International Journal of Greenhouse Gas Control 60 (2017) 140–155

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

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

Evaluation of a new technology for carbon dioxide submarine storage in glass capsules

Stefano Caserini*, Giovanni Dolci, Arianna Azzellino, Caterina Lanfredi, Lucia Rigamonti, Beatriz Barreto, Mario Grosso

Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale, Milano, Italy

ARTICLE INFO

Article history:
Received 3 October 2016
Received in revised form 3 February 2017
Accepted 8 March 2017

Keywords:
CO_2 storage
Life cycle assessment
Emission reduction
Carbon sequestration

ABSTRACT

The paper describes the energy and environmental evaluation of a new patented process for the storage of liquid carbon dioxide (CO_2) in glass capsules on the deep seabed. This technology is proposed as a safe option to store CO_2 captured from flue gas of industrial processes and power plants, as well as directly from the atmosphere, in order to overcome the obstacles that still today limit the commercial deployment of other CO_2 storage techniques, such as the injection in saline aquifers. By keeping the liquid CO_2 separated from the seawater, the technology might be an alternative that presents reduced risk associated with the storage in the marine environment when compared to other alternatives proposed in the past.

A Life Cycle Assessment carried out with different combinations of the geographical and technological parameters showed an average impact of 0.10 tCO_2eq per ton of stored CO_2. The process with the highest impact was the capsule production, due mainly to the consumption of natural gas and electricity, as well as to calcination taking place during the production of glass. The availability of space in the seabed for submarine CO_2 storage in capsules resulted a minor issue for the development of the technology. Close to most coastal areas where CO_2 emission sources are located, large surfaces of the seabed at a suitable depth (between 1500 and 3000 m) and distance from the coast (<200 km) suitable for this technology are available, and particularly in the Mediterranean and Black seas. A preliminary cost analysis resulted in an average CO_2 levelized cost of US$17 per ton of CO_2 delivered by the external source.

1. Introduction

After the Paris Agreement (UNFCCC, 2015), the interest for the technologies that can assure consistent greenhouse gases (GHGs) emission reductions, or even negative ones in case of the capture of biogenic carbon dioxide (CO_2), has continued to grow.

Many analyses highlight that the ambitious targets of the climate international policy signed in Paris, to hold "*the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels*", require that carbon dioxide and other GHGs emissions are reduced at very high rates in the coming decades, and that CO_2 is also actively removed from the atmosphere in large quantities.

Removal of carbon dioxide can be achieved through a variety of processes, including afforestation, forest management, the combination of bioenergy with carbon capture and storage, or through dedicated activities, for example, direct air capture and sequestration, or enhanced weathering of olivine rocks (Keith, 2009). There is a rich literature on the potential obstacles to a large increase of such negative emissions, both for the novelty of many proposals of atmospheric carbon capture and storage (CCS), and for their geophysical limits, i.e. safe carbon storage capacity (Smith et al., 2015).

As noted by Peters (2016), 108 out of the 116 scenarios assessed in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Clarke et al., 2014) as consistent with a likely chance of keeping global average temperature below 2 °C, assume the use of large-scale CCS and 101 reach negative emissions (below zero) by 2100, by combining bioenergy with CCS. According to these scenarios, the current ramping up of renewable energy technologies, even at high rates, is unlikely to be sufficient to achieve a 1.5–2 °C goal if CCS is not deployed.

Although many scenarios defined in the past decades underestimated the growth of renewable energy technologies, it is possible to identify a consensus in the scientific literature that in the absence

* Corresponding author at: Piazza Leonardo da Vinci 32, 20133 Milano, Italy.
E-mail address: stefano.caserini@polimi.it (S. Caserini).

http://dx.doi.org/10.1016/j.ijggc.2017.03.007
1750-5836/

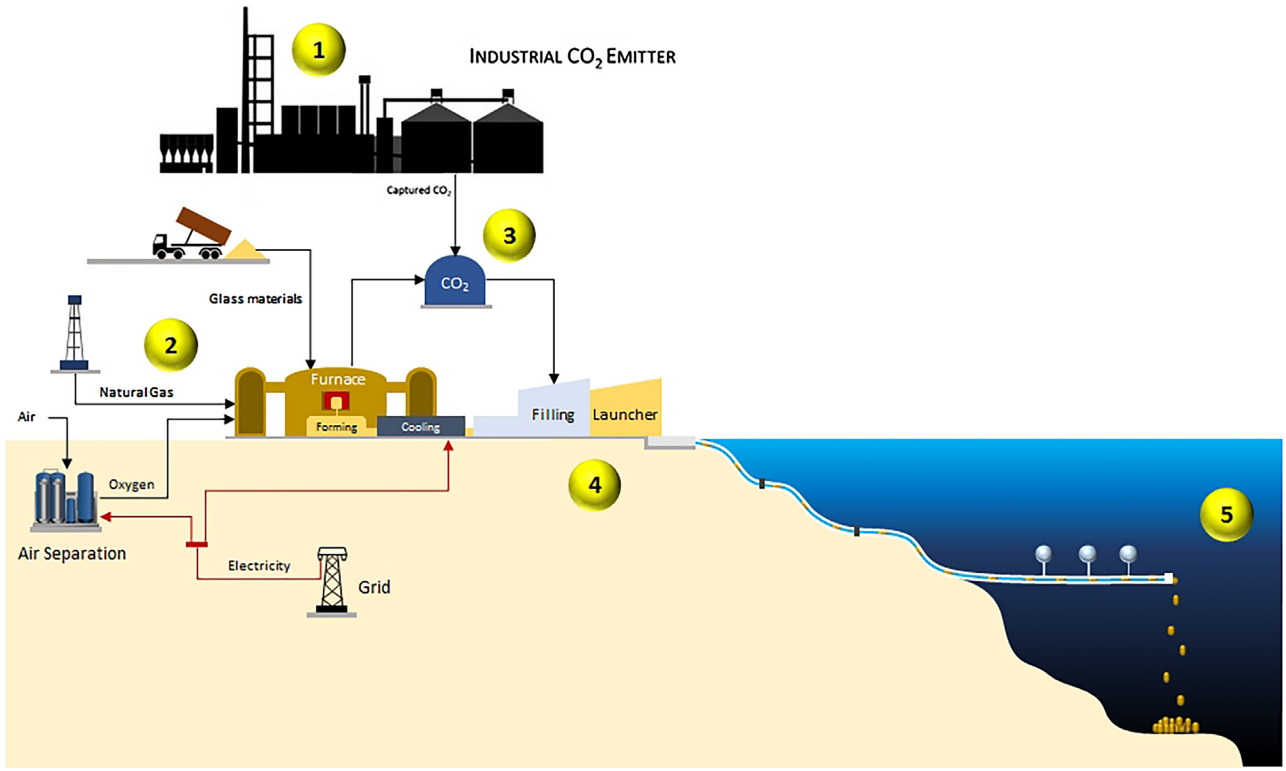

Fig. 1. Scheme of the submarine carbon storage process. 1: The emitter setup the CO_2 capture system. 2: Production of glass capsules. 3: CO_2 collected from emitter and from capsules production. 4: Capsules filling and launching. 5: Filled capsules are transported and released.

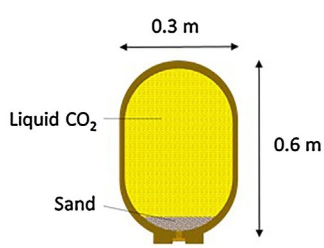

Fig. 2. Scheme of the capsule.

of efficient, large-scale capture and storage of airborne carbon, stringent emission reduction targets are likely out of reach; in the absence of a fast and deep decarbonization of the energy and industrial sectors, carbon emissions that will occur in the future, in addition to those that have already occurred up to now, will cause an irreversible effect on the climate at the timescale of centuries to millennia and longer (Clark et al., 2016).

In this framework, CCS is still a critical GHG reduction solution. CCS technology is currently at a demonstration phase, with more than 30 projects in operation or under construction around the world (GCCSI, 2015). The main application of CCS is at coal-fired power stations and at industrial large emitters such as cement production plants, but CCS could potentially be applied to a wider range of energy production facilities, including those fuelled with biomass; Bioenergy and Carbon Capture and Storage (BECCS or Bio-CCS) becomes a mean for generating carbon negative emissions, because of the previous absorption of CO_2 from the atmosphere through the photosynthesis. In the scenarios assessed by Rogelj et al. (2015), almost all of the additional emissions reductions that are required to move from a 2 °C to a 1.5 °C scenario are achieved by reducing CO_2 emissions from fossil fuel use, and by using CO_2 removal via BECCS.

Since the publication in 2005 of the IPCC Special Report (IPCC, 2005), CCS has so far been developing at a slow pace, despite some technological progress, and urgent action is now needed to accelerate its deployment (GCCSI, 2015). There are different views on the real feasibility of CCS in the medium term, for the power sector and for industrial applications (Azar et al., 2006; Rubin and Davison, 2015; Gale, 2015; Kemper, 2015; Nelder, 2015; Pawar and Carey, 2015; Phillips, 2015). The IPCC Fifth Assessment Report-WG3 highlights that although CCS has not yet been applied to a full-scale, commercial fossil-fired power generation facility, all of the components of integrated CCS systems exist and are in use today by the hydrocarbon exploration, production, and transport sectors, as well as by the petrochemical refining sectors (Bruckner et al., 2014).

Although the "storage" phase is generally less expensive than the capture, it seems to be the most critical one. According to the International Energy Agency (IEA, 2014), it is of particular importance to boost activities in the area of CO_2 storage, at various levels, because storage is critical to any project design and must be addressed up-front. This is because it can take 5–10 years to qualify a new saline formation for CO_2 storage, even when theoretical estimates are already available and look promising, and because of the large up-front investment needed to secure storage capacity. The availability of a safe storage capacity is thus a critical aspect in the process of investing in CCS (IEA, 2014).

The present work describes the energy and environmental evaluation of a new patented process for the storage of liquid CO_2 in glass capsules into the deep seabed, called Submarine Carbon Storage (SCS). A preliminary assessment of the costs of an SCS plant is also discussed. This technology is proposed as a safe option to store CO_2 captured from flue gas of industrial processes and power plants, in order to overcome the obstacles (i.e. public acceptance, risk of leakage, exploration and monitoring costs and duration, legal and regulatory frameworks) that still today limit the commercial