Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 5 Issue 10, October - 2018

Carbon Capture and Storage Optimization Model with Enhanced Oil Recovery

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***Abstract*— This paper presents an optimization model and its application to an infrastructure for the Carbon Capture and Storage (CCS) with Enhanced Oil Recovery (EOR). The CCS is a technology that can be adopted by major emitters (power companies) to mitigate the carbon emissions without affecting people's daily needs for energy and power. One of the major issues involved in the implementation of this technology is the high costs incurred in the capturing process. When this high cost is coupled with the associated transportation and geological storage costs, the overall process is often deemed uneconomical. Unlike the previous models appeared in the literature, the proposed optimization model includes the concept of the injection of CO_2 for EOR operation, which will ensure considerable cost savings. The applicability of the proposed model is demonstrated in the case study of California's CCS planning. The results demonstrate that the proposed model is a practical and flexible tool in gaining insight into an infrastructure for CCS-EOR.**

Keywords—Carbon capture and storage; Enhanced oil recovery; deterministic optimization model

I. INTRODUCTION

The carbon capture and storage (CCS) is a technology, by which carbon dioxide (CO_2) is collected and then injected deep underground instead of being released into the atmosphere. Hence, the CCS can be adopted by major emitters to mitigate the carbon emissions without affecting our daily needs for energy and power. The CCS is also considered as an important "bridging" technology because it allows societies to continue using their existing fossil-fuel infrastructure while minimizing the adverse effects of doing so. The process of CCS involves capturing CO_2 produced by large industrial plants, compressing it for transportation and then injecting it deep into a rock formation at a geological reservoir, where it is permanently stored [1]. The process of CCS technology can be very costly for industries to apply, but it is still cheaper than paying carbon taxes imposed by the U.S. government [2]. Moving beyond the existing CCS process, the logical next step is to extend the process to include economic incentives for CCS such as enhanced oil recovery (EOR). The EOR is a wide variety of techniques for increasing the amount of crude oil that can be extracted from an oil field. The EOR generally involves the injection of gas, or sometimes water, to maintain pressure in the reservoir. Gas injection uses gases such as natural gas, CO_2 or nitrogen that expand in a reservoir to push additional oil to a production wellbore, or it uses other gases that dissolve in the oil to lower its viscosity and improves its flow rate. Among those, the injection of CO_2 for EOR is a well-established technology used to increase oil production, and can increase oil recovery from 20 to 40 percent of the original oil in place to as much as 55 percent [3]. As a result, it can produce more domestic oil effectively bridging the way to a new energy future and reduce dependency on foreign oil [4].

The process of CCS starts by capturing CO_2 at power plants, where CO_2 will be first separated from other gases, and then its gas chemical state will be transferred to supercritical fluid state midway between gas and liquid. The captured CO_2 will then be transported by pipelines to geological reservoirs and/or to oil-fields with EOR potential. The use of a portion of the captured CO_2 for EOR operations will create an income for the energy industries because oil companies buy the CO_2 in order to increase oil production through EOR. Note that the amount of purchased CO_2 may vary from time to time based on the market demand. Any remaining CO_2 that is not sold for EOR will be transported by pipeline to the nearest reservoir (i.e., geological formations) for permanent storage. This stage incurs injection costs, but it helps power companies avoid paying the carbon tax that would be imposed if CO_2 were released into the atmosphere.

Although, during the last decade, there has been a considerable amount of research on CCS, and several optimization models have been developed to analyze the infrastructure, the market, and the cost barriers of the CCS process [5-7], a literature review suggests that there have been minimal attempts to model the process of the CCS with EOR operation. In this short paper, therefore, we present a simple yet practical approach, which employs a mixed integer linear program (MILP) to address this issue. That is, unlike the previous models, the proposed model includes the concept of the injection of CO_2 for EOR operation, which will ensure considerable cost savings. The rest of this paper is organized as follows. In Section 2, we present mathematical notation used throughout the paper. The CCS with EOR operation problem is modeled as a MILP model in Section 3. In Section 4, a case study on California's CCS system is presented. Some concluding remarks are presented in Section 5. Finally, acknowledgements, appendix, and references used in this paper are listed.

II. NOTATION

The notation used throughout this paper is stated below:

Sets

I set of nodes for power plant (source)

J set of nodes for oil field

K set of nodes for reservoir (sink)

Data

α_i cost of capturing CO_2 from power plant $i \in I$

β_{ij} cost of transporting CO_2 from power plant $i \in I$ to oil field $j \in J$

γ_{ik} cost of transporting CO_2 from power plant $i \in I$ to reservoir $k \in K$

δ_k cost of injecting CO_2 at reservoir $k \in K$

μ_i cost of opening a power plant $i \in I$

ν_j cost of opening an oil field $j \in J$

ω_k cost of opening an reservoir $k \in K$

ρ unit price per ton of CO_2 sold for EOR operations

τ carbon tax per ton of CO_2 released into the atmosphere

Q total amount of CO_2 produced by power plants

q_i maximum capacity of power plant $i \in I$

p_j maximum capacity of oil field $j \in J$ for EOR operations

d_j demand amount of CO_2 for EOR operation at oil field $j \in J$

s_k maximum capacity of reservoir $k \in K$

Decision Variables

X_i amount of CO_2 to be captured at power plant $i \in I$

Y_{ij} amount of CO_2 transported from power plant $i \in I$ to oil field $j \in J$

Z_{ik} amount of CO_2 transported from power plant $i \in I$ to reservoir $k \in K$

L_i an indicator of showing if CO_2 is captured at power plant; it has a value of 1 if CO_2 is captured at power plant i, and zero otherwise.

O_j an indicator of showing if CO_2 is used for EOR operation; it has a value of 1 if CO_2 is used for EOR at oil field j, and zero otherwise.

R_k an indicator of showing if CO_2 is stored at reservoir; it has a value of 1 if CO_2 is stored at reservoir k, and zero otherwise.

III. PROBLEM FORMULATION

Given a set of power plants as the sources of CO_2 emissions, a set of reservoirs with different storage capacities, and a set of oil fields with EOR potential, the CCS problem with EOR operation (CCS-EOR) can be formulated based on a network flow MILP that has been successfully applied to a wide range of problems such as facility decision [8], transportation network [9], generation expansion planning [10], energy management [11], manpower modeling [12], and so on.

The objective function of the proposed model is to minimize the sum of costs to capture, transport, and inject/store CO_2. Our objective function also includes the unit price of CO_2 sold for EOR operations and the carbon tax for CO_2 emitted. Note that the cost to capture CO_2 consists of fixed costs (which are required for installation of capture technology) and variable costs (which are for paying energy costs to physically separate CO_2 from the exhaust stream and compress it). Likewise, the cost to inject/store CO_2 includes fixed and variable costs. For the amount of the CO_2 which was transported to oilfield sites, a negative cost is imposed. This is because these amounts of CO_2 will be sold to oil companies for EOR purposes, and thus, it will be an income for the energy industries.

Minimize

$$\sum_{i=1}^{I}\left(\alpha_i X_i + \mu_i L_i\right) + \sum_{i=1}^{I}\sum_{j=1}^{J}\left\{\left(\beta_{ij} - \rho\right)Y_{ij} + \nu_j O_j\right\}$$
$$+\sum_{i=1}^{I}\sum_{k=1}^{K}\left\{\left(\gamma_{ik} + \delta_k\right)Z_{ik} + \omega_k R_k\right\} + \tau\left(Q - \sum_{i=1}^{I} X_i\right) \qquad (1)$$

Subject to various constraints as follows:

The first constraint set ensures that the captured CO_2 at each power plant will be transported to geological reservoirs and/or oilfields through pipelines without any loss. These constraints are the mass balance constraints ensuring that the total amount of CO_2 entering the network equals the amount leaving the network, as well as ensuring that CO_2 is correctly routed through the entire network.

$$X_i = \sum_{j=1}^{J} Y_{ij} + \sum_{k=1}^{K} Z_{ik}, \quad \text{for all } i \in I \qquad (2)$$

Constraint (3) ensures that the total amount of CO_2 captured cannot exceed the total annual emissions capacity from the entire set of power plants. That is, this constraint sets the maximum capture amount for the CCS system by forcing Q amount of CO_2 to enter the system through the set of sources.

$$Q \geq \sum_{i=1}^{I} X_i \qquad (3)$$

Constraints (4) are capacity constraints ensuring that the amount of CO_2 captured at power plant does not exceed the plant's capacity. This constraint also ensures CO_2 cannot be captured unless the plant is opened.

$$X_i \leq q_i L_i, \quad \text{for all } i \in I \qquad (4)$$

Likewise, constraints (5) ensure that the capacity of each oil field are never exceeded and that CO_2 can only be transported to the oil field if the CO_2 is used for EOR operation there. This constraints also ensure that the amount of demand on CO_2 at each oil field are always met.

$$d_j O_j \leq Y_{ij} \leq p_j O_j, \quad \text{for all } j \in J \qquad (5)$$

Constraints (6) are capacity constraints ensuring that the amount of CO_2 transported to a reservoir does not exceed the reservoir's capacity. This constraint also ensures that CO_2 cannot be transported to the reservoir unless it is sequestered and stored at the reservoir.

$$Z_{ik} \leq s_k R_k, \quad \text{for all } i \in I,\ k \in K \qquad (6)$$

Constraints (7) through (9) impose binary integer restrictions ensuring if CO_2 is captured at a power plant, stored at a reservoir, and used for EOR at an oil field, respectively.

$$L_i \in \{0.1\}, \quad \text{for all } i \in I \qquad (7)$$

$$O_j \in \{0,1\}, \quad \text{for all } j \in J \qquad (8)$$

$$R_k \in \{0,1\}, \quad \text{for all } k \in K \qquad (9)$$

Constraints (10) through (12) impose nonnegativity restrictions on the amount of CO_2 and its flow throughout the entire network.

$$X_i \geq 0, \quad \text{for all } i \in I \qquad (10)$$

$$Y_{ij} \geq 0, \quad \text{for all } i \in I,\ j \in J \qquad (11)$$

$$Z_{ik} \geq 0, \quad \text{for all } i \in I,\ k \in K \qquad (12)$$

IV. CASE STUDY

In order to illustrate the implementation of the MILP discussed in the earlier section, we apply it to the California's CCS system. California emitted 426.6 million metric tons (MMT) of greenhouse gases (mainly CO_2) in 1990 and 479.8 MMT in 2004; the California Energy Commission (CEC) forecasts a further increase to 600 MMT by 2020 [13]. In recognition of this problem, the California Global Warming Solutions Act of 2006 legally mandated a sharp reduction of greenhouse gas (GHG) emissions, and set the stage for California's transition to a sustainable, low-carbon future. This is the first program in the U.S. to take a comprehensive, long-term approach to addressing climate change, and it does so in a way that aims to improve the environment and natural resources while maintaining a robust economy. Our case study includes seven power plants (i.e., CO_2 sources), seven oil fields with EOR potential, and seven geological sinks, which were chosen based on their significance in terms of the scale (i.e., production and storage capacities) [14]. In Table 1, we list the seven power plants, their annual CO_2 emissions in tons, the cost of capturing CO_2 from the plants, and the cost of transporting CO_2 to storage sites. With an estimated 90% capture rate, approximately 8.73 million tons of CO_2 per year is available from these plants for EOR operations and/or storage in geological sinks. The data for the candidate oil fields with EOR potential is summarized in Table 2, which includes types of oil field storage reservoirs, their areas in square miles, and storage capacity in tons. These oil fields have a life storage capacity of 141million tons of CO_2. Six of the oil fields are categorized into the "Oil fields with miscible CO_2-EOR potential (depth > 2000 ft. and API >25)" and only one is the "Oil fields with immiscible CO_2-EOR potential (depth > 2000 ft. and 17.5 < API < 25)". Note that carbon dioxide could displace oil by either miscible or immiscible displacement. The miscible process is best applicable to light and medium gravity crude oil, and the immiscible process may apply to heavy oil [15]. Table 3 presents the data for the candidate geological sinks which are used to store the unsold CO_2 for EOR operations. As can be seen in the table, all of the sinks/reservoirs are categorized into the "Oil field with

CO_2 storage potential but no EOR potential (depth > 3000 ft. & API < 17.5)". Storing CO_2 in these fields will create no income for the power companies, but will help them to avoid paying carbon tax. The seven sinks have a storage capacity of 4.9 million tons of CO_2 per year. The geographical locations of the power plants, oil fields, and geological sinks of our case study is shown on the schematic map in Fig. 1, in which the geographical location is defined by a set of latitude and longitude coordinates.

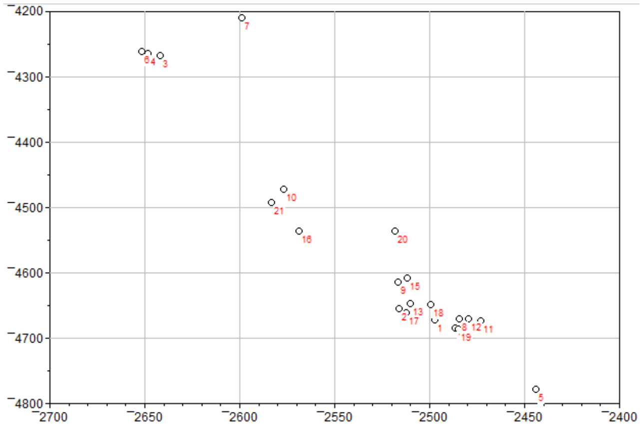


Fig. 1. Schematic map of locations of power plants, oil fields, and geological sinks.

Before proceeding to the results of the case study, some special conditions under which this system evaluation is conducted should be noted. First, the storage (injection) costs are based on a $400,000 dayrate for a 250,000 bbl/day floating production and storage rig [2, 6]. Thus, the injection cost for each ton of CO_2 is assumed to be $1.6/tCO2 throughout this case study. The storage process is done by a storage rig, and prior to final CO_2 storage at a depth of more than 800*m*, and the pressure has to be increased in order to inject CO_2 to such depths [16]. The storage rig recieves CO_2 at an intermediate pressure and increases the pressure by using energy. Second, the capture method in our case study is based on the most typical process of using amine scrubbers and membrance separation, an approach which captures at most 90 percent of the CO_2 that is produced. Unlike other capturing methods, this method allows only CO_2 to pass through, while excluding other components of the flue gas [17]. Third, we assume that the pipelines will be constructed across flat and empty space, and they wil be used for the mode of transporting CO_2. However, many geographic factors in the real world can cause increasing the transportation cost of CO_2 through pipelines, and the cost can also vary based upon the physical characteristics of the land and the presence of social infrastructure such as highways, railroads, and national parks. Fourth, data on CO_2 demand for EOR operations are rarely found in the literature since the purchase/sale agreements are considered confidential business information. However, large volumes of CO_2 are essential to oil recovery operations, and literature review shows that, for every 3 barrels of oil produced in EOR operations, a ton of CO_2 needs to be injected [18]. In this case study, therefore, the volume of CO_2 purchased are estimated based on the number of oil barrels produced per year by an oil field.

The proposed CCS-EOR model was run for ten different carbon taxes ranging from $25/tCO_2$ to $70/tCO_2$ in order to address the economic uncertainty following a possible change in carbon tax. For EOR operations, five different CO_2 prices ranging from $15/tCO_2$ to $35/tCO_2$ were considered, as well. The corresponding results are summarized in Table 4, where we list the amount of CO_2 captured (CO_2) and the corresponding total cost required (TCost). Note that the total cost includes all of the required costs to capture, transport, store, and emit CO_2 into the atmosphere, and also takes into consideration of the revenues resulted from selling CO_2 to oil companies for EOR purposes.

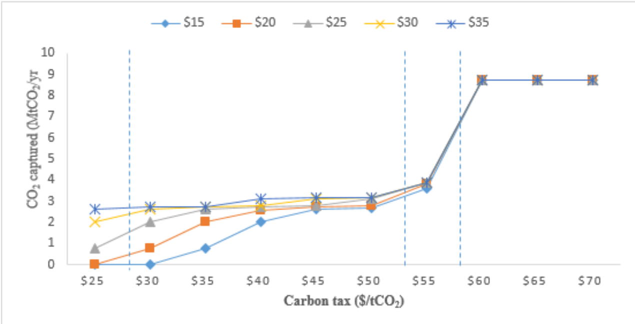
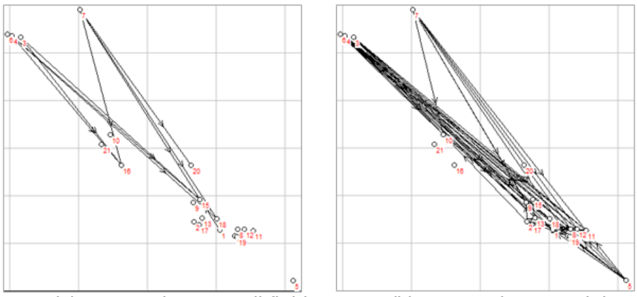


Fig. 2. Amount of CO_2 captured for five different prices of CO_2.

If both the carbon tax and the price of CO_2 for EOR operation are low enough, it is recommended to release them to the atmosphere instead of capturing CO_2. If CO_2 price is $15/tCO_2$ and the carbon tax does not go over $30/tCO_2$, capturing CO_2 is not cost-effective (see Fig. 2). However, once the carbon tax is raised to $35/tCO_2$, for example, it becomes economically beneficial to capture CO_2. As a result, 0.75 million tons of CO_2 would be captured each year from six power plants. As the carbon tax keeps increasing, the larger amounts of CO_2 from all seven power plants are captured, and the yearly captured amount steeply rises within the ranges between $55/tCO_2$ to $60/tCO_2$. Within this range, it is recommended to capture as much CO_2 as possible, since that CO_2 becomes the revenue-creating sale to oil companies for their EOR operations. The excess amount of CO_2 is to be stored in geological sinks. Once the carbon tax reaches $60/tCO_2$, it is recommended to capture all of CO_2 produced by every source, which is 8.73 million tons of CO_2 per year.

Fig. 3 shows, for example, the spatial deployment of CCS-EOR at the $60/tCO_2$ carbon tax and $15/tCO_2$ EOR price, at which CO_2 was captured from all of the seven sources (power plants)- two in the Los Angeles area, one in San Diego, and four in the San Francisco area. The captured CO_2 was stored in seven mature oil fields for EOR opereations. Four of those oil fields are in the Los Angeles area, one is in Santa Clarita, and one is in Kings and Fresno counties. Having two sources and four oil fields in LA will make it cheaper to trnsport CO_2. In this particular case, only four of the geological sinks were chosen to store CO_2, as the prioriety of the CCS-EOR model is to sell CO_2 to oil companies to create revenue. The excess CO_2, if any, that is not used in the productivity enhancement process would be permanently stored in the geological sinks. For cheaper CO_2 pipelines transportations, it would be desirable to combine flow from sources into large trunk lines (i.e., CO_2 tanks) which will help to reduce unit cost (Middleton and Bielicki 2009b). However, the location of sources and reservoirs and their capacities affects the model's potential to combine CO_2 flows into trunks lines.



(a) Power plants to Oil fields (b) Power plants to sinks

Fig. 3. Spatial deployment with $60/tCO_2 carbon tax and $15/tCO_2 EOR price.

If the power industry chooses to pay the carbon tax penalty instead of applying the CCS-EOR system, the industry will face high financial charges. Next, we show how this cost is altered as the carbon tax and the CO_2 price for EOR operation change. Again, for EOR operation, five different CO_2 prices ranging from $15/tCO_2 to $35/tCO_2 were considered.

In Fig. 4, the total costs for each of these five different cases are compared to the one without EOR incentives (i.e., CCS).

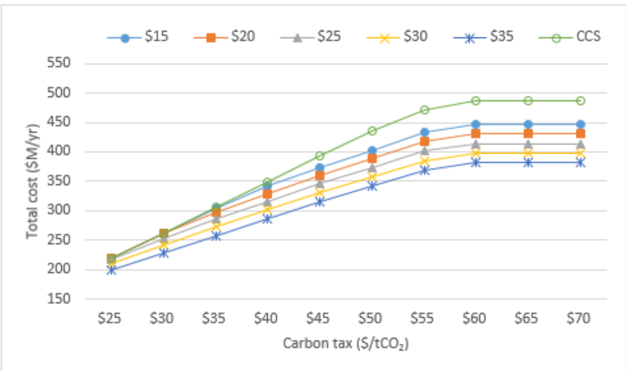
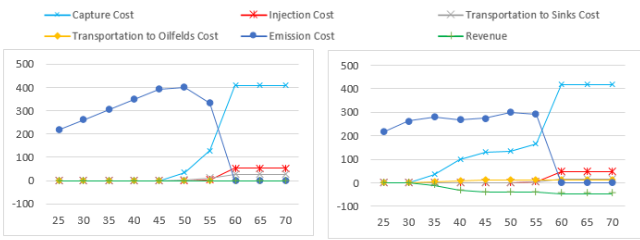


Fig. 4. Comparison of total cost (CCS vs. CCS-EOR).

For all six cases, the total cost steadily increases as both the carbon tax and CO_2 EOR price increase. Once the carbon tax reaches $60/tCO_2, at which the maximum amount of available CO_2 is captured, there is no more increasement in the total cost. However, it is clear that the total cost required for CCS recorded the highest value all the time, which implies that CCS-EOR system is more cost-effective than CCS. This cost-effectiveness become more visually distinctive with higher values of the carbon tax and EOR price for CO_2. Even though the shapes and scales of the lines in Fig. 4 look similar each other, their individual cost components contribute to the total cost in different ways.Next, in Fig. 5, to see more clear behaviors of the individual cost component of the two cases, i.e., CCS and CCS-EOR, the total costs were broken down by various cost components. They include costs to capture CO_2, injection & storage cost, transportation cost, emission cost, and revenue.



(a) CCS (b) CCS-EOR ($15)

Fig. 5. Comparison of individual cost component (CCS vs. CCS-EOR $15/tCO_2).

Note that the transportation cost was further broken down by two different destination, i.e., geological sinks (i.e., injection and storage sites) and oil field sites. For example, in the CCS-EOR model (see Fig. 5b), at a price of $15/tCO_2 sold for EOR operations, the model does not recommend to capture any CO_2 when the carbon tax is below $35/tCO_2. In this case, the total cost is the emission cost only. Once the carbon tax reaches $35/tCO_2, the model recommends to capture 754,000 ton of CO_2 from three power plants, which is the same amount that is captured in the CCS model when the carbon tax is $50/tCO_2 (see Fig. 5a). Most of the captured amount is sold for EOR operations to create an income of $11,300,000/year for the power companies, and brings the total cost down to $305,000,000. It is considerably lower than $488,000,000 /year, which can be occurred when the same amount is captured in the CCS model. While the carbon tax is above $35/tCO_2, the total cost comes up with the costs to capture CO_2, cost to transport CO_2 to oil fields, emission cost, and revenue that was created by meeting the demands for CO_2-EOR operations. The injection & storage cost and the costs to transport CO_2 to the geological sinks become part of the total cost once the carbon tax reaches $55/tCO_2. Like the CCS model, the CCS-EOR model recommends to capture all of CO_2 (i.e., 8.73MtCO_2/yr) produced by all seven power plants, once the carbon tax reaches $60/tCO_2. In this case, the total cost becomes $446,000,000/yr.

We are also able to see how much financial charge the power industry can avoid by implementing the CCS-EOR system rather than applying CCS without considering EOR operations. Fig. 6 shows the percentage of these savings. For example, with $50/tCO_2 of carbon tax, CCS system brings the total anuual cost of $436,000,000, which is a lot higher than $342,000,000, the one with CCS-EOR system at an EOR price for CO_2 of $35/t$CO_2$. In this case, the power industry can expect the annual total savings of $94,000,000, which is about 21.62% of the total cost. As can be seen from this comparison, the CCS-EOR system provides a cost-effective and market-oriented means to capture CO_2, which will benefit both the environment and the U.S. economy.

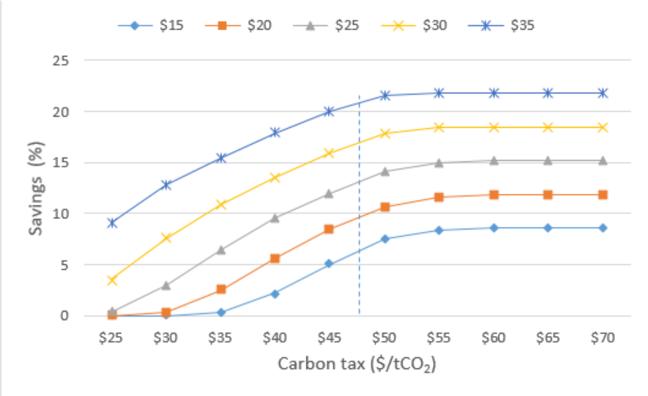


Fig. 6. Savings (%) that power industry can achieve by implementing the CCS-EOR system.

V. Conclusion

This paper presented a way to use a rather common mixed integer linear programming technique to gain insight into an infrastructure for CCS-EOR. Through the case study of California's carbon capture and storage system, we have found that the proposed optimization model guides us in making the right decisions on how much CO_2 to capture at each power plant, which sink to use, how much CO_2 should be sold to oil companies, and how to properly deploy and apply CCS with EOR operations. Therefore, it is anticipated that the implementation of the proposed CCS-EOR optimization model may help the power industries make crucial decisions when it comes to mitigating CO_2 emission. Future research should be carried out to refine the work and related findings

Acknowledgment

This work was supported by Saudi Arabian Cultural Mission (SACM) under grant #2012/12/011042445997. This work was also partially supported by the US Department of Agriculture (USDA) under grants (# 2011-38422-30803 and # 2015-38422-24112).

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Table 1. Data for Candidate Power Plants (Source: WESTCARB, 2010)

ID #	Power Plant	Annual CO_2 Emission (tCO_2)	Capturing Cost ($/$tCO_2$)	Transportation Cost ($/$tCO_2$)
1	AES Alamitos	1,889,507	48.81	2.88
2	AES Redondo Beach	752,967	53.65	3.28
3	Contra Costa Power Plant	448,733	47.19	4.10
4	Delta Energy Center, LLC	2,138,682	46.16	3.10
5	Duke Energy South Bay	1,138,268	51.03	7.46
6	Pittsburg Power Plant (CA)	1,075,999	67.71	2.32
7	Sutter Energy Center	1,282,798	45.53	3.30

Table 2. Data for Candidate Oil fields with EOR potential (source: WESTCARB, 2010).

ID #	Oil Field	Type	AREA (sq mi)	Storage Capacity (tCO_2)
8	West Buena Park (Abd)	Miscible CO_2-EOR potential	0.0502	67,940.29
9	Castaic Junction (Abd.)	Miscible CO_2-EOR potential	3.9646	5,865,284.32
10	Kettleman Middle Dome	Miscible CO_2-EOR potential	0.2453	3,530,559.13
11	East Coyote	Miscible CO_2-EOR potential	6.7540	15,978,244.39
12	West Coyote	Miscible CO_2-EOR potential	5.2716	50,167,539.51
13	Inglewood	Miscible CO_2-EOR potential	2.9742	61,040,115.66
14	West Newport	Immiscible CO_2-EOR potential	5.9903	5,150,100.92

Table 3. Data for Candidate Depleted Oil fields (source: WESTCARB, 2010)

ID #	Oil Field	Type	AREA (sq mi)	Storage Capacity (tCO_2)
15	Elizabeth Canyon (Abd.)	CO_2 storage capacity but no EOR potential	0.0655	332.36
16	Gonyer Anticline (Abd)	CO_2 storage capacity but no EOR potential	0.4016	289.19
17	Gaffey (Abd)	CO_2 storage capacity but no EOR potential	0.6193	438.69
18	Los Angeles City	CO_2 storage capacity but no EOR potential	1.2643	1,016,458.26
19	Newport	CO_2 storage capacity but no EOR potential	1.7042	167,256.54
20	Kern Front	CO_2 storage capacity but no EOR potential	12.2279	3,149,627.11
21	North Antelope Hills	CO_2 storage capacity but no EOR potential	2.5429	638,680.49

Table 4. Summary of Results

CO_2 Tax	EOR Price 15		20		25		30		35	
	CO_2 ($MtCO_2$/yr)	TCost ($/$tCO_2$)	CO_2 ($MtCO_2$/yr)	TCost ($/$tCO_2$)	CO_2 ($MtCO_2$/yr)	TCost ($/$tCO_2$)	CO_2 ($MtCO_2$/yr)	TCost ($/$tCO_2$)	CO_2 ($MtCO_2$/yr)	TCost ($/$CO_2$)
25	0	218	0	217	0.75	217	2.05	211	2.64	198
30	0	261	0.75	260	2.05	254	2.64	242	2.76	228
35	0.75	305	2.05	298	2.64	286	2.76	277	2.76	258
40	1.6	339	2.6	329	2.76	315	2.76	302	3.1	287
45	2.64	373	2.76	359	2.77	345	3.1	330	3.2	314
50	2.7	400	2.8	389	3.1	374	3.2	358	3.2	342
55	3.2	429	3.8	417	3.9	401	3.9	385	3.88	369
60	8.73	442	8.73	430	8.73	414	8.73	398	8.73	382
65	8.73	442	8.73	430	8.73	414	8.73	398	8.73	382
70	8.73	442	8.73	430	8.73	414	8.73	398	8.73	382