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Energy efficiency analysis of CO_2 mineral sequestration in magnesium silicate rock using electrochemical steps

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ABSTRACT

A thermodynamic efficiency analysis using the exergy concept is used to assess CO_2 mineral sequestration process routes where electrochemical steps (electrolysis and fuel cells) are used to produce aqueous hydrochloric acid and sodium hydroxide reactant solutions. Results from three recent publications on the subject that come to different conclusions are used for this case study. It is shown that including electrolysis as one of the steps of a magnesium silicate mineral carbonation process route results in input energy requirements that will exceed the output of a fossil fuel-fired power plant that produces the CO_2 that is bound to (hydro-) carbonates. At the same time, fuel cells are not efficient enough to change this.

Keywords: CO_2 sequestration; Mineral carbonation; Magnesium silicates; Electrolysis; Energy efficiency; Exergy

1. Introduction

Carbon capture and storage (CCS) based on geological storage in underground formations (CCGS), mineral sequestration or, although generally considered more controversial, ocean storage offers significant CO_2 mitigation capacity. Continued use of fossil fuels, while at the same time aiming at reducing CO_2 emissions, will require the widespread implementation of CCS. While CCGS has received most attention of the CCS routes as a result of the quick success of the well-known Sleipner demonstration (1 Mt CO_2 stored annually) and a handful of similar size demonstrations, the rather slow deployment has resulted in increased focus on CO_2 mineral sequestration especially since around two years ago. The well-documented advantages of this CCS route (CO_2 fixation in thermodynamically stable material, no post-storage monitoring needs, more than enough CO_2 fixation capacity, overall heat generating process chemistry, the option to operate on CO_2-containing gas directly, removing the expensive capture step from the CCS chain, etc.) combined with increased markets and use for the (hydro-) carbonate products and by-products have resulted in a sudden increase in R&D activities and registered patents. Note that although CCS often implies underground storage of the CO_2 we here stick its wider definition (IPCC, 2005) where storage implies long-term isolation from the atmosphere. Yet again, mineral sequestration often referred to as CCU (carbon capture and utilization).

Magnesium silicates, primarily olivine and serpentine offer the necessary capacity for CO_2 mineralisation at many locations where CCGS is not possible or not considered preferable. Serpentine, or better said serpentinite rock, which is composed primarily of serpentine mineral, $Mg_3Si_2O_5(OH)_4$, besides iron oxides and other species is the most common and widespread of these (IPCC, 2005; Lackner, 2003; Zevenhoven and Fagerlund, 2010; Zevenhoven et al., 2011).

The main reason why CO_2 mineral carbonation has not been widely implemented is that process chemistry and energy efficiency have not been optimized to a level that gives economically viable CCS on a large scale. A direct, aqueous solution process known as the ARC route was developed in the US (at the Albany Research Center, currently NETL, Albany) which is, however, considered not sufficiently efficient when it comes to energy input requirements and carbonation conversion levels and rates. Other routes involve indirect processing, which implies that magnesium is first extracted from the rock material, followed by carbonation of the intermediate magnesium compound and recovery of extraction chemistry. Already in the mid-1990s strong acids such as hydrochloric acid were

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