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Carbon Capture and Storage: Technology, System Integration, and Deployment Pathways

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Abstract. This document gives a review about carbon capture and storage. Given the severe situation of global climate change, the role of CCS technology in this challenge, and the fact that emission reduction will be particularly difficult for some industrial products that are hard to reduce, such as steel and cement. Article introduces various kinds of ways to trap co2, like post combustion capture, and oxyfuel combustion technology, which is applied and superior in some different cases. In addition, the latest progress in novel materials such as solvents, adsorbents and membranes for improvement has been introduced. And then, document continues, there's some other type of storage like the geological or the minerals storage. However, the large-scale application of CCS technology still faces many difficulties. Technological problem as for how there will be high energy consumption, wear and tear and also a problem regarding the safety while storing. Economic and social problems are related to policy uncertainty, high cost, and acceptance by the public. Therefore, CCS could happen, it also has a journey with policy change as well as public knowledge.

Keywords: Carbon Capture and Storage (CCS), Climate Mitigation, Capture Technology, Geological Storage, System Integration

1. Introduction

The amount of carbon dioxide in the air has gotten to very big numbers. The main reasons for burning fossil fuels and changing the way land is used, and these are the main reasons for climate change caused by humans. This problem will greatly affect the ecosystems and weather of Earth [1]. It is really necessary that there are some ways of taking carbon from different places. These technologies must lower new emissions, deal with old emissions, and take care of unavoidable emissions. Climate changes makes people realizes the importance of carbon capturing and storages. And due to that, Carbon Capture and Storage (CCS) is now viewed as one of the many ways out. In this range are plans to cut carbon, to adjust to impacts. Carbon Capture and Storage has gone from the early amine way to a lot more [1].

Every tech have positive and negative point and mix in system with caution [2]. And the problems and progress which is the focus of the field of solving and promoting the rate of materials recycling. Create new materials such as solid adsorbents like metal-organic frameworks (MOF) to

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lower the energy used for regeneration, and it might work well. And these advances added to the tool kit, to the answers for some uses [2].

The subsurface storage has the most mature carbon sequestration technology, which is mainly saline aquifers and depleted hydrocarbon reservoirs, and the corresponding physical and chemical capture mechanism has been comprehensively mastered at this stage, which lays a solid foundation for the large-scale application of carbon sequestration [3]. Mineralisation, and other industrial processes, might also provide an additional sink for carbon. These processes convert captured carbon dioxide into stable solid carbonates, which could thus provide for permanent storage [3]. The experience of the first two projects of the two storage pathways shows that the monitoring, verification and accounting system has an extremely important function. These systems,when combined with strict regulations,are very important to ensure their long-term safety and public acceptance [3].

2. Research objectives and research significance

2.1. Research objectives and problems

2.1.1. Research objectives

This research is to do a full and combined test of the carbon capturing and storing. And the principal aim for comparison and assessment between the available capture options and geological storage. To carry out a deeper study on the integration of CCS system and industry, such as hydrogen production and heavy industry. Lastly, it makes the clear agenda of future research and policy-making efforts for solving the present-day deployment obstacles [4]. This method is on the basis of the development of the modern science. That is, in the current progress of materials science, it is used with the framework of system analysis [4].

2.1.2. Research problems

There are still some important obstacles in the field of technology and socio-economy that prevent the large-scale application of carbon capture and storage.

In terms of technology, the high-energy consumption characteristics of the current capture process have increased the operation cost of the process and lowered the efficiency of the entire system. At the same time the material properties, especially the stability and service life of solvents and sorbents under actual emission conditions, have to be markedly improved in order to ensure a stable and continuous operation. These are just some of the things that would require the development of models which are more precise for predicting underground activities,alongside with MVA system with lots of power at a low cost. Further more the combination of large-scale exclusive transportation networks and storage facilities leads to multiple issues in the field of logistics and capital-intensive areas, and only by resolving these can we achieve a reasonable scale deployment [5].

On the other hand, It's also has to deal with social and economic problems seriously. It persists with policy and regulation risk that generates investment risk and prevent long-term investment. It is also necessary to ensure that the project is accepted by the public to obtain social support and lay the foundation for the construction of related facilities. Overcome these non-technical obstacles in order to achieve commercial feasibility and acceptance [5].

2.2. Research significance

2.2.1. Theoretical significance of advancing CCS knowledge

Creating theories for carbon recycling and storage is very crucial. And they are need for the model prediction. Models have to link up material science with what is done in the world. This link makes it easier to remove the unknowns and to make it more certain what new improvements will come. Understanding these basics of carbon capture and storage is important. Learn them so that one can make exact models. Model such as these mix science of materials and on-site function to make less uncertain. They will also lead the future improvement well [6].

2.2.2. Practical significance for climate mitigation and energy transition

Carbon capture and storage can play the role of a practical solution for the difficult-to-reduce sectors and the existing fossil fuel infrastructure, to enable a more orderly process of energy transition [7]. Along with bioenergy and capture of CO2 from air, this should be possible at net negative emissions, which will be required if you really want to have very ambitious climate goals.

Theoretical and technical progress directly promotes the broad implementation of such a possibility. For example, the development of material technology can lower the cost of capture, and the more precise geological storage prediction model can improve the safety and acceptance degree of the public. Therefore, in order to realize this possibility, it will be necessary to overcome problems linked to costs, infrastructures and governance through a continuous wave of innovations and integration of basic research [7].

3. Current status of international research

3.1. Advances in post-combustion, pre-combustion and oxy-fuel capture methods

International collaborative research has helped advance all principal capture pathways. Post-combustion technology, as an important direction for the retrofitting of the existing infrastructure, has made progress in the innovation of solvent chemistry, such as advanced amine blend and water-lean solvents, and strengthened the design of process, aiming to reduce the energy penalty brought by post-combustion technology, which is as high as 60-80% of the total operating cost historically. Pre-combustion methods, which are suitable for new Plants such as IGCC, have benefited from the improvement of syngas processing technology and the application of high-temperature solid sorbent materials, which has enhanced the efficiency of the entire process.

3.2. Progress in solvent, sorbent, membrane and cryogenic technologies

Research on carbon capture media includes various materials. The next generation of solvent system like phase change and non-aqueous solvents are aiming to lower regeneration energy (down to 2. 1-2. 5 GJ/tonne CO_2) and also less degradation than the traditional amines [8]. Metal-organic frameworks (MOFs) as solid sorbents with a CO2/N2 selectivity >200 and stability after thousands of cycles were created [8]. Membrane advancements are made to break the permeability-selectivity compromise, and the mixed matrix membrane has already achieved permeability greater than 1, 500 Barrer and selectivity higher than 60. Cryogenic methods are getting better at integrating processes better, using energy down around 1. 0 GJ/tonne for very clean ones.

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3.3. Developments in geological, oceanic and mineral storage approaches

Research on geological storage, the most advanced method, focuses on advanced reservoir characterization and modeling techniques to improve the accuracy of storage capacity and the level of risk over the long term [9]. The global cumulative capacity of all suitable saline aquifers that have been identified is roughly 10, 000 gigatonnes. Alternative mineralization routes that convert carbon dioxide to stable carbonate minerals are under investigation. Although ex-situ carbonation of industrial wastes can achieve conversion rates of 60-80 percent in a short time, there are still problems such as high energy consumption in pre-processing of the feedstock and the economic scale of the process. The notion of ocean storage is yet to be determined mainly on the account of the unresolved worries over ecological damage from huge storage and intricate international governance issues [9].

4. Domestic research status

4.1. National projects and pilot demonstrations of CCS

National pilots can help test how all the pieces work together, lower the risks when we use new stuff, and find better ways to keep track of and check what we do. And they're big, most are around the 10, 000 and 100, 000 tonnes of CO_2 each yea. The ones that use the data to improve things, such as with machine learning type process controls, data helps make the CO_2 capture 5-10% better and plans for the big later use [10].

4.2. Regional site characterization and monitoring capabilities

Effective deployment requires a large number of multiple geological investigation and forming several large volume of baseline data [11]. Use a combination of tools to monitor 4D Seismic, wellbore sensors, near-surface Soil gas, atmospheric gas and other sensors to monitor in time, judge whether there are any abnormalities in a timely manner, and maintain the long-term integrity of the containment system. For the building and sustaining of faith for the regulators and general populace standardized operational workflows and open public reporting would be important [11].

4.3. Policy, regulatory and economic assessments at the national level

The whole state policy framework. This frame work should have carbon pricing mechanism,targeted fiscal incentive measure,site selection regulation,long- term liability rules and supervision norm. Techno-economic and macroeconomic analysis to provide technical and economic reference for the formulation of these policies. At the same time, it is important to actively engage the public and take steps to ensure a just transition to gain the necessary social license to operate.

5. Conclusion

Carbon capture tech is now technologically feasible for use within short term, what has been proven by studies of integration systems such as Bioenergy with Carbon Capture & Storage. Although there are shortcomings, the parasitic energy consumption and related costs are high, especially when retrofitting existing infrastructure. Sustained progress on the materials front and also the convergence of some of the processes that will give us improvement in terms of better systems, systems that lasts longer in an operation sense.

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Choosing a safe place to put it is quite important. Site's geological situation needs to study and analyze carefully. We can use what we know about how physical and chemical things work to make sure it's okay when we try to keep the carbon, such as the gas escaping or an earthquake. Safety operations based on that. Setting up a strong monitor plan is important. This plan will see whether the storage is working properly, assist in the operation of the system, and make the public continue to trust the system.

Future research will make better stuff that uses less power and stays good for a long time. Meanwhile, need to improve the system process to reduce energy waste. Cutting costs needs bigger making, using numbers for changing things, and playing with smart tests that mix labs and real-world stuff.

Expanding CCS requires a whole and integrated plan. The government help has to have continued money for research and development and ways to make new projects less risky. Markets want straight up signals about carbon prices and good systems to count saved CO2. And connect up carbon capture with ways of making use of, or recover, resources so it makes more financial sense to do so. To win public support means to be open to people who are interested and to have reliable checking systems and to have clear local benefits. Finally, whether the most important application of CCS for climate goals depends on the combination of technical advances with the law and public.

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