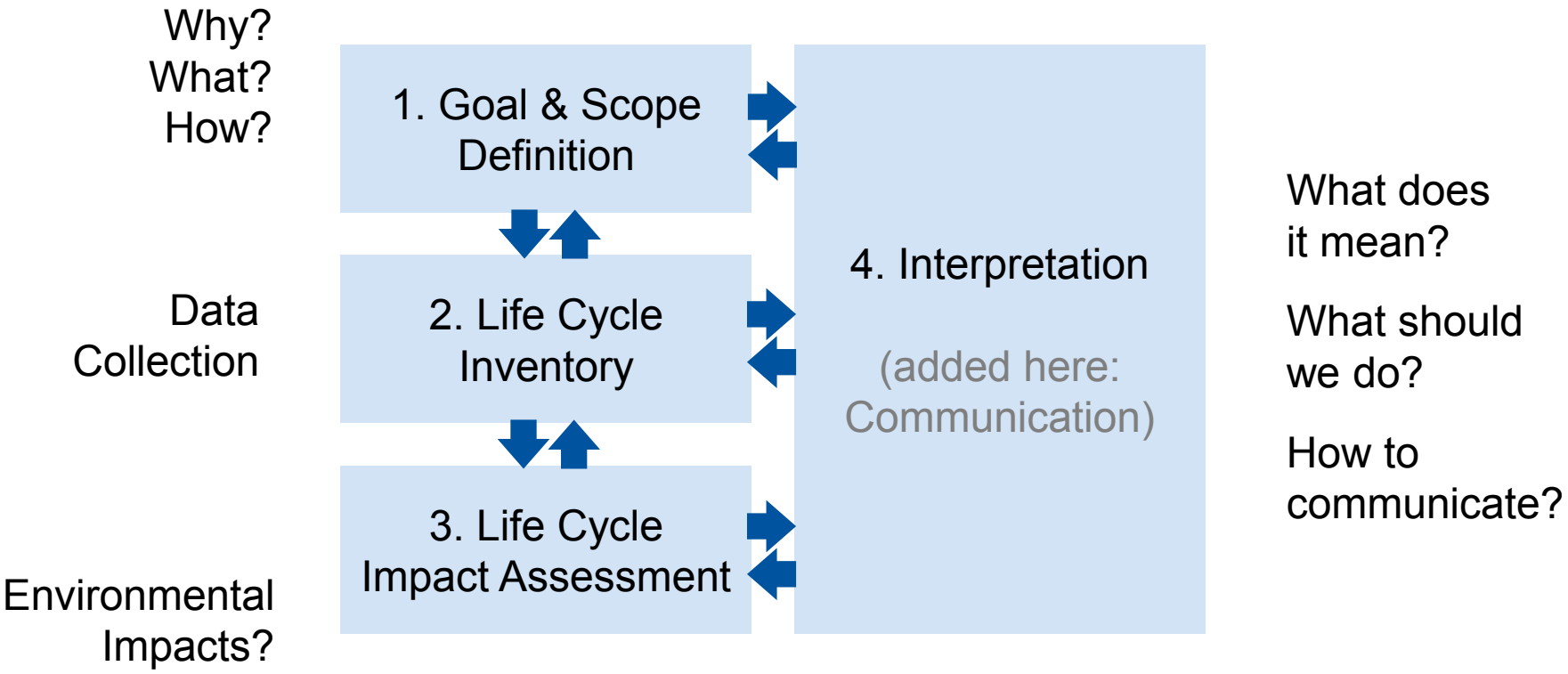
ITMC RWTH

RWE The energy to lead

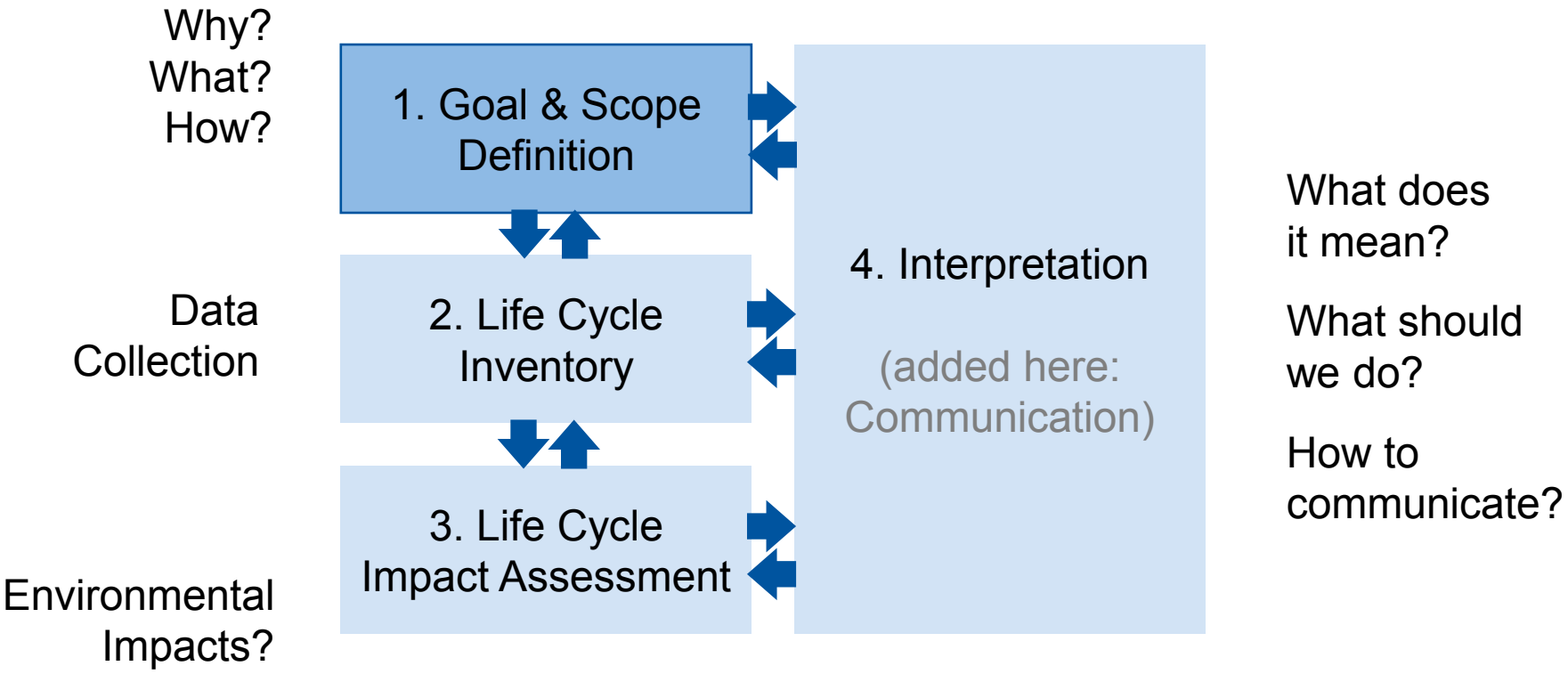
Our LCA+CCU Topics

- CO_2-based polyurethanes
- CO_2-based supply chains
- Power-to-Gas (CH_4)
- Power-to-Fuels (CH_3OH)
- Power-to-Chemicals (CO)
- Formic Acid
- Renewable H_2 production
- Alternative CO_2 sources

Agenda – LCA Structure by ISO 14040/14044



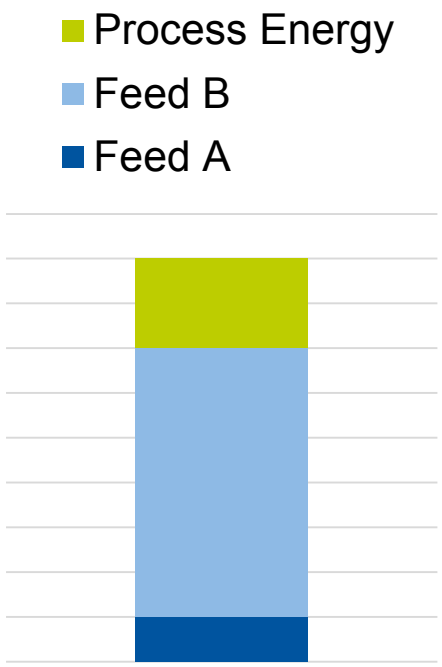
1. Goal & Scope Definition



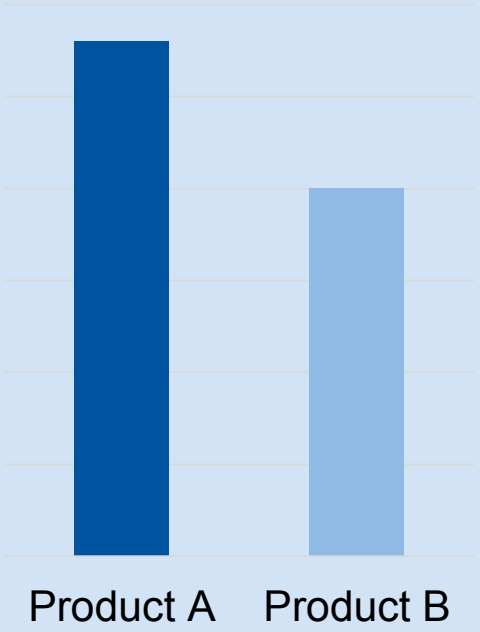
1. Goal & Scope Definition

Why? – Typical Goals in LCA

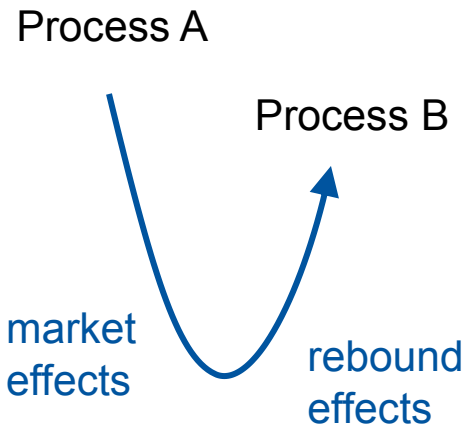
1. Hot-Spots



2. Comparisons



3. Consequences

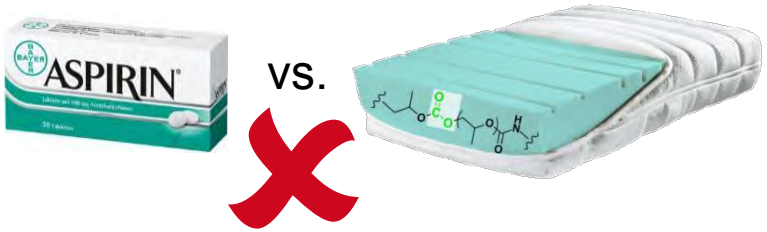


- 100 t CO_2-eq

1. Goal & Scope Definition

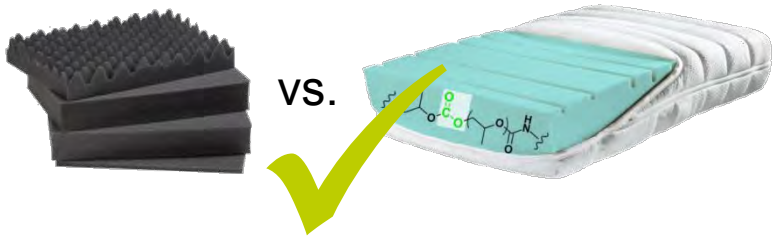
What? – Functional Unit Definition for Fair Comparisons

- Consider *function* and *performance/quality*!



CO_2-based aspirin

CO_2-based polyurethane



fossil-based polyurethane

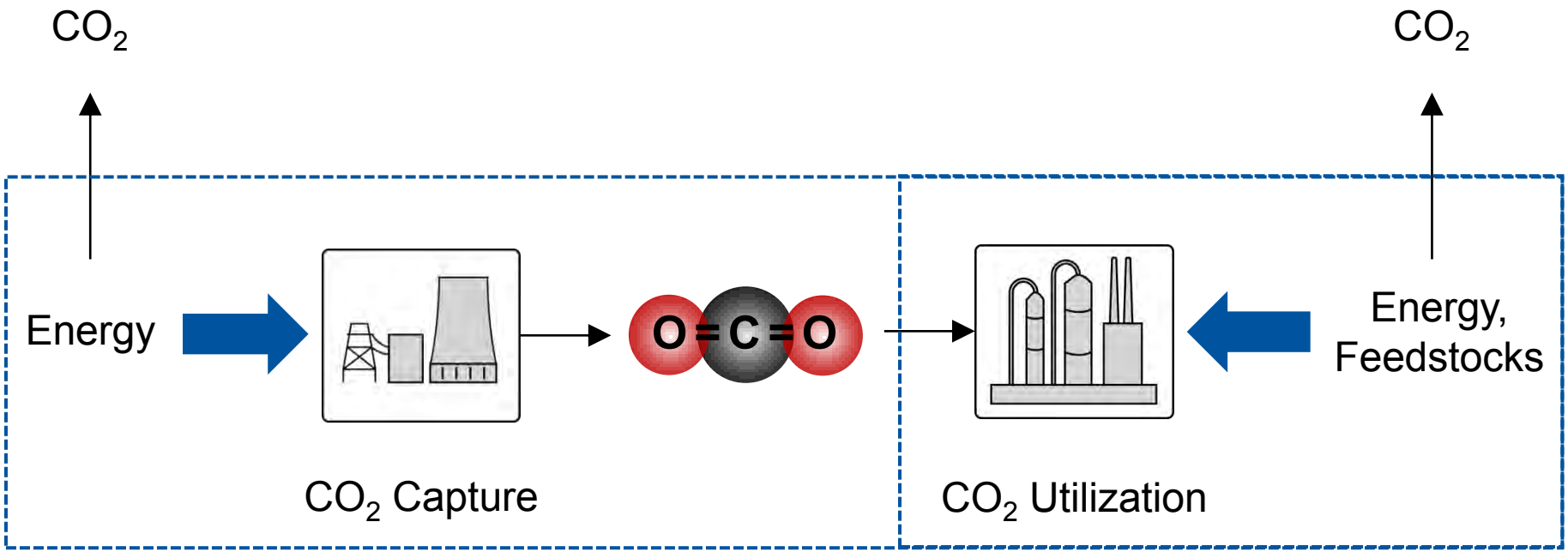
CO_2-based polyurethane

➔ Do not compare apples and oranges !

Reference: von der Assen et al., Chem. Soc. Rev., 2014, 6, 2721

1. Goal & Scope Definition

What? – System Boundaries

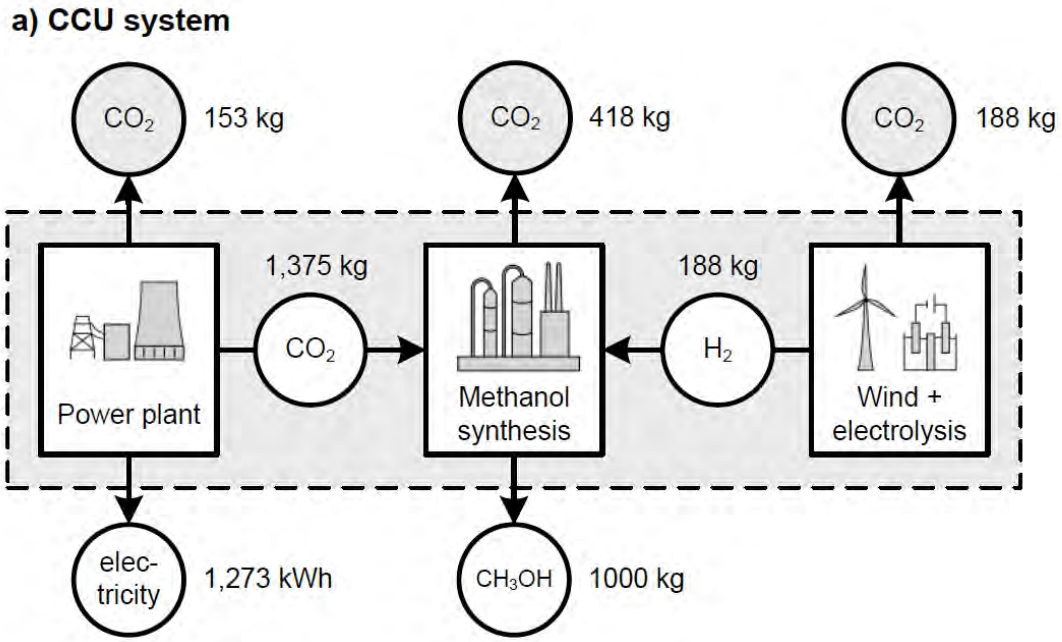


➔ Include the CO_2 source !

Reference: von der Assen et al., Energy Environ. Sci., 2013, 6, 2721

1. Goal & Scope Definition

What? – System Boundaries for a Fair Comparison

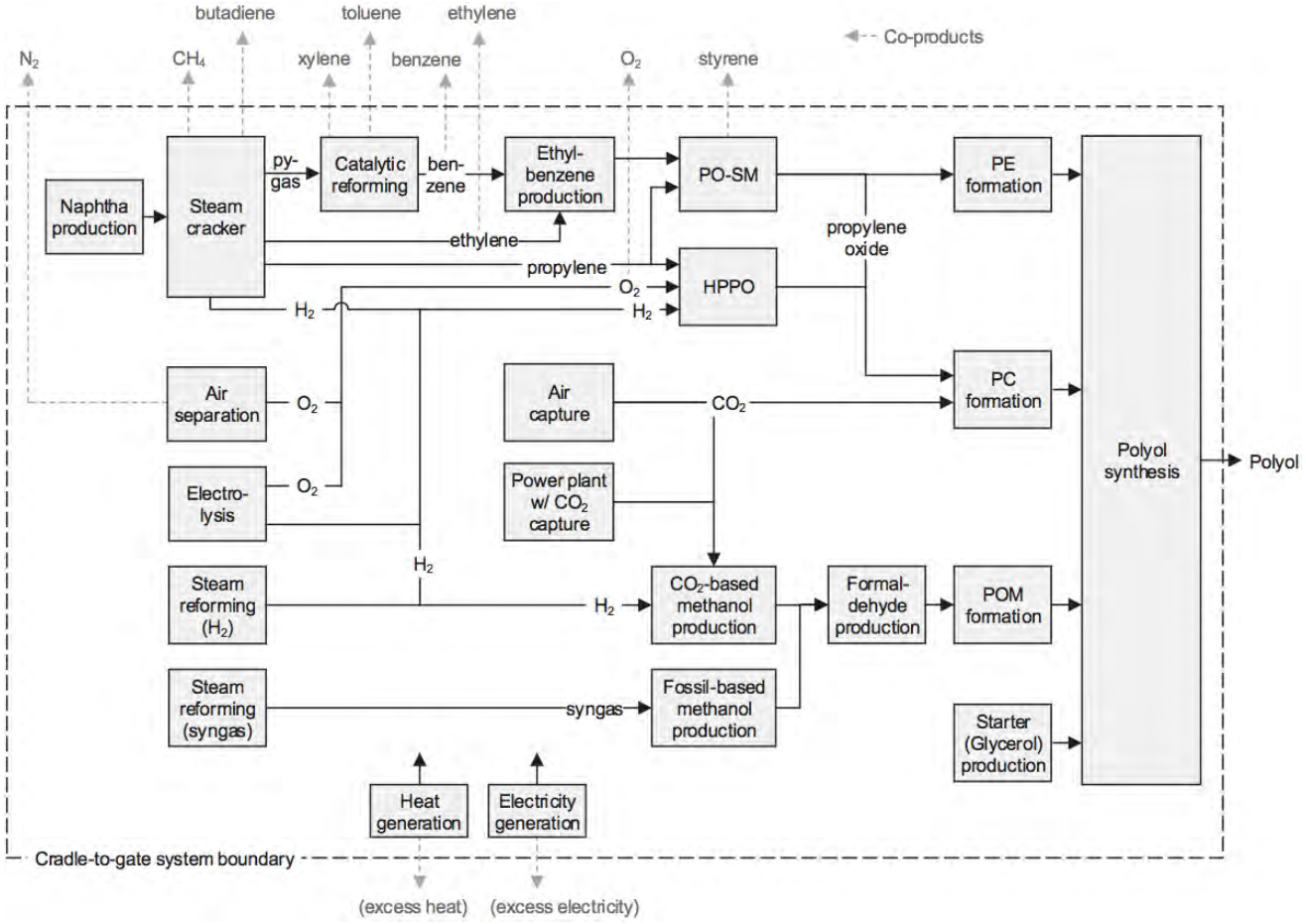


➔ Compare against equivalent system with same products !

Reference: von der Assen et al., Energy Environ. Sci., 2013, 6, 2721
Bernet et al., Energy Procedia, 2014, 63, 7976

1. Goal & Scope Definition

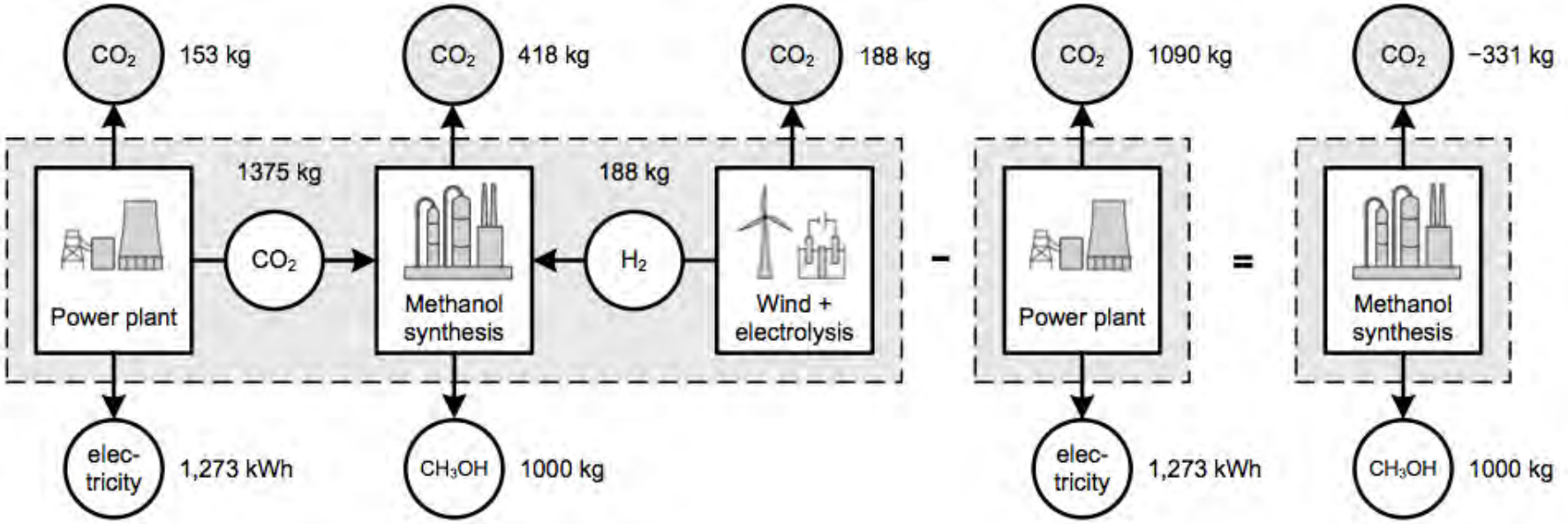
What? – System Boundaries



Reference: von der Assen et al., PSE, 2015, accepted

2. Life Cycle Inventory

Account for all co-products! Here: Avoided Burden

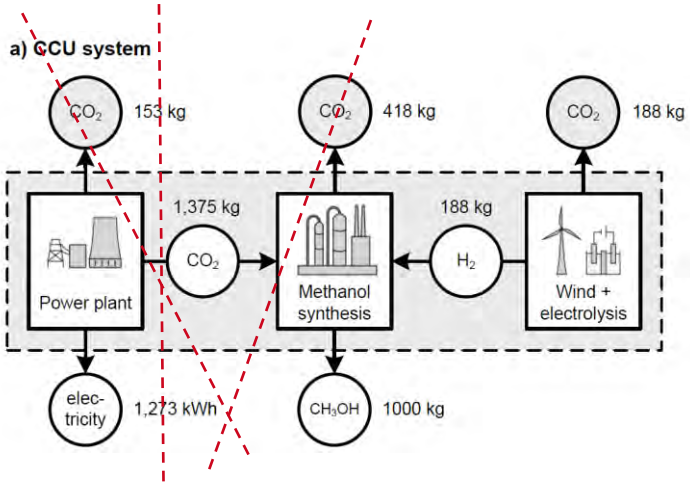


➔ Avoided Burden Implies a Comparison !

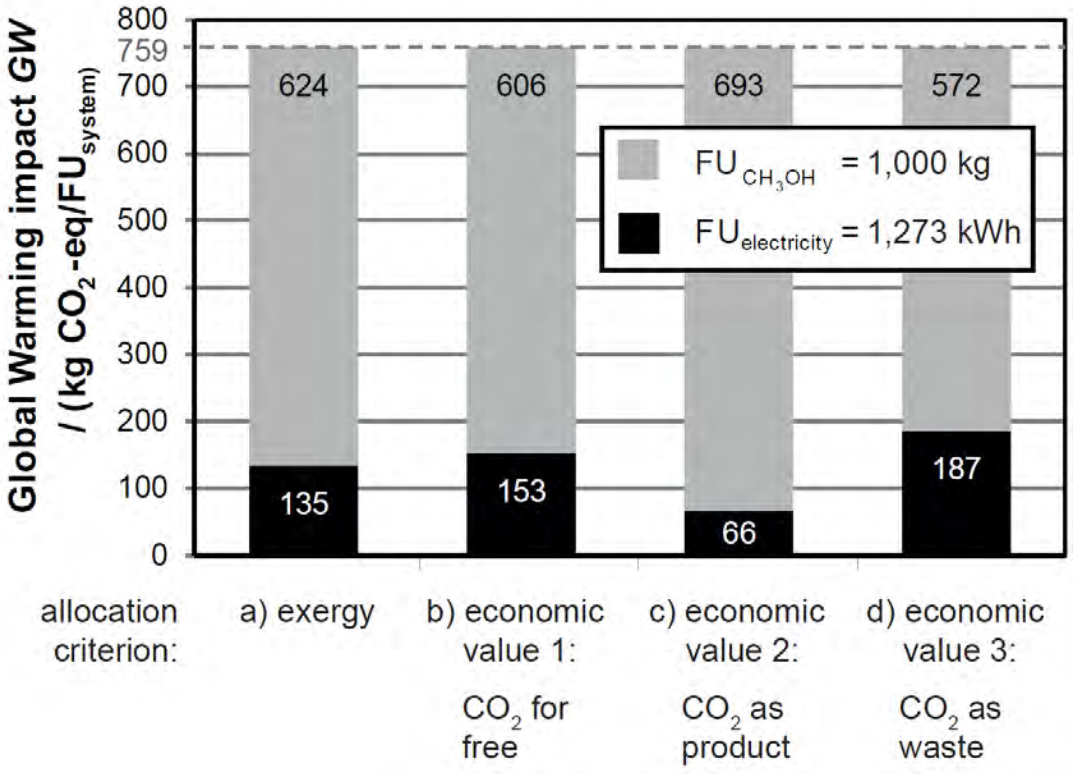
Reference: von der Assen et al., Energy Environ. Sci., 2013, 6, 2721

2. Life Cycle Inventory

Account for all co-products! Here: Allocation



where to „cut“ the integrated system?



Reference: von der Assen et al., Energy Environ. Sci., 2013, 6, 2721

2. Life Cycle Inventory

Account for all co-products! Best practice for CCU?

Attributional LCA

- System expansion favorable:
  - Unambiguous
  - Overall reductions clearly determined
- Avoided Burden:
  - Implies comparison!
- Allocation:
  - Where?
  - Which criterion?

Consequential LCA

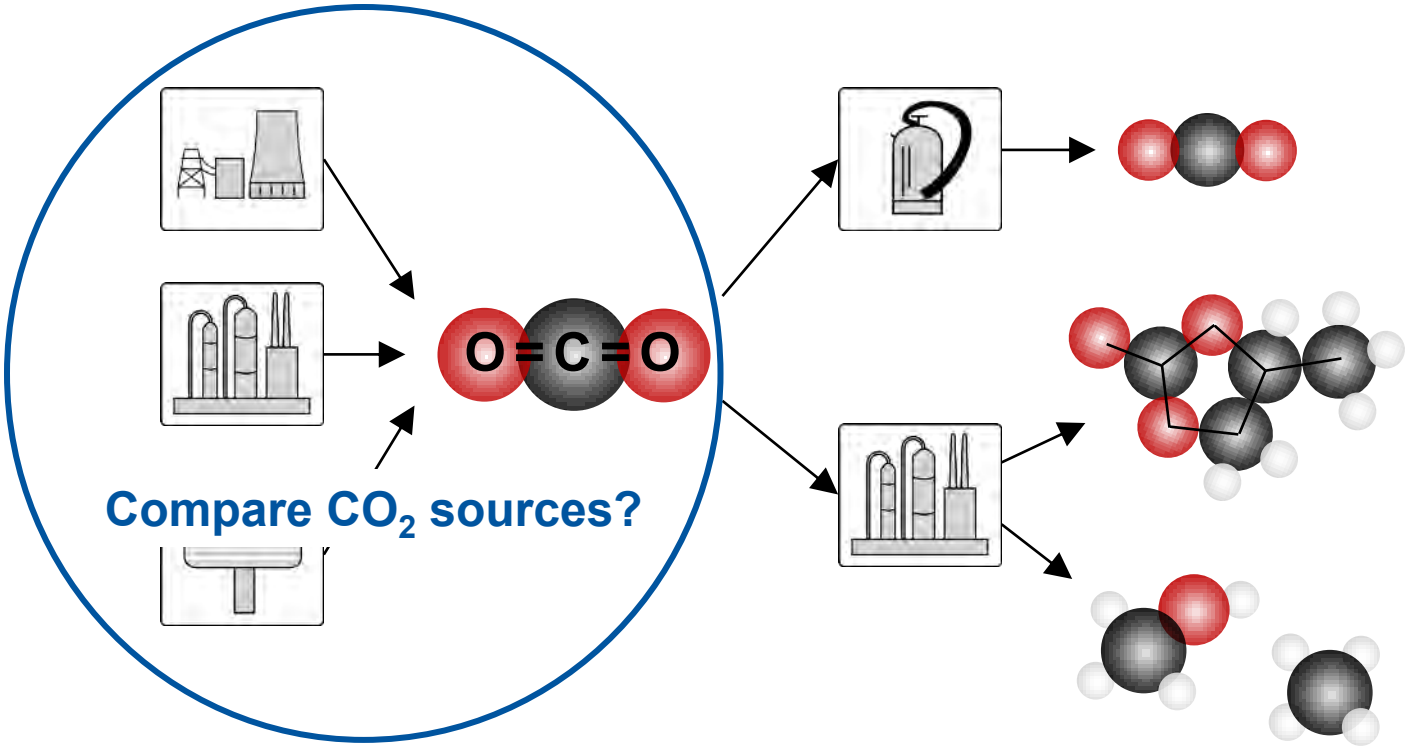
- Avoided Burden

➔ Guidelines / Product Category Rules desired !

References: von der Assen et al., Energy Environ. Sci., 2013, 6, 2721
Pelletier et al., Int J. Life Cycle Assess., 2015, 20(1), 74

1. Goal & Scope Definition

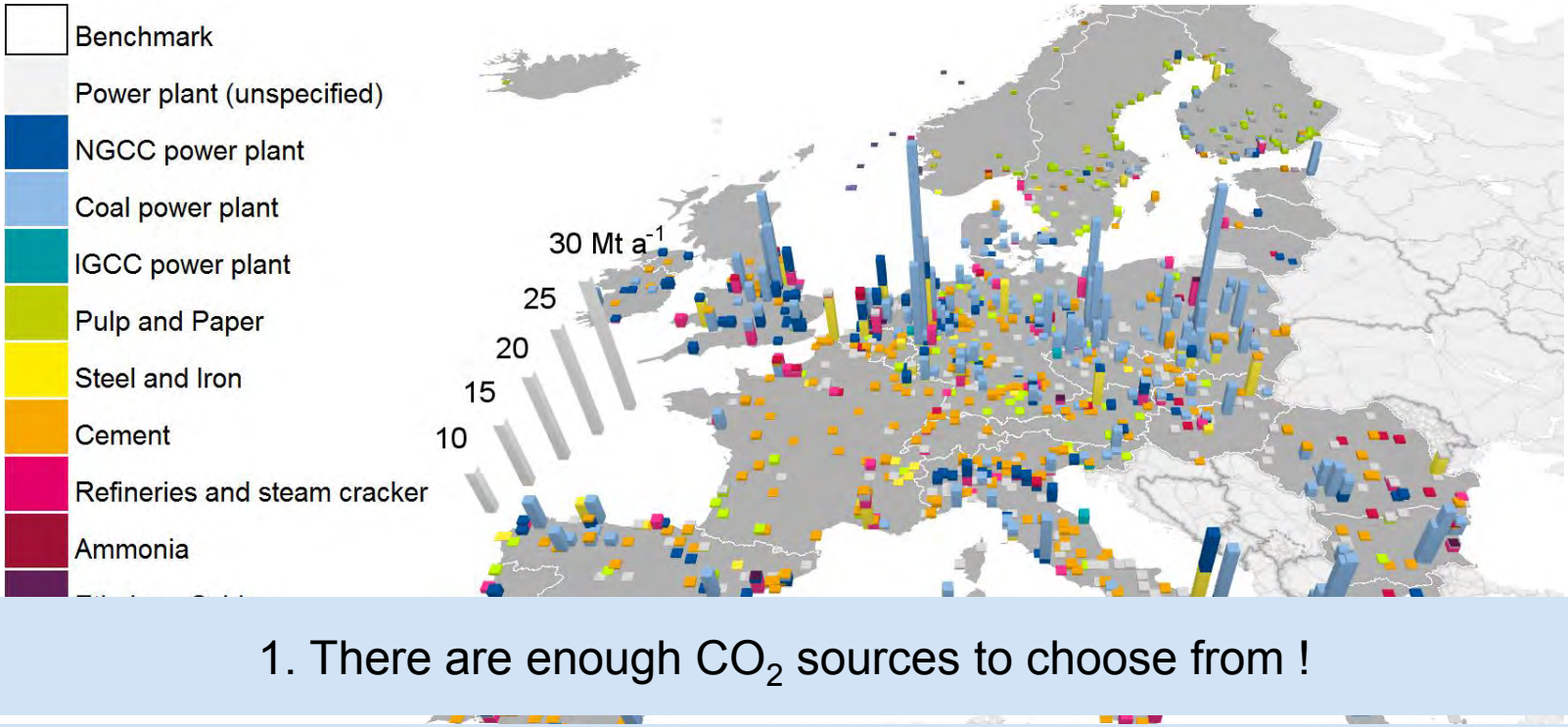
What to compare? – Real choices and limiting factors!



1. Goal & Scope Definition – What to compare?

Selecting CO_2 sources for CO_2 utilization

Total: 1700 Mt CO_2



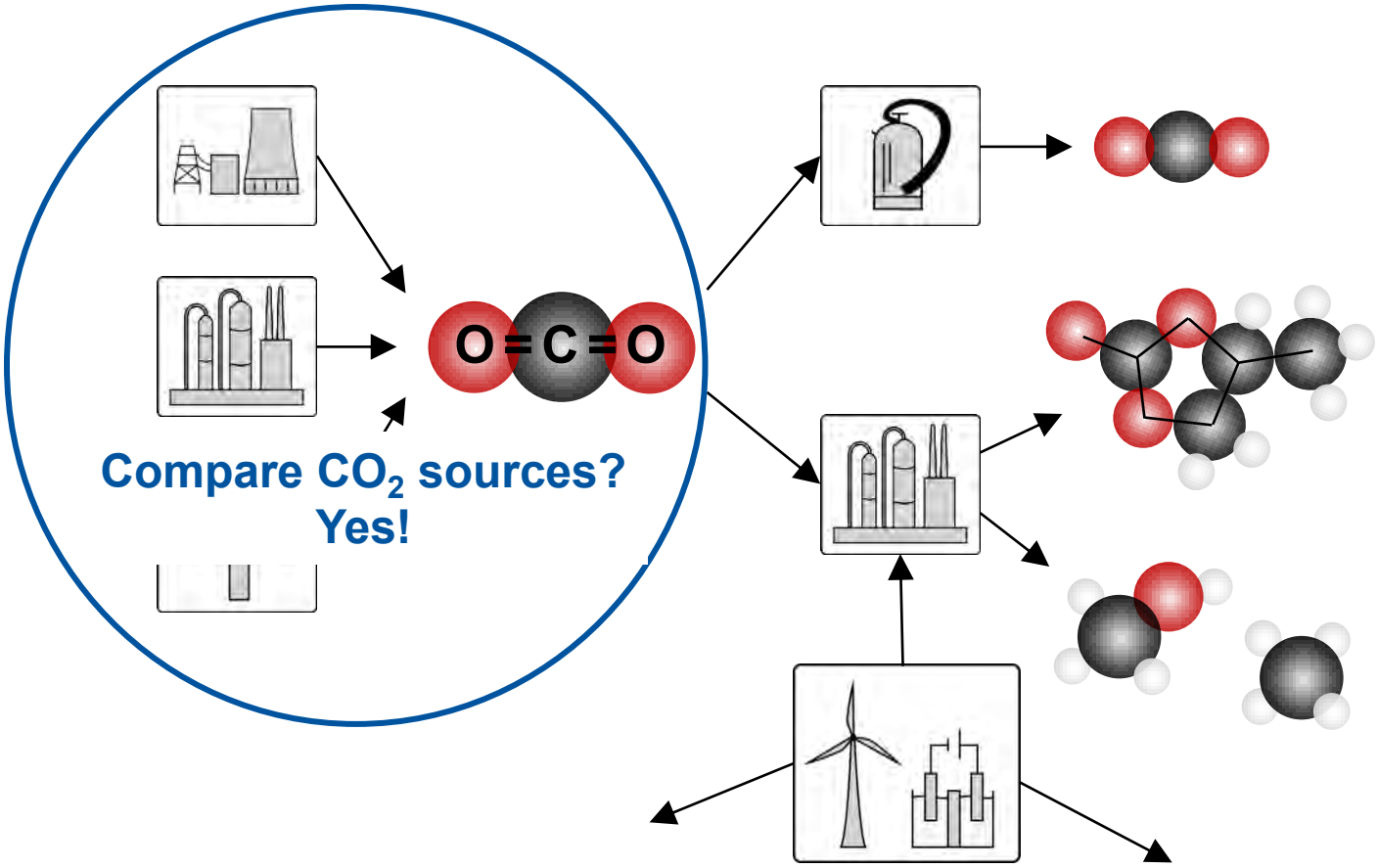
1. There are enough CO_2 sources to choose from !

2. There is enough CO_2 for **all** CO_2 utilization options !

Reference: von der Assen et al., 2015, submitted

1. Goal & Scope Definition

What to compare? – Real choices and limiting factors!



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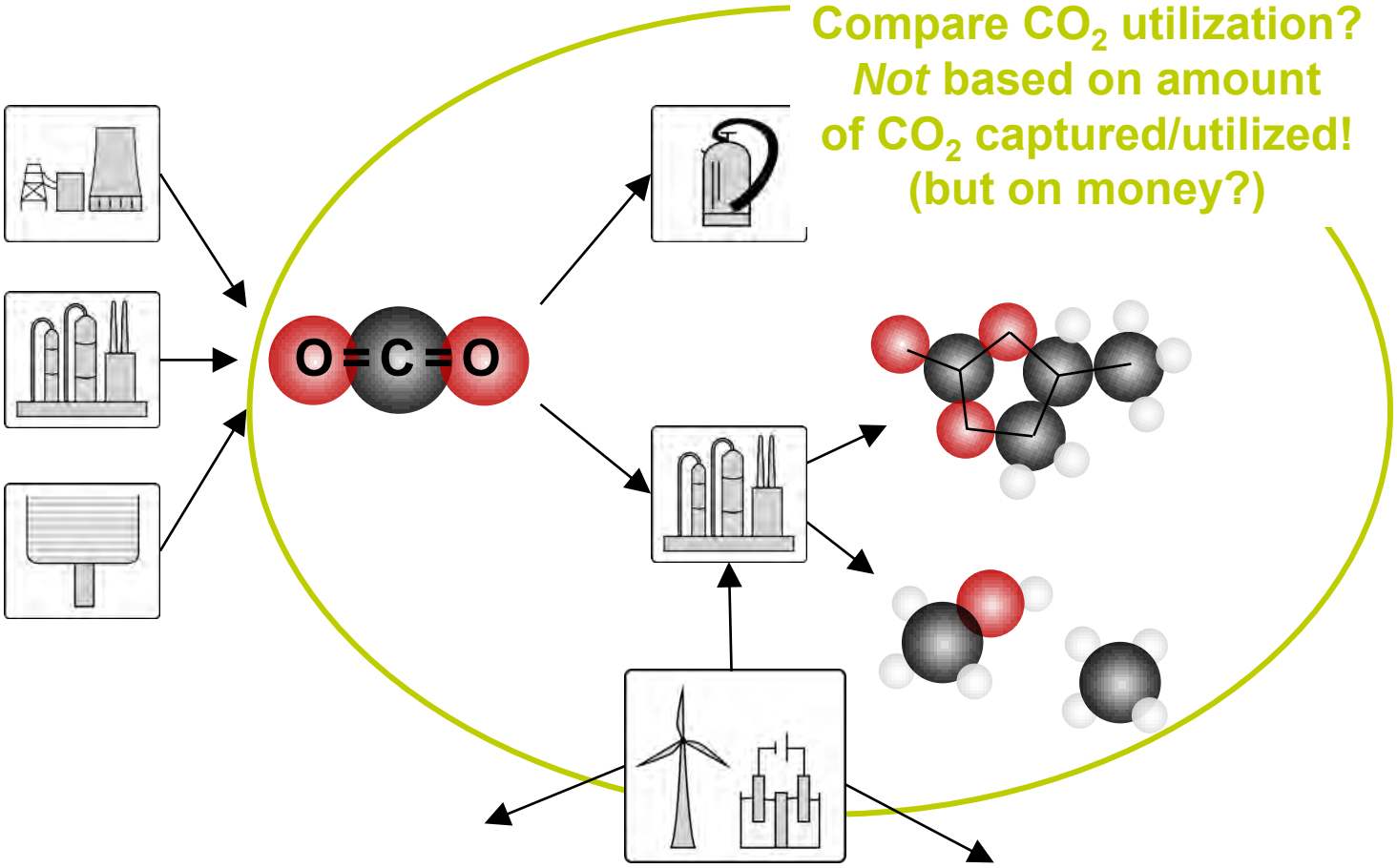
What to compare? – Real choices and limiting factors!



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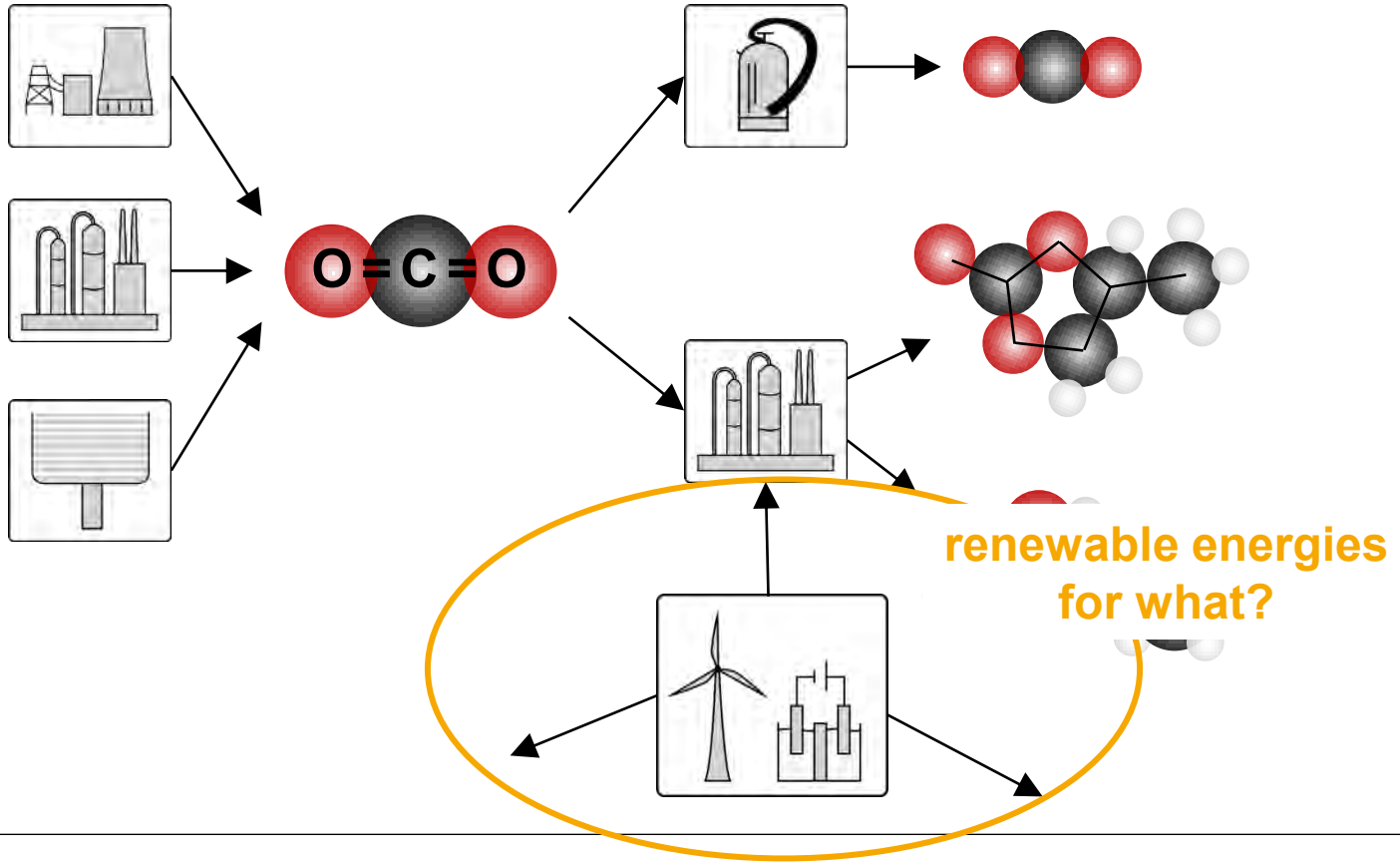
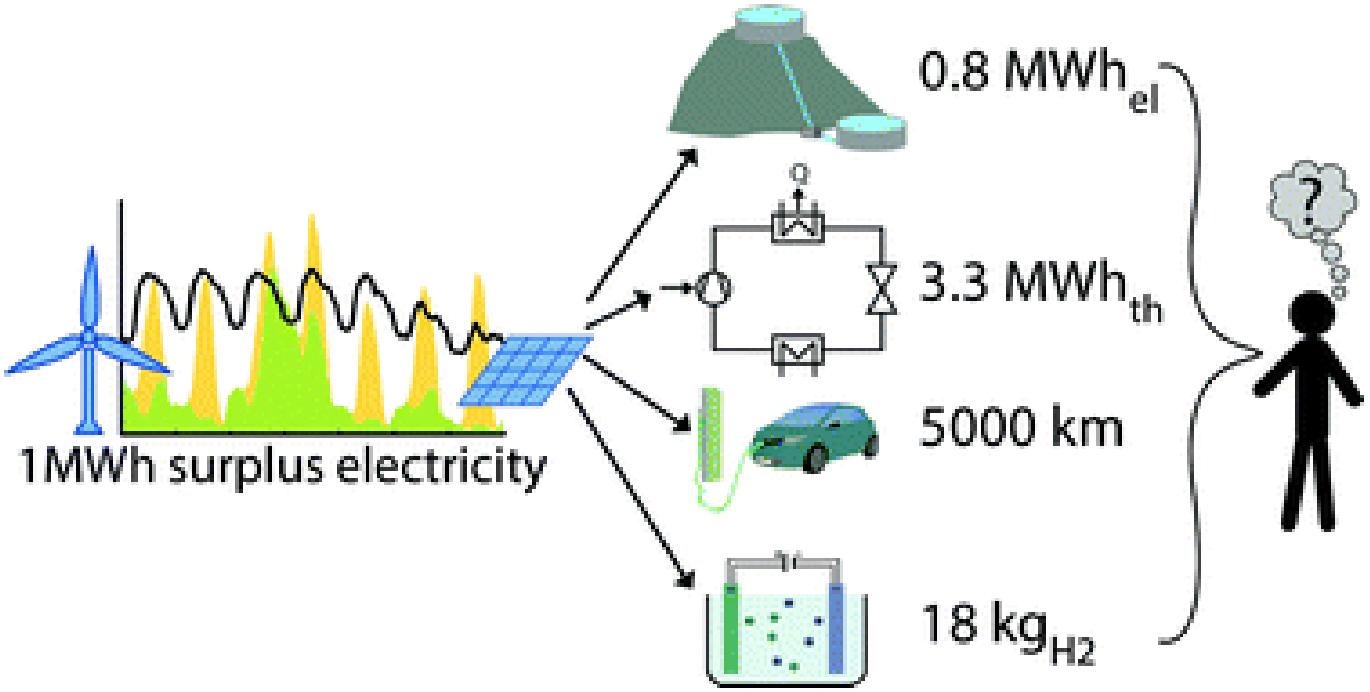
What to compare? – Real choices and limiting factors!



1. Goal & Scope Definition – What to compare?

Power-to-What?

What should the limited renewable energy / surplus power be used for?



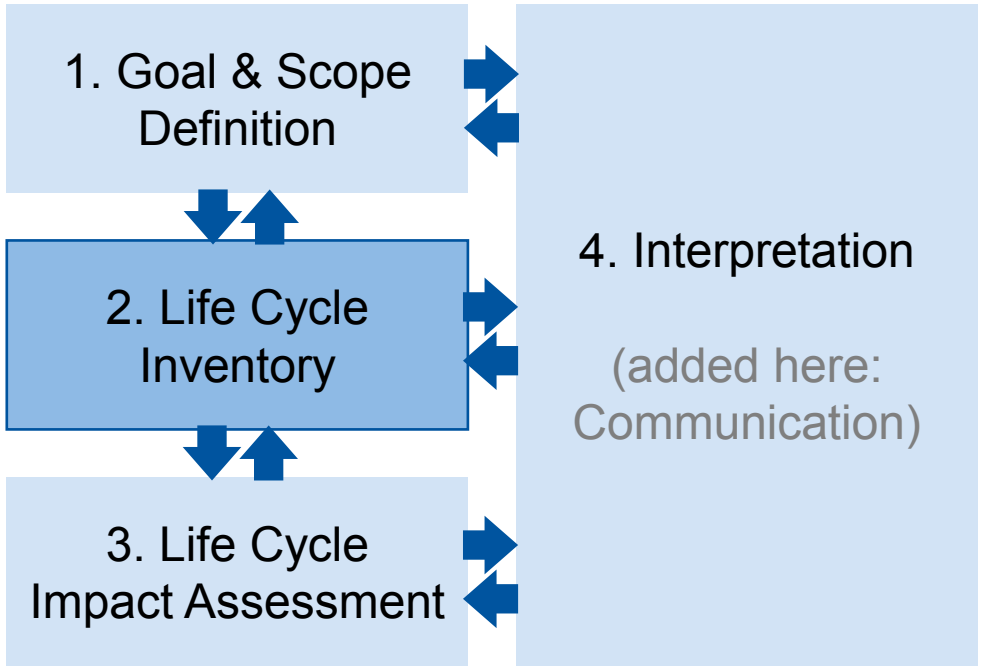
Reference: Sternberg et al., Energy Environ. Sci., 2015, 8, 389

2. Life Cycle Inventory

Why?
What?
How?

Data Collection

Environmental Impacts?



What does it mean?

What should we do?

How to communicate?

2. Life Cycle Inventory

Simplified LCA for screening

Methanol production from CO_2:

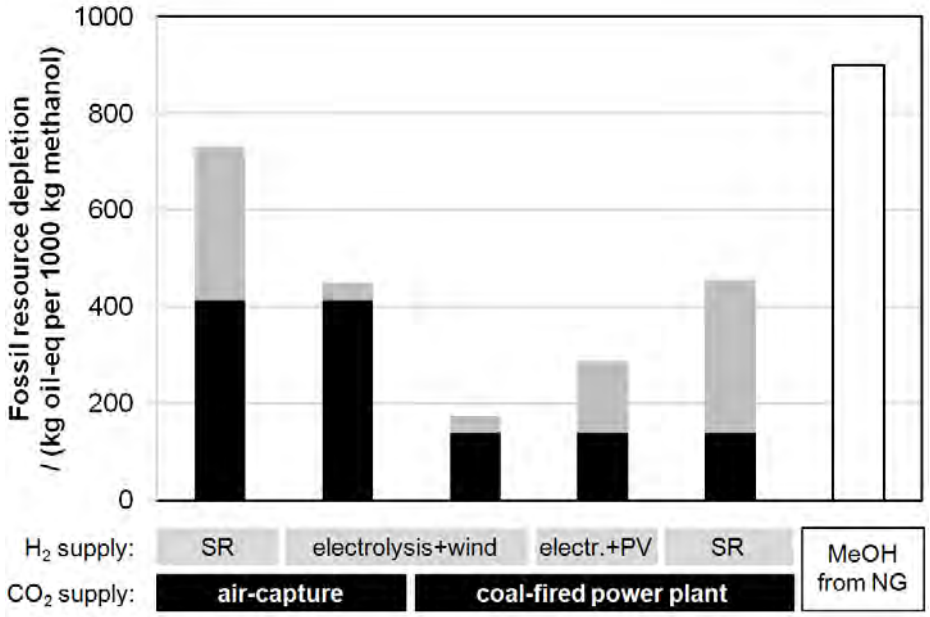
- $CO_2 + 3\ H_2 \rightarrow CH_3OH + H_2O$

Stoichiometry:

- 1375 kg CO_2 + 187.5 kg H_2

  → 1000 kg CH_3OH + 562.5 kg H_2O

Feedstock Impacts from Databases➔



➔ Lower-bounds for Environmental Impacts !

Reference: von der Assen et al., Chem. Soc. Rev., 2014, 6, 2721

Bridging Data Gaps

- Thermodynamics / Engineering Principles (e.g. Energy and Exergy balance)
- Process estimation tools (e.g. based on presence of water, product concentration etc.) [2]
- Estimation tools for chemicals based on molecular structure [1]

➔ Integrate with Chemical Process Design !

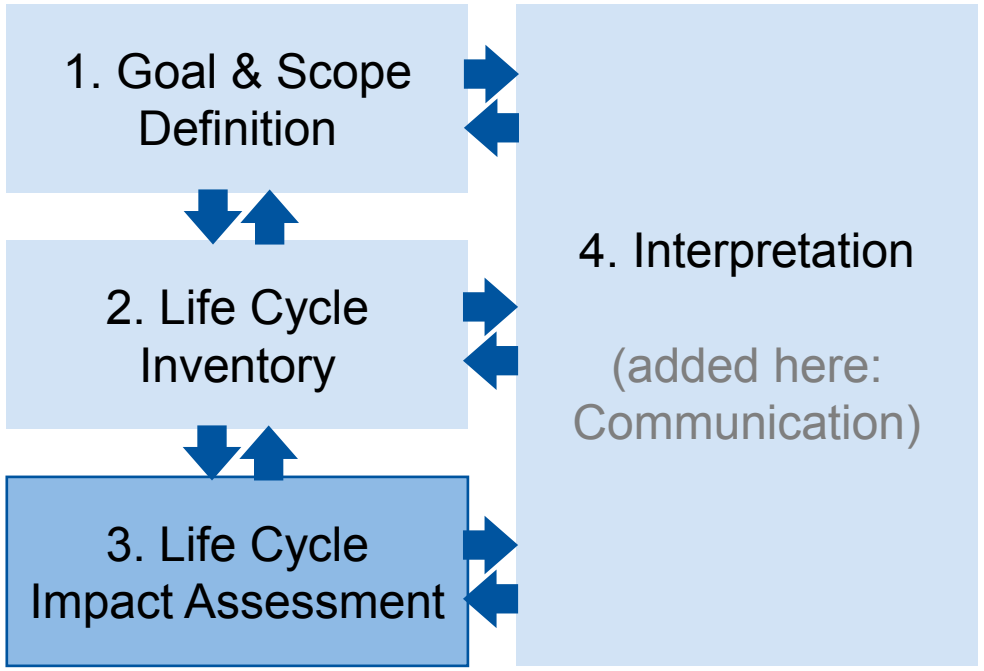
References: [1] Wernet et al., Green Chem., 2009, 11, 1826
[2] Patel et al., Energy Environ. Sci., 2012, 5(9), 8430

3. Life Cycle Impact Assessment

Why?
What?
How?

Data Collection

Environmental Impacts?



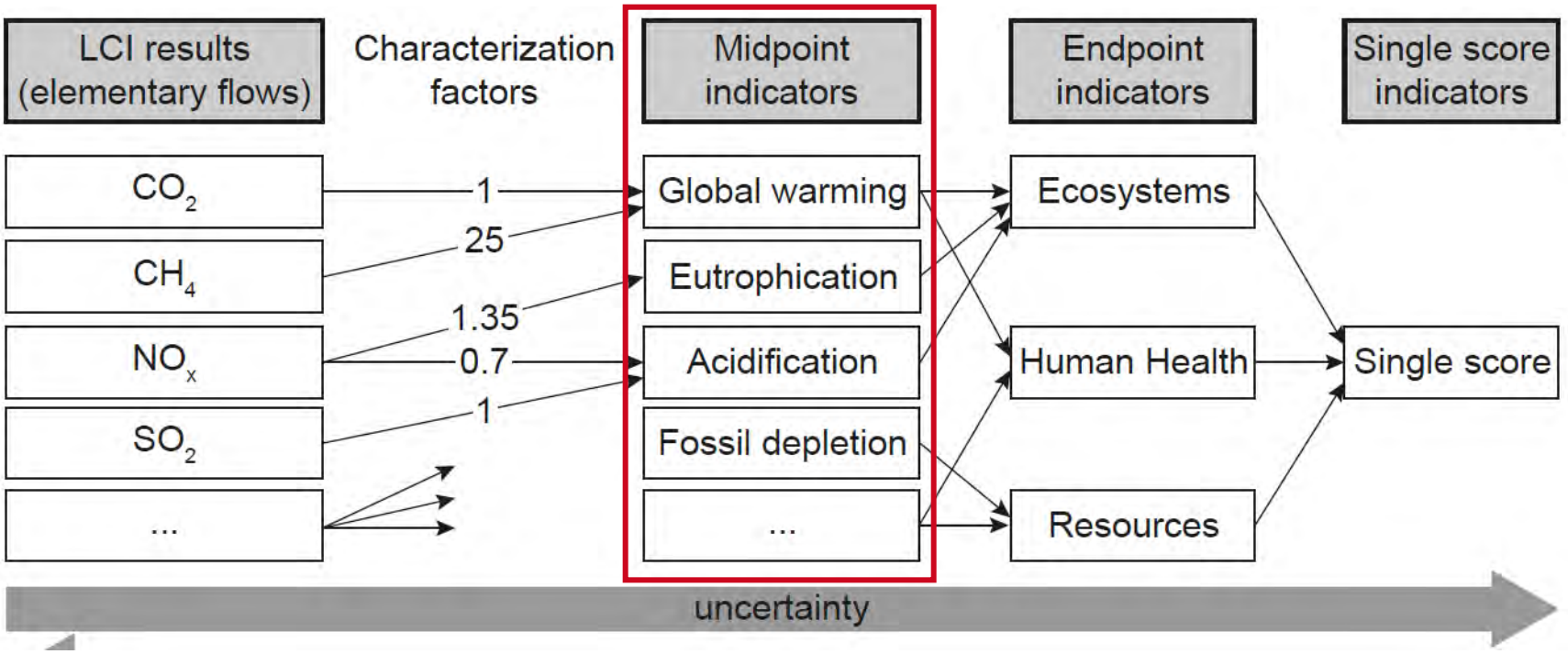
What does it mean?

What should we do?

How to communicate?

3. Life Cycle Impact Assessment

Midpoint, Endpoint or Single Score?



3. Life Cycle Impact Assessment

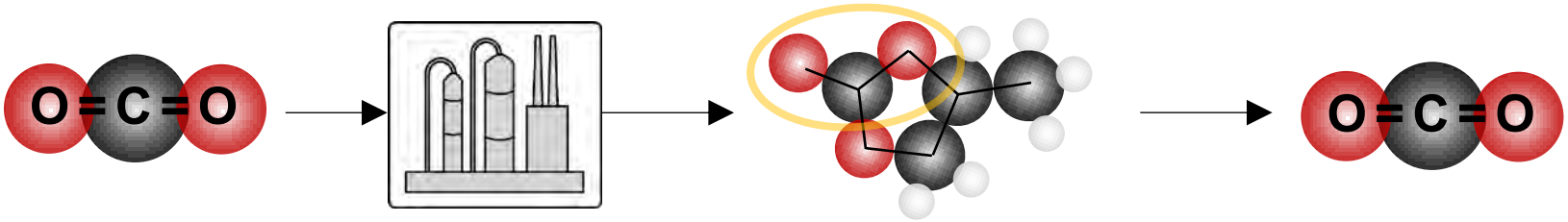
Which environmental impacts should be considered?

Quality level I	Quality level II	Quality level III
- Global warming	- Ionizing radiation, human health	- Land use
- Ozone depletion	- Photochemical ozone formation	- Water use
- Particulate matter I/II	- Acidification	
	- Eutrophication, terrestrial and aquatic	
	- **Resource depletion, mineral and fossil**	
	- Human toxicity	
	- Ecotoxicity, freshwater II/III	

Reference: Hauschild et al., Int. J. Life Cycle Assess., 2013, 18, 683

3. Life Cycle Impact Assessment

Effect of CO_2 storage duration on climate?



Temporary CO_2 storage

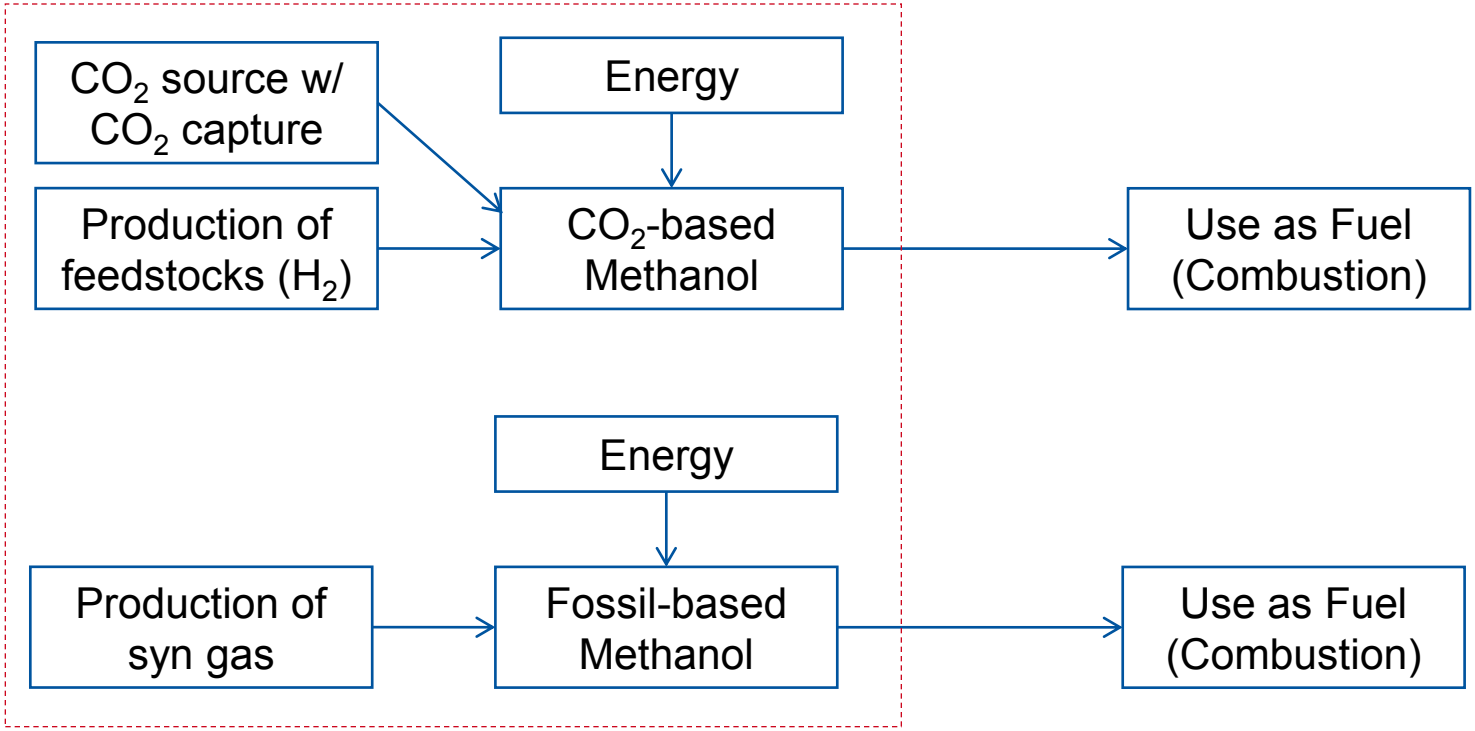
Frequent claim:

options with **short CO_2 storage duration** have **no climate benefit!**

Really?

3. Life Cycle Impact Assessment

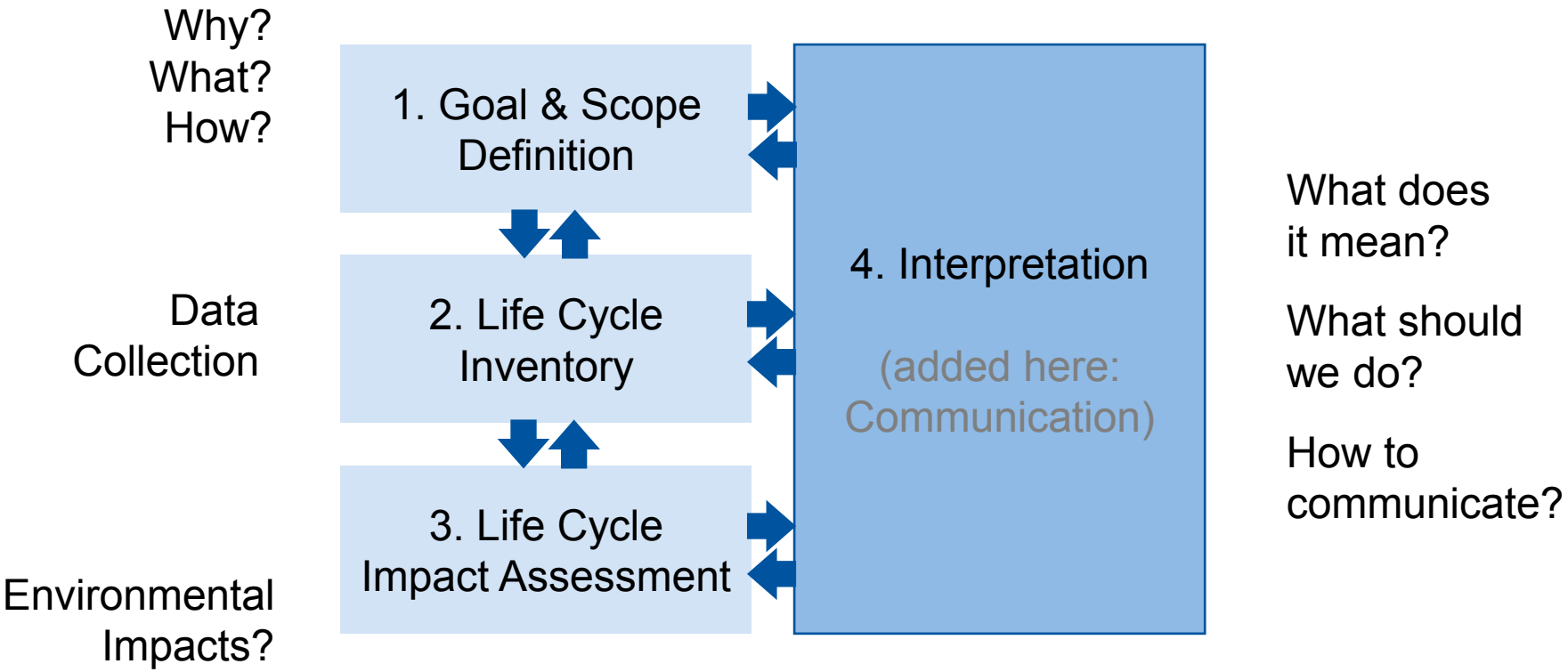
Incorporate CO_2 storage duration in global warming metric



➔ Effect of CO_2 storage duration is typically overrated !

Reference: von der Assen et al., Energy Environ. Sci., 2013, 6, 2721

4. Interpretation and Communication



4. Interpretation and Communication – “Dream Production“

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Reference: von der Assen et al., Green Chem., 2014, 16, 3272

Scrubbing and supply of CO_2

VORWEG GEHEN

Process development and conversion of CO_2

Bayer Technology Services

Production and testing of polyurethanes with CO_2

Bayer MaterialScience

Fundamental research

CAT® Catalytic Center

RWTH AACHEN UNIVERSITY

Life Cycle Assessment

4. Interpretation and Communication – “Dream Production“

Reference: von der Assen et al., Green Chem., 2014, 16, 3272

Power

CO_2

CO_2

Scrubbing and supply of CO_2

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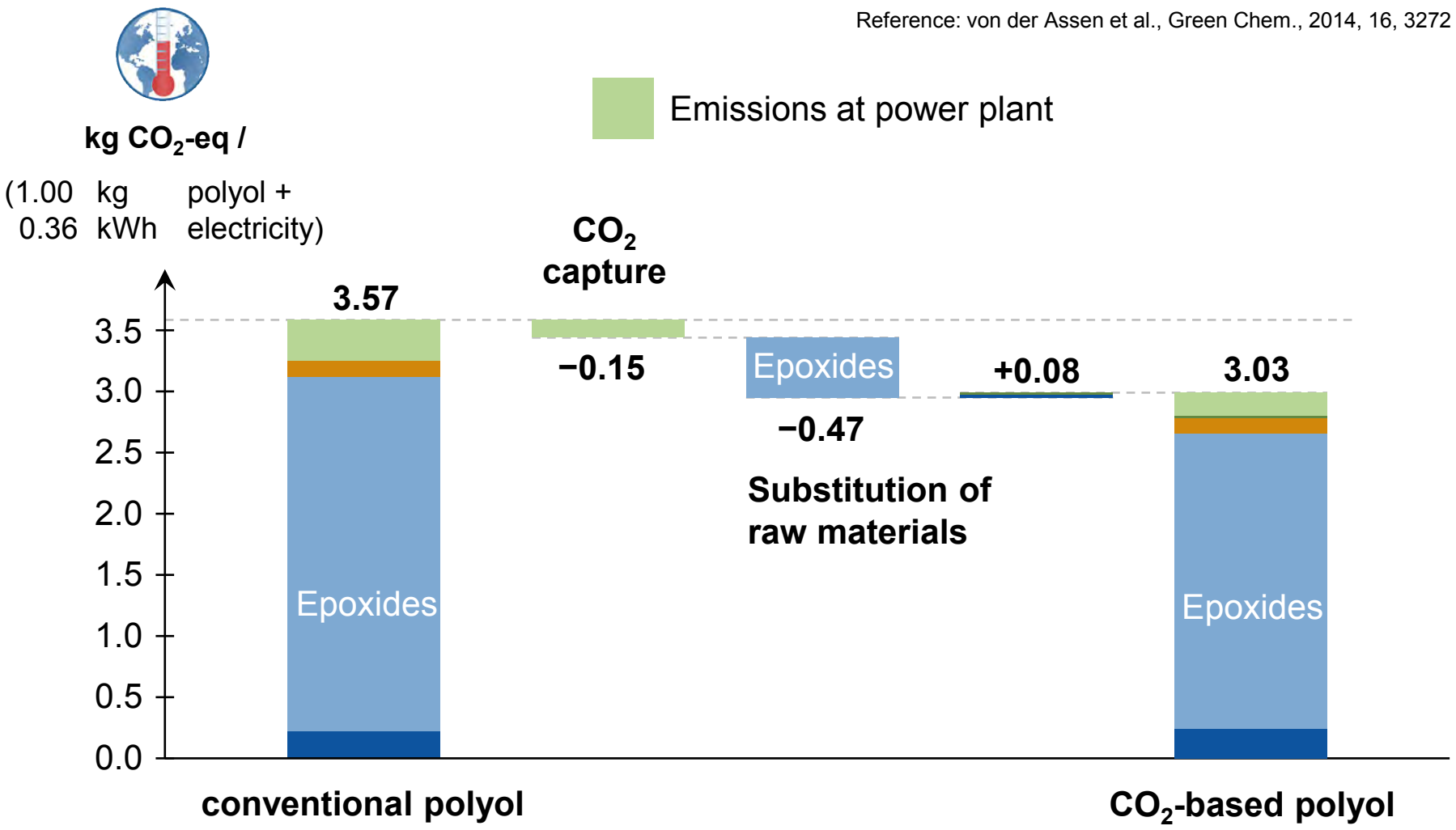

Experience and Advise

- Don‘t get tired! – Data collection from/with industry is possible!
- Give explicit values only if results are final/robust (semi-internal and external)!
- Clear communication to media: “no mattress is best for climate”
- (Dis)Advantage of LCA: everyone wants to/can join the discussion!

Thank you for your attention!

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Chair of Technical Thermodynamics

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