INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 39 (2014) 11071–11081

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Hydrogen underground storage in Romania, potential directions of development, stakeholders and general aspects

Ioan Iordache [a,b,c,*], *Dorin Schitea* [a,b,c], *Adrian V. Gheorghe* [c,d], *Mihaela Iordache* [e]

[a] Romanian Association for Hydrogen Energy, Rm. Valcea, Romania
[b] National Research and Development Institute for Cryogenics and Isotopic Technologies ICTI, Rm. Valcea, Romania
[c] University POLITEHNICA of Bucharest, Bucharest, Romania
[d] Old Dominion University, Norfolk, VA, USA
[e] National Research and Development Institute for Industrial Ecology INCD-ECOIND, Rm. Valcea, Romania

A R T I C L E I N F O

Article history:
Received 14 April 2014
Received in revised form
5 May 2014
Accepted 12 May 2014
Available online 10 June 2014

Keywords:
Hydrogen
HyUnder
Underground hydrogen storage
Salt caverns
Romania

A B S T R A C T

Romania is a country with relatively good opportunities to manage the transition from the dependence on fossil energy to an energy industry based on renewable energy sources (RES), supported by hydrogen as an energy carrier. In order to ensure Romania's energy security in the next decades, it will be necessary to consider a fresh approach incorporating a global long-term perspective based on the latest trends in energy systems. The present article focuses on an analysis of the potential use of salt caverns for hydrogen underground storage in Romania. Romanian industry has a long technical and geological tradition in salt exploitation and therefore is believed to have the potential to use the salt structures also in the future for gas and specifically hydrogen underground storage. This paper indicates that more analysis works needs to be undertaken in order to value this potential, based on which macroeconomic decisions then can be taken. The present work examines the structures of today's energy system in Romania and features an analysis of Romania's current potential of hydrogen underground storage as well as, reports on the potential use of this hydrogen in chemical industry, the transport sector and salt industry in Romania and highlighting issues implied by a possible introduction and use of hydrogen and fuel cell technologies.

Introduction

Romania's energy sector is facing the need to store extremely large energy quantities for short to long-term (days to weeks) in order to adapt to the increasingly intermittent renewable energy production. In Romania, energy storage will become a subject of obvious importance both with regard to renewable energy resources and nuclear power. One potential flexibility option for the power sector is the use of large scale energy

* *Corresponding author*. Romanian Association for Hydrogen Energy, Rm. Valcea, Romania. Fax: +40 250732746.
E-mail addresses: iordache.ioan@icsi.ro, jordache2001ro@yahoo.co.uk (I. Iordache).
http://dx.doi.org/10.1016/j.ijhydene.2014.05.067

storage, storing the energy produced mostly as electricity in periods of surplus for later use during times of peak demand. Today, pumped hydro schemes are the preferred technical solution due to its favorable economics, but, as these are limited in potential, in the long-term, energy storage schemes with considerably higher energy storage capacities will be needed.

Hydrogen storage at large scale can be expected to support the integration of intermittent renewable energy sources in the current energy system. Large quantities of hydrogen will be produced from renewable electricity through the electrolysis of water, known also as green hydrogen. Hydrogen storage in salt caverns by a large pressure differential and at elevated pressures is a suitable candidate for dynamic peak load energy storage and hydrogen can be released within an adequate period of time. The salt caverns are highly impermeable for hydrogen even under high pressures and are virtually leak proof. The cushion gas requirements for the hydrogen storage are large and depend on the minimum possible cavern pressure, but are defined as economic inventory, and hence are part of the total capital expenditure [1].

Early open literature references about hydrogen underground storage were made in 1976 [2], respectively 1979 [3]. These publications reported on analysis work on physical, chemical, environmental and energy issues, all in the context of large scale energy storage. In the same period of time a major study on the same topic was conducted by the Institute of Gas Technology, USA [4]. A few years later, other groups of researchers also discussed issues related to technical and economic aspects. In the latter source, a scenario about hydrogen underground storage in salt caverns in connection with the use of renewable energy has been laid out for the first time, by presenting a hydrogen underground storage scheme for balancing out tidal energy fluctuations [5]. Other groups disclosed a conceptual design for compressed hydrogen storage in mined caverns, i.e. in excavated tunnel-shaped caverns [6]. At that time hydrogen underground storage appeared to be the most promising solution to the problem of large scale energy storage which seems to be learnt a fresh today. Despite the principle idea of large scale hydrogen underground storage in salt caverns is already three decades old, much work remains to be done to put real systems into operation and demonstrate their effect. This paper intends to contribute a basis for a potential future implementation strategy.

Having disappeared from literature for about 15 years, in 2000 the idea of hydrogen underground storage reappears. Some sources disclose relevant comparisons between hydrogen underground storage and high-pressure overground storage [7], the potential of large scale hydrogen storage in the UK [8], the USA [9], Denmark [10,11], Germany [12] and Russia [13]. Also one study has reported about a possible integration of large scale hydrogen underground storage into European energy infrastructure [14].

The work for this report has originated from an ongoing European assessment project by the name of HyUnder. HyUnder is supported by the FCH JU (Fuel Cell and Hydrogen Joint Undertaking, grant no. 303417) and has set out to reveal more about the storage potentials, relevant salt and other relevant underground energy storage geologies, process technology and cavern operating conditions, potential business models and relevant energy markets for the use of large scale hydrogen underground storage in Europe. Romania is one out of six regions serving as prototypical energy market with sufficient salt structures. More about the project can be found on the project webpage, www.hyunder.eu. In HyUnder project, the system boundaries are defined such that the analyzed cavern plant includes electrolysis, compression prior to the underground salt cavern as hydrogen storage and all topside equipment (i.e. hydrogen drying, purification, compression for trailer filling, re-electrification unit and NG grid injection unit).

Today, a number of industrial hydrogen underground storage applications are in operation. Chemical industry is operating hydrogen salt caverns in Clemens and Moss Bluff in the U.S., as well as in Teesside in the UK, where hydrogen is stored in three small and shallow caverns, using pumping of brine into above ground brine ponds instead of differential pressure for hydrogen storage underground. In all three cases the stored hydrogen is used in chemical industry and not as an energy vector. Also, in the past, hydrogen has successfully been stored underground in France, Germany and former Czechoslovakia, as pure hydrogen for aerospace industry needs in Russia, or as town gas: a gas mixture including hydrogen (40–60%), carbon monoxide, methane and volatile hydrocarbons [15].

Another section of this paper develops an actual snapshot of the Romanian energy system and at the potential role hydrogen might play in it, for storage and end-use. A future hydrogen (storage) infrastructure may take years lead time for its development. Therefore, early scientific, technical and business analysis is needed in time, involving representatives of the relevant communities to sharing their know how in an attempt to develop a realistic plot that may help to better understand the role of hydrogen in Romania's future renewable energy based energy system. Even though the share of renewable energy in Romania is one of the highest already today, the consequences of an integration of further renewable energy will require further fundamental changes in the energy system. The best approach to develop this pathway is by developing the transition using both a long-term and short-term forecast (backcasting/forecasting approach). Romania has a long tradition (more than 2000 years) of salt extractions. Today, Romania operates several active mines, but some older mines have also been closed. Many of these sites may have the potential to be used for hydrogen storage to form part of a wider hydrogen infrastructure.

Overview of the energy system in Romania and the potential role of hydrogen in it

Romanian's energy system has followed its own development strategy in line with the country's own needs, but also influenced by European energy policy. As such, a potential evolution of the role of hydrogen in the energy system will have an impact on the Romanian energy system.

The hydrogen energy literature includes details of demonstration projects, results of infrastructure development economics and cash flow analysis, the environmental and energy system impact, industry positions, etc. [16,17]. In the