



**ANALYSIS OF ECOLOGICAL-ECONOMIC
APPROACHES AND CIRCULAR ECONOMY MODEL
IN HOUSEHOLD WASTE RECYCLING**

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ABSTRACT

The article is devoted to a comprehensive study of the environmental and economic efficiency of converting household waste into resources based on the principles of a circular economy. The study systematically analyzes the techno-economic indicators of anaerobic fermentation and biogas technologies of organic waste, decentralized processing of plastic waste based on additive technologies, and the production of wood-polymer composites. The results show that anaerobic processing of organic waste sharply reduces greenhouse gas emissions and creates a constant flow of energy in the form of electricity and heat. Local processing of plastic polymers reduces logistics costs from \$19.64/kg to \$0.61/kg. The article scientifically substantiates the institutional and technological mechanisms of the transition to a circular economy and the possibilities of their application in the conditions of Uzbekistan.

INTRODUCTION. The global increase in the volume of household waste and the limited availability of natural resources indicate that the traditional linear economic model of “take-make-dispose” is in deep crisis. According to the United Nations Industrial Development Organization (UNIDO) and the World Bank, the share of organic matter and plastic in solid household waste is the highest. While organic waste can reach 50-60% of the total waste in



developing countries, polymer waste does not decompose in the environment for hundreds of years, posing a serious threat to ecosystems in the form of microplastics.

The concept of a circular economy is emerging as an effective solution to these problems. The circular economy is based on converting waste into secondary raw materials and resources, extending the life cycle of products, and maximizing resource efficiency. The use of household waste as a resource encompasses two main priority areas: converting organic waste into energy through bioconversion (anaerobic fermentation) and recycling plastic waste to produce composite and structural materials with high added value.

METHODOLOGY. The study used circular economy, life cycle analysis, mass and energy balance calculations, and econometric modeling methods. Based on international experience and UN and European Union standards, data on two main technological areas were analyzed: Bioconversion of organic waste. Anaerobic fermentation is the process of decomposition of complex organic compounds into biogas (CH_4 50-70%, CO_2 30-50%) and digested residue under the influence of microorganisms (hydrolytic, acetogenic and methanogenic bacteria) in an oxygen-free environment. The process consists of four stages: Hydrolysis → Fermentation → Acetogenesis → Methanogenesis. The methanogenesis stage requires a neutral pH (7.0–7.5) and a stable temperature regime (mesophilic 35°C or thermophilic 55°C).

Distributed recycling of polymer waste and Wood-plastic composites. In the processing of plastic waste (HDPE, LDPE, PP, PET), decentralized processing technology and methods for the production of wood-polymer composites based on additive manufacturing at the local level were compared with centralized industrial processing enterprises. In the preparation of wood-polymer composites, secondary polymers are mixed with wood flour and binders in a ratio of 40/54/3/3 and formed by extrusion.

RESULTS. The obtained indicators on the net energy balance (the difference between the energy produced and the energy consumed) of organic household waste processing technologies are presented in Table 1. The analyses show that in an anaerobic fermentation system aimed at 100% electricity generation, a net energy balance of +450 kWh is provided from 1 ton of bio-waste.

Table 1

Difference between energy produced and energy consumed

Technological Process / Method	Electricity (kWh/t)	Heat (kWh/t)	Fuel (kWh/t)	Total Net Energy (kWh/t)
Anaerobic Digestion (100% Electricity)	130	320*	0	+450
Anaerobic Digestion (100% Motor Fuel)	-120	-100	600	+380



Anaerobic Digestion – Cogeneration (50/50 CHP)	5	110*	300	+415
Wood Residue Heating System	0	1000	-25	+975
Open Composting System	0	0	-30	-30
Enclosed Composting System	-100	0	-20	-120

Table 1. Net Energy Balance of Different Biowaste Treatment Technologies (based on UNIDO MSWM data).

Note: Heat energy is often consumed on-site at industrial facilities.

The analysis shows that traditional aerobic composting processes have a negative energy balance (-30 to -120 kWh/t) because they consume electricity and fuel for constant aeration and mechanical mixing. Anaerobic digestion, on the other hand, captures methane gas, converting it into a renewable energy source and preventing the release of greenhouse gases into the air. Traditional centralized plastic recycling systems face high logistics costs due to the long-distance transportation of low-density plastics. The cost of producing 1 kg of rPET pellets using a decentralized recycling model based on additive manufacturing at the local community level is calculated in Table 2.

Table 2

Resource, Time, and Operating Cost Requirements for Processing 1 kg of Recycled PET (rPET)

Stage	Resource Source	Quantity	Time (Hours)	Cost (\$)
Collection	Volunteer labor	N/A	N/A	\$0.00
Sorting	Volunteer labor	N/A	N/A	\$0.00
Washing	Water resource	10 gallons	0.5	\$0.02
Drying	Electricity	1.88 kWh	6.0	\$0.45
Shredding	Electricity	0.75 kWh	8.0	\$0.14
TOTAL OPERATING COST	Total local resources	1 kg rPET	14.5	\$0.61



Table 2. Cost Structure for Producing 1 kg of rPET Granules at a Distributed Recycling Center (based on research conducted at the University of Michigan).

The results, when compared to the market price of commercial rPET pellets (\$19.64/kg), confirm the possibility of reducing economic costs by 97% through a decentralized recycling model based on additive manufacturing. This demonstrates the high profitability of converting plastic waste into finished 3D printed and structural products for local communities and small industrial enterprises.

Moisture absorption and UV degradation are the main problems in wood-polymer composites made from secondary polymers. In experiments, the introduction of 3% Pyrolysis carbon residue (PB_C4_CB) into the PB_C4 (69% PE blend) sample increased the hydrophobicity of the material and reduced the moisture absorption index from 14.8% to 12.4%. While the flexural strength of the plain composite decreased by 24% during freeze-thaw cycles, the composite with pyrolysis carbon residue retained 100% of its mechanical properties and the flexural modulus increased by 7%.

CONCLUSIONS AND PRACTICAL RECOMMENDATIONS

Energy and environmental efficiency: Processing organic household waste through anaerobic fermentation allows for the extraction of +450 kWh of pure energy from 1 ton of raw materials and the preparation of high-quality digestate that can replace mineral fertilizers.

Economic advantage of local processing: Decentralized processing of plastic waste through Additive Manufacturing and Melt-Forming Granulation technologies eliminates logistics costs and keeps the cost of raw materials at \$0.61/kg.

Improving material quality: The use of polyethylene modifiers modified with 3% Pyrolysis carbon residue and Maleic anhydride in Wood-Plastic Composites made from secondary polymers increases the resistance of the material to ultraviolet light and moisture, extending its service life by 2-3 times.

Institutional recommendations: It is necessary to establish a system of household waste sorting at source, introduce "green" tariffs and tax incentives for recycling enterprises, and develop public-private partnerships.

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