STRATELLIGENCE
decision support

Comparing hydrogen carriers:

a multi-criteria analysis of supply chains in the Netherlands

Gigi van Rhee, 2nd December, Antwerp

A cornerstone for the Dutch policy strategy on hydrogen carriers

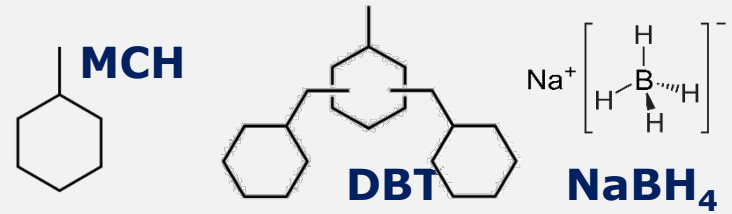
- Import of hydrogen carriers, necessity for climate goals.
- Advantages and disadvantages considered in future policy choices.
- Study: comparison of various hydrogen carriers for specific chains.
- Multicriteria analysis on the public interests involved in the energy and raw materials transition.
- Focus on imports and physical flows destined for end-use in both the Netherlands and the European hinterland (especially Germany).
- Strategy by Dutch Ministry of Climate Policy and Green Growth (KGG) on the extend, means, and conditions of facilitation and incentives.*

* More information in presentation *Dutch policy strategy on hydrogen carriers*

Seven hydrogen carriers, divided into two categories

End use hydrogen	End use as carrier
1. Liquid hydrogen (LH_2)	1. Liquid hydrogen (LH_2)
2. Ammonia (NH_3)	2. Ammonia (NH_3)
3. Methanol (MeOH)	3. Methanol (MeOH)
4. Liquid Synthetic Methane (LSM)	4. Liquid Synthetic Methane (LSM)
5. Methylcyclohexane (MCH – a LOHC)	
6. (Perhydro)Dibenzyltoluene (DBT - a LOHC)	
7. Sodium borohydride ($NaBH_4$)	

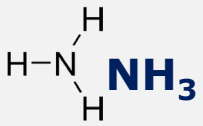
[LOHC = Liquid organic hydrogen carrier]



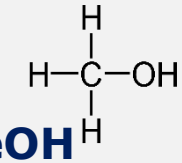
Hydrogen carrier

Hydrogen carrier and as raw material or fuel

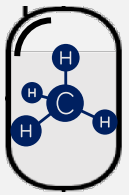
LH_2



NH_3

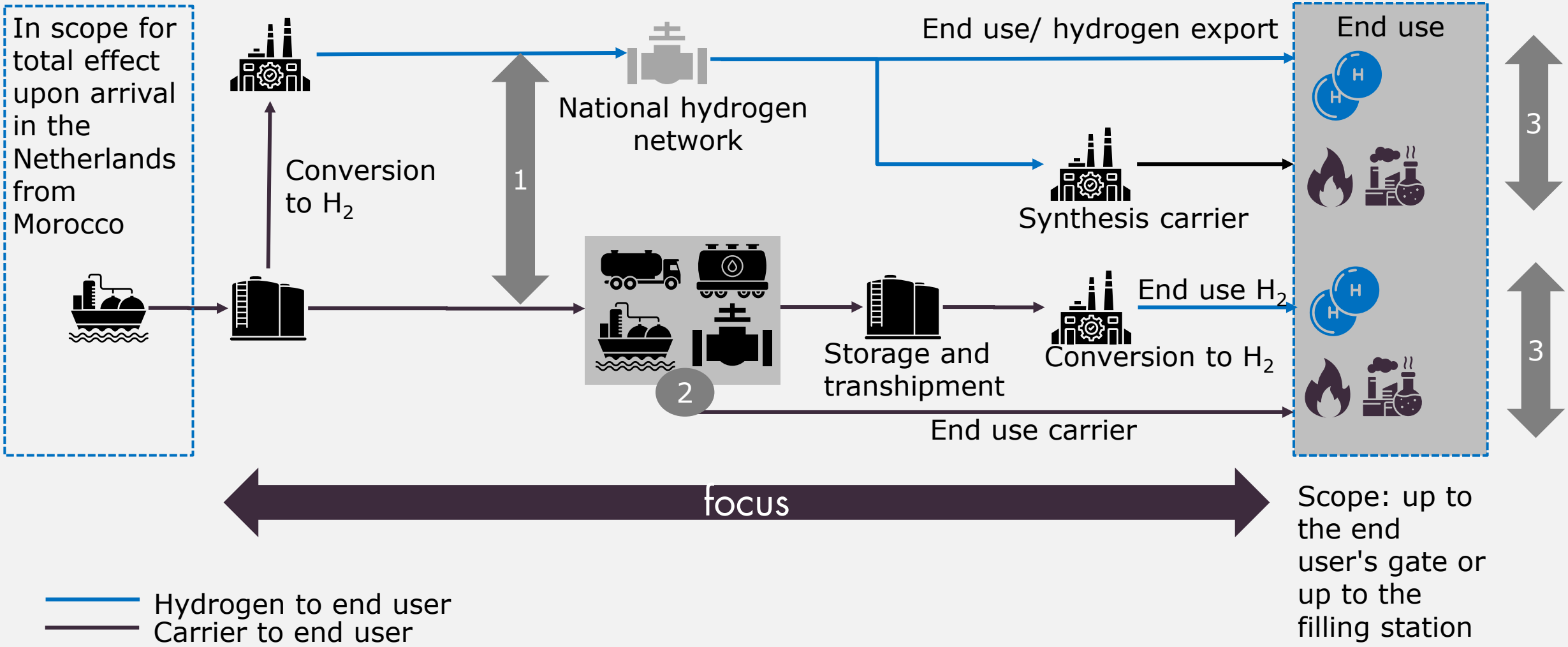


MeOH



LSM

Focus: domestic hydrogen carrier supply chains up to the end user's gate



Maximum ten different supply chains per carrier

End use hydrogen(gas) ⟷ 3 ⟷ End use as carrier

Domestic transport as hydrogen carrier ⟷ 1

End use of hydrogen	End use of carrier
Transport by road and conversion at the end-user	Transporting the carrier by road to the end user
Transport by water and conversion at the end-user	Transporting the carrier by water to the end user
Transport by rail and conversion at the end-user	Transporting the carrier by rail to the end user
Transport by pipeline and conversion at the end-user	Transporting the carrier by pipeline to the end user
Conversion at the port of entry and transport via the hydrogen network to the end user	Conversion at the port of entry and transport via the hydrogen network, and decentral synthesis to carrier

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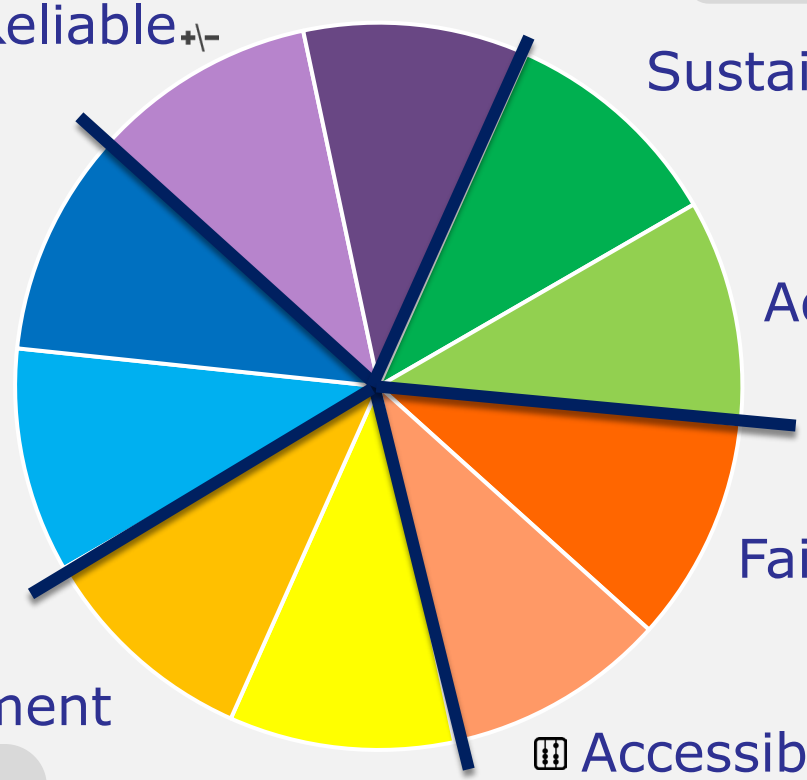
Transport mode carrier: road, water, rail, pipeline;

Transport mode hydrogen gas: hydrogen network

Public interests from the Dutch national energy system plan supplemented with adaptability



Safe & Secure +\-

1) Environmental safety +\-
2) Cybersecurity and terrorism +\-
3) Transport safety

Reliable +\-

Robustness and security of supply of carrier and supply chain

Sustainable

1) Greenhouse gas emissions (CO2, CH4, H2)
2) Consumption of scarce non-renewable materials
3) Energy use and loss in the supply chain

Economically robust

Added value in the Netherlands corrected for vehicle loss hours

Adaptable +\-

Size of new investments and degree of reusability of investments in the event a supply chain alternative becomes obsolete

Affordable

Costs per hydrogen equivalent for each supply chain (CAPEX and OPEX)

Fair

1) Degree of shifting of external costs to producing countries
2) Degree of shifting of external costs to the Dutch society

Environment

External costs of:
- Air emissions (particulate matter, NOx, NH_3)
- Noise emissions
- Habitat damage

Accessible

1) Accessibility to hydrogen economy; same cost level hinterland
2) Accessibility to hydrogen economy; proximity to chain

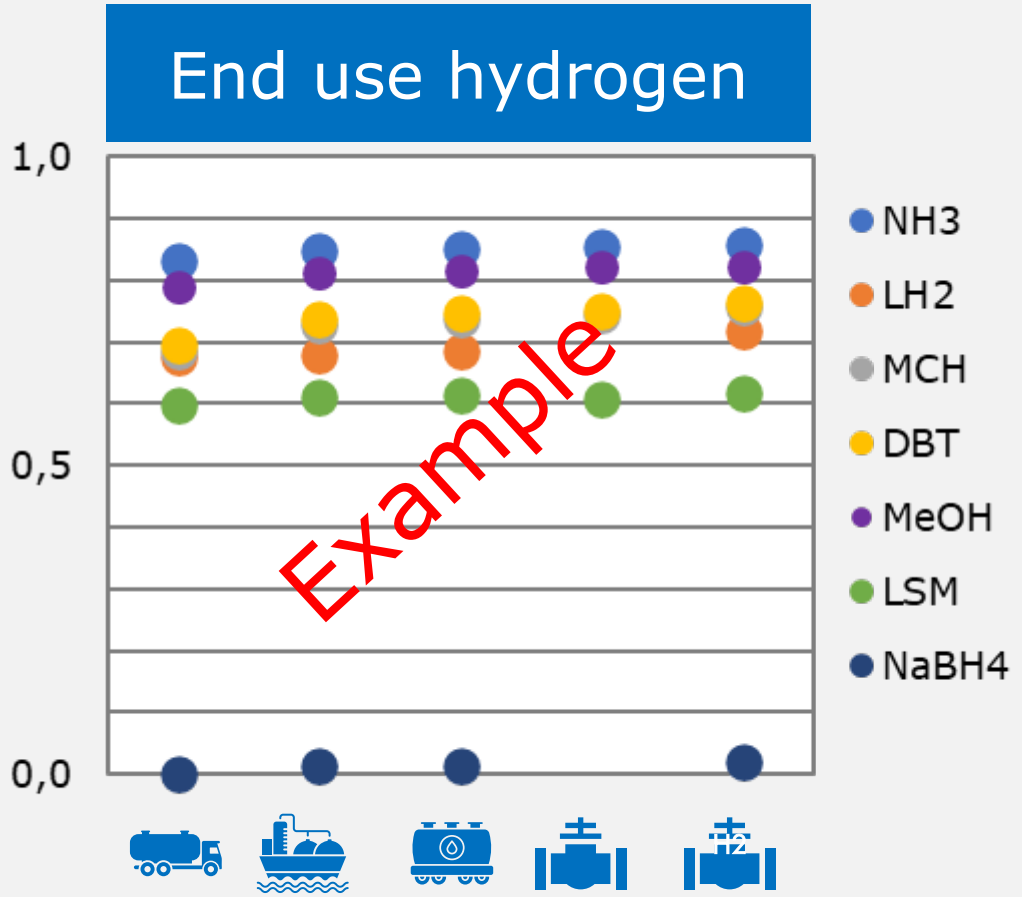
Space use

Opportunity costs of space use, above and below ground

Monetary
Quantitative
+\- Qualitative

Scoring and visualisation of different chains

- All public interests yield a score per supply chain based on literature, market data and expert input.
- In four situations:
  - Baseline 2030, end use 200 km inland
  - End use in port of entry
  - Transit and export, end use abroad
  - Projection 2050
- Final score is a combination of weighted scores per public interest.*
- X-axis: the different types of chains.
- Y-axis: weighted final score (0-1), 1 is the highest (= best possible) score.



* Ranking with VIKOR multicriteria ranking. The report also contains the results per public interest and per sub-indicator

Baseline 2030, end use hydrogen (gas)

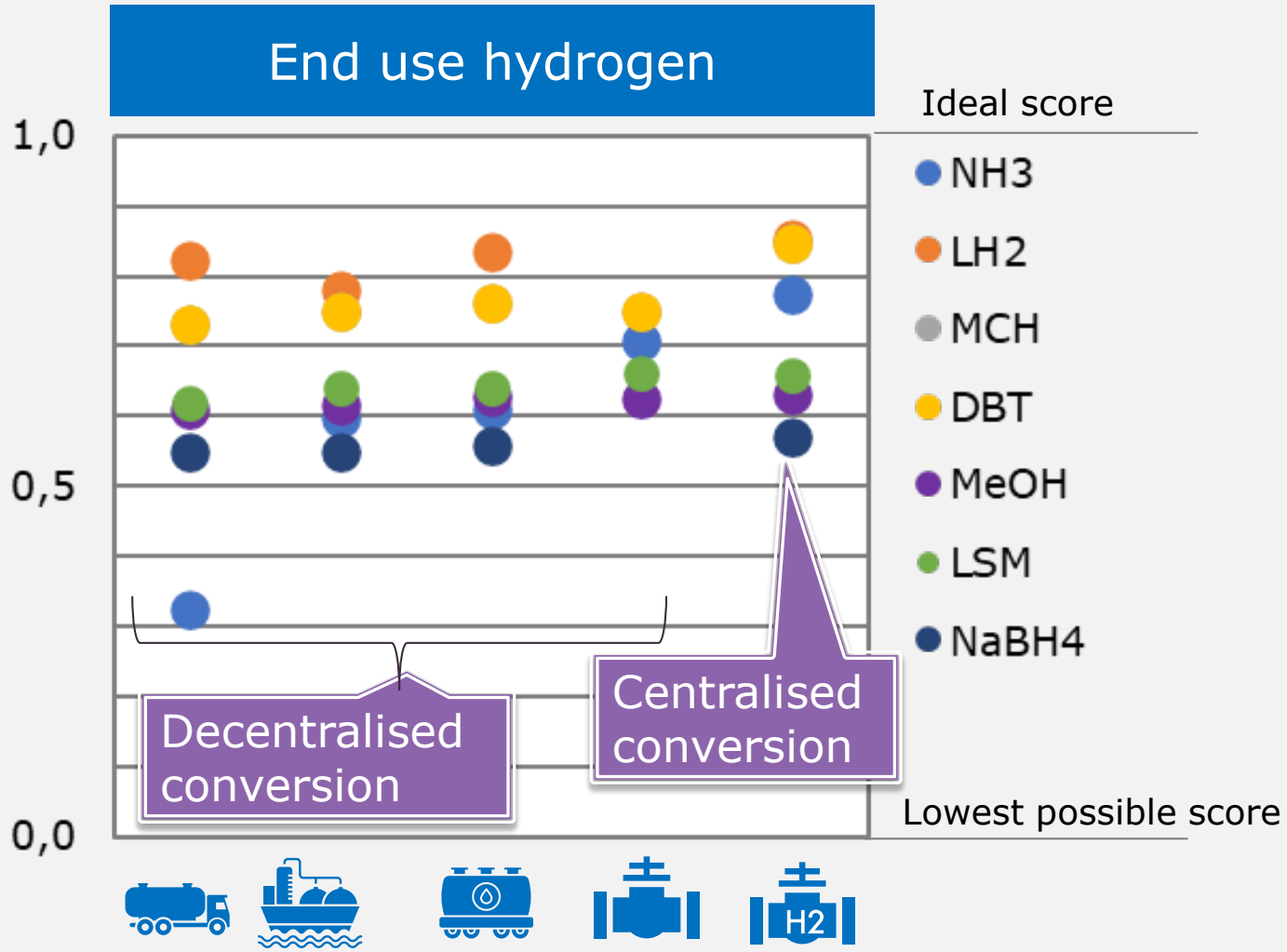
Ammonia: - Safe & Secure, Environment, + Affordable

Methanol en LSM: - Sustainable (CO_2), + Affordable (methanol), Accessible (LSM)

LOHCs*: - Reliable, Adaptable, Accessible, Space Use, Environment, + Safe & Secure, Sustainable

Liquid hydrogen: - Affordable, Reliable, + Sustainable, Adaptable, Fair, Environment

Sodium borohydride: - Affordable, Reliable, Sustainable (Material use and Energy loss) + Safe & Secure, Fair



* Difference in LOHCs is very small. For modelling it was necessary to compile a hybrid dataset. As a result, mutual differences may not be representative.

Baseline: direct end use as carrier; typically, higher scores than end use hydrogen

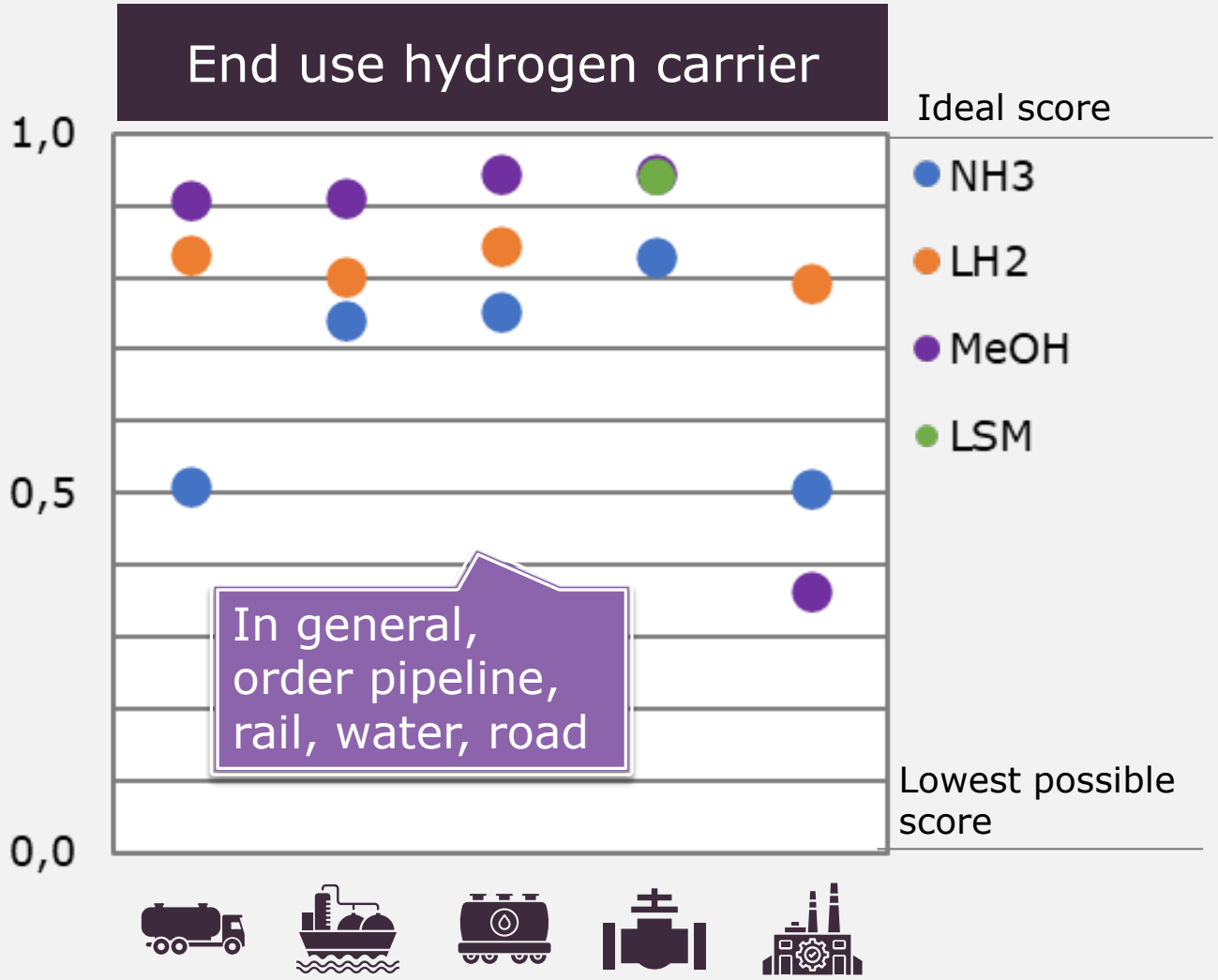
Ammonia: - Safe & Secure, Environment,
+ Affordable

Methanol en LSM: - None (no conversion),
+ Affordable (methanol), Accessible (LSM)

Liquid hydrogen: - Affordable, Reliable, +
Sustainable, Adaptable, Fair, Environment

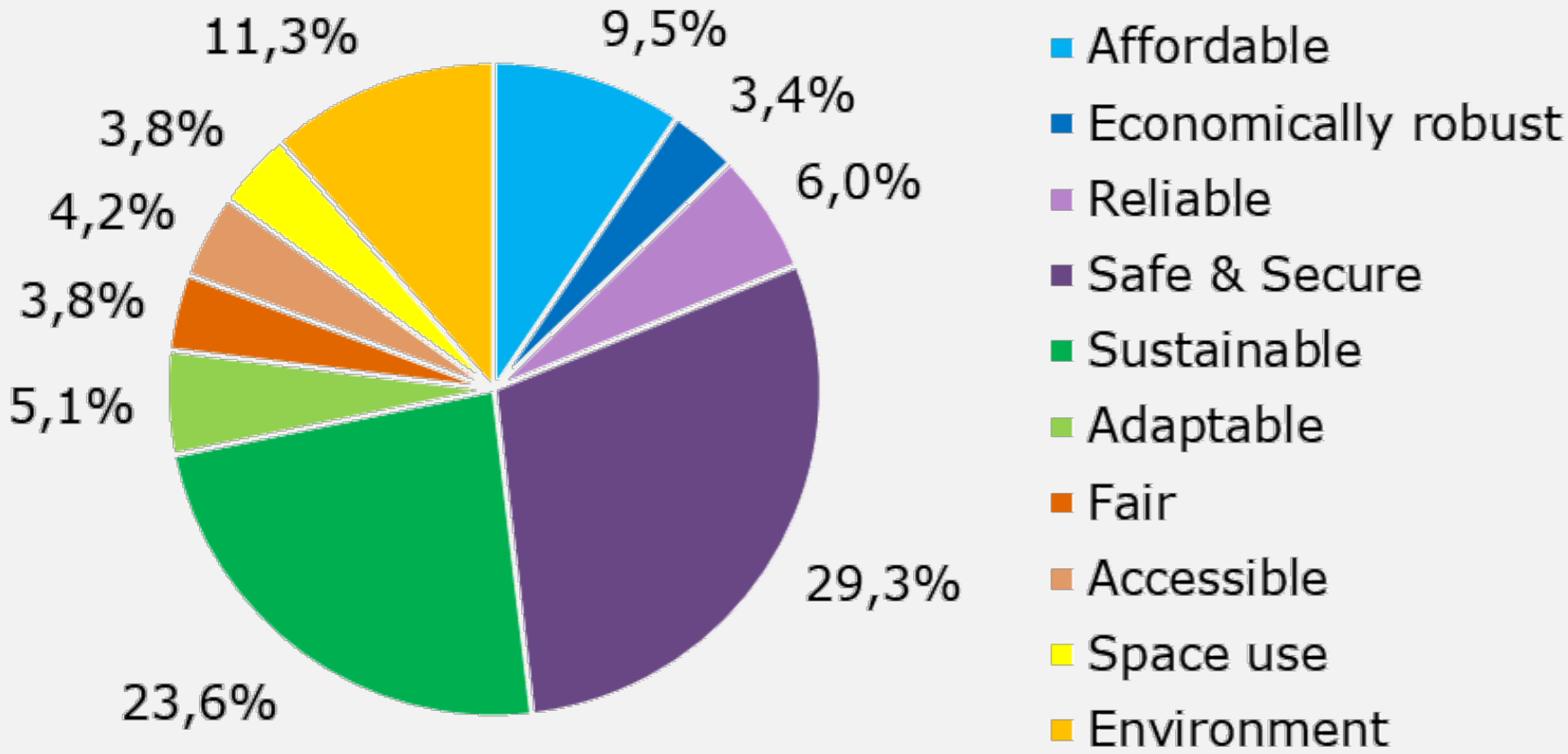
Higher scores than hydrogen use following carrier conversion (particularly methanol and LSM), except for decentral synthesis.

Not every chain and carrier are feasible for every type of end user.*



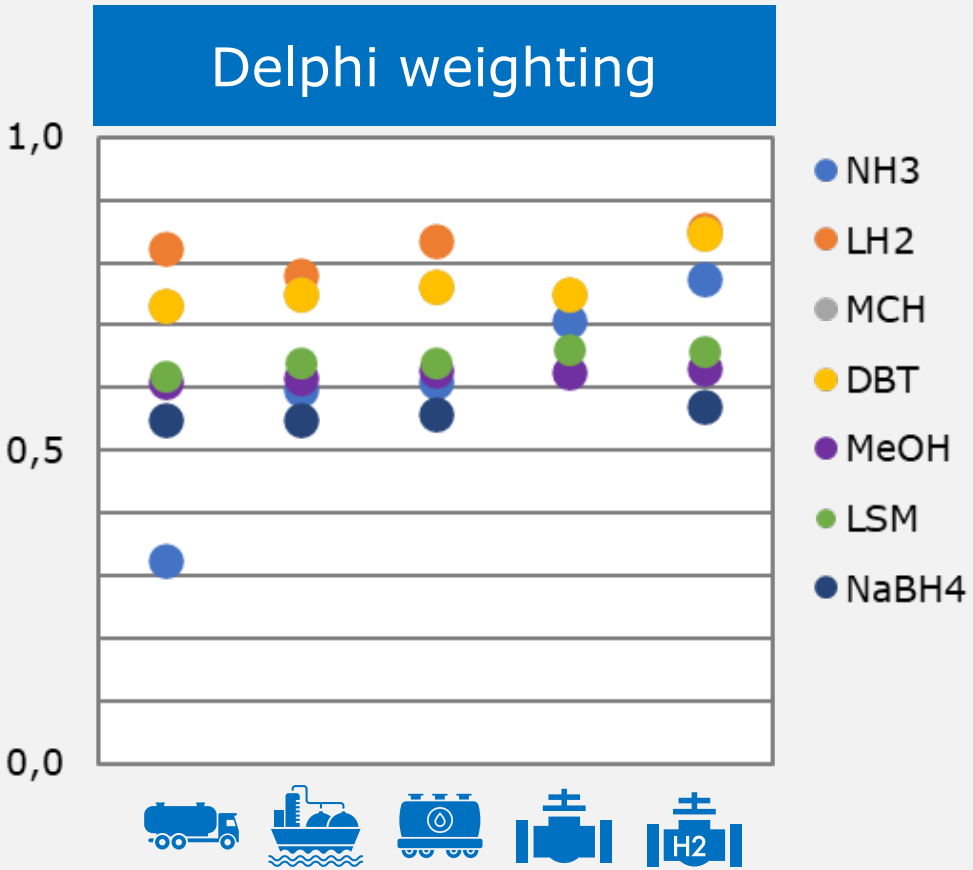
* We distinguish six types of end users in the study: in industrial clusters, industries outside the five main industrial clusters, fertiliser industry, power stations, filling stations, bunkering stations.

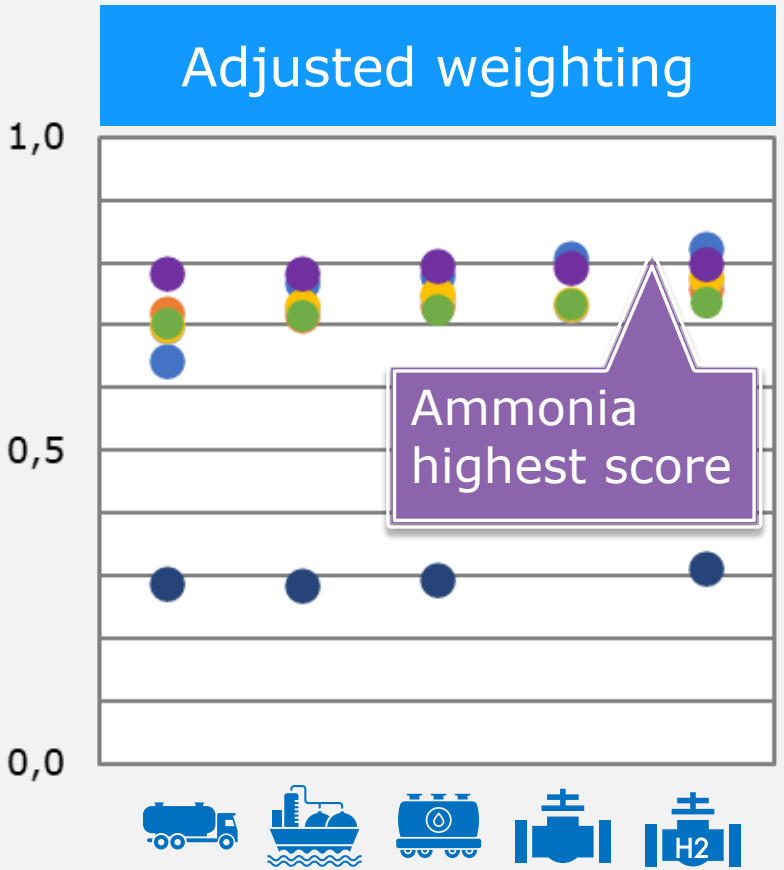
Used weighting factors outcome of a Delphi session

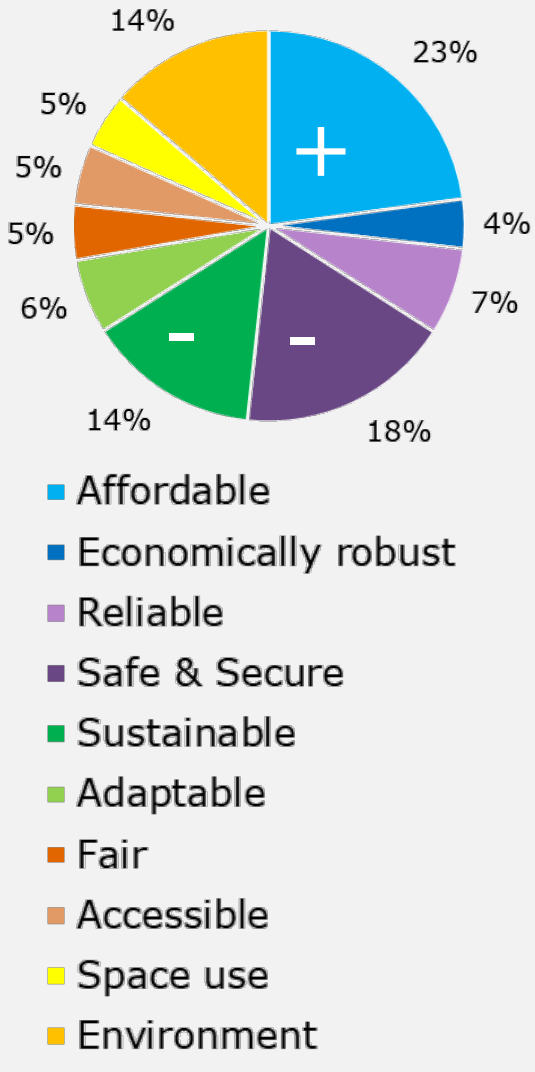


- Outcome of process with 21 participants from government, public organisations, industry organisations, knowledge institutes, NGO's.
- Analytical Hierarchy Process (AHP): pairwise comparison alternatives.

Weighting has a large impact on the final scores: example end use hydrogen







Conclusions other situations; location of end use and reference year can change results

End use at Port of Entry

- No impact inland transport – overall higher scores public interests.
- Significant improvement:
  - Ammonia – impact inland transport risks,
  - LOHCs - costs and externalities of domestic transport are relatively large.
- Limited shift in ranking.

Transit and export

- No impact of storage and conversion at the end-user – higher scores than baseline.
- Positive effect mainly on:
  - Ammonia - safety risks, environmental emissions, and space requirements decrease,
  - LOHCs - lower negative impact of decentralised installations on Adaptable, Space Use and Environment.

2050

- Significant improvement liquid hydrogen, sodium borohydride.
- LSM and methanol benefit greatly from the reduced CO_2 emissions from DAC.
- Top scores methanol chains in hydrogen end-use scenarios (direct use already highest scores).
- LSM chains similar scores to those of the LOHCs.
- Liquid hydrogen slightly lower than methanol.

Conclusions sensitivity analyses: CCS and conversion offshore may be attractive

≈	JRC import cost data instead of HyDelta	■ Import costs dominant factor. Other data set changes scores (liquid hydrogen and LSM higher), LOHCs and methanol (slightly lower) but ranking in general same.
≈	Import from Argentina instead of Morocco	■ Importing carriers from farther afield has very little impact on the final scores and ranking.
≈	Progressive assumptions energy loss 2050	■ Reduced energy loss in conversion results in slightly higher scores but a minimal impact on the relative positions/ranking final scores.
!	Storage and conversion offshore	■ Offshore storage and conversion could be advantageous for carriers with high safety and security risks; higher score ammonia, in particular for centralised conversion.
!	Use of Carbon Capture & Storage (CCS)	■ Import of carbon-based carriers (methanol and LSM) for hydrogen end use attractive option with CCS. The final scores improve significantly; methanol highest scores.

Thank you for your attention
Any questions?

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For more information:

Gigi van Rhee

Stratelligence

Rijnsburgerweg 161

2334 BP Leiden

The Netherlands

+31 6 20634076

vanrhee@stratelligence.nl