ISSN 1691-5208 ENVIRONMENTAL AND CLIMATE TECHNOLOGIES
VIDES UN KLIMATA TEHNOLOĢIJAS 2008-1

IS CO_2 COMPRESSING AND PIPING ENVIRONMENTALLY FEASIBLE

VAI CO2 SASPIEŠANA UN SŪKNEŠANA IR VIDEI DRAUDZĪGA

Sylvestre Njakou Djomo
Riga Technical University
Faculty of Energy and Electrical Engineering
Institute of Energy Systems and Environment
Kronvalda boulv. 1, Riga, LV-1010
e-mail: sylvestre@eef.rtu.lv

F.Romagnoli, *researcher, M.Sc.*
Riga Technical University
Faculty of Energy and Electrical Engineering
Institute of Energy Systems and Environment
Kronvalda boulv. 1, Riga, LV-1010
francesko.romagnoli@rtu.lv

Julija Gusca, *PhD student, M.Sc.*
Riga Technical University
Institute of Energy Systems and Environment
Address: Kronvalda bulvaris 1, LV-1010, Riga, Latvia
Phone: +371 67089908, Fax: +371 67089908
e-mail: julija.gusca@rtu.lv

Dagnija Blumberga, *Professor, Dr. Hab.Sc.Ing.*
Riga Technical University
Institute of Energy Systems and Environment
Address: Kronvalda bulvaris 1, LV-1010, Riga, Latvia
Phone: +371 67089908, Fax: +371 67089908
e-mail: dagnija.blumberga@rtu.lv

Keywords: carbon dioxide, compression transportation, pipeline, sequestration, LCA

Introduction

Under the provisions of the Kyoto Protocol, many countries have made commitment to limit their greenhouse gas emissions compared to the 1990 level. Carbon dioxide is the main major pollutant causing climate change and one method to reduce carbon dioxide is to capture and store it into underground reservoirs. Carbon dioxide (CO_2) sequestration or "storage" is the storage of carbon dioxide (usually captured from the "atmosphere") in a solid material through biological or physical processes [1]. Carbon dioxide can be captured as a pure by-product in processes related to petroleum refining (upgrading) and power generation [2]. Carbon dioxide sequestration can then be seen as being synonymous with the "storage" part of carbon capture and storage, a term which refers to the large-scale, permanent artificial capture and storage (sequestration) of industrially-produced CO_2 using subsurface saline aquifers, reservoirs, ocean water, or other sinks. It has been proposed as a way to mitigate the accumulation of greenhouse gases in the atmosphere released by the burning of fossil fuels.

The objective of this article was to develop a calculation scheme for CO_2 transport by pipeline and to establish a streamlined life cycle assessment of carbon dioxide transport by pipeline. In this article is presented analysis of only two blocks of CO_2 storage and capture system.

This article takes into account methodology for analysis, by use of calculation for a CO_2 flow rate equal to 1.0 Mtonne/year over a fixed distance equal to 100km.

On LCA analysis is taken into account only the transport of CO_2 including the CO_2 compression power and CO_2 pumping power independently from the pipeline thickness.

Deeper analyses could be performed for different lengths of pipeline and/or for difference flow rates. Pipelines thickness evaluation could also be done in the aim to provide a cost analysis.

Methodology

Assessment method

Methodology includes four steps for analysis of impact to environment which includes human health, ecosystem quality, climate change and resources.

- First step. Initial data for calculation. Statement of task and assumptions

- Second step. Calculation of electricity consumption of transport system of CO_2
- Third step. Calculation of electricity consumption of compressing of CO_2
- Fourth step. LCA from viewpoint of power used for transport and compressing of CO_2.

To effectively meet the objective set above, we first calculate the optimal inside diameter of the pipeline, then the power requirement for compressing (from gaseous form to either liquid or dense phase) and pumping carbon dioxide through the pipeline taken into account losses equal to 10%/100km. Finally the environmental impact was calculated using the emission rates of electricity supply in Latvia as established by [3]. Sensitivity analysis was carried out to check the robustness of the method used. The inside diameter of the pipeline was calculated using the equation below number 1-3 [4]. The compression power requirement for each stage is given by the following equation (equation 4), which is adapted from [5] and [6], the reader is referred to [7] for more details about equation 4. The power requirement for boosting the CO_2 is given by equation 5 [5].

Initial data for calculations

In order to estimate the electricity power consumption of the process, including power for compression and power for transport both, initial data are needed. Because of at the moment there is a lack of quantitative information some initial assumptions are needed.
Since CO_2 exhibits unusual trends in its properties over the range of temperature and pressures that would be experienced in pipeline transport, it is difficult to provide just one value for either density of viscosity, the reader is referred to [7] to have more details about CO_2 properties.
Consequently the following assumptions, including physical properties for CO_2 and efficiency parameters during compression and pumping stages both, have been taken into account. Segment pipeline elevation changes and kinetic losses inside the pipeline have been considered negligible.

- CO_2 mass flow rate to be transported, m = 1.0 Mtonne/year;
- Pipeline length, L=100km;
- Inlet pipeline pressure, p_{in}=15.0MPa;
- Outlet pipeline pressure, p_{out}=13.5MPa;
- Losses, 10%/100km;
- CO_2 viscosity in pipeline, μ= 0.,1 kg·sec/m;
- CO_2 density in pipeline, ρ= 630,0 kg/m^3;
- Pipeline roughness factor, $\varepsilon=4.573\cdot10^{-5}$m;
- Number of compression stage, N_{stage}=5;
- Isentropic efficiency of compressor, η_{is}=0.75;
- Efficiency of pump, η_p=0.75.
- No kinetic losses ($\Delta U=0$);
- No potential energy losses ($\Delta h=0$).

Calculation of pipeline inside diameter

Calculation of optimal diameter is an iterative process based on an energy balance on the flowing CO_2, where the required pipeline diameter for a pipeline segment is calculated while holding the upstream and downstream pressures constant [7]. On LCA analysis reported on this article is taken into account only the transport of CO_2 independently from the pipeline thickness, nevertheless evaluation could also be examined in the aim to provide a cost analysis.
The following formula (equation 1-3) explain the optimal diameter depending on: mass flow rate, density, pressure drop in the pipeline, pipeline length, friction and roughness factors.

$$D=\left[\frac{32\cdot F_f\cdot m^2}{\pi\cdot\rho\cdot\left(\Delta P/L\right)}\cdot10^3\right] \qquad (1)$$

where:
m = mass flow rate ;
ρ = density of CO_2 compressed;
ΔP = pressure drop in pipeline ;
L = pipeline lenght;
F_f = Fanning factor;

$$F_f=\frac{1}{4\cdot\left[-1.8\log_{10}\left\{\frac{6,91}{\mathrm{Re}}+\left(\frac{12\cdot(\varepsilon/D)}{3,7}\right)^{1.11}\right\}\right]^2} \qquad (2)$$

ε = Pipeline roughness factor;
Re = Reynolds number;
D = pipeline diameter;

$$\mathrm{Re} = \frac{4 \cdot m}{\pi \cdot \mu \cdot D} \tag{3}$$

With reference to the assumptions previously reported, for the calculation of diameter, the specific following assumptions were made:
CO_2 mass flow rate to be transported, m = 1.0Mtonne/year; pipeline length, L=100km; inlet pipeline pressure, p_{in}=15.0MPa; outlet pipeline pressure, p_{out}=13.5MPa; Losses, 10%/100km; CO_2 viscosity in pipeline, μ= 0.1 kg·sec/m; CO_2 density in pipeline, ρ= 630,0 kg/m^3; pipeline roughness factor, $\varepsilon=4.573\cdot10^{-5}$m; no kinetic losses (ΔU=0); no potential energy losses (Δh=0).
The analysis shows an optimal inside diameter approximately equal to 0.05m.

Calculation of power requirement for compression of Carbon Dioxide for each compression stage

Equation 4 together with equation 5 represent the base to make LCA analysis because, depending from a certain fixed number of parameters, they provide an estimation of the total power consumption and consequently evaluate the emission occurring on the examined process.
The compression power requirement for each stage stage ($W_{i,s}$) is given from the next equation 4 with reference to [7] where the following five step of compression are assumed due to the unusual behavior of CO_2 properties:

- stage of compression 1: pressure range 0.1-0.24 MPa;
- stage of compression 2: pressure range 0.24-0.56 MPa;
- stage of compression 3: pressure range 0.56-1.32 MPa;
- stage of compression 4: pressure range 1.32-3.12 MPa;
- stage of compression 5: pressure range 3.12-7.38 MPa.

$$W_{s,i} = \left(\frac{mZ_s RT_{in}}{M\eta_{is}}\right)\left(\frac{k_s}{k_s - 1}\right)\left[\left(CR\right)^{\frac{k_s-1}{k_s}} - 1\right] \tag{4}$$

where:
m=1000Mtonnes/year
R = perfect gas constant = 8.314 kJ/(kmol K)
M = molecular weight of the fluid = 44,01 kg/mol
T_{in} = 40°C;
η_{is} = 0.75,
k_s = average ratio of specific heat of CO_2 for each individual compressor stage;
CR = optimal compression ratio for each stage by Mohitpour = $(p_{cut\text{-}off}/p_{initial})^{1/Nstage}$;
N_{stage} = number of compression stages = 5;
$p_{cut\text{-}off}$ = pressure at which compression switches to pumping=7.38MPa;
$p_{initial}$ = initial pressure at each stage of compression (see ANNEXE).

Calculation of power requirement for transport of Carbon dioxide

The equation 5, depending from a certain fixed number of parameters, provides an estimation of the power required for CO_2 transport. On the final calculation shown in the paragraph 3 losses equal to 10%/100km are included.

$$W_p = \left(\frac{m \cdot (p_{final} - p_{cut-off})}{\rho \cdot \eta_p}\right) \tag{5}$$

where:
$p_{cut\text{-}off}$ = pressure at which compression switches to pumping;
p_{final} = final pressure before inlet pipeline;
ρ= CO_2 density in pipeline = 630.0 kg/m^3;
η_p = 0.75.

Life cycle assessment (LCA)

The ecological assessment of carbon capture and storage is done via a life cycle analysis (LCA). An LCA assesses the resources consumptions and the emissions occurring along the whole life cycle of a product that means the extraction of raw materials, their processing, the material's transport, the manufacture of the product its use, dismantling, and disposal. While the Standard ISO 14040 [8] state extended requirements on LCA including and external review process, in this work, only a screening LCA is carried out. Full LCA requires more detailed data which are not all available at the time this work is be carried out. The energy use for compression and transport of carbon dioxide is modeled as a material and material flow network using the data for eco-indicator of power supply in Latvia as established by [3].

Results and discussion

The results of electricity consumption calculated using the above formula are shown in table 1. It can be seen from table 1 that the compression stage represents the 92% of the total power consumption while the transport of CO_2 along the pipeline consumes about 8% of the total electricity.

Table 1.

Power rate and power consumption for compression and transport

Stages	POWER RATE [kW]	POWER CONSUMPTION [kWh]
Compression	6729.2	161500.7
Transport (10% losses incl.)	612.0	14689.2
Total	7341.2	176189.9

The results of the environmental impacts obtained by applying IMPACT 2002+ [9] to life cycle inventory (per tonne CO_2 capture) for the carbon capture and sequestration plant are presented in Figure 1. It can be seen that resources and climate change cause the dominating environmental effects. The total damage of carbon capture and storage is 4785 μPt[1] , where one point is the unit of environmental penalty and represents the average damage in Europe per person and year. More in detail, the damage derives from resources for 37%, from climate change (30%), from human health (21%) and from ecosystem quality (2%). It has to be kept in mind that these impacts represent the ecological effects arising from compression and boosting stages. Article presents methodology and approach for environmental analysis. More accurate evaluation of ecological effects of carbon capture and storage is needed. The system boundary should be expanded to include other processes such as capture and injection processes.

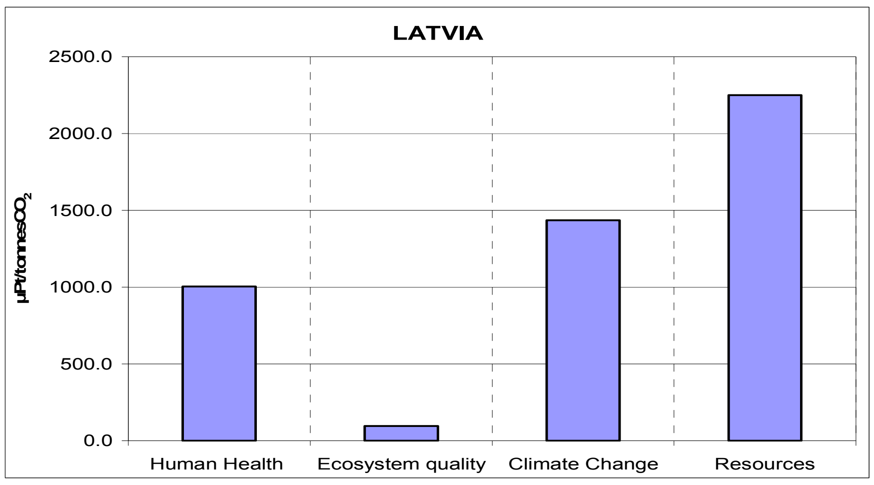

Figure 1. Ecological profile of the carbon capture and storage processes

The above results assume that the power source for compression and transport of CO_2 come from Latvian grid. To analyze the impact of electricity source on the ecological effect of carbon capture and storage, a sensitivity analysis was performed on the electricity source. The sensitivity analysis shows that the power source influence significantly the total ecological effects as well as the impacts in all four damage categories. Indeed for a total power consumption of 64.3 kWh/kg CO_2 the total ecological effects increase by 147% from 4785 μPt to 11830 μPt when the European average mix (UCTE) is chosen as source of power supply (table 1). This increase doubles, respectively triples the impacts in damage categories resources and climate, respectively and human health and ecosystems quality (Figure 2).

Table 2.

Energy consumption and emissions

	LATVIA			UCTE		
	μPt/kWh	μPt/tonnes$C0_2$	[%]	μPt/kWh	μPt/tonnes$C0_2$	[%]
Human Health	15.624	1004.8	21.0	47.00	3022.5	25.6
Ecosystem quality	1.488	95.7	2.0	7.24	465.6	3.9
Climate Change	22.32	1435.4	30.0	52.00	3344.1	28.3
Resources	34.968	2248.8	47.0	77.70	4996.8	42.2
tot.	**74.4**	**4784.6**	**100.0**	**183.9**	**11829.1**	**100.0**

Therefore a good chose of electricity source can help to reduce the ecological effect of carbon capture and storage.

---

[1] Based on IMPACT 2002+ v2.1 [6], 1 Point represent 0,0071 DALY, 13700 PDF.m^2.yr, 9950 kg CO_2 eq. and 152000 MJ for Human Health, Ecosystem Quality, Climate Change and Resource consumption respectively

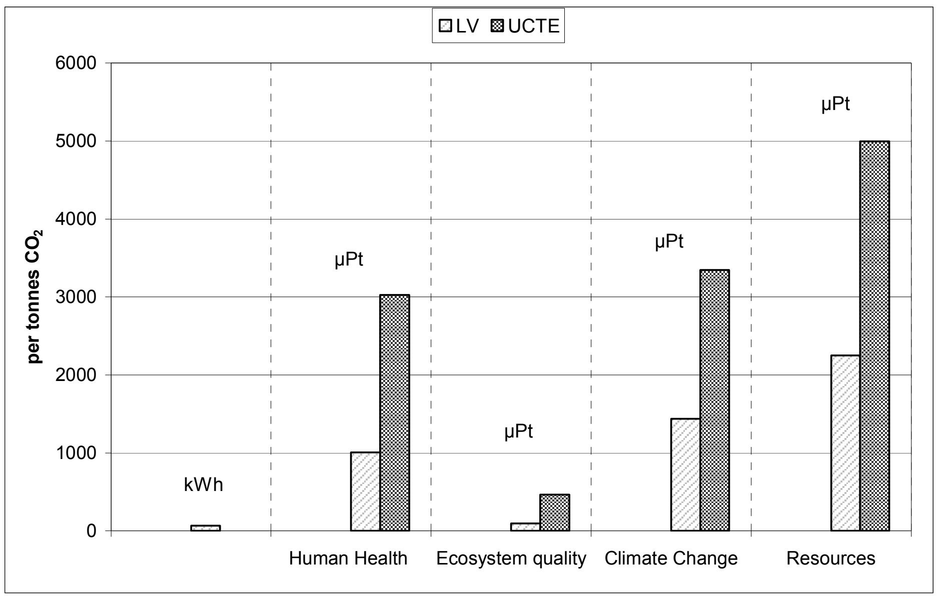

Figure 2. Sensitivity analysis on the choice of power source

Conclusion

This analysis shows that total ecological effects of carbon dioxide capture and storage is 4785 µPt for a pipeline with a length of 100km, a mass flow rate equal to 1.0 Mtonne/year and losses equal to 10%/100km. Resource consumption and Climate Change are the main contributors of these total ecological impacts (77%).

Deeper analyses could be performed for different lengths of pipeline and/or for difference flow rates involving diameter estimations. Pipelines thickness evaluation could also be done in the aim to provide a cost analysis.

Further work is necessary to properly assess the environmental impact of carbon capture and storage technology.

References

1. http://www.neo.ne.gov/statshtml/glossarys.htm

2. http://www.pointcarbon.com/

3. Njakou D.S, Simanoska J, Bazbauers G, Valters K (2008). *“Eco-indicator of latvian power supply”*. Manuscript submitted to the Latvian Journal of Physics and Technical Sciences.

4. Herzo, Heddle and Klett (2003). *“The conomics of carbon dioxide storage”*, MIT Laboratory for energy and the environment, Pub# LFEE 2003-003 RP

5. IEA Greenhouse Gas R&D Programme *“Transmission of CO_2 and Energy”* Report no. PH4/6, March 2002.

6.. Mohitpour M., Golshan H., Murray A (2000). *“Pipeline design and construction: A practical approach”*, The Ameriacan Society of Mechanical Engineers, New York 2000

7. Mccollum D.L, Ogden J.M (2006). *“Technoeconomic models for carbon dioxide compression, transport, and storage and correlations for estimating carbon dioxide density and viscosity”*,. Institute of transportation studies, University of California- Davis, Report UCD-ITS-RR-06-14

8. ISO 14040 (2006), *“Environmental Management- Life Cycle Assessment- Principles and Framework”*,. International Standard Organisation (ISO), Geneve 2006

9. Jolliet O, M Margni, R Charles, S Humbert, J Payet, G Rebitzer, R Rosenbaum: *“IMPACT 2002+: A New Life Cycle Impact Assessment Method”,* Int. J. LCA 8 (6) 324-330, 2003

Djomo S.N., Romagnoli F., Gusca J., Blumberga D. Vai CO2 saspiešana un iesūknēšana ir videi draudzīga
Saskaņā ar Kioto protokolā minētiem atzinumiem, ir nepieciešams ievērojami samazināt oglekļa dioksīda (CO2) emisijas, lai mazinātu klimata pārmaiņu ietekmi.Ogļskābā gāze ir galvenais piesārņotājs, kurš izraisa klimata izmaiņas un viena no ogļskābas gāzes samazināšanas metodēm ir tā uztveršana un noglabāšana pazemes krātuvēs. Šī tehnoloģija ir uzskatāma par tehnoloģiju, kas nākotnē spēs ievērojami samazināt CO2 emisiju nonākšanu atmosfērā. Šī raksta mērķis ir izstrādāt aprēķina shēmu ogļskābās gāzes transportēšanai pa cauruļvadiem un veikt dzīves cikla novērtējumu (DCA) ogļskābās gāzes transportēšanai pa cauruļvadiem . Dzīves cikla analīzes laikā tiek novērtēti resursu patēriņš un emisijas, kuras rodas produkta pilna dzīves cikla laikā; lai gan šajā darbā tiek veikts tikai dzīves cikla pārskats, jo pilnai dzīves cikla analīzei ir nepieciešama papildus informācija, kas uz raksta izstrādes laiku vēl nebija pieejama. Šajā rakstā ir parādīta dzīves cikla analīze tikai diviem posmiem no CO2 uztveršanas un uzglabāšanas saimniecībās. Darba metodika balstās uz pieņēmumiem, ka ogļskābās gāzes plūsma ir vienāda ar 1.0 Mtonna/gadā , pie noteikta transportēšanas attāluma 100 km.Nākotnē pētījumu ir jāpapildina ar precīzāku datu vākšanu, lai veiktu pilnu dzīves cikla novērtējumu pie dažādiem cauruļvadu garumiem, CO2 plūsmu, biezumu novērtējumu un izmaksu analīzi. Turpmākais darbs varētu būt nepieciešams oglekļa dioksīda uztveršanas un uzglabāšanas pareizai vides ietekmes novērtēšanai.

Djomo S.N., Romagnoli F., Gusca J., Blumberga D. Is CO_2 compressing and piping environmentally feasible
Under the provisions of the Kyoto Protocol large reductions in carbon dioxide (CO_2) emissions are needed to to mitigate the impacts of climate change.Carbon dioxide is the main major pollutant causing climate change and one method to reduce carbon dioxide is to capture and store it into underground reservoirs. Carbon dioxide (CO_2) sequestration or "storage" is the storage of carbon dioxide (usually captured from the "atmosphere") in a solid material through biological or physical processes. This technology seems to be the most effective for a large future reduction in CO_2 emissions.The objective of this article was to develop a calculation scheme for CO_2 transport by

pipeline and to establish a streamlined life cycle assessment (LCA) of carbon dioxide transport by pipeline. An LCA assesses the resources consumptions and the emissions occurring along the whole life cycle of a product; in this work, only a screening LCA is carried out cause full LCA requires more detailed data which are not all available at the time this work is be carried out. In this article is presented analysis of only two blocks of CO_2 *storage and capture system.This article takes into account methodology for analysis, by use of calculation for a* CO_2 *flow rate equal to 1.0 Mtonne/year over a fixed distance equal to 100km.Future researches should include collection of more specific data for a more detailed and complete LCA, different lengths of pipeline for difference flow rates, thickness evaluation and cost analysis. Further work could be necessary to properly assess the environmental impact of carbon capture and storage technology.*

Джомо С.Н., Ромагноли Ф., Гуща Ю., Блумберга Д. Влияет ли на среду сжатие и закачивание CO2

Согласно заключениям Киотского протокола, необходимо значительно снизить выбросы диоксида углерода, чтобы уменьшить влияние на изменение климата. Углекислый газ главный загрязнитель, который вызывает изменения климата и один из методов уменьшения углекислого газа это улавливание и хранение в подземных хранилищах. Эта технология считается технологией, которая в будущем сможет значительно уменьшить попадание CO2 в атмосферу. Цель статьи разработать схему расчета для транспортировки углекислого газа по трубопроводам и провести анализ жизненного цикла для транспортировки углекислого газа по трубопроводам. Во время анализа жизненного цикла оценено потребление ресурсов и эмиссии, которые появились во время всего жизненного цикла; хотя в этой работе реализован только обзор жизненного цикла, потому что для полного анализа жизненного цикла необходима дополнительная информация, которая на момент написания статьи не была доступна. В статье показан анализ жизненного цикла только для двух этапов из системы улавливания и хранения CO2. Методика работы основывается на предположениях, что поток углекислого газа равен 1.0 Мтонна/год, при определённом расстоянии транспортировки 100 км. В будущем исследование надо пополнить более точным сбором данных, чтобы можно было бы сделать полную оценку жизненного цикла при разной длине трубопроводов, потоке CO2, оценке густоты, и оценке влияние хранения на среду.