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Clean Coal Technology: The Solution to Global Warming by Reducing the Emission of Carbon Dioxide and Methane

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ABSTRACT

One of the primary causes of energy and global warming is coal. Acid rain, smog, and health issues are associated with the sulfur dioxide, nitrogen dioxide, heavy metals, and acid gasses that coal generates. Carbon dioxide emissions from coal are the primary source of greenhouse gases. In 2010, "The Environmental Protection Agency" discovered that almost one-third of carbon dioxide emissions were from coal-based power plants. Coal will no longer be a source of greenhouse gas emissions if energy is produced from it without burning it. Coal is still a significant source of power generation and is only growing despite its negative effects, but why? Soon, coal burning may no longer have any negative effects. Scientists have discovered numerous clean coal methods. They have found a method of producing energy that virtually eliminates pollution by not using coal. The technique, known as the Coal-Direct Chemical Looping (CDCL) approach, will virtually eradicate over 95% of the pollutants caused by burning coal. This will significantly impact the rate at which global warming occurs. Burning fossil fuels, mostly coal, releases a material known as soot, or black cotton. Due to the dark particles' ability to absorb heat from the atmosphere, it is a dangerous dark matter. On a larger scale, black carbon also accelerates glacier melting, which alters local weather patterns because of the melted freshwater. As of right now, it is the second most important human-caused element contributing to climate change. The most important man-made factor influencing Earth's climate is still CO_2, and soot emissions from diesel engines and chimneys have a big effect on the environment. Significantly lowering global soot emissions would positively affect the environment and human health. As natural gas and renewable energy take center stage, this technology is gradually being pushed to the sidelines as it leads to the reduction of inefficient coal plants. In the US and Europe, coal-fired power plants have been phased out, but they are becoming more prevalent in Asia. Advances in technology have made it possible to emit heat without burning coal. Carefully regulating the chemical process to ensure that the carbon dioxide stays entirely inside the furnace and the coal is chemically consumed without ever burning. Water and coal ash are the only waste products from iron oxide to metal, which is recyclable. We need a remedy as the world's carbon emissions are out of control. Currently, CDCL appears to be the only sensible solution to slowing down the current rate of global warming without doing away with coal, one of the primary energy sources.

INTRODUCTION

Bangladesh, a populous country experiencing rapid economic growth, faces a growing energy demand. Notwithstanding initiatives to create renewable energy sources, coal still makes up a significant amount of the energy mix with 2,099,900 tons burned annually. Traditional coal use, however, raises environmental concerns about harmful pollutants and greenhouse gas emissions. Technologies for clean coal are one workable solution to these issues (Faysal *et al.*, 2024). Bangladesh, a swiftly advancing South Asian nation, undergoes substantial economic growth yet grapples with energy security due to dwindling indigenous natural gas (51%) and limited coal (7.85%) (Ltd., 2022). National stability is threatened by the country's growing reliance on energy imports, which is made worse by Bangladesh's vulnerability to the effects of climate change. In line with the IPCC's (Intergovernmental Panel on Climate Change) 2021 report, which calls for total global decarbonization to keep warming to 1.5 °C, immediate action is crucial (Henderson & Sen, 2021). Fossil fuels account for over 80% of global energy consumption, with nuclear and renewable energy sources contributing 14% and 6%, respectively (Holechek *et al.*, 2022). "Global warming is now a debatable topic, and it has bad effects on the climate. The climate is changing rapidly due to global warming. Fuel burning in vehicles and industries generates excess heat and disturbs the thermal balance of nature. As a result, chaos has arisen in nature (Samiul Islam, 2023)."

Available in large quantities, coal is inexpensive, dependable, widely dispersed geographically, and transportable with ease and safety. Concerning coal's effects on the environment, this is the biggest problem. Climate change is a worldwide issue that calls for a coordinated international response. The majority of human-induced Green House Gas (GHG) emissions (80%) are CO_2. Due in major part to the usage of fossil

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fuels, the amount of CO_2 in the atmosphere has increased during the past century. With coal generating around 40% of global electricity, the electricity generation industry is a major contributor to greenhouse gas emissions. Instead of completely stopping the production of electricity, it makes more sense to implement environmentally beneficial solutions. Meeting society's energy needs using short-, medium-, and long-term resources can lead to a sustainable energy future. This strategy must also put a high priority on reducing negative effects on the environment while optimizing positive social and economic effects. "All wastes are particularly hazardous if not disposed of carefully, they will impact on the environment, be it unsightly litter on urban streets or polluted air, soil, or water (Samiul Islam, 2023)."

One of coal's main problems is its environmental impact. Nonetheless, efficient solutions have been created to reduce the emission of contaminants such as sulfur oxides (SOx), nitrogen oxides (NOx), and trace elements like mercury. Adopting these technologies will ensure a cleaner and more sustainable energy landscape.

LITERATURE REVIEW

Fossil fuels account for 80% of global energy use and 65% of greenhouse gas emissions. Due to its unpredictable location, the world's enormous energy reserves are crucial in times of crisis. Therefore, climate security and energy security seem to be both significant and incompatible. Laws addressing climate change aim to create an energy industry that emits zero carbon in the developed world and significantly less carbon in the developing world. The energy sector will need to shift dramatically over the next few decades to attain both energy and climate security. Using most renewable energy sources and greater energy efficiency will improve climate and energy security.

Global warming and climate change have made greenhouse gas (GHG) emissions, such as carbon dioxide (CO_2) and methane (CH_4), a serious concern.

Table 1: Coal classification & heating value

Type	Description	Usage	Carbon Content	Heating Value
Anthracite	Black and brittle with a glassy appearance; usually the oldest type; also called "hard coal"	Electric power, some space heating, industrial uses	86-97%	Nearly 15,000 Btu's per pound
Bituminous	Softer than anthracite, also the most common, used called "soft coal"; low moisture content; 100 to 300 million years old	Most commonly used for electric power, production of coke for the steel industry	45-86%	10:500-14:500 Bru's per pound
Sub-bituminous	Harder and darker than lignite; dates, at least 100 million years; lower sulfur content. than bituminous coal.	Electric power, industrial uses	35-45%	8, 300-13,000 Btu's per pound
Lignite	Soft, crumbly, and light-colored; relatively young: high moisture and ash content.	Electric power, synthetic gas and 25-35%. liquids	25-35%	4,000 - 8,300 Btu's per pound

Source: U.S. Energy Information Agency, "Coal Explained"

Electric power is virtually entirely generated from ignitable coal. The coal known as lignite is a young one. In addition to brownish-black, lignite contains a lot of moisture (up to 45%) and sulfur. The most metamorphosed coal form, anthracite, has a carbon percentage of 92.1% to 98%, although it still indicates low-grade metamorphism. Bituminous coal is an organic sedimentary rock compressed by peat bog material through diagenetic and sub-metamorphic processes. Its main components are exinite, vitrinite, and macerals. The carbon content of bituminous coal is between 60 and 80 percent.

Table 2: 2008 Electric Generation and CO_2, Emission Statistics for Coal and Natural Gas

Fuel	Coal	Natural Gas
Total Combustion CO_2 Emissions (million metric tons)	2072	1,224
Electric Generation CO_2, Emissions (million metric tons)	1958	362
Net Generation Energy (Quads, or 1015 Btu)	20.55	6.80
Fuel Carbon Content (kg- CO_2/MMBtu)	95.3	53:2
Average Heat. Rate, or Generation Fuel Efficiency	10350	7700
Total Electric Generation (billion kWh)	1986	883
Combustion-Only CO_2 Emission Intensity (kg- CO_2/kWh)	0.986	0.410

Clean coal technology is a collection of technologies being developed to mitigate the environmental impact of coal energy generation.

MATERIALS AND METHODS

It is explanatory research. Both primary and secondary data are used in the investigation. The investigation was carried out between January 15, 2024, and November 30, 2024. In this paper, both theoretical and empirical investigations were taken into consideration.

To identify solutions for carbon and methane emissions, a variety of research papers, news, worldwide reports, books, and journals are taken into consideration. The ultimate goal of this research is to demonstrate clean coal technological solutions.

Environmental Pollution Caused by Carbon Dioxide and Methane

Pollution of carbon dioxide (CO_2) and methane (CH_4), two potent greenhouse gases that hold heat in the atmosphere and produce global warming, results in rising temperatures, melting glaciers, rising sea levels, extreme weather events, and ecological damage. Methane is especially powerful because of its greater capacity to trap heat despite having a shorter lifespan than carbon dioxide. Because they absorb infrared radiation from the Earth and keep it from escaping into space, carbon dioxide and methane both contribute to the greenhouse effect by warming the planet. Although carbon dioxide is the main greenhouse gas, methane traps heat far more effectively in the short term. Thus, even small amounts of methane can have a big effect on warming. Fossil fuel combustion (coal, oil, and natural gas) for industrial processes, transportation, and energy production are major contributors to carbon dioxide emissions. The Earth's natural greenhouse effect would not be strong enough to maintain the average world surface temperature above freezing without carbon dioxide. People are intensifying the natural greenhouse effect by increasing the amount of carbon dioxide in the atmosphere, which raises the global temperature. Methane is the primary hydrocarbon included in natural gas (CH_4). Being a greenhouse gas (GHG), methane has an impact on the earth's climate and temperature when it is present in the atmosphere. We are currently experiencing almost 25% of the global warming caused by methane. For 20 years after emission, methane is 80 times more destructive than carbon dioxide (CO_2) because of the way it is structured, which retains more heat in the atmosphere per molecule.

What Are Clean Coal Technologies

A black rock with a high carbon content is coal. Coal may be burned to release energy, just like any other fossil fuel. In addition to having different concentrations of minerals, coal is thought to be an organic mineral and contains elements like nitrogen, oxygen, and hydrogen. Carbon (50–98%), hydrogen (3–13%), and oxygen make up the majority of its composition, with minor amounts of nitrogen, sulfur, and other elements. Water and other inorganic matter particles are also present. Coal releases energy as heat during combustion, which can be used for several purposes. The four types of coal are lignite, bituminous, sub-bituminous, and anthracite. The elemental analysis provides empirical formulas, such as $C_{240}H_{90}O_4NS$ for high-grade anthracite and $C_{137}H_{97}O_9NS$ for bituminous coal. A hard, thick rock with a metallic sheen and a jet-black hue is anthracite coal. There is no one "coal formula" because different coal types (such as anthracite, bituminous, and lignite) have varied ratios of carbon, hydrogen, oxygen, and other components.

Most scientists believe that one of the main causes of climate change is the use of fossil fuels, especially coal. Because coal is so widely available and inexpensive when compared to other energy sources, the world cannot suddenly stop using it without seeing a significant decline in living standards. Therefore, it is unlikely that burning coal for energy will change anytime soon. According to the International Energy Association, coal will still be the largest main energy source in 2030, producing 35% of the world's electricity.

The world's proportional reliance on coal does not imply that burning coal will continue to contribute to climate change unchecked. Around the world, a range of alternatives known as "Clean Coal Technologies" are being investigated and put into practice.

Clean Coal Technologies (CCTs) generate electricity from coal in more economically and environmentally friendly ways. They consist of procedures that can be used before, during, and following use. When it comes to creating Clean Coal Technologies, there are two fundamental strategies. The first is to create more thermally efficient systems that reduce emissions by using less coal to produce the same amount of power. One benefit of this is that it lessens the amount of flue gas cleaning that is necessary. The other is to improve and create new techniques to efficiently and economically clean the emissions (Eskom, 2022).

Technology is Key

The necessity of technological advancements in addressing climate change is becoming increasingly apparent. The usage of coal is expanding in many major economies, including the biggest and fastest-growing nations like the USA and China, which makes this especially true. There are two main strategies to lower CO_2 emissions from burning coal.

i. The greatest potential is offered by carbon capture and storage (CCS) which can reduce CO_2 emissions to the atmosphere by 80-90%.

ii. Improving efficiencies at coal-fired power stations - meaning lower emissions per unit of energy output.

Storing CO_2 in geological formations is a secure option. The Intergovernmental Panel on Climate Change (IPCC) 2005 Special Report on Carbon Dioxide Capture and Storage found that the risk of leakage from geological storage was very likely

1. To be less than 1% over 100 years
2. To be less than 1% over 1000 years.

A one percentage point improvement in the efficiency of conventional pulverized coal combustion plants results in a 2-3% reduction in CO_2 emissions.

CDCL (Coal-Direct Chemical Looping)

The chemical process of combustion uses oxygen and generates heat, but it also releases carbon dioxide, which is harmful to the environment and hard to collect. Thus, scientists managed to dissipate the heat without causing any fire. The energy is used chemically, carbon dioxide is completely trapped in the reactor, and coal is never burned to drive the chemical process.

The technology's secret is the employment of small metal beads to transport oxygen to the fuel to accelerate the chemical process. The metal beads for CDCL are composed of iron oxide composites, while the fuel is coal that has been ground into a powder around 1.5 to 2 millimeters across, the iron beads are larger than the coal particles, which are around 100 micrometers across, or roughly the diameter of a human hair. Then comes the ice cream, sprinkles, and two different quantities of talcum powder, though the mixture isn't nearly as colorful. The iron oxide and coal are heated to high temperatures, causing the ingredients to react. When the oxygen from the iron oxide and the carbon from the coal combine, carbon dioxide is produced.

This gas rises into a chamber where it is trapped. Coal ash and hot iron are left behind. The iron beads are easily removed from the coal ash and sent to a chamber where the heat energy would typically be captured for electricity since they are so much larger than the ash. The system gets cleared of the coal ash. After being separated, the carbon dioxide can be stored or recycled. Inside the reactor, the iron beads are exposed to air, which re-oxidizes them for future usage. The beads can be recycled or used again for a very long time.

Reducer

Coal + Fe_2O_3 → Fe/FeO+ CO_2 + H_2O (endothermic)

Oxidizer

Air + Fe/FeO → Fe_2O_3 + Spent Air (exothermic)

Overall

Coal + Air → CO_2 + H_2O - Spent Air (exothermic)

Conventional Emission Control Technologies

Fluidized-Bed Combustion

To reduce the production of sulfur dioxide, limestone and dolomite are added during burning.

Integrated Gasification Combined Cycle (IGCC)

To transform coal into a gas or liquid that may be further purified and used cleanly, heat and pressure are applied. Steam turbines are also powered by the heat energy generated by gas turbines. Coal's fuel efficiency rate might be increased by 50% with IGCC.

Carbon Capture and Storage (CCS)

Emissions of CO_2 are captured and stored in geologic formations or deep into the ocean, where they disintegrate under pressure. The following CCS technologies are being developed:

- Post-combustion capture from flue gas using amine solvent and chilled ammonia.
- Pre-combustion capture using IGCC to isolate and capture CO_2 before it is released.
- Oxy-coal combustion using pure oxygen in the boiler to significantly reduce the dilution of CO_2 in the exhaust gas stream.
- High-efficiency fuel cells- To operate on a range of domestic fuels with virtually emissions-free performance at unsurpassed efficiencies.
- Advanced high-efficiency combustion- For generating systems with increased 'operating temperatures, new computerized controls, improved burner designs, and higher-performance turbines.
- Hydrogen production- A clean energy carrier via gasification.

Wet Scrubbing

Globally, wet scrubbers are the most popular FGD method for controlling SO_2. To reduce SO_2 emissions globally, wet FGD (flue gas desulfurization) systems utilizing limestone and lime are the standard. A slurry mixture of sorbents based on calcium, sodium, and ammonium is injected into a specifically made vessel to react with the SO_2 in the flue gas. Lime is the second most popular sorbent when using wet scrubbers. These are preferred due to their accessibility and affordable price. A straightforward way to describe the total chemical reaction that takes place with a limestone or lime sorbent is as follows:

$SO_2 + CaCO_3 = CaSO_3 + CO_2$

In actuality, some oxidation is brought on by the air in the flue gas, and the result is a moist mixture of calcium sulfate and calcium sulfite (sludge). The following reaction results in the saleable by-product, gypsum, from a forced oxidation step that can be done in situ or ex-situ (in the scrubber or a different reaction chamber) and involves the injection of air:

$SO_2 + CaCO_3 + ½O_2 + 2H_2O = CaSO_4.2H_2O + CO_2$

In the early systems, scale development was often caused by the naturally oxidized calcium sulfate ($CaSO_4.2H_2O$ [gypsum]) from the recirculating slurry crystallizing out of control. The blocky gypsum crystals typically represented 15 to 50 mol % of the absorbed SO_2 and, when intermingled with those of deoxidized calcium sulfite ($CaSO_3.1/2H_2O$) platelets in the slurry, were responsible for much of the difficulty in dewatering. For limestone systems, blowing air into the slurry to force oxidation to near 100% provides seed crystals that minimize scaling; while at the same time producing more homogeneous slurries that dewater to concentrations over 90% solids. For these: reasons, the Limestone Forced Oxidation (LSFO) system has become the preferred: technology worldwide.

Dry Scrubbing

Typically found in small to medium-sized coal-fired power stations, spray dry scrubbers are the second most popular FGD technology. An ESP or cloth filter are examples of effective particulate control devices that are necessary for spray dry scrubbers. Based on the atomization of a sorbent, usually an aqueous lime slurry, in a reaction chamber upstream of a particulate collecting device, this technique for controlling SO_2 emissions is derived from spray drying technology. Usually, the systems are made to function at temperatures between 15 and 25 degrees Celsius (27 and 45 degrees Fahrenheit), which is close to the flue gas's adiabatic saturation. As the water evaporates, the fine droplets collect SO_2 and produce calcium sulfite and sulfate. The dry salts and fly ash in the flue gas are collected by a downstream electrostatic precipitator (ESP) or baghouse. Because more SO_2 is absorbed as the flue gas flows through the built cake on the bags, using a baghouse improves the dry scrubber's efficacy. The enhanced removal efficiency achieved through close contact is further supported by operation closer to the flue gas saturation temperature.

Limestone Injection Dry Scrubbing (LIDS)

A process in which limestone is first injected into the furnace, and the resulting excess. calcined lime (CaO) is used as the reagent for dry scrubbing.

Cool Side

This method combines the humidification of flue gases with the injection of hydrated lime [$Ca(OH)_2$] into the duct downstream of the air heater.

SOx-NOx Rox Box (SNRB)

This method involves injecting hydrated lime and ammonia upstream of a heated, catalytic baghouse (Box) where the solid products, calcium sulfite and sulfate, and particle matter (Rox) are eliminated, and the NOx is converted to nitrogen and water.

Table 3: Control Technology Emission Reduction Effect

	SO_2	**NOx**	**Hg**	**HCL**	**PM**	**Dioxins/ Furans.**
Combustion Controls	N	Y	C	N	N	Y
SNCR	N	Y	N	N	N	N
SCR	N	Y	C	N	N	C
Particulate Matter Controls	N	N	C	N	Y.	C
Low Sulfur Fuel	Y	C	N	C	N	N
Wet Scrubber	Y	N	C	Y	C	N
Dry Scrubber	Y	N	C.	Y	C	N

N.= Technology has little or no emission reduction effect.
Y = Technology reduces emissions.
C = Technology is normally used for other pollutants but has a co-benefit emission reduction effect.

Stoker Boilers

Similar features are shared by traveling grates and chain furnaces. Continuous feeding of coal lumps onto a moving chain or grate occurs. Through the coal bed on top and the grate itself, air is sucked. Internal radiation from the refractory arch heats the coal as it enters. It drives out moisture and volatile substances. The coal is gradually moved into the area where ignition is established by the chain or grate, and the coal bed's temperature increases. Ash is left behind when the carbon slowly burns off, falling into a container at the end and being taken out for disposal. There could be as much as 4–5% carbon in the resulting ash.

Pressurized Midsized Bed Combustion (PFBC)

Boilers with variable coal content and/or high ash coals may benefit greatly from FBC. Features PFBC has also been utilized commercially, although, with PIBC, the hot gas cyclones and combustor are completely contained within a pressure vessel. The pressure boundary must be crossed by both coal and sorbent, and a comparable mechanism for ash removal is required. When using hard coal, the coal and limestone can be crushed together and then mixed with 25% water to form a paste.

The combustion temperature between 800-900°C has the advantage of producing less NOx than PCC but more N_2O, just like atmospheric MBC (CFB or BFBC). When a sorbent is injected and then removed with ash, SO_2 emissions can be decreased. The goal of PFBC units is to have an efficiency value greater than 40%. When it burns at temperatures between 800 and 900 degrees Celsius, less NOx is produced than when PCC is used.

Low NOx Burners

The purpose of low NOx burners is to produce larger, more branched flames by regulating the mixture of fuel and air at each burner. This lowers the peak flame temperature and reduces the production of NOx.

Efficiency Improvements

Certain steps are necessary to increase plant efficiency and lower carbon dioxide (CO_2) and other emissions. Certain efficiency technologies, like Ultra Supercritical Pulverized Coal (USPC) and IGCC, need more research, development, and demonstration before they can be sold commercially. By 2027, new units could cut CO_2 emissions by up to 35%. An existing plant's efficiency can cut CO_2 emissions by 10–16%.

Carbon or soot cotton is an undesirable byproduct of burning carbon-based materials to produce heat, and energy, or to dispose of garbage. Particulate properties and the proportion and kind of carbon in soot can differ significantly depending on its nature. Ash and solvent-extractable organic compounds make up far larger percentages of soot than carbon, which makes up less than 60% of the total soot particulate mass.

RESULT AND DISCUSSION

The result and discussion of this study is that we should pursue the clean coal technologies discussed in this paper above. Various methods are discussed in this paper to reduce carbon dioxide and methane emissions. Coal has long been referred to as the "black diamond." For a very long time, coal has been one of the most abused energies. This is because coal energy has so many advantages. The quality and consistency of coal's output are much higher than those of other energy sources. Coal has historically been a cornerstone of global energy due to its affordability, availability, and reliability. However, its extensive use has resulted in serious environmental concerns, particularly from greenhouse gas emissions. Clean coal technologies (CCTs) provide a pathway to address these issues, enabling the continued use of coal while mitigating its environmental impact.

CONCLUSION

The clean coal technology suggested in this research can address the severe environmental pollution caused by carbon dioxide and methane, which also cause global warming. One important step in lowering emissions associated with coal is the combination of technologies for the collection, storage, and use of chemicals. By capturing CO_2 during or after combustion, these techniques stop it from escaping into the atmosphere. After being captured, the CO_2 can be used in chemical reactions or safely stored in geological formations, turning a significant pollutant into a useful resource. By utilizing these cutting-edge technologies, clean coal provides a viable way to strike a compromise between the need to reduce the ecological impact of coal and its economic advantages, bringing coal-based energy production into line with contemporary environmental objectives. This research seeks to develop clean coal technologies soon with the use of carbon dioxide and methane collection, storage, or chemical utilization technologies.

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