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ALTERNATIVE ENERGY SYSTEMS: THE ROLE AND DEVELOPMENT TRENDS OF BIOGAS TECHNOLOGIES

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Abstract
This article analyzes the role of biogas technologies in the alternative energy system, their historical stages of development, and modern development trends. The article covers the initial fermentation processes that arose in ancient China and India based on the processing of organic waste, scientific research conducted in the 17th–19th centuries, and the industrial application of biogas technologies in the 20th century. It also analyzes the development of biogas energy in Europe, the USA, China, and India, its role in the system of renewable energy sources, and the state policy and regulatory framework for the development of this sector in Uzbekistan. The article highlights the importance of biogas technologies in ensuring environmental safety, increasing energy efficiency, and developing a "green economy".

Keywords: Biogas, anaerobic digestion, methane, renewable energy, alternative energy, biogas plant, green economy, energy efficiency, development trends.

Introduction

Abstract (English as provided) – the article already includes an English abstract; I will keep it as is but ensure consistency.
The role of biogas technology in the alternative energy system is increasingly growing. Its roots go back to ancient times, but its scientific and industrial-scale development mainly occurred in the 18th–21st centuries.

Ancient times. In 2000 BC, in ancient China, using chicken manure and other organic waste, initial fermentation processes were carried out in simple underground structures. Also, in ancient India, local people observed the release of gas from the decomposition of organic waste and used it for their own needs. The formation and development of biogas technology in China intensified at the beginning of the 20th century, especially in the 1930s. During this period, the

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"Chinese fixed-dome biogas digester" was developed and widely spread. This device is a fixed-dome fermenter made of concrete or brick, and it is considered the first prototype of modern small-scale biogas plants. The early emergence of biogas technology in China is associated with the following factors: dense population and limited energy resources; large amounts of manure waste due to widespread livestock farming; traditions of efficient use of natural resources; and the use of residues from biogas production as fertilizer due to the high demand for fertilizer in agriculture.

Scientific discoveries. In 1667, the English scientist Robert Boyle observed the release of gas during the decomposition of organic matter. He determined that these gases were flammable and had physical properties different from air. Boyle noted that temperature, pressure, and lack of oxygen in the environment affect gas release. This gas, later called "methane", became the main component of biogas. Boyle's experiments were one of the first scientific steps to prove that gases such as methane are naturally released from decomposed organic matter, laying the foundation for further research by scientists such as Alessandro Volta and Humphry Davy. In 1776, Alessandro Volta observed gas bubbles rising to the water surface in swampy areas near Lake Como in Italy and decided to study the gas in these bubbles. He collected gas bubbles emerging from beneath decaying plant material in the swamp, placed them in a closed container, and tested their flammability. When he ignited the gas with a flame, it exploded, confirming that the gas was methane (CH_4). In 1808, Sir Humphry Davy determined that methane is released from plant materials. Davy aimed to determine what gases are released during the anaerobic decomposition of organic materials – specifically plant materials and animal manure – in closed containers. He placed soil and decaying plant materials into containers and kept them under conditions with limited air access. Over time, the released gases were collected, analyzed, and their flammability was tested. In this experiment, Davy determined that methane gas (CH_4) is released and noted that the gas is flammable, odorless, and lighter than air. This experiment scientifically confirmed the formation of methane from decaying plants in an anaerobic environment. These discoveries laid a solid foundation for the modern development of biogas technology.

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Industrialization period (19th–20th centuries). 1859: The city of Bombay in India witnessed one of the first practical applications of this technology. The first biogas plant designed to obtain energy from human waste was put into operation there. The system used sewage waste (mainly human feces and other organic waste) to extract methane gas and used it to illuminate city streets. Special underground fermentation ponds produced biogas by anaerobically decomposing waste. This system aimed both to sanitize waste and to produce energy, and it is considered an early example of modern biogas technologies. 1895: The city of Exeter in England conducted an experiment using biogas obtained from sewage sludge to illuminate city streets. This project was one of the world's first major steps in the practical use of biogas in cities and later served as a basis for similar projects throughout England and other European countries. 1920s–1930s: Germany and France rapidly developed biogas technology in the context of the economic crisis and energy resource shortages following World War I. In Germany, the production of biogas from agricultural waste (animal manure, plant residues) and municipal sewage systems became widespread. The goals were to produce electricity and heat, sanitize waste, and provide energy self-sufficiency for rural areas. In France, interest in processing agricultural and industrial waste also increased. Systems for extracting gas from sewage sludge were built near large cities such as Paris, and attempts were made to use biogas experimentally for transport (gas-powered buses). During this period, although biogas plants mainly operated using anaerobic fermentation, the technologies were still simple and had low efficiency. Nevertheless, the use of biogas in areas such as electricity generation, heating, and lighting began to expand.

Modernization period (late 20th – 21st centuries). 1970s–1980s: The global energy crisis prompted the introduction of millions of small-scale biogas plants in developing countries, particularly China and India. In India, the “National Biogas and Manure Management Programme” (NBMMP) was launched, aiming to build small biogas plants for each household in rural areas. By the 1980s, more than 1 million plants, mainly using cow manure, had been installed in the country. In China, biogas development programs also began after the energy crisis. By the mid-1980s, more than 5 million small biogas plants were operating in China. Cheap and simple underground dome fermenters of the “Chinese dome” type

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became especially widespread. From the 2000s onwards: In the European Union, the USA, and other developed countries, biogas technology was elevated to the level of state policy among renewable energy sources. The European Union's "Renewable Energy Directive" (2001/77/EC) and its updated version "Renewable Energy Directive" (2009) obliged member states to obtain at least 20% of their energy from renewable sources by 2020. Special subsidies and tax incentives were introduced for biogas projects. As a result, more than 10,000 biogas plants were built in Europe between 2000 and 2010, with countries such as Germany, France, and Denmark leading the way. In the USA, the "Anaerobe Digester Program" was launched under the "Farm Bill" in 2002. The Department of Energy (DOE) and the Environmental Protection Agency (EPA) funded grants, loans, and scientific research projects to develop biogas technologies. The Energy Independence and Security Act (EISA) adopted in 2007 aimed to use biomethane as a biofuel for transport. More than 500 large biogas plants were built for processing agricultural farms, municipal, and household waste. These trends are strengthening the position of biogas in the alternative energy system.

Development of biogas technology in Uzbekistan: The introduction of biological energy sources is one of the important priorities in transitioning the economy of Uzbekistan to innovative directions and environmentally friendly technologies. The relevance of this direction has been emphasized several times by the government: the decision of the First President of the Republic of Uzbekistan Islam Karimov dated March 1, 2013 "On measures for further development of alternative energy sources"; the decision of the President of the Republic of Uzbekistan Shavkat Mirziyoyev "On the program of measures for further development of renewable energy sources, increasing energy efficiency in economic sectors and the social sphere"; the decision of May 26, 2017 "On urgent measures to increase energy efficiency of the economy and social sectors, introduce energy-saving technologies and develop renewable energy sources"; the Presidential decision of August 22, 2019 "On approval of the strategy for the transition of the Republic of Uzbekistan to a 'green' economy" – the "Action Strategy for the transition to a green economy for 2019-2030"; and the decision of the Cabinet of Ministers of November 25, 2015 "On measures to stimulate the construction of biogas plants in republican livestock and poultry farms". These

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documents create a legal basis for the development of biogas technology in Uzbekistan, emphasizing the rational use of natural resources through its modernization and improvement of financial mechanisms. This is an important component of the country's strategy for transitioning to a “green” economy. In the coming years, the share of biogas in the alternative energy system is expected to increase further.

Conclusion

Although biogas technologies in the alternative energy system have been used since ancient times, their scientifically based and industrial-scale development mainly occurred in the 18th–21st centuries. The use of methane gas produced from the anaerobic decomposition of organic waste is becoming increasingly important in overcoming energy shortages and environmental problems. Development trends are aimed at integrating biogas with other renewable energy sources and strengthening its role in the global energy system.

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