ATLANTIS PRESS

Advances in Social Science, Education and Humanities Research, volume 242

2nd International Conference on Vocational Education and Training (ICOVET 2018)

Biomass Dry Storage for Capture and Storage of CO_2 and Energy

S. Amara[1]
Unité de Recherche Matériaux et Energies Renouvelables (URMER)
Université de Tlemcen, BP 119
Tlemcen 13000
sofiane.amara@yahoo.fr

B. Nordell[2]
Division of Architecture and Water, Luleå University of Technology (LTU), SE-97187, Luleå, SWEDEN, bon@ltu.se

Z. Mostefaoui[3]
Unité de Recherche Matériaux et Energies Renouvelables (URMER)
Université de Tlemcen, BP 119
Tlemcen 13000

Abstract - Carbon dioxide (CO_2) and other greenhouse gases (GHG) are considered the main cause of many environmental issues that lead to climate change and global warming. Carbon Capture and Storage (CCS) is a promising sustainable method used for decreasing CO2 emissions. Nevertheless, for the CCS technology to be effectively put into use, some aspects should be taken into account, namely cost, capacity and durability of storage. In this paper, different CCS methods are described and the work proposes an alternative way of storing CO2 (and energy) using large-scale dry storage of biomass. The main advantage of suggested carbon storage system is that has no operation cost, and no need for maintenance and monitoring. By comparing the present project with other advanced and hi-tech projects, it is concluded that the proposed biomass storage is a cost-effective CCS technique. In the future, when the CO2 emissions are not seen as a global problem, this dry storage method enables recovery of stored wood for various purposes.

Keywords - Dry storage, biomass, CO_2 emissions, Carbon Capture and Storage (CCS), Global warming.

1. INTRODUCTION

According to the Intergovernmental Panel on Climate Change, an ascent in the Earth's surface temperatures is factual without any doubt [1]. A growing body of perceptions gives an overall picture of why the world is getting abnormally warm and also of different changes in the climate [2]. Throughout the past century, the estimated rise in temperature was between 0.4°C and 0.8°C while the warmest 10 years took place in the most recent 15 years [3]. Despite the fact that there is a scientific accord on the existence of global warming, there is no full agreement on its cause. Nevertheless, based on most studies' the global warming is resulting from the increased concentration of greenhouse gas in the atmosphere, i.e. the greenhouse effect.

The greenhouse conception states that there is a correspondence between the growing greenhouse gases emissions such as carbon dioxide (CO_2) in the atmosphere and the increase of the Earth's surface average temperature.

Climate scientists have observed that that the atmospheres´ concentration of CO_2 has increased considerably during the last century, i.e. since the time of the industrial revolution. In 2017, the average CO_2 concentration was 403 ppm (parts per million) and this value was approximately 40% greater than that of the mid-1800s, with a 2 ppm annual increase over the most recent decade. From a general perception, this increase is understood as resulting from the increasing use of fossil fuels [4] and that CO_2 is released by the increasingly warmer seawater.

1.1. Energy and CO_2 emissions

The main two ways of reducing CO2 gas concentration in the atmosphere are: A) reducing the use of fossil energy sources, meanwhile, depending on nature to recover previously emitted gases or B) to absorb existing emissions using long-term storage. Also, it is worth to mention that both methods can be adopted together.

Nature accumulates CO2 and energy in biomass. However, its content of energy and CO2 is eventually released to the environment when the biomass is burnt or decayed. It is also possible to reduce the atmosphere´s CO2 concentration by increasing the natural CO2 uptake. To achieve this, several strategies can be adopted such as taking care of existing forests, enhancing their growth rate and growing more biomass.

The existing technical solutions for sequestration and capture of CO2 are commonly known as CCS (Carbon Capture and Storage). It is preferred that the CO2 is captured at the source of emittance i.e. at any CO2 emitting technology and industry. Large-scale storage for long-term (forever) storage is needed. Required large storage volumes may be present underground, in aquifers or in gas and oil reservoirs.

Here is a new method suggested. The idea behind it is to harvest the forest without causing CO_2 emissions to the environment by dry storing of wood, timber logs or

Copyright © 2019, the Authors. Published by Atlantis Press.
This is an open access article under the CC BY-NC license (http://creativecommons.org/licenses/by-nc/4.0/).

some other biomass. In this technique, CO_2 and energy are contained within the logs that can be stored for a very long time. The logs can be stored in dry areas, either in desert climate or arctic environment without any protection needed. Maybe in the near future when the CO_2 emissions are no longer an environmental threat to the global climate, the stored biomass could be utilized for several purposes.

1.2. Carbon taxes

One of the most frequent proposition to promote the reduction of greenhouse gas emissions (GHGE) is carbon taxes, in which the polluter must pay for its pollution. This policy is exemplified by Alberta, Canada, which suggested increasing the taxes to C$30 per ton CO_2 in 2018 [17]. The European Union also suggested CO_2 taxes to reduce the released emissions in the electricity sector. This carbon tax is an environmental tax on the polluting production activities that negatively affect the environment [18].

1.3. Objective

The general objective of this study is to investigate the viability of storing CO_2 (and energy) using large scale dry storage of biomass. In addition, the work includes an evaluation of the ways and costs of buying, transporting, and storing huge volumes of timber in desert areas as well as a comparison with other methods of capturing and storing CO_2.

2. NATURAL UPTAKE OF CO_2

Forests of the world are reducing or at least slow down climate change. The forested area in Russia (7.71 10^6 km^2) accounts for 95% of the forest resources of the former Soviet Union and 20 % of the world's total forested areas. Another fact is that 50 % of the world's total coniferous resources exist in Russia. Russia´s forest is able to set off greenhouse gas emissions corresponding to 10^9t carbon per year.

2.1. Forest GHG offset

There is an ongoing GHG mitigation forestry project between the United States and Russia, RUSAFOR-SAP (Russian/USA Forestry and Climate Change Project-Saratov Afforestation Project), situated in the Saratov Oblast, 700 km SE of Moscow. It is considered the first dual implementation of its kind between the two countries. The principal objective is assessing the functional, biological and institutional opportunities to give a picture of how to manage a Russian forest cultivated area as a carbon sink. Based on studies, a planted area of 9 km^2 will be able to sequester nearly 32000 tons of carbon throughout the project's lifetime (40-60 years) [5].

According to calculations done by Marland (1988), Moulton and Richards (1990), and the U.S. Congress OTA (1991), it is concluded that the U.S. could set off 56% of its current CO_2 emissions resulting from nonrenewable fuels by means of growing trees on 1.4 x 10^6 km^2 [6]. Plantation of trees is one of the broadly acceptable strategies to play a very crucial role in confronting the global climate change. The trees by its role absorb CO_2, thus CO_2 accumulation in the atmospheric decreases [6].

2.2. CCS projects

Currently, there are more than twenty CCS projects either ongoing or in final stages of planning (Fig.1), which is significantly less than what is needed. The majority of today's CCS projects involve the technique of separating CO_2 from natural gas. Furthermore, gas wells are adaptable to be used for storing CO_2, however there is an essential need for some additional expertise and equipment. There are many examples of operating commercial projects from different parts of the world such as the Sleipner and Snøhvit fields in Norway, the In Salah project in Algeria, the K12B project in Netherlands, the Gorgon project in Australia, and the CarmitoArtesa project in Mexico. [8]

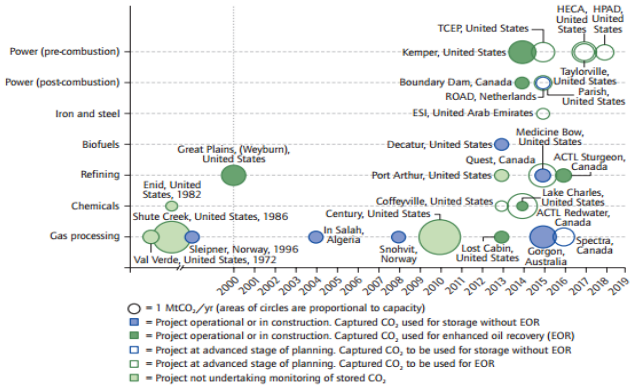

Fig.1 Large-scale CCS projects in operation, under construction or at an advanced stage of planning as of end-2012, by sector, storage type, capture potential and actual or estimated star date [7]

2.2.1. Algeria

The In Salah CCS project in Algeria is a very unique CO_2 capture and storage project as it is world pioneering onshore CCS project. This projects as a groundbreaking venture has contributed to building up a hands-on practice and experience highly relevant to CCS projects worldwide. The partners of this project are British Petroleum (BP), Sonatrach and Statoil. The aim of designing the project was to assess the economic feasibility of CO_2 storage as a mitigation solution. In the first stage of the project that started in 2004, the injection daily rate of carbon dioxide was 4000 tons of CO_2/day. Carbon dioxide in gas fields with a CO_2 content of 1-10%, which is higher than the acceptable exportation specs, is separated and removed from the gas stream. The Central Gas Processing Facility (CPF) is used for treatment using the MEA Amine process and then the carbon dioxide is subjected to compression, transported and stored in the 1.9km deep Carboniferous sandstone formation at the Krechba field [9].

The compressed CO_2 is inserted into three re-injection wells, in a briny formation underground, beneath the gas reservoir. The annually injected amount of CO_2 is about 1 Mt with an intended total storage of 17 Mt of CO_2 throughout the lifetime of the project. The estimation of

added investment for the CCS is M$100 or ~$6/t CO_2, which is significantly less than the cost of offshore gas processing. Monitoring is also carried out by the partners and it involves seismic data acquisition and borehole measurements. There is a partial support in the monitoring operations from the EU CO_2ReMoVe project (Wright, 2007) and these operations cost M$30.

2.2.2. Norway

The Norwegian Snøhvit (Snow White) is a CCS project located in the Barents Sea and it somehow has similarities with the Sleipner project (Freund, 2007). The partners that are in charge of running the venture are Statoil Hydro, has Petoro, Total, Amerada Hess Norge, RWE-DEA Norge and Swedish Petroleum Exploration.

The project is a subsea development operated distantly from onshore. Given the fact that it is remote from gas markets, it has been established as a LNG project. Multi-phase pipelines are used for transporting natural gas and its CO_2 content 145 km to the onshore liquefaction plant nearby the city of Hammerfest, then separation occurs and results in gas and condensates. Before the liquefaction process, CO_2 is removed from the gas via an amine process at elevated pressure. An additional 145 km pipeline has been constructed for transporting back the removed CO_2 to the offshore Snøhvit field. The next step is injecting this CO_2 into a formation of 45-75 m thickness called Tubasenat, which is about 2500 m underneath the seabed. The cost of the pipeline and injection is estimated to be M€125. The first CO_2 was inserted into the offshore geological formation as a CCS in April 2008. There is a partial financial support from EU R&D programs, such as CO_2 ReMoVe (Frederiksen and Torp, 2007) for carrying out the required monitoring.

Table 1: Non-Power Plant Carbon Dioxide Capture and Storage Projects [20]

Project/link	Leader Million $	Location	CO_2 Source	Size Mt/yr	CO_2Sink	Status
USA						
US Regional Sequestration Partnership's Phase III CCS Projects						
Decatur	MGSC 208	Illinois	Ethanol Production	(Total 1)	Saline	Completed 2011-2014
Kevin Dome	BigSky 1	Montana	Natural Source	0.125	Saline	Planning
US Industrial CCS Projects						
Port Arthur	Air Products 431	Texas	Steam-Methane	1	EOR	Operational January 2013
Fort Nelson	SpectraEnergy 12.5	British Columbia	Gas Processing	1.2	Saline	Planning
Canada						
Quest	Shell 1350	Alberta	Steam-Methane	1.2	Saline	Operational June 2015
Alberta CarbonTrunk Line	EnhanceEnergy 1200	Alberta	Fertilizer and Refinery	14.6	EOR	Planning
Europe						
Sleipner	StatoilHydro	Norway	Gas Processing	0.9	Saline	Operational August 1996
Snohvit	StatoilHydro	Norway	LNG Processing	0.7	Saline	Operational 2008
Rest of the World						
In Salah	BP-Sonatrach-Statoil 2700	Algeria	Gas Processing	1.2	Depleted Gas	Operated 2004-2011
Otway	CO_2CRC 40	Australia	Natural Deposit	0.065	Depleted Gas	Operational January 2008
Ordos	Shenhua group 10000	China	Liquefaction	0.1	EOR / Saline	Operational 2011

Abbreviations: EOR = Enhanced Oil Recovery; LNG Processing = Liquid Natural Gas Processing;
H2Production = Hydrogen Gas Production; Depleted Gas = Depleted Gas Reservoir; Saline= Saline Reservoir; Steam-Methane= Steam to Methane Reformers; TBD = To Be Decided

2.2.3. Canada

This project is a joint venture between Enhance Energy Inc and North West Redwater Partnership Sturgeon Refinery. They successfully have established a fully integrated project that involves gasification, CO_2 capture, transportation, storage and Enhanced Oil Recovery (EOR).

The Alberta Carbon Trunk Line ("ACTL"), a 16" 240 km pipeline exists at the heart of the planned project. Laterals have been designed to allow multiple entry points and collect CO_2 from places carrying out emitting activities such as coal-fired power plants, upgrading/refining operations, petrochemicals and natural gas processing plants. Collecting CO_2 will occur in Alberta Industrial Heartland as well as the surrounding areas, then CO_2 is transported to old reservoirs in southern Alberta to be stored in EOR projects. The storage capacity of the reservoirs which will be accessed by the ACTL is about 2 Billion tons of CO_2 or more. In addition, it will be possible to produce an additional 1 Billion barrels of high quality light crude oil using CO_2 EOR. The ACTL project will start with only two CO_2 suppliers and optimistically expand to have other facilities in 2018 when it is in full operation.

The Global CCS Institute has compiled information about large-scale projects. Table 1 shows a summary of active CCS projects, which include power plant CCS, non-power CCS and CCS pilot plants [20].

2.2.4. CCS Cost

The IPCC, 2005 estimates construction costs for CCS storage in saline aquifers, see Table 2 [8]:

Table 2: Construction cost of CCS in Saline Aquifers [8]

	$/t$CO_2$		$/t$CO_2$
USA onshore:	0.40	–	4.50
Europe onshore	1.90	–	6.20
Europe/North Sea	4.70	–	12.00
Australia onshore	0.20	–	5.10
Australia offshore	0.50	–	30.00

Most probably, the construction cost has increased by a factor like the one of the oil and gas upstream cost ever since the IPCC report was published. The additional investment needed for CO_2 storage in the In Salah gas projected was about M$100, with an estimated cost of about M$30 for the monitoring activities. The estimated cost of the Salah project, with a total storage capacity of 17 Mt CO_2, is $6/t CO_2. Current studies are somehow focused on matching sites suitable for storage and capture together. Practically, this considered to be a real concern. For example, a coal-fired power plant with a capacity of 500 MW is supposed to store 1Mt of CO_2 yearly. So, 40

years of operation means that 40 Mt of CO2. must be stored Because of the properties of the aquifer, it was estimated that the gas storage would cover an area of 240 km².. For storing 16 Gt CO_2/year, an underground storage area of 40000 km^2 is needed (200 km by 200 km per year, i.e. the size of Netherlands). In a project like Sleipner, the cost of compression and injection of carbon dioxide was M$80, whereas the cost for the Snohvit project including all stages (compression, transportation and injection) will be nearly M$191 (Audus, 2003). Without any doubt, these cost levels are obviously greater in values than the normal levels for CCS evaluation studies, and this might be because of the extreme conditions in the North Sea offshore and the Arctic and also because these are first of a kind facilities [8].

3. DRY STORAGE OF BIOMASS

The present project aims at assessing the viability of using large scale dry biomass storage for storing CO_2 and energy content. An investigation of the costs of buying, transporting and storing big volumes of wood in desert environment is carried out plus comparing this technique with other CCS techniques.

The main idea of the current project is dry storing big volumes of biomass after cutting them off. The meaning of dry storage is that both CO_2 and energy are stored and conserved in the dry wood or in other dry biomass, without any leakage to the external environment. After cutting the wood needed for the project from the forest area, the empty area can be utilized efficiently by growing new biomass for storing more CO_2 and energy.

The storage capacity of such dry storage is at least 1 t of CO_2 per m^3 of dry wood (density: 500 kg/m^3).
Subsequently, the study aimed at investigating the feasibility of decreasing CO_2 in the atmosphere through buying trees from forest areas like Scandinavia, Russia etc. [8] and transporting the biomass to desert areas of Algeria. This is most suitable place since it has vast sand deserts covering 70 % of the country. The dry and very warm climate, with an abundance of sunshine (3370 sun hours/a), is perfect for dry storage of biomass.

One of the fundamental strategies adopted and considered in thinking about this project is the balance between what is technically possible and environmentally sensible i.e. afforestation and sustainable wood utilization. The forest areas and their plantations in the world have great environmental significance as natural resources, and this makes them irreplaceable. It establishes also a unique tactic on the road to decreasing atmospheric CO_2 and saving energy.

3.1. Cost of wood

From an economic point of view, the least expensive trees are the best choice for large-scale dry storage of wood. Various tree species and corresponding prices are shown in Fig.2. The most expensive is Black walnut at a price of 280 $/m^3 for, whereas the lowermost price is 43 $/m^3 for Round wood (Leaf and Coniferous), [11, 12, 13, 14, 21]. The cost of imported round wood in Sweden is 450 SEK/m^3 ($55/m$^{3)}$ including transportation, which accounts for 30-35% of the total cost [21]. This wood price is given for “wood under the bark”, which means a solid cubic meter of wood without bark. Without transportation, the wood cost amounts to $43/m^3.

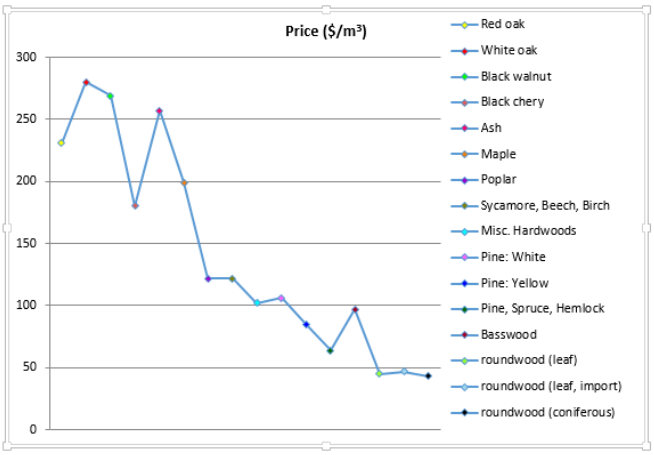

Fig.2 Timber prices

3.2. Cost of dry storing CO_2

The trees with high prices are not the best choice and not considered for dry storing of CO_2, and that is why the round wood (coniferous) at a price of 43 $/m^3 is the type chosen. Fig.3 illustrates the CO_2 storage cost comparison made for different CCS projects. It can be seen that dry storing of CO_2 is less expensive than some of the other projects (Ordos, In Salah and Quest). One proposed idea to further cut the cost would be to buy less expensive biomass (wood) from less distant places (e.g. Germany and France).

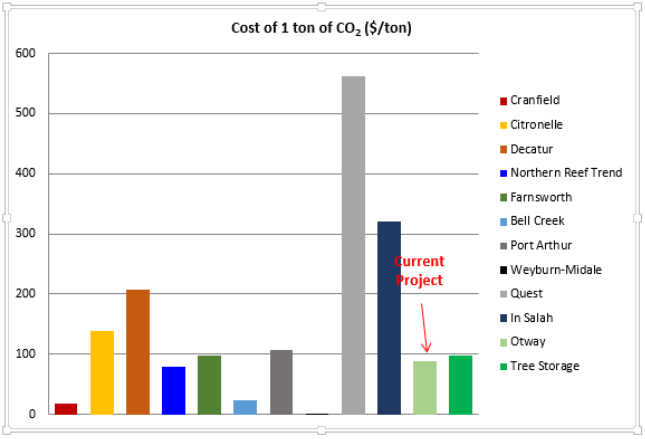

Fig.3 Cost of storing 1 ton of CO_2 for the different projects.

II. DISCUSSION AND CONCLUSION

This study presents some CCS projects from different parts of the world, which are considered potential future solutions for putting an end to the increasing GHG emissions. There are many available technologies that can be used for CO_2 capture and storage. The operation cost is the main factor that controls the choice of technology. According to several studies in this field, CCS is the most promising and feasible CO_2 reduction technique for large-scale sources of CO_2 emissions. Nevertheless, further

studies are needed to find solutions for other existing issues such as technical, economic and safety issues, especially as regards cost, effective capacity, and storage's life length.

Current project proposes a new simple CCS method using large-scale dry storage of biomass. The planned scheme for the project starts with transporting large volumes of timber and then storing them in desert areas. By adopting this technique, CO_2 and the contained energy (2.15 MWh/m^3 of wood) will be stored, whereas the evacuated areas in which the trees were growing are available for new planting activities. The main advantage of such storages is that there is no operation cost, no maintenance and no need for monitoring of the storage. In the near future, when CO_2 emissions are no longer a global problem, the dry stored biomass will be recovered for various purposes.

REFERENCES

[1] Macilwain, C. (2000). Global warming sceptics left out in the cold. Nature 403, 233.

[2] Intergovernmental Panel on Climate Change (IPCC) (2001). The Scientific Basis. http://www.ipcc.ch

[3] United States Environmental Protection Agency (EPA) (2001).http://www.epa.gov/globalwarming

[4] Carbon Dioxide Information Analysis Center (CDIAC) (2002). http://cdiac.esd.ornl.gov

[5] Vinson, T. S., Kolchugina, T. P., & Andrasko, K. A. (1996). Greenhouse gas mitigation options in the forest sector of Russia: national and project level assessments. Environmental Management, 20(1), S111-S118.

[6] Marland, G., & Marland, S. (1992). Should we store carbon in trees? Water, Air, &Soil Pollution, 64(1), 181-195.

[7] International Energy Agency (IEA), Carbon Capture and Storage(2013)http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf

[8] International Energy Agency (IEA), Energy Technology Analysis(2008)https://www.iea.org/publications/freepublications/publication/CCS_2008.pdf

[9] Ringrose, P. S., Mathieson, A. S., Wright, I. W., Selama, F., Hansen, O., Bissell, R., ... & Midgley, J. (2013). The In Salah CO 2 storage project: lessons learned and knowledge transfer. Energy Procedia, 37, 6226-6236.

[10] "Statistisk årsbok för Sverige 2011" *(PDF) (in Swedish).* Statistics Sweden. *p. 42*. Retrieved 14 June 2011

[11] Illinois Forestry Association: http://www. ilforestry. org/timberprices

[12] Sunrise Sawmill:http://www.sunrisesawmill.com/Log-Prices

[13] Indiana woodland Steward: http://www.inwoodlands.org/

[14] Met Wood A. S. Forest Products Ukraine: http://www. cheaptimber. net/icerik/14/17/timber-prices

[15] Global Petrol Prices: http://www.Global petrolprices. com/diesel_prices/

[16] Neil Packer,Le b.a.-ba de l'énergie et de la puissance, Staffordshire University, Royaume-Uni, (2011). http://www. rets-project.eu/UserFiles/File/pdf/respedia/A-Beginners-Guide-to-Energy-and-Power-FR.pdf

[17] Government of Alberta. Budget 2016: the Alberta jobs plan – fiscal plan. Legislative Assembly of Alberta; 2016.

[18] Chiu, F. P., Kuo, H. I., Chen, C. C., & Hsu, C. S. (2015). The energy price equivalence of carbon taxes and emissions trading—theory and evidence. AppliedEnergy, 160, 164-171.

[19] Global CCS Institute (GCCSI), (2017). https://www.globalccsinstitute.com/projects/large-scale-ccs-projects#overview

[20] Carbon Capture and Sequestration Technologies, (2016), https://sequestration.mit.edu/tools/projects/index_capture.html

[21] Smurfit Kappa in Sweden (http://www.smurfitkappa.com)