Cost Quantification of CO2 Sequestration and Utilization in S Field

Juhairi Aris Bin Muhamad Shuhili
School of Engineering
Asia Pacific University of Technology & Innovation
Perak, Malaysia/Kuala Lumpur, Malaysia
juhairi.shuhili@apu.edu.my

Muhammad Adidinizar Zia Ahmad Kusairee
Department of Business and Management
Universiti Teknologi Mara Perak Branch Tapah Campus
Perak, Malaysia
adidi627@uitm.edu.my

Lee Jang Hyun
Petroleum Engineering Department
Universiti Teknologi PETRONAS
Perak, Malaysia
lee.janghyun@utp.edu.my

Ismail Mohd Saaid
Petroleum Engineering Department
Universiti Teknologi PETRONAS
Perak, Malaysia
ismailsaaid@utp.edu.my

Hazliza Haron
Department of Business and Management
Universiti Teknologi Mara Perak Branch Tapah Campus
Perak, Malaysia
hliza457@uitm.edu.my

Sunil Kwon
Dong-A University, 37 Nakdong-daero 550beon-gil, Saha-gu
Busan, South Korea
sikwon@dau.ac.kr

***Abstract*— This paper narrated the cost quantification of CO2 sequestration and utilization in S Field located in Sabah basin. CO2 sequestration was a novel technology introduced as a counter act against global warming but received rather a cold response due to uncertainty in the costing. Thus, this paper investigated the cost required to store CO2 permanently via EOR and permanent sequestration scheme. This paper discussed only the economics of the storage utilizing some pre-acquired data such as the storage capacity, injection amount, and oil to be recovered from the action of CO2 injection or sequestration. The cost quantification was done by evaluating the CAPEX and OPEX of the sequestration and injection without accounting for the capturing of the CO2 cost. The CAPEX was divided into major components of the costs namely pipeline, platform, and drilling activities while the OPEX was expressed as a percentage of the CAPEX. Results from the study indicated for the case of EOR coupled with CO2 sequestration and CO sequestration alone incurred expenses of USD 1.9 and 1.7 billion respectively with an OPEX of USD 76 and 68 million annually. The major component of the CAPEX was derived from the cost of pipeline influenced by the distance from the onshore terminal to the storage site in S Field while the major component from the OPEX was logistics and consumables which finding resonated with the CAPEX. This study was an important step which should be taken prior to implementation of CO2 sequestration project in Malaysia arena. The project provided an overview or commitment to any company who wishes to embark in the similar journey.**

Keywords*— *CO2 sequestration, Capital Expenditure (CAPEX), Operating Expenditure (OPEX), Enhanced Oil Recovery (EOR), Economics, Climate Change

I. Introduction

Climate change had been a serious problem that haunted people all around the world. Among the negative impact of climate change was increase in the global temperature that led to flash flood in low-land due to melting of ice, spread of disease due to dry climate, drought and poor growth of crops that may eventually lead to shortage of food and famine (Kasotia, 2022). The main cause of climate change was due to emission of greenhouse gases (GHG) namely methane and carbon dioxide (CO2) where the former had more capacity to trap heat than latter (Denchak, 2019). The main hiccup for a CCS project to happen was because the poor quantification of the cost. CCS is rather a new technology which was associated with lack of study being conducted on the topic even from technical aspect which explained only 2 capturing mechanisms from several that had surpassed TRL 3. (Rubin, Davison, & Herzog, 2015). The cost quantification for sequestration and utilization was always done in a very general sense where a lump sum figure given to represent the sequestration cost in entirety without dissecting further into the stage. This practice shall contribute adversely to the overall cost estimation as sequestration cost was exorbitant. Apart from lump sum costing, the revenue of utilization of CO2 from tertiary recovery often expressed in the reduction of electricity cost of carbon capture for policymakers as shown in (Metz, Davidson, Coninck, Loos, & Meyer, 2005).

In CCS particularly related to CO2 sequestration, enormous amount of money had to be spent in drilling wells and building platforms which was only cost incurring in nature with no monetary returns (Ouyang & Cao, 2023). Apart from no revenue, the discrepancies of the costing associated with CO2 sequestration made the effort to estimate costing of CO2 sequestration within the local context became more complex. Cost of CO2 injection was mentioned that ranged from 2 to 7 USD/ton depending on the injection and storage. This study was done in US and the amount of CO2 that can be stored within the depth range of 1600 m. was 0.18 to 0.31 metric ton (Eccles, Pratson, Newell, & Jackson, 2009). Drilling cost which was one of the elements of the overall cost was expected to vary exponentially or quadratically with the depth The increment of the cost with depth deviated from the trend upon reaching 3000 m. where further addition of depth shall cost more than the trend. (Eccles, Pratson, Newell, & Jackson, 2009). The cost saving mechanism for CO2 sequestration lied deeply in the amount of CO2 that could be stored where a formation with higher storage capacity shall result in less cost by avoiding redundancy of midstream operation connecting collection points to the injection site (IEAGHG, 2011).
In this study, the offshore midstream transportation cost was captured under the CO2 sequestration as well where the cost

of pipeline being studied as the mode of CO2 transportation. Pipeline was found as the most sensitive cost in economic analysis based on a study conducted in Europe. Among the factors that governed the costs of pipeline were the different in height between the delivery point and the upstream part, the amount of flow, and the distance. CO2 received rather a "special treatment" due to the acidic nature of the gas (Knoope, Ramirez, & Faaij, 2013). Another factor for CO2 transportation was the geological factor as mentioned in a CO2 transportation study conducted in China. North China in where the Capital was situated had higher cost compared to the East China. Basically, the geographical factor here reflecting on the manpower cost index not the terrain. (Ning Wei, Wang, & Gao, 2016).

II. METHODS

To dive deep into the implementation of the methods, a chronology of the procedures comprising the research design, variables and measures, and data selection would be explained. The research design for the first objective was to procure costs first. The main component of the costs was CAPEX and OPEX where OPEX were assumed to be 4% of the CAPEX if there was no avenue in finding OPEX (IEAGHG, 2011). The approach was using literature review based on the most similar operation to Malaysian offshore drilling. Any of the costs obtained in the past would be discounted using a cost escalation of 3% per annum (IEAGHG, 2011). However, the author managed to obtain a different rate based on analysis conducted.

The next step was the construction of reservoir model from which the oil recovery, the injection amount, and pressure build-up evaluation were studied. The reservoir model was constructed utilizing petrophysical, special core analysis laboratory (SCAL) data, and routine core analysis (RCA) data of the S Field. Since the injected gas must be CO2 specific instead of general gas phase, thus, compositional reservoir simulation was employed instead of black oil. The oil recovery was needed to provide ground that the CO2 injection was indeed working based on the additional oil recovery and to quantify the costs for the producers as well. The build-up in the bottom hole pressure (BHP) was needed to further support that the injection implemented did not exceed the safety limit.

Despite of the calculation being done in the realm of economics; the reservoir characterization was very important since the amount of the gas that can be stored in the reservoir very much dependent on the reservoir properties and the amount of gas to be stored governed the number of injection wells needed. Apart from that, the amount of gas needed for utilization for economic increment in oil production also very much dependent on the reservoir characterization. Since the study was divided into utilization (EOR) and standalone CO2 sequestration, cost quantification mechanism was split. The cost quantification was modelled using a commercial upstream oil and gas sector software in which the CAPEX and OPEX were obtained.

The main components of the CAPEX for an oil and gas upstream project were equipment, materials, fabrication, installation, hook-up & commissioning, design, project management, insurance & certification, and contingency. All the sub-components of the CAPEX were captured in Table 1. The main components of OPEX were captured in Figure 5. The components were operating personnel, inspection and maintenance, logistic & consumables, wells, and insurance. The examples under the equipment were x-mas tree, wellhead, and artificial lift. This equipment was under the category of offshore drilling portrayed in Figure 1. For materials, the casings used were part of the CAPEX. Fabrication, installation, and hook-up & commissioning referred to platforms. The same went for design, project management, and the rest of the CAPEX component (Barateiro, Casado, Makarovsky, & Filho, 2023).

For the OPEX, personnel referred to manpower, inspection and maintenance referred to the platform and pipeline, logistic& consumable referred to helicopter and supply boat including diesel and chemicals, wells referred to daily rate of rig, and the insurance was just a premium charged based on the CAPEX. Despite of having the thorough costing mechanism, 2 shortcomings happened while utilizing the commercial software. The first setback was due to the constraints imposed on the maximum length of pipeline used in the software which was less than 1000 km. This limitation somehow contradicted in terms of the general findings on length of pipeline constructed in oil and gas industry where the longest for gas was West-East Gas Pipeline built by PetroChina which transported gas from Xianjing to Shanghai. The longest oil pipeline was Druzhba Pipeline built by the several countries in Europe as an embodiment of friendship which transported oil all the way from Russia to Germany (Husseini, 2018).

The contradiction arose mainly due to limitation of the cost computation in the commercial software where exceeding certain distance, the cost structure might deviate from a designated pattern which prompted the idea to perform the regression as shown in Figure 6 and Figure 8. Analysis of the regression would be further discussed in the findings section. The second modification made for the standalone CO2 sequestration cost quantification due to absence of explicit option in performing cases without oil or gas production. The workaround for this shortcoming was obtaining the costs by benchmarking utilization case which had the similar cost structure without hydrocarbon transportation to onshore. The findings of the regressions done prior in utilization case was utilized for standalone sequestration as well.

III. FINDINGS

Before cost quantification analysis was done, the analysis must be preceded with the field schematics first to obtain the expenses required for the operation to take place as shown in Figure 1 (for utilization) and Figure 2 (for standalone). Both cases required the same development option which included the major CAPEX element such as platform (labelled with topsides and jacket), offshore drilling (the drilling activities), and the pipelines. For the pipelines, however, utilization case required an additional pipeline for the hydrocarbon transportation from the platform to LCOT. LCOT and TCOT referred to Labuan Crude Oil Terminal and Terengganu

Crude Oil Terminal respectively. The idea behind the operation was to utilize or sequestrate the CO2 captured from the 2 sides of Malaysia i.e., peninsular, and east, and be stored or utilized in S Field which was located in Sabah Basin.

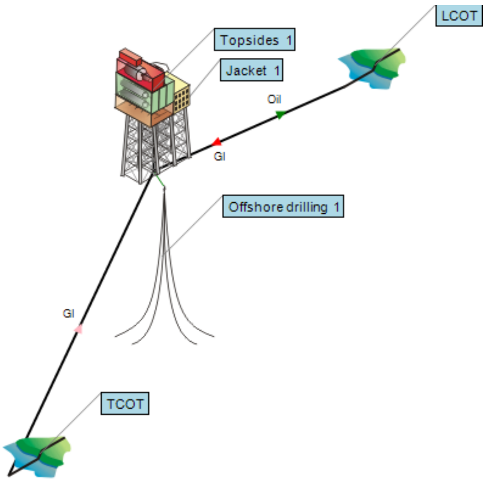

Figure 1: Field Schematics of Utilization

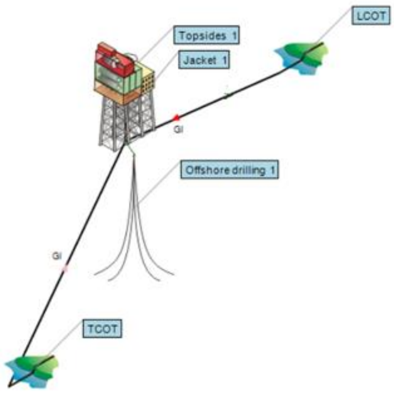

Figure 2: Field Schematics of Standalone CO2 Sequestration

Among the 3 major CAPEX, highest cost was incurred by the pipeline from TCOT since the distance spanned around more than 1000 km which created huge surplus in CAPEX. A future recommendation for this plan would be analyzing the impact if tanker was used instead of pipeline. In a comparison between tanker and pipeline for case studied using Greece to northern part of Crete, where shipping route took 299 km while pipeline due to the terrain took 360 km, recorded and expenses of minimum 397 mil USD (CAPEX) and 4.45 ml USD (OPEX) for pipeline while for tanker was 25.2 mil USD (CAPEX) and 16.93 mil USD (OPEX) (Atteridge & Lloyd, 2020).

This showed that there was not a single conclusive option that best served the interest of the project economics . The options simply depended on the number of operation years which were illustrated in Figure 3 and Figure 4. Figure 3 showed the plot of the cumulative cost over the year for the option of tanker and pipeline in the case of CO2 sequestration which showed a big gap awarding victory to tanker. For the CO2 sequestration case, the injection period was up until 12 years which was computed based on the saline aquifer storage while 20 years for the utilization (inclusive of production year without injection) where the CO2 was injected into the reservoir section instead for the aided oil recovery. For the CO2 sequestration, monitoring period followed the injection period was done for 20 years following a suggestion from trustable source (McKinsey, 2008). However, there was no OPEX for pipeline in the case of standalone CO2 sequestration post injection since no gas transportation happened hence in Figure 3, the operation period was limited to 12 years. The utilization case had a contract period of 20 years where the pipeline had to be operating throughout the years since production occurred earlier than injection. An interesting observation made in

Figure 4 where the cost incurred by tanker was encroaching pipeline showing that as the operation years increased, the cost of pipeline would be more economical. Pipeline was chosen as the midstream option because pipeline had less carbon print compared to tanker (Atteridge & Lloyd, 2020). The project revolved around carbon offset, thus, considering an option which was less detrimental to the environment from the point of view of carbon emission was definitely a choice made out of wisdom. The second justification on pipeline being chosen without much preliminary study done with tanker as the comparison because the technology or application of tanker in transporting CO2 for sequestration was yet to be established thus rendering tanker as not yet a viable option considering technology readiness level (TRL).

Part from the argument presented, the case of Greece to Crete was not a good analogy for S Field. The distance spanned around 299 km while LCOT to S Field was around 38 km which gave a significant advantage for pipeline. The overall study considering CO2 emission from whole Malaysia thus had the need to consider TCOT or the peninsular emission as well. However, in reality, considering nearby fields in Penyu or Malay Basin should be a prudent choice to store CO2 captured from peninsular which would be transported from TCOT.

Nevertheless, since the scope covered the emission from both sides of Malaysia and S Field as the injection site, the need to consider the cost of the pipeline was resolved. Based on Figure 7, a sensitivity study was performed using the commercial software where the distance of pipeline was varied and the impact on the overall Figure 7,CAPEX amount studied. A strong linear correlation was obtained as shown in Figure 7, with a regression coefficient of 0.999 which proved that the cost of pipeline indeed dependent on the distance and provided a leeway to use the equation to compute the pipeline cost for LCOT for both sequestration and utilization case. Thus, the first shortcoming was resolved successfully, and the next regression was for CAPEX and OPEX. This regression was done to observe the relationship between CAPEX and OPEX. The OPEX value was taken by arithmetically averaging the values obtained over the contract years. The relationship obtained showed a strong linear relationship between the 2 factors with the regression coefficient of 0.9993 as shown in Figure 8. This was indeed a good finding as this allowed for the prediction of the OPEX using CAPEX which was found to be 5.5% as shown in the gradient of Figure 8. The last check needed to be done was pattern of

OPEX with the distance which was shown that indeed the OPEX cost increment tallied with the distance as shown in Figure 7. A linear proportional finding between distance, CAPEX, and OPEX allowed the authors to conveniently predicted the CAPEX and OPEX incurred by pipeline covering distance of more than 1000 km. Thus, by the virtue of regression and benchmarking, the TCOT cost and absence of the standalone sequestration in the commercial software were successfully resolved.

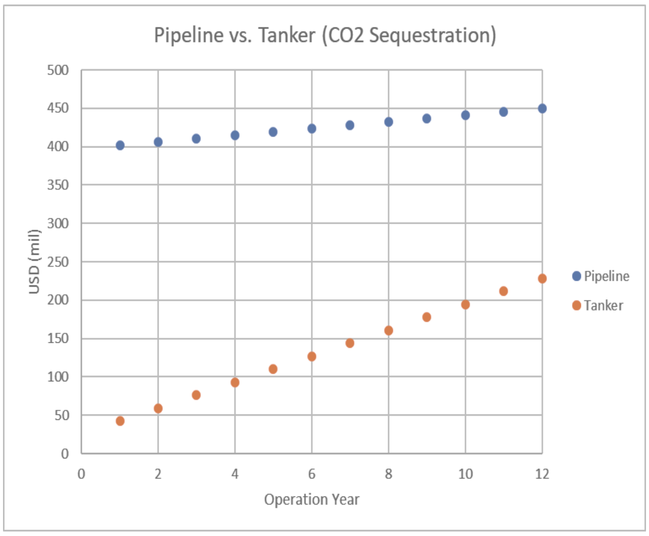

Figure 3: Pipeline vs. Tanker (CO2 Sequestration)

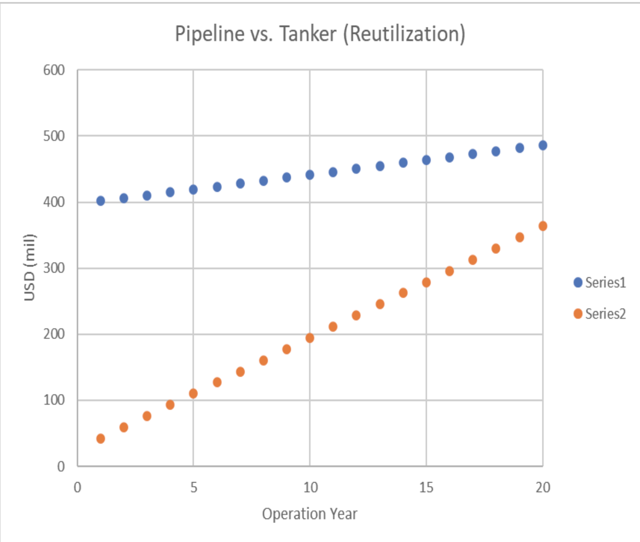

Figure 4: Pipeline vs. Tanker (Utilization)

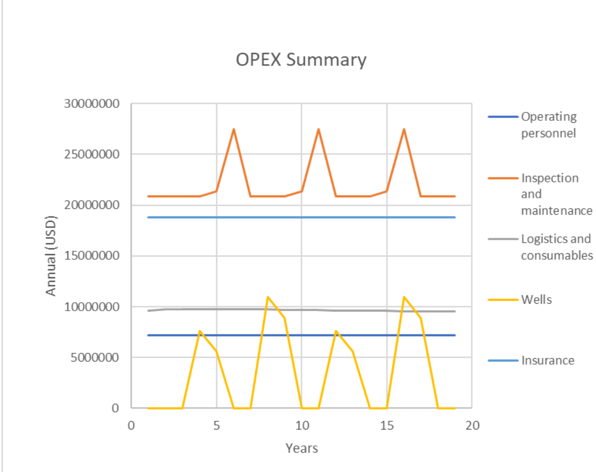

Figure 5: OPEX Summary for General Case

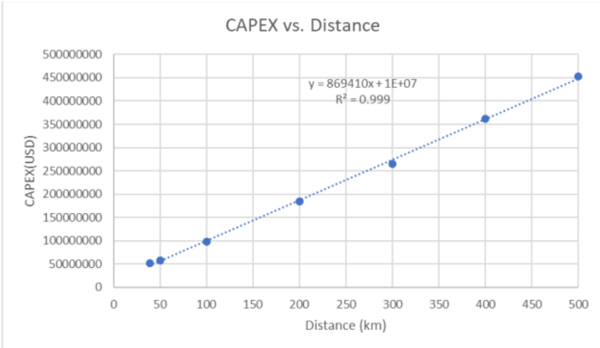

Figure 6: CAPEX vs. Distance

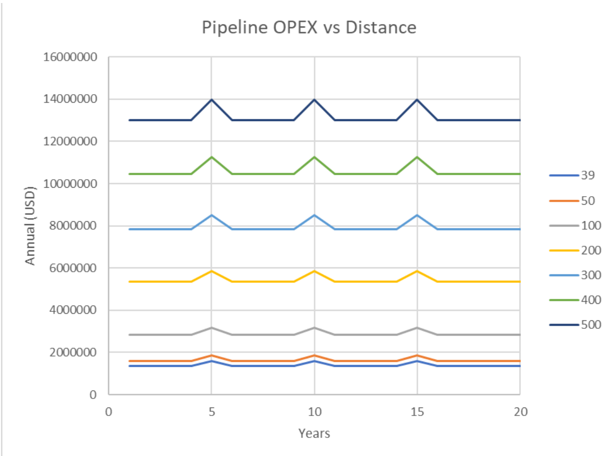

Figure 7: Pipeline OPEX vs. Distance

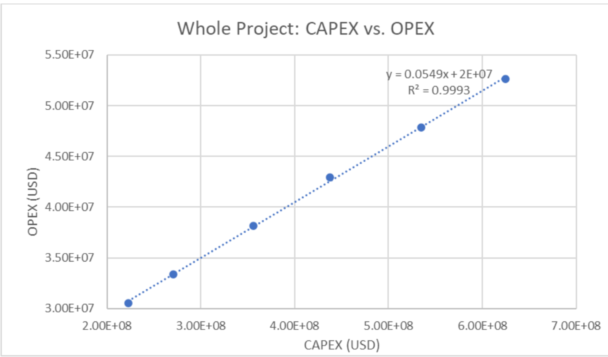

Figure 8: CAPEX vs. OPEX

Table 1: Cost Summary of Utilization

Cost centre	Topsides 1	Jacket 1	Gas injection pipeline (LCOT)	Gas injection pipeline (TCOT)	Oil pipeline (LCOT)	Offshore Drilling
Equipment	6.71E+07					1.14E+07
Materials	1.56E+07	5.45E+06	8.74E+06	7.96E+08	6.68E+06	8.98E+06
Fabrication	2.82E+07	6.57E+06				
Installation	1.20E+07	2.82E+07	3.38E+07	4.34E+08	3.25E+07	3.53E+07
Hook-up & commissioning	1.45E+07					
Design	2.05E+07	1.31E+06	6.12E+05	7.53E+06	1.24E+06	7.51E+05
Project management	6.38E+06	9.40E+05	1.32E+06	1.63E+07	2.66E+06	8.20E+05
Insurance & certification	6.57E+06	1.70E+06	1.78E+06	5.02E+07	1.72E+06	2.29E+06
Contingency	1.71E+07	4.41E+06	6.94E+06	1.96E+08	6.72E+06	1.19E+07
Totals	1.88E+08	4.85E+07	5.32E+07	1.50E+09	5.15E+07	7.14E+07

Table 2: Cost Structure of Standalone CO2 Sequestration

CAPEX	USD mil	Remarks
Platform	168	The cost of CPP (Topsides + 8-leg jacket) with injection facilities
Wells	18	2 injection wells injecting at a rate of 50 mmscfd
Pipeline	1550	2 pipeline connecting S-Field with TCOT and LCOT
Total	1736	Total CAPEX
OPEX (annual)	96	5.5 % of the total CAPEX

Finally, the costs of both the standalone CO2 sequestration and utilization were captured in Table 1 and Table 2. The cost of platform was 236 mil USD for the utilization while for standalone sequestration was 168 mil USD. The reason utilization registered a higher figure was due to higher number of wells (both producers and injectors) while for sequestration, only injection wells were considered. For the wells cost, obviously, utilization had less due to less no of wells. However, a linear relationship of the number of wells and costing might be absence due to the nature a well cost being assessed which was based on the measured depth (MD) and number of wells which are the required input in the commercial software. The last major CAPEX component was pipelines where again utilization had more costs due to the need of transporting oil back to onshore (LCOT) from platform (S Field). The OPEX was simply 5.5% of the CAPEX incurred as proven by the relationship established by inferring Figure 5, Figure 6, Figure 7, and Figure 8.

IV. Acknowledgment

"This work was conducted in Asia Pacific University of Technology & Innovation using the academically licensed commercial software for the reservoir simulation. In term of knowledge sharing, this work was supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (MOTIE) (20225B10300080), Developing a Business Model for CO2 Storage Overseas and Screening the Prospective Sites for Depleted Oil and Gas Fields in Southeast Asia). A special thanks to Petroleum Engineering Department of Universiti Teknologi PETRONAS and UiTM Business School for providing expertise on sequestration technically and economical constraints for the project to work especially in the real case. A special thanks to Universiti Teknologi PETRONAS as well for the economics software provision"

V. References

Atteridge, W., & Lloyd, S. (2020). *Comparing the costs to transport liquids offshore using pipelines and ships.* Pipelines International Summer 2020.

Barateiro, C. E., Casado, M., Makarovsky, C., & Filho, J. R. (2023). Business Risk and CAPEX/OPEX Analysis: Impact on Natural Gas Fiscal Measurement Systems. *International Information and Engineering Technology Association (IIETA)*, 113-120.

Denchak, M. (2019). *Greenhouse Effect 101.* New York: Natural Resources Defense Council, Inc.

Eccles, J. K., Pratson, L., Newell, R. G., & Jackson, R. B. (2009). Physical and Economic Potential of Geological CO2 Storage in Saline Aquifers. *Journal of Environmental Science & Technology*, 1962-1969.

Husseini, T. (2018). *Transporting oil and gas: the world's longest pipelines.* Offshore Technology.

IEAGHG. (2011). *The Costs of CO2 Storage: Post-demonstration CCS in the EU.* Brussels: Technology Platform for Zero Emission Fossil Fuels Power Plant .

Kasotia, P. (2022, March 27). *The Health Effects Of Global Warming: Developing Countries Are The Most Vulnerable*. Retrieved from United Nations: h

Knoope, M., Ramirez, A., & Faaij, A. (2013). A state-of-the-art review of techno-economic models predicting the costs of CO2 pipeline transport. *International Journal of Greenhouse Gas Control*, 241-270.

McKinsey. (2008). *Cabon Capture and Storage: Assessing the Economics.* McKInsey.

Metz, B., Davidson, O., Coninck, H. d., Loos, M., & Meyer, L. (2005). *Carbon Dioxide Capture and Storage.* Cambridge: Cambridge University Press.

Ning Wei, X. L., Wang, Q., & Gao, S. (2016). Budget-type techno-economic model for onshore CO2 pipeline transportation in China. *International Journal of Greenhouse Gas Control*, 176-192.

Ouyang, M., & Cao, Y. (2023). Utilizations of reaction exothermic heat to compensate the cost of the permanent CO2 sequestration through the geological mineral CO2 carbonation. *Energy*, 1-9.

Rubin, E. S., Davison, J. E., & Herzog, H. J. (2015). The Cost of CO2 Capture and Storage. *International Journal of Greenhouse Gas Control*, 378-400.