

Environmental LCA comparison of hydrogen delivery options within Europe

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Joint Research Centre

Our purpose

The Joint Research Centre provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society.



Introduction – Hydrogen in the EU

2022

REPowerEU
with Clean Energy

2030 ambitious objectives

- **10 Mt** domestic renewable H₂ production
- **10 Mt** renewable H₂ imports

2024



EUROPE'S CHOICE

POLITICAL GUIDELINES
FOR THE NEXT EUROPEAN COMMISSION
2024–2029

Ursula von der Leyen
Candidate for the European Commission President

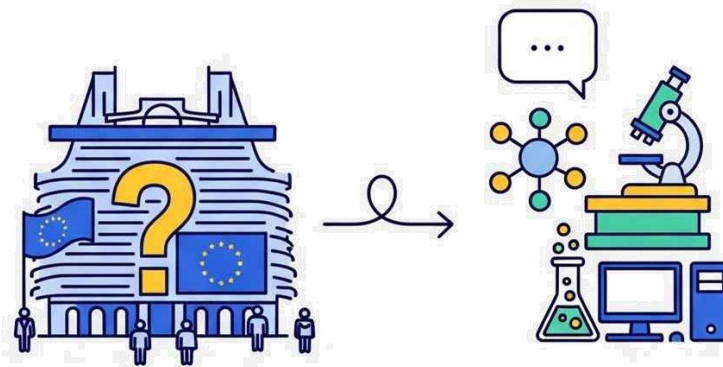
We will also invest in [...] the deployment of a hydrogen network

[...] we will drive investments in [...] green hydrogen production and raw material value chains

Research goal

?

*which is the most sustainable way to deliver **renewable H_2** to the EU?*



Case study

Delivery of 1 Mt/y of **renewable** H_2 to a single industrial customer via direct transport pathway (by ships or pipelines)



delivery options

- Compressed H₂ (C-H₂)
- Liquefied H₂ (L-H₂)
- Ammonia (NH₃)
- Liquid organic H₂ carrier (LOHC)
- Methanol (MeOH)
- Synthetic natural gas (SNG)
- *Reference: on-site SMR/electrolysis*

Methodology

Techno-economic assessment ^[1]

Environmental lifecycle assessment (LCA) ^[2]

Social LCA ^[3]

^[1] [Ortiz et al. \(2022\)](#)

^[2] [Arrigoni et al. \(2024\)](#)

^[3] [Martin Gamboa et al. \(2024\)](#)

Methodology

Techno-economic assessment ^[1]

Environmental LCA ^[2]

Social LCA ^[3]

LCA scope

Assessment method: Attributional prospective LCA

Functional unit: delivery of 1 Mt of H₂ in one year (30 bar, 99.97% purity)

Impact assessment method: Environmental Footprint (16 impact categories)

Inventory: JRC calculations, ecoinvent 3.9, scientific literature

Time horizon: 2030+

System boundaries: from cradle to gate



^[1] [Ortiz et al. \(2022\)](#)

^[2] [Arrigoni et al. \(2024\)](#)

^[3] [Martin Gamboa et al. \(2024\)](#)

Main assumptions [2030+]

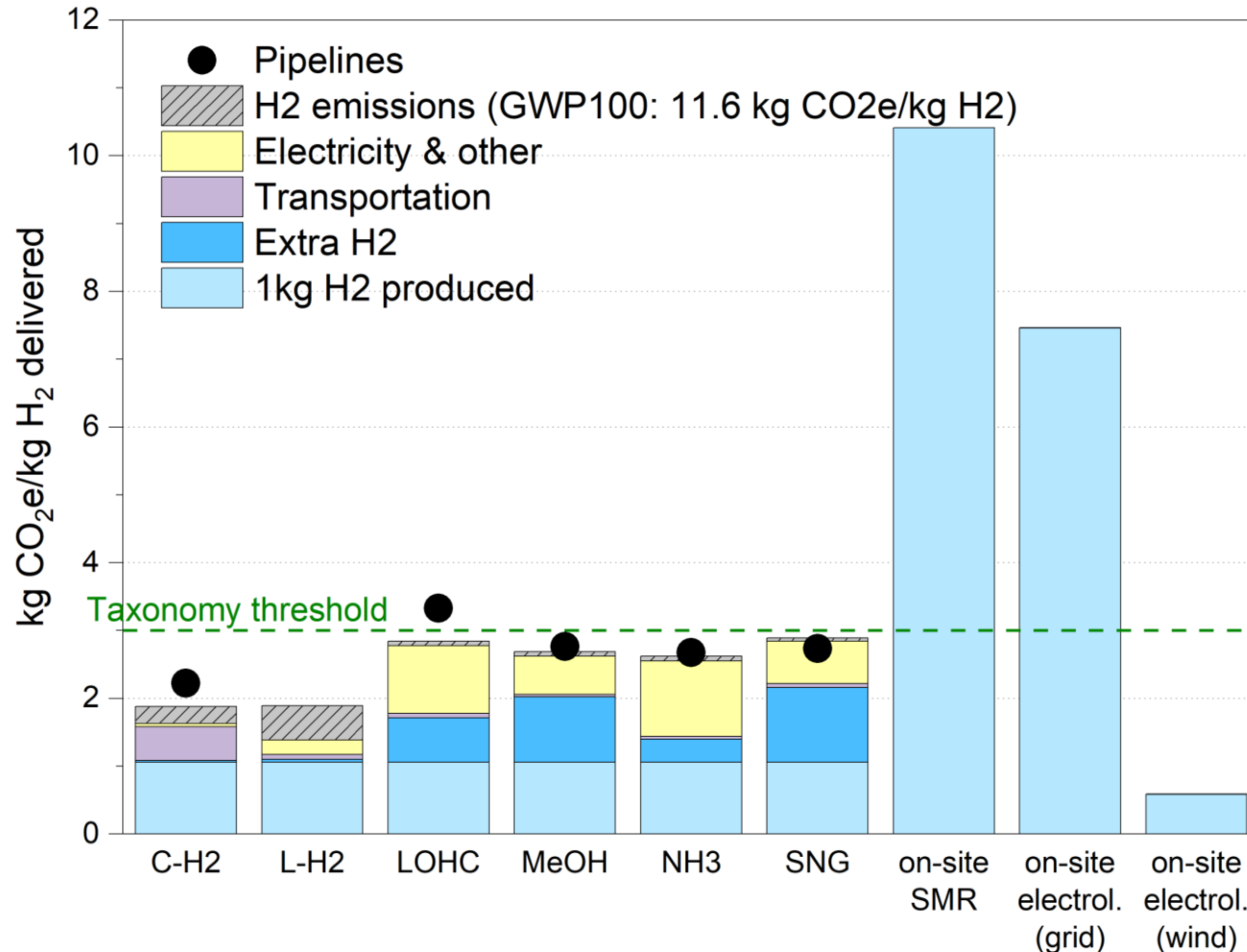
- **Renewable H₂**: electrolysis [50 kWh/kg H₂] via solar electricity ^a
- **Electricity grid**: mixes of 2030 in line with EU Fit for 55 plan ^b
- **Storage**: both at production and use sites to guarantee constant H₂ supply
- **Ships**: powered by biodiesel
- **CO₂ for carriers** (i.e., MeOH, SNG): sourced from direct air capture (DAC)
- **Heat for processes** (e.g., DAC, LOHC unpacking): from extra renewable H₂
- **H₂ Global Warming Potential over 100 years**: 11.6 kg CO₂e/kg H₂ ^c

^a Hydrogen Council. 2021. Hydrogen decarbonization pathways. A life-cycle assessment

^b E3Modelling, "Fit for 55" MIX Scenario. Summary Report: Energy, Transport and GHG Emissions, 2021

^c Sand et al. A multi-model assessment of the Global Warming Potential of hydrogen. Commun Earth Environ 2023

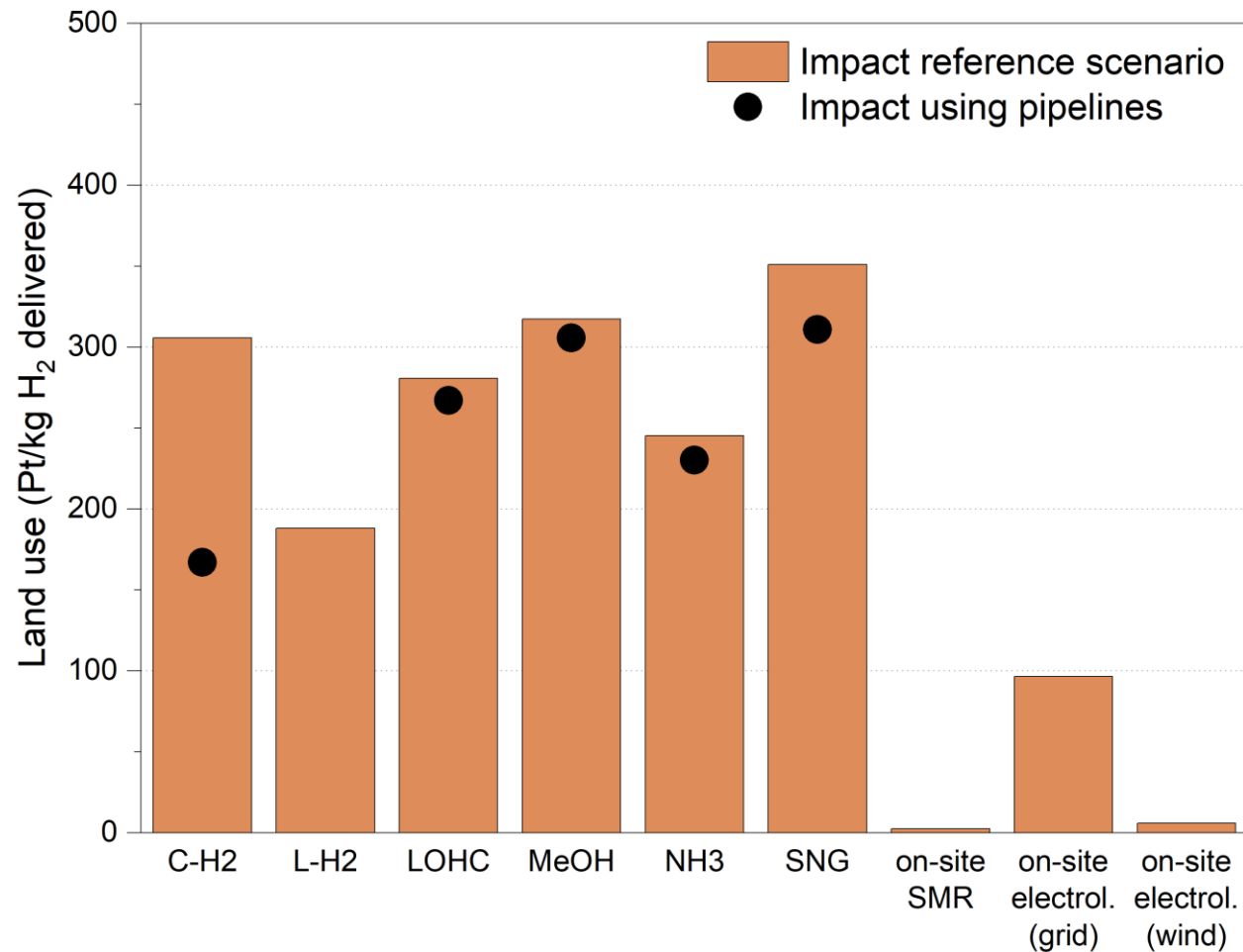
Results: Climate change potential impact



Extra H₂: H₂ to make up for losses, and H₂ used for heat

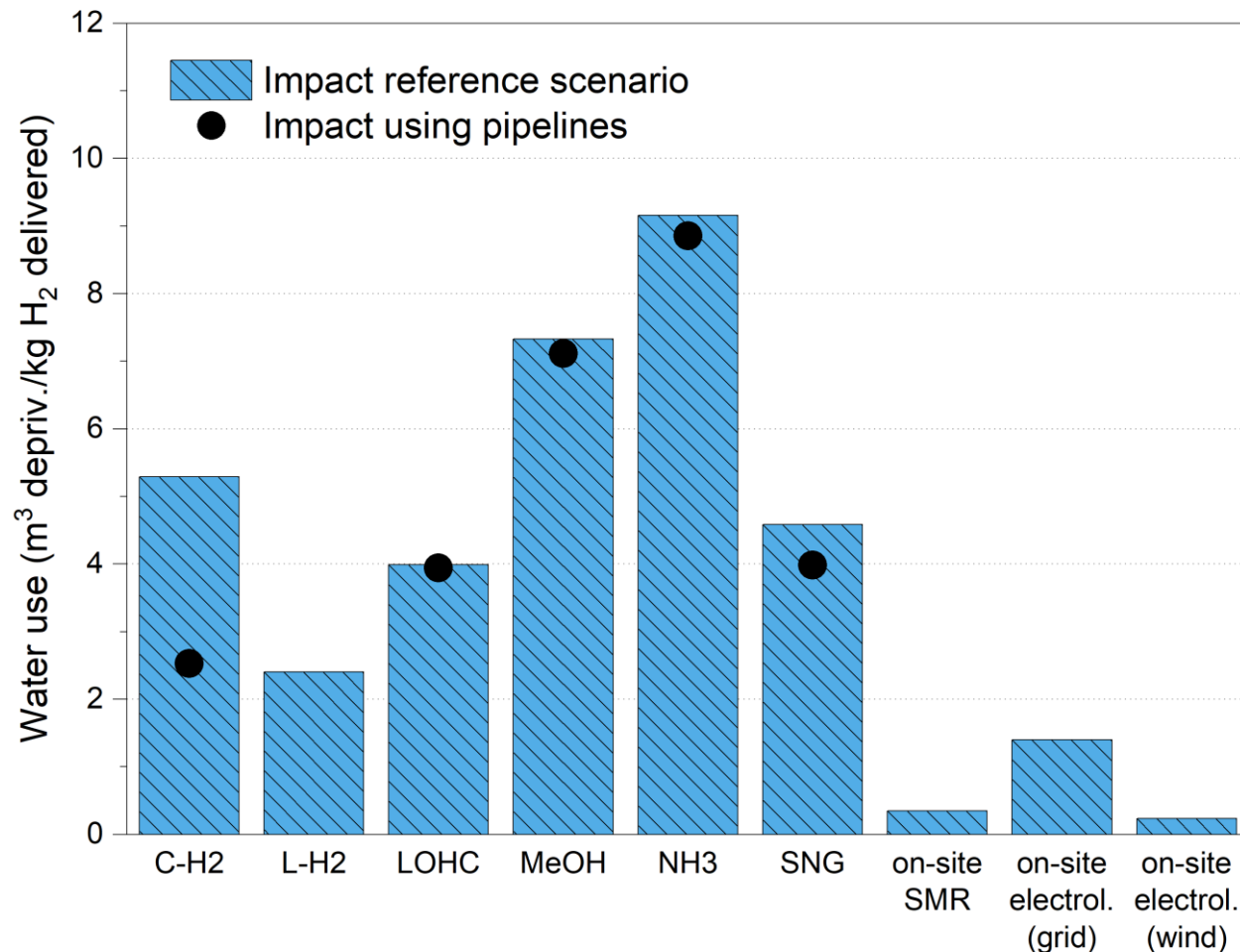
- **H₂ delivery** from a location where renewable energy is cheaper would generate a **lower climate impact** than producing hydrogen on-site via either SMR or electrolysis powered by the grid mix
- The transportation advantage of packing H₂ into a more **manageable carrier** does not seem to translate in a GHG advantage, due to the energy required to pack and unpack the carrier

Results: Land use potential impact



Impact can be ascribed to land used for solar power generation and to grow biomass for biodiesel

Results: Water use potential impact



Impact is mainly due to the water consumed for electrolysis, for electricity production, and for cooling processes.

Impact depends on the location where water is consumed: using freshwater in Portugal is 40 times higher than in the Netherlands, due to the different availability of water resources.

Results: Normalization and weighting

Absolute results were normalized and weighted to obtain a single impact score according to the Environmental Footprint (EF) method.

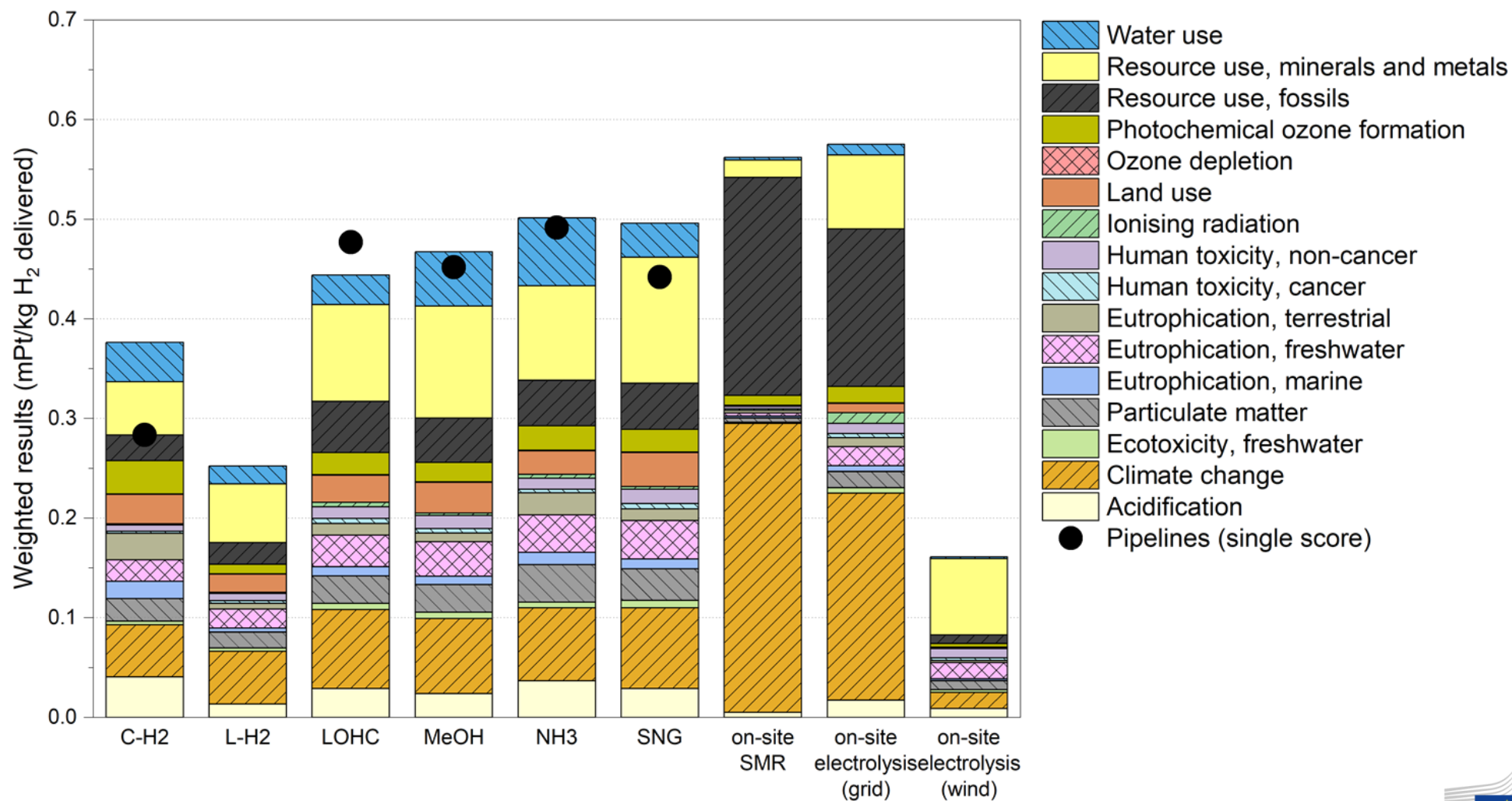
Normalization compares the magnitude of the impact with respect to the global impact on a per capita basis.

Normalized results are multiplied for a set of **weighting factors** that are intended to represent the relative importance of each environmental impact category considered.

Impact category	Weighting factor (%)
Climate change	21.06
Ozone depletion	6.31
Ionising radiation	5.01
Photochemical ozone formation	4.78
Particulate matter	8.96
Human toxicity, non-cancer	1.84
Human toxicity, cancer	2.13
Acidification	6.20
Eutrophication, freshwater	2.80
Eutrophication, marine	2.96
Eutrophication, terrestrial	3.71
Ecotoxicity, freshwater	1.92
Land use	7.94
Water use	8.51
Resource use, fossils	8.32
Resource use, minerals and metals	7.55

Source: Sala, Cerutti, and Pant (2018)

Results: Single score



Conclusions

Results are referred to a **well-defined geographical context and time horizon**, and they are driven by the **numerous assumptions** made throughout the study

- The **least environmentally impactful option** of supplying hydrogen is to produce it on-site via efficient renewable sources, followed by shipping of liquid hydrogen and compressed hydrogen by pipeline
- Energy required to pack and unpack hydrogen into more **suitable carriers** (i.e., ammonia, LOHC, methanol, and SNG) makes this option **less attractive in terms of environmental impacts**
- The **renewable energy infrastructure** (i.e., solar panels manufacture) plays a critical role in the environmental performance of the hydrogen delivered
- Limiting the scope of the assessment to GHG emissions can lead to unintended consequences in terms of other environmental impacts

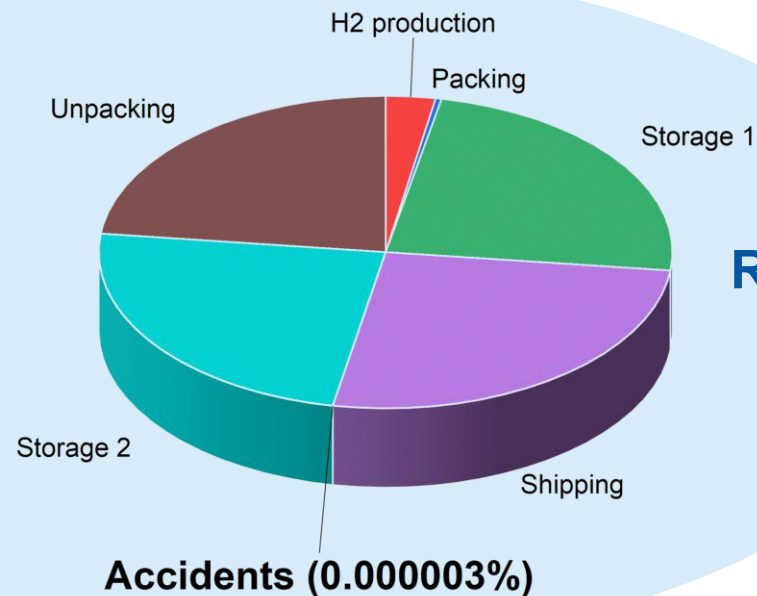
Recommendations

- **Prioritizing on-site hydrogen production utilizing local abundant renewable sources** when viable;
- **Focusing research and development efforts on** hydrogen transportation methods, such as **pipelines for compressed hydrogen and maritime transport for liquid hydrogen;**
- **Reducing the environmental impact of the infrastructure used for renewable electricity production**, namely solar PV panels
- Optimizing energy efficiency throughout the supply chain of chemical carriers involved in hydrogen distribution, with special attention to the delivery phase;
- Preventing hydrogen losses along the delivery chains
- Perform environmental LCAs to determine the best hydrogen supply chain for each specific scenario

Future work

- Investigate the **social implications** of using different carriers
- Assess the **environmental impact from potential accidents**

**Ammonia
emissions
[air]**



Release of ammonia due to potential accidents

147 kg/year (1 Mt transported/year)

0.00001% of ammonia transported



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Thank you and keep in touch

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