UNIVERSITY OF EAST SARAJEVO

FACULTY OF MECHANICAL ENGINEERING

6th INTERNATIONAL SCIENTIFIC CONFERENCE

COMETa 2022

„Conference on Mechanical Engineering Technologies and Applications“

PROCEEDINGS

17th-19th November

East Sarajevo, RS, B&H

COMETa 2022

6th INTERNATIONAL SCIENTIFIC CONFERENCE

17th - 19th December 2022
Jahorina, B&H, Republic of Srpska

University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

---

Z B O R N I K   R A D O V A

P R O C E E D I N G S

Istočno Sarajevo, BiH, RS
17 - 19. novembar 2022.

East Sarajevo, B&H, RS
17th – 19th November, 2022

ZBORNIK RADOVA SA 6. MEĐUNARODNE NAUČNE KONFERENCIJE
"Primijenjene tehnologije u mašinskom inženjerstvu"
COMETa2022, Istočno Sarajevo, 2022.

PROCEEDINGS OF THE 6th INTERNATIONAL SCIENTIFIC CONFERENCE
"Conference on Mechanical Engineering Technologies and Applications"
COMETa2022, East Sarajevo, 2022

Organizator:	Univerzitet u Istočnom Sarajevu Mašinski fakultet Istočno Sarajevo
Organization:	University of East Sarajevo Faculty of Mechanical Engineering East Sarajevo
Izdavač:	Univerzitet u Istočnom Sarajevu Mašinski fakultet Istočno Sarajevo
Publisher:	University of East Sarajevo Faculty of Mechanical Engineering East Sarajevo
Za izdavača: *For publisher:*	PhD Milija Kraišnik, associate professor
Urednici: *Editors:*	PhD Dušan Golubović, full professor PhD Miroslav Milutinović, associate professor PhD Saša Prodanović, associate professor
Tehnička obrada i dizajn: *Technical treatment and desing:*	PhD Aleksije Đurić, senior assistant MSc Jovana Blagojević, senior assistant MSc Milica Bošković, senior assistant Krsto Batinić, assistant
Izdanje: *Printing:*	Prvo 1st
Register: *Register:*	ISBN 978-99976-947-6-8 COBISS.RS-ID 137162497

REVIEWERS

PhD Dušan Golubović, FME UES (B&H)
PhD Dušan Gordić, FE Kragujevac (Serbia)
PhD Ljubiša Dubonjić, FMCE Kraljevo (Serbia)
PhD Mirko Blagojević, FE Kragujevac (Serbia)
PhD Miroslav Stanojević, FME Belgrade (Serbia)
PhD Adisa Vučina, FMEC Mostar (B&H)
PhD Aleksandar Jovović , FME Belgrade (Serbia)
PhD Aleksandar Košarac , FME UES (B&H)
PhD Aleksandar Živković, FTS Novi Sad (Serbia)
PhD Biljana Marković, FME UES (B&H)
PhD Bogdan Marić, FME UES (B&H)
PhD Branimir Krstić , University of Difence, Military Academy (Serbia)
PhD Damjan Klobčar , FME Ljubljana (Slovenia)
PhD Darko Bajić , FME Podgorica (MNE)
PhD Dejan Jeremić , FME UES (B&H)
PhD Dragan Milčić, FME Nis (Serbia)
PhD Dragan Pršić, FMCE Kraljevo (Serbia)
PhD Goran Orašanin, FME UES (B&H)
PhD Jasmina Pekez, TF “Mihajlo Pupin” Zrenjanin (Serbia)
PhD Jelena Jovanović, FME Podgorica (MNE)
PhD Lozica Ivanović, FE Kragujevac (Serbia)
PhD Milan Banić , FME Niš (Serbia)
PhD Milan Rackov, FTS Novi Sad (Serbia)
PhD Milan Tica, FME Banja Luka (B&H)
PhD Milan Zeljković, FTS Novi Sad (Serbia)
PhD Milija Kraišnik , FME UES (B&H)
PhD Milomir Šoja, FEE UES (B&H)
PhD Miloš Milovančević, FME Nis (Serbia)
PhD Miodrag Žigić, FTS Novi Sad (Serbia)
PhD Mirko Dobrnjac , FME Banja Luka (B&H)
PhD Miroslav Milutinović, FME UES (B&H)
PhD Mladen Josijević, FE Kragujevac (Serbia)
PhD Mladen Tomić, FTS Novi Sad (Serbia)
PhD Mladomir Milutinović, FTS Novi Sad (Serbia)
PhD Nebojša Radić, FME UES (B&H)
PhD Nenad Grahovac , FTS Novi Sad (Serbia)
PhD Nikola Tanasić, FME Belgrade (Serbia)
PhD Nikola Vučetić, FME UES (B&H)
PhD Ranka Gojković , FME UES (B&H)
PhD Ranko Antunović , FME UES (B&H)
PhD Saša Prodanović, FME UES (B&H)
PhD Saša Živanović, FME Belgrade (Serbia)
PhD Silva Lozančić , Faculty of Civil Engineering Osijek (Croatia)
PhD Slaviša Moljević, FME UES (B&H)
PhD Slobodan Lubura, FEE UES (B&H)
PhD Slobodan Tabaković, FTS Novi Sad (Serbia)
PhD Snežana Nestić, FE Kragujevac (Serbia)
PhD Spasoje Trifković, FME UES (B&H)
PhD Srđan Vasković, FME UES (B&H)
PhD Stojan Simić, FME UES (B&H)
PhD Uroš Karadžić , FME Podgorica (MNE)

PhD Vladimir Milovanović, FE Kragujevac (Serbia)
PhD Vladimir Stojanović, FMCE Kraljevo (Serbia)
PhD Vlado Medaković, FME UES (B&H)
PhD Zdravko Pandur, FFWT UZ (Croatia)

INTERNATIONAL SCIENTIFIC COMMITTEE

PhD Dušan Golubović, FME UES (B&H) – president
PhD Adisa Vučina, FMEC Mostar (B&H)
PhD Aleksandar Aleksić, FE Kragujevac (Serbia)
PhD Aleksandar Jovović, FME Belgrade (Serbia)
PhD Aleksandar Košarac, FME UES (B&H)
PhD Balasaheb M. Patre, SGGS IET (India)
PhD Biljana Marković, FME UES (B&H)
PhD Bogdan Marić, FME UES (B&H)
PhD Borut Kosec, NTF Ljubljana, (Slovenia)
PhD Božidar Rosić, FME Belgrade (Serbia)
PhD Branimir Krstić, Military academy, University of Defence in Belgrade (Serbia)
PhD Branko Vučijak, FME Sarajevo (B&H)
PhD Bratislav Blagojević, FME Niš (Serbia)
PhD Damjan Klobčar, FME Ljubljana (Slovenia)
PhD Danijela Tadić, FE Kragujevac (Serbia)
PhD Darko Knežević, FME Banja Luka (B&H)
PhD Dejan Jeremić, FME UES (B&H)
PhD Dragan Milčić, FME Niš (Serbia)
PhD Dragan Spasić, FTS Novi Sad (Serbia)
PhD George Nenes, UOWM (Greece)
PhD Goran Janevski, FME Niš (Serbia)
PhD Goran Orašanin, FME UES (B&H)
PhD Goran Putnik, University of Minho, (Portugal)
PhD Goran Šimunović, MEFSB (Croatia)
PhD Indiran Thirunavukkarasu, Manipal Institute of Technology, Indija
PhD Isak Karabegović, FTS Bihać (B&H)
PhD Ivan Samardžić, MEFSB (Croatia)
PhD Izet Bjelonja, FME Sarajevo (B&H)
PhD Jozsef Nyers, The Obuda University Budapest (Hungary)
PhD Kyros Yakinthos, AUTH, (Greece)
PhD Lozica Ivanović, FE Kragujevac (Serbia)
PhD Ljubodrag Tanović, FME Belgrade (Serbia)
PhD Ljubomir Miladinović, FME Belgrade (Serbia)
PhD Mathias Liewald, IFU, (Germany)
PhD Milan Rackov, FTS Novi Sad (Serbia)
PhD Milan Rakita, Purdue Univerzitet, SAD
PhD Milan Tica, FME Banja Luka (B&H)
PhD Milan Zeljković, FTS Novi Sad (Serbia)
PhD Mile Savković, FMCE Kraljevo (Serbia)
PhD Milorad Milovančević, FME Belgrade (Serbia)
PhD Milosav Ognjanović, FME Belgrade (Serbia)
PhD Mirko Blagojević, FE Kragujevac (Serbia)
PhD Mirko Dobrnjac, FME Banja Luka (B&H)
PhD Mirko Ficko,UM FPME, (Slovenia)
PhD Miroslav Stanojević, FME Belgrade (Serbia)

PhD Miroslav Živković, FE Kragujevac (Serbia)
PhD Mladen Tomić, FTS Novi Sad (Serbia)
PhD Mladomir Milutinović, FTS Novi Sad (Serbia)
PhD Nebojša Lukić, FE Kragujevac (Serbia)
PhD Nebojša Radić, FME UES (B&H)
PhD Nenad Pavlović, FME Niš (Serbia)
PhD Nikola Vučetić, FME UES (B&H)
PhD Nina Anđelić, FME Belgrade (Serbia)
PhD Novak Nedić, FMCE Kraljevo (Serbia)
PhD Obrad Spaić, UES PFM, (B&H)
PhD Pavel Kovač, FTS Novi Sad (Serbia)
PhD Ranislav Bulatović, FME Podgorica (MNE)
PhD Radivoje Mitrović, FME Belgrade (Serbia)
PhD Radoslav Tomović, FME Podgorica (MNE)
PhD Radovan Radovanović, The Academy of criminalistic and police studies Belgrade (Serbia)
PhD Ranko Antunović, FME UES (B&H)
PhD Risto Ciconkov, FME Skopje (Macedonia)
PhD Saša Ranđelović, FME Niš (Serbia)
PhD Sergej Alexandrov, Institute for Problems in Mechanics (Russia)
PhD Siniša Kuzmanović, FTS Novi Sad (Serbia)
PhD Slaviša Moljević, FME UES (B&H)
PhD Slavko Arsovski, FE Kragujevac (Serbia)
PhD Snežana Nestić, FE Kragujevac (Serbia)
PhD Spasoje Trifković, FME UES (B&H)
PhD Srđan Vasković, FME UES (B&H)
PhD Sreten Perić, Military academy, University of Defence in Belgrade (Serbia)
PhD Stanislav Karapetrović, University of Alberta (Canada)
PhD Stevan Stankovski, FTS Novi Sad (Serbia)
PhD Stojan Simić, FME UES (B&H)
PhD Strain Posavljak, FME Banja Luka (B&H)
PhD Velimir Stefanović, FME Niš (Serbia)
PhD Vencislav Grabulov, Institut IMS, Srbija
PhD Vladimir Popović, FME Belgrade (Serbia)
PhD Vlado Medaković, FME UES (B&H)
PhD Vojislav Miltenović, FME Niš (Serbia)
PhD Zdravko Krivokapić, FME Podgorica (MNE)
PhD Zorana Tanasić, FME Banja Luka (B&H)

ORGANIZING COMMITTEE

PhD Milija Kraišnik, FME UES – president
PhD Miroslav Milutinović, FME UES
PhD Saša Prodanović, FME UES
PhD Nikola Vučetić, FME UES
PhD Davor Milić, FME UES
PhD Aleksije Đurić, FME UES
Krsto Batinić, FME UES - Technical Secretary
Milica Bošković, ma, FME UES - Technical Secretary
Stanišić Vera – Secretary

COMETa 2022
6th INTERNATIONAL SCIENTIFIC CONFERENCE
17th - 19th December 2022
Jahorina, B&H, Republic of Srpska
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

PERSPECTIVES FOR ENERGY GENERATION IN SOUTHEAST EUROPE USING CLEAN COAL TECHNOLOGIES

Kristina Paunova[1], Vlatko Cingoski[2]

Abstract: Fossil fuels, especially coal, due to their unique composition and characteristics, are indispensable sources of electricity generation, especially in the Southeast European countries, North Macedonia, Serbia,and Bosnia and Herzegovina, among others. Strict environmental regulations, together with the tendency to continue with coal utilization,the long period needed for energy transition are the main reasons for the development of various concepts for clean use of coal. This paper addresses some technologies for clean coal utilization, a detailed description of the principle of operation and how they contribute to the environment and reduce pollution. The traditional process of burning coal in powder coal power plants is used as a comparison model and the new energy generation technologies using supercritical and ultra-supercritical power plants are presented. A description of the gasification process, integrated gasification in a combined cycle, and the types of gasifiers used are also given. Because each of these processes is accompanied by carbon dioxide emissions, the procedure for capturing and storing carbon in the long run is also considered.

Keywords: clean coal technologies, coal gasification, carbon capture.

1 INTRODUCTION

Energy needs are currently mostly satisfied by fossil fuels such as oil, coal, and natural gas. Fossil fuels belong to the group of non-renewable energy sources, thus their reserves are limited, so it's necessary to consider the possibility of their depletion in the future. Coal is the most widespread fossil fuel in the world. Around 27% of the needs for primary energy and 37% for electricity are obtained based on coal [1]. Some countries that heavily rely on coal, among other energy sources, for energy generation such as Southeast European countries, where most of the power plants are old and extremely polluting. Also, this region is home to 7 of the 10 most polluting power plants

[1] Student, Kristina Paunova, Faculty of Electrical Engineering, University "Goce Delcev"- Shtip, RN Macedonia, kristina.20609@student.ugd.edu.mk
[2] Prof. D-r Vlatko Chingoski, Faculty of Electrical Engineering, University "Goce Delcev"- Shtip, RN Macedonia, vlatko.cingoski@ugd.edu.mk

based on coal in Europe. On an average level, power plants situated in the Western Balkans (Albania, Bosnia and Herzegovina, Montenegro, Kosovo, North Macedonia, Serbia) emit 20 times more sulfur dioxide than European Union power plants. In 2016, 16 coal-fired power plants in Western Balkans produced as much pollution as the 250 active power plants in the European Union [2]. To ensure a secure energy future, researches are being done in the field of theoretical possibilities and the real rational application of energy sources. These researches go in two directions: extending the life of non-renewable energy sources and organization of energy sources and technological procedures that have minimal impact on pollution. This is when clean coal technologies come into play. Clean technologies are designed to improve the efficiency and environmental acceptability of coal throughout its life cycle stages. In the current scenario of accelerated global warming and the global need for energy security, these technologies are of great importance. In what follows some of these technologies that can be implemented in Southeast European power plants will be presented.

2 PULVERIZED COAL COMBUSTION

Combustion of pulverized coal is the most commonly used process to generate electrical energy. Approximately 97% of the coal-fired capacity in the world is produced by pulverized coal power plants [3]. This technology is not considered clean, unless it's combined with some advanced modern technologies. In these power plants, pulverized coal is placed in a boiler with air where is burned, releasing the chemical energy of the coal into heat. Then, the heat is used to generate steam from the water that flows through the tubes placed in the walls of the boiler. Next, the high-pressure and high-temperature steam is transmitted to the steam turbine, which is connected to an electrical generator for electricity production. After passing to the turbine, the steam is cooled and condensed back into a liquid and then it returns to the boiler's tubes to start the cycle over again. A pulverized coal system can burn a variety of coal types, but systems made to burn various types of coal are more sophisticated and expensive [4]. This process is presented in Figure 1.

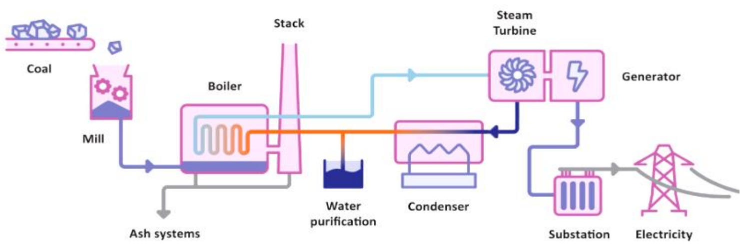

Figure 1. *Pulverized coal power plant [5]*

3 SUPERCRITICAL AND ULTRA-SUPERCRITICAL POWER PLANTS

Supercritical power plants are a new generation of coal-fied power plants. The difference between supercritical power plants and traditional power plants is that in supercritical plants the water flowing through them operates as a supercritical fluid, meaning it's neither a liquid nor a gas. This happens when water reaches its critical point at high temperatures and high pressures, especially at 22 MPa and 374ºC. As the liquid approaches its critical point, its heat of vaporization begins to decrease until it reaches zero. This means that the amount of energy required to convert water to steam decreases over time, until the transition to the vapor phase is instantaneous. This reduces the amount of heat transfer to water that is usually required in conventional coal-fired power plants, requiring less coal to heat the same amount of water. This significantly improves the plant's thermal efficiency. These plants are the gold standard for new coal-fired plants because their efficiency can reach around 44%, compared to older coal-fired plants, which operate at 33%. Also, higher temperature and pressure coal-fired power plants, known as *ultra-supercritical*, are being studied and developed, with the potential to achieve efficiency of nearly 50%. Higher efficiency results in lower greenhouse gas emissions along with pollutants such as sulfur dioxide, nitrogen oxides, and particles that are dangerous to people's health [6].

4 FLUIDIZED BED COMBUSTION

Fluidized bed combustion is a method of burning solid fuels, like coal. Fluidization of the layer of solid particles occurs when a pressurized fluid (liquid or gas) passes through the medium and causes, under certain circumstances, the solid particles to behave like a fluid. As a result of fluidization, the state of the particles changes, from static to dynamic. [7]. Fluidized bed combustion is classified into two types: atmospheric fluidized bed combustion and pressurized fluidized bed combustion. Each type includes bubbling fluidized bed combustion and circulating fluidized bed combustion [8]. The working principle of fluidized bed combustion is shown in Figure 2.

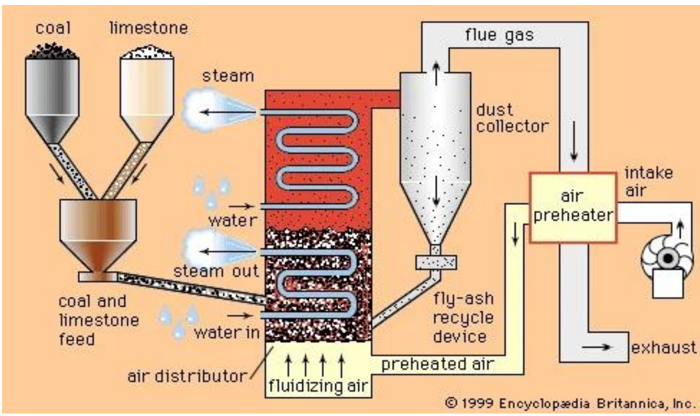

Figure 2. *Schematic diagram of fluidized bed combustion boiler [9]*

The layer of solid particles is formed by mixing coal and limestone. Evaporation pipes are placed directly in the layer itself. From the air preheater, the warm air is transferred from the bottom, up to the finely divided layer of solid particles. When the air flows at a low speed, the particles remain undisturbed, if the speed gradually increases the particles become suspended in the airflow. With a further increase in the air speed, the layer becomes very turbulent, and mixing of the particles occurs, which resembles the formation of bubbles in a boiling liquid. The velocity of the air that causes fluidization depends on parameters such as the particle size of the coal and the density of the air-coal mixture. Since the evaporation tubes are directly placed in the layer of solid particles, they are in direct contact with the burning coal and produce high heat transfer rates. Due to this, the size of the unit is reduced to a great extent, and it also produces combustion with very high efficiency. Fluidized bed combustion systems are particularly suitable for low-quality, high-sulfur coal because of their capacity to retain sulfur dioxide in the bed as well as their ability to burn coal with high or variable ash content [10]. This technology offers many advantages such as:

- High thermal efficiency,
- Simple ash removing system,
- Fully automated process that ensures safe operation,
- Possible operation at temperatures as low as 150ºC,
- Decreased coal crushing, because pulverized coal is not a necessity,
- The system can quickly respond to changes in load demand,
- Lowering the temperature of the fluidized bed furnace helps to reduce air pollution.

5 COAL GASIFICATION

Coal gasification is the process of producing syngas (synthetic gas), a mixture primarily consisting of carbon monoxide, carbon dioxide, and hydrogen. Gasification can be defined as the transformation of solids into flammable gases in the presence of steam and air, oxygen or carbon dioxide. The gasification process consists of several steps, as shown in Figure 3.

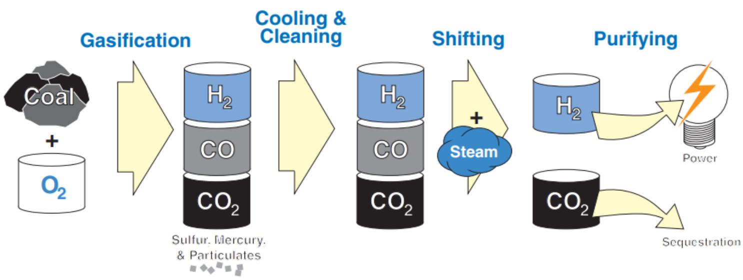

Figure 3. *Gasification process [11]*

Gasification is the process by which coal is converted into a very hot (up to 1800°C) synthesis gas, or syngas, which contains carbon monoxide, carbon dioxide, and hydrogen, as well as trace amounts of other gases and particles. This is accomplished by combining pulverized coal with an oxidant, most commonly steam, air, or oxygen. The syngas is then cooled and cleaned to remove any remaining gases and particles, leaving only carbon monoxide, carbon dioxide, and hydrogen. Syngas emissions are less difficult to clean up than pulverized coal power plant emissions. Mercury, sulfur, trace pollutants, and particulates are all removed during syngas cleaning. The syngas is then routed to a "shift reactor." By mixing with steam, carbon monoxide is converted into more carbon dioxide and hydrogen during the shift reaction. Then there's syngas, which is mostly hydrogen and carbon dioxide. After the syngas is shifted, it is separated into streams of hydrogen and carbon dioxide. The hydrogen, once purified, is ready for use. Carbon dioxide can be captured and sent for sequestration [11].

5.1 Types of gasifiers

Coal gasifiers come in three varieties, and each one is shown in Figure 4.

- Entrained flow gasifier,
- Moving bed gasifier,
- Fluidized bed gasifier.

The most aggressive form of gasification is *entrained flow*, in which pulverized coal and oxidizing gas flow concurrently. Optionally, the pulverized coal can be fed into the gasifier as a slurry with water, which serves as a source of steam for the reaction. Under high pressures and high temperatures, almost complete gasification is obtained with little formations of tars and char. These gasifiers are designed for coal with low reactivity and high throughput. *Moving-bed gasifiers* operate at 3 MPa and are very similar to blast furnaces. In a refractory-lined vessel, crushed coal with fine particles removed is placed on the top of a descending bed. The primary requirement for moving-bed gasifiers is high bed permeability to avoid pressure drops and channel burning. The coal is gradually heated as it moves downward and comes into contact with steam and oxygen-enriched air flowing upward counter-currently. The Lurgi moving-bed gasifier is the oldest and most well-known type of gasifier of this type, although some different kinds have also been developed. A *fluidized bed gasifier* is a vessel in which fine solids are suspended by an upwardly flowing gas, causing the entire bed to behave fluidically. Finely grounded coal is injected into a bed of inert particles that is fluidized at high pressure with steam and air (or oxygen). At a temperature of 1,223 – 1,373 K and a pressure of 2-3 MPa, the rising oxygen-enriched gas reacts with the coal [12].

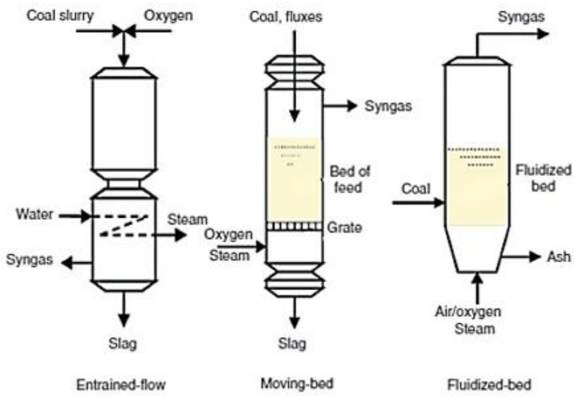

Figure 4. *Schematic representation of coal gasifier types [12]*

6 INTEGRATED GASIFICATION COMBINED CYCLE

The use of solid and liquid fuels in a power plant which has the environmental advantages of a gas power plant and the thermal properties of a combined cycle is possible with Integrated gasification combined cycle technology. After gasifying a solid or liquid fuel with oxygen, the resulting gas, called syngas is cooled and cleaned, then released into a gas turbine. The hot air from the gas turbine is routed to a heat recovery steam generator, which generates steam to power the steam turbine. Both gas and steam turbines generate power. This IGCC scheme has many different variants, most notably in the level of integration. Usually, boiler feed water is warmed in a heat recovery steam generator (HRSG) and then passed to the gasification section where saturated steam is generated by cooling the syngas. The saturated steam is superheated and reheated in the HRSG, before being introduced to the steam turbine for power generation. The most common integration design is the level of integration of the gas turbine with the air separation unit. This unit is critical to increasing the efficiency, accessibility and functionality of an oxygen-fed IGCC power plant. The following figure shows a schematic representation of an IGCC power plant [13].

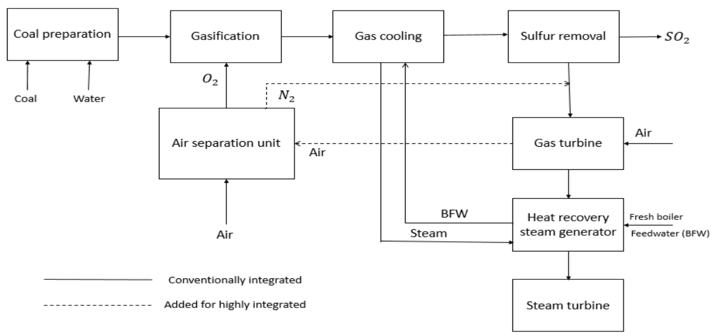

Figure 5. *Integrated gasification combined cycle block diagram [13]*

7 CARBON CAPTURE AND STORAGE

Carbon dioxide capture and storage (CCS) is a method that entails separating carbon dioxide from industrial and power sources, transporting it to a storage location, and isolating it from the atmosphere for an extended period of time. Carbon dioxide is captured from the places where it is produced such as thermal power plants or other industrial facilities.

7.1 Carbon capture systems

There are three basic systems for carbon capture: post-combustion capture, pre-combustion capture, and oxyfuel combustion capture.

7.1.1 Post-combustion capture

Post-combustion capture is a technique used to separate carbon dioxide from flue gas produced by the combustion of fossil fuels. The flue gas, a mixture of carbon dioxide, nitrogen, and some oxygenated compounds, is first processed in order to remove particles, nitrogen, and sulfur oxides. In most cases, they come into contact with a liquid solvent, usually a liquid amine solution. Carbon dioxide is selectively absorbed by the amine solution, capturing more than 85% of the carbon dioxide, allowing for the release of oxygen and nitrogen in the atmosphere. Furthermore, an amine rich in carbon dioxide is regenerated by using steam to remove the carbon dioxide from the liquid, enabling the amine to be reprocessed to the absorber while generating a concentrated carbon dioxide stream. The carbon dioxide is compressed and cooled as a liquid [14]. The advantages of this process are:

- Can usually be built into existing industrial facilities and power plants without requiring important changes to the original plant,
- Can be incorporated into new plants to accomplish reduction of greenhouse gasses close to zero-emission,

- It has a high level of operational flexibility (partial retrofit, zero to full capture operation) and therefore can fit market conditions for both current and new power plants,
- This process allows the integration of renewable technologies [14].

7.1.2 Pre-combustion capture

In pre-combustion capture, the carbon dioxide is removed prior to combustion. The capture procedure is divided into three stages:

1) The hydrocarbon fuel, usually gasified coal, is transformed into carbon monoxide and hydrogen in order to produce syngas,
2) The carbon monoxide is then transformed into carbon dioxide by a water gas shift reaction,
3) The resulting carbon dioxide is separated from the hydrogen, which can be burned safely. Carbon dioxide can be compressed into a liquid and transferred to a storage location [14].

7.1.3 Oxyfuel combustion

Oxyfuel combustion involves the process of burning a hydrocarbon fuel such as coal with almost pure hydrogen instead of air. In order to regulate the temperature, the oxygen is diluted with exhaust gas instead of nitrogen. The primary reason for using oxy-fuel combustion in a coal power plant is to produce flue gas with extremely high concentration levels of carbon dioxide and water vapor, allowing the carbon dioxide to be separated or captured purely through dehydration and desulfurization processes. The advantages of this type of combustion are lowered NOx emissions, high carbon dioxide pureness, and lower gas volume caused by increased density.

7.2 Carbon transport

Pipelines are preferable for transporting large quantities of carbon dioxide over long ranges up to 1,000 kilometers. Ships, where applicable, may be more economically appealing for amounts below a few million tons of carbon dioxide per year or longer distances abroad [16]. Transport of carbon dioxide by truck and railway is possible for small quantities. Trucks are used at some sites, moving carbon dioxide from the capture site to a nearby storage site. For quantities of less than a few million tonnes of carbon dioxide per year or longer distances overseas, the use of ships, where applicable, could be more economically attractive [17].

7.3 Carbon storage

Geologic formations, especially depleted oil and gas reservoirs, have been considered the best possible option for carbon dioxide storage because the environmental risks and uncertainties related to geologic storage are much lower when compared with ocean storage. EOR (Enhanced Oil Recovery) companies transfer and store the liquefied carbon dioxide for tertiary recovery by reducing the density of the oil and thus mobilizing the oil. According to current research, storing carbon dioxide in depleted oil and gas reservoirs poses the least environmental risk. It has already been attempted, and the locations have proven their ability to retain fluids (under pressure) for millions of years. Aside from depleted gas and oil reservoirs, deep aquifers are a long-term viable option. Furthermore, the transport costs for this kind of storage are relatively low [16]. Geological storage is shown in Figure 6.

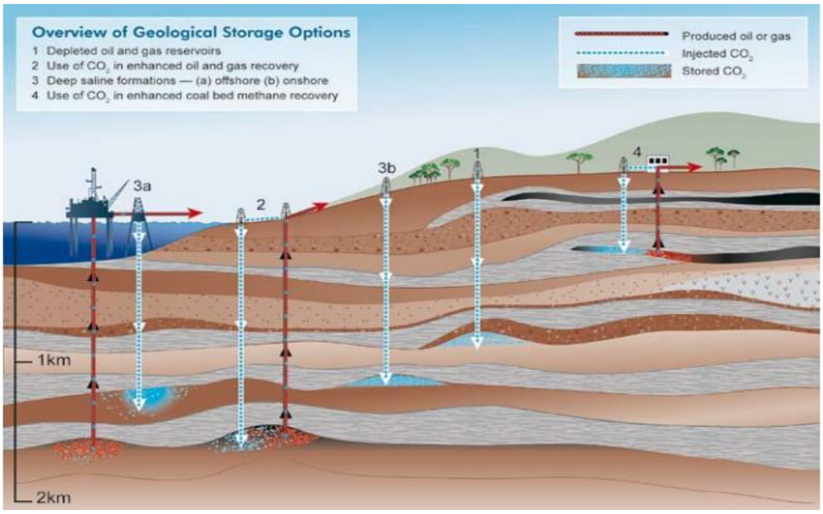

Figure 6. *Geological storage options [17]*

According to capacity, the ocean is by far the best location to store captured carbon. The direct injection of the captured carbon dioxide causes increased acidity of the ocean, but at such a slow speed which allows the marine organisms to adapt. Some researchers verify that injecting carbon dioxide at a depth of 1,000-1,500 m via a pipeline producing a jet of carbon dioxide can be absorbed in the surrounding water. As stated in another study, if carbon dioxide is injected at depths larger than 3,000 m, it will overcome the density of the ocean water followed by sinking at the ocean bottom and creating a securely isolated lake, as shown in Figure 7 [16].

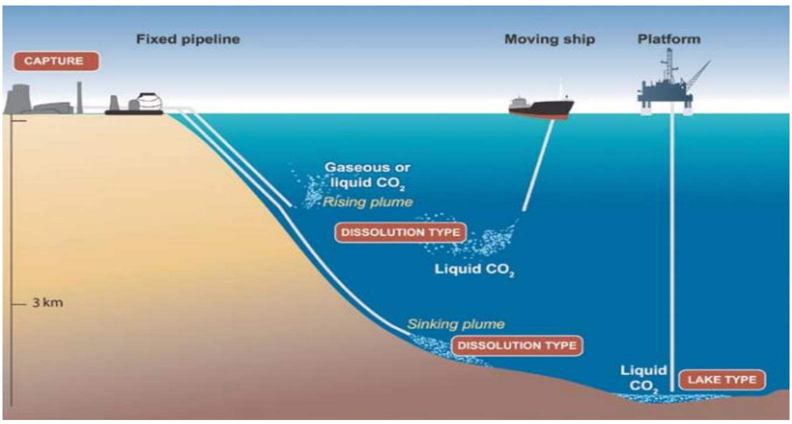

Figure 7. *Ocean storage of carbon dioxide [17]*

8 CONCLUSION

Considering that large amounts of coal are still available, it will continue to be the main source for generating electricity in the future. The important thing is to aim for the use of clean coal technologies to reduce the impact of climate changes on the environment and the health of living organisms. The classic burning of coal in power plants could be replaced by supercritical and ultra-supercritical technologies, which reduce emissions of sulfur and nitrogen oxides. Gasification is also a technology that significantly reduces pollutants compared to conventional coal burning. The higher pressures and temperatures used in the gasification process allow for easier removal of carbon dioxide, for its further capture and geological storage. The future of clean coal technologies is bright and they will play a key role in global efforts to reduce the environmental impacts of electricity production.

REFERENCES

[1] Hannah Ritchie, Max Roser and Pablo Rosado (2020) - "Energy". *Published online at OurWorldInData.org.* Available: https://ourworldindata.org/energy

[2] Maria Giulia Anceschi (2019), *The Balkans (and Europe) are choking on coal pollution*, Available: https://www.balcanicaucaso.org/eng/Areas/Balkans/The-Balkans-and-Europe-are-choking-on-coal-pollution-193459

[3] CTCN, *Pulverised coal combustion with higher efficiency*, Available: https://www.ctc-n.org/technologies/pulverised-coal-combustion-higher-efficiency

[4] State utility forecasting group, *Clean Coal Technologies,* Purdue University*,*2007 Available:https://www.purdue.edu/discoverypark/energy/assets/pdfs/SUFG-CleanCoalTechnologiesReport.pdf

[5] World Coal Association, https://www.worldcoal.org/coal-facts/coal-electricity/

[6] J.M.K.C. Donev et al. (2018). Energy Education - Supercritical coal plant [Online]. Available: https://energyeducation.ca/encyclopedia/Supercritical_coal_plant

[7] Energy purse, Fluidized bed combustion boilers, Available: https://www.energypurse.com/why-fluidized-bed-combustion-boilers/

[8] Dipak K. Sarkar, Chapter 5 - Fluidized-Bed Combustion Boilers, Editor(s): Dipak K. Sarkar, *Thermal Power Plant, Elsevier,* 2015, pp. 159-187.

[9] Sarma V.L.N Pisupati, Alan W. Scaroni, fluidized-bed combustion, Available: https://www.britannica.com/technology/fluidized-bed-combustion

[10] Electrical 4 U, *Fluidized Bed Combustion | Types and advantages* (2020), Available: https://www.electrical4u.com/fluidized-bed-combustion-types-and-advantages-of-fluidized-bed-combustion/

[11] Fact sheet, *Hydrogen production from coal*, Available: file:///C:/Users/User/Downloads/factSheet_productionCoal%20(2).pdf

[12] Rand. D, Coal Gasification (2009), CSIRO Energy Technology, Clayton, VIC, Australia.

[13] Nevile. A.H. Holt, Integrated Gasification Combined Cycle Power Plants, *Encyclopedia of Physical Science and Technolgy, Academic Press,* 2001.

[14] A. Basile, A. Gugliuzza, A. Iulianelli, P. Morrone, 5 - Membrane technology for carbon dioxide (CO2) capture in power plants, In Woodhead Publishing Series in Energy, *Advanced Membrane Science and Technology for Sustainable Energy and Environmental Applications*, Woodhead Publishing, 2011, pp. 113-159.

[15] Steven M. Carpenter, Henry A. Long, 13 - Integration of carbon capture in IGCC systems, Editor(s): Ting Wang, Gary Stiegel, *Integrated Gasification Combined Cycle (IGCC) Technologies*, *Woodhead Publishing*, 2017, pp. 445-463.

[16] Shubham Das, Jayant Kumar, Carbon Capture and Storage, *International Journal of Scientific & Engineering Research,* Volume 7, Issue 10, October 2016.

[17] IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. *Cambridge University Press*, *Cambridge, United Kingdom and New York, NY, USA.*

ISBN 978-99976-947-6-8