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Combining analytical and numerical modelling of gas flow in depleted natural gas fields to identify potential Underground Hydrogen Storage (UHS) sites in the Netherlands

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The Netherlands is seeking ways to integrate large amounts of renewable energy production capacity (wind/solar) into its energy system, in order to reduce CO_2 emissions and decrease dependency on future energy imports. Currently the Netherlands uses underground gas storage (UGS) to provide flexibility to its natural gas system, and secure supply during the winter season. However, hydrogen is considered to be a potential candidate to substitute natural gas, because it is a versatile energy carrier that can be produced from renewable electricity and be used as a CO_2-neutral fuel and feedstock. It can also be stored in large amounts underground. Storage of compressed hydrogen in salt caverns is a proven technology, with single-cavern storage capacities in the range of 10-100 million m^3. Yet some studies on the future Dutch energy system suggest much larger volumes of hydrogen storage may be required (1 to 50 billion m^3). This large storage capacity can only be practically achieved in depleted natural gas fields. UHS in gas fields is not yet a proven technology. Only some pilot projects have successfully injected small amounts of hydrogen in some available underground reservoirs. In order to make possible future development of UHS, screening methodologies are needed for the readily identification and characterization of potential underground candidates. In this study, we develop a methodology that allows assessing UHS performances of large portfolios of underground reservoirs. As a case study we use the entire portfolio of natural gas fields in the Netherlands, including three UGSs.

In a first stage of our study, we conducted a nodal analysis of the Inflow Performance Relationship (IPR) and the vertical flow performance (outflow) curves, in order to obtain a first order estimate of the potential UHS performance for each field (e.g. rates of injection/withdrawal, working/cushion gas volumes and ranges of working pressures). Results show that withdrawal performances of wells in an UHS can be 2-3 times higher than those in an UGS. High bottom-hole drawdowns and erosional velocities in the production tubing may however significantly restrict the potential flow of hydrogen. Furthermore, the working gas volume of an UHS may contain up to four times less energy than that of an UGS, if operated at the same ranges of working pressures. Secondly, we used Eclipse 300, and the geological Petrel model of some of the best candidates, to conduct a

more detail analysis of their potential UHS performances and the controlling factors. For that we ran consecutive injection/withdrawal cycles at different timescales (daily-weekly-monthly), and distinct working pressure ranges and types of cushion gas (e.g. nitrogen/hydrogen). Results allow to determine the efficiency of the different operational strategies and the number of wells required to match the expected future demands of hydrogen in the Netherlands. They also show the degree of hydrogen mixing with the residual and cushion gas during each cycle. Therefore our analytical/numerical modelling approach provides a good methodology to quantify and rank potential UHS reservoir candidates, and a means to classify the potential storage capacity of the entire portfolio.