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AN EXAMINATION OF COAL AS AN ENERGY SOURCE

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ABSTRACT

Coal is the most abundant fossil fuel found on the planet. It is still the most used energy source for generating electricity. In most developed countries, it is firmly established, and it is fast expanding in underdeveloped countries. Coal reserves around the world are enormous, with hundreds of years yet to be mined. This paper presents coal formation, classification, mining, processing, storage, transportation, conversion to other forms of energy, efficiency, pollution problems, and remedies.

Keywords: coal energy, power generation, carbon content, combustion

1. INTRODUCTION

Coal is a combustible black or brownish-black sedimentary rock with a high amount of carbon and hydrocarbons [1]. Coal is a fossil fuel. It is formed from the remains of ancient life forms that were buried deep in the earth millions of years ago. The main use for coal is to produce energy but it can also be used to manufacture steel and is an important source of some of the chemicals used in pharmaceuticals, pesticides, fertilizers, etc. Coal has a relatively high energy density of approximately 24 MJ/kg. Energy density is the amount of energy per mass. Its SI units are J/kg but MJ/kg is more common [2].

1.1 **Coal Formation**

Coal is a fossil fuel and as a fossil fuel, it is formed from the decomposition of organic matter. The process that creates coal varies slightly in different areas depending on the plants and conditions that are present, but the overall process is similar. There are two main phases in coal formation: peatification and coalification [3]

a. Peatification:

When Plant matter in swamps and wetlands, such as ferns, shrubs, vines, trees, and algae dies and accumulates on the surface. Initially, the organic matter is decomposed by bacteria, yielding carbon dioxide and methane. The plant matter becomes buried and is no longer exposed to air. Anaerobic bacteria then start to decompose the material. Burial and accumulation occur for several thousands of years, producing several meters of partially decayed plant matter known as peat.

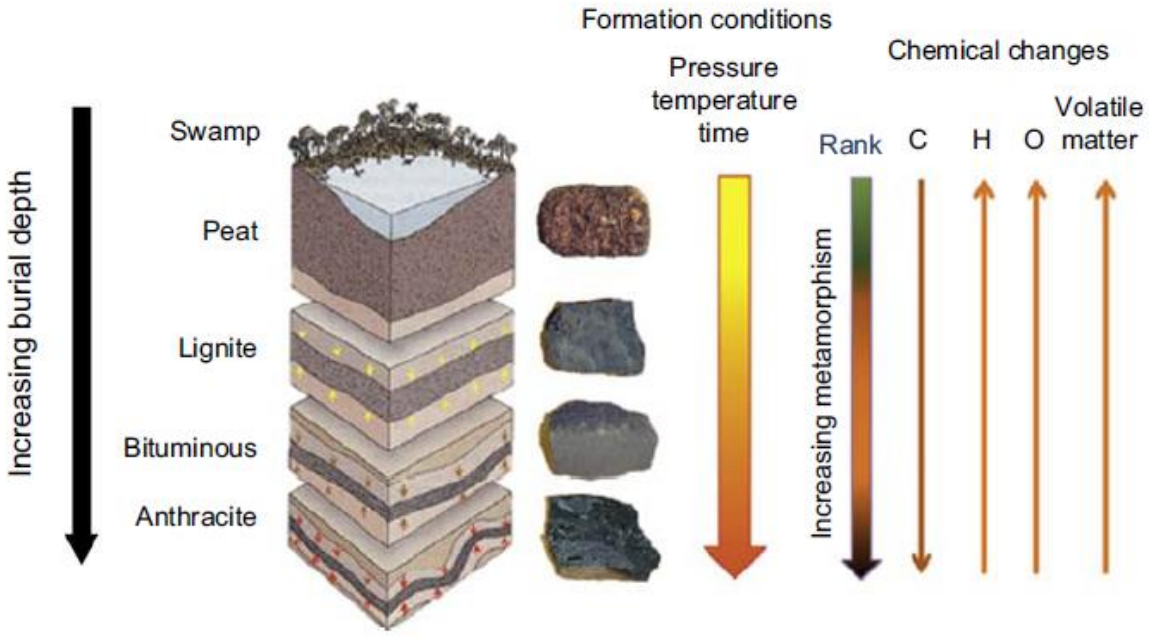

Figure 1: Scheme of the formation of coal in terms of rank [4].

b. Coalification:

When this peat is deeply buried, water and other compounds are squeezed out from the increasing pressure and the lowest quality of coal, lignite, begins to form. Continued burial, resulting in

increasing pressures and temperatures, causes this low-quality lignite coal to be transformed into higher-quality "black coals". The first lignite becomes sub-bituminous coal, then bituminous coal, and finally the highest quality anthracite coal. As these transformations occur, the amount of water and other compounds in the coal decreases, and the coal becomes denser. Along with this comes a higher carbon concentration [5].

1.2 Classification of Coal

Coal can be classified based on its usage or their carbon content

a) Based on their usage:

i. Thermal Coal
ii. Metallurgical Coal

i. Thermal coal

Thermal coal or steaming coal is burned for steam to run turbines to generate electricity either for public electricity grids or directly by industry consuming electrical power. During power generation, the coal is ground to a powder and fired into a boiler to produce steam to drive turbines to produce electricity. Thermal coal is more abundant, has lower carbon content, and is higher in moisture content than metallurgical coal.

ii. Metallurgical Coal

Metallurgical coal or coking coal is mostly used in the process of creating coke necessary for iron and steel-making, graphite production, etc. Coke is a porous, hard black rock of concentrated carbon that is created by heating bituminous coal without air to extremely high temperatures [6]

b) Based on Carbon content:

Based on carbon content, coal can be classified as Anthracite, Bituminous, Sub Bituminous, Lignite, and peat. Although peat is not coal, but rather the precursor to coal. The types and properties are as follows:

The following is an overview of the different grades of coal, ordered from the lowest to the highest quality.

Table 1: Types of Coal (Source: Modified from [7]).

S/N	Coal	Dry, Carbon content (%)	Moisture content before drying (%)	Dry, volatile content (%)	Heat Content (MJ/kg)	Use

1	Anthracite	86-92	7-10	3-14	32-33	Since so much energy is released when burned, this fuel is exceptional at heating up quickly and burning very hot. Anthracite is used for space heating as it is one of the cleanest types of coal to burn—producing less smoke than other types. Its clean-burning properties allow anthracite to burn longer than wood, making it appealing to use in home heating stoves.
2	Bituminous coal	76-86	8-18	14-46	23-33	The high carbon and low moisture content of this particular type of coal make it ideal for the production of steel and cement, as well as in electricity generation and coke production.
3	Sub-Bituminous coal	70-76	18-38	42-53	18-23	Coal is not only an ingredient in cement but is also used in large quantities to fire the kilns which bake the material used in many of the world's buildings. It is also needed to make carbon fibre which is used for strong, lightweight products from bicycles to tennis rackets.
4	Lignite	65-70	35-55	53-63	17-18	Lignite's high moisture content and lower carbon content result in more carbon dioxide emissions than harder black coals.
5	Peat	<60	75	63-69	15	Left to itself, it burns like wood, gives less heat, emits more smoke and leaves a lot of ash. Producer gas is manufactured from peat. It is also known as brown coal.

1.3 Mining, Processing, Storage and Transportation of Coal

1.3.1 Coal Mining

Coal mining is the process of extracting coal from the ground with the help of machines. U.S Energy Information Administration (EIA) [1], opines that depending on the distance of the coal from the earth's surface coal miners use two primary methods to remove coal from the earth's crust: Surface mining and Underground mining.

a) **Surface mining** is often used when coal is less than 200 feet underground. In surface mining, large machines remove the topsoil and layers of rock known as overburden to expose the coal. Mountaintop removal is a form of surface mining where the tops of mountains are dynamited and removed to access coal seams. Once the coal is removed, the disturbed area may be covered with topsoil for planting grass and trees. Surface mining is less expensive than underground mining.

b) **Underground mining**, sometimes called deep mining, is necessary when the coal is several hundred feet below the surface. Some underground mines are thousands of feet deep with tunnels that may extend out from the vertical mine shafts for miles. Miners ride elevators down deep mine shafts and travel on small trains in long tunnels to get to the coal. The miners use large machines to dig out the coal.

1.3.2 Coal Processing

Coal processing involves crushing, screening and beneficiation. Processing is where coal is converted from run-of-mine (ROM) coal to a product that meets the customer’s requirements. Mined coal comes in lumps. Coal crushing is dependent on deposit size. Screening is used to separate different sizes of crushed coal. In this process, coarse and fine coal is separated to accommodate specific markets and industrial usage. During beneficiation, coal is processed to remove impurities, reducing ash and sulphur, thereby improving the market value of the coal. Most cleaning processes involve washing coal to separate coal particles from stone particles. Coal can be charred, a process wherein hydrogen and oxygen are removed from coal to make it a purer form of carbon [8]

1.3.3 Transporting coal

Coal can be transported from mines and processing plants to consumers in several different ways:

- Conveyors, trams, and trucks move coal around mines, short distances from mines to consumers close to the mines, or other modes of long-distance transportation.
- Trains transport nearly 70% of coal deliveries for at least part of the way from mines to consumers.
- Ships transport coal on the Great Lakes and the oceans to consumers. Slurry pipelines move mixtures of crushed coal and water.

Transporting coal can be more expensive than the cost of mining coal. Some coal consumers, such as coal-fired electric power plants, are near coal mines to lower transportation costs [9]

1.3.4 Coal Storage

Coal can be stored in a coal scuttle or bucket, a storage chest/basket, a basement/cellar, Plastic tubs etc. The main aim of good coal storage is to minimize spontaneous combustion and carpet loss. Spontaneous combustion in coal heaps can be caused by the gradual increase in temperature resulting from oxidation. Carpet loss is mainly due to the loss of surface coal due to wind. It can be controlled by planting trees surrounding the coal yard, storing coal under a shed and watering the surface of the coal heap [10]. Measures that can help to reduce losses are as follows:

• Preparing a hard ground for coal to be stacked.

• Preparing standard storage bays in concrete and brick

2. CONVERSION TO OTHER FORMS OF ELECTRICAL ENERGY

Coal is used to generate electricity by burning coal to heat water in a boiler, creating steam. Steam released from the boiler powers an engine called a turbine, transforming heat energy from burning coal into mechanical energy that spins the turbine engine, which in turn rotates a generator that generates electricity. Thus chemical energy stored in coal is converted successively into thermal energy, mechanical energy and, finally, electrical energy. This is the basic principle behind coal-powered plants.

2.1 Major Coal-Based Power Generation Technologies

Burnard and Bhattacharya (2011) opine that the major coal-based power generation technologies available today, and/or under development, include:

a. Pulverized coal-fired (PC) combustion
b. Fluidised bed combustion (FBC)
c. Integrated gasification combined cycle (IGCC)

a. Pulverized Coal (PC) – In a PC boiler, crushed coal is pulverized to a fine powder and blown directly to individual burners where it is mixed with pre-heated combustion air and combusted in a flame. The heat energy from the combustion process is used to produce steam which drives a turbine-generator set to produce electricity. PC is more commonly used.

b. Fluidized Bed (FB) – In fluidized-bed combustion, a bed of crushed solid particles (usually six millimetres or less) is made to behave like a fluid by an airstream passing from the bottom of the bed at sufficient velocity to suspend the material in it. The bed material—usually a mixture of coal and sand, ash, or limestone—possesses many of the properties of, and behaves like, a fluid. The crushed coal is introduced into the bubbling bed, which is usually preheated. Since the bed is continuously bubbling and mixing like a boiling liquid, the transfer of heat to and

from the bed is very efficient and, hence, uniform temperatures can be achieved throughout the bed.

c. Integrated Gasification Combined Cycle (IGCC) – In the IGCC process, coal is transformed into a synthetic gas under pressure and temperature. The syngas is processed to remove impurities such as sulfur and particulates. The cleaned syngas is fired in a combustion turbine (gas turbine) that drives a generator to produce electricity. The hot exhaust from the turbine is passed through a heat recovery steam generator (HRSG) to produce steam used to drive a second turbine generator set.

2.1.2 Pulverized coal-fired (PC) combustion

The type widely used is Pulverized coal. Pulverized coal power plants are broken down into three categories;

a. Subcritical pulverized coal (SubCPC) plants,
b. Supercritical pulverized coal (SCPC) plants, and
c. Ultra-supercritical pulverized coal (USCPC) plants.

The primary difference between the three types of pulverized coal boilers is the operating temperatures and pressures. Subcritical plants operate below the critical point of water (647.096 K and 22.064 MPa). Supercritical and ultra-supercritical plants operate above the critical point. As the pressures and temperatures increase, so does the operating efficiency. Subcritical plants are at about 37%, supercritical at about 40%, and ultra-supercritical at 42-45%.

2.2. Stages Involved in Transforming Coal Energy to Electricity

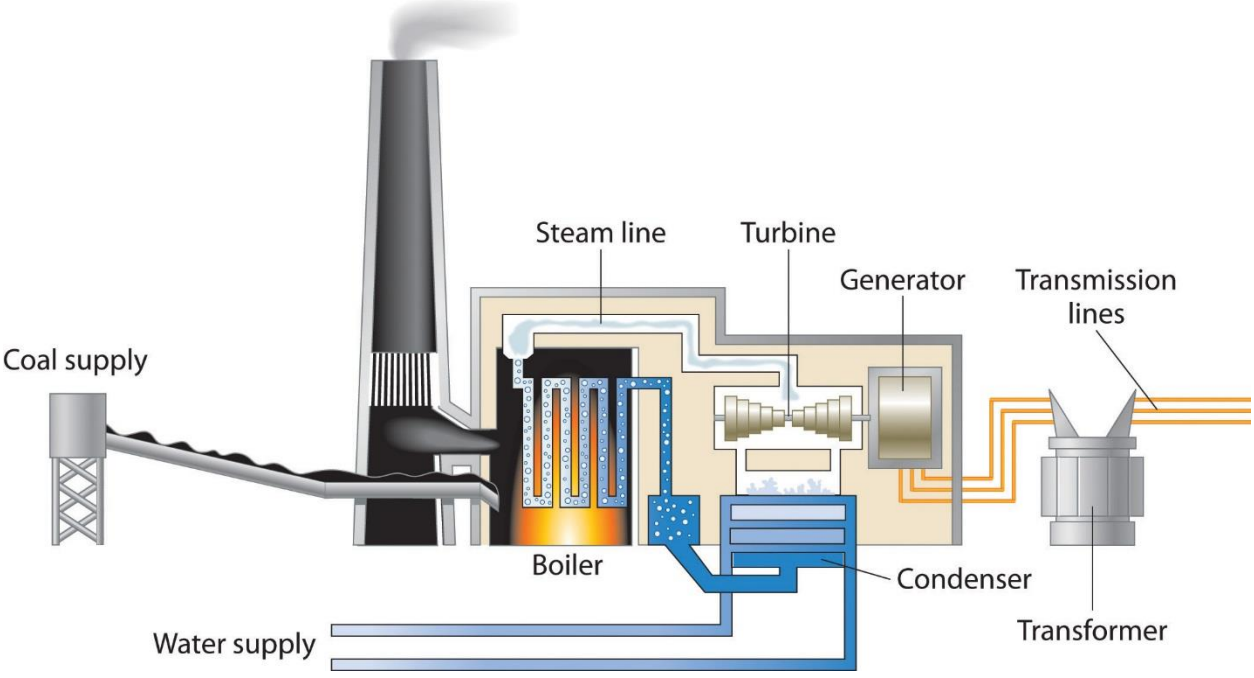

Figure 2: Schematic Of A Coal Power Plant [11]

STAGE 1

- Pulverized coal is burnt to produce steam.
- Water from the feed pump, after pre-heating, enters the boiler. This water may be obtained from a nearby river or lake. The condensed water from the cooling tower is re-used.
- The heated or vaporized fluid exits the boiler for use in various processes and heating applications**.**

STAGE 2

- The steam produced in the boiler goes to the steam drum and is then piped to superheaters where it is heated above the saturation temperature.
- At this point, steam is now turned into a very powerful source of energy.
- This rotates the turbine.

STAGE 3

- Flue gases coming out of the boiler carry a lot of heat. An economizer extracts a part of this heat from flue gases and uses it for heating feed water.
- This use of economizer results in saving coal consumption and higher boiler efficiency.

STAGE 4

- The turbine generator consists of a series of steam turbines interconnected to each other and a generator on a common shaft.
- There is high pressure at one end, followed by an intermediate-pressure turbine. A low-pressure turbine, and a generator.
- As steam moves through the system, it losses pressure and thermal energy and expands in volume, requiring increasing diameter and longer blades at each succeeding to extract the remaining energy.

STAGE 5

- Steam after rotating the steam turbine comes to the condenser.
- The purpose of a condenser is to condense the outlet stream from the steam turbine to get the condensed steam in the form of pure water.
- This water is then pumped back into the boiler.

STAGE 6

- A steam-generating boiler requires that the boiler feed water should be devoid of air and other dissolved gases, particularly corrosive ones.
- To avoid corrosion of the metal power station uses a deaerator, for the removal of air and other dissolved gases from the boiler feedwater.
- A deaerator has a vertical. Domed deaeration section mounted on top of a horizontal cylindrical vessel which serves as a deaerated boiler feedwater storage tank.

STAGE 7

- The enormous pressure of the steam pushing against a series of giant turbine blades turns the turbine shaft. The turbine shaft is connected to the shaft of the generator, where magnets spin within wire coils to produce electricity.
- Electricity is sent through power grid lines and then travelled to substations located in towns.

2.1.5 Ash removal

There are two methods of ash removal at the furnace bottom: Bottom Ash and Fly Ash

Bottom ash: The slag that accumulates inside the boiler and then falls to the bottom due to gravity is known as bottom ash. It's too big to be transported out by air (usually between one and ten millimetres in diameter). It is unsuitable for several sorts of re-use due to its huge particle size.

Fly ash: Coal ash is discharged from a power plant's boiler and collected in a variety of ways, with so-called fly ash, or pulverised fuel ash (PFA), collected by electrostatic or mechanical precipitators that operate as filters. The average diameter of fly ash particles is 40 microns, however, they can range from one to 150 microns [12].

3. DISCUSSIONS

3.1. EFFICIENCY

Efficiency is generally the ratio of output to input. Getting the efficiency of coal power plants is quite complex cause the combustion efficiency, boiler efficiency, turbine efficiency, Condenser efficiency electrical etc, is considered separately and it's beyond the scope of this work. Below is a graphical representation of the efficiency of a typical coal-powered plant.

Generally Efficiency = $\frac{output}{input}$ (1)

Where Output = output of system/device under consideration

Input = input of system/device under consideration

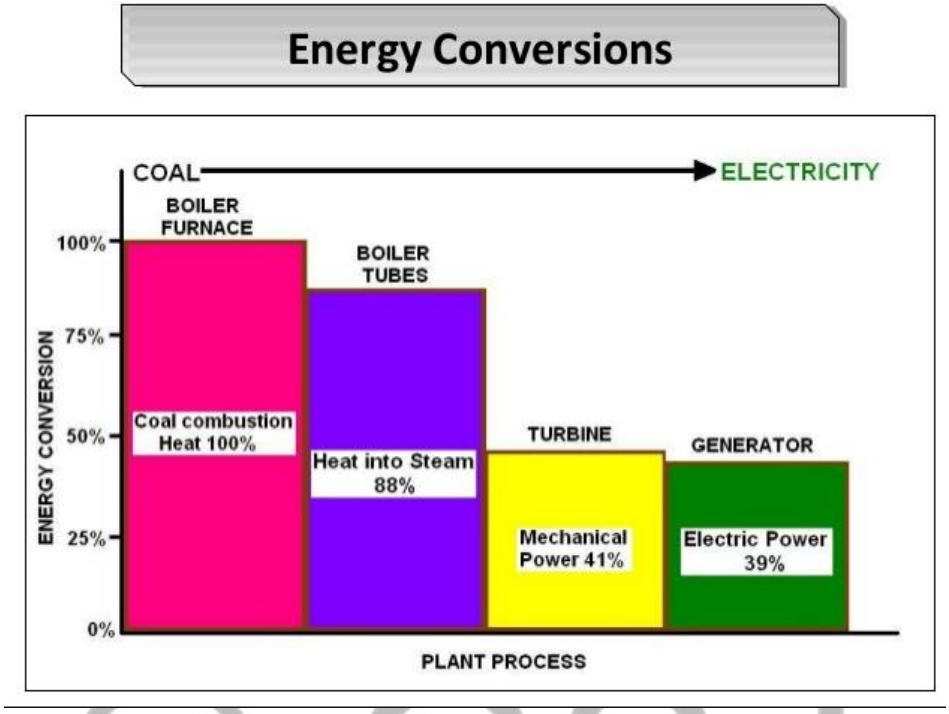

Figure 3: Coal power plant efficiency chart.

3.2. Pollution Problem and Remedies

Air pollution is often due to burning low-quality coal, such as lignite, and lack of modern flue gas treatment. However, they may be higher around power plants where scrubbers are not used or lower if they are far from cities.

Remedy: Use of scrubbers and modern gas flue gas treatment equipment, use of high-quality coal and well-processed coal

Water pollution. Pollutants such as heavy metals leaching into groundwater from unlined coal ash storage ponds or landfills pollute water. Pollutant discharges from ash ponds to rivers (or other surface water bodies) typically include arsenic, lead, mercury, selenium, chromium, and cadmium.

Remedy: Proper treatment of water before disposal into water bodies, use of advanced cooling systems etc.

3.3. COAL ENERGY PROS AND CONS

Advantages: Some advantages are as follows:

- Easily combustible, and burns at low temperatures, making coal-fired boilers cheaper and simpler than many others.
- Widely and easily distributed all over the world.
- Comparatively inexpensive to buy on the open market due to large reserves and easy accessibility.
- Good availability for much of the world (i.e. coal is found in many more places than other fossil fuels).
- Most coal is rather simple to mine, making it by far the least expensive fossil fuel to obtain.
- Coal-powered generation scales well, making it economically possible to build a wide variety of sizes of generation plants.
- A fossil-fuelled power station can be built almost anywhere, so long as you can get large quantities of fuel to it. Most coal-fired power stations have dedicated rail links to supply the coal.
- Very large amounts of electricity can be generated in one place using coal, fairly cheaply**.**

Disadvantages: Some disadvantages of coal are:

- It is Non-renewable and fast depleting.
- Coal has the lowest energy density of any fossil fuel - that is, it produces the least energy per ton of fuel.
- It also has the lowest energy density per unit volume, meaning that the amount of energy generated per cubic meter is lower than any other fossil fuel.
- High coal transportation costs due to the bulk of coal (as a result of the preceding two low energy density problems), especially for countries with no coal resources and hence will require special harbours for coal import and storage.
- Coal dust is an extreme explosion hazard, so transportation and storage must take special precautions to mitigate this danger.
- Coal storage cost is high especially if required to have enough stock for a few years to assure power production availability.

4. CONCLUSION & RECOMMENDATIONS

Coal remains a very relevant fossil fuel, as it is the most abundant and widely spread fossil energy resource on earth. Coal-fired power stations currently account for 38% of the power produced in the world [13]. The cost of electricity is greatly influenced by the cost of fuel, coal's relatively low cost has made it an attractive country energy source for low-income countries and developing economies. Thus, low-cost fuel can be used to produce low-cost electricity, which acts as a stimulus to the economy, providing more disposable income to consumers and creating a competitive edge for manufacturers supplying globally. Coal supply stability is aided by the capacity to transport coal by ship, barge, rail, and truck without the use of pipeline infrastructure. Coal also has the distinct advantage of being able to be kept on-site, ensuring a fuel supply for weeks or even months at the power station. This critical feature adds to grid stability, resiliency,

and fuel supply bottleneck reduction. Coal generation, unlike intermittent energy sources like wind and solar, can offer constant baseload electricity. Hydropower, wind power, and solar power all rely heavily on meteorological conditions beyond man's control.

Though, most coal power plants emit large quantities of greenhouse gases when compared to other sources. This is mainly because most of the plants still use old technology. The main options for the next generation are pulverised coal power plant and the Integrated gasification combined cycle (IGCC) power plant. This is because the greenhouse gas emissions from these plants are minimal. Most of the shortfalls of the older coal power station were properly optimised in the design. Therefore, the focus is on these two options and the extent to which they can contribute to climate policies.

REFERENCE

[1] U.S. Energy Information Administration (EIA) (October 11, 2019). Coal Explained. Retrieved from https://www.eia.gov/energyexplained/coal/

[2] Fisher, J. (2003, para. 1). The Physics Factbook: Energy Density of Coal. Retrieved from https://hypertextbook.com/facts/2003/JuliyaFisher.shtml

[3] Affolter, R.H., Hatch. J.R. (2015). *Geologic Overview* [Online]. U.S. Geological Survey Professional Paper Retrieved from: http://pubs.usgs.gov/pp/p1625d/Chapter_C.pdf

[4] Suárez-Ruiz, I., Diez, M. A., & Rubiera, F. (2019). *Coal. New Trends in Coal Conversion, 1–30.* doi:10.1016/b978-0-08-102201-6.00001-7

[5] Donev Jason, Edwin Cey, Jordan Hanania, Chau Le, Rudi Meyer, Ashley Sheardown, Kailyn Stenhouse (2019). Energy Education - Coal formation [Online]. Available: https://energyeducation.ca/encyclopedia/Coal_formation. [Accessed: May 2, 2022].

[6] Baker, P. (2013) The Global News: The Coal Facts: thermal coal vs. metallurgical coal. Retrieved from https://globalnews.ca/news/627069/the-coal-facts-thermal-coal-vs-metallurgical-coal/

[7] Donev Jason, Bethel Afework, Jordan Hanania, Kailyn Stenhouse (2018). Energy Education - Peat [Online]. Available: https://energyeducation.ca/encyclopedia/Peat. [Accessed: May 2, 2022].

[8] RPM Solutions (2020). ENVIRONMENTAL & ECONOMIC IMPACT: Coal Processing. Retrieved from http://www.rpmsolve.com/coal-processing

[9] Energy Information Administration (EIA), (2019). Coal explained: Mining and transportation of coal Retrieved from

https://www.eia.gov/energyexplained/coal/mining-and-transportation.php

[10] Lynn Cielec (2017). Keys to Proper Coal Storage.Midwest. Retrieved from: https://blog.midwestind.com/proper-coal-storage/

[11] Schalk Cloete (2017). What are the risks related to coal power plant investment?. Energy Central as retrieved from: https://energycentral.com/c/ec/what-are-risks-related-coal-power-plant-investment.

[12] Power Engineering International, 2015). Best practices for managing power plant coal ash. Retrieved from: https://www.powerengineeringint.com/coal-fired/managing-coal-ash/#:~:text=Coal%20ash%20is%20discharged%20from,which%20act%20as%20a%20filter.

[13] World Coal Association (2020). COAL & ELECTRICITY. Retrieved from: https://www.worldcoal.org/coal-facts/coal-electricity/