

# Comparative techno-economic analysis of lignite coal gasification technologies

## Vergleichende technisch-ökonomische Analyse von Braunkohlevergasungstechnologien

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**Abstract** — Gasification of lignite coal is a complex and expensive technology, but it offers a number of potential benefits for Bulgaria. In the context of increasing demands for carbon reduction and energy security, lignite gasification can be an essential part of the country's energy strategy. This paper discusses the technological specificities of different lignite pyrolysis and gasification technologies and their environmental and economic performance.

**Zusammenfassung** – Die Vergasung von Braunkohle ist eine komplexe und teure Technologie, die für Bulgarien jedoch eine Reihe potenzieller Vorteile bietet. Vor dem Hintergrund steigender Anforderungen an CO<sub>2</sub>-Reduzierung und Energiesicherheit kann die Braunkohlevergasung ein wesentlicher Bestandteil der Energiestrategie des Landes sein. In diesem Artikel werden die technologischen Besonderheiten verschiedener Braunkohlepyrolyse- und -vergasungstechnologien sowie deren ökologische und wirtschaftliche Leistung erörtert.

### I. INTRODUCTION

The pursuit of carbon reduction has become a paramount global concern, reflecting a collective recognition of the urgent need to address climate change. Across the globe, nations are navigating the complex landscape of transitioning to sustainable energy solutions. The overarching goal is clear: reduce carbon emissions to mitigate the impact of climate change and ensure a more sustainable future.

As a country seeking to balance economic growth, energy security, and environmental stewardship, Bulgaria faces the imperative to explore innovative solutions.

This paper sets out to unravel the intricacies of both lignite gasification and pyrolysis, laying bare the technological specifics, environmental implications, and economic considerations. By exploring the challenges and investments required for implementation, aim is to shed light on the potential positive impacts of lignite gasification on carbon reduction. This paper aims to explore the complexities and expenses of lignite gasification, as well as highlight the potential benefits for Bulgaria.

### II. IMPORTANCE OF ADDRESSING CARBON REDUCTION AND ENERGY SECURITY

#### A. Carbon reduction and energy security

Carbon reduction and energy security are two of the most pressing challenges facing the world today. Climate change is a serious threat to the planet and its inhabitants, and it is essential to reduce greenhouse gas emissions to mitigate its effects. Energy security is also important, as countries need to ensure that they have a reliable and affordable supply of energy to meet their needs.

#### B. Significance of lignite gasification in Bulgaria's energy strategy

Lignite gasification is a promising technology that can help Bulgaria address both carbon reduction and energy security.

Lignite is Bulgaria's most abundant fossil fuel resource, and gasification can convert it into a clean-burning syngas that can be used to generate electricity, produce chemicals, or synthesize liquid fuels.

Lignite gasification can also be used to produce hydrogen, a clean fuel that can be used in fuel cells or other applications.

#### C. Complexities of lignite gasification

Lignite gasification is a complex process that involves a number of chemical reactions. The following are some of the key challenges associated with lignite gasification [1]:

- Lignite is high in ash and moisture, which can impact the performance and efficiency of gasification technologies.
- The gasification process produces a variety of byproducts, including tars, char, and sulfur compounds. These byproducts must be properly managed to avoid environmental impacts.
- Lignite gasification is a capital-intensive technology, and the upfront investment costs can be high.

#### D. Expenses of lignite gasification

The cost of lignite gasification is expected to decline in the future as the technology continues to develop and economies of scale are achieved. However, it is likely that lignite gasification will remain more expensive than conventional coal-fired power generation for the foreseeable future.

The cost of lignite gasification depends on a number of factors, including the type of gasifier used, the size of the plant, and the cost of lignite and other inputs. However, lignite gasification is generally more expensive than conventional coal-fired power generation. This is due to a number of factors, including:

#### E. Potential benefits of lignite gasification for Bulgaria

Despite the complexities and expenses of lignite gasification, there are a number of potential benefits for Bulgaria, including [4]:

- Reduced greenhouse gas emissions: Lignite gasification can help Bulgaria reduce its greenhouse gas emissions by converting lignite into a cleaner-burning syngas.
- Reduced air pollution: Lignite gasification can produce syngas with a lower carbon content than the flue gas produced from conventional coal-fired power plants. This can make lignite gasification a more environmentally friendly way to generate electricity and other products.
- Improved energy security: Bulgaria currently relies heavily on imported energy, including natural gas and oil. Lignite gasification could help to reduce Bulgaria's reliance on imported energy by providing a domestic source of fuel for power generation and other industrial applications.
- New economic opportunities: Lignite gasification could create new economic opportunities in Bulgaria by creating jobs in the construction, operation, and maintenance of gasification plants. Additionally, gasification plants could produce a variety of byproducts that could be used to produce new products and services.

Here are some specific examples of how lignite gasification could benefit Bulgaria:

- A lignite gasification plant could be used to produce electricity for the national grid. This would help to reduce Bulgaria's reliance on imported energy and improve its energy security.
- A lignite gasification plant could also be used to produce hydrogen. Hydrogen can be used to produce electricity, heat, and chemicals. It can also be used as a fuel for vehicles.
- The byproducts of lignite gasification, such as syngas and biochar, could be used to produce new products and services. For example, syngas could be used to produce synthetic fuels and chemicals. Biochar could be used as a soil amendment or as a fuel for cooking and heating.

In the context of increasing demands for carbon reduction and energy security, lignite gasification can be an essential part of the country's energy strategy.

Overall, lignite gasification has the potential to offer a number of benefits for Bulgaria [5]. By reducing reliance on imported energy, improving energy security, reducing air pollution, and creating new economic opportunities, lignite gasification could help to make Bulgaria a more sustainable and prosperous country.

### III. TECHNOLOGICAL SPECIFICITIES OF LIGNITE PYROLYSIS AND GASIFICATION

Lignite is a low-rank coal with high moisture and ash content. This makes it challenging to convert to useful products using traditional thermal processing methods. Pyrolysis and gasification are two thermochemical conversion processes that can be used to produce valuable products from lignite, but they require specific technological considerations. Specificities depend on factors like temperature, pressure, and the type of gasifying agent used. Lignite's high moisture content and low carbon content can pose challenges, influencing the efficiency and product composition of these processes.

#### A. Lignite Pyrolysis

Lignite pyrolysis is a thermochemical process that converts lignite coal into a solid residue (char), a liquid product (bio-

oil), and a gaseous product (syngas). The resulting gas contains hydrogen, methane, carbon monoxide, and other volatile compounds. The product distribution depends on the pyrolysis conditions, such as temperature, heating rate, and residence time. The process takes place in the absence of oxygen at temperatures ranging from 400 to 800 degrees Celsius. The basic principles of lignite pyrolysis are as follows [3]:

- When lignite is heated, the moisture and volatile matter are released.
- The volatile matter condenses to form bio-oil.
- The non-volatile matter remains as char.

#### B. The following are some important technological nuances of lignite pyrolysis:

- The particle size of the lignite feedstock has a significant impact on the pyrolysis process. Smaller particles will heat up more quickly and evenly, resulting in higher yields of bio-oil and syngas.
- The heating rate also has a significant impact on the pyrolysis process. Faster heating rates will favor the formation of bio-oil, while slower heating rates will favor the formation of char.
- The pyrolysis atmosphere (inert or reducing) can also affect the yields and composition of the products. A reducing atmosphere (e.g., hydrogen) will favor the formation of char and syngas, while an inert atmosphere (e.g., nitrogen) will favor the formation of bio-oil.
- One of the main challenges in pyrolyzing lignite is its high moisture content. The moisture must be removed before pyrolysis, or it will condense and form tars and oils that are difficult to separate. This can be done by drying the lignite or by using a hydrothermal upgrading process to convert the moisture into a byproduct.
- Another challenge is the high ash content of lignite. The ash must be removed from the pyrolysis products, or it will contaminate the products and make them difficult to use. This can be done using a variety of techniques, such as cyclone separation, electrostatic precipitators, and wet scrubbers.

#### C. Gasification

Gasification is the conversion of a solid fuel into a syngas (a mixture of carbon monoxide, hydrogen, and methane) by reacting it with a gasifying agent, such as air, oxygen, or steam. Syngas can be used to produce electricity, heat, and chemicals. Gasifying lignite presents a number of challenges.

- First, lignite has a high moisture content, which can lead to problems with slagging and fouling of the gasifier.
- Second, lignite has a high ash content, which can also contaminate the syngas.
- Third, lignite has a low reactivity, which means that it requires a high gasification temperature and pressure.

To overcome these challenges, gasifiers for lignite typically use a fluidized bed configuration. In a fluidized bed gasifier, the lignite is suspended in a bed of hot sand or ash. This allows for efficient heat transfer and good mixing of the lignite and gasifying agent.

There are two main types of gasification methods: entrained flow gasification and fluidized bed gasification.

- Entrained flow gasification is a high-temperature, high-pressure process in which lignite coal is ground into a fine powder and injected into a gasifier reactor. The lignite is then gasified with oxygen or steam to produce a syngas. Entrained flow gasification is the most efficient type of gasification technology, but it is also the most expensive.
- Fluidized bed gasification is a lower-temperature, lower-pressure process in which lignite coal is gasified in a fluidized bed of sand or limestone. Fluidized bed gasification is less efficient than entrained flow gasification, but it is also less expensive and more tolerant of impurities in the lignite coal.

#### D. Technological Specificities

The following are some of the technological specificities of pyrolysis and gasification of lignite:

- Pretreatment: Lignite must often be pretreated to remove moisture and ash before it can be pyrolyzed or gasified. This can be done using a variety of techniques, such as drying, hydrothermal upgrading, and chemical leaching.
- Pyrolysis reactor: The type of pyrolysis reactor used will depend on the desired product distribution. For example, a fluidized bed pyrolysis reactor is well-suited for producing a high yield of tar and oil, while a fixed bed pyrolysis reactor is better suited for producing a high yield of char.
- Gasification reactor: The type of gasification reactor used will depend on the desired syngas composition. For example, a fluidized bed gasifier is well-suited for producing a high yield of hydrogen, while an entrained flow gasifier is better suited for producing a high yield of methane.
- Product separation: The pyrolysis and gasification products must be separated from each other and from the unconverted fuel. This can be done using a variety of techniques, such as distillation, solvent extraction, and filtration.

The selection of lignite pyrolysis or gasification technology depends on a number of factors, including the desired end products, the investment budget, and the specific characteristics of the lignite feedstock. Entrained flow gasification is generally more efficient and can produce a higher quality syngas, but it is also more expensive. Fluidized bed gasification is less efficient, but it is also less expensive and more tolerant of impurities in the lignite coal.

Despite the challenges, pyrolysis and gasification are promising technologies for converting lignite into valuable products. By carefully considering the technological specificities of these processes, it is possible to develop efficient and cost-effective methods for utilizing lignite.

#### IV. CHARACTERISTICS OF BULGARIAN LIGNITE, UNIQUE PROPERTIES AND CHALLENGES

Bulgarian lignite is characterized by its high ash content, moisture content, and low heating value. These characteristics can present some challenges for lignite gasification, but there are a number of technologies and mitigation measures that can be used to address these challenges.

**High ash content:** The high ash content of Bulgarian lignite can lead to slagging and fouling in gasification reactors. Slagging is the formation of molten ash deposits on the walls of the reactor, which can reduce the efficiency of the process and block the flow of syngas. Fouling is the buildup of solid ash deposits on the surfaces of the reactor, which can also reduce the efficiency of the process and lead to corrosion.

There are a number of ways to mitigate the challenges posed by the high ash content of Bulgarian lignite, including:

- Pre-treatment: The lignite can be pre-treated to remove some of the ash content before it is gasified. This can be done using a variety of methods, such as screening, washing, and flotation
- Gasifier design: Gasifiers can be designed to minimize the risk of slagging and fouling. For example, fluidized bed gasifiers are well-suited for gasifying high-ash lignite because they keep the lignite particles suspended in a bed of hot sand or ash. This helps to prevent the ash from melting and forming slag.
- Ash removal: Ash removal systems can be installed to remove ash from the syngas and prevent it from fouling the gasification reactor and downstream equipment.

**High moisture content:** The high moisture content of Bulgarian lignite can reduce the efficiency of the gasification process and increase the cost of drying the lignite. The moisture content of the lignite must be reduced before it can be gasified, or it will condense and form tars and oils that are difficult to separate.

The lignite can be dried using a variety of methods, such as thermal drying, solar drying, and microwave drying. Thermal drying is the most common method, but it can be expensive and energy-intensive. Solar drying and microwave drying are more energy-efficient methods, but they can be slower and more complex.

**Low heating value:** The low heating value of Bulgarian lignite means that more lignite is needed to produce the same amount of syngas or other products as compared to other types of coal with a higher heating value. This can increase the cost of producing syngas and other products from Bulgarian lignite.

There are a number of ways to compensate for the low heating value of Bulgarian lignite, including:

- Using a more efficient gasification process: Some gasification processes are more efficient than others at converting lignite into syngas. For example, entrained flow gasifiers are more efficient than fluidized bed gasifiers.
- Using a co-gasification process: Bulgarian lignite can be co-gasified with other fuels, such as biomass or natural gas, to improve the overall heating value of the feedstock.
- Using a co-gasification process: Bulgarian lignite can be co-gasified with other fuels, such as biomass or natural gas, to improve the overall heating value of the feedstock.

Despite the challenges posed by the high ash content, moisture content, and low heating value of Bulgarian lignite, gasification is a promising technology for converting Bulgarian lignite into valuable products. By using the appropriate technologies and mitigation measures, it is possible to gasify Bulgarian lignite efficiently and cost-effectively.

## V. ECONOMIC FEASIBILITY. COST ANALYSIS OF LIGNITE PYROLYSIS AND GASIFICATION

The economic feasibility of both lignite gasification and pyrolysis depends on a number of factors, including the cost of lignite, the cost of capital, and the price of electricity or other products that are produced from the syngas and bio-oil.

### A. Cost Analysis of Lignite Pyrolysis and Gasification

**Initial costs:** The initial costs of implementing both lignite gasification and pyrolysis can be high. This is because gasification plants are complex and require a significant investment of capital. The initial costs include the cost of the gasifier, the air separation unit, the syngas cleanup system, and the power generation equipment [2].

**Operational expenses:** The operational expenses of lignite gasification include the cost of lignite, the cost of oxygen and steam, and the cost of maintaining and operating the gasification plant. The cost of lignite is the main operational expense, accounting for up to 70% of the total cost.

**Potential long-term savings:** Lignite gasification can produce a variety of products, including electricity, hydrogen, and synthetic fuels. These products can be sold to generate revenue, which can offset the initial costs and operational expenses of the gasification plant. The revenue from the sale of products can be used to repay the initial investment and generate profits for the investors. Efficient operations, market conditions, and advancements in gasification technology can all play a role in maximizing the long-term savings potential.

Overall, the economic feasibility of lignite pyrolysis in Bulgaria is mixed. The initial costs of implementing lignite pyrolysis are high, but the potential long-term savings from the sale of products could offset these costs. The economic feasibility of lignite pyrolysis in Bulgaria will depend on a number of factors, including the cost of lignite, the cost of capital, the price of electricity and pyrolysis products in the future, and the efficiency of the pyrolysis process.

### B. Potential Economic Benefits for Bulgaria

Lignite pyrolysis and gasification has the potential to produce a number of economic benefits for Bulgaria, including:

- **Job creation:** The construction and operation of lignite gasification plants can create jobs in Bulgaria.
- **Resource utilization:** Lignite gasification can help Bulgaria utilize its domestic lignite resources more efficiently.

One of the main advantages in the processing (gasification) of lignite coal is related to the political, social and economic situation in the Maritsa East mine. The closure of the thermal power plants in the area in connection with the environmental problems and the commitments made to the EU under the green energy plan, opens new perspectives for the global solution of the problem. Through the new technologies, it is possible to preserve the operation of the mine and the jobs of those currently working in the mining industry.

However, it is important to carefully consider the costs, benefits, and risks before implementing lignite gasification on a commercial scale.

## VI. RECOMMENDATIONS AND CONCLUSION

The following are some ways to mitigate the challenges discussed above in the Bulgarian context:

- **High initial costs:** The Bulgarian government can provide financial assistance to help offset the high initial costs of constructing lignite gasification plants. The government can also work with the private sector to develop innovative financing mechanisms.
- **Technical challenges:** The Bulgarian government and industry should work with research and development institutions to address the technical challenges associated with lignite gasification technology. The government should also encourage the transfer of technology from other countries with experience in lignite gasification.
- **Establish partnerships with foreign governments and research institutions:** The government can establish partnerships with foreign governments and research institutions to promote the transfer of lignite gasification technology. These partnerships could involve joint research projects, exchanges of scientists and engineers, and technology transfer agreements.
- **Fund research on new gasification technologies:** The Bulgarian government can provide funding to universities and research institutions to develop new gasification technologies that are specifically suited to Bulgarian lignite. This research could focus on developing more efficient gasification processes, reducing emissions from gasification plants, and improving the reliability and durability of gasification equipment.
- **Support the development of pilot and demonstration projects:** The government can support the development of pilot and demonstration projects for new lignite gasification technologies. This would allow researchers and industry partners to test new technologies in a real-world environment and to identify any challenges that need to be addressed before the technologies can be commercialized.
- **Establish a center of excellence for lignite gasification:** It could be established a center of excellence for lignite gasification. This center would bring together researchers, industry partners, and government officials to collaborate on the development and deployment of lignite gasification technology.
- **Integration with existing infrastructure is important:** Lignite gasification plants should be integrated with the existing energy infrastructure in Bulgaria to ensure that the syngas or other products produced by these plants can be used effectively.
- **Public opposition:** The Industry and authorities should engage in open and transparent communication with the public about the benefits and risks of lignite gasification
- **Develop a national lignite gasification strategy:** The Bulgarian government should develop a national lignite gasification strategy that sets out a clear roadmap for the development and deployment of lignite gasification technology in the country.
- **Conduct a feasibility studies:** A feasibility study should be conducted to assess the technical, economic, and

environmental feasibility of lignite gasification in Bulgaria. Proven technologies should be used. Industry should focus on using proven and reliable lignite gasification technologies.

Lignite gasification is a complex and expensive technology, but it offers a number of potential benefits for Bulgaria. Lignite gasification can help Bulgaria reduce greenhouse gas emissions, improve energy security, boost economic development, and promote technological innovation. Lignite gasification also aligns with and contributes to Bulgaria's energy strategy. By carefully considering the recommendations for future research and implementation, Bulgaria can successfully deploy lignite gasification technology to reap its many benefits.

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