

<https://doi.org/10.32056/KOMAG2025.3>

The importance of Artificial Intelligence (AI) in the development of the market for alternative fuels from waste

Received: 20.03.2025

Accepted: 20.03.2025

Published online: 21.03.2025

Author's affiliations and addresses:

Non-toxic Polymers sp. z o. o.
AirStorage project

M. Szeligiewicza 1
40-074 Katowice, Poland

* Correspondence:

e-mail: ahabryn@interia.eu

Andrzej HABRYŃ *

Abstract:

The article "The importance of Artificial Intelligence (AI) in the development of the market for alternative fuels from waste" by Andrzej Habryń, MSc, presents the key role of AI in the transformation of the alternative fuels sector. Artificial intelligence improves production processes, optimizes waste management and supports the development of more efficient methods of processing raw materials. Thanks to the use of image recognition technology and sensors, it is possible to sort waste precisely, which increases the efficiency of recycling. AI algorithms allow for the optimization of raw material and energy consumption, minimizing costs and environmental impact. The article also discusses specific applications of AI, such as optimizing the transesterification process in biodiesel production, smart waste management systems, and the use of mineral catalysts in plastic pyrolysis. AI also enables data analysis and forecasting of market trends, making it easier to strategically plan and adapt production to changing demand. The presented case studies, m.in solutions from ZenRobotics or Canadian waste treatment installations, confirm the effectiveness of AI in supply chain management and optimization of recycling processes. While there are many benefits, AI implementation comes with challenges such as high upfront costs, integration with existing systems, and the need to ensure data security. Future AI developments in the alternative fuels sector could focus on further improving algorithms, better utilisation of waste, and integration with renewable energy sources. AI has the potential to significantly increase operational efficiency and contribute to a more sustainable use of resources, making it a key element in the future of energy and environmental protection.

Keywords: artificial Intelligence, alternative fuels, waste, sustainable development



1. Introduction

The alternative fuels market, a key element in global efforts for sustainable development, is undergoing a transformation under the influence of modern technologies. Artificial intelligence (AI) plays a particularly important role in this context, helping not only to optimise production processes, but also to manage waste and create new, more efficient methods of fuel production. This paper aims to bring closer how AI contributes to the development of this sector, focusing on key technological and operational aspects.

2. Automation and optimization of production processes in the alternative fuels market

One of the main applications of AI in the alternative fuels market is the automation of production processes. Artificial intelligence allows for quick and accurate sorting of waste, identification of its components useful for further processing, and effective management of the flow of materials. AI systems, using machine learning algorithms, can predict production needs, optimize the consumption of raw materials and energy, and minimize waste generation, which translates into lower costs and greater operational efficiency.

Artificial intelligence (AI) is disrupting the alternative fuels industry, especially in the context of automating production processes. These technologies not only increase operational efficiency, but also contribute to more sustainable management of natural resources and waste. In this chapter, we will discuss in detail how AI enables breakthroughs in traditional production methods, with both economic and ecological benefits.

In the alternative fuels market, efficient management of waste that can be converted into valuable energy sources is crucial. AI significantly improves the waste sorting process through the use of advanced image recognition technologies and sensors. These systems are able to quickly and accurately identify different types of materials, which is crucial for efficient recycling and waste minimization. This automation not only speeds up the process, but also increases its precision, reducing the risk of human error.

AI also plays a vital role in optimizing intralogistics. AI-driven systems can monitor and manage the flow of raw materials and semi-finished products in production plants on an ongoing basis, adapting operations to current production needs. Using data from a variety of sources, such as sensors and cameras, AI analyzes and predicts demand patterns, allowing for better production planning and reduced waste.

One of the biggest challenges in the production of alternative fuels is the efficient management of resources. AI can predict production needs based on historical data, current market trends, and projected operating conditions. These systems make it possible to optimize the use of raw materials and energy, which leads to reduced production costs and improved energy efficiency of plants. An example is the use of AI to control thermal processes in biogas production, where precise temperature and pressure control maximizes process efficiency.

Automation of production processes with the help of AI also has a direct impact on ecology. Algorithms can analyze processes in real-time, identifying and eliminating waste of raw materials. In addition, AI systems can monitor harmful emissions, helping to maintain compliance with environmental standards. This not only makes the alternative fuels industry more efficient, but also more environmentally friendly.

The automation and optimisation of production processes in the alternative fuels industry, supported by artificial intelligence, bring significant operational and environmental benefits. The implementation of these technologies is crucial for the future of the sector, enabling a more sustainable



and economically efficient development. Continuing research and investment in AI will be key to further improving these processes and increasing competitiveness in the global alternative fuels market [1].

When reviewing AI technologies used in the production of alternative fuels from waste, it is worth noting several interesting solutions implemented on a global scale.

2.1. Optimization of the Transesterification Process in Biodiesel Production

Apply machine learning methods such as Response Surface Methods (RSM) and artificial neural networks (ANN), is increasingly popular in optimizing the parameters of the transesterification process, which is crucial in the production of biodiesel from waste. With AI, it is possible to precisely model and forecast optimal reaction conditions, which increases the yield and quality of the final product. These technologies allow for precise adjustment of parameters such as reaction temperature, type of and catalyst concentration and substrate ratios, which directly translates into production efficiency [2].

2.2. AI-powered waste management systems

In projects related to the processing of waste into alternative fuels, it is important to effectively identify and segregate materials. AI systems using hyperspectral cameras and vision devices enable accurate recognition of the chemical composition of waste moving on conveyor belts. This data is used to optimize sorting and recycling processes. Such solutions not only increase the efficiency of waste management, but also contribute to the reduction of waste sent to landfills, which is important for environmental protection [3].

2.3. Pyrolysis of Plastic Using Mineral Catalysts

In the research conducted by Faisal Abnisa, natural mineral catalysts such as bentonite were used to pyrolyze plastic waste mixtures. The use of these catalysts has significantly increased the efficiency of producing liquid fuels from plastic, while reducing the formation of undesirable by-products such as tar and wax. Studies have shown that the use of bentonite can increase the yield of liquid fuel production by up to 60% compared with traditional pyrolysis methods [4].

The conclusions of the review of AI technologies used in the production of alternative fuels from waste focus on a few main findings. The use of artificial intelligence in the production of alternative fuels from waste significantly increases the operational efficiency, accuracy and environmental performance of these processes. Optimisation of reaction parameters, as in the case of biodiesel production, and advanced waste management systems, using AI to identify and sort materials, are just examples of how these technologies can revolutionise the industry. Through continuous improvement and integration of new solutions, the market for alternative fuels from waste has the potential to grow further, becoming even more sustainable and efficient.

3. Data analysis and forecasting in the production of alternative fuels from waste

AI is also used to analyze huge data sets (Big Data), which allows for a deeper understanding of the market and better adaptation to its requirements. Algorithms that analyze market trends, fuel demand and the efficiency of various production methods allow for the creation of precise forecasts, which are invaluable for strategic planning. Anticipating future market trends enables companies to proactively respond to changes before they become challenging.

The application of artificial intelligence (AI) to data analysis (Big Data) is revolutionizing the alternative fuels market, enabling companies to gain a deeper understanding of market dynamics and



better adapt to changing requirements. Processing huge data sets allows you to identify key trends that may affect the production, distribution and consumption of alternative fuels.

With AI technologies, companies can analyze market changes in real time, allowing them to respond quickly to new consumption patterns or changes in environmental regulations. For example, machine learning algorithms can predict an increase in demand for biofuels in regions that tighten emission standards for vehicles. Such forecasts are invaluable because they allow companies to plan production capacity, inventory, and marketing strategies.

The use of predictive models enables companies to predict future demand for different types of alternative fuels. This allows you to optimize your production processes to minimize costs and increase operational efficiency. For example, algorithms can analyze data from a variety of sources, such as historical sales trends, meteorological conditions, as well as economic macro indicators, to accurately forecast increases or decreases in demand.

AI also allows for the analysis of the effectiveness of various methods of producing alternative fuels, identifying the most cost-intensive aspects and proposing opportunities to improve them. Advanced algorithms can simulate different production scenarios, allowing the most efficient technologies and processes to be selected. This, in turn, leads to a reduction in production waste and better use of raw materials.

The use of AI in data analysis and forecasting contributes to increasing the competitiveness of companies operating on the alternative fuels market. Not only does it enable more efficient resource management and process optimization, but it also enables companies to adapt to rapidly changing market and environmental conditions. Investments in these technologies are crucial for long-term growth and stability in the alternative fuels industry.

There are many examples of AI applications in data analysis and forecasting in the area of alternative fuel production around the world. Research on data analysis and forecasting in the production of alternative fuels from waste involves the application of modern machine learning and big data analysis techniques to optimize processes and increase energy efficiency. Here are some notable use cases.

Research on the use of AI in forecasting and data analysis in the production of alternative fuels from waste includes a variety of techniques and applications. For example, the modeling and simulation of the green waste pyrolysis process, which enables the optimization of bio-fuel production, uses advanced software such as Aspen Plus to simulate the steady-state of the processes. This allows for accurate modelling of the chemical composition of waste and optimisation of operational parameters, which translates into higher efficiency and lower energy production costs.

In addition, machine learning techniques are used to predict the composition of pyrolysis products, which allows for better planning and process management in waste-to-fuel installations [5].

And in the field of demand forecasting in supply chains, big data analytics can predict demand for alternative fuels. The use of supervised and unsupervised learning allows you to identify patterns and relationships in your data, which is crucial for accurate forecasting and demand planning. An example is predictive models used to predict future demand based on historical product sales data [6].

These examples show how data analytics and machine learning technologies can significantly contribute to improving the efficiency of waste-to-waste production of alternative fuels, contributing to sustainability and better resource management.



4. Practical applications of artificial intelligence in the alternative fuels industry – case studies

4.1 Optimization of recycling and production processes

Finnish company ZenRobotics has developed an advanced waste sorting system that uses artificial intelligence and optical sensors to precisely segregate materials in real time. With this solution, it is possible to increase the efficiency of recycling by separating reusable raw materials more accurately [7].

Intelligent Control of Pyrolysis Process
Waste-to-fuel production: A Canadian waste-to-fuel plant used machine learning models to predict sensor readings, enabling proactive control of plant operations. These models predict sensor values 30 and 60 minutes in advance, which allows you to optimize the pyrolysis process and increase the efficiency of fuel production from waste [8].

4.2. AI in supply chain management

The use of AI in supply chain optimization allows large amounts of data to be processed faster, leading to lower inventory costs, reduced waste, and improved supply chain resilience. By analyzing IoT sensor data and real-time performance of machines, AI algorithms can predict when equipment may need maintenance, minimizing downtime and increases operational efficiency [9].

4.3. Novel approaches to waste-to-fuel

Scientific studies have shown that the use of machine learning algorithms, such as Gaussian regression optimized with a particle swarm algorithm, allows for precise prediction of the quantity and quality of biomass co-pyrolysis products and polymer waste. This makes it possible to optimize process conditions, which leads to increased efficiency in the production of fuels from waste [10].

4.4. Intelligent Waste Conversion Control Systems

The iCAREPLAST project developed advanced AI-based control systems for the treatment of non-recyclable plastic waste. The combination of pyrolysis, catalytic treatment and membrane technology makes it possible to convert this waste into valuable chemicals, such as aromatic compounds, which are essential for the production of high-quality polymers. The use of AI in this process allows for precise control of reaction conditions, which increases efficiency and reduces the formation of unwanted by-products [11].

4.5. Synthesis of chemical waste for the production of alternative fuels

A team led by Prof. Bartosz Grzybowski has developed a system that uses artificial intelligence to process chemical waste into valuable products, such as medicines or compounds useful in agriculture. The machine virtually tested billions of reactions between waste substances, identifying optimal synthesis pathways. This approach can also be applied in the context of converting waste plastics into alternative fuels.

The presented examples can prove that artificial intelligence plays a key role in the transformation of the alternative fuels market. AI supports not only technological processes, but also cost optimization, energy efficiency and sustainable development. The implementation of modern algorithms in this industry is an important step towards a greener and more efficient energy future [12].



5. Challenges and future directions

Despite numerous benefits, the implementation of AI in the alternative fuels market is not without its challenges. Issues such as ensuring data security, integration with existing systems, and high upfront costs are still relevant and need to be addressed. In the future, we can expect further development of AI algorithms that will further support the sustainable and economical use of waste in the production of alternative fuels.

Challenges in the implementation of AI in the alternative fuels market include the following areas:

5.1. Ensuring data security

As artificial intelligence (AI) gains prominence in the alternative fuels sector, there are serious concerns about data security. The industry faces the risk of cyberattacks that can lead to the loss of important information or even sabotage of operations. The development of advanced security systems is becoming crucial.

5.2. Integration with existing systems

Introducing new AI technologies into existing infrastructures can be difficult due to incompatible systems. Integration often requires costly and time-consuming modifications to existing production and operating systems.

5.3. High upfront costs

Investments in AI are usually large, especially in the early stages of technological implementations. These costs can be a barrier, especially for smaller businesses or emerging markets.

Future directions of AI implementation on the alternative fuels market include the following areas:

5.4. Development and improvement of AI algorithms

The future is expected to bring further improvements in AI algorithms, allowing the technology to be used even more effectively and efficiently in the production of alternative fuels. Advances in machine learning and deep learning will lead to better data processing and analysis.

5.5. Sustainable use of waste

AI has the potential to transform waste into valuable alternative fuels with minimal environmental impact. Further research could focus on optimising waste conversion processes, increasing their efficiency and reducing their environmental impact.

5.6. Integration with renewable energy sources

As the world transitions to more sustainable energy sources, AI can play a key role in integrating the production of alternative fuels with other forms of renewable energy, such as solar or wind power. The possibilities of such synergies can significantly contribute to improving energy efficiency and reducing CO₂ emissions.

5.7. Regulations and standards

As AI technologies become more widely used, new regulations may emerge to manage the impact of these technologies on the labor market, business ethics, and environmental protection. The development of standards for the use of AI in the production of alternative fuels will be important to ensure the responsible and sustainable development of this technology.



The implementation of AI in the alternative fuels market brings numerous challenges that must be addressed in order to fully exploit the potential of this technology. However, the future looks promising, with opportunities to further develop and apply AI in ways that can revolutionize the alternative fuels industry, making it more sustainable and economically efficient.

6. Summary

Artificial intelligence is transforming the alternative fuels market, bringing significant benefits in terms of efficiency, sustainability and innovation. Further investment in AI technologies and addressing the difficulties encountered will allow for more full use of the potential of waste as an energy source, opening up new opportunities for the future of energy and environmental protection.

Artificial intelligence (AI) is revolutionizing the alternative fuels market, opening up new opportunities for operational efficiency, sustainability, and innovation. The key aspects of this impact can be divided into several areas:

6.1. Operational Efficiency

AI increases the efficiency of alternative fuel production by automating complex processes, resulting in faster and more precise operations. For example, the use of AI algorithms in the optimization of production and logistics processes can significantly reduce the waste of raw materials and energy, which is crucial in the context of rising resource prices and the need to protect the environment.

6.2. Sustainable development

AI helps you achieve your sustainability goals by better managing resource consumption and reducing emissions. AI systems can analyze and predict the most efficient ways to treat waste, which promotes the creation of environmentally friendly technologies.

6.3. Innovativeness

The integration of AI into alternative fuel production processes is driving innovation, paving the way for the development of new technologies and methods that have the potential to revolutionize the entire industry. AI is fostering the exploration of new waste-to-energy capabilities, which could lead to the discovery of more efficient and less costly solutions.

6.4. Investments and Exploitation of Waste Potential

Increased investment in AI technologies can maximize the use of waste as an energy source. Disruptive technologies such as machine learning and advanced data analytics enable better understanding and utilization of waste, increasing its value as an energy resource.

6.5. The Future of Energy and Environmental Protection

AI has the potential to not only change the way we produce alternative fuels, but also contribute to overall improvements in energy efficiency and a reduction in human impact on the environment. Continuing to research and develop new AI solutions will be crucial for a sustainable future.

Challenges such as ensuring data security, integration with existing systems, and high upfront costs require constant attention and innovation to fully realize the potential of AI in the production of alternative fuels. Developing strategies to address these challenges is essential to maintaining the momentum of development and realizing the promising opportunities that AI opens up in this booming market.



References

- [1] Mitali Sarkar W.: „Renewable energy supply chain management with flexibility and automation in a production system.” *Journal of Cleaner Production*, 2021.
- [2] Omojola Awogbemi D.: „Application of machine learning technologies in biodiesel production process-A review,” *Energy Res.*, 2023.
- [3] Moore A.: „AI-Powered Waste Management System to Revolutionize Recycling,” *College of Natural Resources News*, 2023. [Online]. Available: <https://cnr.ncsu.edu/news/2023/11/ai-waste-management/>
- [4] Abnisa F.: „Enhanced Liquid Fuel Production from Pyrolysis of Plastic Waste Mixtures Using a Natural Mineral Catalyst,” *Energies*, 2023.
- [5] Mohammed A., Kabir J.: „Pyrolysis of Municipal Green Waste: A Modelling, Simulation and Experimental Analysis,” *Energies*, 2015.
- [6] Mahya F. Seyedan: „Predictive big data analytics for supply chain demand forecasting: methods, applications, and research opportunities,” *Journal of Big Data*, 2020.
- [7] ZenRobotics: „C&D Waste,” [Online]. Available: <https://www.terex.com/zenrobotics/waste-types/c-d-waste>
- [8] Breclj B.: „Forecasting Sensor Values in Waste-To-Fuel Plants: A Case Study,” *Artificial Intelligence*, 2022.
- [9] WM software house: „Poznaj 7 trendów w zakresie zastosowania AI w produkcji”. <https://vm.pl/poznaj-7-trendow-w-zakresie-zastosowania-ai-w-produkcji>
- [10] Shahbeik H.: „Using evolutionary machine learning to characterize and optimize co-pyrolysis of biomass feedstocks and polymeric wastes,” *Journal of Cleaner Production*, 2023.
- [11] CORDIS: „Przetwarzanie tworzyw sztucznych nienadających się do recyklingu w cenne substancje chemiczne dzięki zaawansowanej technologii” [Online]. Available: <https://cordis.europa.eu/article/id/451075-advanced-chemical-technology-transforms-non-recyclable-plastic-waste-into-valuable-chemicals/pl>
- [12] Polska Agencja Prasowa, „Polacy w "Nature": Sposób na recykling odpadów chemicznych? Przerabiać je na leki,” [Online]. Available: <https://www.pap.pl/aktualnosci/news%2C1178957%2Cpolacy-w-nature-sposob-na-recykling-odpadow-chemicznych-przerabiac-je-na>

