Feasibility Study on Production of Decarbonized Ammonia in the United States

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CO_2 Enhanced Oil Recovery (EOR) has been widely utilized in the United States for a handful decades and industrial CO_2 sources such as ammonia production and gas processing are projected to be the primal supplier as well as natural CO_2 source fields in the future when both CO_2-EOR production and ammonia production capacity are estimated to grow steadily. This study presents a feasibility study on production of decarbonized ammonia derived from combination of CO_2-EOR business and ammonia production business through CO_2 pipelines in the United States. Analysis using equity internal rate of return (EIRR) reveals that the C&F price of decarbonized ammonia to Japan ranges from \$0.2/Nm^3-H_2 to \$0.32/Nm^3-H_2 which include profitability of CO_2-EOR and ammonia production business base on \$80/bbl crude oil price.

1. Introduction

Enhanced oil recovery through the injection of carbon dioxide (CO_2-EOR) has been practiced in the United States for nearly 50 years. In 2014, it contributed to crude oil production at the rate of about 300,000 barrels per day (b/d).[1)] A large proportion of CO_2 injected for EOR is presently supplied from natural CO_2 fields that offer a relatively low procurement cost. However, with increased crude oil production by CO_2-EOR in the future, the quantity of CO_2 available from natural CO_2 fields is expected to become insufficient, creating the need to procure CO_2 from industries and the power generation sector. Among the potential sources of additional CO_2 for CO_2-EOR, ammonia production plants are regarded as promising candidates for the following reasons: 1) they produce high purity CO_2 in the production process; 2) the Gulf Coast, which is the center of the CO_2-EOR business, also acts as a hub for ammonia production; and 3) ammonia production capacity is forecasted to grow thanks to increasing demand.

In Japan on the other hand, ammonia is attracting attention chiefly from the perspective of reducing CO_2 emissions. Ammonia may emerge as a new energy carrier that does not produce CO_2 by combustion. The capture and storage of CO_2 arising from the production process may realize "carbon-neutrality" of the entire supply chain, creating additional environmental values. Among the various approaches to CO_2 segregation, the ones that are solely for the purpose of sequestration (e.g. deep saline aquifer) are costly; the number of projects based on such approaches worldwide is limited. Decarbonized ammonia production through coupling with CO_2-EOR, on the other hand, can be less costly because of the added value of CO_2. If the CO_2-EOR sector and the ammonia production sector collaborate as they both continue to grow in the future in the United States, the export of decarbonized ammonia to Japan may become possible.

In this study, we examined the feasibility of decarbonized ammonia production in the above-mentioned manner in the Gulf Coast of the United States. After analyzing quantitatively how the profitability of the two businesses involved in this scheme would change with fluctuations in the crude oil price, natural gas price, etc., we determined the lowest ex-factory price of decarbonized ammonia that would still keep the two businesses profitable, and estimated the C&F price of ammonia to Japan.

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2. Current Status of Ammonia Production and CO_2-EOR in the United States

As of 2015, the annual capacity of ammonia production in the United States was about 12 million tons. About 60% of this production capacity is in the Gulf Coast (which is assumed here to include the states of Texas, Arkansas, Louisiana, Mississippi, Alabama, New Mexico and Oklahoma). This area is known for the massive production of natural gas that serves as a raw material in the production of ammonia. In terms of proven reserves of natural gas, the area has about 55% of the US total, which is 10.5 trillion m^3 (at the end of 2014). Helped by low natural gas prices, ammonia production capacity has grown in recent years and is expected to reach 18 million tons nationwide by around 2020. About 10 million tons of this capacity will come from the Gulf Coast.

In 2014, there were 136 CO_2-EOR projects under way in the United States. These are estimated to have injected a total of about 60 million tons of CO_2 during the year, contributing to crude oil production at the rate of about 300,000 b/d. The Permian Basin in western Texas has the greatest density of CO_2-EOR projects, and hosts as many as 77 projects. About 80% of the injected CO_2 is procured from natural CO_2 fields such as McElmo Dome (Colorado) and Jackson Dome (Mississippi). According to a forecast by the DOE, crude oil production by CO_2-EOR is likely to reach 740,000 b/d by 2040, with the annual CO_2 injection volume increasing to 150 million tons even if no new CO_2 trunk pipeline is constructed.[2)] The share of CO_2 procured from industry is expected to increase significantly and reach 50%.

In the United States, CO_2 pipelines with a total length of 7,200 km are already in operation[2)], and a further 960 km are scheduled to be constructed and commissioned by 2020. As the quantity of CO_2 supplied from industry to CO_2-EOR projects increases in future, it will become necessary to compensate for fluctuations in CO_2 output from individual CO_2 suppliers in industry due to factors such as factory operation status. To enable supply and demand to be adjusted stably, therefore, CO_2 pipeline networks will be developed, interconnecting multiple CO_2 suppliers and CO_2-EOR project operators. As CO_2 pipeline networks become larger and more integrated, CO_2 trading prices are likely to be based on market prices instead of varying from contract to contract.

3. Profitability Assessment Methodology

In the present study, we assessed the profitability of decarbonized ammonia production in two steps. First, we analyzed separately the profitability of CO_2-EOR and the profitability of ammonia production focusing on parameters such as the crude oil price and the natural gas price. Then, we conducted a coupled profitability assessment with attention to both of the two businesses involved in the scheme to determine the lowest ex-factory price of decarbonized ammonia that would still keep the two businesses profitable. We employed the equity internal rate of return (EIRR) as the indicator for assessing profitability. EIRR is an indicator of business profitability from the standpoint of investors, indicating the ratio of the return in cash to the amount of investment.

As shown in **Figure 1**, we postulated the case of an ammonia production plant and a CO_2-EOR site in the eastern part of Texas, which is in the Gulf Coast, near the Green CO_2 Pipeline extending west from Louisiana.

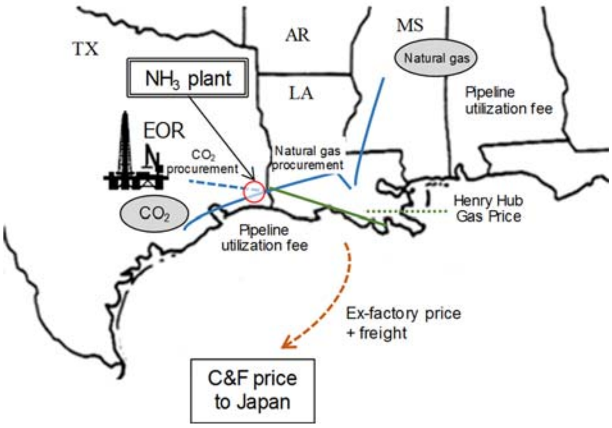


Figure 1: Locations of the postulated CO_2-EOR site and ammonia production plant

Tables 1 and 2 show details of the CO_2-EOR project and the ammonia production business. It is assumed that the CO_2-EOR project is launched at the Conroe oil field in the eastern part of Texas. At the site, crude oil production is continued at the rate of 8,200 b/d (a large-scale project). The cost of constructing a feeder line connecting the CO_2 trunk pipeline with the oil field was included in the CAPEX of the CO_2-EOR project. The ammonia production plant is assumed to be located in Beaumont, Texas. It has two production units, each having an annual production capacity of 625,000 tons, giving a total of 1.25 million tons. Natural gas, a raw material for ammonia production, is procured using an existing pipeline connected with the Henry Hub. The CO_2 is supplied using the Green CO_2

Pipeline. The pipeline utilization fee is assumed to be $10/t-$CO_2$. It is assumed that the pipeline is managed by a third-party operator independent from the CO_2-EOR project operator and the ammonia production plant operator. It is also assumed that the project conditions remain the same throughout its lifetime. The profitability of a CO_2-EOR project depends heavily on the geological characteristics of oil field; therefore, further study is required before we can address the question of how well the assumptions and conclusions from this study may apply to cases in other regions.

Table 1: Exogenous variables of the CO_2-EOR project

Production capacity	8.2	1000 b/d
Utilization ratio	95%	
CO_2 injection rate	0.56	t-CO_2/bbl
CAPEX	522	million $
Years of depreciation	10	years
Fixed cost	15	$/bbl
CO_2 purchasing cost	Parameter	$/t-$CO_2$
Royalty	10%	
Corporate tax (federal tax)	39%	
D/E ratio	2.3	
Borrowing rate	2.0%	
Project duration	20	years

Table 2: Exogenous variables of the ammonia production business

Production capacity	1,250	1000 t/y
Utilization ratio	100%	
Natural gas feeding intensity	36	MMBtu/t
CO_2 capture intensity	1.3	t-CO_2/t
CAPEX	1,970	million $
Years of depreciation	10	years
Fixed cost	46.4	$/t
Natural gas purchasing cost	Parameter	$/MMBtu
CO_2 selling price	Parameter	$/t-$CO_2$
Corporate tax (federal tax)	39%	
D/E ratio	2.3	
Borrowing rate	2.0%	
Project duration	20	years

4. Results

4.1 Profitability of CO_2-EOR

The profitability of CO_2-EOR will change with the crude oil price (selling price) and the CO_2 purchasing price.

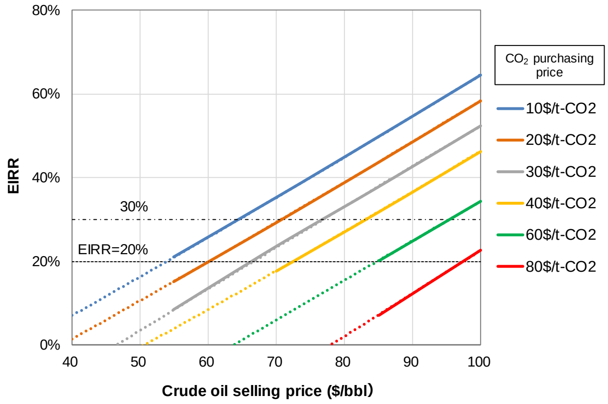
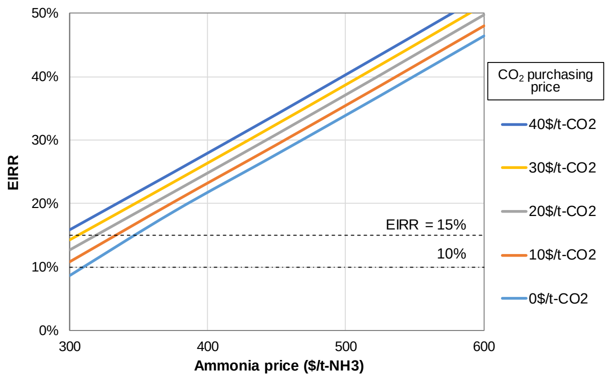


Figure 2: Profitability of CO_2-EOR

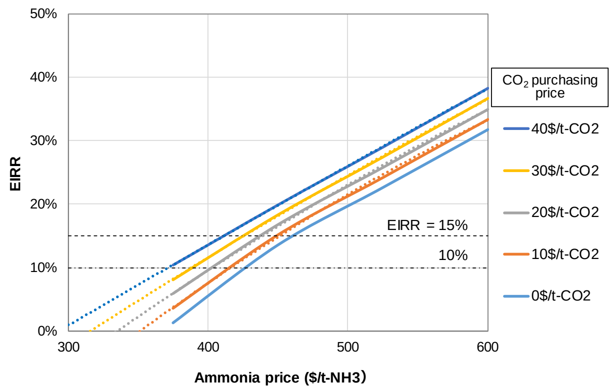
Figure 2 illustrates how changes in these two parameters could affect the profitability. Assuming that the EIRR of 30% (reference case) is the threshold for justifying investment in a CO_2-EOR project, the CO_2-EOR will not be sufficiently profitable when the crude oil price is $60/bbl. When the price rises to around $80/bbl, then the project will be economically feasible as long as the CO_2 purchasing price is not higher than $35/t-$CO_2$. Deducting the pipeline utilization fee from this CO_2 purchasing cost, the CO_2 selling price would be $25/t-$CO_2$. Supposing that the cost of CO_2 capture is around $40/t-$CO_2$ (estimated by the authors from the literature [3]), the ammonia production plant operator will be able to cover a major proportion of this cost by selling CO_2. If it is possible to cover the rest of the cost through a higher sales price of ammonia, then the ammonia production plant operator will undertake the capture and sales of CO_2. If the crude oil price goes higher, the upper limit of the CO_2 purchasing price that would still keep CO_2-EOR profitable will exceed the cost of CO_2 capture. This would likely result in steady increases in the supply of CO_2 from ammonia production plant operators to CO_2-EOR project operators.

4.2 Profitability of Ammonia Production

The profitability of ammonia production changes with the price of natural gas as a raw material, the ammonia ex-factory selling price and the CO_2 selling price. Using two different assumptions for the natural gas price (high and low cases), **Figure 3** shows how changes in the ammonia ex-factory price and the CO_2 sales price may affect the profitability of ammonia production. If we regard the EIRR of 15% (reference case) as the threshold that justifies investment in an ammonia production business, considering that the business risk is smaller compared with CO_2-EOR, the profitability of ammonia production is high when a low natural gas price is assumed. As long as the ex-factory price of ammonia is $350/t or higher, the business will be sufficiently profitable even without selling CO_2. If CO_2 can be sold at $30/t-$CO_2$ or higher, the lowest acceptable limit of the ammonia ex-factory price will become as low as $300/t. On the other hand, if the natural gas price is as high as $6.0/MMBtu, ammonia must be sold at $410/t or higher even if CO_2 is sold at $40/t-$CO_2$ in order to make the business sufficiently profitable. If the CO_2 cannot be sold, then the ammonia ex-factory price must be even higher than $460/t. That is to say, if CO_2 can be sold at a higher price, the lowest acceptable ex-factory price of ammonia may remain relatively low even when the price of natural gas as a raw material is high.



(a) Natural gas price: $2.75/MMBtu



(b) Natural gas price: $6.0/MMBtu

Figure 3: Profitability of ammonia production

4.3 Ex-factory Price of decarbonized Ammonia

Based on the above, we analyzed the conditions for progress in the coupling of the two businesses, namely, the supply of CO_2 for crude oil production by CO_2-EOR from the ammonia production plant via the CO_2 pipeline, and estimated the lowest acceptable ex-factory price for the ammonia produced under this scheme. The calculation procedure is as follows. Assuming a certain crude oil price, we first determined the CO_2 purchasing price that is low enough to make the CO_2-EOR project profitable. Deducting the pipeline utilization fee from this CO_2 purchasing price, we determined the CO_2 net selling price. Then, assuming this CO_2 selling price and handling the natural gas price as a parameter, we determined the lowest ammonia ex-factory price that would still ensure the profitability of ammonia production. We disregarded the possibility of the CO_2 selling price turning negative.

Figure 4 shows the results of analysis performed using profitability threshold assumptions based on the reference case (EIRR of 30% for CO_2-EOR, 15% for ammonia production). The higher the crude oil price is and the lower the natural gas price is, the lower will be the lowest ammonia ex-factory price that will still keep the two businesses profitable. As stated in **Section 4.1**, maintaining stable production of decarbonized ammonia is likely to require a crude oil price of around $80/bbl. Then the ex-factory price of ammonia is expected to rise with the natural gas price: $303/t at $2.5/MMBtu, $375/t at $4.5/MMBtu, and $447/t at $6.5/MMBtu.

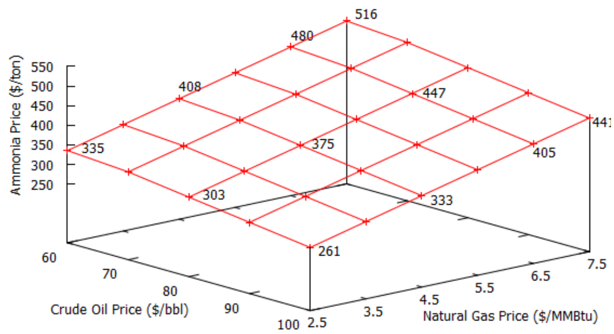


Figure 4: How changes in the crude oil and natural gas prices may affect the lowest acceptable ex-factory price of ammonia (profitability threshold according to the reference case)

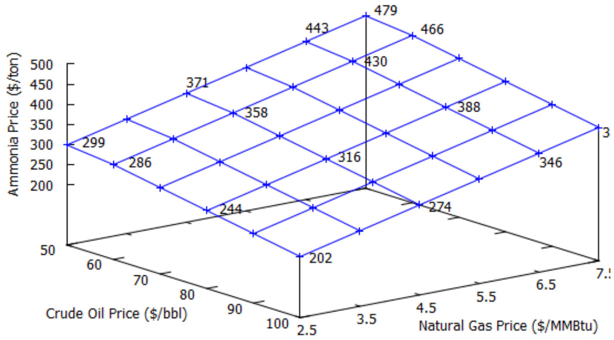


Figure 5: How changes in the crude oil and natural gas prices may affect the lowest acceptable ex-factory price of ammonia (lowered profitability case)

Figure 5 shows estimates of the ammonia ex-factory price derived from an analysis in which the threshold for profitability was lowered: EIRR of 20% for CO_2-EOR and 10% for ammonia production. Easing the profitability threshold enables the CO_2-EOR project operator to tolerate higher CO_2 purchasing prices while maintaining the same crude oil sales price. This, combined with the lowered profitability threshold for ammonia production, will reduce the lowest acceptable ex-factory ammonia price. Supposing that the cost of transportation from the factory to port, the costs at the export terminal, and the cost of freight transportation to Japan add up to $100/t, the C&F price to Japan will be as listed in **Table 3**. To enable the CO_2-EOR project operators to use CO_2 captured at ammonia production plants, the C&F price of decarbonized ammonia to Japan will be in the range of 22 to 35 yen/Nm^3 (hydrogen equivalent) at the crude oil price of $80/bbl assuming the exchange rate of 110 yen to the US dollar.

Table 3: C&F price of decarbonized ammonia to Japan (crude oil price at $80/bbl)

	Natural gas price ($/MMBtu)		
	2.5	4.5	6.5
Ammonia price	(reference case / lower profitability case)		
($/t)	403 / 344	475 / 416	547 / 488
(H_2 equivalent $/$Nm^3$)	0.23 / 0.20	0.28 / 0.24	0.32 / 0.28

5. Conclusion

Ammonia is attracting attention because of its potential role as a new energy carrier. It can be combusted without generating CO_2; it can be transported and stored using existing technologies and infrastructure; and it can serve directly as a fuel. In this paper, we analyzed the necessary conditions for CO_2-EOR projects to be combined with ammonia production plants in the United States by CO_2 pipelines for the production of decarbonized ammonia, and estimated the desirable C&F price of the ammonia produced in this manner to Japan. The analysis showed that the C&F price of decarbonized ammonia to Japan should be in the range of 22 to 35 yen/Nm^3. This price level for ammonia, attainable on the basis of existing technologies, is comparable to the target price level for hydrogen, which is also attracting attention as a new energy carrier.

References

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