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Transport in the biomass supply chain for a power plant

Transport w łańcuchu dostaw biomasy dla elektrociepłowni

Abstract. The article discusses the planning of biomass supply chain for combined heat and power plants in the context of energy security. In order to guarantee the continuity of energy and heat supplies, the biomass CHP plant must have adequate raw material reserves. Properly selected supply processes can significantly reduce the operating costs of a CHP plant. In a crisis situation, the logistics chain boils down to supply logistics. This ensures combined heat and power plant's security of energy supply continuity through proper formulation of biomass supply procedures, as well as supporting its efficiency.

Key words: transportation, supply chain, biomass

Synopsis. W artykule omówiono planowanie łańcucha dostaw biomasy do elektrociepłowni w kontekście bezpieczeństwa energetycznego. Elektrociepłownia konsumująca biomasę, aby zagwarantować ciągłość dostaw energii i ciepła, musi posiadać zapasy surowca. Odpowiednio dobrane procesy zaopatrzenia mogą zasadniczo ograniczyć koszty funkcjonowania elektrociepłowni. W sytuacji kryzysowej łańcuch logistyczny sprowadza się do realizacji procesów zaopatrzenia. Zapewnia to elektrociepłowni bezpieczeństwo ciągłości dostaw energii poprzez właściwe sformułowanie procedur dostaw biomasy, a także wspiera osiągnięcie efektywności dostaw.

Słowa kluczowe: transport, łańcuch dostaw, biomasa

Introduction

From the national security's point of view, the production and distribution of electricity is key. Transport of biomass as an alternative energy source belongs to critical infrastructure within the framework of logistics macrosystem.

The purpose of the article is to present the role of alternative energy source, which is the biomass in the supply chain for the CHP, with particular consideration for transport processes, the principles of operation of the energy sector utilizing biomass, its role in the economy and functions. Particular attention was paid to the construction of the biomass supply chain to the combined heat and power plants. The data was illustrated using tables. The models presented in the article were made in a dedicated program using Business Process Model and Notation (BPMN). The research method used in the publication is the existing data analysis and the literary criticism. Literature, netography and statistical data show that the biomass can constitute an important energy source for industrial use. However, one must be aware of both its advantages and shortcomings.

Definition of biomass and supply chain

According to Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources, biomass means: "the biodegradable fraction of products, waste or residues of biological origin from agriculture, including plant and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal biological waste".

In connection with the entry into force of the Polish Act of 7 June 2018 amending the Act on renewable energy sources, the term biomass should be understood as "the biodegradable part of products, waste or residues of biological origin from agriculture, including plant and animal substances, forestry and related industries, including fisheries and aquaculture, processed biomass, in particular in the form of briquettes, pellets, torrefat and biochar, as well as the biodegradable part of industrial or municipal waste of plant or animal origin, including waste from waste treatment installations and waste from water and wastewater treatment, in particular sewage sludge, in accordance with waste regulations regarding the qualification of part of the energy recovered from the thermal transformation of waste".

Solarewicz [2019], on the other hand, defines biomass as "solid or liquid substances of plant and animal origin, obtained from products, waste and residues from agricultural and forestry production, as well as from parts of other waste that are biodegradable".

The supply chain is seen as a network of organizations, process or structure. It is because the supply chain is created by:
- a single enterprise – then we are talking about an internal supply chain;
- two co-operating with each other enterprises, where one is a supplier and the other is a recipient;
- network of cooperating with each other enterprises in the function "supplier–recipient".

According to Bechtel and Jayanth [1997], the supply chain is the network of producers and service providers who cooperate with each other in order to process and move goods from the raw material phase to the end-user level. All those entities are connected by flows of physical goods, information and money. On the other hand, Christopher [2001] defines the supply chain as a sequence of events on the movement of goods increasing their value. Yet another definition of the supply chain is presented by Johansson [1994], who states that it is a physical network that starts with the supplier and ends with the final customer. This network includes aspects connected to the product development, purchasing, manufacturing, physical distribution and after-sale services, as well as deliveries made by external bidders.

Essence and instruments of supply chain management

Contemporary supply chain management should focus on satisfying the requirements of the end-user; in case of energy sector, this will be the energy consumer. Combined heat and power plants should understand these needs. The process of supply chain management is related to synchronizing the physical, information and financial streams of demand and supply flowing between its participants in order to achieve their competitive advantage and create added value [Witkowski 2010]. Supply chain management processes include:
- planning, forecasting, replenishing inventory and monitoring and controlling related processes in the supply chain;
- product and network configuration;
- designing products using the knowledge potential of suppliers;
- forming production network aimed at selecting and defining manufacture tasks;
- optimization of processes in the supply chain;
- analysis and tracking of indicators and measures of business parameters' effectiveness.

The main objectives of the CHP plant in operation and functioning of the supply chain are [Witkowski 2003]:
- minimizing of total costs of product and information flow whilst maintaining required by the client level of quality of service delivery;
- ensuring shortest possible period of order implementation and the highest possible reliability, frequency and flexibility of deliveries at the assumed level of flow costs;
- optimization of the inventory level on the scale of supply chain along with flexible adjustment to the preferences within the scope of service delivery of individual market segments.

In order to achieve the best possible level of supply chain management in the CHP plant, numerous management tools and instruments can be used, such as [Szymonik 2011]:
- LM (Lean Management) – slimming management;
- AM (Agile Management) – flexible (agile) management;
- QR (Quick Response) – fast reaction;
- ECR (Efficient Consumer Response) – efficient service in the chains of customer delivery;
- TQM (Total Quality Management) – comprehensive quality management;
- JiT (Just in Time) – punctual deliveries;
- VMI (Vendor Managed Inventory) – inventory management by the supplier;
- CS (Consignment Stock) – consignment stock;
- CPFR (Collaborated Planning, Forecasting & Replenishment) – common planning, forecasting and replenishment of inventories.

Supply chain of biomass CHP plants

Supplying biomass power plants is a big challenge because energy companies are subject to the same economic laws as manufacturing or commercial companies. An important factor affecting the safety of biomass CHP plants is the need to ensure continuity of heat and electricity supply for consumer demand.

At present, one of the problems of biomass burning units in Poland is the availability of the biomass raw material on the domestic market. In Germany, biomass imported from Poland may be burned in power plants and combined heat and power plants. According to the data of the Federal Statistical Office of Germany (Statistisches Bundesamt), in 2019 the import of Polish wood to Germany reached the level of 1.17 million t, while just a few years ago it was on average about 150 thousand t per year [Centrum Informacji o Rynku Energii 2019].

Currently, for energy purposes in the enterprise you can use plants from energy crops, wood and wood waste, agricultural products and waste as well as waste wood from the wood industry (lumber, chips, bark, wood briquette, wood chips, sawdust, pellets) [Janowicz 2006].

In order to consider biomass as a fuel for energy, we must also recognize the barriers that limit its use. The barriers include:

- relatively low heat of combustion and calorific value;
- large variation in moisture content, depending on the type of biomass and its period seasoning (up to 50%);
- high volatile matter content – problems in controlling combustion, exactly changing ignition and combustion conditions;
- difficulties in dispensing fuel resulting from the form of biomass;
- large storage area and transport difficulties due to low density bulk;
- difficulties maintaining fuel quality at a constant level;
- high content of alkaline compounds, such as potassium, phosphorus, calcium.

Most of these problems can be avoided by increasing the biomass density [Tokarska and Kościelska-Chmurko 2004].

The basis of the employed logistics solutions in the CHP plant should be systematic approach. The operation of the CHP plant using biomass remains in permanent and strong relationship with the activities of supply deliverers, distribution subcontractors, as well as recipients. The requirements of the market have a decisive impact on the process of supply and quality of importer raw materials, as well as storing processes, technology and process of electricity production, and implementation of its distribution [Krajewska and Łukasik 2012].

In order to ensure the energy security of its recipients, the heat and power plant must plan the activities relating to production and delivery of energy and heat, in practice covering a complete logistics chain, ensuring the continuity of energy supply to the recipients through planning the appropriate biomass reserves. Integration of actions in the supply chain involved in the customer service on the target market and organizational cells within enterprise requires coupling in planning of actions that have their beginning and finale on the market. This results from the necessity of adjusting the deliverance of electricity to the needs reported by the market. Fulfilling the requirements of energy security is even more difficult due to the fact that the suppliers at the same time strive to ensure the flow of energy supply and the low levels of operating costs.

Fast and uninterrupted service to recipients is not possible without information exchange between the consumers and distributor, which allows quick implementation of orders influencing planning of the production and supply, as well as informing about changes in demand.

The basic problem that needs to be resolved on each stage of electricity and heat production is obtaining the precise forecast of energy demand in the energy system and appropriate planning of fuel supplies to the CHP plant, without creating unnecessary reserves that generate costs [Szymla 2013]. Unfortunately, the problem for CHP plant may be the availability of biomass on the market, as well as the quality of the raw material itself. The tables below represent the quality requirements that should characterize various types of biomass delivered to the CHP plant.

The temperature of the supplied forest biomass in the form of chips cannot be higher than 40°C. The fraction content in the delivered biomass should be below 3.15 mm (crumble). The proportion of contamination in the form of wet sand or wet soil cannot exceed 1.2% of total mass taken to perform the test of a sample. Table 1 presents physical and chemical parameters of wood chips made of forest biomass.

Table 1. Physical and chemical parameters of forest biomass in the form of wood chips
Tabela 1. Parametry fizyczno-chemiczne biomasy leśnej w formie zrębek

External dimension (mm)	Calorific value (GJ/Mg)	Average calorific value (GJ/Mg)	Moisture content in working condition (%)	Chlorine content (%)	Ash content in working condition (%)
L = 10–63	7.1–10.3	8.7	40.0–55.0	≤ 0.008	≤ 1.5

Source: Quality requirements and conditions for the supply of biomass to PGE GiEK S.A., Dolna Odra Power Plant Complex (Elektrociepłownia Szczecin).

The temperature of the supplied biomass in the form of chips from energy crops cannot be higher than 40°C. The fraction content should be below 3.15 mm (crumble), and the proportion of contamination in the form of wet sand/soil cannot exceed 1.2% wet sand in the total mass. Table 2 presents physical and chemical parameters of chips made of energy crops.

Table 2. Physical and chemical parameters of forest biomass in the form of chips from energy crops
Tabela 2. Parametry fizyczno-chemiczne biomasy leśnej w formie zrębek z upraw energetycznych

External dimension (mm)	Calorific value (GJ/Mg)	Average calorific value (GJ/Mg)	Moisture content in working condition (%)	Chlorine content (%)	Ash content in working condition (%)
L = 10–63	5.9–10.1	8.0	40.0–60.0	≤ 0.009	≤ 1.8

Source: Quality requirements and conditions for the supply of biomass to PGE GiEK S.A., Dolna Odra Power Plant Complex (Elektrociepłownia Szczecin).

The temperature of supplied straw pellets cannot be higher than 40°C. The fraction content below 3.15 mm (crumble) cannot exceed 6% of total mass. Table 3 presents physical and chemical parameters of straw pellets.

The temperature of the supplied chips from orchards cannot be higher than 40°C. The fraction below 3.15 mm (crumble) in the supplied biomass must not exceed 8%. The fraction content below minimum external dimension of biomass (i.e. 10 mm) must not

Table 3. Physical and chemical parameters of biomass in the form of straw pellets
Tabela 3. Parametry fizyczno-chemiczne biomasy w formie peletów ze słomy

External dimension (mm)	Calorific value (GJ/Mg)	Average calorific value (GJ/Mg)	Moisture content in working condition (%)	Chlorine content (%)	Ash content (%)
L ≤ 30 D = 6–25	15.2–16.7	15.95	5.0–12.0	≤ 0.15	≤ 6.0

Source: Quality requirements and conditions for the supply of biomass to PGE GiEK S.A., Dolna Odra Power Plant Complex (Elektrociepłownia Szczecin).

exceed 15%. The fraction content of the maximum external dimension of the biomass (i.e. 63 mm) must not exceed 10%. The content of wet soil/wet sand after the carried-out test must not be higher than 0.65% of the mass of sample tested. Table 4 presents physical and chemical parameters of chips made of orchards biomass.

Table 4. Physical and chemical parameters of biomass in the form of chips from orchards
Tabela 4. Parametry fizyczno-chemiczne biomasy w formie zrębków z sadów

External dimension (mm)	Calorific value (GJ/Mg)	Average calorific value (GJ/Mg)	Moisture content in working condition (%)	Chlorine content (%)	Ash content in working condition (%)
L = 10–63	7.05–10.50	8.77	38.0–53.0	≤ 0.009	≤ 2.0

Source: Quality requirements and conditions for the supply of biomass to PGE GiEK S.A., Dolna Odra Power Plant Complex (Elektrociepłownia Szczecin).

The temperature of the supplied wood chips from the rubber tree cannot be higher than 40°C. The fraction below 3.15 mm (crumble) must not exceed 8%. On the other hand, the fraction content below the minimal external dimension of the biomass (i.e. 10 mm) must not be above 15%, and the fraction increasing the maximum external dimension of biomass (i.e. 63 mm) must not exceed 10%. The content of wet soil/wet sand after the carried-out test cannot be higher than 0.65% of the mass of sample tested. Table 5 presents physical and chemical parameters of wood chips made of rubber tree.

Table 5. Physical and chemical parameters of biomass in the form of wood chips from the rubber tree
Tabela 5. Parametry fizyczno-chemiczne biomasy w formie zrębków z drzewa gumowego

External dimension (mm)	Calorific value (GJ/Mg)	Average calorific value (GJ/Mg)	Moisture content in working condition (%)	Chlorine content (%)	Ash content in working condition (%)
L = 10–63	7.05–10.50	8.77	38.0–53.0	≤ 0.009	≤ 1.8

Source: Quality requirements and conditions for the supply of biomass to PGE GiEK S.A., Dolna Odra Power Plant Complex (Elektrociepłownia Szczecin).

Procedure of biomass delivery to a combined heat and power plant

The main goal of combined heat and power plant is ensuring the continuity of energy supply to the recipients through appropriate planning of biomass supply whilst maintaining the emergency level of reserves (security) in the warehouse. The maintained biomass supply should be sufficient to cover the assumed amounts of monthly raw material consumption. Planning of these reserves is made based on the archival usage at the beginning of the annual heating period commencing in November and ending in October of the following year. The combined heat and power plant in special cases may adjust the plan for biomass supply.

Figure 1 presents the model for supplying the combined heat and power plant with biomass, with particular emphasis on planning transport activities. Biomass can be delivered by water, road, rail and/or combined means of transport. This allows limiting the pejorative impact of transport on the natural environment and reaction to the changes in transport prices.

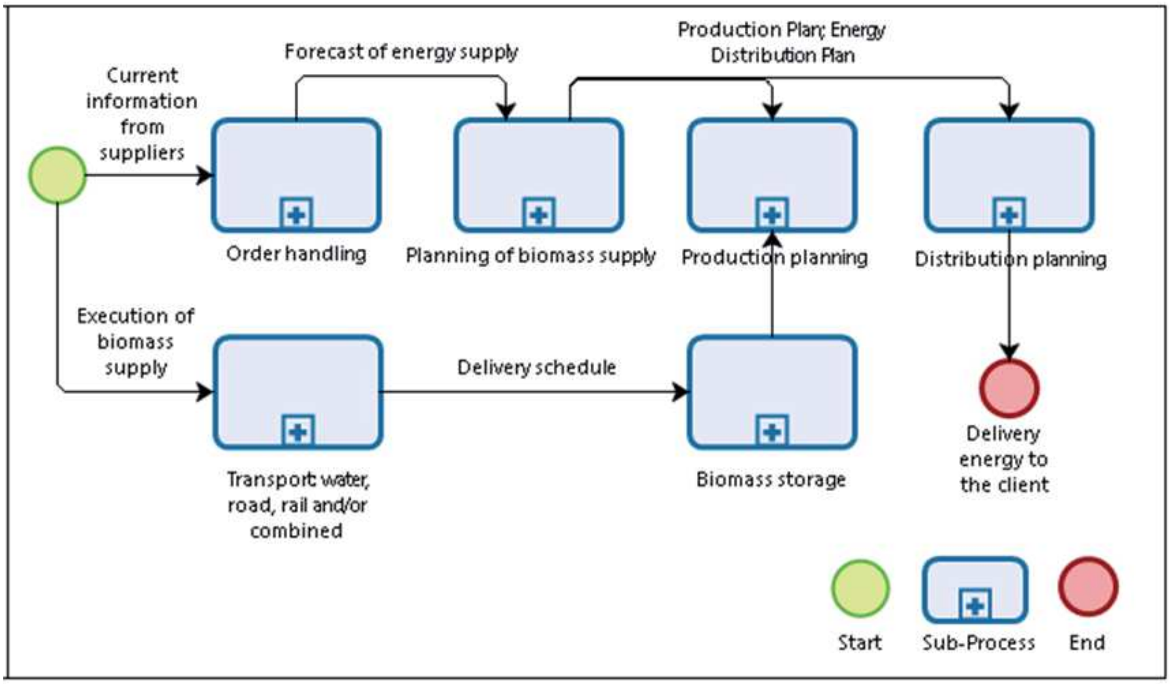

Figure 1. Model of the CHP plant's biomass supply, with emphasis on planning transport activities
Rysunek 1. Model zaopatrzenia elektrociepłowni w biomasę z uwzględnieniem planowania czynności transportowych
Source: own study.

Figure 2 shows the model of management of supplying the CHP plant with biomass. The biomass supply model aims to ensure efficient and effective procedures of planning the critical reserve for the combined heat and power plants, considering the necessity to adapt the evolving energy needs. During the heating period the procedures are initiated in

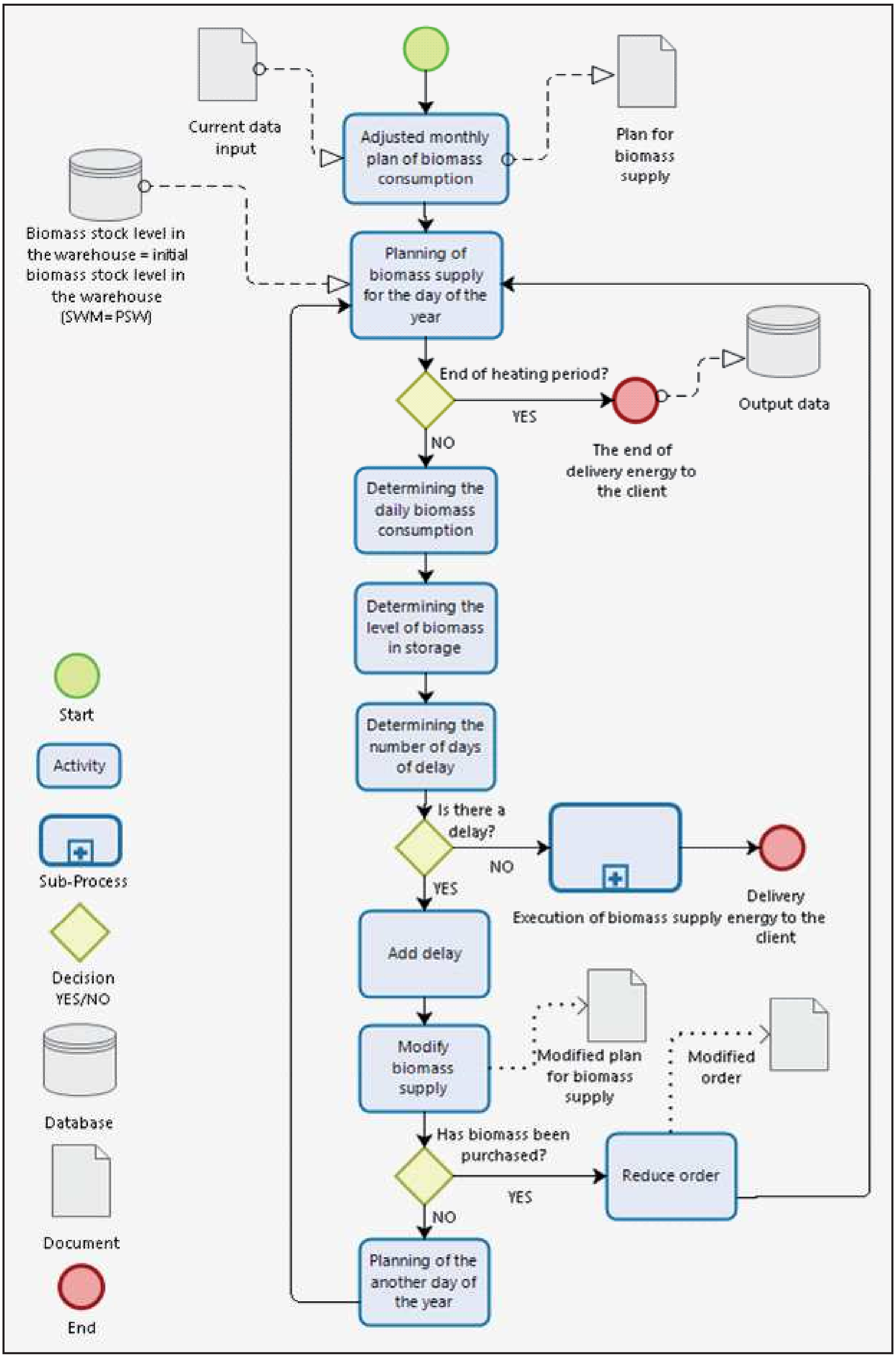

Figure 2. Model of management of the CHP plant's biomass supply

Rysunek 2. Model zarządzania zaopatrzeniem elektrociepłowni w biomasę

Source: own study.

response to the levels of biomass in storage that require purchasing extra mass or resignation from the previously contracted raw material.

The first action resulting from the model (Fig. 2) is developing the plan of monthly consumption of biomass at the CHP plant. Model gives two options for action:
- firstly, establishing the planned monthly consumption on a certain assumed level, independent of the current contractual demand;
- secondly, determining the plan based on the archival data.

The next step is determining the daily plan for supplying the CHP plant with biomass. This operation is carried out separately for each month of the year. Monthly demand for the raw material is calculated first on the n-part of the size not exceeding the maximum quantity that can be delivered daily to the warehouse. These elements are assigned to the first working days (excluding Saturdays, Sundays and holidays) in the month. The remnants of the previous day are delivered on the next working day. In each day, the amount of delivered biomass may not exceed the n-part of maximum quantity in storage. Next, the biomass amount in warehouse is calculated, which on the first day of the heating period is equal to the initial amount of raw material in the warehouse (i.e. the biomass level in the warehouse equals initial biomass level in storage). On every day of the heating year the change of inventory takes place by:
- random value of daily raw material consumption;
- volume of raw material with delayed delivery;
- daily amount of biomass delivered to the warehouse.

In addition, each day the warehouse capacity is examined, as well as daily delivery plan. Based on the analysis the decisions are made about the size of purchase and reduction of contracted biomass.

Biomass, usually after cutting, is first transported to the company that deals with the shredding of biomass into sawdust, and it is stored there. The example of such biomass is biomass from felling trees in the forest or in an inhabited area. Only the biomass obtained from plantations on which plants are cultivated that are adapted for quick processing allows shortening the period of obtaining ready fuel and its direct transport to the CHP plant.

Summary

To ensure security of continuity of energy delivery, the biomass CHP plants must have appropriate raw material reserves, which are secured in the crisis situations. Biomass can be delivered to the CHP plants with the use of different branches and types of transport. In practice, first it is transported to the enterprise which deals with shredding of biomass, and then to the CHP plant.

Energy producing companies must also consider costs that affect the profitability or losses that impact the increase of energy costs for the recipients. Keeping too large reserves of biomass cannot be explained by the lack of that raw material on the market or by significant differences of prices during the year. The CHP plants have concluded annual or long-term agreements that ensure the stability of raw material prices. Appropriately selected processes of supply can significantly reduce the costs of CHP plant operation. In the crisis situation the logistics chain boils down to supply. Ensuring the security of continuity of energy delivery through appropriate formulation of procedures of the biomass supply, as well as its effectiveness, is understood as optimization of the CHP plant's costs.

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