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ORCID: <https://orcid.org/0000-0003-2432-2357>



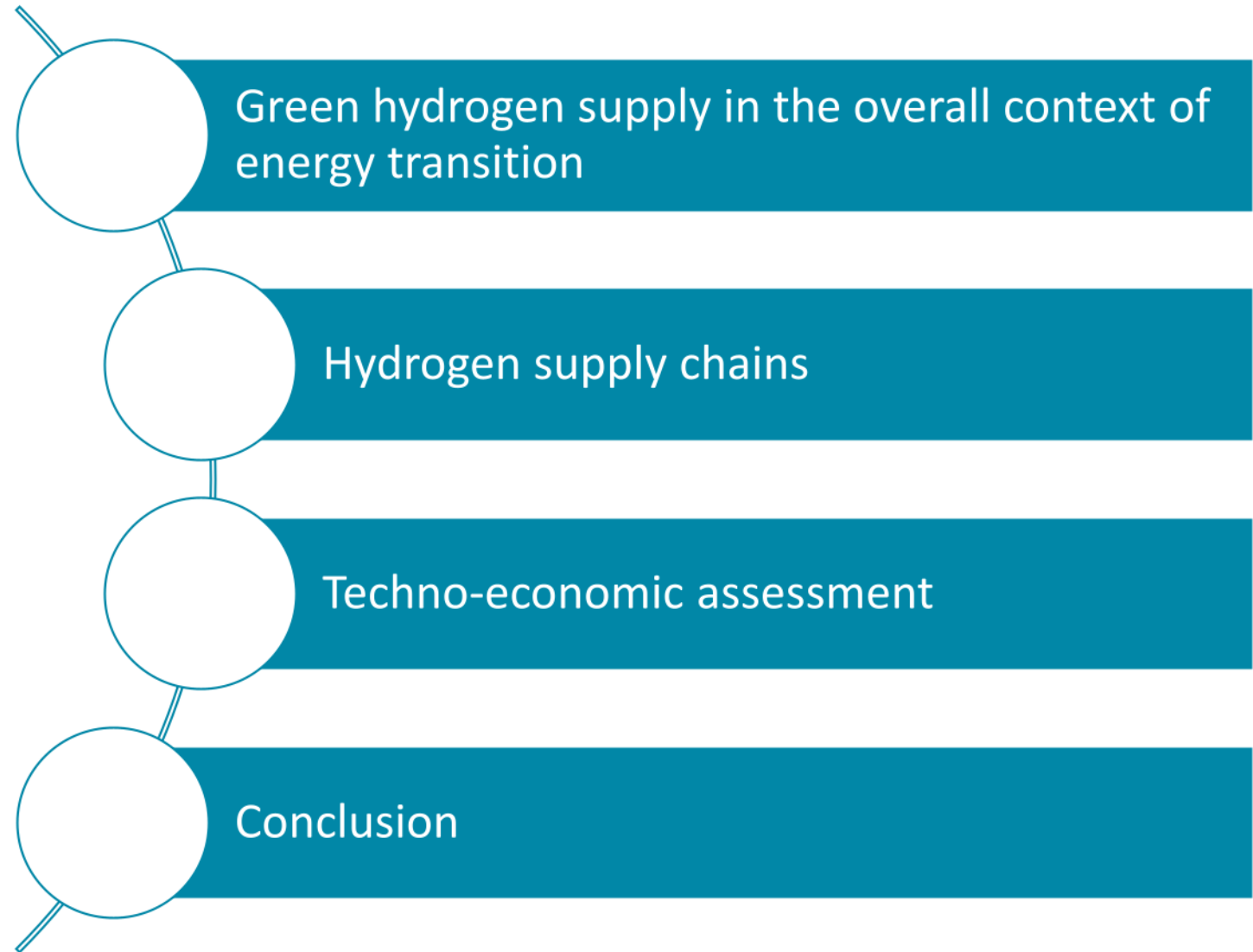
Springschool Hydrogen Technology 2024, Heide
18.03.2024

Green Hydrogen Supply Chains

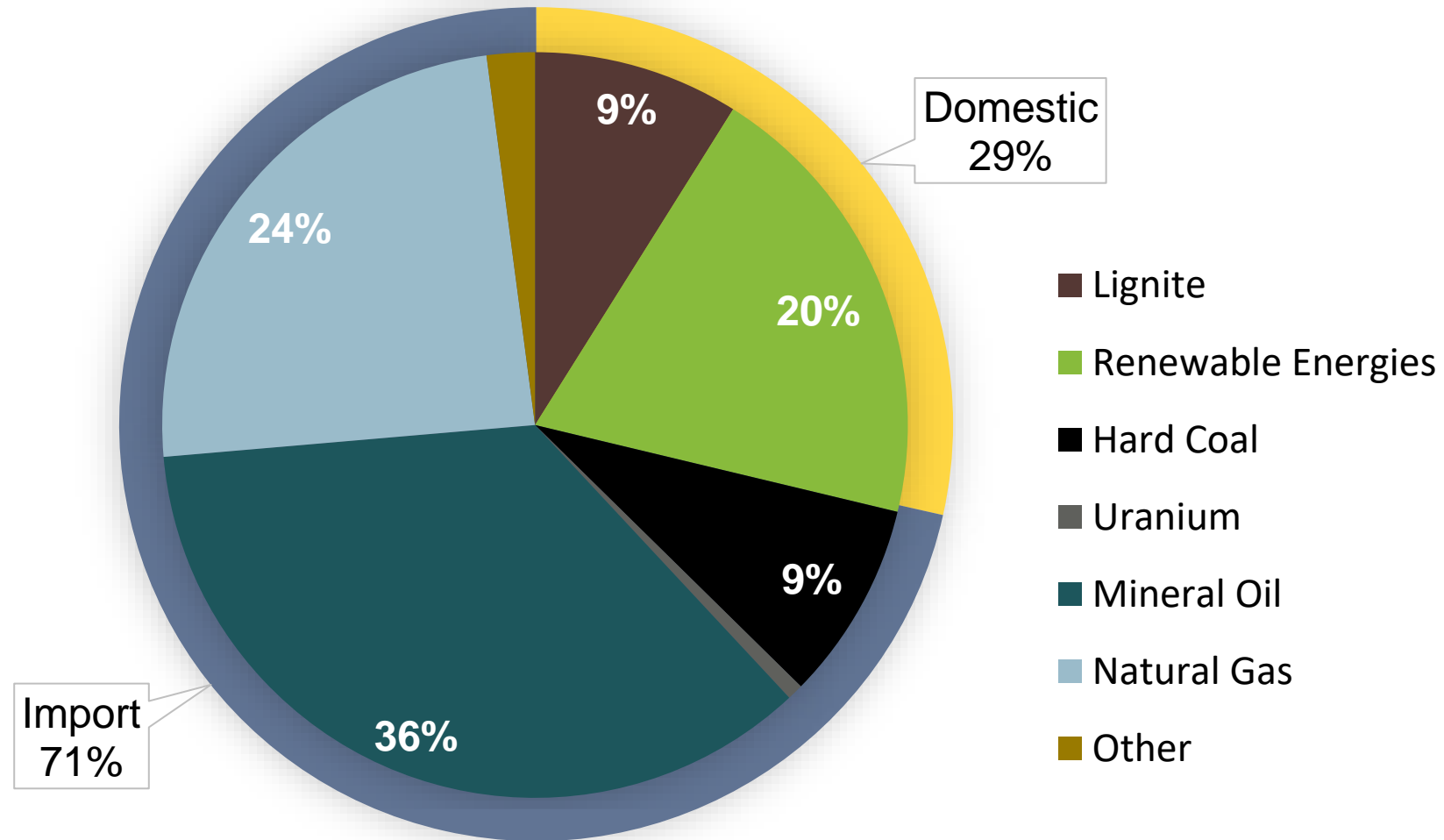
– A Techno-economic Assessment –

Fabian Carels, Lucas Sens, Martin Kaltschmitt

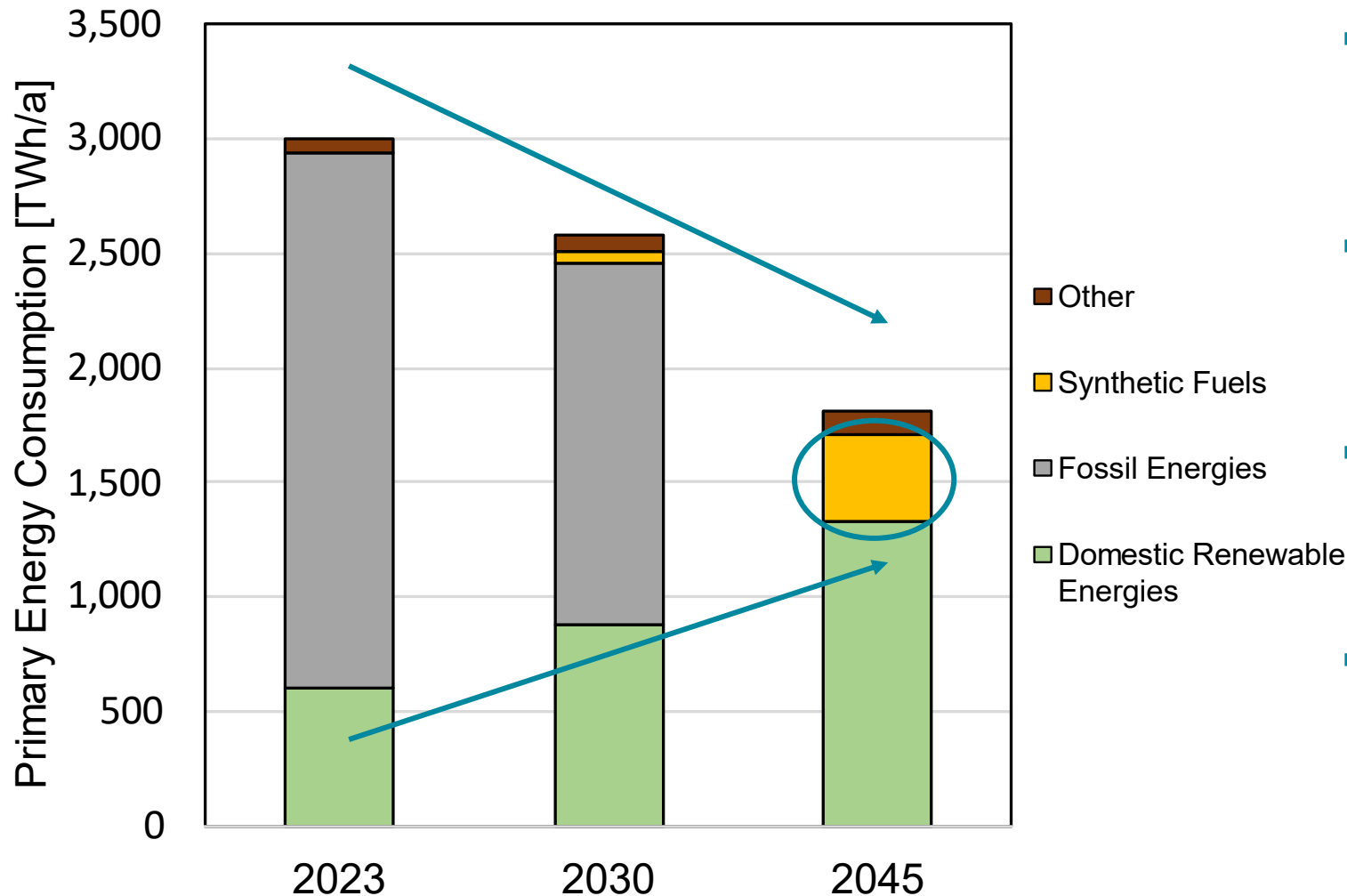
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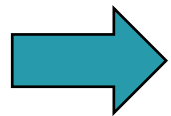
Total Primary Energy Consumption in 2023 – 2.997 TWh



Germany's Energy Supply – In a Climate-Neutral Future

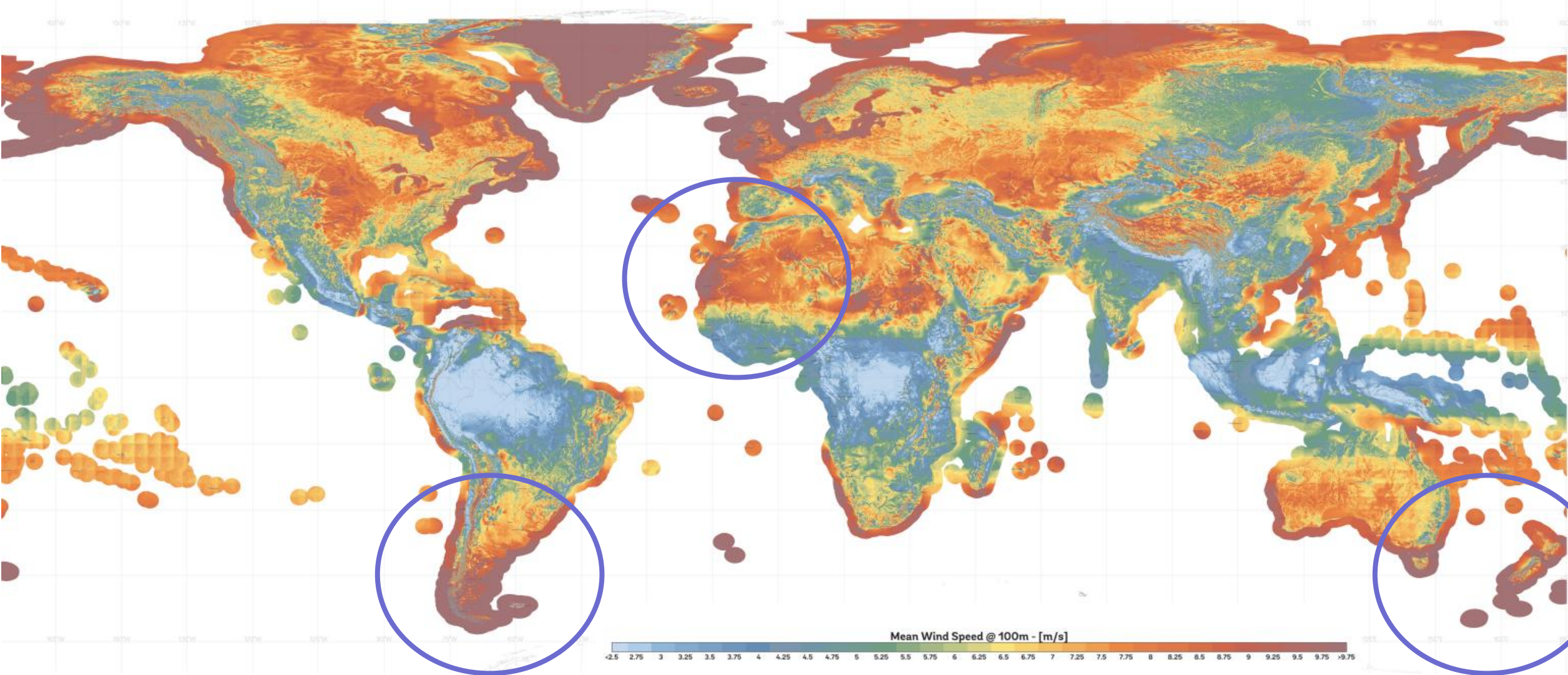


- Energy efficiency measures and electrification lead to a reduction in primary energy demand.
- Electricity from domestic wind and solar energy will become the central pillar of energy supply.
- PV and wind power capacities must quadruple (from 150 to ~600 GW) to supply the required renewable energy.
- An **additional** PV and wind capacity of ~300 GW would be needed to fully produce the required synthetic fuels domestically.

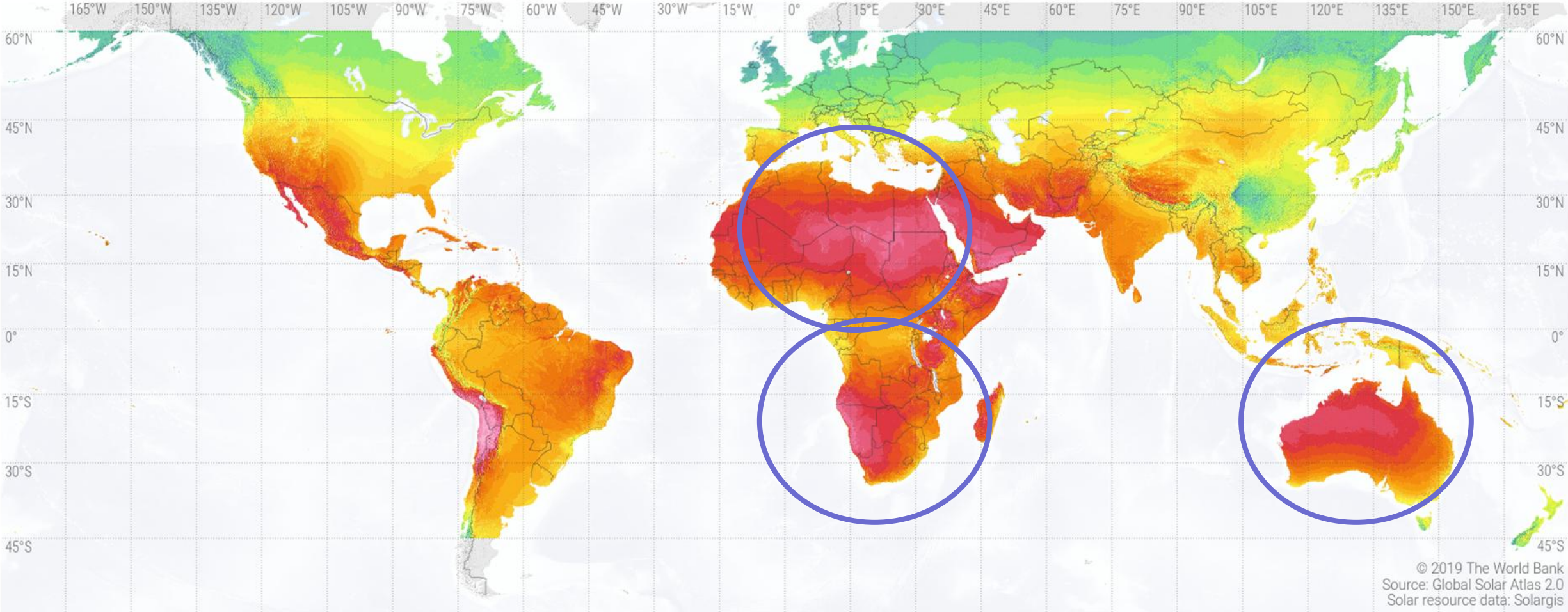


Defossilization of energy supply using only domestic renewables is theoretically possible, but hardly practicable. Importing renewable energy will likely be crucial for Germany's future energy system.

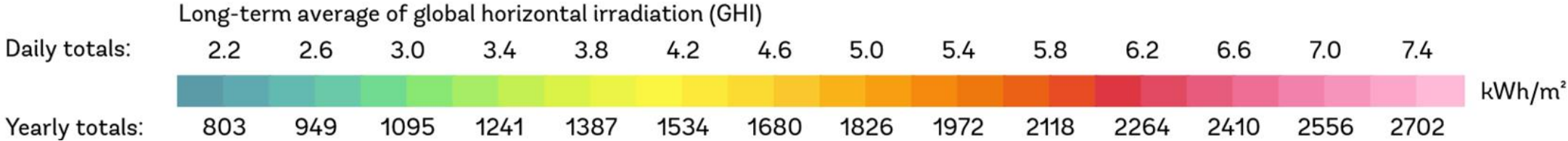
Global Availability of Renewable Energies – Wind



Global Availability of Renewable Energies – Solar Radiation



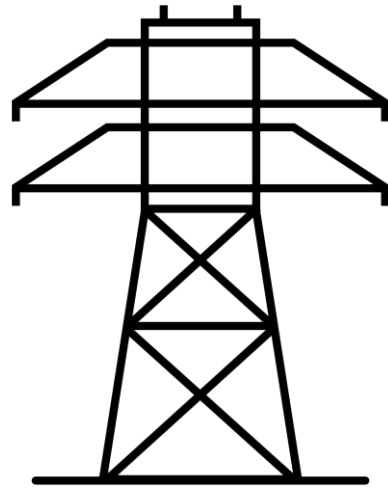
© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis



„Green“ electricity

Benefits

- ❖ No / very low conversion losses
- ❖ All technology components available on a large scale



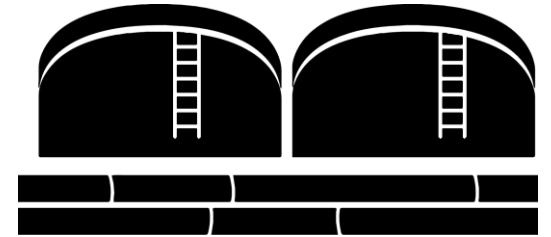
Limitations & Challenges

- ❖ Bound to inflexible infrastructure (power lines),
→ overseas transport not/barely possible
- ❖ Some sectors can't be electrified (e.g., aviation, steel)
- ❖ Large-scale storage technology not yet available (except pumped storage power plants)

„Green“ molecules

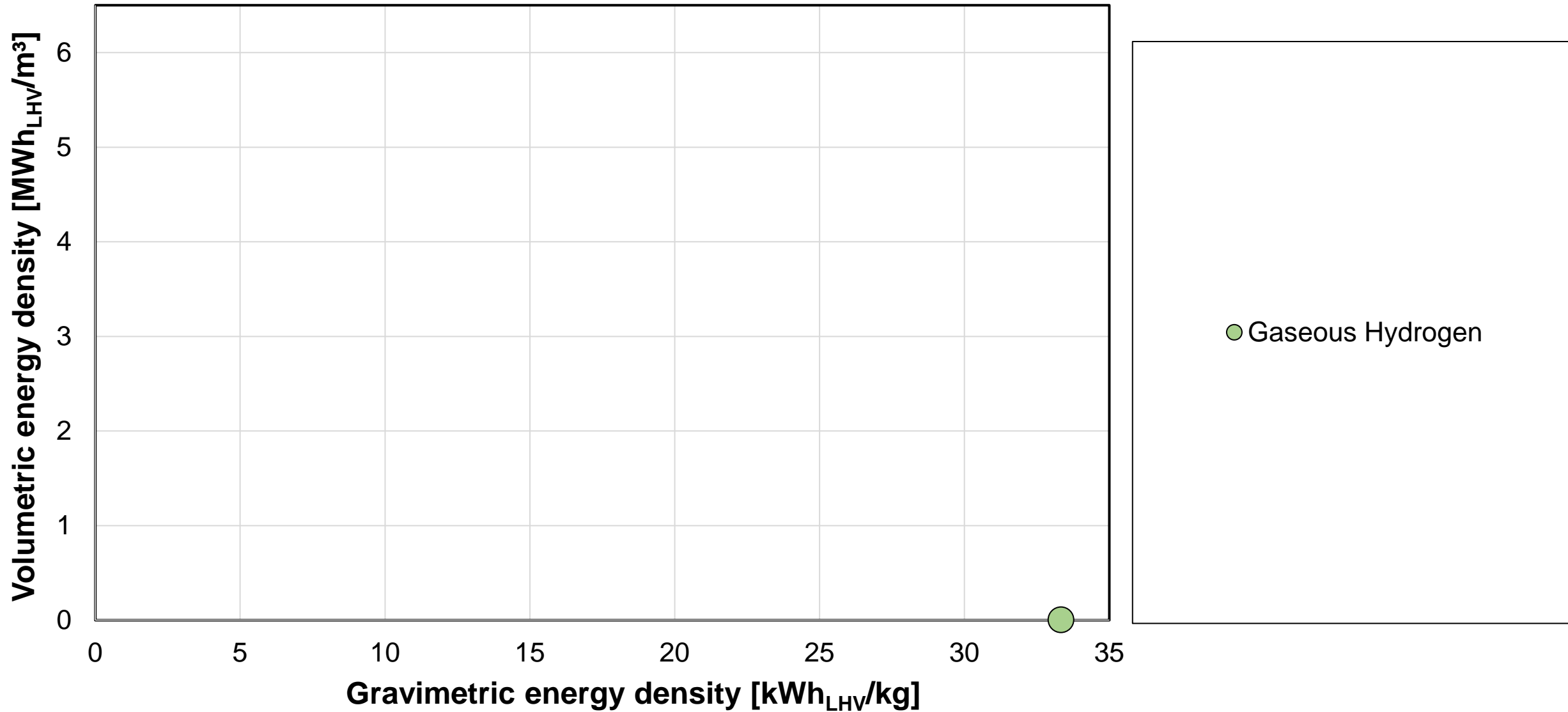
Benefits

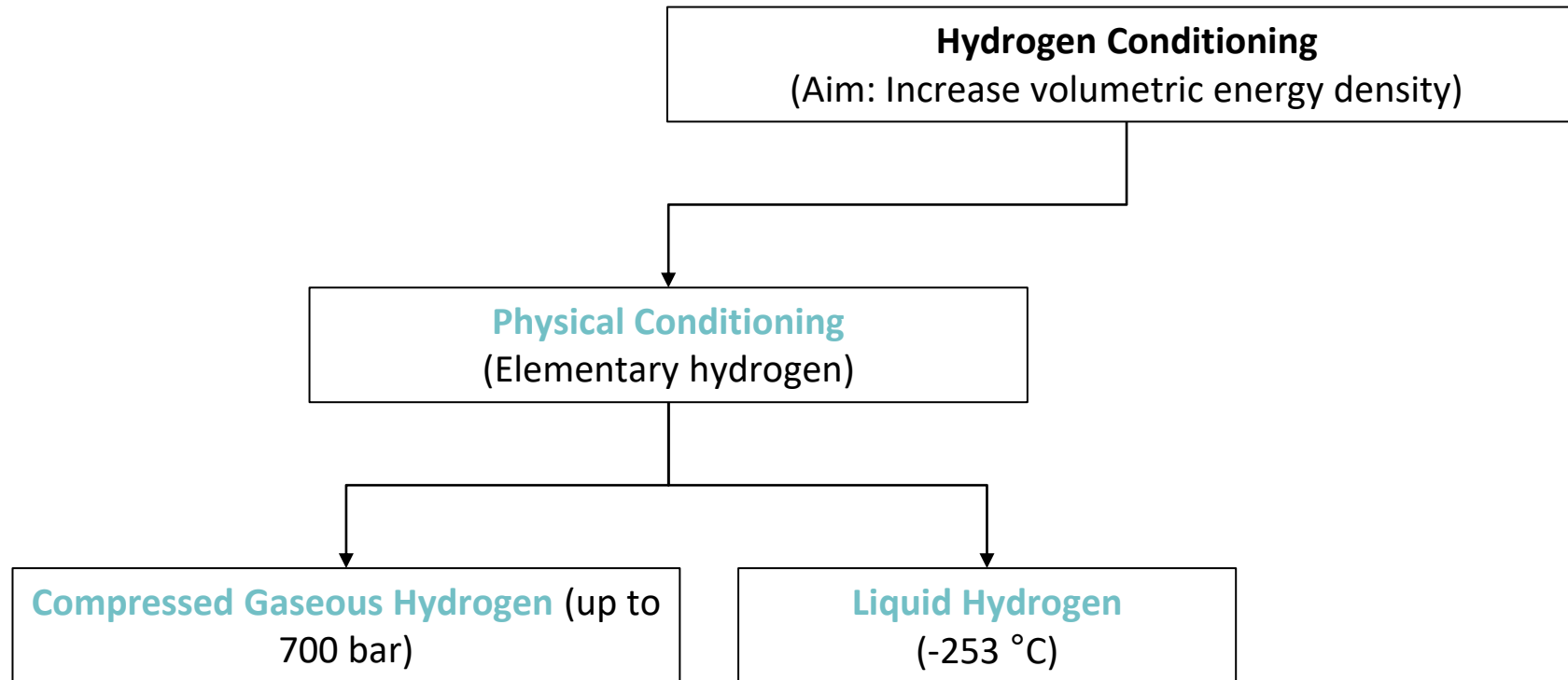
- ❖ Easy integration of large-scale energy storage
- ❖ Development of flexible, global markets possible
- ❖ Use of hydrogen and/or hydrogen derivatives is potentially in (nearly) all sectors possible

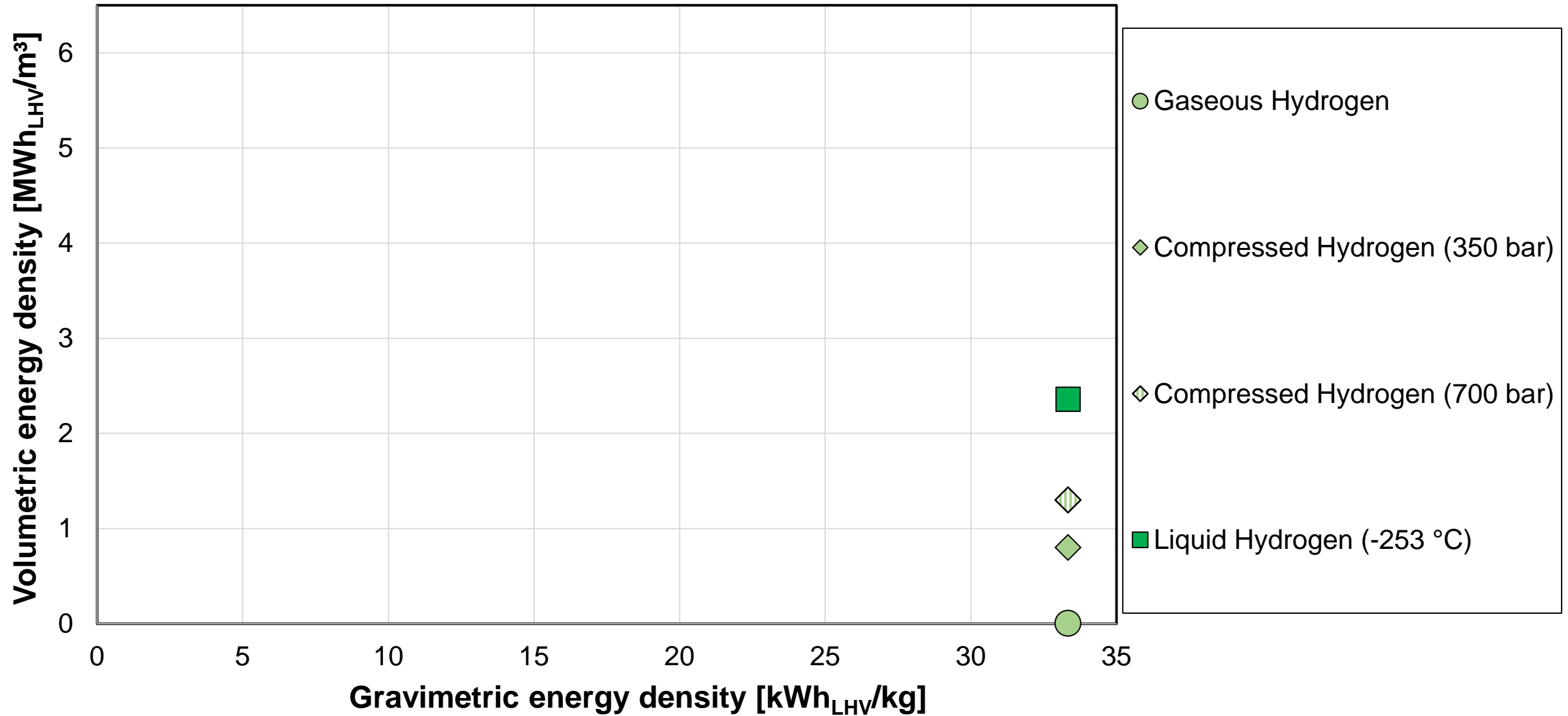


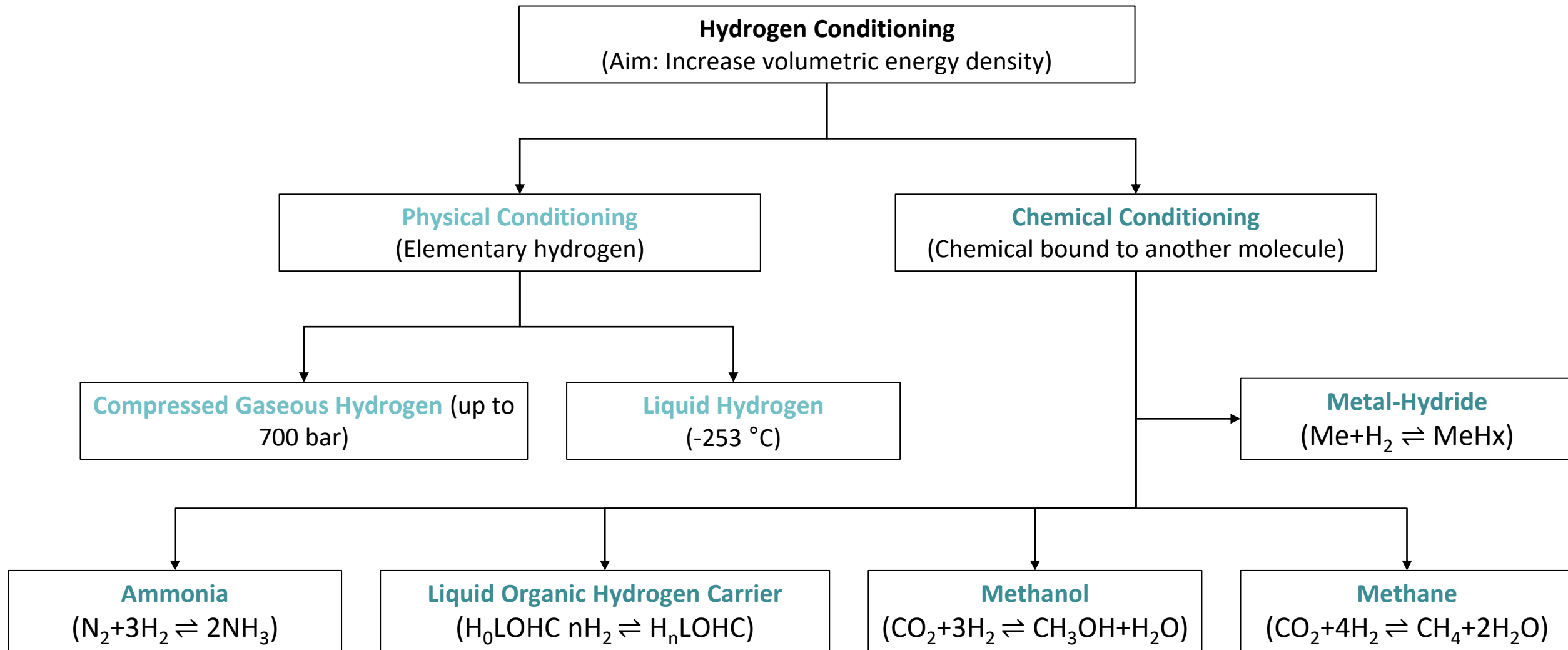
Limitations & Challenges

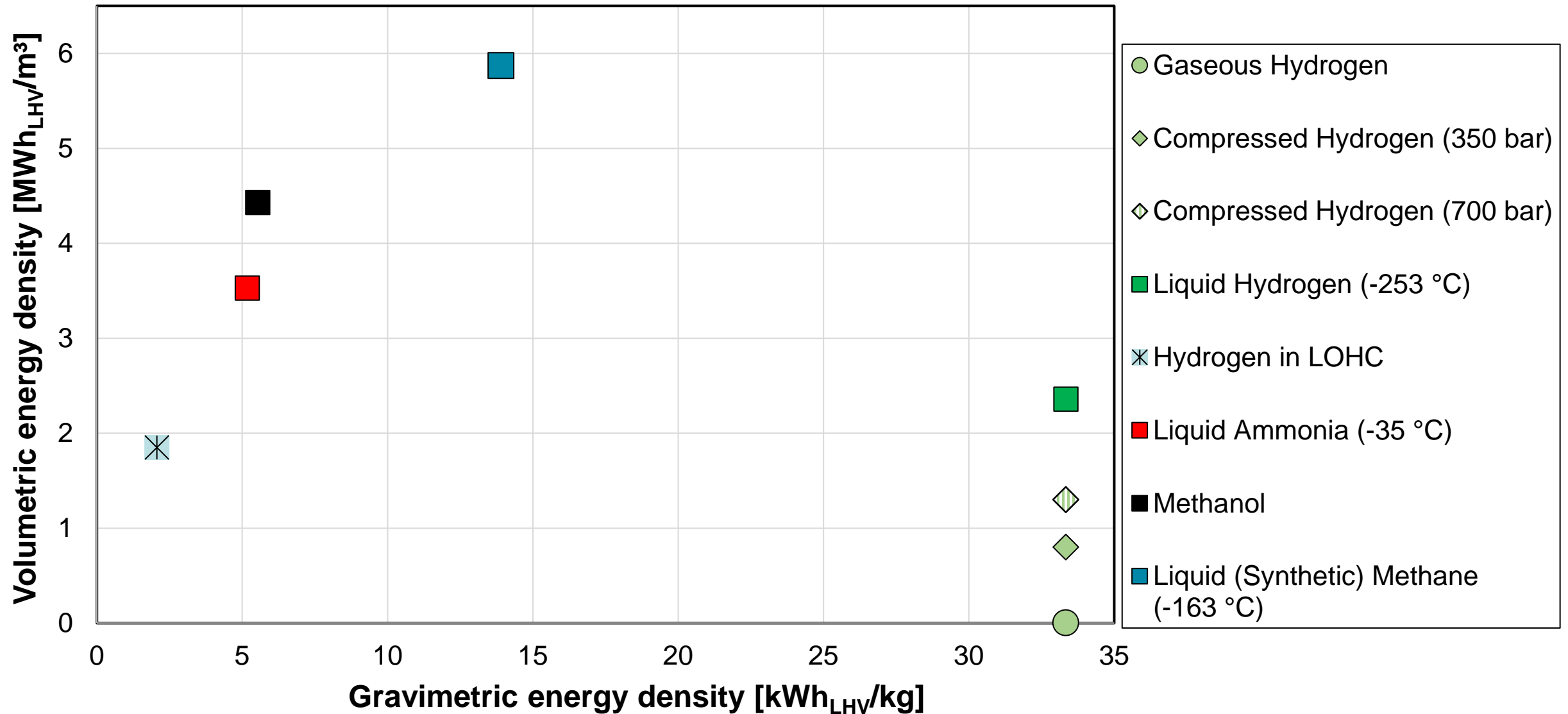
- ❖ Necessarily losses due to conversion from electrical energy into hydrogen and/or hydrogen derivatives
- ❖ Technological readiness and/or availability of some components currently not yet given



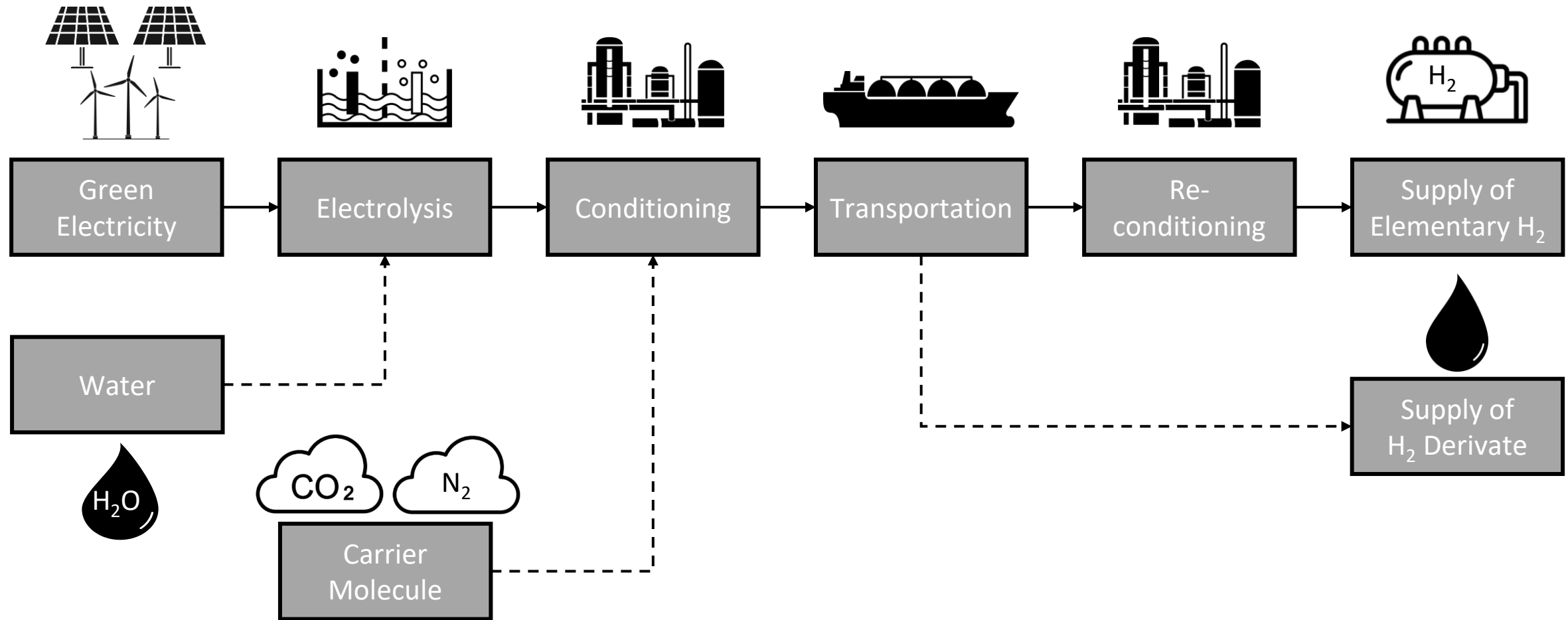




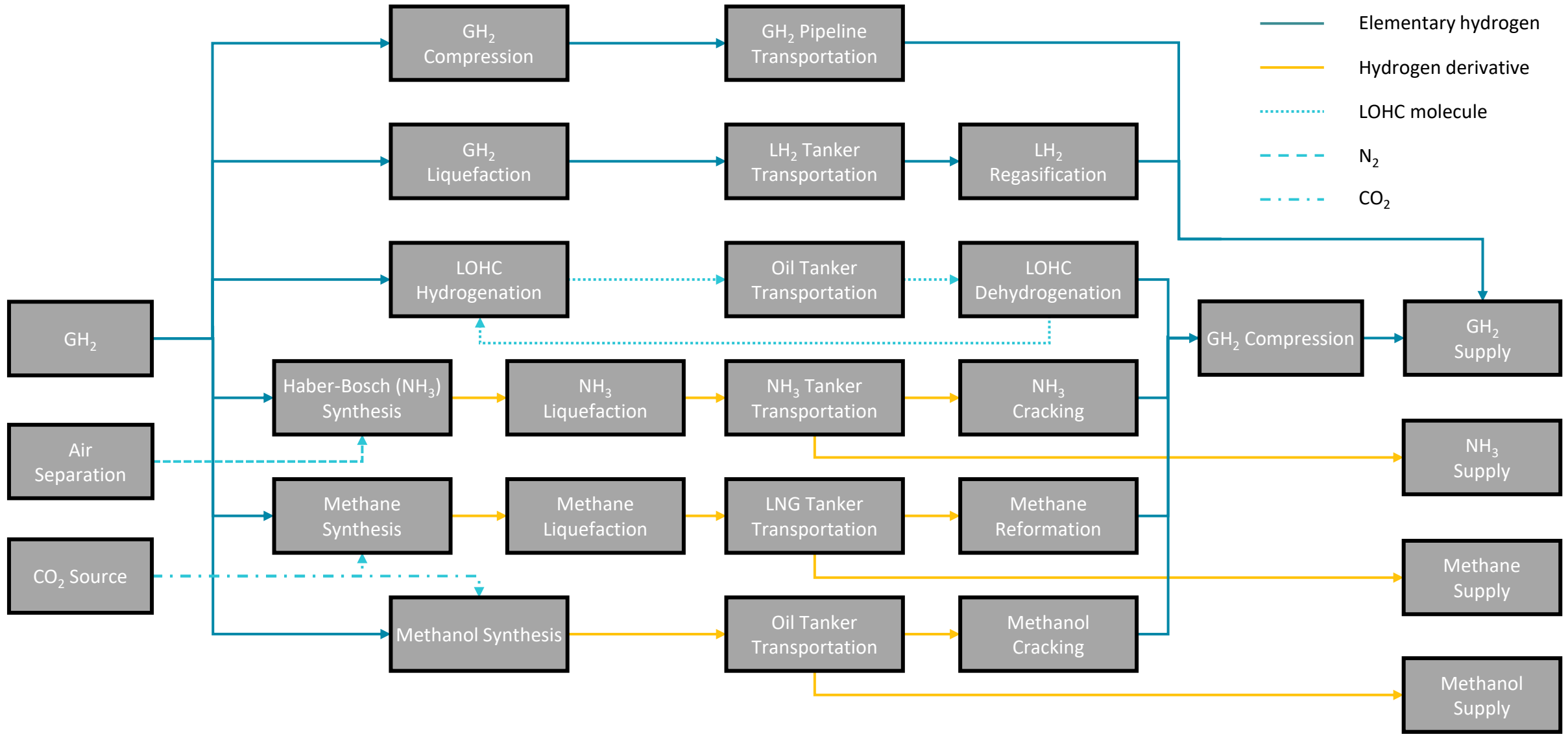




Energy Supply Chains based on Hydrogen



Energy Supply Chains based on Hydrogen

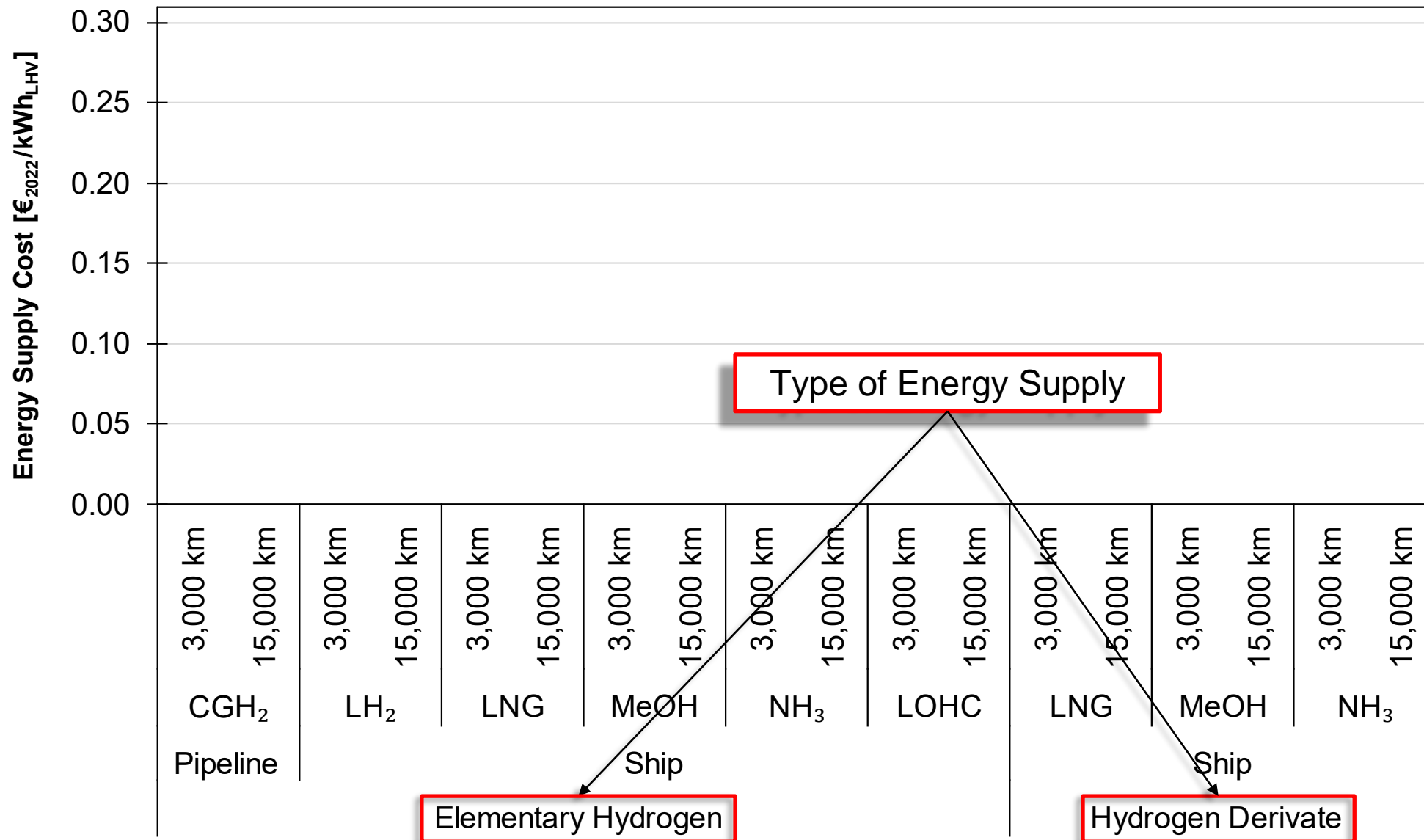


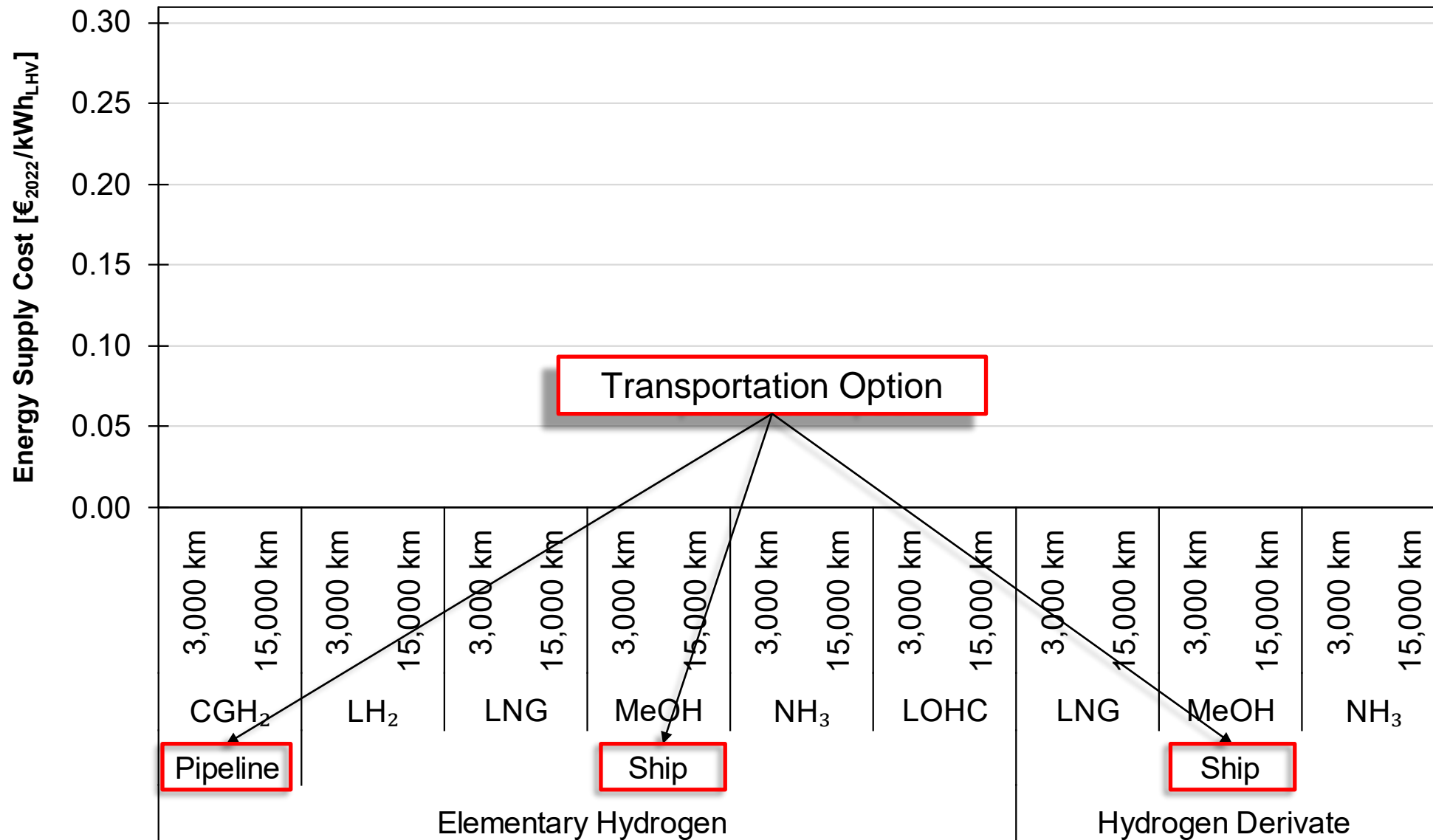
Approach

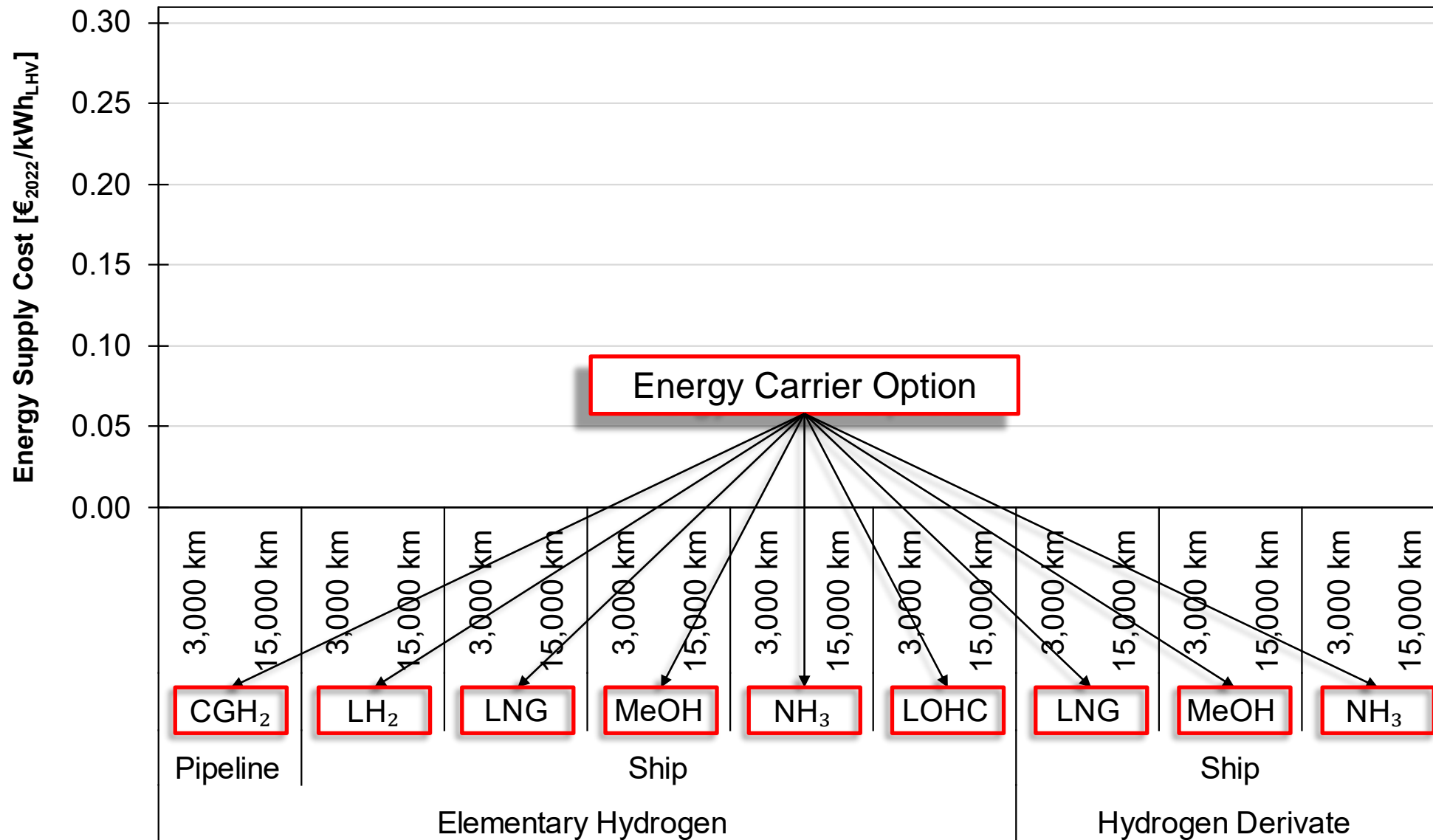
- Annuity method
- Depreciation time = technology lifetime
- Real weighted average cost of capital (WACC) = 6%
- Time horizon: Year 2035 (large scale technology roll out assumed)

Assumptions

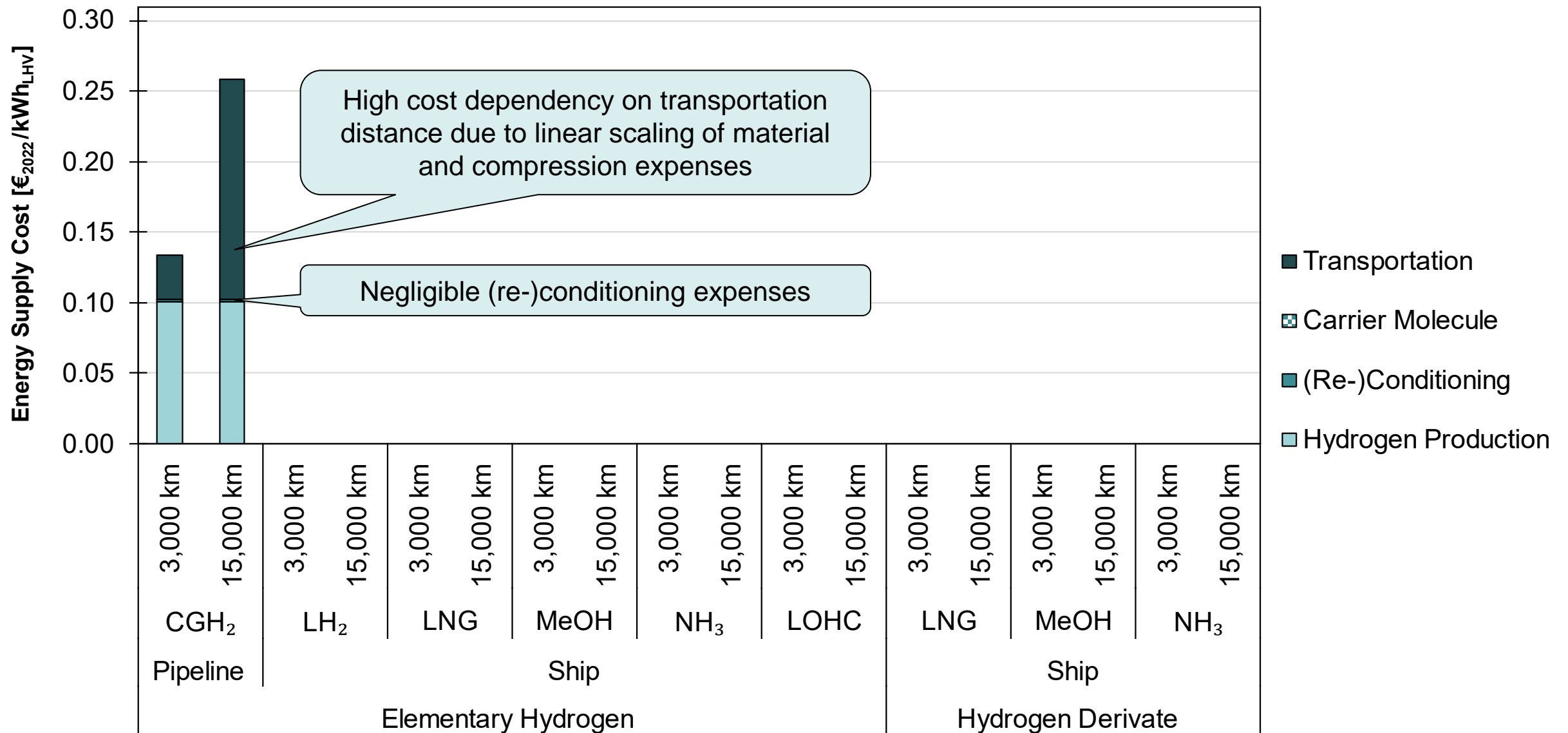
- Techno-economic parameters based on
- Cost of gaseous hydrogen at the point-of-export: $3.35 \text{ €}_{2022}/\text{kg}_{\text{H}_2}$
- CO_2 supply via DAC considering the integration of synthesis waste heat leading to cost between 130 €_{2022} and $150 \text{ €}_{2022}/\text{t}_{\text{CO}_2}$
- Internal heat supply for reconversion to hydrogen



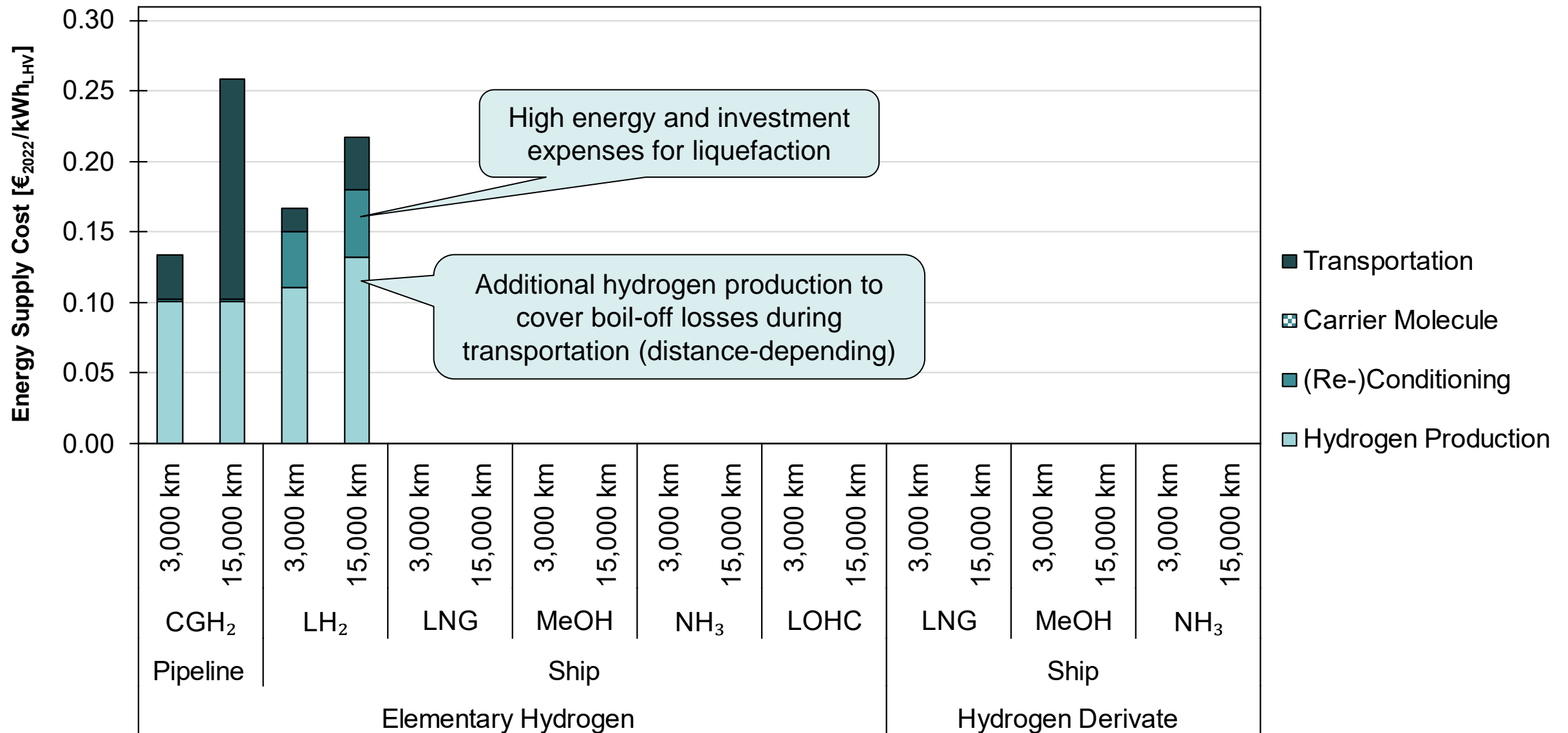




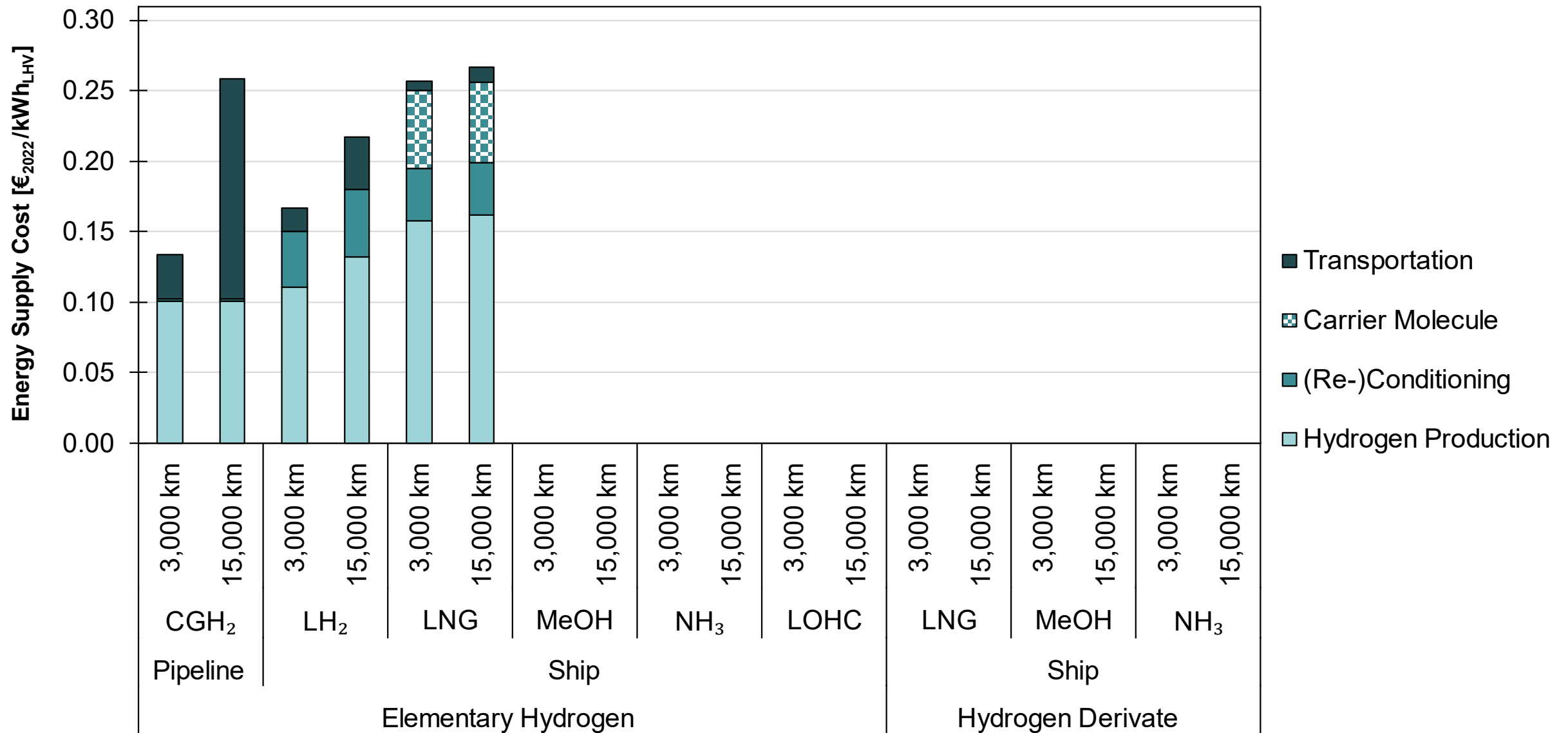
Energy Supply Cost



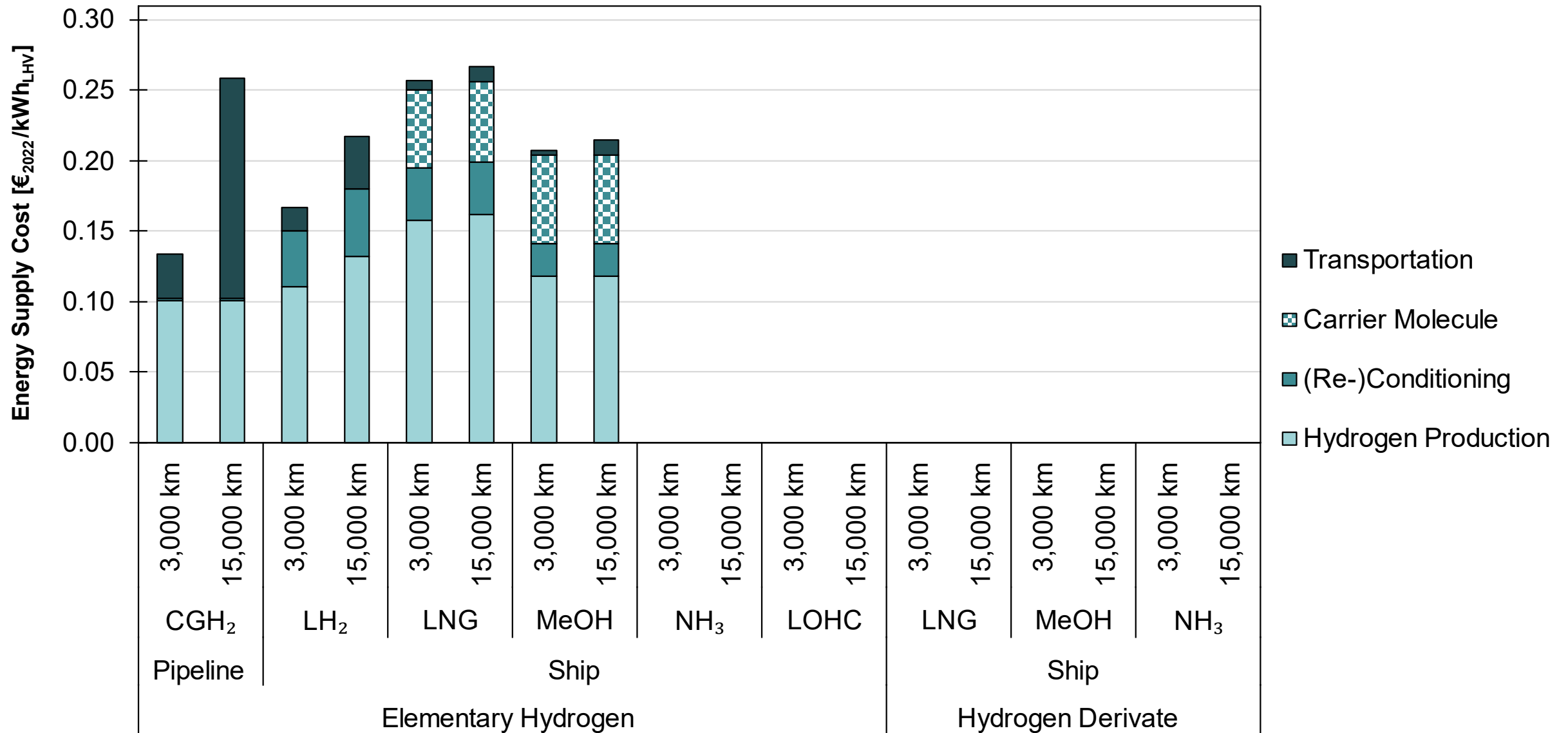
Energy Supply Cost



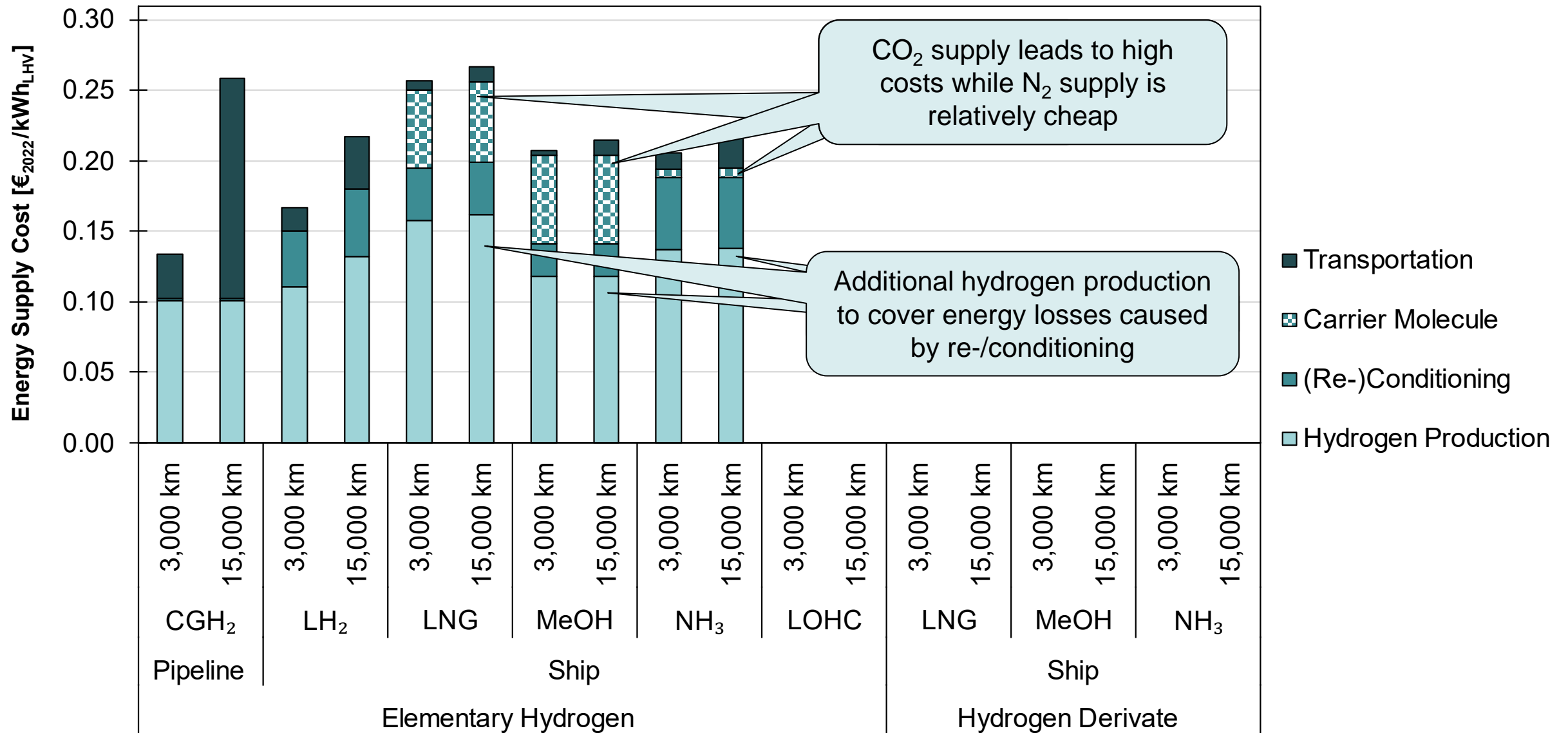
Energy Supply Cost



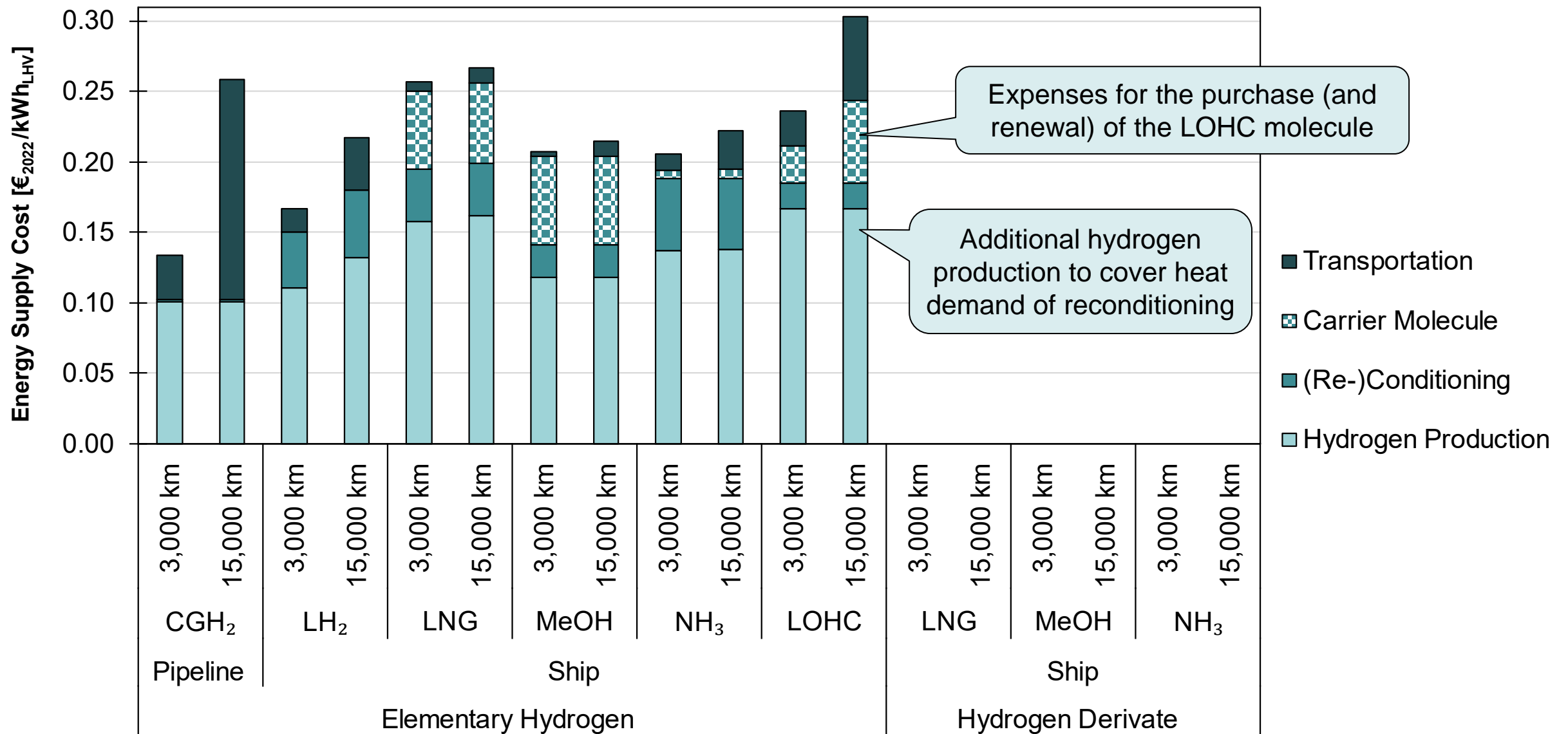
Energy Supply Cost



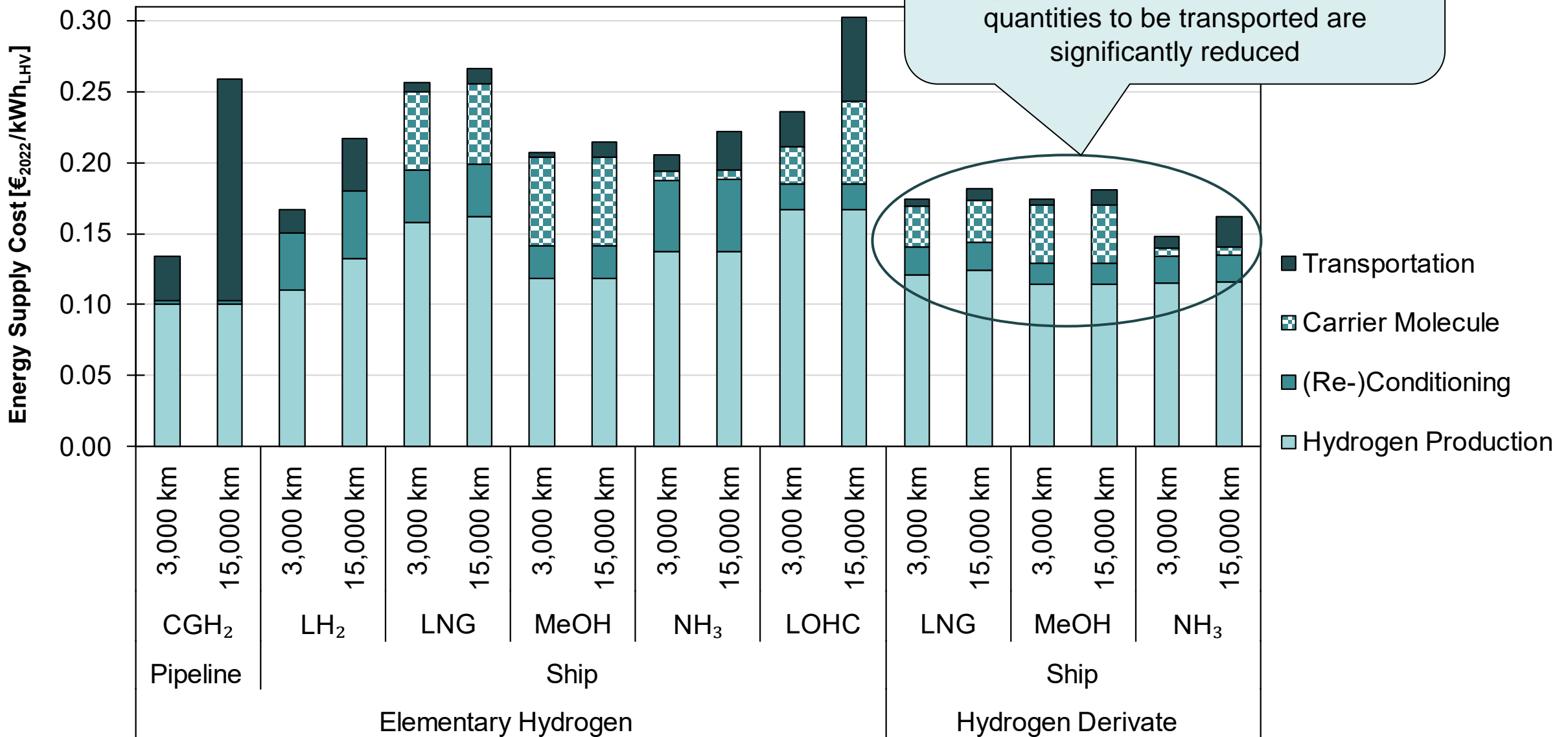
Energy Supply Cost

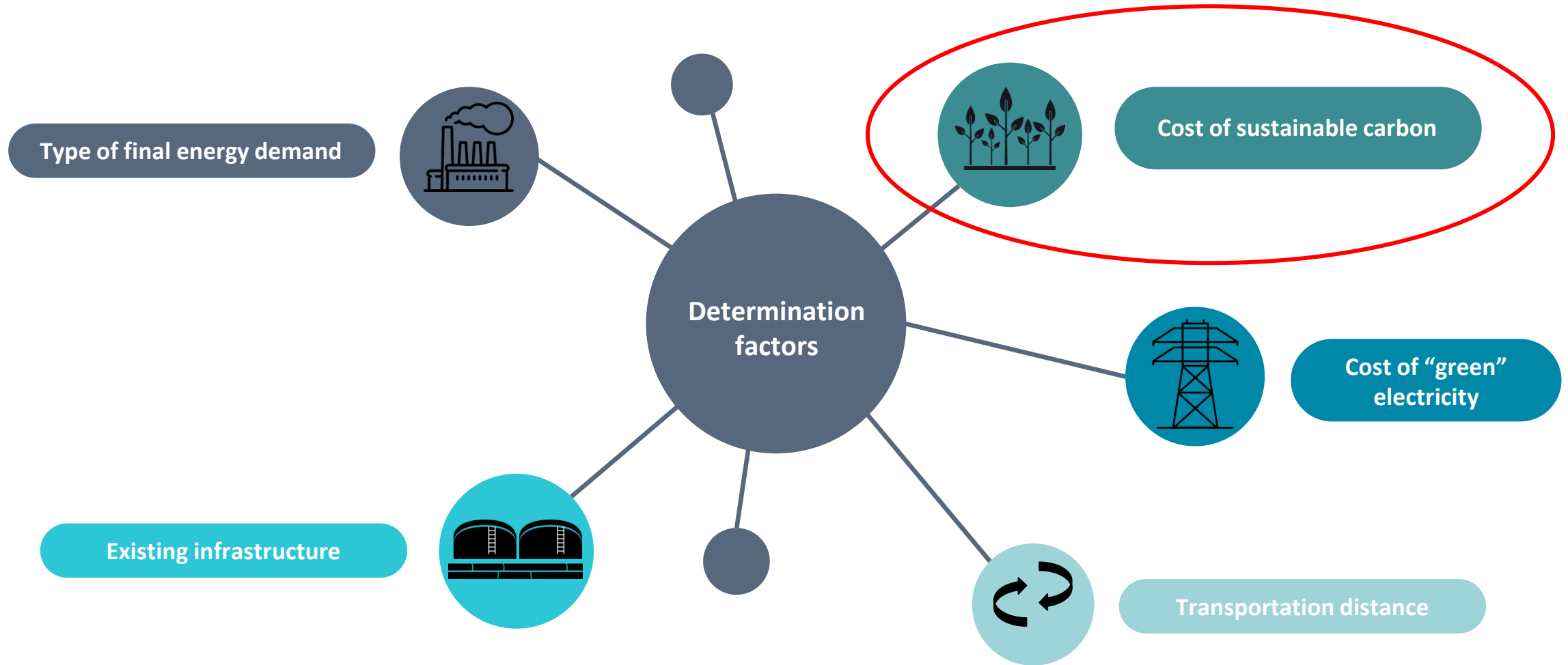


Energy Supply Cost



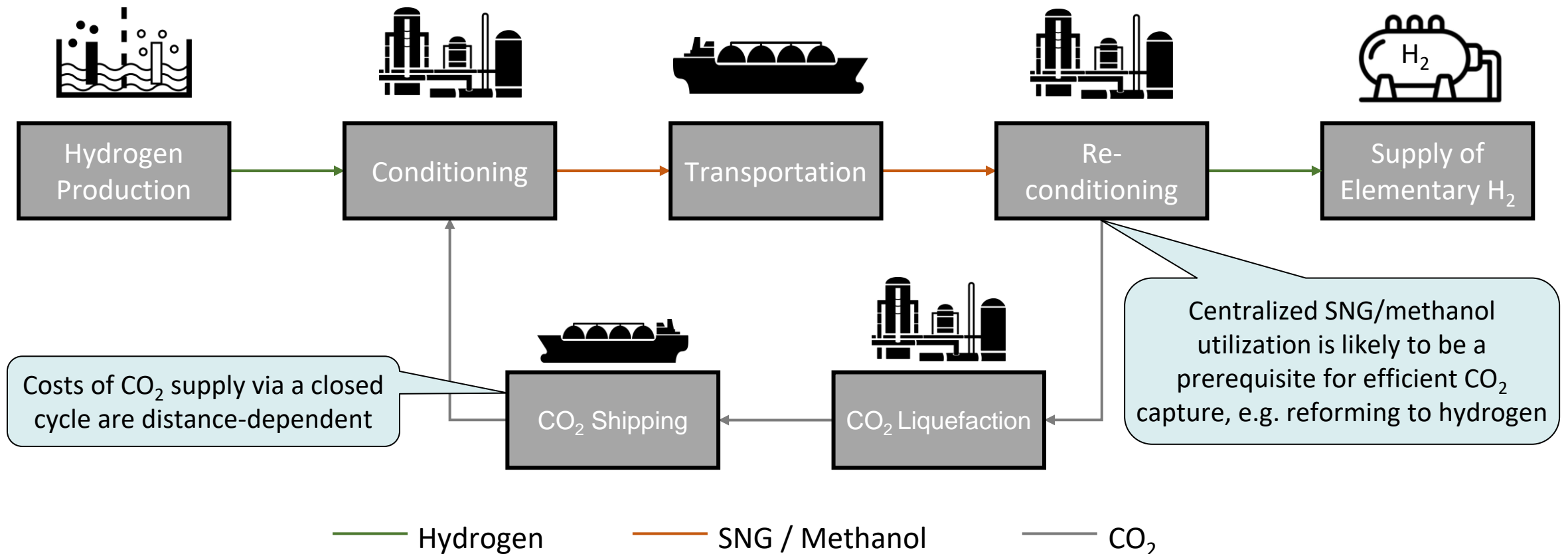
Energy Supply Cost



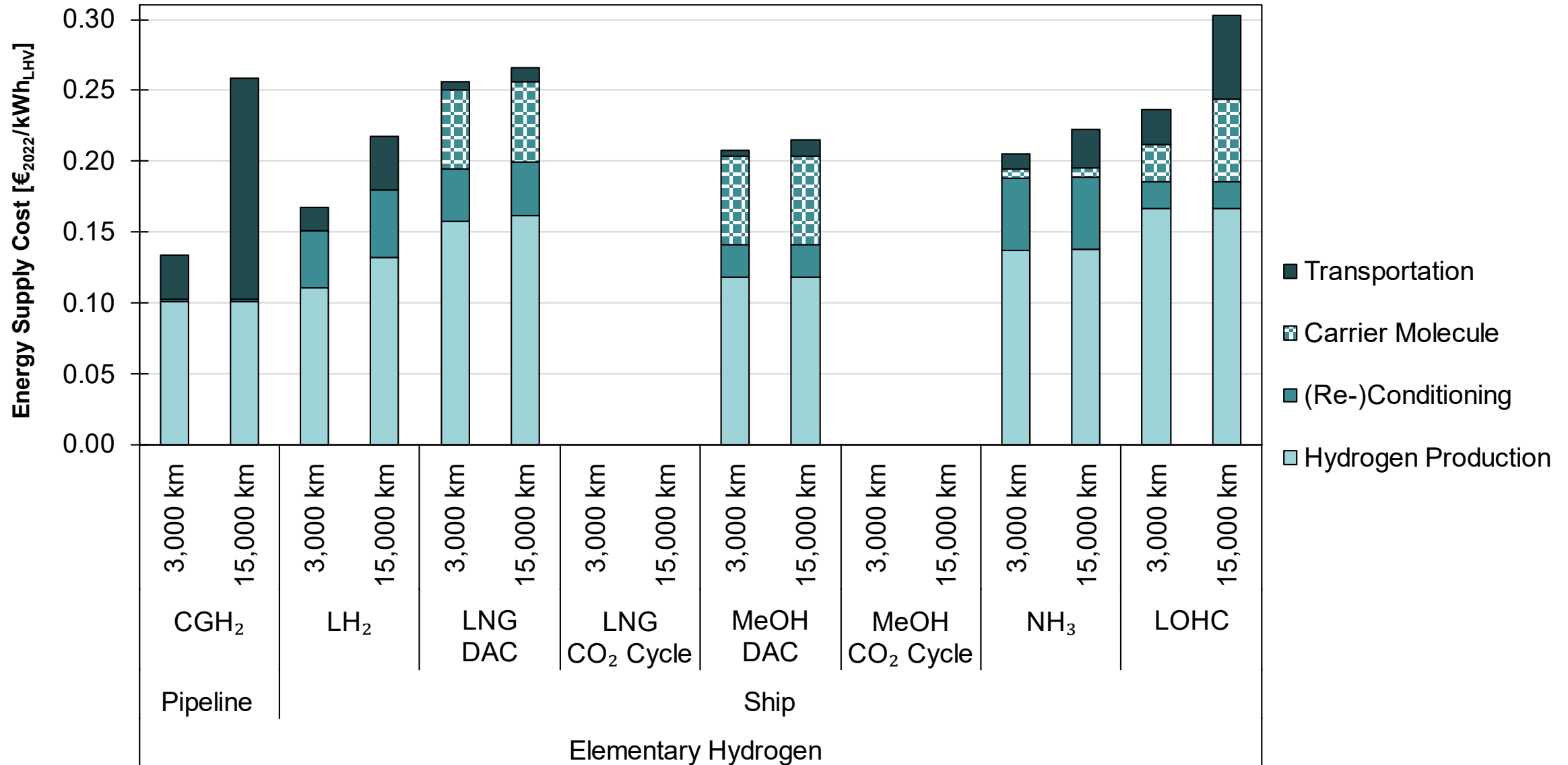


Energy Supply Cost – Implementing Closed CO₂ Cycles

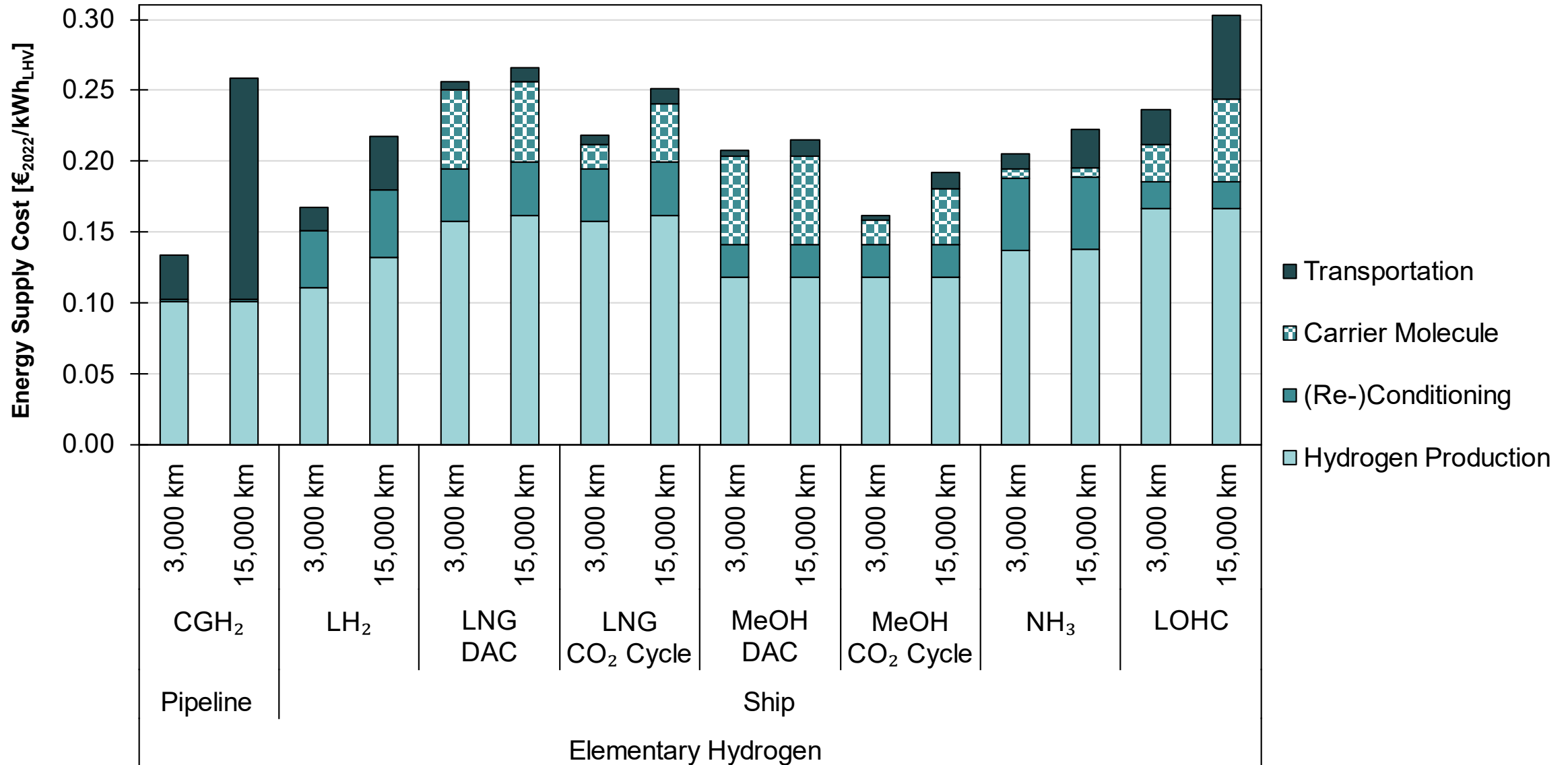
Closed CO₂ cycles can be a way to reduce the cost of CO₂ provision and thereby the cost of energy supply based on green carbon-based carriers.



Energy Supply Cost – Implementing Closed CO₂ Cycles



Energy Supply Cost – Implementing Closed CO₂ Cycles



- The import of hydrogen and/or hydrogen-based energy carriers will in all likelihood play a crucial role in a defossilized energy supply.
- For shorter distances, the import of gaseous hydrogen via pipelines ($< 0.14 \text{ €}_{2022}/\text{kWh}_{\text{LHV}}$) and of liquid hydrogen via ship ($\approx 0.16 \text{ €}_{2022}/\text{kWh}_{\text{LHV}}$) obtain the lowest energy supply cost.
- Supply of elementary hydrogen based on hydrogen carrier molecules imported via ships generally shows higher costs. Hence, supply costs are less dependent on transportation distance.
- If hydrogen derivatives are supplied, the energy supply cost can be decrease significantly ($\approx 0.15 \text{ €}_{2022}/\text{kWh}_{\text{LHV}}$), since the energy and cost intensive recondition process is not needed.
- Energy supply based on green hydrocarbons is significantly influenced by the cost of CO_2 provision. The implementation of a closed CO_2 cycle might reduce the overall energy supply cost.

Questions and Discussion

Fabian Carels M.Sc.
Technische Universität Hamburg (TUHH)
Institut für Umwelttechnik und Energiewirtschaft (IUE)
Eißendorfer Str. 40, D-21073 Hamburg
+49 40 42878 4293 | fabian.carels@tuhh.de | www.tuhh.de/iue