Economic analysis and comparison of three large-scale physical hydrogen storage and transportation methods

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Abstract

Hydrogen has a low density under ambient conditions and faces challenges in storage and transportation. Accordingly, a variety of high-density hydrogen storage and transportation methods exist, including compressed gaseous hydrogen, liquid hydrogen, and cryo-compressed hydrogen. Nevertheless, the cost comparison among the three methods remains unclear. Therefore, this paper presents an economic analysis of these three methods of hydrogen storage and transportation. Compressed gaseous hydrogen storage technology is more mature and widely used, but the economics are relatively poor. Liquid hydrogen is suitable for low electricity prices and long transportation distances. Cryo-compressed hydrogen is more advantageous at normal electricity prices and for short and medium distances. This provides a reference for the applicable range of cryo-compressed hydrogen storage and transportation mode.

Economic Calculation Boundary

Economic calculation boundary: compression/liquefaction/compression and refrigeration of feedstock hydrogen, which is then added to a gas-hydrogen trailer/liquid-hydrogen tanker and transported to a hydrogen refuelling station.

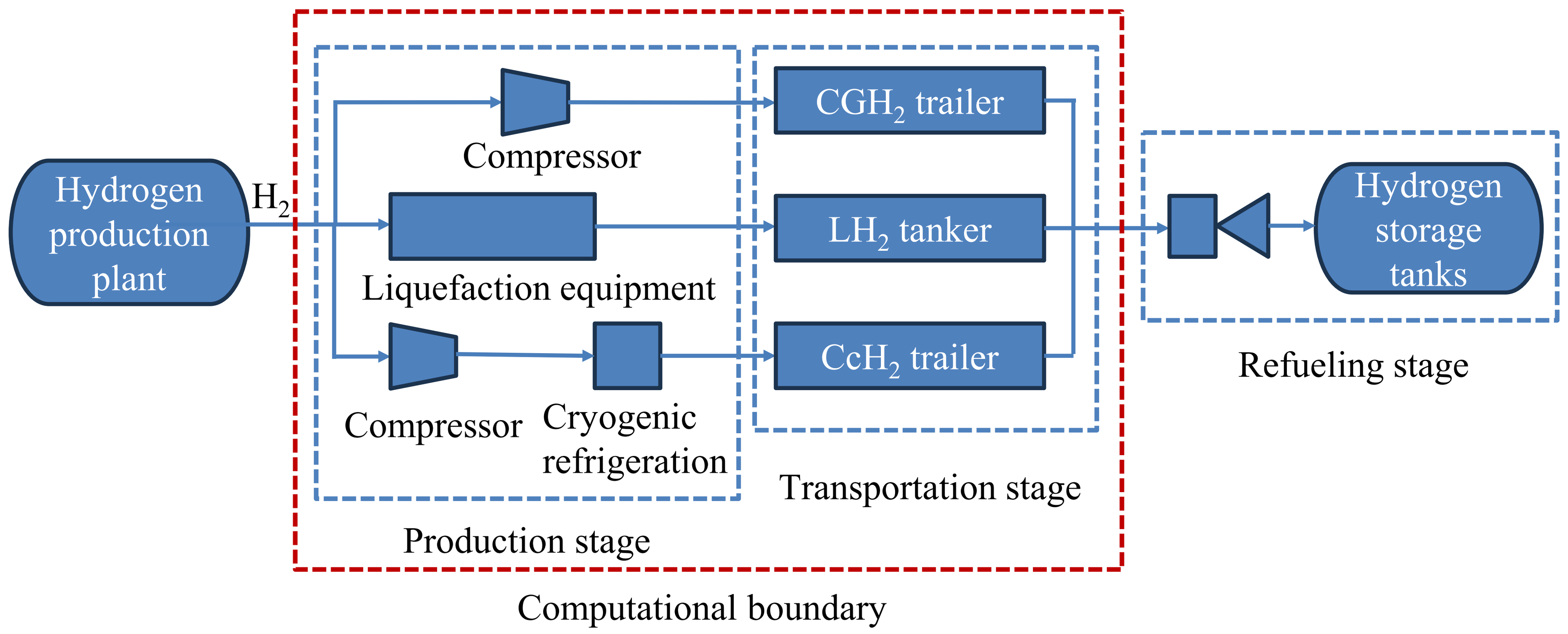


Table 1. Cost components of the studied hydrogen storage and transportation modes:

CGH_2	LH_2	CcH_2
Compressor	Liquefaction equipment	Compressor and cryogenic refrigeration
Compressed energy consumption	Liquefaction energy consumption	Compression and refrigeration energy consumption
Trailers / tankers		
Labor cost		
Fuel and vehicle maintenance costs		

Analysis Model

- The total consists of a production cost (C_P) and a transportation cost (C_T).

$$C = C_P + C_T$$

- The annual transportation of hydrogen is:

$$M = m(1-j-i)N_y$$

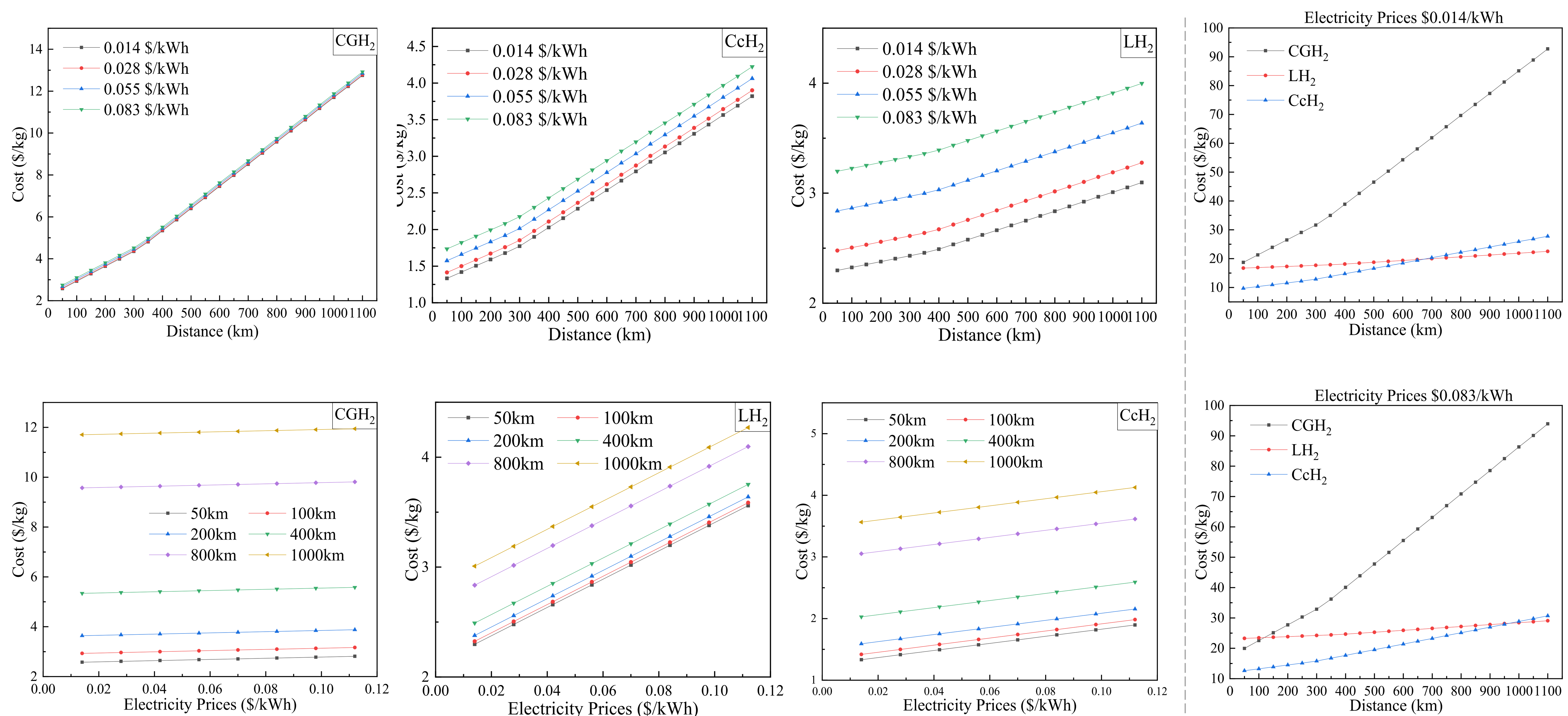
- The time required for one trailer transportation is:

$$T_S = \frac{2s}{v} + t_l + t_d$$

- Depreciation of each piece of equipment is:

$$E = E_b(1-E_r)/Y_D$$

Results and Discussion



- CGH_2: The cost curve is nearly linear with transportation distance. The unit cost is highly affected by changes in transportation distance, resulting in a steep cost curve.
- LH_2: LH_2 can transport large quantities of hydrogen at a time, so the unit cost is less sensitive to changes in transportation distance and the slope of the cost curve is slower. the high energy consumption of LH_2 liquefaction, which is highly sensitive to the price of electricity, results in a steeper slope of the cost curve.
- CcH_2: Both production and transportation costs are more balanced in their contribution to the total cost. As a result, the unit cost is more evenly affected by both transportation distance and varying electricity prices.

- Electricity price $0.083 /kWh: LH2 is advantageous for long-distance transport, with CcH2 excelling in medium to short distances.
- Electricity price of $0.014 /kWh: CGH2 has the highest unit cost, while LH2 extends its feasible transport range and CcH2 maintains its short-distance advantage.

Conclusion

- CGH_2 storage technology is relatively mature and widely applied; however, its economic efficiency could be improved.
- The unit cost of LH_2 is sensitive to production cost. LH_2 is suitable for scenarios with low electricity prices and long-distance transportation. For instance, at an electricity price of $0.014/kWh, LH_2 demonstrates advantages when transporting distances exceed 700 km.
- The effect of each factor on CcH_2 is more balanced. CcH_2 is more advantageous under normal tariffs and short- to medium-distance transportation. For example, at an electricity price of $0.083/kWh, CcH_2 storage shows lower unit costs for distances up to 950 km.