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Life cycle perspectives on ammonia-based technologies representing AMBHER

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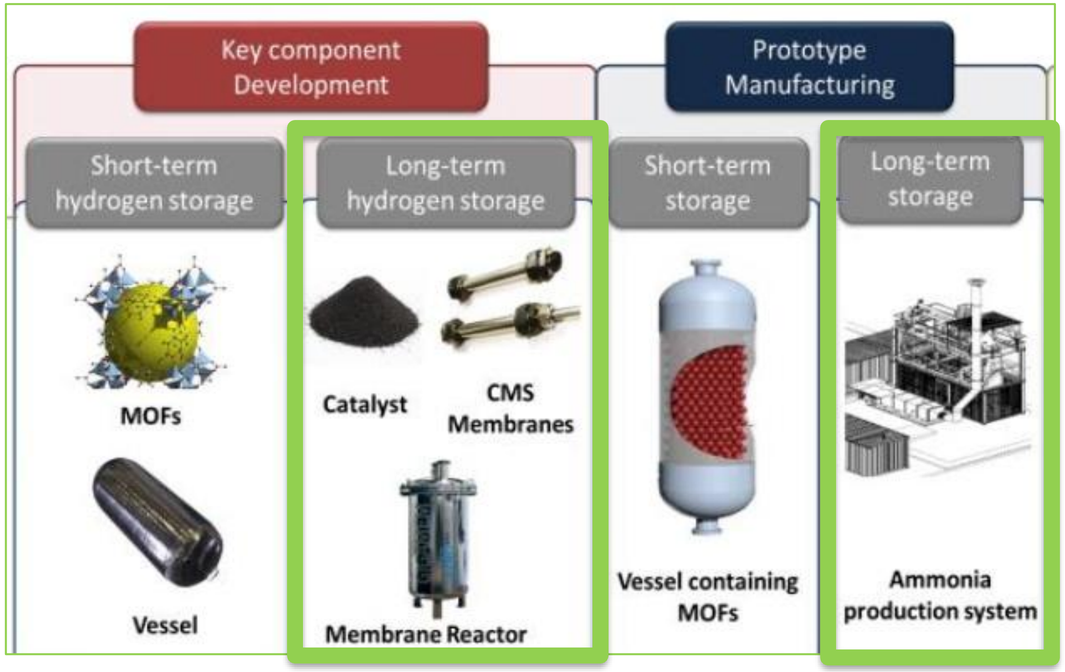
AMBHER project overview

AMBHER is a European research project focused on developing innovative technologies for hydrogen storage and energy systems based on ammonia as an energy carrier.

AMBHER innovation

- Development of novel materials and components (POCS, catalysts, membranes)
- Integration into advanced reactor systems
- Evaluation through life cycle perspective (LCA, LCC, S-LCA)



Scope of the analysis

Enable **efficient, scalable and sustainable ammonia-based energy systems.**

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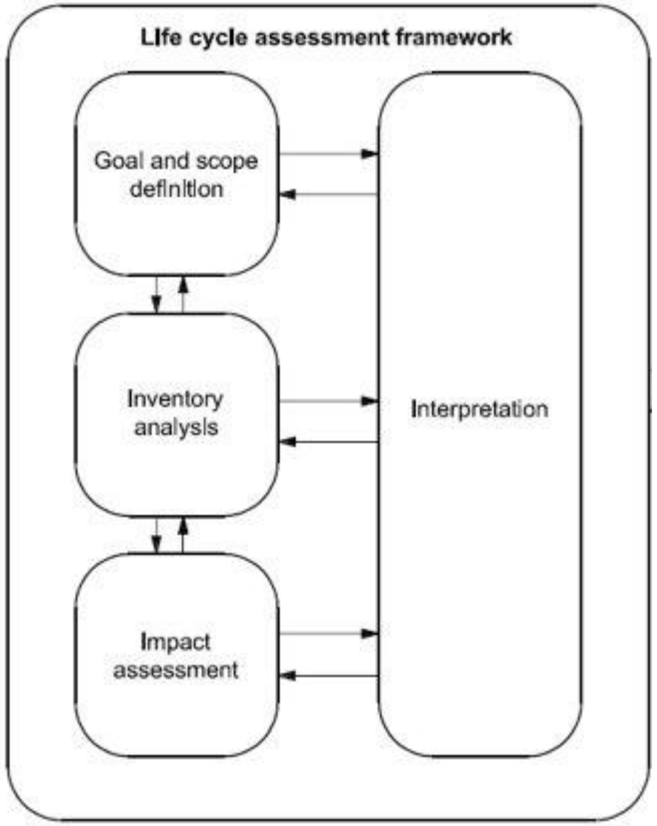
Life Cycle Assessment approach

LCA (environmental impact assessment, according to ISO 14040, ISO 14044 and ILCD guidelines), is deployed in a 4-steps process:

- **Goal and scope** definition: defining the functional unit, system boundaries, and other parameters of the study.
- **Inventory analysis:** collecting data on inputs and outputs throughout the life cycle of the product or system.
- **Impact assessment:** characterizing the environmental impacts of the product or system based on the data collected in the inventory analysis.
- **Interpretation:** analyzing and communicating the results, including identifying areas for improvement and making recommendations for environmental management.



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Goal & Scope

The assessment is a decision-support tool for technology development

Goal

Support design choices, compare alternatives, identify hotspots and prepare future scale-up decisions across environmental, economic and social dimensions.

Scope

The work evolves from component-level modelling to subsystem and demonstrator logic as partner data become more mature and consistent.

Two analysis levels

Components

Catalyst, POCS, Membrane, Reactor

Systems

Long-term storage allocation

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Goal and Scope

System boundaries

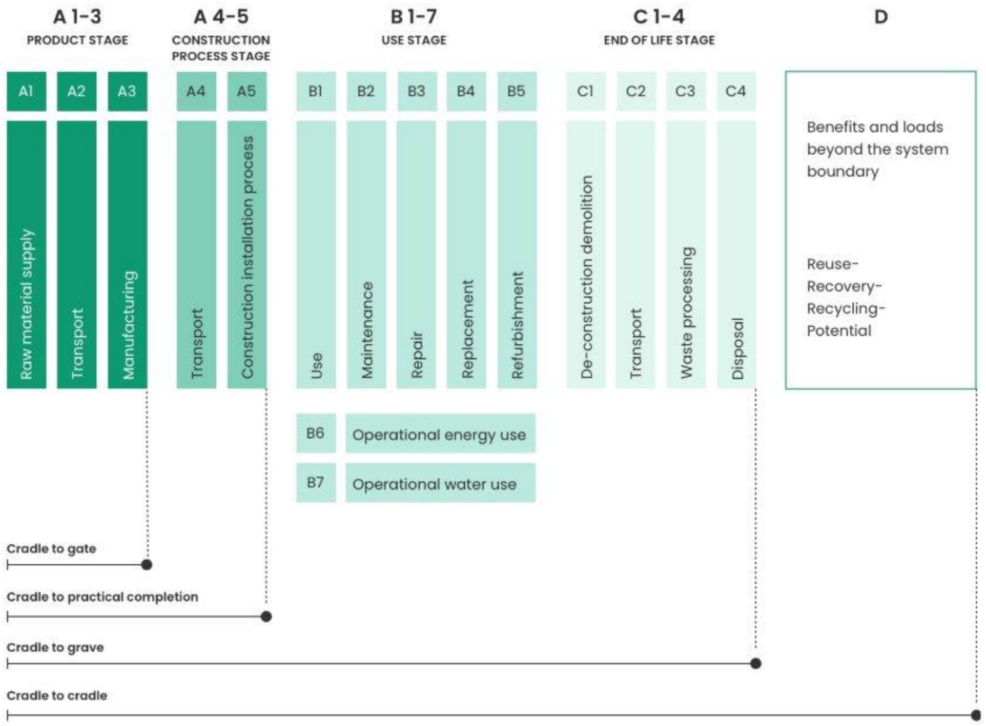
Cradle-to-gate, with use phase and operation treated separately in business model WP to avoid double counting.

Inside the present study

Materials, utilities, manufacturing steps, direct emissions.

Outside/separately handled

- Operational use phase and performance logic already treated in other WP.
- No duplication of use-related energy.



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Goal and Scope

Functional unit

The study combines **multiple component functional units** with one system-level meaning, so reference flows, lifetimes and replacements must be allocated to its unit.

Component-level references

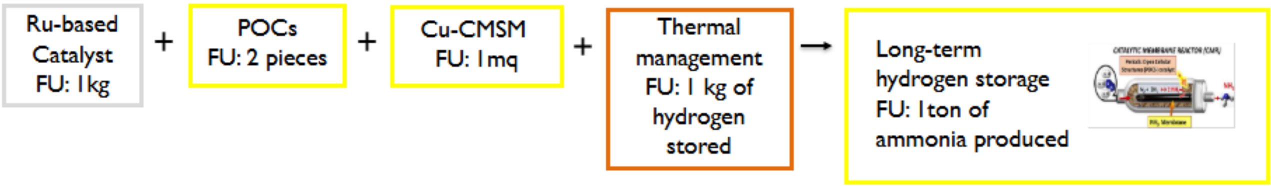
- Ru-based catalyst: 1 kg
- Bare/coated POCS: 2 pcs
- Cu-CMSM membrane: 1 m2

System FU

1 ton of ammonia

Example: Choice of POCS FU

- ➢ Bare POCS configuration = Coated POCS = POCS used in the Reactor.
- ➢ Piece FU instead of Mass FU.



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Life Cycle Inventory (LCI) approach

Inventory building was **iterative**: data maturity differed across partners, so consistency of logic mattered more than apparent precision. Primary partner data were combined with harmonised background datasets and progressively updated as the project evolved.

Collect
Use partner inventories, BFD and cost sheets directly.

→

Separate
Keep processes modular and partner-specific (each process is batch-based).

→

Map
Link flows to ecoinvent 3.10 datasets or document robust proxies.

→

Close
Allocation rules + impact assessment modelling

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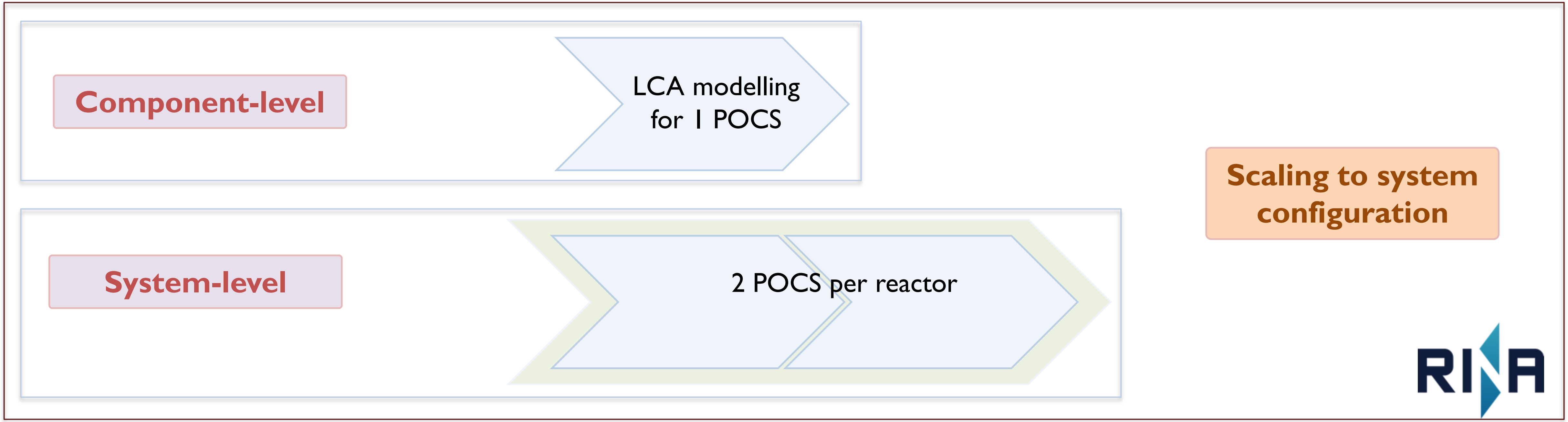
Life Cycle Inventory (LCI) approach

Scaling

Data gathered at lab/pilot-scale: the scaling used here is **structural** – from component inventory to system configuration.

What does it answer?
→ *How much of each component is required at system level?*
What it does
→ Translates component inventories into system configuration (a membrane inventory calculated per 1 m² is scaled according to the total membrane area required by the AMBHER reactor.)

Example
POCS→ 2 POCS are required per reactor system



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Life Cycle Inventory (LCI) approach

Lifetime logic

What does it answer?

→ *How many times does the component enter the system over its lifetime?*

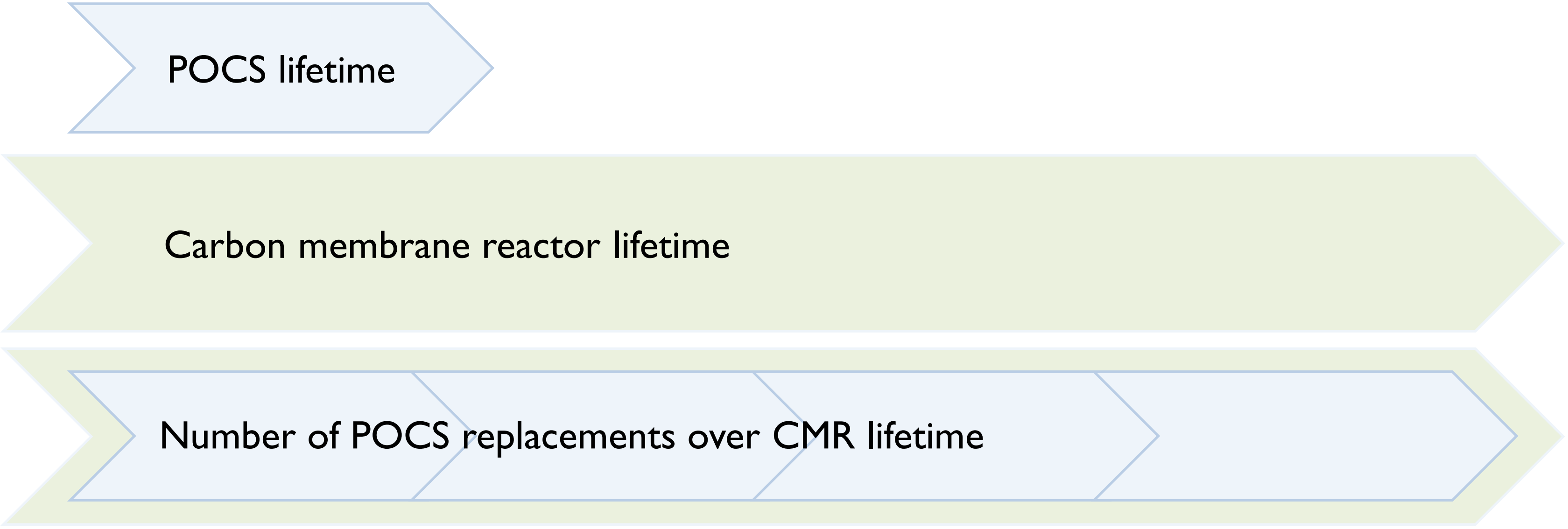
What it does

→ Accounts for replacement cycles based on component lifespan

Example (hypothesis)

POCS lifetime → 5 years

Carbon membrane reactor → 20 years



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Life Cycle Inventory (LCI) approach

Allocation logic

What does it answer?
→ *How are impacts distributed over the system output?*

What it does
→ Spreads total impacts over the functional unit

Example
→ Impacts of POCS are distributed over total NH_3 processed

Total impact per FU = (Component impact × structural scaling × lifetime replacements) ÷ total system output

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Key assumptions

Assumptions are part of the model architecture, especially for emerging technologies where datasets and operating evidence are incomplete.

Project reality:

- Incomplete data
- Modified/updated data over time
- Different levels of detail across partners

IN625 for bare POCS

No dedicated ecoinvent dataset was available, so a proxy/custom dataset was built from the main alloy constituents: Ni, Cr, Mo, Nb and Fe.

PVA for coated POCS

Polyvinyl alcohol was not available in ecoinvent 3.10; Vinyl acetate was kept as a proxy.

Direct emissions from coating

Organic auxiliary decomposition was identified qualitatively by the partner; it was introduced via stoichiometric estimation rather than generic solvent proxies.

Market and electricity choices

Purchased materials were represented with market datasets; machining uses were linked to low-voltage electricity where no better evidence was available.

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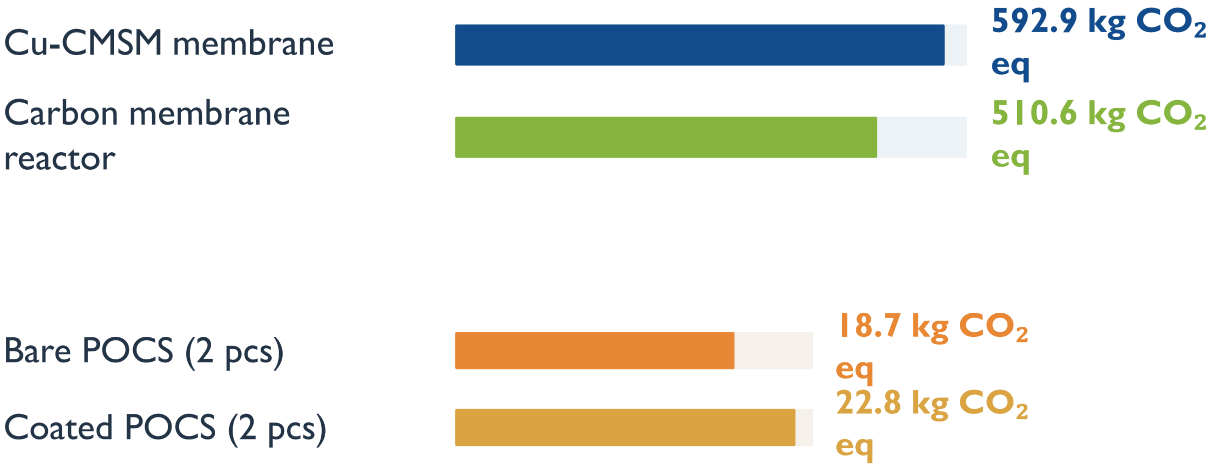
Preliminary results

Contribution analysis



Indicative takeaways

- Within the long-term subsystem, coated/bare POCS remain small compared to membrane and reactor manufacturing.
- Membrane and reactor dominate the environmental impacts also due to higher mass and material intensity.
- Results must be interpreted together with lifetime and allocation logic, as component impacts depend not only on production intensity but also on durability and replacement frequency, in a system-level perspective.

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Key takeaways

1. **LCA in R&D requires flexibility**
2. **Data consistency is more important than data precision**
3. **Avoid reinterpretation of partner data**
4. **Use proxies, but document them clearly**
5. **Scaling, lifetime and allocation rules are essential to connect component results to system-level meaning**

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A comprehensive life-cycle perspective to achieve full sustainability

ENVIRONMENTAL

ECONOMIC

SOCIAL

Linking environmental flows (LCA) with economic flows (LCC)

LCA FLOWS
Raw materials → Transport → Production → Gate

Conversion from physical units → monetary values (€)

LCC COSTS
Material cost → Logistics cost → Manufacturing cost & Operation cost + CAPEX

In a cradle-to-gate analysis, the same physical flows modeled in the LCA (materials, energy, transport) are monetized in the LCC to evaluate the total cost up to the factory gate.

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