A

BUSINESS DISSERTATION

ON

"FACTORS AFFECTING THE ADAPTATION OF CARBON CAPTURE, UTILIZATION & STORAGE (CCUS) TECHNOLOGY IN NET ZERO MISSION IN INDIA"

SUBMITTED TO

SCHOOL OF PETROLEUM MANAGEMENT
PANDIT DEENDAYAL ENERGY UNIVERSITY (Formerly PDPU)
GANDHINAGAR

IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF
MASTER OF BUSINESS ADMINISTRATION

UNDER THE GUIDANCE OF

FACULTY GUIDE
DR. SATISH CHANDRA PANDEY
Associate professor

Submitted by

PRAYUSHI SHARMA
[Batch: 2020-22, Enrollment No.: 20201041]

March 2022

DECLARATION

I, **Prayushi Sharma**, student of MBA Batch 2020-22 School of Petroleum Management (SPM), Pandit Deendayal Energy University (formerly PDPU), Gandhinagar hereby declare that the Business Dissertation entitled "**FACTORS AFFECTING THE ADAPTATION OF CARBON CAPTURE, UTILIZATION & STORAGE (CCUS) TECHNOLOGY IN NET ZERO MISSION IN INDIA**" is a result of my own research work and our indebtedness to other work publications, references, if any, have been duly acknowledged. I shall be solely responsible for any plagiarism or other irregularities, if noticed in the thesis.

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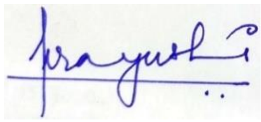

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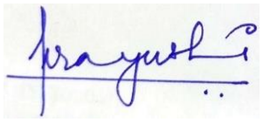

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A BUSINESS DISSERTATION ON "FACTORS AFFECTING THE ADAPTATION OF CARBON CAPTURE, UTILIZATION & STORAGE (CCUS) TECHNOLOGY IN NET ZERO MISSION IN INDIA" SUBMITTED TO SCHOOL OF PETROLEUM MANAGEMENT PANDIT DEENDAYAL ENERGY UNIVERSITY (Formerly PDPU) GANDHINAGAR IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF BUSINESS ADMINISTRATION UNDER THE GUIDANCE OF FACULTY GUIDE DR. SATISH CHANDRA PANDEY Associate professor Submitted by PRAYUSHI SHARMA [Batch: 2020-22, Enrollment No.: 20201041] March 2022 DECLARATION I, Prayushi Sharma, student of MBA Batch 2020-22 School of Petroleum Management (SPM), Pandit Deendayal Energy University (formerly PDPU), Gandhinagar hereby declare that the Business Dissertation entitled "FACTORS AFFECTING THE ADAPTATION OF CARBON CAPTURE, UTILIZATION & STORAGE (CCUS) TECHNOLOGY IN NET ZERO MISSION IN INDIA" is a result of my own research work and our indebtedness to other work publications, references, if any, have been duly acknowledged. 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To the best of my knowledge: (i) the student has not submitted the same research work to any other institution for any degree/diploma, Fellowship or other similar titles (ii) the Business Dissertation submitted is a record of original research work done by the student during the period of study under my supervision, and (iii) the Business Dissertation represents independent research work on the part of the student. Place: Gandhinagar Date: (Signature) (Name of Supervisor) IV PREFACE This report has been submitted as a part of Business Dissertation Research Project, in the partial fulfilment of degree of Master of Business Administration at School of Petroleum Management, Pandit Deendayal Energy University (formerly PDPU), Gandhinagar. The report documents the work done by Ms. Prayushi Sharma for the project titled, "FACTORS AFFECTING THE ADAPTATION OF CARBON CAPTURE, UTILIZATION & STORAGE (CCUS) TECHNOLOGY IN NET ZERO MISSION IN INDIA" under the supervision of Dr. Satish Chandra Pandey. This report intends to understand the Carbon Capture, Utilization & Storage (CCUS) technology and study the factors that are affecting the India as country for adapting this technology in term of contribution towards the Net Zero Mission in India. The report is based on the literature review of various research papers, news articles, magazines, social media content and from the recollection of data from a few industry professionals. The factors are analyzed and presented in this report to represent the facts found out from the secondary research for the titled project. V ACKNOWLEDGEMENT It is often said that life is a mixture of achievements, failures, experiences, exposures and efforts to make your dream come true. There are people around you who help you realize your dream. I take this opportunity with much pleasure to acknowledge the invaluable assistance of all the people who have helped me through the course of my journey in successful completion of this project. I wish to express my sincere gratitude to Dr. Satish Chandra Pandey, Associate Professor & my mentor for providing me an opportunity to do my Business Dissertation Research Project under his guidance. I sincerely thank my mentor, professors and batchmates for their help and encouragement in carrying out this research project, who rendered their help during the tenure of my project work. I owe whatever I have learnt and I am deeply obliged to them for providing me the impetus and the support of their abstruse knowledge and experience. Prayushi Sharma School of Petroleum Management, PDEU Gandhinagar VI VI TABLE OF CONTENTS DECLARATION.. .....I PLAGIARISM DECLARATION ....II PLAGIARISM REPORT........................ .... 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CERTIFICATE

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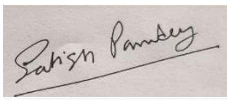

Place: Gandhinagar

Date: 27th April 2022

Dr. Satish Chandra Pandey

PREFACE

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Prayushi Sharma
School of Petroleum Management,
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LIST OF ABBREVIATIONS

ACT	Accelerating CCUS Technologies
BHEL	Bharat Heavy Electricals Limited
BUR	Biennial Update Report
CCUS	Carbon Capture, Utilization & Storage
CO_2	Carbon Dioxide
DBT	Department of Biotechnology
DST	Department of Science and Technology
EOR	Enhanced Oil Recovery
EU	European Union
GDP	Gross Domestic Product
GHG	Green House Gases
ICOSAR	Indian CO_2 Sequestration Applied Research
IPCC	Intergovernmental Panel on Climate Change
MI	Mission Innovation
MoEFCC	Ministry of Environment, Forest and Climate Change
NALCO	National Aluminium Company
NAPCC	National Action Plan on Climate Change
ONGC	Oil and Natural Gas Corporation
R&D	Research & Development
SNC	Second National Communication
UNFCCC	United Nations Framework Convention on Climate Change
USTDA	United States Trade and Development Agency

EXECUTIVE SUMMARY

Carbon emission has always been an issue and a growing concern for the global energy and climate goals. Despite the decline in 2020, global energy-related CO_2 emissions remained at 31.5 Gt, which contributed to CO_2 reaching its highest ever average annual concentration in the atmosphere of 412.5 parts per million in 2020 – around 50% higher than when the industrial revolution began.

Carbon capture, utilization and storage (CCUS) refers to a suite of technologies that can play an important and diverse role in meeting global energy and climate goals. CCUS involves the capture of CO_2 from large point sources, including power generation or industrial facilities that use either fossil fuels or biomass for fuel. The CO_2 can also be captured directly from the atmosphere. If not being used on-site, the captured CO_2 is compressed and transported by pipeline, ship, rail or truck to be used in a range of applications, or injected into deep geological formations (including depleted oil and gas reservoirs or saline formations) which trap the CO_2 for permanent storage.

Many projects are initiated and are in on-going mode for this technology, but accepting the same in country like India, considering the factors like budgetary constraints, energy policies, climate change policies and sustainability plays a vital role.

The aim of this report is to understand the CCUS technology and the factors that are affecting the adaptation of this technology in the net zero mission in India.

CHAPTER 01

INTRODUCTION

1.1 Carbon dioxide (CO_2) Emissions Overview

Carbon dioxide (CO_2) is one of the primary greenhouse gases (GHG) that contributes to global warming and climate change. The combustion of fossil fuels is the principal source of increased CO_2 concentrations in the atmosphere. Anthropogenic CO_2 emissions, both past and future, will continue to contribute to global warming and sea level rise, with dire consequences. Developing countries are particularly vulnerable, as their infrastructure is most vulnerable to extreme occurrences, and it is expected that global climate change will damage their food security, water accessibility, and health, as well as accelerate biodiversity loss. India is a developing country that perfectly exemplifies the nature of the dilemma of growing its economy while simultaneously avoiding disastrous global climate change.

1.1.1 Global Scenario

In 2020, global CO_2 emissions fell by 5.8%, or about 2 Gt CO_2, the greatest record drop and nearly five times bigger than the drop following the global financial crisis in 2009. Because the pandemic reduced demand for oil and coal harder than other energy sources, CO_2 emissions decreased further than energy demand in 2020, while renewables soared *(Global Energy Review, 2021)*.

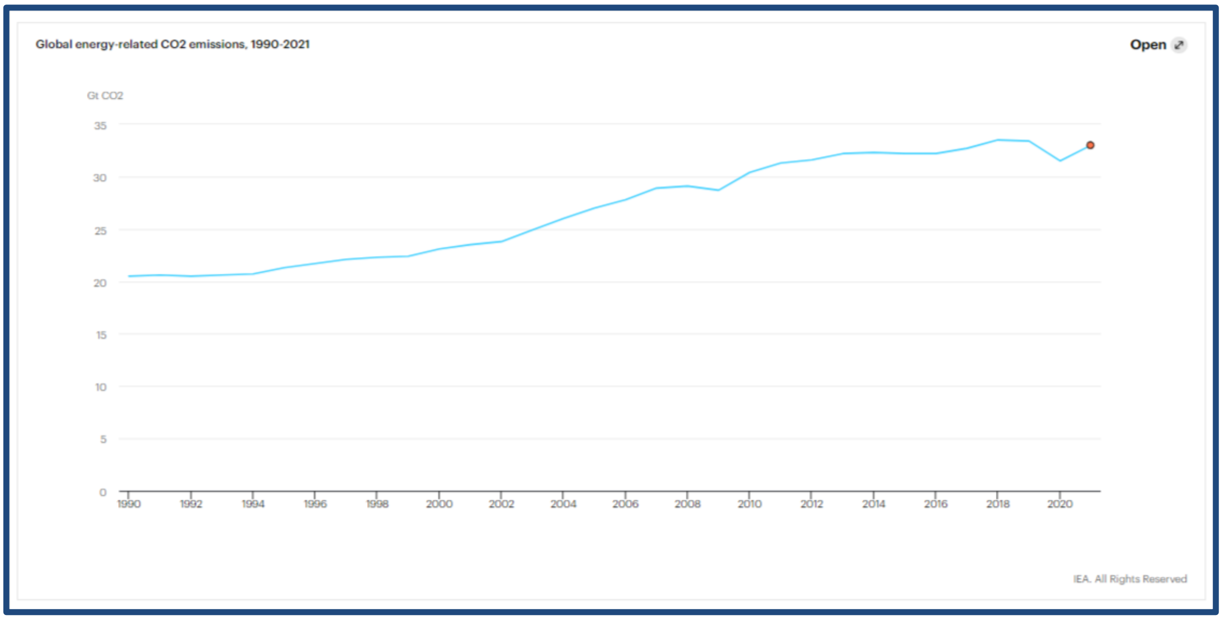

Figure 1: Global Energy-Related CO2 Emissions 1990-2021

(**Source:** CO2 emissions – Global Energy Review 2021 – Analysis - IEA)

Concerns about anthropogenically induced climate change caused by CO_2 emissions are now widely recognised, and numerous attempts to minimise CO_2 emissions have resulted. According to the latest report from the United Nations Panel on Climate Change *(IPCC, 2021)*, manmade world net CO_2 emissions would need to plummet by around 45 percent by 2030 from 2010 levels, and reach 'net zero' by 2050 to keep warming below 1.5 degrees Celsius.

According to the Intergovernmental Panel on Climate Change *(IPCC, 2021)* report , all emission scenarios evaluated suggest that global surface temperatures will continue to rise until at least the mid-century. It issued a red alert on global warming of 1.5-2 degrees Celsius, which is anticipated to exceed in the 21st century unless CO2 levels and GHG emissions are drastically reduced in the following decades.

1.1.2 Indian Scenario

As India's growth accelerates, energy demand is expected to rise, putting strain on the environment and adding to the difficulty of reducing greenhouse gas emissions at a faster rate.

Given that India is the 4th largest CO_2 producer, it's critical to understand what the country's emissions are now and where they're headed. Given India's early economic development, low per-capita emissions, and enormous population, there is significant room for increased emissions. India's energy-related CO_2 emissions are the fourth highest in the world, and they're on the rise. India's energy destiny has ramifications for global outcomes as well as national development goals.

India's goal was to reduce the emission intensity of its GDP by 33–35 % by 2030 from 2005 levels, to achieve 40% cumulative electric power installed capacity from non-fossil fuel resources by 2030, and to create an additional carbon sink of 2.5–3 billion tonnes of CO_2 equivalent through increased forest and tree cover *(Gupta, 2018)*. However, global climate models have so far been unable to produce cost-effective outcomes consistent with the Paris Agreement's targets without taking into account critical technologies like as carbon capture, utilisation, and storage (CCUS), as well as their combination (BECCS).

This research report focuses on one of the technologies, i.e., Carbon Capture, Storage & Utilization, for controlling and reducing the carbon emission in India and explores the factors affecting the adaption of this technology in India and its contribution in the net-zero mission.

1.2 Carbon Capture, Storage & Utilization (CCUS) Technology

1.2.1 What is CCUS & How does it works?

CCUS refers to a set of methods for capturing CO_2 from large point sources, such as power plants or industrial sites that burn fossil fuels or biomass for energy. CO_2 can also be directly extracted from the atmosphere. If the CO_2 is not used on-site, it is compressed and transferred by pipeline, ship, rail, or truck for use in a variety of applications, or it is injected into deep geological formations (such as depleted oil and gas reservoirs or saline formations) for permanent storage. The amount of CO_2 caught from the point source, as well as whether and how the CO_2 is used, determines how much CO_2 is reduced in net terms..

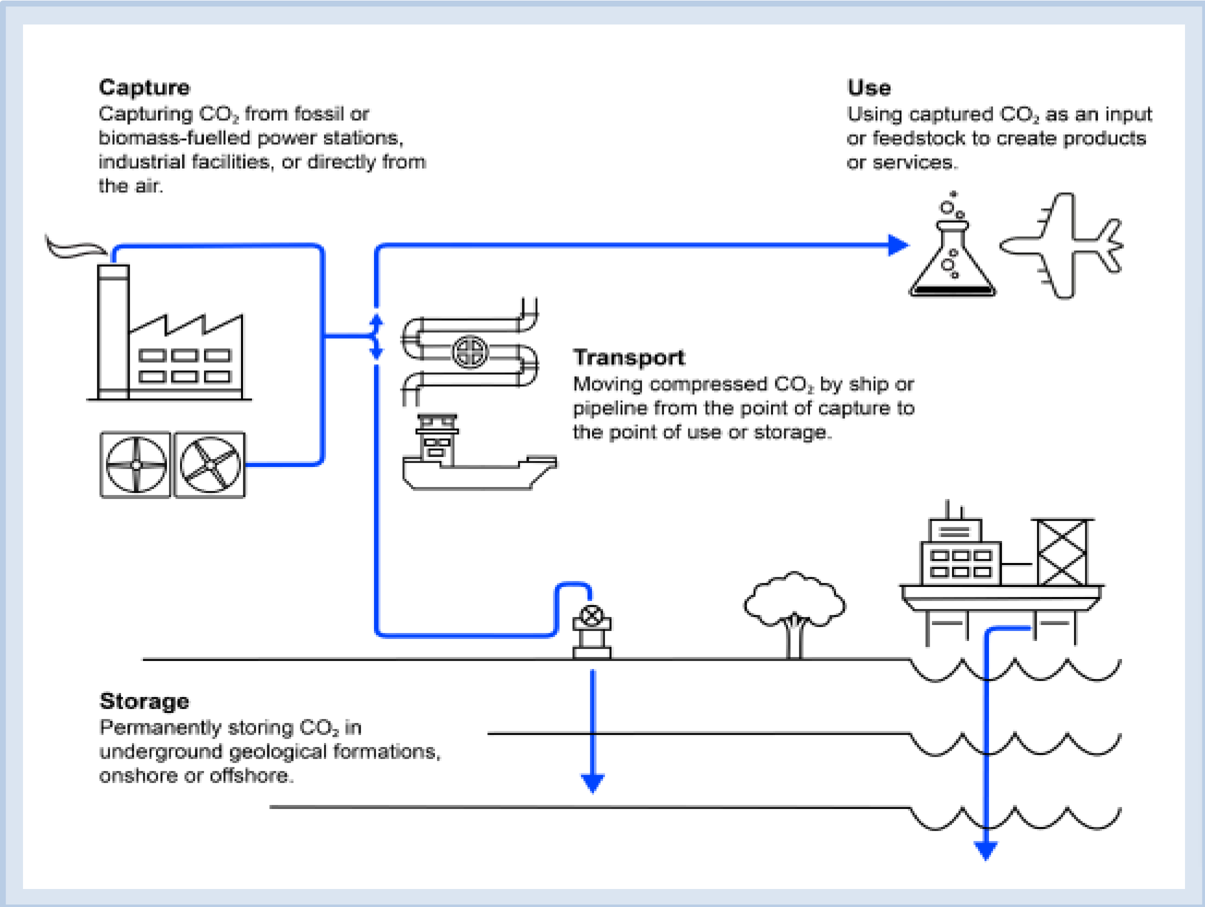

Figure 2: Schematic of CCUS

(**Source:** CCUS in Clean Energy Transitions – Analysis - IEA, Accessed on 18 Jan 2022)

CO2 can be captured from a range of sources, including the air, and transported by pipeline or ship for use or permanent storage.

Different terminology is often adopted when discussing CCUS technologies.

- Carbon capture and storage (CCS): includes applications where the CO_2 is captured and permanently stored.
- Carbon capture and utilization (CCU) or CO_2 use: includes where the CO_2 is used, for example in the production of fuels and chemicals.
- Carbon capture, utilization and storage (CCUS): includes CCS, CCU and also where the CO_2 is both used and stored, for example in EOR or in building materials, where the use results in some or all of the CO_2 being permanently stored.

1.2.2 Strategic Values of CCUS

As a climate mitigation option, CCUS has a lot of strategic significance. It may be used in a variety of ways and across a variety of industries, and it has the potential to reduce emissions in practically every component of the global energy system, either directly or indirectly. As a result, advances in developing and deploying CCUS technologies in one industry could have major spillover effects in other sectors or applications, such as technological learning, cost savings, and infrastructure development. CCUS can help the global energy system transition to net-zero emissions in four ways: tackling emissions from current energy assets, offering a platform for low-carbon hydrogen generation, providing a solution for sectors with hard-to-abate emissions, and removing carbon from the atmosphere. *(International Energy Agency (IEA), 2020)*

- **Tackling emissions from existing energy assets**: The worldwide clean energy transition will need to prioritize reducing emissions from today's power stations and industrial plants. Existing power and industrial facilities can only be repurposed to run at reduced rates of capacity utilization or with alternative fuels if they are retired early or repurposed. Retrofitting CO_2 collection technology allows existing facilities, as well as supporting infrastructure and supply lines, to continue operating while emitting much less CO_2.
- **Platform for low carbon hydrogen production**: Hydrogen is a versatile energy carrier that can help decarbonize a variety of industries, including transportation, manufacturing, power, and buildings. CCUS can make it easier to make clean hydrogen from natural gas or coal, which are the primary sources of hydrogen today, and give a low-cost way to introduce low-carbon hydrogen into new markets in the near future.
- **A solution for sectors with hard-to-abate emissions**: To achieve net-zero emissions, all energy sectors must be addressed, including those that are commonly referred to as "hard to eliminate." Heavy industry, which accounts for over 20% of worldwide CO_2 emissions, as well as long-distance modes of transportation, such as aircraft, road freight, and sea shipping, are all included. Alternatives to fossil fuels in these industries are either excessively expensive, such as electricity for high heat generation, or unfeasible, such as electric-powered aircraft or tankers.

  In actuality, without CCUS, some industries will simply be unable to reach net-zero emissions. **Cement manufacture** is a good example: heating limestone (calcium carbonate) to break it down into calcium oxide and CO_2 produces large process emissions. These non-fossil-fuel-related process emissions account for around two-thirds of the 2.4 Gt of emissions from worldwide cement manufacturing and more than 4% of total energy sector emissions. Because no other method of manufacturing cement has been proved, absorbing and permanently storing CO_2 emissions is effectively the only choice *(International Energy Agency (IEA), 2020)*.
- **Removing Carbon from the atmosphere**: Meeting international climate objectives, such as net-zero emissions, will almost probably necessitate carbon removal in some form. Nature-based solutions

like afforestation and reforestation, as well as enhanced natural processes like the addition of biochar (charcoal made from biomass) to soils, are all options for removing carbon from the atmosphere.

In its Special Report *(IPCC, 2021)* on 1.5°C, the Intergovernmental Panel on Climate Change (IPCC) stressed the importance of carbon removal in reaching ambitious climate targets. The IPCC analyzed 90 scenarios, and 88 of them assumed some amount of net-negative emissions to keep future temperature rises to 1.5°C. Where direct mitigation is now technically challenging or prohibitively expensive, such as some industrial operations and long-distance transportation, carbon removal can neutralize or balance emissions. Carbon removal is also a hedge – although not a substitute – against the risk of slower-than-expected innovation or commercialization of other technologies.

1.3 CCUS in India

To achieve ambitious long-term climate objectives like net-zero/carbon neutrality and limiting global temperature rise to less than 1.5°C or 2.0°C, immediate action to cut anthropogenic emissions is required first. To limit temperature rise at 1.5°C and achieve net-zero by 2050, global emissions must be decreased by 45 percent from 2010 levels (IPCC 2018).

India's stance on the usage of CCUS in its long-term climate plan has been equivocal *(Global CCS Institute, 2013)*. Because India's energy demand has expanded by a factor of ten in recent decades and is set to become one of the world's largest energy markets in the future, the government has prioritized the transition to a green economy.

The essential role of CCUS in India’s low-carbon future revolves around three key areas: (i) research and development (R&D), (ii) finance, and (iii) policy. Historically, there have been little attempts to comprehend the possibilities of CCUS technology and associated geological assessment. Despite over five decades of global development since the USA's Carbon dioxide enhanced oil recovery (CO_2-EOR) project, the high cost of capital and generation (about 63–75 percent increase in the base cost of generation) has been a significant obstacle to adopting CCUS technology. Apart from technological considerations, politico-economic considerations are also important in paving the way for CCUS adoption in the low-carbon transition. Because India is a price-sensitive market, the higher costs incurred as a result of CCUS could be damaging in the long run *(Malyan, 2021)*.

The CCUS issue in India has received little critical attention, but it is not new in the realm of energy and climate policy. The main milestones in the evolution of the CCS/CCUS controversy in India are depicted in Figure 3.

- The establishment of the Indian CO_2 Sequestration Applied Research (ICOSAR) Network by the Department of Science and Technology (DST), Government of India, in 2007 was one of the key developments to initiate and facilitate research dialogue on CCS applications among stakeholders (Viebahn, Vallentin, and Höller 2014; Viebahn et al. 2011; Bumb and Rituraj n.d.).

- In 2008, the Government of India came up with the National Action Plan on Climate Change (NAPCC), which did mention the CCS in reference to reducing emissions from coal power plants while highlighting concerns regarding its high cost and (in)stability of CO2 storage repositories.
- In the Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC) as well, India presented a demonstration project for carbon dioxide capture and storage (MoEF 2012).
- Soon, the CCS conversation lost its momentum in India's growth story and climate debate. The subsequent BURs did not include the progress of CCS in the country. Both BUR-I and BUR-II did not mention much about India's carbon capture activities (MoEFCC 2015, 2018).
- In 2015, the Conference of Parties (COP)-21 launching Mission Innovation (MI) emerged as another milestone for R&D on CCS technology in India (MoEFCC 2018).

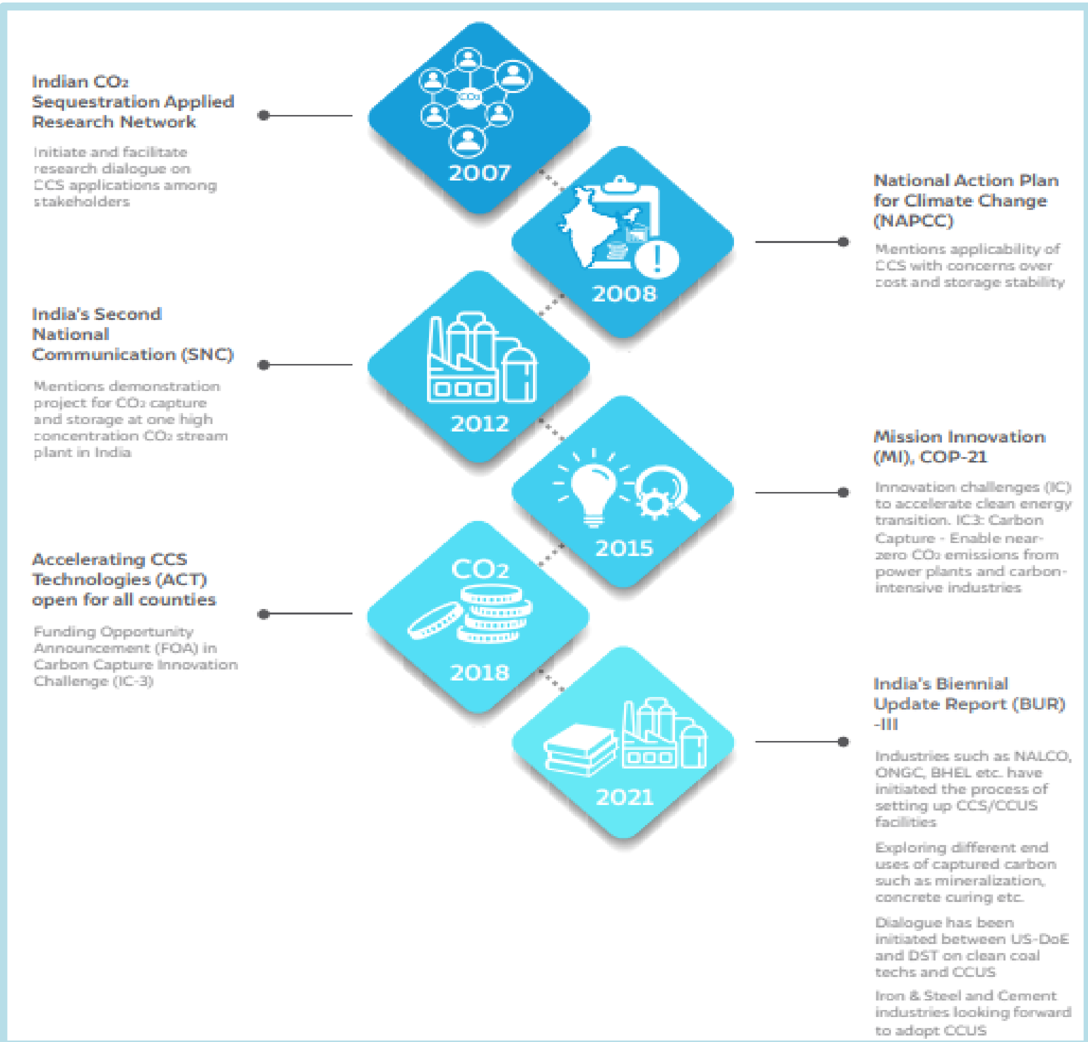

Figure 3: Key milestones in the evolution of the CCS/CCUS in India

(**Source:** Analyzing India's Carbon Capture, Utilisation & Storage Technology (ceew.in))

1.3.1 Mission Innovation

Mission Innovation is a global programme that aims to mobilize action and investment in research, development, and demonstration in order to make clean energy affordable, appealing, and accessible to everyone in this decade. This will hasten the implementation of the Paris Agreement's goals and paths to net zero emissions. *(Mission Innovation, n.d.)*

Mission Innovation, which was launched in 2015 in conjunction with the Paris Agreement, brings together governments, public authorities, corporations, investors, and academia to allow globally affordable renewable energy to meet the Paris Agreement's goals.

Mission Innovation is the primary intergovernmental platform for advancing renewable energy innovation through collaborative action. Over 90% of global public investments in clean energy innovation are made by the members, who have raised their annual spending by USD$5.8 billion since 2015. As part of an urgent and long-term response to climate change, Mission Innovation has become a catalyst for stronger worldwide cooperation on clean energy innovation.

India is engaging with 24 member countries and the European Union (EU) on eight innovative challenges as part of Mission Innovation (MI). Carbon capture—Enable near-zero CO_2 emissions from power plants and carbon-intensive sectors is the topic of the third innovation challenge (IC) (MoEFCC 2021). Because India lacks expertise adopting CCUS on a large scale, the innovation plan focuses on establishing and speeding up innovations through peer learning across MI countries (DBT and DST 2018).

The Department of Biotechnology (DBT) and DST, along with Accelerating CCUS Technologies (ACT) initiative under MI, has played an essential role in bringing back focus on CCS/CCUS in the Indian context by peer technology exchange and allocating funds for R&D.

CCUS has started gaining momentum across industrial sectors in India. Heavy industries such as National Aluminium Company (NALCO), Oil and Natural Gas Corporation (ONGC), and Bharat Heavy Electricals Limited (BHEL) are initiating the process of setting up the CCUS facilities. The leading companies from the most emission-intensive iron and steel and cement industries are following the path to exploring CCUS technologies with a vision stay carbon-neutral (MoEFCC, 2021).

Nonetheless, the dialogue between the United States Department of Energy (US-DoE) and the DST has led to India's participation in Accelerating CCUS Technologies (ACT), which has resulted in a US–India collaboration for CCUS development in the country (MoEFCC 2021). Also, the recently launched roadmap 2030 for India-UK future relations considers CCUS under clean energy and transport focus areas (MEA 2021). Thus, multiple initiatives highlight the resumption of the application of CCUS across industries in India. This regained thrust of the CCUS debate is likely to sustain with many nations and industries coming up with ambitious climate change mitigation targets *(Malyan, 2021).*

CHAPTER 02

LITERATURE REVIEW

Climate protection is the need of the hour which involves greenhouse gas emission reduction that can be achieved by reducing the carbon emission on a large scale as is described in The Paris Climate Agreement. CCUS is viewed as a critical climate protection technique for coal-rich countries like India, a comprehensive review by *(Gupta, 2018)*, states that CCUS comprises of the ability to reduce CO_2 emissions significantly more than any other existing technology but also poses challenges from the policy and regulatory point of view.

Opportunities for a low carbon transition to be deployed in India is explored in Northeast parts like Assam by *(Datta, 2019)*, which includes that for any CCUS implementation, plant design, age and preparedness are factors that influence the economics and can lead to huge differentials. With huge changes like deploying CCUS in country like India, come a greater responsibility of understanding the adoption of this technology in proper manner and scaling up this adoption with the help of some insights which are to be gained by standard research conducted by right organizations, as is done by *(Decarb Connect)*. Various factors proposed in the insights gained for scaling up the adoption of this technology as a whole in India, which might create a big deal in the coming years for deploying this technology could be technical & operational issues, which poses a big challenge like the methods used for storing CO_2, transporting option for CO_2 and operating this on big scale might affect many other factors as well. One thing which can be said for sure about posing a challenge to adapting this technology in a developing country like India is FINANCIAL issues/factor. While considering the financial factors in deploying this technology, one should also consider the cost to control the emissions from hard-to-abate sectors as well, wherein if the technology like CCUS is deployed efficiently, it can save a huge amount of money, as described in the *(International Energy Agency (IEA), 2020)* Report, which ultimately will contribute to net zero mission of India.

CCUS can be described as a 3-tier process that includes capture, storage & transportation of CO_2, wherein the *(Mukherjee, 2022)* mentions that: 1) Transportation of CO2 is most viable through pipelines. 2) Storage can be achieved through storing CO2 in depleted hydrocarbon reserves as India holds substantial potential in this field. It also presents the idea of deploying this technology in a public-private partnership & also has highlights the need of suitable, adaptable & scalable policy measures targeted at CCUS technology in India.

Also, when discussing about the importance of considering suitable policy measures as a factor for adapting CCUS technology in India, one should also consider that policies not only affect just the sectors, but also affects common people, each and every working professional in some way or the other. Spreading the knowledge and making people aware about this technology is of key importance as well.

So, CCUS relaxes the pace and magnitude of transformations in the fossil energy system in a net-zero scenario. As a result of which, it could offer a lifeline to investors, corporations, and fossil fuel-dependent communities adapting to the energy transition. This is why CCUS is essential to a low-carbon development pathway. The major factor behind the CCUS deployment in India is primarily driven by climate change mitigation and has commented that there is a need to understand the techno-economic feasibility and scalability of this technology for successful deployment *(Malyan, 2021)*.

CHAPTER 03

RESEARCH METHODLOGY

3.1 Title of the Research

The title of my research is "**factors affecting the adaptation of carbon capture, utilization & storage (CCUS) technology in net zero mission in India**".

This title for the research was selected based on the growing concern & the interest about the carbon emission in the atmosphere and the attempts of controlling the same in the whole wide world, which has attracted me to pursue this research.

3.2 Objective(s) of the Research

- Understand the concept of CCUS technology and identify its adaption factors in India.
- Analyze the factors that will affect the adaptation process for Indian companies for the CCUS technology.

3.3 Research Type

The research is based upon the **secondary data** collected from various research papers, websites, news articles, magazines, authentic data available on the governmental/non-governmental websites.

The limitation and scope of the research is that this area of research is still under-developed.

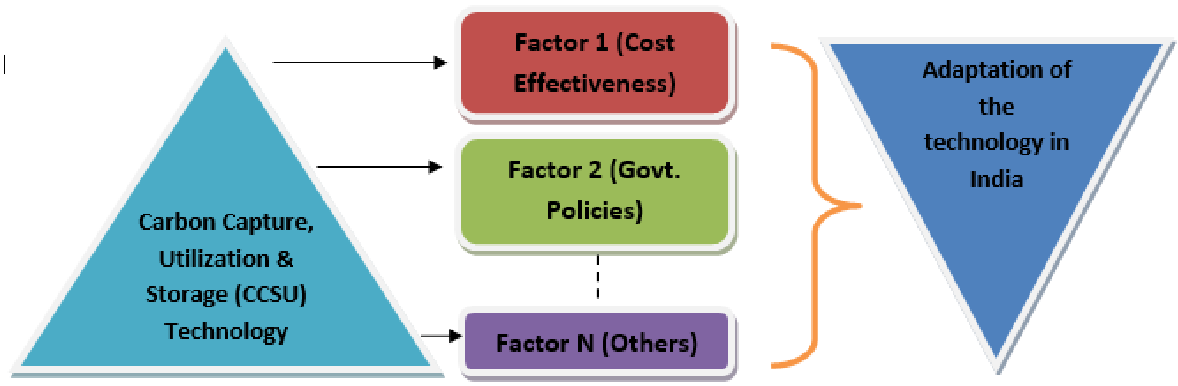

Figure 4: Research Framework

CHAPTER 04

RESULTS & DISCUSSIONS

4.1 Facts

From the secondary research that I have done, I have come across various facts for the research that will help me to understand the factors affecting the adaptation of CCUS technology in India, which are as follows:

- The carbon dioxide (CO_2) concentrations are the highest in atleast 2 million years, wherein humans have emitted 2400 billion tonnes of CO_2 since the late 1800s and along with it, the world has already depleted 86% of its available carbon budget as well.
- According to the Intergovernmental Panel on Climate Change (IPCC) report, global net-zero by 2050 was the minimum required to keep the temperature rise to 1.5 degree Celsius.
- A net-zero energy system necessitates a significant shift in how we create and use energy, which can only be accomplished with a diverse set of technologies. CCUS will need to play a significant role in addition to electrification, hydrogen, and sustainable bioenergy. It is the only category of technologies that directly reduces emissions in major sectors while also removing CO_2 to balance emissions that cannot be avoided - an important aspect of achieving "net" zero targets. *(International Energy Agency (IEA), 2020)*
- **Policy considerations, boosting technology deployment & creating the environment** for the accelerated deployment of CCUS: *(International Energy Agency (IEA), 2020)* has focused upon these factors that can help in accelerating the deployment of CCUS technology in different countries. As per the report, “To put the global energy system on pace for net-zero emissions in the next decade, a significant increase in CCUS deployment is required. Governments play a vital role in establishing a sustained and successful market for CCUS through policies”.
- **Cost Reduction, Suitable Infrastructure, Suitable storage facility of CO_2 and Policy & Regulatory Framework**: (Gupta, 2018) stated these factors as the roadmap to successful CCS in India, wherein the authors also mentions that National Aluminum Company (NALCO), ONGC, Bharat heavy Electrical Ltd. (BHEL) and APGENCO are some industries which are in early stages of setting up facilities associated with CCS.
- Assessment of relevant documents like report from Mission Innovation, information from relevant government website like Department of Science & Technology (DST) ACT and other global policy is put forward in the report of (Malyan, 2021) wherein it infers that to solve the issues that CCUS encounters in India, an ecosystem supporting CCUS facilities in the Indian market must be developed and evolved. The ecosystem should be built and strengthened around the essential pillars, namely, **R&D, policy, finance, and governance**.

4.2 Findings

Based on the above facts from the reviewed secondary research, following are the identified factors that may affect the adaptation of CCUS technology in net-zero mission in a developing country India:

- Financial Viability
- Government Policies
- Environmental Feasibility
- Technical-Operational Feasibility
- Knowledge/Information

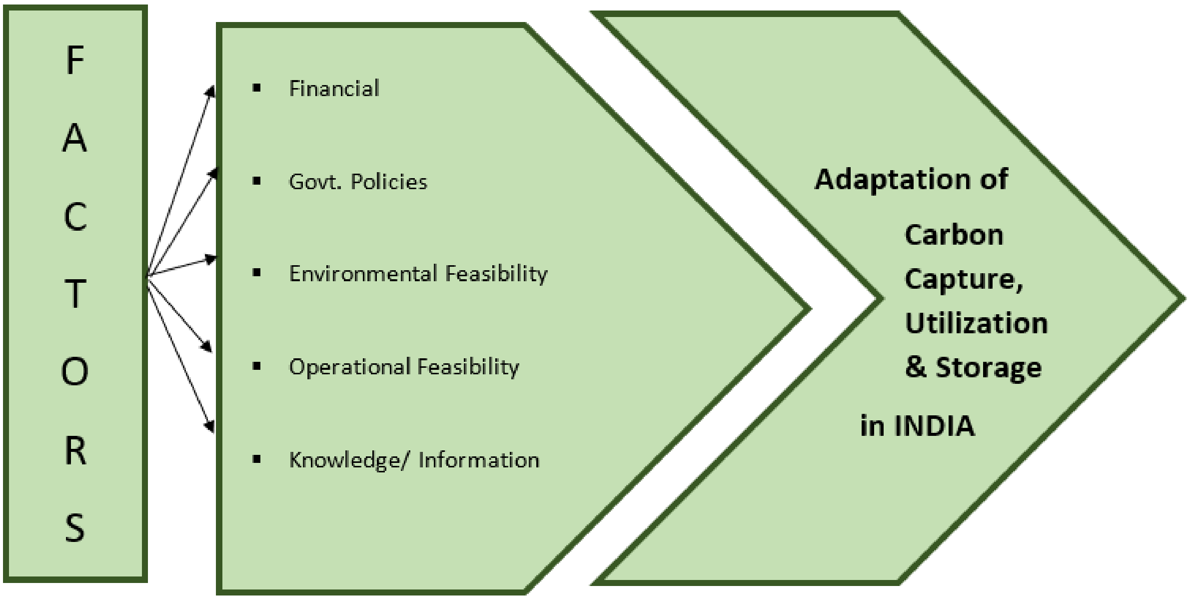

Figure 5: Factors Identified for Adaptation of CCUS in India

Based on the above identified factors, how each factor will affect the adaptation of CCUS technology in India can be expressed as the result of this research, which is as follows:

4.3 Financial Viability

Based on the research papers referred, CCUS technology is still on the higher side of the capital investment. As per the *(International Energy Agency (IEA), 2020)*, The cost of each CCUS application varies.

Carbon capture costs vary greatly depending on the CO_2 source, ranging from USD 15-25/t CO_2 for industrial processes that produce "pure" or highly concentrated CO_2 streams (such as ethanol production or natural gas processing) to USD 40-120/t CO_2 for processes that produce "dilute" gas streams (such as cement production and power generation). Directly capturing CO_2 from the air is currently the most expensive method, but it has the potential to play a unique role in carbon removal. Some CO_2 collecting systems are already commercially available, while others are still in development, adding to the wide cost disparity.

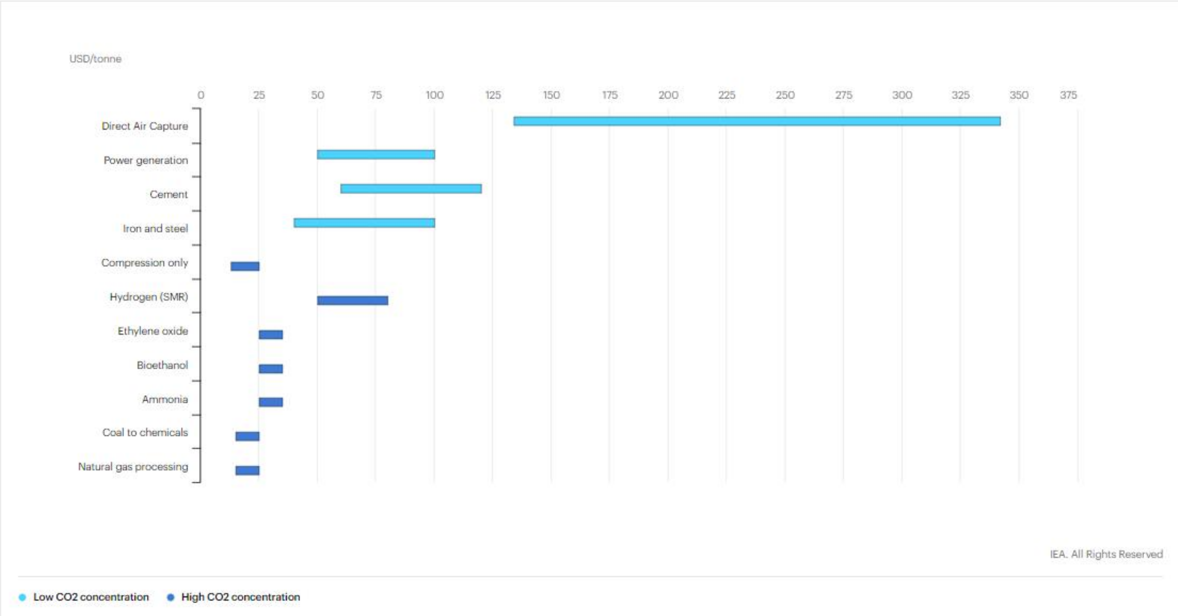

Figure 6: Levelised cost of CO2 capture by sector and initial CO2 concentration, 2019

(**Source:** Is carbon capture too expensive? – Analysis - IEA)

Moving on to the cost of **transportation and storage**, this varies widely from case to case, mostly due to CO_2 volumes, transport distances, and storage conditions. In the United States, for example, onshore pipeline transport costs range from USD 2 to USD 14 per tonne of CO_2, while onshore storage costs vary even more. However, it is projected that more than half of onshore storage capacity is accessible for less than USD 10/t CO2. When CO_2 is pumped into (and permanently kept in) oilfields to boost output and so create more cash from oil sales, storage costs can even be negative.

4.4 Government Policies

Based on the referred research paper, For CCUS, there is no one-size-fits-all policy template. Local market conditions and institutional factors, such as the current stage of CCUS infrastructure development, emissions targets, domestic energy resources, and the availability and cost of alternative approaches to cutting emissions, all influence the appropriate choice or mix of instruments for each country.

The appropriateness of each form of policy instrument differs depending on the CCUS application. Some capture uses, such as natural gas processing, are well-established and relatively inexpensive, with only minor policy changes. Other applications, such as heavy industry, are still in the early stages of development, and greater CO_2 collection costs and their potential influence on competitiveness – notably in the case of internationally traded commodities like steel – are a key hurdle to CCUS adoption. Infrastructure for transportation and storage is expensive, and future demand from capture facilities is unpredictable, posing a significant risk to project developers and investors. As CCUS expands, government support and coordination will be critical in constructing new transportation and storage infrastructure.

India does not have a CCS regulatory regime. In its Country Study of India, GCCSI found that the lack of regulation is 'the single largest impediment to investment of CCS project in India' and suggested that India consider amending existing regulations or enacting dedicated legislation (GCCSI India, 2009). Pending India's acceptance of CCS as a solution, it is not likely that the country will develop a comprehensive stand-alone CCS regime, and when it does, India will have to deal with the same regulatory issues currently being addressed by other countries. Until then, India may be able to adapt its current regulatory scheme to accommodate pilot and demonstration projects that can help India make choices about CCS.

A robust legal and regulatory framework is required to support the development of CO_2 storage resources. This should assure proper site selection and safe CO_2 storage operations, as well as a framework for risk mitigation and management at all stages of facility development, operation, and closure. It should also provide a legal framework for CO_2 storage, including allocating property rights, managing resource competition (such as with oil and gas development), and defining roles and obligations, such as ownership and liability for stored CO_2. International standards for CO_2 storage that have previously been defined (e.g., ISO/TC 265, ISO 27914) can help guide national attempts to create such a system.

4.5 Environmental Feasibility

The effect of CCUS technology on the environment can also be negative in terms of the following conditions:

- Migration of CO_2 into neighbor geologic formations: Lateral and/or descendent diffusion of CO_2 from the storage complex into neighbor formations.
- Migration of CO_2 into neighbor aquifers or aquitards: Dissolution of CO_2 into the water, possible pH decreases and water acidification; Reaction of CO_2 with other water dissolved substances; Potable water contamination with impurities (from the CO_2 stream such as H2S).
- Soil and ground water disruption after long-term storage: Possibility of ground movement and fracture through induced micro seismicity and stress, Possibility of groundwater circulation disturbance cause by fracturing activation or expansion, Possibility of uplift or subsidence of layers caused by overpressure of the reservoir.

4.6 Technical-Operational Feasibility

Storage capacity for CO_2 is uncertain as the availability of geological storage is not considered a barrier in the short to medium term. However, there are uncertainties with regards to the long-term ability of storage sites to sequester carbon without significant leakage. There is some potential for seismic activity caused by underground injection of CO_2. Furthermore, it is also estimated that not all countries will have enough CO_2 storage capacity to properly implement CCUS. Transportation considerations While the risk of accidents during transportation is relatively low, the potential for leaks still exists. Transportation of CO_2 to the storage sites is also very costly, since significant energy is required to compress the CO_2 and maintain high pressure throughout the pipelines, which are expensive themselves. Potential leakage in high concentration can also cause problems for human health. Each CO_2 source must be connected to an appropriate storage site via pipeline.

Understanding the technical-operational feasibility of any CCUS project in India at this point of time is a difficult task, but one such example of a project in the study phase is of IOCL's Koyali refinery.

Dastur has been selected to lead the design and feasibility study for a CCUS project at the 13.7 million tons per annum Koyali refinery of Indian Oil Corporation Ltd.

IOCL is India's leading refiner, operating 11 of the country's 23 refineries. The refinery at Koyali, near Vadodara, is its flagship refinery, and has the potential to capture over 5000 tonnes per day (tpd) or more than 1.5 mtpa of CO_2 for large scale EOR operations. The CO_2 captured from its hydrogen generation units will be primarily used for EOR at the Oil and Natural Gas Commission's (ONGC) oilfield at Gandhar, Gujarat, near Koyali.

The project is funded by the United States Trade and Development Agency (USTDA), as part of its mission to promote the development of sustainable infrastructure projects and fostering economic growth in partner countries like India.

Dastur will conceive and develop this project using intellectual property and skills from its Austin, TX-based affiliate Dastur Energy in the fields of energy engineering, carbon capture, EOR, energy supply chains, energy economics, and low-carbon fuels.

4.7 Knowledge/Information

The successful implementation of CCUS will necessitate a determined effort to ensure that local communities and the general public are aware of the technology and embrace it. Because geological CO_2 storage is a relatively novel notion for many people, real questions regarding safety and dangers may arise.

To gain community support, communication and participation should begin as early as feasible in the project development process, as was the case with Shell's Quest project in Canada and the Tomakomai project in Japan. Governments, as well as non-governmental organizations and the scientific community, will play a key role in emphasizing the importance of CCUS in the portfolio of technologies required to accomplish climate targets.

CHAPTER 05

CONCLUSION

Based on the facts and findings presented above, the conclusion for this research can be summed up as follows:

- The narrative around carbon capture and storage (CCS/CCUS) technology has been regaining traction in the Indian and global contexts, in line with countries that have made aggressive commitments to carbon neutrality.

- For a variety of reasons, achieving significant emissions reductions in heavy industries (cement, steel, and chemicals manufacturing) can be difficult. CCUS, on the other hand, is a very advanced and cost-competitive method for drastically reducing CO_2 emissions during the manufacture of these critical materials. Retrofitting CCUS to existing facilities can also be more cost-effective than developing new capacity with alternative technologies.
    - For ex: CCUS is currently the only scalable approach for decreasing emissions in **cement production**, where chemical reactions linked to heating limestone (rather than burning fossil fuels) account for two-thirds of emissions. In the iron and steel industry, CCUS-based production pathways are now the most sophisticated and least expensive low-carbon solutions. When compared to today's traditional production methods, incorporating CO_2 collection raises predicted costs by less than 10%, but approaches based on electrolytic hydrogen can raise costs by 35-70%.

- Policy actions must also be customized to the stage of CCUS technology development in the industry or application where it is used. As the number of CCUS systems deployed grows, the market for these systems should become more self-sufficient, requiring less government intervention. Subsidies targeted at a certain group of people might be phased out, and measures that affect the entire economy, such as carbon pricing, could become the mainstay of investment support.

- Policymakers and the general public need to be provided with information and education on CCUS more often and more effectively. This includes information on the use of CCUS in energy systems and broad-based mitigation efforts. For example, it is critical to broaden public understanding of the potential of the industry to reduce carbon intensity in operational contexts beyond fossil fuel use and production. This is important for public endorsement and social acceptance of CCUS, and in terms of fully exploring the scope of potential uses for CCUS technologies.

- To solve the issues that CCUS encounters in India, an ecosystem supporting CCUS facilities in the Indian market must be developed and evolved. CCUS's success is hampered not only by technology, which will improve in the future years, but also by a lack of a policy ecology. The ecosystem should be established and strengthened around four key pillars: research and development, policy, funding, and governance.
- Nonetheless, in comparison to developed countries, CCUS technology is relatively new to India, necessitating more detailed study, initiatives, and talks to keep the debate continuing while debating India's low-carbon story.

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