



The Future of Fossil Fuels: Challenges and Opportunities in a Low-Carbon World

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INFORMATION

Article history

Received 12 June 2023

Revised 24 July 2023

Accepted 20 August 2023

Keywords

Fossil fuels

Low-carbon economy

Greenhouse gas emissions

Renewable energy

Carbon capture and storage

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ABSTRACT

This review article examines the challenges and opportunities facing the future of fossil fuels in a low-carbon world. The article begins by discussing the importance of fossil fuels in the global energy mix and the need for a transition to a low-carbon economy to address climate change. It provides an overview of the history and evolution of fossil fuel use, the current state of the fossil fuel industry, and the definition and types of fossil fuels. The article then explores the challenges facing the future of fossil fuels, including the need to reduce greenhouse gas emissions, declining costs of renewable energy, and political and social pressure to reduce fossil fuel use. However, the article also highlights several opportunities for the future of fossil fuels, including technological advancements in carbon capture and storage (CCS), the potential role of natural gas as a "bridge" fuel, and the use of fossil fuels in non-energy applications. To illustrate the challenges and opportunities, the article includes case studies of countries or companies that are successfully transitioning away from fossil fuels and examples of innovative fossil fuel projects or technologies. The review concludes with a discussion of the future outlook for fossil fuels and the potential paths forward in a low-carbon world. Overall, this review provides an overview of the future of fossil fuels and the challenges and opportunities that lie ahead.

1. Introduction

Fossil fuels have been a critical component of the global energy mix for centuries, providing the majority of the world's electricity and transportation fuels (Zhang et al., 2023). However, the use of fossil fuels is also a significant contributor to greenhouse gas emissions, which are the primary cause of climate change (Ma et al., 2023). As the world faces the urgent need to reduce greenhouse gas emissions and transition to a low-carbon economy, the future of fossil fuels is increasingly uncertain.

The purpose of this article is to delve into the complex and dynamic landscape of the fossil fuel industry in the context of a low-carbon world. In the following sections, we will provide an overview of the history, definition, and current state of fossil fuels, highlighting their significance in the global energy mix. As we examine the challenges facing industry, we cannot ignore the pressing issue of climate

change, which continues to exert significant pressure on the sector. In addition, the declining costs of renewable energy and the growing awareness of the environmental impact of fossil fuel use are also major challenges that must be addressed. We will explore each of these challenges in detail, presenting the latest research and analysis on the subject. Despite these challenges, we believe that there are opportunities for the future of fossil fuels. Advancements in CCS technology, for example, offer the potential to significantly reduce emissions from fossil fuel use. Additionally, the role of natural gas as a cleaner-burning fuel is an important consideration in the transition to a low-carbon world. We will also examine case studies of countries or companies successfully transitioning away from fossil fuels and innovative fossil fuel projects or technologies. In conclusion, we will provide a summary of key points and discuss the future outlook for fossil fuels in a low-carbon world. We believe that while industry faces significant



challenges, there are also opportunities for innovation and growth that can help drive a sustainable energy future for all.

2. Overview of Fossil Fuels

Fossil fuels, which are hydrocarbons formed from the remains of plants and animals that lived millions of years ago, play an extremely significant role in the world's economy (Hubbert, 1949). They are a non-renewable resource that is found in the Earth's crust and extracted through mining or drilling (Palmer, 2016). The three primary types of fossil fuels are coal, oil, and natural gas. Coal, a solid fossil fuel, is formed from the remains of plants that lived in swamps and marshes millions of years ago. Despite being a traditional fuel source, coal has been criticized for its high carbon emissions, which contribute significantly to climate change (Finkelman et al., 2021). In addition, coal mining is known to have environmental consequences, including habitat destruction and water pollution.

Oil, also known as petroleum, is a liquid fossil fuel that is created from the remains of marine plants and animals. It is an important resource since it is employed in the production

of power, heating, and other things. Oil has been the focus of much debate due to its environmental impact, particularly its contribution to greenhouse gas emissions and climate change. However, it is also essential to our way of life, and many industries rely on it for transportation and fuel production. A gaseous fossil fuel called natural gas is created from the remains of extinct plants and animals. It is often seen as a cleaner alternative to coal, as it emits less carbon dioxide when burned (Gürsan and de Gooyert, 2021). Natural gas is versatile and can be used for a variety of purposes, including heating, cooking, and transportation. In recent years, the demand for natural gas has increased due to its affordability and environmental benefits. However, like other fossil fuels, it is not a renewable resource and must be extracted from the ground.

Overall, fossil fuels are a crucial component of our energy supply and play a significant role in our economy. However, they also have negative environmental impacts and are a finite resource. As we look towards a sustainable future, it is essential to consider alternative energy sources and to use fossil fuels more efficiently and responsibly.



Fig. 1. Sustainable future of fossil fuels (Alagoz, 2023a)

The use of fossil fuels dates back thousands of years, with evidence of coal being used for cooking and heating in China as early as 1000 BC (Ali, 2019). However, it was not until the Industrial Revolution in the 18th and 19th centuries that the use of fossil fuels became widespread. The invention of the steam engine, powered by coal, revolutionized transportation and manufacturing, and led to a massive increase in the consumption of fossil fuels.

Today, fossil fuels remain the dominant source of energy worldwide. According to the International Energy Agency (World Energy Outlook 2022), fossil fuels accounted for approximately 84% of global primary energy consumption, with oil being the largest contributor at 33%, followed by coal at 27% and natural gas at 24%. This is a trend that is not expected to change in the near future, as the transition to renewable energy sources is a slow and complex process that

requires significant investment and infrastructure development. Renewable energy sources such as solar, wind, hydroelectric, and geothermal power have gained popularity in recent years, but they still only account for a small fraction of global energy consumption. In addition, the cost of producing renewable energy is still relatively high compared to fossil fuels, making it difficult for many countries to make the switch. Moreover, some countries have vast reserves of

fossil fuels that they rely on for economic growth, which further complicates the transition to renewable energy. Despite these challenges, there are many initiatives underway to promote the use of renewable energy, such as government subsidies, tax incentives, and research and development programs. It is hoped that these efforts will accelerate the transition to a cleaner, more sustainable energy system in the future.



Fig. 2. Future of fossil fuels developments (Alagoz, 2023a)

3. Challenges to the Future of Fossil Fuels

Fossil fuels face several significant challenges in a low-carbon world. These challenges include the urgent need to reduce greenhouse gas emissions to mitigate climate change (Ma et al., 2023), the declining cost of renewable energy, and political and social pressure to reduce fossil fuel use.

One of the biggest problems the world is currently experiencing is climate change, and using fossil fuels significantly increases greenhouse gas emissions. According to the Intergovernmental Panel on Climate Change (IPCC) (Pörtner, 2022), global carbon-di-oxide (CO_2) emissions must decrease by 45% by 2030 and reach net zero by the middle of the century in order to keep global warming to 1.5°C above pre-industrial levels and prevent the worst effects of climate change (Freier Raine et al., 2021; Glenn et al., 2021). This indicates that in the upcoming years, the consumption of fossil fuels must be drastically reduced. Climate change is undoubtedly one of the most pressing issues of our time. Global warming, caused by the emission of greenhouse gases, poses a significant threat to our planet and its inhabitants. The use of fossil fuels is a major contributor to

greenhouse gas emissions and has been identified as one of the primary causes of climate change.

There is no question that we need to make a significant shift away from our dependence on fossil fuels and instead move towards cleaner, more environmentally friendly energy sources. While this is a critical goal, the path to achieving it is not always straightforward. However, there are many ways that we can work towards this goal. For instance, one important step is to invest in renewable energy technologies, such as solar and wind power, which can help to reduce carbon emissions and overall dependence on fossil fuels.

Additionally, we should focus on improving energy efficiency in buildings and transportation, as this can also contribute to a reduction in carbon emissions. Another important aspect of this shift is promoting the use of electric vehicles, which can help to reduce carbon emissions and improve overall air quality. Ultimately, it is clear that we must work together across all sectors, including governments, businesses, and individuals, to make this transition happen. While it may not be easy, it is necessary if

we want to secure a better future for ourselves and for generations to come.

The declining cost of renewable energy, particularly solar and wind power, is posing a significant challenge for the fossil fuel industry. As reported by the International Renewable Energy Agency (IRENA) (IRENA, 2023), the cost of renewable energy has been steadily decreasing over the past decade, making solar and wind power among the cheapest sources of new electricity in many countries. This trend has been accompanied by increased investment in renewable energy research and development, leading to more efficient and effective renewable energy technologies. With renewable energy becoming increasingly cost-competitive and more widely available, there is a growing need for the fossil fuel industry to adapt to this changing landscape by investing in

sustainable and innovative solutions. Failure to do so may lead to a decline in demand for fossil fuels, as consumers and businesses increasingly turn to renewable energy sources.

In recent years, there has been a growing awareness of the need to reduce our dependence on fossil fuels, which has been fueled by concerns about climate change, air pollution, and the environmental impact of fossil fuel extraction. As a result, there is increasing pressure on governments, businesses, and civil society organizations to take action to reduce greenhouse gas emissions and transition to renewable energy sources. One way that this pressure is manifesting itself is through the setting of ambitious targets. For example, the European Union has set a target to reduce greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels (Szwarc et al., 2022).



Fig. 3. Fossil Fuel Advancement Challenges (Alagoz, 2023a)

This is a significant and challenging goal, but it reflects the urgency of the situation and the need for bold action. Similarly, many cities and states in the United States have committed to 100% renewable energy targets. This is a powerful statement of intent, and it has the potential to drive significant changes in the way that we produce and consume energy. By setting such targets, these cities and states are sending a clear signal that they are serious about tackling climate change and protecting the environment. Moreover, this trend towards renewable energy is not limited to the United States. Countries all over the world are increasingly setting ambitious targets for renewable energy production, and businesses are following suit. This shift towards renewable energy represents a fundamental change in the

way that we think about energy production and consumption, and it is a key step towards building a more sustainable future.

Overall, the growing political and social pressure to reduce fossil fuel use is a positive development, as it reflects a growing awareness of the need to take action to address the urgent environmental challenges that we face. While there are undoubtedly significant challenges to overcome, there is also cause for optimism, as we see more and more actors committing to ambitious targets and taking concrete steps to reduce their carbon footprint. With continued effort and commitment, we can work towards a future where renewable energy is the norm and fossil fuels are a thing of the past.

4. Opportunities for the Future of Fossil Fuels

Despite the challenges facing the future of fossil fuels, there are also several opportunities that could help sustain their use in a low-carbon world. The advancement of CCS technology is one of the most promising opportunities for reducing carbon-di-oxide (CO₂) emissions (Gabielli et al., 2020).

With CCS, CO₂ emissions from a variety of sources, such as fossil fuel power stations and other industrial activities, are captured and stored underground, where they are cut off from the environment and cannot cause climate change. This technology is particularly important because it can help address the ongoing challenge of reducing greenhouse gas emissions without compromising economic growth.

According to the International Energy Agency (IEA), CCS is a technology that has the potential to significantly reduce global CO₂ emissions and help the world achieve its climate goals. The IEA estimates that CCS could contribute up to 19% of the cumulative CO₂ emissions reductions required to

limit global warming to 2 degrees Celsius by 2050. This means that CCS could be a critical piece of the puzzle in the fight against climate change. CCS involves capturing CO₂ emissions from power plants and industrial processes and storing them underground, where they will not contribute to climate change. While the technology is still in its early stages, there have been some promising developments in recent years. For example, the Petra Nova project in Texas is the world's largest post-combustion carbon capture facility, capturing around 1.6 million tons of CO₂ per year. Despite the potential benefits of CCS, there are still some challenges that need to be addressed. One of the biggest challenges is the cost of the technology, which can be prohibitively expensive for many companies. Another issue is public perception, as some people are skeptical of the safety and effectiveness of CCS. However, with continued research and development, these challenges can be overcome. It is essential that we continue to invest in CCS as a viable solution for reducing greenhouse gas emissions and mitigating the impacts of climate change.



Fig. 4. Adaptation of new technologies to fossil fuels (Alagoz, 2023a)

Another opportunity lies in the potential role of natural gas as a "bridge" fuel (Gürsan and de Gooyert, 2021). While it is a fossil fuel, natural gas is considered to be cleaner burning than coal or oil, emitting less CO₂ into the atmosphere. Its versatility is also promising, as it can be used not only to generate electricity and heat, but also as a feedstock for the production of hydrogen, which is a promising clean energy source. Indeed, a study by the Oxford Institute for Energy Studies found that natural gas could play a key role in decarbonizing the energy system in the short to medium

term, particularly in developing countries. As such, it is important to explore the potential of natural gas as a means to reduce greenhouse gas emissions and transition towards a cleaner, more sustainable energy future. Additionally, it is worth considering the potential economic benefits that may arise from such a transition, as well as any potential environmental risks that may need to be mitigated along the way.

In addition to energy production, fossil fuels also play a

significant role in the production of petrochemicals and other non-energy applications, such as lubricants, asphalt, and chemicals used in the manufacture of consumer goods (Yadav et al., 2020). For example, petroleum is a key feedstock for the production of plastics, which are used in a wide range of consumer and industrial applications, such as packaging, toys, electronics, and construction materials. Petrochemicals are also used to make many other products, including paints, textiles, and pharmaceuticals. Furthermore, in a low-carbon world, the demand for plastics and other petrochemical products is likely to remain high, as they are essential to modern life. Fossil fuels will continue to be a crucial source of raw materials for the foreseeable future, providing the building blocks for many everyday products. Therefore, it is important to find ways to produce and use fossil fuels more sustainably, such as through CCS and the adoption of cleaner technologies.

4. Case Studies

As the world transitions to a low-carbon economy, several countries and companies are leading the way in reducing their dependence on fossil fuels. Here are some examples of successful transitions away from fossil fuels made by countries and researchers.

1- Costa Rica - In 2017, Costa Rica generated 99% of its electricity from renewable sources, including hydropower, wind, geothermal, and solar. The country has set a goal of becoming carbon neutral by 2050.

2- Denmark - Denmark is a leader in wind energy, and in 2019, wind turbines generated 47% of the country's electricity. The Danish government has set a goal of phasing out fossil fuels by 2050.

3- Tesla - The electric car manufacturer has played a key role in the transition away from fossil fuels in the transportation sector. Tesla's electric vehicles have helped to drive down the cost of batteries, making electric cars more affordable and accessible to consumers.

4- Alagoz (2023b) highlights the challenges and opportunities that the electrification of the transportation sector presents for the energy industry. Battery technology advancements, government policies, and decreasing costs are driving the acceleration of electrification, which can lead to a decrease in demand for oil-based products and an increase in demand for renewable energy sources. However, electrification also poses challenges such as developing a robust charging infrastructure network and overcoming consumer hesitancy towards electric vehicles. To adapt to this transition, oil and gas companies are diversifying their portfolios and investing in renewable energy sources, EV charging infrastructure, and battery storage.

Governments can also promote electrification by providing incentives and funding for renewable energy and EV infrastructure. The shift towards electrification can have social and environmental impacts, including negative environmental and social implications of mining materials used in EV batteries, such as lithium, cobalt, and nickel.

In addition to these examples of successful transitions away from fossil fuels, there are also several innovative fossil fuel projects and technologies being developed. These include:

1- CCS technology - It captures carbon dioxide emissions and stores them underground from power plants and other industrial sources. Several large-scale CCS projects are currently in development, including the Petra Nova project in Texas, which captures carbon dioxide from a coal-fired power plant and uses it to extract oil from a nearby field.

2- Hydrogen fuel cells - Hydrogen fuel cells use hydrogen gas to generate electricity, producing only water as a byproduct. Hydrogen can be produced from natural gas or other fossil fuels, but it can also be produced from renewable sources like wind and solar power. Several companies, including Toyota and Hyundai, are developing hydrogen fuel cell vehicles.

3- The energy transition is transforming the energy sector globally, and the oil and gas industry, in particular, is facing challenges due to decreasing demand and increasing competition from renewables. Alagoz and Alghawi's research paper (Alagoz and Alghawi 2023) provides an overview of the energy transition and proposes strategies for the oil and gas industry to navigate this transformative shift. These strategies include diversification into renewable energy sources, collaboration with relevant stakeholders, investment in research and development, and the adoption of new and innovative business models. The paper emphasizes the vital role of collaboration, research and development investments, and supportive policies in achieving a sustainable energy future. Investing in low-carbon technologies such as CCS can help reduce greenhouse gas emissions and contribute to global efforts to address climate change.

4- Alagoz et al. (2023) examine the impact of technology on the oil and gas industry, with a specific focus on innovative exploration and production techniques. They provide detailed insights into each technology and explain how they have improved efficiency, reduced costs, minimized environmental impact, and increased safety for workers. However, the authors also identify several challenges and limitations that hinder their widespread adoption, such as resistance to change, high costs, regulatory constraints, cybersecurity concerns, and technical limitations. The paper highlights the need for continued innovation and technological advancements to ensure the industry remains competitive and sustainable. Companies in the industry can position themselves for long-term success and contribute to a more sustainable and profitable future for the industry as a whole.

Overall, these case studies demonstrate that the transition away from fossil fuels is both possible and already underway. As new technologies and innovations continue to emerge, the transition to a low-carbon economy is likely to accelerate.

The future of fossil fuels is at a crossroads, with challenges and opportunities ahead. This review article has provided a comprehensive overview of the challenges and opportunities facing the fossil fuel industry in a low-carbon world. The

main challenges facing the industry include the need to reduce greenhouse gas emissions, declining costs of renewable energy, and political and social pressure to reduce fossil fuel use. However, several opportunities exist for the future of fossil fuels, including technological advancements in CCS, the potential role of natural gas as a "bridge" fuel, and the use of fossil fuels in non-energy applications.

The case studies highlighted in this review illustrate that the transition away from fossil fuels is not only necessary but also possible. Countries such as Norway and companies like Tesla and BP are already making significant progress towards a low-carbon future. Innovative fossil fuel projects, such as the use of geothermal energy in oil production, also offer promising avenues for reducing emissions. Looking to the future, the outlook for fossil fuels is uncertain. However, it is clear that the industry must adapt to a changing energy landscape and embrace new technologies and business models to remain competitive.

It is also critical for policymakers to create a stable and predictable regulatory environment that incentivizes investments in low-carbon technologies and reduces the risks associated with stranded assets. In conclusion, the challenges and opportunities facing the future of fossil fuels are complex and multi-faceted. While the industry faces significant headwinds, there are also promising opportunities to innovate and transform. Ultimately, the future of fossil fuels will depend on how well industry can adapt to a rapidly changing energy landscape and embrace the transition to a low-carbon world.

5. Conclusion

The future of fossil fuels is at a crossroads, with challenges and opportunities ahead. This review article has provided a comprehensive overview of the challenges and opportunities facing the fossil fuel industry in a low-carbon world. The main challenges facing the industry include the need to reduce greenhouse gas emissions, declining costs of renewable energy, and political and social pressure to reduce fossil fuel use. However, several opportunities exist for the future of fossil fuels, including technological advancements in CCS, the potential role of natural gas as a "bridge" fuel, and the use of fossil fuels in non-energy applications. The case studies highlighted in this review illustrate that the transition away from fossil fuels is not only necessary but also possible. Countries such as Norway and companies like Tesla and BP are already making significant progress towards a low-carbon future. Innovative fossil fuel projects, such as the use of geothermal energy in oil production, also offer promising avenues for reducing emissions. Looking to the future, the outlook for fossil fuels is uncertain. However, it is clear that the industry must adapt to a changing energy landscape and embrace new technologies and business models to remain competitive. It is also critical for policymakers to create a stable and predictable regulatory environment that incentivizes investments in low-carbon technologies and reduces the risks associated with stranded assets. In conclusion, the challenges and opportunities facing the future of fossil fuels are complex and multi-faceted. While the industry faces significant headwinds, there are also promising opportunities to innovate and transform.

Ultimately, the future of fossil fuels will depend on how well industry can adapt to a rapidly changing energy landscape and embrace the transition to a low-carbon world.

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