EuroSun2026

HYDROGEN ENERGY STORAGE – PROSPECTS IN RENEWABLE (WIND) ENERGY DELIVERY – A REVIEW

Summary

In an effort to mitigate greenhouse gas emissions, renewable energy sources in energy supply are being advocated for. One such renewable energy source is wind energy, especially for countries that have significant wind resource (e.g. coastal regions). While renewable energy sources are clean, intermittence is their nature and this complicates the efforts of balancing supply and demand. The characteristics of excess wind power, its conversion and subsequent storage for later utilization are of importance. With the drive towards a renewable energy-intensive future energy supply, the paper reviews the technical and economic status of green hydrogen energy systems. There is potential competitiveness of the hydrogen storage through utilization of excess wind energy. Secondly, Hydrogen energy storage (HES) technologies are still to reach full maturity hence with more R&D, competitiveness can be achievable. The paper highlights the techno-economic potential of HES that aim to inspire further researches and development towards promoting wind-to-hydrogen implementations. With appropriate accounting of energy streams, energy return on investment (EROI) or Energy stored on energy investment ($ESOI_e$) analysis can be effectively applied to evaluate the hydrogen energy storage strategy.

Keywords: Energy, hydrogen energy storage, intermittent wind energy resource, return on energy investment

Field of application for the findings: The findings contribute to academic literature, research and development by way of highlighting possibilities and potential areas of improvement using simple analyses.

Addressed audience: ***academics, research and development, energy developers***

1. Introduction

Energy supply and its impact on the environment have been and remains a topical issue (Mohamad et al., 2018). To mitigate the impact of energy supply on the environment, renewable sources of energy have since become the focus of attention. These include wind energy resource among others such as solar, hydro, geothermal and biomass. Wind energy has experienced significant growth, approximately 600% growth over a period of ten years from 2005 to 2015 world over (Hou et al., 2017).

Integration of wind energy into the grid poses challenges due to the intermittent nature of the resource (Babic et al., 2017). Wind power integration to the grid calls for interventions to ensure supply/load matching, smoothening of power fluctuations, frequency support, in order to ensure reliability and quality. In the absence of storage significant amount of intermittent renewable energy would go to waste (Sinn, 2017). Electrical energy storage can be put into six main broad categories; mechanical, electrochemical, electrical, thermochemical, chemical and thermal (Luo et al., 2015). The choice depends on the storage system characteristics vis-a-vis the intended application.

2. Electrical energy storage

Energy storage is expected to play a central role in the transformation of the energy supply sector. Renewable energy sources such as wind are intermittent, hence requirement for some storage. A number of electricity storage technologies are available with varying characteristics. Multiplicity of options and characteristic spectra make it difficult to appraise available alternatives (Luo et al., 2015). Use of a storage type is dependent on its performance characteristics vis a vis intended application. High energy density (energy content per unit weight) 142MJ/kg, non-polluting nature of hydrogen makes it a favorable energy carrier (vector).

3.1. Hydrogen energy storage

Hydrogen energy storage systems based on water electrolysis are currently characterized by low efficiencies and high investments (Algburi et al., 2025). A number of researches are targeted on the reduction of noble metal use or complete substitution with alternative less expensive materials (Sun et al., 2018). Cost reduction is being given a great deal of attention since it is being viewed as one of the major obstacles towards economic viability of HES (Saba et al., 2018).

3.1.1. Electrolysis technology

Best performing industrial/commercial electrolyzers have electricity to hydrogen conversion efficiency of around 80% operating around 80-100ºC (Xiang et al., 2016). Under adiabatic conditions, the total enthalpy of reaction ($\Delta H° = 285.795$kJ/mol) must be provided as electrical energy (Holmes-Gentle & Hellgardt, 2018). The produced hydrogen has energy value of 241.788kJ/mol and this gives electricity to hydrogen efficiency of 84.6% at standard temperature. While the cost of electricity input to the electrolyzer has a huge bearing on the economic competitiveness of the P2H2 system, overall energy transfer efficiency in a hydrogen storage system is also very important in determining future competitiveness, hence storage and fuel cell efficiencies are critical.

3.1.2. Fuel cell technology

Fuel cell efficiencies are much lower than their electrolyser counterparts. As with electrolyser technology understanding of the possible maximum theoretical efficiency has an important bearing towards the development of the technology. A cursory analysis seems to suggest that the fuel cell efficiency exceeds the thermal efficiency of a heat engine since in fuel cell there is direct conversion of chemical energy into electricity. It being higher than the thermal efficiency does not preclude a limiting maximum thermodynamic efficiency and the limit is constrained by the second law of thermodynamics, and neither process is able to break this law (Hassanzadeh & Mansouri, 2005).

Simple thermal analysis, considering the flame temperature of hydrogen as 2400K at 1atm and standard initial temperature, 298K, the maximum efficiency based on Carnot principle is 87.6%. No single agreed efficiency limit has been posited so far in literature. Reversible work is equivalent to the Gibbs energy (Luna et al., 2017), (ΔG=228.6 kJ/kmol) leading to the following maximum limiting efficiency of 94.5%.

3. Economic assessment

Hydrogen from renewable electricity is said to be cost effective if low-cost, excess electricity is used (Eveloy & Gebreegziabher, 2018), however, is this always the case or it depends on the scale. It is here posited that schedule of cooperation between the wind power plant and storage as well as the level of penetration are all contributors towards economic viability.

Energy return on investment (($EROI_e$) is a tool for assessing energy benefit on the invested energy in electricity terms or equivalence (King & van den Bergh, 2018). Noted are inconsistencies in the reported EROI figures for various energy options, stemming from largely the estimates and data used. For the hydrogen-based wind energy storage system, excess wind energy for hydrogen production needs a special treatment that considers energy recovery aspect of the storage strategy. Due regard for storage scale and options with appropriate accounting of energy streams is of crucial importance in the appraisals.

4. Conclusions

Energy return on investment (EROI) or Energy stored on energy investment ($ESOI_e$) analysis can be the effective way of evaluating the hydrogen storage strategy. However, the present way of evaluation of the EROI metric has to be revisited, especially regarding the way energy losses are accounted for. With technological improvements and appropriate accounting of recovered losses an optimally designed WH_2S system will find itself away from the 'energy cliff' edge. The EROI input data imprecision and method of treatment lead to inconsistent EROI values by different authors, bringing forward the need for harmonization.

Hydrogen storage's future is anchored on the following strengths;

- Its low-carbon tag.
- Low energy cost of night wind (because of night-time energy valley) used for hydrogen production.
- Recovery nature through utilization of excess energy and curtailments.
- Economic peak-load sale of the hydrogen generated electricity.

More wind curtailment studies are required to assess and quantify potential, it is imperative to estimate the available excess electricity for hydrogen production in order to ascertain economic viability. Reduction in investment costs is expected – e.g. cost reduction through economies of scale, as companies move from project manufacturing to product manufacturing.

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