Journal of Energy Research and Environmental Technology (JERET)
p-ISSN: 2394-1561; e-ISSN: 2394-157X; Volume 11, Issue 1; January-March, 2024, pp. 1-6

http://www.krishisanskriti.org/Publication.html

Carbon Capture and Storage (CCS) for the Indian Oil and Gas Industry: In-depth Analysis

Anand Acharya[1] **and Raunaq Jiandani**[2]

[1]*Senior Manager, Sustainability Development, GAIL (India) Ltd.*
[2]*Senior Engineer, Petrochemical Operations, GAIL (India) Ltd.*
E-mail: [1]*aacharya@gail.co.in,* [2]*raunaq.jiandani@gail.co.in*

Abstract—*The International Energy Agency (IEA) regards CCS/CCUS technologies as one of the 4 pillars of global energy transformation [1]. The International Panel on Climate Change (IPCC) have estimated 138% increase in mitigation cost in 2100 if CCS is not adopted [2]. While there have been studies in the past on CCS from an Indian perspective, the focus has either been on the power or industrial sector in general. However, in the vast industry, the concentration of* CO_2 *in the emission streams varies considerably among the different sectors. This in turn impacts cost of capture and thus decisions related to best technology. Furthermore, the key steps of transport and storage depend significantly on the geographical location of the plant/factory and its existing infrastructural facilities. To arrive at definitive, concrete plan for CCS, it is not sufficient to study the different sectors under the single umbrella of industry. The oil and gas sector which is an integral, indispensable part of the Indian economy, does demand a closer and deeper analysis. This paper focusses on the capture, transport, and storage aspects of CCS specifically for the Indian oil and gas industry covering PSUs like IOCL, HPCL, BPCL, GAIL as well private players like Reliance, Haldia petrochemicals and others. A concise overview of the practical and most suitable technologies for Indian oil and gas companies has been provided. Furthermore, based on the geographical location of the refineries, petrochemical complexes of the various companies, the feasibility of the different CCS technologies have been assessed, mapping them with the nearest* CO_2 *sink. The possible integrations between the infrastructural facilities of the companies have been analysed to facilitate economies of scale for making CCS viable and a qualitative rating has been given to the different solutions based on their cost.*

1. INTRODUCTION.

While the forest fires, heat waves, floods and other calamities have increased in their severity as well as recurrence [3]; climate change has also bought with it events that have not manifested before. Keeping in view these impacts, the target of Net Zero emission of greenhouse gases has been taken up by different countries. Among the various technologies, Carbon Capture and Storage (CCS) holds a pivotal position as agreed upon by IEA, IPCC and other authorities. The importance of CCS becomes even more since it is the transition pathway which serves the dual purpose to reduce emissions and continue economic growth till other technologies like renewables and green hydrogen become fully established and matured.

CCS will play a key role for India which plans to achieve net zero by 2070. While there have been studies on CCS from an Indian perspective, the uniqueness of this work lies in studying CCS specifically focussing on the Indian oil and gas sector. This is essential because cost involved in capturing carbon depends on the concentration of CO2 in the emission stream. While ammonia and methanol have highly concentrated CO2 streams, their cost of capture per tonne of carbon dioxide is less. On the other hand, the concentration of CO2 from the oil and gas industry is about 3 to 20% and the corresponding cost ranges from 35 to 100 dollars/tCO2 [4]. Such fundamental differences change the whole equation of selecting the best possible CCS method. Furthermore, given that economic viability is the major deterrent in adopting CCS [5]; studying the different sectors of industry is also a must to enable the policymakers prioritise the sectors which deserve immediate attention and changes. Moreover, given the limitations which may arise in transportation and storage capacities, an in-depth analysis of each sector will be instrumental in the wise allocation of the available resources.

It is in the light of the above objectives that this paper is written. The manuscript is divided into three main sections: The first section gives a crisp understanding of the different CCS technologies for capture, transport, and storage. Based on the Technology Readiness Level (TRL) of these, the ones which are available now and in the coming few years have been highlighted. Since geographical location is the key factor for decision making related to transport and storage, the refineries and plants of both PSUs and private players in India have been marked and have been mapped to the nearest oil field, nearest gas field and the nearest saline aquifer. The best possible sinks in a region have been identified for each refinery, plant and complex of various companies. This constitutes the second section. The subject of discussion of the third section is how the different oil and gas companies can collaborate and integrate with each other to use the existing and future infrastructural facilities to achieve economies of scale and make CCS financially attractive. The role of Government in encouraging, facilitating such ventures and other policies have also been discussed.

2. TECHNO-ECONOMIC ASSESSMENT

2.1. CCS Technologies

The pathway of CCS involves three main steps namely; Capture, Transport and Storage. And there are multiple alternatives/technologies for each of these [6]. The Capture can be performed pre-combustion, post-combustion, oxy-combustion, or chemical-looping combustion via different technologies broadly classified into absorption, adsorption, membrane-based methods, cryogenics, microbial/biological methods, mineralization, and others. Within each of these technologies as well, research is underway on many fronts. Selection of best solvent that exhibits good stability [7], minimum loss, maximum capture; Mesoporous silicates, Zeolites and other adsorption materials are some of the areas in absorption and adsorption [8] respectively. For membrane separation, constructing a membrane with maximum selectivity and low mass transfer resistance is important and different materials are being studied to best suit the application [9]. Different micro-organisms have been identified as prospects for capture [10] and further work is exploring the best option based on conditions of pressure, temperature, pH, stability, and other factors. Nanotechnology is finding its way into almost every field and carbon capture is no exception. Enhancing mass transfer, absorption rates and low energy recovery of mono-ethanol amine (MEA) solvent via use of nanoparticles [11] are some of the important areas. Each of the techniques discussed above have their own advantages and challenges. In order to assess these technologies in proper perspective, dividing them based on their Technology Readiness Level (TRL) is a very useful way. Bui et al. [12] categorised these as per their TRL and the findings show that the only capture method that has achieved commercial level (TRL 9) is absorption. Other methods like Polymeric membranes, Direct air capture (DAC), post combustion adsorption, calcium carbonate looping are either at the pilot level (TRL 6) or in the demonstration phase (TRL 7). And there are some other methods which are still at the level of laboratory tests/proof of concept (TRL 3).

In the second step of transport, the situation is relatively simple and clear. While transporting CO2 via road is technologically possible, it may not be very practical owing to the sheer volume of CO2 that has to be transported. The only two options that are then practical are transport through ships and transport through pipelines both of which have mature commercial technologies (TRL 9). Storage of the captured CO2 can mainly be done in depleted oil fields, gas fields, coal fields; in saline aquifers or by CO2-EOR (Enhanced Oil Recovery) and CO2-EGR (Enhanced Gas Recovery). Out of these possible storages, Saline aquifers and CO2-EOR have achieved TRL 9 i.e., commercial maturity. Storage in depleted oil, gas fields and CO2-EGR have also made significant progress over the years and have reached TRL 7 i.e., the demonstration phase. On the other hand, storing CO2 deep in oceans still requires good amount of work to be done practically. Among the commercially possible pathways of storing CO2; enhanced oil recovery is the most attractive one owing to the huge wealth it can generate by recovering the oil which would be processed further [13]. There are many factors like storage capacity, EOR/EGR potential and location (onshore/offshore) which must be considered while choosing a storage site; and these have been discussed in this work to provide a complete understanding about CCS.

Despite having been regarded as one of the most important means to achieve Net zero; CCS has still not found widespread adoption. While we have the necessary know-how in terms of technology for capture, transport as well as storage; it is the financial aspect that is making CCS unattractive and thus acting as a barrier to implement it. Thus, it is of prime importance to understand the economic aspects of CCS and analyse things, propose plans, methodologies, and policies in this light. This is the subject matter in the subsequent sections of this paper.

2.2. Monetary aspects of CCS

While calculating the cost of any CCS project, one has to naturally take into account separately the cost of capture, the cost of transport and the cost of storage. Out of these three, the task of capture is almost always the most expensive [4] and can range anywhere from 3 times to 15 times the cost of storage. The cost of storage depends on factors related to the storage facility. Storing in depleted oil and gas fields is usually cheaper than storing in an aquifer. Furthermore, storing in an onshore site (oil/gas field, aquifer) is usually cheaper than storing in an offshore site. Also, storage becomes more viable when the oil/gas field has the potential for enhanced oil/gas recovery rather than a field which does not. Transportation cost for pipelines primarily depends on the distance the CO2 has to travel i.e., the length of the pipeline. It also varies between onshore pipelines and offshore pipelines with the former being cheaper. The cost of transportation is variable and depending on the pipeline length, it can even exceed the cost of capturing.

Storage costs are independent of the geographical location of the plant/refinery/emission source, while transportation costs are governed by the location. It is also interesting to take note that both transportation and storage costs are independent of the type of industry (cement, iron and steel, refinery, fertilizers, chemicals, etc) i.e., once the CO2 is captured it makes no difference economically with regards to from where this CO2 has been captured. Thus, the financial aspects for transport and storage are almost same across all the industries. It is the cost of capture that is different for different sectors and thus it is this realm which demands an industry specific analysis. Moreover, focussing closely on it becomes all the more important given the fact that capture is the most expensive step in the entire process of CCS and thus is the key driver behind the success or failure of any CCS project.

2.3. Carbon Capture Cost

The cost of capturing the emitted CO2 is given by the following equation [14]:

log($/kg) = -0.5558*log(CO2 concentration)-1.8462

where the CO2 concentration is in mole fraction.

From this equation, it can be seen that the cost is indirectly proportional to the concentration of carbon dioxide. The more concentrated the stream, cheaper is the process of capture. Conversely, capturing CO2 from dilute steams is expensive. This is where the difference arises: while fertilizers, methanol, ammonia plants have highly concentrated streams with concentration of 98% for fertilizers; the concentration in emissions from refineries is about 3-20% [4]. The least concentrated CO2 streams are produced in gas-based power plants with concentration of 3-5% [15]. Thus, the cost of separating carbon dioxide from the above equation is about 14 dollars per tonne of CO2 for fertilizers, while that for refineries is about 35-100 dollars per tonne. The cost for cement and iron-steel industry [16,17] is around 26-49 dollars/tCO2 and 30-35 dollars/tCO2 corresponding to concentrations of about 14-33 and 20-27 respectively.

Out of the total CO2 emissions from India's industrial sector in 2019 [4], cement industry is the largest contributor emitting about 28.7% of the total quantity while Iron and Steel stand at second position emitting 11.6%. Refineries emit 4.1% and are third in the list while Fertilizers emit about 1.4% of the total CO2. Implementation of CCS projects at a practical level will require different policy measures, flow of money from investors, as well as gradual stepwise utilization of the storage fields and aquifers. Since limited resources are available at disposal, their allocation among different industries requires judicious decision making based on the magnitude of emissions from the industry and the cost incurred by the industry. This will be further discussed in the last section; for understanding which, it is important to analyse CO2 sinks for the oil and gas sector

3.0. STORAGE FACILITIES FOR INDIAN OIL AND GAS COMPANIES

Public Sector Undertakings (PSUs) like Indian Oil Corporation Limited (IOCL), Hindustan Petroleum Corporation Limited (HPCL), Bharat Petroleum Corporation Limited (BPCL), GAIL (India) Limited, Oil and Natural Gas Corporation (ONGC) and private companies like Reliance, Brahmaputra Crackers and Polymer Limited (BCPL), Haldia Petrochemicals, Nayara Energy and Chennai Petroleum Corporation Limited have been covered. Thus, a total of 32 sites comprising refineries, gas processing plants, petrochemical complexes of these companies have been studied with respect to their geographical location and have been allocated/linked to the nearest oil field, the nearest gas field and the nearest saline aquifer. This linking has been performed by taking into account 19 major oil fields, 7 major gas fields and 22 sedimentary basins in India [4]. The result of this tedious exercise has been presented in the form of a table as shown below (The two figures for this have been added at the end of the paper to maintain the double-column format intact). A uniqueness of this work also lies in the fact that only those oil fields which have good potential for EOR.

An important observation from this mapping is that while EOR and storage can be viable for companies having facilities on the western cost and in the north-eastern region (both are regions of exploration), for companies which are not in their proximity, the cost of transportation of CO2 can become sufficiently high so much so to dominate even the capture cost.

4.0. PATH FOR FUTURE: MAKING CCS PRACTICAL.

To set the theme for this section, it is important to reiterate the reality that the prime cause for the lack of implementation of CCS in India and across the world is the high cost involved. While Indian PSUs and private players are conducting research as well as entering into collaborations, agreements with other technology suppliers [18]; the efforts must be complemented with other tools which can be categorised under the following 4 heads: policies to make CO2 emissions less attractive, policies to encourage use of CCS technologies, integrations between companies and policies for allocation of CO2 sinks among the different industrial sector. While the first two categories include instruments like carbon tax, carbon credit, subsidies [19,20], etc which have already gained attention; the focus here would be on the other 2 categories which will play a very critical role and must be studied and discussed elaborately in forums, gatherings and conferences across the country.

Integration between companies refers to achieving economies of scale by sharing/jointly using the infrastructural facilities which either exist already or are yet to materialise. In the realm of CCS, the maximum scope of such integration lies in transport of the captured CO2 through pipelines. Those companies which are situated in proximity of each other and/or have sinks that are common or near; can take advantage of using a single pipeline of the appropriate size. This strategy which appears very simple, can prove to be very effective and crucial given that cost of transportation can become equal to or even greater than the cost of storage depending on the distance between the source and sink. The point to understand here is that while companies may try to achieve integration internally i.e., within their different sites; it may actually be more profitable to rather integrate with other company located closer to it. Thus, for different sites of a given organisation, site-specific integration maybe adopted i.e., integrating its different sites with different companies based on geographical location. Giving priority to geography rather than arbitrarily integrating its own sites may prove to have greater monetary benefits. This will vary from case to case and demands a much-detailed analysis. For such things to happen, more open communication between companies is required through open platforms and other channels. The government by serving as an intermediary can very well help in streamlining such discussions between companies. It is very important to have a free flow of such proposals, plans between the different companies.

Lastly, it must be understood that while there may be sufficient capacity in the aquifers, oil and gas fields to store emissions from the entire industrial sector; the practical implementation can only happen in stages and not all at once. This means decisions will have to be taken with regards to which industry be given access to storage at a priority higher than others. Moreover, out of the three possible storage options (aquifer, oil field, gas field); which facility must be allocated to a given industry is another very important decision to make. In the discussion that follows, an attempt has been made to provide solutions to the above questions. The cement, iron and steel industry are two such industries which are the largest contributors of CO2; thus, it is very important to make these two sectors net zero first if India wants to meet our targets in the stipulated time. At the same time both these sectors are also those where the emissions are hard to abate. So, while decarbonisation in other sectors can be achieved through other technologies, these two sectors primarily rely on CCS for their decarbonisation. Thus, if the plans for CCS are to be rolled out in different phases/stages; cement, iron and steel should be given the highest priority. With regards to the type of storage facility, there are two factors to be considered: cost of capture (per tonne of CO2) and the magnitude of emission for the sector. The sector with the highest cost of capture thus should be allocated oil fields with EOR potential in order to make it viable for them. The cement industry having emissions about 500 million tonnes/year and capture cost ranging from 26-49 dollars/tonne CO2 incurs the maximum capture cost. It is followed by refineries which have a very high capture cost of about 35-100 dollars/tonne CO2 but relatively smaller emissions (71 million tonnes/year). With annual emissions of about 203 MTPA and capture cost of 30-35 dollars/tonne of CO2; the iron and steel industry competes closely with the refineries. The gas processing plants have majority of their emissions coming from the gas sweetening process which produces a relatively concentrated stream of carbon dioxide that is relatively cheap to capture. This low cost of capture (per tonne CO2) combined with relatively lower magnitude of emissions make CCS less financially burdensome for gas processing plants. The same is true for petrochemical plants where the cost of capture (per tonne CO2) despite being higher is outweighed by small magnitude of emissions, overall making CCS easier for the petrochemical sector. The fertilizer sector has very high purity CO2 streams [21] and very less emissions. And thus, among all industries, fertilizers are almost at the bottom in terms of expenses for CCS. Thus, the cement industry must be allocated oil fields with EOR on a priority basis followed by refineries and iron-steel. Among the oil fields, onshore being relatively cheaper can be occupied first, followed by offshore fields. Emissions from the fertilizer industry on the other hand, can be accommodated in aquifers that are relatively expensive than oil, gas fields. Gas processing plants and petrochemical plants lie somewhere in between the two extremes and thus can be allocated storage facilities based on the availability. In the above discussion, it has been reasonably assumed that the transportation costs are comparable for all sectors. This usually holds true, but in certain specific case, if the cost of transportation becomes too high, then one may re-allocate the emissions to some other storage option.

5.0. CONCLUSIONS.

The different CCS technologies have been discussed for all three aspects: capture, transport and storage. The Technology Readiness Level (TRL) of these technologies was also highlighted. Absorption, transport through pipelines, ships and CO2-EOR, storage in saline aquifers were identified as the techniques that have reached commercial development (TRL 9) while other methods (polymeric membranes, carbonate looping, storage in oil, gas fields, CO2-EGR, etc.) were also rated into different categories like demonstration level, pilot level, proof of concept and others.

The three stages of CCS were analysed individually and the key factors governing their cost were bought forth. Lower the concentration of CO2 in the emission stream higher is the cost of capture. Transportation cost is influenced by the distance that the carbon dioxide has to travel. For storage; onshore sites are cheaper than offshore. Of the three facilities: oil field, gas field and saline aquifer; aquifers are the most expensive. As one would expect, potential of EOR/EGR in the oil/gas field increases the viability of the project. Capture costs vary across the Indian industry and are maximum for the cement industry followed by refineries, iron and steel.

A total of 32 operational sites (refineries, gas processing plants, petrochemical complexes) of the Indian Oil and Gas companies (HPCL, IOCL, BPCL, ONGC, GAIL, Reliance, CPCL, Haldia petrochemicals and others) were considered and the nearest oil field, the nearest gas field and the nearest saline aquifer have been identified for each of them from a set of 19 major oil fields, 22 saline aquifers and 7 major gas fields in India.

Since financial viability issues are the main hurdle in CCS gaining widespread implementation; three important policy, managerial aspects have been discussed: firstly, integration between different companies to achieve economies of scale. Rather than integrating between different sites of the same company, preference should be given to collaborate with other companies based on geographical divisions. Secondly, the criticality of CCS for different sectors was discussed and it was concluded that cement, iron and steel should be given highest priority in terms of sequence of implementing CCS projects. Lastly, based on monetary calculations, the allocation of storage facilities was studied leading to the understanding that oil fields with CO2-EOR potential must first be allocated to the cement industry followed by oil refineries. Fertilizers should be allocated saline aquifers for storing their emissions. Gas processing plants, petrochemical complexes fall within the spectrum of the above two and allocation for them can be done based on convenience and other factors.

One of the key insights gained from the process of geographically connecting emission sites to sinks in India was that transporting CO2 to the sites for EOR or storage is not feasible for many units of the companies studied. The distance for these cases will make the transportation cost very high, escalating the total cost to make CCS infeasible. Storage and EOR are good options for units located on the west coast and those located in the north-east but for other units located in the interiors or far-off locations, other pathways for achieving net zero will have to take the centre-stage.

REFERENCES.

[1] IEA (2020), CCUS in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/ccus-in-clean-energy-transitions, License: CC BY 4.0

[2] Intergovernmental Panel on Climate Change. The fifth assessment report (AR5). Report. New York: Intergovernmental Panel on Climate Change; 2014.

[3] United States Environmental Protection Agency- ‘Climate Change Indicators: Weather and Climate’

[4] Zhang, K., Lau, H. C., Bokka, H. K., & Hadia, N. J. (2022). Decarbonizing the power and industry sectors in India by carbon capture and storage. *Energy*, *249*, 123751.

[5] Schmelz, W. J., Hochman, G., & Miller, K. G. (2020). Total cost of carbon capture and storage implemented at a regional scale: northeastern and midwestern United States. *Interface focus*, *10*(5), 20190065.

[6] Krishnan, A., Nighojkar, A., & Kandasubramanian, B. (2023). Emerging towards zero carbon footprint via carbon dioxide capturing and sequestration. *Carbon Capture Science & Technology*, 100137.

[7] Pishro, Khatereh & Murshid, Ghulam & Mjalli, Farouq & Naser, Jamil. (2020). Investigation of CO2 solubility in monoethanolamine hydrochloride based deep eutectic solvents and physical properties measurements. Chinese Journal of Chemical Engineering. 28.

[8] Pardakhti, M., Jafari, T., Tobin, Z., Dutta, B., Moharreri, E., Shemshaki, N. S., ... & Srivastava, R. (2019). Trends in solid adsorbent materials development for CO2 capture. *ACS applied materials & interfaces*, *11*(38), 34533-34559.

[9] Han Y, Yang Y, Ho WSW. Recent Progress in the Engineering of Polymeric Membranes for CO_2 Capture from Flue Gas. *Membranes*. 2020; 10(11):365

[10] Alivisatos, P., & Buchanan, M. (2010). *Basic research needs for carbon capture: beyond 2020*. USDOE Office of Science (SC)(United States).

[11] Raghav Chaturvedi, K., Kumar, R., Trivedi, J., Sheng, J. J., & Sharma, T. (2018). Stable silica nanofluids of an oilfield polymer for enhanced CO2 absorption for oilfield applications. *Energy & Fuels*, *32*(12), 12730-12741.

[12] Bui, M., Adjiman, C. S., Bardow, A., Anthony, E. J., Boston, A., Brown, S., ... & Mac Dowell, N. (2018). Carbon capture and storage (CCS): the way forward. *Energy & Environmental Science*, *11*(5), 1062-1176.

[13] Global CCS Institute. Global status of CCS 2020. 2021. https://www. globalccsinstitute.com/wp-content/uploads/2020/11/Global-Status-of-CCSReport-2020_FINAL.pdf

[14] Bains, P., Psarras, P., & Wilcox, J. (2017). CO2 capture from the industry sector. *Progress in Energy and Combustion Science*, *63*, 146-172.

[15] Energy Information Administration (EIA). Emissions by plant and by region, annual data for 2019. 2020.

[16] World Steel Association (WSA). Steel's contribution to a low carbon future. 2012. World Steel Position Paper, https://www.worldsteel.org/en/dam/jcr: c3acc5fd-e3c2-458c-a2cc-8c4880b9334c/Steel%

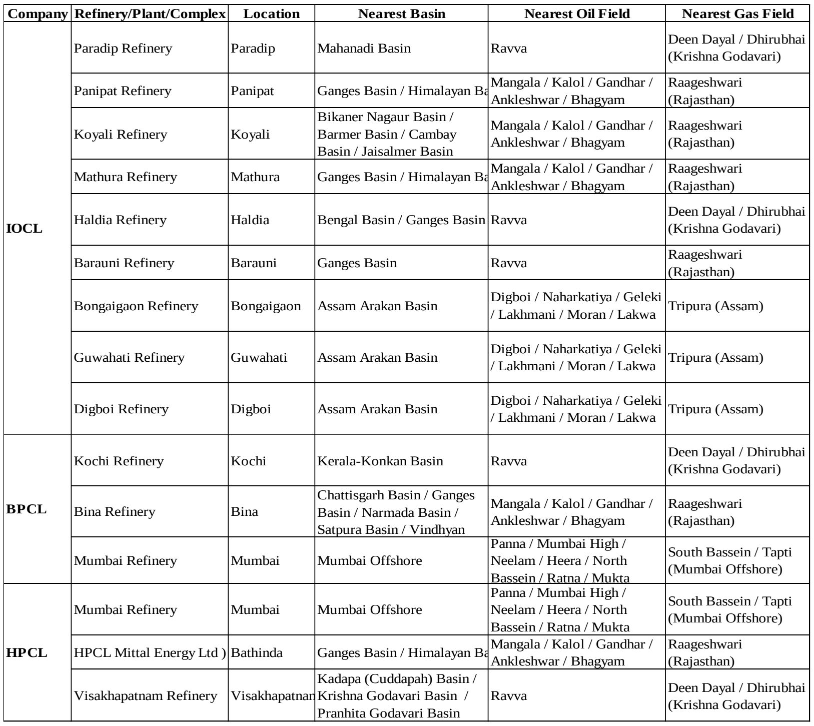
[17] Indian Bureau of Mines. Indian minerals yearbook 2019 (part-III: mineral reviews). 2020. https://ibm.gov.in/writereaddata/files/ 07072020143800Cement_2019.pdf

[18] The Green Shift-The low carbon transition of India’s Oil & Gas Sector-Final Report, Energy Transition Advisory Committee Ministry of Petroleum & Natural Gas, Government of India, 2023.

[19] Cheng, Y., Sinha, A., Ghosh, V., Sengupta, T., & Luo, H. (2021). Carbon tax and energy innovation at crossroads of carbon neutrality: Designing a sustainable decarbonization policy. *Journal of Environmental Management*, *294*, 112957.

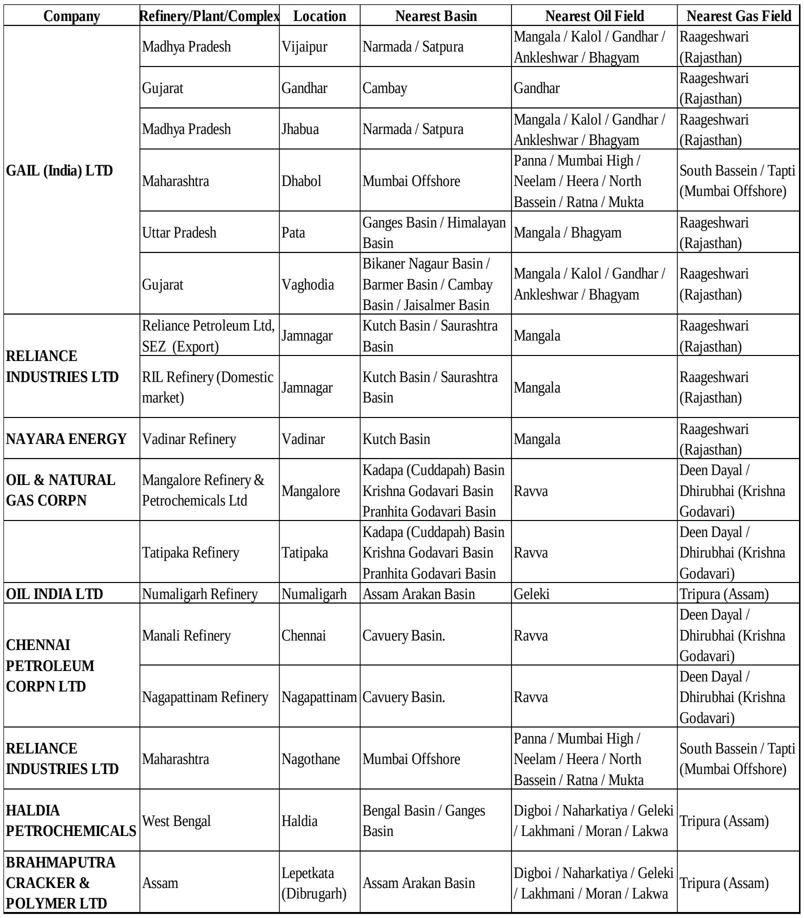
[20] Trouwloon, D., Streck, C., Chagas, T., & Martinus, G. (2023). Understanding the Use of Carbon Credits by Companies: A Review of the Defining Elements of Corporate Climate Claims. *Global Challenges*, *7*(4), 2200158.

[21] Statista. Fertilizer industry in India - statistics & facts. 2021. https://www. statista.com/topics/7488/fertilizer-industry-in-india/.



Company	Refinery/Plant/Complex	Location	Nearest Basin	Nearest Oil Field	Nearest Gas Field
IOCL	Paradip Refinery	Paradip	Mahanadi Basin	Ravva	Deen Dayal / Dhirubhai (Krishna Godavari)
	Panipat Refinery	Panipat	Ganges Basin / Himalayan Ba	Mangala / Kalol / Gandhar / Ankleshwar / Bhagyam	Raageshwari (Rajasthan)
	Koyali Refinery	Koyali	Bikaner Nagaur Basin / Barmer Basin / Cambay Basin / Jaisalmer Basin	Mangala / Kalol / Gandhar / Ankleshwar / Bhagyam	Raageshwari (Rajasthan)
	Mathura Refinery	Mathura	Ganges Basin / Himalayan Ba	Mangala / Kalol / Gandhar / Ankleshwar / Bhagyam	Raageshwari (Rajasthan)
	Haldia Refinery	Haldia	Bengal Basin / Ganges Basin	Ravva	Deen Dayal / Dhirubhai (Krishna Godavari)
	Barauni Refinery	Barauni	Ganges Basin	Ravva	Raageshwari (Rajasthan)
	Bongaigaon Refinery	Bongaigaon	Assam Arakan Basin	Digboi / Naharkatiya / Geleki / Lakhmani / Moran / Lakwa	Tripura (Assam)
	Guwahati Refinery	Guwahati	Assam Arakan Basin	Digboi / Naharkatiya / Geleki / Lakhmani / Moran / Lakwa	Tripura (Assam)
	Digboi Refinery	Digboi	Assam Arakan Basin	Digboi / Naharkatiya / Geleki / Lakhmani / Moran / Lakwa	Tripura (Assam)
BPCL	Kochi Refinery	Kochi	Kerala-Konkan Basin	Ravva	Deen Dayal / Dhirubhai (Krishna Godavari)
	Bina Refinery	Bina	Chattisgarh Basin / Ganges Basin / Narmada Basin / Satpura Basin / Vindhyan	Mangala / Kalol / Gandhar / Ankleshwar / Bhagyam	Raageshwari (Rajasthan)
	Mumbai Refinery	Mumbai	Mumbai Offshore	Panna / Mumbai High / Neelam / Heera / North Bassein / Ratna / Mukta	South Bassein / Tapti (Mumbai Offshore)
HPCL	Mumbai Refinery	Mumbai	Mumbai Offshore	Panna / Mumbai High / Neelam / Heera / North Bassein / Ratna / Mukta	South Bassein / Tapti (Mumbai Offshore)
	HPCL Mittal Energy Ltd)	Bathinda	Ganges Basin / Himalayan Ba	Mangala / Kalol / Gandhar / Ankleshwar / Bhagyam	Raageshwari (Rajasthan)
	Visakhapatnam Refinery	Visakhapatnam	Kadapa (Cuddapah) Basin / Krishna Godavari Basin / Pranhita Godavari Basin	Ravva	Deen Dayal / Dhirubhai (Krishna Godavari)

Figure 1: Linking Indian oil and gas companies to sinks (part-1)



Company	Refinery/Plant/Complex	Location	Nearest Basin	Nearest Oil Field	Nearest Gas Field
GAIL (India) LTD	Madhya Pradesh	Vijaipur	Narmada / Satpura	Mangala / Kalol / Gandhar / Ankleshwar / Bhagyam	Raageshwari (Rajasthan)
	Gujarat	Gandhar	Cambay	Gandhar	Raageshwari (Rajasthan)
	Madhya Pradesh	Jhabua	Narmada / Satpura	Mangala / Kalol / Gandhar / Ankleshwar / Bhagyam	Raageshwari (Rajasthan)
	Maharashtra	Dhabol	Mumbai Offshore	Panna / Mumbai High / Neelam / Heera / North Bassein / Ratna / Mukta	South Bassein / Tapti (Mumbai Offshore)
	Uttar Pradesh	Pata	Ganges Basin / Himalayan Basin	Mangala / Bhagyam	Raageshwari (Rajasthan)
	Gujarat	Vaghodia	Bikaner Nagaur Basin / Barmer Basin / Cambay Basin / Jaisalmer Basin	Mangala / Kalol / Gandhar / Ankleshwar / Bhagyam	Raageshwari (Rajasthan)
RELIANCE INDUSTRIES LTD	Reliance Petroleum Ltd, SEZ (Export)	Jamnagar	Kutch Basin / Saurashtra Basin	Mangala	Raageshwari (Rajasthan)
	RIL Refinery (Domestic market)	Jamnagar	Kutch Basin / Saurashtra Basin	Mangala	Raageshwari (Rajasthan)
NAYARA ENERGY	Vadinar Refinery	Vadinar	Kutch Basin	Mangala	Raageshwari (Rajasthan)
OIL & NATURAL GAS CORPN	Mangalore Refinery & Petrochemicals Ltd	Mangalore	Kadapa (Cuddapah) Basin Krishna Godavari Basin Pranhita Godavari Basin	Ravva	Deen Dayal / Dhirubhai (Krishna Godavari)
	Tatipaka Refinery	Tatipaka	Kadapa (Cuddapah) Basin Krishna Godavari Basin Pranhita Godavari Basin	Ravva	Deen Dayal / Dhirubhai (Krishna Godavari)
OIL INDIA LTD	Numaligarh Refinery	Numaligarh	Assam Arakan Basin	Geleki	Tripura (Assam)
CHENNAI PETROLEUM CORPN LTD	Manali Refinery	Chennai	Cavuery Basin.	Ravva	Deen Dayal / Dhirubhai (Krishna Godavari)
	Nagapattinam Refinery	Nagapattinam	Cavuery Basin.	Ravva	Deen Dayal / Dhirubhai (Krishna Godavari)
RELIANCE INDUSTRIES LTD	Maharashtra	Nagothane	Mumbai Offshore	Panna / Mumbai High / Neelam / Heera / North Bassein / Ratna / Mukta	South Bassein / Tapti (Mumbai Offshore)
HALDIA PETROCHEMICALS	West Bengal	Haldia	Bengal Basin / Ganges Basin	Digboi / Naharkatiya / Geleki / Lakhmani / Moran / Lakwa	Tripura (Assam)
BRAHMAPUTRA CRACKER & POLYMER LTD	Assam	Lepetkata (Dibrugarh)	Assam Arakan Basin	Digboi / Naharkatiya / Geleki / Lakhmani / Moran / Lakwa	Tripura (Assam)

Figure 2: Linking Indian oil and gas companies to sinks (part-2)