Carbon Capture and Sequestration- A Review

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Abstract. The Drastic increase of CO_2 emission in the last 30 years is due to the combustion of fossil fuels and it causes a major change in the environment such as global warming. In India, the emission of fossil fuels is developed in the recent years. The alternate energy sources are not sufficient to meet the values of this emission reduction and the framework of climate change demands the emission reduction, the CCS technology can be used as a mitigation tool which evaluates the feasibility for implementation of this technology in India. CCS is a process to capture the carbon dioxide from large sources like fossil fuel station to avoid the entrance of CO_2 in the atmosphere. IPCC accredited this technology and its path for mitigation for the developing countries. In this paper, we present the technologies of CCS with its development and external factors. The main goal of this process is to avoid the release the CO_2 into the atmosphere and also investigates the sequestration and mitigation technologies of carbon.

1. Introduction

The climate variability and changes are one of the evidence for global warming, it increases the average temperature of the globe. It is due to the increase of greenhouse gas in the atmosphere. CO_2 is the main component in greenhouse gas. The processes in industries are the main reason for the emission of CO_2. It is mostly emitted from the burnings of carbonaceous fuels. Greenhouse gas is also emitted by the natural phenomenon like agriculture and live stocks. The mechanism of nature is to absorb the CO_2 to maintain the biosphere balance in the atmosphere. The emission of greenhouse gas is increased when comparing with the initial revolution of the industries. It is due to the usage of fossil fuels, Thermal power generation, Logistics, and transport. Coal is mainly used in the power sector and it consumes 70% of Indian economy. The Economic growth of India is accelerated to add more 600000 MW by 2030 approximately [1]. The emission of CO_2 must be reduced to minimize the global warming. Nuclear energy, hydro energy, fossil fuels, coal power have to produce power in large amount to accommodate the need of power but clean coal technologies and coal combustion in the efficient and clean methods are required to be developed to reduce the emission level of CO_2. Capture and Storage Technologies are used to reduce the emission of Greenhouse gasses by capturing the CO_2 gas from the viable surface.

Carbon capture and sequestration is a physical process which involves in the capturing of CO_2 and its storage. CCS technology is used to reduce the emission of CO_2 in the atmosphere. The integrated system of CCS has the following process, the CO_2 will be captured and separated from the other gasses. Then it will be purified, compressed and transported to the sequestration site. CO_2 will be injected into the geological surface of the reservoir or it will be stored in the ocean. This review is focused to analyze, study and evaluate the importance of CCS technology to reduce the GHG emission to avoid global warming with the implications of economic. The main objective is to research about the Technology of CCS with power sector to understand the feasibility of the technologies. The

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applicability of the power sector is applied to the demonstration of the requirements to establish the technology. The aim of CCS technology is listed as follows, it enhances the power plant efficiency with the latest technologies to reduce the emission of Carbon dioxide by using the capture technology. CO_2 is captured and it is separated from the gas streams which is emitted from the mixture of combustion gasses. The captured CO_2 will be transported to the underground storage. CO_2 will be stored in underground sedimentary basins, saline aquifers, and coal reservoirs. CO_2 will be stored in the potential areas of the country. Trapping mechanism will be used for the storage process. It is important to ensure the safety of the storage area. The main goal of the CCS technology is to reduce the amount of CO_2 in the environment. CO_2 emitted by the fossil fuels will be stored in secured places for hundreds of years with affordable prices.

2. CCS Scenario in India

Nearly 53.7% of electricity is generated through coal which means direct carbon emission to atmosphere. Around 40% of CO_2 emission is for power generation and further emission by the industrial side and transport will be 15% and 32% respectively. Then 11% of carbon released by the residential and commercial sectors [1]–[3]. These overall percentage of carbon dioxide are not flexible to CO_2 Capture and Sequestration. The CCS is well suited for large industry, power plant and stationary sources of carbon dioxide emission due to economic cost and high capital cost. But the oil refining company, cement production industry and, iron and steel manufacturing combust the fuels and release the carbon. These are all the intensive industries. The cost based on the flue gas cost properties, basically down with high carbon dioxide concentrations and less temperature. The sequestration of CO_2 accumulation in earth is due to unacceptable combustion of fuels such as fossil. Even though the cost invested in fuel acquisition, domestic infrastructure and reserves, the maintenance, and the alternate energy source combustion. The alternate sources are the wind, solar and biomass energy. This CCS technology provides the solution to the dilemma. The solution provided by the carbon emission reduction costs due to the storage of acquired CO_2 and transportation which will increase in helping to control the evaded cost of capture [4].

According to 2007-2008 in India, a particular care had been taken to carbon capture and sequestration field. During the financial year, a various number of researchers sponsored nearly thirty projects depends upon storage or sequestration. CCS technology is one of the interesting processes. By comparing with those years, after 2013 only some researcher’s standby in open market. In India, there is no particular CCS policy needs to be expressed. Due to this policy, India lag on R&D dynamic approach. The absence of CCS will cause the cost about 70% increased at 2050 due to the ejection of carbon. In India, CCS is at an initial stage only, because the government does not consider the CCS technology is the key factor for climate and national energy policies [5]. Instead of involving in coordination CCS development process and coordination process, the DST (Department of Science and Technology) started the (ICOSAR) "Indian CO_2 sequestration Applied Research. These CCS projects are always executed in three steps given as absorbing, pre-combustion and post-combustion. The power sector does not yet have demonstration -scale. These levels provide the projects for carbon dioxide capture in 1988 [6]. In India, the four initiating key points are as follows:

- **Capture of pure carbon dioxide streams in Industry**
  The process is very easy to produce a pure stream of carbon dioxide. The examples are fertilizer and gas industries. The shortage of CO_2 at fertilizer plants in India because of the CO_2 usage produced from the production of ammonia. The excess of Carbon dioxide is also used for the urea manufacture. The waste supply of carbon dioxide replaces the generation of this excess CO_2 [7].
- **EOR (Enhanced Oil Recovery) offshore and onshore**
  The CO_2 developing plans are already initiated from the offshore sour gas by the Indian government at Gujarat, Hazira. This recovery is done at the onshore site about 70 km far away. Nearly 1200 tons of received carbon dioxide transportation takes place every day to the oil field. It maintains the pressure and reduces the oil viscosity.
- **CCS technology with power sector and coal**

This process starts with technology generation such as advanced supercritical steam conditions. It includes new power plant design in India, such as UMPP's ("unimpaired performance and less upfront costs").

- **Export CO_2 for foreign EOR activities**
  The UMPP project design is mainly for imported coal such as Mundra. The project integration formed by the shipping terminals [8].

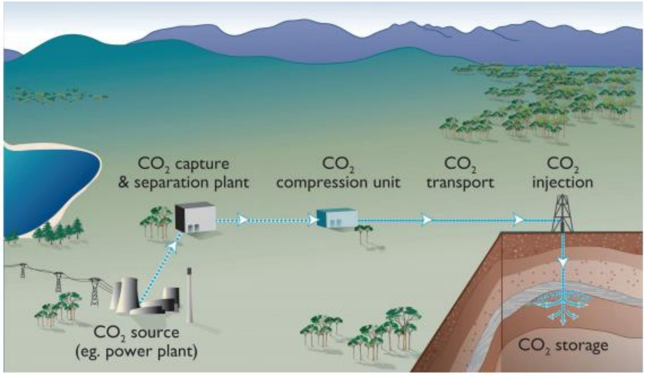

Fig. 2.1 Process flow of geo-sequestration of CO_2 [9]

CCS process has three main steps (as seen in fig. 2.1):

1. **Capture of CO_2-** CO_2 is captured from the industrial sources, power plants and natural gas as they have high content of CO_2.
2. **Transportation-** Transportation is the process of transferring the CO_2 to the storage site.
3. **Geological storage**: In the last step, the transferred CO_2 is saved in geological storage such as in deep saline formations, un-mine-able coal seams, depleted oil/gas fields or gas recovery sites.

The combustion processes used to capture the CO_2 gas are in three modes. They are pre-combustion mode, post-combustion mode and oxy-fuel combustion [10].

3. CO_2 Capture

There are three main sources available for emission of CO_2 gasses. They are from power plants, natural gas, and industrial gas. The most important CO_2 gas emission takes place in power plants. This CCS technology is used to reduce the CO_2 emissions. The pre-combustion technique is used to collect the gas from the coal combustion streams and depose it geographically. So, this method is used to protect the gas to enters into the atmosphere.

3.1. Carbon transportation

Transport the connection between the carbon captured and storage sites. This uses the pipeline process to transfer the carbon. Transport the connection between the carbon captured and storage sites. This uses the pipeline process to transfer the carbon. For transferring gas long distance, this pipeline technique is used. Liquid, gas and solid are the three states of carbon transformation available. The liquid and gaseous carbon are transported by using the commercial scale transport like pipelines, ships, and tanks. The use of ships in transferring gas is the most usable method. There are four types of ships that are used for this transportation. These four types of ships are used to transport the liquefied carbon from the large type of sources such as ammonia plants. The ships then transfer these liquefied carbons to the coastal distribution terminals [11]–[13].

3.2. Carbon Sequestration

This stage is the critical stage in this technology. The emissions of the carbon in the atmosphere are protected by this stage. In this sequestration stage, the captured carbon is stored in the geological site. Based on the economic point of view, the famous sites for storing the carbon is un-mineable coal seams, deep saline formations, enhanced oil or gas recovery (EOR or EGR) and depleted oil/gas fields. There are many techniques that are used for storing the carbon into the storage reservoirs [14].

3.3. Potential sources of GHG emissions

According to the ministry of power, India, there are five division available in India: Western, Eastern, Northern, Southern and North-Eastern. Coal is found in India in the central regions, eastern, and southern region. Lignite is found in big hydro-power and the southern region. But, for more power generation the lignite required to develop in the north-eastern and northern region. Efficient technologies are used in the growth of the power generation. At this time, there is also a need to maintain the GHG emission to protect the environment [10].

The power sector is one of the largest sources for emission of GHG. In the power sector, the fossil fuel-fired power plants are supplied the base load electricity. This is the major part that affects the environment by GHG emissions. There are some solutions to reduce the emission of GHG as listed below [15],

- Waste reduction and timely maintenance are efficient way to increase the efficiency of power plants.
- Recycling the old power plants and application of new technologies.
- Change the base load generation using the fossil fuel power plants to power plants as renewable energy.
- Should use CCS technology for upcoming power plants.

4. CCS Technologies

4.1. Oxyfuel combustion

This technology is used to remove the fuel in the air with oxygen. The air in atmosphere contains 78.08% nitrogen, 20.95% oxygen and the remaining percentage of air contains gasses like Helium Xenon, Neon etc. (inert gases). In this technology, the fuel is added to the existing atmospheric air for combustion. Inert gases in the atmospheric air do not reach the high temperature then the combustion is incomplete. But instead of air if oxygen is used in the process, a higher temperature can be attained. The process of Oxy- Fuel Combustion technique therefore is burning the fuel with pure oxygen. This process acts in the air as primary oxidant air [16]. The process flow of plant is shown in fig. 4.1 the process shows oxy-fuel cement plant, which runs on the oxyfuel technology, where the amount of CO_2 was raised in a rotary kiln by combusting oxygen and fuel to get high concentration of CO_2 flue gas which was sent to CO_2 purification unit.

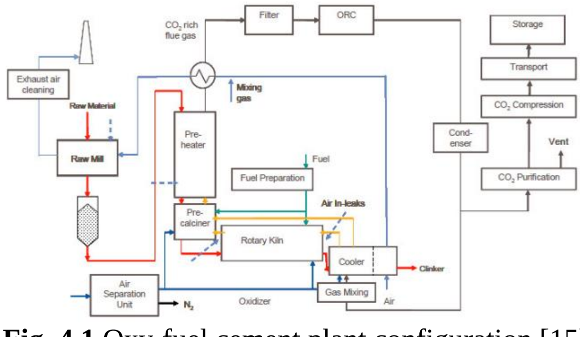

Fig. 4.1 Oxy-fuel cement plant configuration [15]

4.2. Pre-combustion

Pre-combustion is the process to obtain the fossil fuel without carbon. This process is done before the combustion process is completed. First, the coal is oxidized in steam. Then the coal is mixed with the air. This mixture forms the synthesis gas at high temperature. This gas is also referred as 'syngas' and it is the mixture of carbon mono-oxide, hydrogen, CO_2 and a smaller amount of methane. This process is called as gasification. The next level is water-gas shift reaction. In this level, the carbon monoxide and the water are converted to hydrogen H_2 and carbon dioxide (CO_2). In this mixture, the range of the CO_2 is 15-50%. After this pre-combustion method, the CO_2 is captured, transfers and then sequestrated, the fig. 4.2 shows the process of pre-combustion explain the process steps. As compared to the post-combustion method, pre-combustion is used to remove dilute CO_2 at low pressure. At high pressure, this combustion removes rich CO_2 gas before the hydrogen is combusted on the water-gas shift reaction. Pre-combustion is the more efficient technique at the time of availability of more concentrated CO_2. But, more expensive for the base gasification process [9], [15].

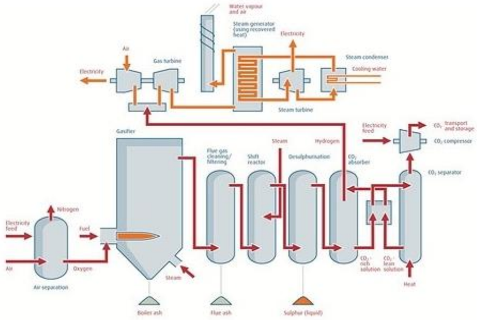

Fig. 4.2 Pre-combustion process [17]

4.3. Post-combustion

The post-combustion method is used to remove the CO_2 from the flue gasses. The post-combustion method in power plants uses the chemical absorption processes with solvents of monoethanolamine (MEA). This process is called as amine separation process. The Fig 4.3 shows the flow diagram of amine process. In an absorber, the MEA solution is added with the absorber. The MEA is used to get the CO_2 by selectively absorbing from the overall CO_2. Then the selective CO_2 is sent to the stripper. In the stripper, pure CO_2 is made by heating the CO_2-rich with MEA solution. After that the generated the CO_2 lean with MEA solution is out from the stripper. This gas is again sent to the absorber and recycled [18].

The main principle of post-combustion technology is to separate the carbon dioxide from the flue gasses. In the power generation system, for generation of steam, coal is burnt in the boiler with the help of air. Steam is used to drive the turbine and it generates the electricity. The exhaust from the flue gases contains CO_2 and N_2. For coal power plants this Post-combustion technology is best as compared to other technologies. The leading technology is used to scrub the solvents with an amine. This scrubbing of solvents is based on the chemicals which react with the carbon dioxide to generate a high temperature of CO_2, which is suitable for storage and compression of gas.

In post-combustion technology, the advantage of amine scrubbing is that it can be retrofitted with the industries and existing power plants in the suitable location. It is commercially used in small scale industries. MEA can be used with the low pressure of CO_2 to capture CO_2 in flue gas. Separation of CO_2 from the stream of flue gas is one of the challenging tasks. CO_2 with low pressure, high volume and dilute concentration are treated. Scrubbing plants are used to reduce the concentration of acid gasses such as SO_2 and NO_2. The impurities of flue gasses degrade the solvents.

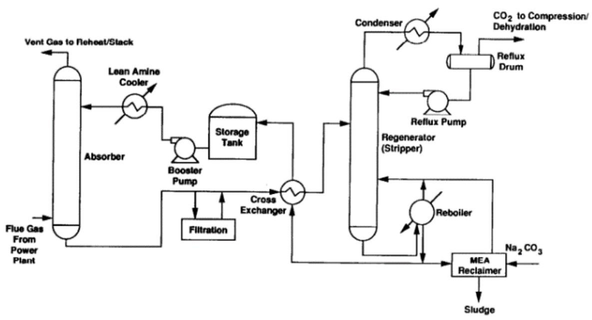

Fig.4.3 Post-combustion process [19]

The degraded items are linked with the problems of corrosion. The limited evolutions are expected for the development of solvents. CO_2 captured by the solvents may use for some other processes. This solvent scrubbing is an existing technology and it has limited experience for the operation of large scale. It has a large operating unit with 800 tons capacity for capturing of CO_2 per day and this power plant produces 8000 ton of CO_2 per day.

5. Research in post-combustion capture process

The research in post-combustion can be divided into two types. Short time research and long-term research. Short term research focuses on the development of existing technologies. It is important to minimize the requirement of heat and temperature.
The improvement of solvents can be divided into three types.

- Concentration of solvents
- Corrosion and degradation of solvents
- Alternative for MEA

The solution of MEA for the absorption of acid gas contains 30 wt% of MEA. To reduce the cost of plant operation and circulation, the concentration and capacity of amine can be increased. Solvent degradation increases the cost of the material, waste disposal and creates a demand for capturing of CO_2. There have been many research conducted to find a superior solvent of MEA as alternative to MEA.

6. Barriers to implement CCS

The adoption of CCS barriers are divided into three categories. They are,

- Financial barriers
- Technical barriers
- Institutional barrier
- Other barriers

The Financial barriers are involving the high capital cost and high energy penalty. The Institutional barriers do not meet the overall development goals. It involves the non-productive expenditure which does not contribute to sustainable development. The Technical barriers are commercially demonstrating the high point sources of CO_2. It is used to capture technologies, but it is not standard for high point sources. It identifies the sinks and its capacities. The technical barriers have some permanence issues and the issues are seismically active in many parts of India. It establishes the EGR/EOR and ECBM in India. The technical barriers are used to determine the potential and cost for the depleted gas and oil. It also optimizes matching and mapping of the sinks and their sources [20].
The other barriers include,

- Financial
- Regulatory
- Storage
- Acceptance

The Storage is used to identify the leakages and their carbon accounting. The regulatory is used to provide the EC establishment and it used to allow the CCS for the European trading.

6.1. Post-combustion

In the world, the CCS is present in the demonstration phase and it gained only one degree of a technology confidence through the deployment of the large scale. The CCS deployment has one major barrier in India. It lacks capture of technology and geological storage side data which can be installed in power plants and their sources are permeability, capacity and location. The CCS implementation has some issues such as increasing the electricity cost and power output. One of the biggest barriers of CCS in India, is electrification and deficit of electricity in the country. In the world, the CO_2 storage uses the Enhanced oil recovery and it is one of the most attractive options for the CCS deployment. In this procedure use, the CO_2 storage cost is offset by accrued revenues. In the petroleum sector, it has been stated by the stakeholders and it has few oil fields that are partially depleted for the enhanced oil recovery [21].
The enhanced oil recovery based on the characteristics of miscibility of the oil that oil is not suitable for all cases. The CCS implementation needs to clarity through retrofit of the capture equipment to the previous plants. The previous plants will modify and change the term of plan references. The barriers are used to access the financial agencies such as Asian development bank and World Bank etc. The previous requirements are verification, monitoring, and measure. The requirements are depending on

the specific clearance of the CCS. The specific clearances of CCS present from the government bodies and Ministry of power to the previous clearance requirement.
The Large scale of CCS deployment requires the best infrastructure and specialized manpower which is not present in India. The CO_2 storage monitors to assure the fulfilment of the CCS implementation and it ensure the rigorous monitor. The monitoring is needed to overlook the techniques and scale development and these are introduced to the Indian stakeholders. The barriers have many legal issues and they are related to the CO_2 leakages, land acquisition and ground water contamination etc. and these are needs to be addressed including the large-scale CO_2 storage and transports. The CO_2 storage and large-scale transports can be permitted via CCS deployment in India.

6.2. Policy amendments by India for CCS implementation
India is world's third largest coal consumer. Coal represents 62% of the nation's power distribution. About 75 percentage of the coal delivered in India which helps to produce an electricity, the remaining 25 percentage is utilized as a part of the steel, binding material, and manure manufacturing. Given the plenitude of coal in India, joined with quickly developing power request, the Indian government is supporting activities, to create up to 9 Ultra-Mega Power Projects. This will include nearly 36 GW of coal driven quantity while suggesting essential chances to examine CCS. The emission of CO_2 is increased up to 1300 Mt, about a portion of which is from expansive point sources that are reasonable for the CO_2 attack. The 25 biggest emitters provided around 36% of aggregate national CO_2 discharge in 2000 which demonstrating the possible presence of various valuable CCS opportunities. As a non-Annex I country to the United Nations Framework Convention on Climate Change (UNFCCC), India has consented to finish Greenhouse Gas emission (GHG) inventories that are still not necessary to meet a binding target for GHG emission under the Kyoto Protocol. India confronts various specialized and administrative obstructions to the use of CCS and cleans coal innovations as a major aspect of a bigger environmental change methodology. In order to acknowledge these problems, the legislature has built up a Clean Coal Technology (CCT) Roadmap with the intention to support the aim of clean coal improvement and strategy (policy) inventions. A CCRD (Clean Coal Research & Development) centre has additionally been set up by industry. CBP (Capacity Binding Programs) has been projected to generate more technology advancement in CCS. Moreover, India has joined various global endeavour to propel the improvement and dispersal of CCS advances. India has become one of founding member countries of the CSLF (Carbon Sequestration Leadership Forum).

6.3. Policy amendments by India for CCS implementation
In 2007, the Department of Science and Technology and Technology Bhawan has started the Indian CO_2 Sequestration Applied Research organizes in New Delhi, which encourages exchange with partners and to build up a system for actions. The Indian CCS research incorporates Carbon Dioxide Enhanced Oil Recovery (CO_2-EOR) perusing thinks about in developing oil fields. Hazira power plant is decided to inject an acid gas. The expenses of CO_2 catch have additionally been surveyed. For instance, emission capture is evaluated to be 21 percentage costlier from Integrated Gasification Combined Cycle (IGCC) and high-ash coal plant than from pulverized coal fired power plant and 12% costlier than from the Ultra Super Critical plant. The Fertilizers Corporation of India has introduced two CO2 attacks plants with 450 t quantity for every day at its Aonla and Phulpur edifices. The study, based on the Deccan Basalt Province in Western India that is one of the biggest surge basalt regions in the world has started in cooperated with Pacific Northwest National Laboratory (PNNL) in the United States [4].

6.4. COP-$_2$1 and outcomes
The United Nations Climate Change Conference COP-21 was held in Paris on November 30, 2015. This agreement explains, there are minimum 55 countries that need to represent 55 percent of greenhouse gas emissions. 174 countries have signed this agreement on April 22, 2016. The main aim of the conference is to reduce the increase in global temperature by greenhouse emissions. In the previous climate conferences, a global agreement pact was signed by the countries to agree to an outline action. These agreements are called as INDCs (Intended Nationally Determined Contributions).

The INDCs used to reduce the global warming and also reduce the emissions [22]. The outcome of this conference holds the binding on reduction of green gas emissions. As per this document, the members agreed to reduce the carbon emissions globally to reduce the global warming. In this agreement, the island states such as the Seychelles, the Pacific and also the non-island state the Philippines strongly mentioned that they will reduce the sea level rise of GHG emissions. They were set the goal as reduce the warm from 2 ℃ to 1.5 ℃ [23].

7. Barriers to implement CCS

7.1. CO_2 emission reduction scenario (without CCS)

CO_2 emissions reduction without CCS reduce the CO_2 emissions. BAU has a target of more than 40% time series reduction for CO_2 emission. The CO_2 emission maximum reduction occurs in the power sector by using the clean coal technology deployment as shown in fig 7.1, 7.2 and 7.3 for year 2011, 2021 and 2031 respectively. It has the highest accuracy measurements of the CO_2 concentration atmospheric and documented and it's changing the atmosphere composition with the time series. In CO_2 emissions use the Fossil fuel because it is the CO_2 primary sources. Basically, it involves the deforestation, degradation of soils and land clearing for agriculture. It improves the soils and their activities [24]. The greenhouse gasses emission focuses on the minimizing the emissions. It increases the environmental awareness and regulations. The below diagram explains the sector wise CO_2 emissions in 2011, 2021 and 2031.

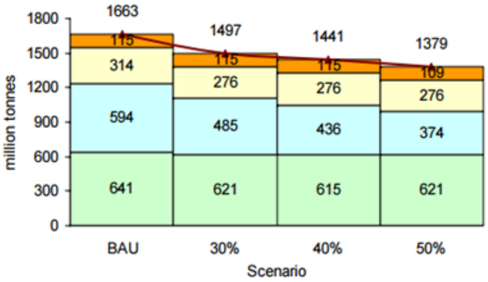

Fig. 7.1 CO_2 emission level in 2011 [20]

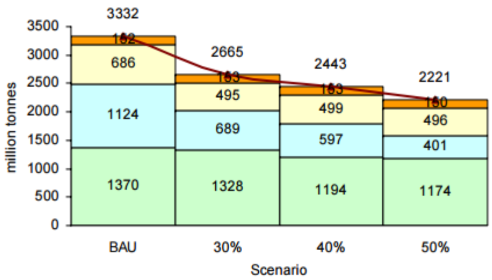

Fig. 7.2 CO_2 emission level in 2021 [20]

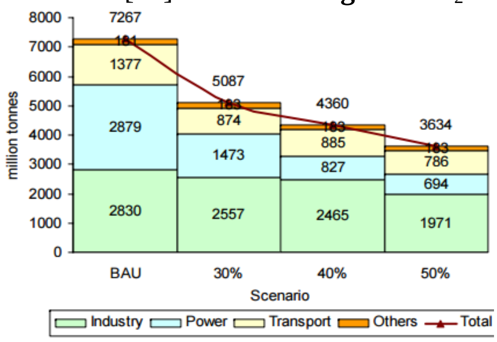

Fig. 7.3 CO_2 emission level in 2031 [20]

7.2. CO_2 mitigation using power generation technology (without CCS)

The power sector has the best opportunity for CCS implementation and it is used to increase the clean coal technology uptake from 10GW in the BAU. The power energy technologies also increase the CCS development opportunities. The power and energy division comprises of various units such as energy policy, petroleum, coal, and power. It reviews, the rising environmental and energy balance concerns and it ensures the energy security. The power energy technologies evolving the energy policy and it covers the commercial and non-commercial energy sources. It includes the natural gas, petroleum, power, and coal [25]. The fig. 7.4, 7.5, and 7.6 explains the power generating technologies in year 2011, 2021 and 2031 respectively.

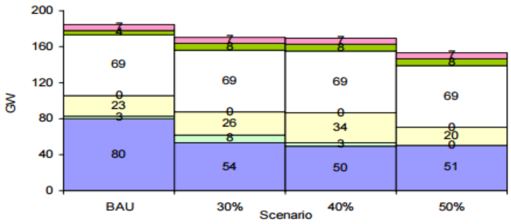

Fig.7.4 Power generation technologies in 2011[20]

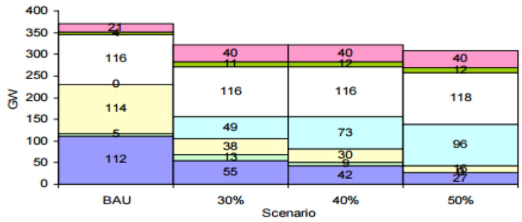

Fig.7.5 Power generation technologies in 2021[20]

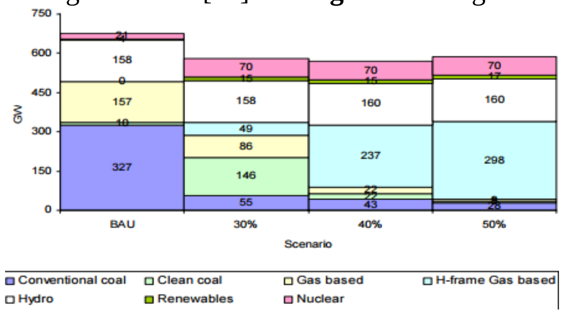

Fig. 7.6 Technologies for Power Generation in 2031 [20]

7.3. Energy related CO_2 emissions (with CCS)

The energy-related CO_2 emissions also reduces the carbon emissions. It only considers the energy-related CO_2 emissions and it analyses the CO_2 emission distribution related to the energy sector. The CCS in energy sector predict the energy consumption. It uses the baseline scenarios, blue map scenarios and the emission level is more than 40% [26] as shown in fig 7.7 the BLUE map scenario offers 14 Gt CO_2/yr if CCS is implemented other else the projected will be 62 Gt CO_2/yr.

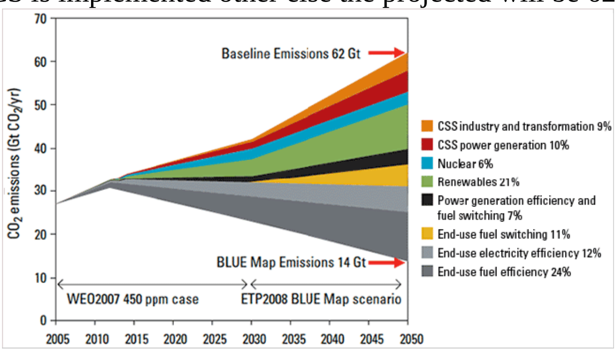

Fig.7.7 CO_2 emission based on energy level [27]

8. Conclusion

The contribution of Indian government in the accumulation of CO_2 and other GHG's from the atmosphere due to the improper fossil fuel combustion with significant amount of fuel procurement with its maintenance is appreciable. The combined infrastructure and domestic reserves are based on the energy sources like wind, solar energy and biomass are needed to be promoted at first level along with integration of CCS with coal fired plants. The clean coal technologies and CCS are the prime media which can be useful to achieve the carbon target and implement the de-carbonization manufacturing processes. The CCS has completed the CO_2 emission reduction in the power sector and it measures the energy efficiency. The CO_2 emissions are projected to reach the more than 55% of the global aggregate in India. The CCS uses the three technologies such as pre-combustion capture, post combustion capture and oxy-fuel combustion capture, among which pre-combustion and post-combustion capture are the most viable options in regards to India due to their flexibility and retrofitting capability with existing fossil fuel fired plants. The technology holds one major barrier of energy penalty which can also be reduced by integrating solar thermal power generation system with post combustion process.

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