Slush H_2 for long-distance shipping

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In a future global energy economy led by renewable sources, such as solar/wind, hydrogen will have a key role as an energy vector, requiring efficient methods to transport it over long distances – from production to utilization. It is estimated that about 50 percent of internationally traded hydrogen will be through maritime transport [1]. However, shipping hydrogen across long distances remains a challenging problem – e.g., long-distance hydrogen transport in the form of chemical carriers (ammonia and liquid organic hydrogen carriers—LOHC) may incur in high reconversion costs, as well as potential toxicity and larger CO_2 intensities [2]; pure hydrogen transported by means of liquefied hydrogen incurs in losses from boil-off during loading/transportation/unloading.

Slush hydrogen, a mixture of liquid and solid hydrogen, can potentially achieve all the benefits of using liquid hydrogen (low CO_2 intensity, high-purity, easy to gasify) while reducing boil-off, hence lower net energy costs. At mixtures of approximately 50% solid, a 15% increase in density and an 18% increase in refrigeration capacities can be obtained. Losses from boil-off can be significantly reduced by minimizing fluid sloshing and improving transfer characteristics (reduced fluid friction losses through pipes, valves, etc.). These improvements can be achieved at relatively moderate costs of production [3]. A specific energy of consumption (SEC) of 4.5 kWh/Kg was estimated for slush produced via the Auger method, accounting for the thermodynamically reversible energy [4]. Adding liquefaction, an SEC lower bound of ~ 18 kWh/Kg can be obtained, which is comparable to that of ammonia production via the Haber-Bosch process [5].

Our studies found that, assuming a cost of carrier synthesis proportional to the SEC of the process, and the resulting boil-offs being comparable to those of other chemical carriers, the projected resulting costs of slush synthesis/loading/transportation/unloading can be estimated in the range of 2-2.5 USD/kg. This is in the same range as the comparable costs for ammonia and LOHC, but without the drawbacks of the chemical carriers, and with more favorable economics overall than liquefied hydrogen. Further exergy analysis could improve our understanding of the scalability of hydrogen slush production.

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[4] Sherif, Sherif A., D. Yogi Goswami, EK Lee Stefanakos, and Aldo Steinfeld, eds. Handbook of hydrogen energy. CRC press, 2014.

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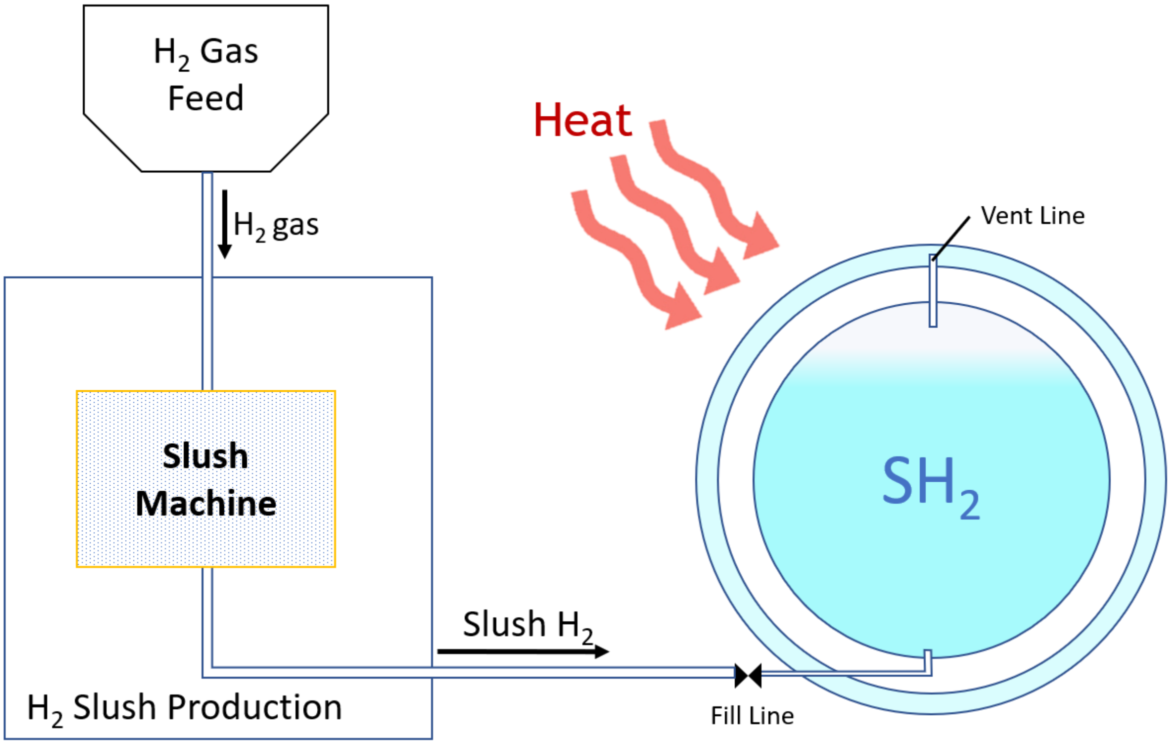

H_2 Gas Feed
H_2 gas
Slush Machine
Slush H_2
H_2 Slush Production
Heat
Vent Line
SH_2
Fill Line