# The impact of fuel delivery logistics on the cost of thermal energy on the example of biofuels boilers in Ukraine

**O Yu Bogoslavska[1], V V Stanytsina[1], V O Artemchuk[2,3], O V Maevsky[4], O M Garmata[5], V M Lavrinenko[5] and I S Zinovieva[6]**

[1] Institute of General Energy of NAS of Ukraine, 172 Antonovycha Str., Kyiv, 03150, Ukraine
[2] G. E. Pukhov Institute for Modelling in Energy Engineering of NAS of Ukraine, 15 Generala Naumova Str., Kyiv, 03164, Ukraine
[3] State Institution "The Institute of Environmental Geochemistry of National Academy of Sciences of Ukraine", 34a Palladin Ave., Kyiv, 03142, Ukraine
[4] Polissia National University, 7 Stary Boulevard, Zhytomyr, 10002, Ukraine
[5] National Pedagogical Dragomanov University, 9 Pyrohova str., Kyiv, 01601, Ukraine
[6] Kyiv National Economic University named after Vadym Hetman, 54/1 Peremogy Ave., Kyiv, 03057, Ukraine

E-mail: olga.bogoslavska@gmail.com, st_v_v@hotmail.com, ak24avo@gmail.com, alexbel740@gmail.com, a.canon@ukr.net, viktlav@ukr.net, ira.zinovyeva@kneu.edu.ua

**Abstract.** One of the important directions for achieving the goals of sustainable development and decarbonization is to increase the share of biofuels, including in heat supply systems. In this case, an important factor in deciding on the use of biofuel boilers is the cost of fuel, which is affected by the delivery logistics. The authors determined the impact of logistics for different types of fuel for low-power boilers (0.5 and 1 MW, burning biofuels) on LCOH. The calculations take into account the existing rates of environmental tax. The paper considers the transportation of biofuels by road to small consumers over short distances (within a radius of several hundred kilometers). The study showed that the cost of delivery of pellets from producer to consumer can be up to 20% of their cost. It is established that the transportation of a ton of pellets per 1 km increases the cost of this ton by about 1.35 UAH, therefore, the logistical component in the final cost of pellets can be significant.

## 1. Introduction

One of the important directions for achieving the goals of sustainable development and decarbonization is to increase the share of biofuels, including in heat supply systems.

Recently there have been significant changes in the energy sector of Ukraine, including the use of renewable energy sources, as well as individual and centralized heating. The issues of energy safety of the country, reduction of dependence on imported energy carriers, especially natural gas, are becoming increasingly important. A number of documents have been adopted, strengthening the legislative field for the introduction of renewable energy sources (RES), in particular the use of biomass, as well as stimulating the replacement of natural gas in heat supply with other energy carriers [1]. The actuality of biomass energy and fossil fuel substitution projects has increased significantly. Biomass is a renewable local fuel that, if used sustainably, is a virtually inexhaustible source of energy.

Water heating boilers on biomass are widely used for heating individual structures and private houses, as well as several structures and even micro districts when they are used in the centralized heat supply. The main types of fuel for such heating equipment are anthracite, peat, wood, wood pellets, sunflower husk pellets, straw briquettes, wood chips and wood waste.

Boilers for biofuels are usually projected on the thermal capacity of not more than 1 MW, because with a higher capacity significantly complicates their operation.

It is not only the procurement prices for different types of wood and agro-biomass that are an important factor in the choice of fuel. The logistical component also makes a significant and sometimes decisive contribution. Transportation of biofuel over long distances leads to high freight costs, as well as significant costs for handling operations, which significantly increases the final cost of fuel.

For instance, burning sunflower husks in the boiler of an oil extraction plant, or using wood waste for CHP at a woodworking plant, because the logistics expenses in this case are minimal and no money is spent on waste disposal [2].

Papers [3–9] are devoted to the study of the impact of biofuel delivery on the cost of heat.

The most relevant for this study is the paper [3], in which the heat supply problem of the city of Baikalsk is considered. The most environmentally friendly solution to this problem is using timber, which was felled during forest sanitation outside the Anchuk village. Environmental friendliness and other advantages of biofuel are the main reason for using this type of heat source. The article [3] presents a comparative analysis of the production and delivery costs of the fuelwood chips and pellets for Baikalsk. Pressed fuel wood chips and chips with standard bulk density are considered. The Levelized cost of heat, unit cost, and capital costs are used as indicators of the economic efficiency of pellets and fuelwood chips.

Authors of [4] show, that combined heat and power (CHP) production in combination with a district heating (DH) grid gives an energy-efficient use of wood fuels.

Paper [7] discusses alternatives for biofuel-based district heating using simulation analysis in a real-life case example and illustrates the current supply chain structure of forest chips from harvest to the heat energy plant. Also, the study demonstrates how a regional bioenergy system could be developed with the help of a simulation model for evaluating the feasibility of different wood fuel supply chain options. The model mimics a real-life example of an industrial area in a small Finnish municipality planning to invest in a CHP plant.

Given that Ukraine is the largest country in Europe, the transportation of biofuels in it can be carried out over long distances. Thus, the aim of this study is to investigate the impact of delivery logistics of biofuel on the cost of thermal energy, which will develop practical recommendations for the use of remote sources of biofuels for low-power solid fuel boilers.

## 2. Methods

### *2.1. Features of biofuel transportation*

The profitability of a boiler plant depends on a well-functioning logistics system. After all, delivery requires certain costs, and if this process is not optimized, these costs can be too high. It is important to ensure full protection of fuel, especially pellets, from moisture, precipitation and other damages during transportation. Therefore, the best option will be closed bodies, hoppers, wagons. The use of fuel pellets or granules was chosen for analysis only in this article.

Pellets for solid fuel boilers can be loaded:

- in bulk;
- in big-bags;
- in bags of different volumes.

Types of packaging depend on two factors. The first - how exactly is planned to provide transportation of fuel. The second - how it will be used.

The high bulk density of pellets is a positive feature, which reduces the cost of transportation, in contrary to packaging in big-bags and bags. In fact, loading and unloading of pellets in bulk, as well as their feeding into the boiler, is easily automated, which reduces the cost of these works.

Bulk delivery of pellets is used in most European countries, which allows significant savings on packaging and loading and unloading operations. More than 50% of pellets are burned in the boilers of large boilers and CHP plants in Europe. Therefore, it is much easier and more profitable for them to purchase such fuel in bulk from vehicles, to reload it from wagons, ships or motor vehicles into hoppers from which it will be fed directly to the boiler.

Packaging in big-bags. Fuel pellets, like many other bulk products, are often packaged in large, most often propylene bags - the so-called "big-bags". Such packaging is quite convenient for transportation, provides protection of the product from physical effects, allows the use of conventional techniques for loading and unloading operations (crane, forklift). In some cases, delivery of pellets to consumers is also made in big bags, which are then loaded into the furnace with a crane or forklift. In addition, big-bags are suitable not only for transportation of pellets, but also briquettes. In relatively small industrial boilers, large bags play the role of storage, from which fuel is automatically fed to the boilers.

Packing in ordinary bags. Ordinary polyethylene bags of different volumes are often used for transportation. Most often small packaging is a practical choice for private households. Such bags are mostly designed for weights of 10 to 20 kilograms. That is, they can be easily carried by hand and put pellets in the boiler. The bags with pellets are placed on pallets for easy loading and unloading onto trucks. Most often the bags are packed with extra-class pellets intended for private consumers who burn them in special stoves and fireplaces or use them for barbecues instead of traditional charcoal.

The choice of specific transport for delivery of solid biofuel depends on the location of the consumer. Let's take a look at several options.

River and sea transportation is an inexpensive way to transport biofuel over long distances. Depending on customer requirements and plant capabilities, pellets can be loaded on a ship in bulk, in big-bags or in consumer packaging. Many European customers prefer to receive fuel in bulk. Most customers who consume pellets in large volumes, have their own terminal complexes in sea and/or river ports. Transportation to specific customers is carried out from these complexes.

Transportation by river within one country is performed if the producer is located in the immediate vicinity of the waterway. However, this method of delivery has its disadvantages - one of them is that not all rivers are navigable in winter. And it is the winter time of the year that is the most important for the solid biofuel market.

Trucks is one of the most expensive, but also the most flexible method of delivery. This type of transport is used if you need to deliver pellets for a relatively short distance (the best option if you need transportation for a few hundred kilometers, no more). Handling can be done in bulk, if a covered crate. If the products are packed, cranes or forklifts are used. If the company's production facilities are located far from railroads or river (sea) ports, it is also more reasonable to use trucks [2, 10, 11].

Selection of a specific transport for the delivery of solid biofuel. Let's look at how the process of biofuel delivery is organized in Germany and Austria [12, 13]. The specialized truck equipped with a pneumatic unloader is used in most cases, for the transportation of pellets. Such truck has a large tank, which is divided into several parts (the container can be mounted directly on the truck chassis or on a trailer attached to the truck). The tank is divided into four chambers, so it can be unloaded at different locations, at different consumers. When delivery of solid biofuel is required, the vehicle loads the chambers. The pellets are fed by a conveyor belt. At the end of the transporter there is a sleeve made of synthetic materials. It is lowered into the chamber and the pellets are poured into this chamber of the tank. The unloading process is not complicated. The machine has a hose that connects to the pellet storage unit. The driver of the vehicle with the help of the control panel starts the compressor. The average pressure of the compressor reaches a mark of 0.5 bar. Such pressure is enough to pump over a hose up to 400 kilograms of pellets in a minute. If the hose is too long, the pressure drops to about 0.3 bar, and the fuel transfer rate drops to 340 kilograms a minute. The truck can carry from 15 to 28 tons. It usually takes one working day to load, deliver and unload. The popularity of solid biofuels has provoked a significant expansion of the network. That is why the warehouses are designed to cover the largest radius of 150 km.

Such transportation technology is not used, primarily because consumers do not have the necessary equipment in Ukraine. Indeed, unloading must be carried out in a specialized container, from which the fuel is automatically transferred to the furnace chamber of the boiler. As soon as Ukrainian consumers will actively install boilers that run on alternative energy sources and start equipping their homes accordingly, modern equipment will appear in Ukraine.

Rail transportation is the best option for transporting large amounts of biofuel to industrial consumers, who usually have rail infrastructure, i.e.: sidings; shunting locomotives; hoppers unloading devices, etc. Pellets are transported by railroad both in covered wagons - in bags or big-bags, and in special hopper wagons designed for transportation of bulk cargo [2, 10, 11].

For a product, the retail price of which rarely exceeds 250 Euros per ton, and the production cost is 60-80 Euros per ton, the efficiency of transport and logistics operations is one of the key factors of profitability. The cost of delivering pellets from the manufacturer to consumers can be up to 50% of the cost of production. Savings of 1 euro per ton for a large producer will save tens of thousands of Euros over a year and will amount to only 3-4% of logistics costs [2].

### *2.2. Delivery of solid biofuel within Ukraine*

Pellets and briquettes are commonly used in the Ukrainian market. They are made from different raw materials:

- in bulk;
- wood;
- sunflower husk;
- husks of other crops;
- straw;
- peat.

Often the supplier announces the price of pellets EX-works (warehouse) in terms of INCOTERMS-2020, without taking into account the loading and unloading of vehicles, delivery to the place of unloading, as well as transporting pellets to the boiler hopper.

Delivery can be carried out as indirectly from the manufacturer's warehouse, as well as from the industrial warehouse. Of course, delivery from the manufacturer's warehouse without reloading is better, since the reloading of pellets does not improve their quality, and the conditions of storage in the secondary warehouse may not meet the requirements (above all for the indicators of volatility).

Most manufacturers deliver pellets packed in plastic or papery bags. Delivery of pellets with the help of specialized transport in Ukraine to the country we have not yet seen.

Also, it should be noted that any reloading increases the number of harmful particles of pellets, not given for combustion. According to the [14] one "hard" reloading of 25 kg of pulp (eg, warehouse-machine) reduces the amount of waste approximately by 0.15-0.3% of the total mass of the pulp.

If the pellets were brought in an open car (without a tent) in the autumn-winter period and some of the bags are blocked by the road pond, there is a chance that these pellets are not suitable for use, because where the pond, there is often water.

Terms of storage of pellets depend primarily on the conditions of their packaging. As a general rule, pellets are not subjected to direct exposure to water, but on the other hand, pellets actively absorb moisture from the ambient air. In addition, in winter, when you put pellets in a warm room can create condensation, so the question of how the pellets are packed, comes to the fore [14].

In this work, we will consider biofuel in the form of pellets, which are packed in a trolley of 1 ton. The size of this bag is 90×90×190 cm. The volume of the package is 1.54 cubic meters.

### *2.3. The levelized cost of heat*

For economic efficiency comparison of heating projects with different biomass types boilers, the method of levelized cost of heat was used [15, 16].

The levelized cost of heat (LCOH) is widely used for determining optimal projects in heating [17–25]. In particular, work [18] proposed a new dynamic price model based on the LCOH and the predicted hourly heat demand.

Sometimes the term LCOH is used when it comes to burning fuel and producing energy as heat. This method is universal and convenient when comparing different types of heat production technologies and is used by many organizations, including the International Energy Agency (IEA). The general formula of this method is as follows:

$$LCOH = \frac{\sum_{t=1}^{N} \frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{H_t}{(1+r)^t}}, \tag{1}$$

where

$I_t$ is investment expenditures in year $t$;
$M_t$ is operations and maintenance expenditures in year $t$;
$F_t$ is fuel expenditures in year $t$;
$H_t$ is energy (heat) generation in year $t$;
$r$ is discount rate;
$N$ is lifetime of the technology.

The use of LCOH makes it possible to specify prospective heat generation technologies for implementation. This in turn is needed to forecasting the structure of fuel and energy consumption for heating systems [25].

The environmental factor in the LCOH it is necessary to take into account as both the environmental requirements for incinerators and the environmental tax rate are constantly growing. Therefore, when determining the LCOH for small combustion plants, it is necessary to take into account the environmental tax [26].

For a more accurate calculation of LCOH it is also necessary to take into account the cost of delivery of biofuels, therefore it is proposed to calculate the average cost of thermal energy for the life cycle, taking into account the delivery logistics, by the expression:

$$LCOH_{F^{log}} = \frac{\sum_{t=1}^{N} \frac{I_t+M_t+F_t+F_t^{log}}{(1+r)^t}}{\sum_{t=1}^{N} \frac{H_t}{(1+r)^t}}, \tag{2}$$

where $F_t^{log}$ is fuel delivery logistics expenditures in year $t$.

Thus, the logistic component of LCOH ($\Delta LCOH_{Flog}$) can be defined by expression:

$$\Delta LCOH_{Flog} = LCOH_{Flog} - LCOH. \quad (3)$$

## 3. Results

We chose biofuel boilers of Ukrainian production by KZOT and Gefest 500 and 1000 kW capacities, which burn such fuel: straw pellets, sunflower husk pellets and wood pellets. Calculations were made for three distances - for 100, 300 and 500 km. Such distances are selected as averages within different types of administrative units of Ukraine - within one district, one region, and between regions.

Fuel price is taken from online ads: wood pellets is 5000 UAH/t, straw pellets is 3300 UAH/t, sunflower husk pellets is 3980 UAH/t. Usually the cost of fuel is indicated without the cost of delivery. The cost of delivery is 27 UAH/km by truck with a capacity of 20 tons [27].

The discount rate is 10%, salary of boiler house employees - 6500 UAH/month.

The cost of boilers is taken from the Internet ads as follows (table 1) [28, 29]. Due to the significant increase in natural gas, which took place in autumn 2021, pellets became more expensive too, for example, in autumn 2020 wood pellets cost 2100 UAH/t, sunflower husk pellets - 1200 UAH/t. The cost of motor fuel and delivery [27] has grown less rapidly over the same period.

**Table 1.** Boilers and their main characteristics in January 2022.

| The boiler | The boiler‘s power, kW | Efficiency, % | The boiler‘s cost, UAH |
|---|---|---|---|
| KZOT ARS 500 Comfort | 520 | 85 | 294579 |
| KZOT BRS 500 Comfort BM | 500 | 92 | 293980 |
| Gefest Profi-P 500 | 500 | 92 | 248400 |
| KZOT ARS 1000 Comfort | 1000 | 85 | 446344 |
| KZOT BRS 1000 Comfort BM | 1000 | 92 | 430883 |
| Gefest Profi-P 1000 | 1000 | 91 | 465000 |

The exchange rate of the national currency - the hryvnia (UAH) - is constantly unstable and has fluctuated in the last 5 years in the range of 25.24-35.35 UAH/EUR [26]. The exchange rate of the National Bank of Ukraine is 31,74 UAH per 1 euro on 1 February 1, 2022.

Using the formula (1) is calculated LCOH, using the formula (2) - levelized cost of heat taking into account the cost of fuel delivery $LCOH_{Flog}$ for 3 cases - delivery of pellets at 100, 300 and 500 km, as well as using the approach of [26] calculated levelized cost of heat taking into account the environmental tax $LCOH_{T_{eco}}$ (table 2). The fuel component of LCOH, which takes into account the cost of fuel and electricity, was also calculated. Environmental tax rates have increased since January, 2022 and their values are given in [30].

The results of calculations show that at a transport distance of 100 km the logistics component $\Delta LCOH_{Flog}$ is 2.6-3.9%, for a transport distance of 300 km - 7.7-11.7%, for a transport distance of 300 km - 12.8-19.5%. The minimum value is for boilers burning wood pellets, the maximum is for boilers burning straw pellets. Taking into account the cost of delivery increases LCOH by 34.95-44.81 UAH/Gcal for a transport distance of 100 km, by 104.85-134.42 UAH/Gcal for a transport distance of 300 km, by 174.75-224.04 UAH/Gcal for a transport distance of 500 km. The minimum value is for boilers burning sunflower husk pellets, the maximum is for boilers burning straw pellets.

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**Table 2.** Levelized cost of heat (LCOH) with and without taking into account the cost of fuel delivery and environmental tax from boilers that burn different types of pellets UAH/Gcal.

| The boiler, fuel type | LCOH | Fuel component LCOH | $LCOH_{T_{eco}}$ | $LCOH_{F^{log}}$ 100 km | $LCOH_{F^{log}}$ 300 km | $LCOH_{F^{log}}$ 500 km |
|---|---|---|---|---|---|---|
| KZOT ARS 500 Comfort, wood pellets | 1549.3 | 1448.7 | 1555.7 | 1589.0 | 1668.2 | 1747.5 |
| KZOT ARS 500 Comfort, sunflower husk pellets | 1189.7 | 1089.1 | 1198.7 | 1227.6 | 1303.5 | 1379.3 |
| KZOT ARS 500 Comfort, straw pellets | 1179.5 | 1079.6 | 1187.9 | 1224.3 | 1313.9 | 1403.5 |
| KZOT BRS 500 Comfort BM, wood pellets | 1442.2 | 1338.5 | 1447.0 | 1479.8 | 1555.1 | 1630.4 |
| KZOT BRS 500 Comfort BM, sunflower husk pellets | 1260.9 | 1157.2 | 1270.6 | 1300.3 | 1379.2 | 1458.1 |
| KZOT BRS 500 Comfort BM, straw pellets | 1101.2 | 997.5 | 1107.9 | 1142.4 | 1224.9 | 1307.3 |
| Gefest Profi-P 500, wood pellets | 1434.7 | 1338.5 | 1439.5 | 1472.4 | 1547.7 | 1622.9 |
| Gefest-Profi P 500, sunflower husk pellets | 1102.5 | 1006.2 | 1109.6 | 1138.3 | 1210.0 | 1281.7 |
| Gefest-Profi P 500, straw pellets | 1104.7 | 1008.4 | 1111.5 | 1147.7 | 1233.7 | 1319.8 |
| KZOT ARS 1000 Comfort, wood pellets | 1526.6 | 1448.7 | 1537.5 | 1566.0 | 1644.8 | 1723.7 |
| KZOT ARS 1000 Comfort, sunflower husk pellets | 1154.0 | 1089.1 | 1167.5 | 1191.6 | 1266.9 | 1342.2 |
| KZOT ARS 1000 Comfort, straw pellets | 1157.5 | 1079.6 | 1170.5 | 1202.3 | 1291.9 | 1381.5 |
| KZOT BRS 1000 Comfort BM, wood pellets | 1415.0 | 1338.5 | 1424.8 | 1451.7 | 1525.2 | 1598.7 |
| KZOT BRS 1000 Comfort BM, sunflower husk pellets | 1146.4 | 1004.1 | 1158.5 | 1181.3 | 1251.2 | 1321.1 |
| KZOT BRS 1000 Comfort BM, straw pellets | 1074.0 | 997.5 | 1085.6 | 1115.2 | 1197.7 | 1280.1 |
| Gefest Profi-P 1000, wood pellets | 1432.8 | 1353.2 | 1442.7 | 1469.5 | 1543.0 | 1616.5 |
| Gefest Profi-P 1000, sunflower husk pellets | 1096.9 | 1017.3 | 1109.2 | 1131.8 | 1201.7 | 1271.6 |
| Gefest Profi-P 1000, straw pellets | 1088.0 | 1008.4 | 1099.9 | 1130.2 | 1214.4 | 1298.6 |

The fuel component is 91-95% of LCOH.

The value of environmental tax is calculated for 2022 for the following pollutants -

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$CO_2, NO_x, SO_2$, solids. Now in Ukraine exist an environmental tax for $CO_2$ emissions from the combustion of all biomass [31]. According to the Tax Code of Ukraine, business entities that carry out such emissions in the amount of not more than 500 tons per year are not payers of the environmental tax for carbon dioxide emissions, i.e. the tax base for carbon dioxide emissions is reduced by such emissions of 500 tons per year. $\Delta LCOH_{T_{eco}}$ is 0.33-1.12% of LCOH, in monetary terms this component is 4.77-13.52 UAH/Gcal. The minimum value is for boilers 500 kW burning wood pellets, the maximum is for boilers 1 MW burning sunflower husk pellets.

## 4. Discussion and conclusions

In the autumn of 2021, the cost of natural gas and biofuels increased many times over. Fuel delivery also became more expensive, but the increase was not so significant. The high cost of gas encourages the use of other sources for heat supply, including using biofuels more widely. Ukraine is a large country, and at current natural gas prices, customers buy pellets with delivery not only within one or two regions, but also within half of the country. The results of calculations show that under the condition of pellets transportation for 500 km the cost of heat increases by 13-20%. The minimum value is for boilers burning sunflower husk pellets, the maximum is for boilers burning straw pellets.

The results of calculations show that the environmental tax component is many times smaller than the fuel delivery component and at current environmental tax rates is 1% of LCOH, which does not significantly affect the Levelized cost of heat. An approach in which biofuels are considered $CO_2$-neutral and no tax is paid for $CO_2$ emissions from their combustion will not significantly affect LCOH.

Different types of pellets have different calorific value and cost. Wood pellets are 20-30% more expensive than other pellets, but have the lowest calorific value. The highest cost has heat produced from wood pellets - an average of 20% more expensive. Taking into account the cost of logistics does not change this - heat produced from wood pellets remains 20% more expensive. Even with pellet delivery over 500 km, the LCOH will be lower for boilers burning sunflower husk pellets and straw pellets compared to wood pellets and no shipping charges.

Thus, it is most economical to use sunflower husk pellets and straw pellets. Decarbonization is a separate issue, in many countries biofuels are considered carbon-neutral in addition to the cost of producing and transporting fuels. And from this point of view it is most expedient to use fuels with the shortest way of transportation.

Although biofuels are considered to be more environmentally friendly because they are considered $CO_2$-neutral, their combustion produces emissions of other pollutants and ash. It is obvious that biofuel ash has a different composition and physicochemical properties than coal ash, but all ash dumps from solid fuel combustion have a negative impact on the environment and human health [31–44]. Further research should consider the ways and costs of handling pellet ash in the LCOH.

## ORCID iDs

O Yu Bogoslavska https://orcid.org/0000-0002-4286-7505
V V Stanytsina https://orcid.org/0000-0002-1005-6185
V O Artemchuk https://orcid.org/0000-0001-8819-4564
O V Maevsky https://orcid.org/0000-0002-0335-6358
O M Garmata https://orcid.org/0000-0003-1680-441X
V M Lavrinenko https://orcid.org/0000-0001-5359-8702
I S Zinovieva https://orcid.org/0000-0001-5122-8994

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