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Logistical Connestions of Bioreactors

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1. Introduction and Objectives

One of the major problems of our era is the upset of the environmental harmony. Not only our activities, customs and everyday life but in global on the Earth and its system elements is affected by this natural dynamical balance. The development of the technology has served nothing but our comfort and the actual profit maximization for a long period of time. But soon it must be admitted that we have to pay the price of this luxury. Such problems - starting from global warming through climatic irregularities, starvations, degenerations of the human genome, to the forming and development of the hole in the ozone layer - appeared in our world, which have to be treated and it is the task of the present. These are not local manifestations but overall, they can be seen in the system of natural-, social- and economic environment, too.

The energy sector has also got into a difficult situation. This field of the national economy is one of the most significant emitter of harmful materials especially carbon-dioxide. It is not accidental that one of the development priorities of the EU is the establishment of an advanced energy market, which ensures both the safe energy supply and the decrease of the causes of climate and environmental change (*Meadows et al.* 2005).

Developments condensed on such technologies which realize natural or almost natural processes. The principle of „there is no waste in nature" also led to this recognition (*Prezenszky J.* 2003). In other words: the by-product of each process is the input material of another one.

Such technologies appeared – occasionally renewed – which try to fully or partly substitute the procedures not harmonizing with the environmental. Although the long-term target probably is the safe and sustainable production of fusionable energy but researches pointing to this direction are still in crude state. For this reason those developments which aim the long-term and secure utilization of renewable energy resources (also known as *bioenergy*) are so important and determining.

Bioenergy has been used by mankind for such a long period of time, since that was the only available energy resource. Let us think about foddering or the collection and burning of firewood. Both in the world and in Hungary these processes were well-known and used extensively till the beginning of the industrial revolution when coal was used in large scale at the first time and the accumulation of its burning material has kept going to these days. (E.g. coal-power plants are still being built at present in China). During the World War II the development of bioenergy production was started but its reason was mostly the lack of resources and not the environment-conscious behaviour.

After 1945 Hungary was dependant on the Soviet crude oil and this state is not going to change in the next few decades. Therefore the research and development related to bioenergy failed compared to the West European ones. Although at the end of the '80s there were attempts but no significant plants could be built due to both the increasing shortage of funds and the slight supporting state interests. Neither the society nor the economy was prepared for receiving a new comprehensive energy concept and bioenergy large-scale production as the part of that. After the political transformation in the '90s – by the expressive influence of the EU – bioenergy utilization and the related researches got progressively higher attention not just in the professional but the everyday life, too.

The notion of **biodiesel, bioethanol, biomass heat plant** or **biogas plant** is in the common

knowledge. It is hoped that in the close future we are not just going to hear about these but they will take part in the *practical* everyday life. With the words of *Aurellio Peccei*, the founder of the Club of Rome:
„ The future is no longer ….what it would have become if people had used their common sense and potentials. But the future can become what we want if we stay within the borders of rationalism and reality.

The structure of the bioreactor is similar to the environmental harmony existing in the nature. In these plants the logistic system of the transformation of organic materials in an environmental harmonious way, the gas production and utilization are essential points. Since the production is continuous in time – in accordance with economic, technological and biological aspects – one of the most important factors the logistic systems have to establish is this continuity of this. Namely:

- the transportation of the available input materials from a specific site to the area of the usage has to be organized by the transport demands and strategy,
- the special storing of the unusable input materials and the quality decaying of biological origin materials have to be considered,
- the storage and the transportation of output (principal and by-) products has to be realized by considering utilization and economic aspects.

To examine these logistic issues the discussion of the situation of biogas production in Hungary and in the EU, the review of the main steps of the methane production and the detailing of the differences of the biogas technologies are also required. All of this provides the background of the spread of bioreactors and biogas production in these days and gain more attention to the energy and environment protection sector.

Input materials of bioreactors make profit just in that case if the costs of production are lower than the income of the plant. One decisive factor of these costs is transportation. Moreover, the determination of the „limits of the growth" is also pending. Referring to this:

- **what is the connection between the costs, income and the delivering distance regarding the input materials from plant and animal origin,**
- **how does the kind of the input materials have an influence on the logistics costs,**
- **What is the relationship between the transportation costs and the profit.**

The objectives of the dissertation are the theoretical substantiation of the logistic subsystem of biogas plants (bioreactors henceforward), the set up of its major system-models and the determination and survey of the acquisition and distribution subsystems. The survey of the output materials is discussed partially. The dissertation can provide a base for further research of this field.

2. MATERIAL AND METHODS

2.1 Logistical backgrounds of agrarian bioreactors

There are different determinations of logistics as a field of science. One of them: „Logistics are the processes of the flow of -as well as- base materials, semi-finished and finished goods, as the related information from the place of origin to the site of consuming including planning, implementation and controlling by the intention of the consumer expectations" (*Prezenszky* 2003). The task of logistics is the planning, organizing, managing and controlling the *flow* within and among the systems of materials and information.

The aim of logistic activity can be summarized by the so-called **6R** principle. This concept means that the task of the logistics is getting the

- **R**ight item,
- at the **R**ight time,
- in the **R**ight place,
- in the **R**ight quantity,
- of the **R**ight quality,
- at the **R**ight price

from the suppliers to the consumers suitably for the demands of the market. According to this principle the objective is not the minimization of costs but the optimization of the processes (*Prezenszky* 2003). The logistics as science can not be reckon as either divisions of science because certain fields of that are parts of social economy (marketing, management, business economy, etc.) while the other are parts of technical sciences (production technology), mathematics (operational research) or informatics (info-communications). In accordance with all of the aboves logistics can be considered as a multi- and interdisciplinary, integrative-like science.

The planning of logistic processes determines the efficiency and economic parameters of a producer unit. This designing routine has direct and indirect effects on the fitting logistic subsystem, the development and the (production, transportation and material handling) costs. The developed countries recognized the fact at the beginning of the 1970s that logistics costs could reach the 20-25% of profit. (*Benkő* 2000).

One of the greatest achievements of logistics is the integration of the separated activities so far. But often this virtue is also a drawback at the same time because paradigm shift is needed for the spread of logistic views.

2.1.1 Input material logistics of bioreactors

From the 1970s the endeavor for integration has got a greater and greater influence on the management of companies. The reason for this was that the highest profit could be achieved by not minimizing the costs of each division but realizing the relative optimum. The determination of this optimum is the task of business management and logistics. The same optimum could be determined at the biomass producer and utilizer economic units, too. There are researches in the developed countries for decreasing logistic costs therefore increasing the incomes. This can be achieved if there are methods for the estimation of these expenses. The estimation of the costs is possible by:

- heuristic approach,
- supporting with models,
- simulation.

Heuristic approach can be adapted successfully without using any exact model which describes the relation among the connexion of a system with the help of mathematic methods (*Nguyen et al.* 1996). But if the optimizations can not be solved (or that would be too expensive) neither by the heuristic approach nor by using models and then simulations can be applied but the answers for the problems given by this method are often insecure.

There are researches in the US for the decrease of the logistic costs of biomass utilization (*Sokhansanj et al.* 2006). The concrete scientific purpose of the research is the revelation of a new model or demonstrating the adaptability of this model by simulation. It concentrates on the problems of the utilization of solid biomass products (figure 1, IBSAL – Integrated Biomass Supply Analysis & Logistics).

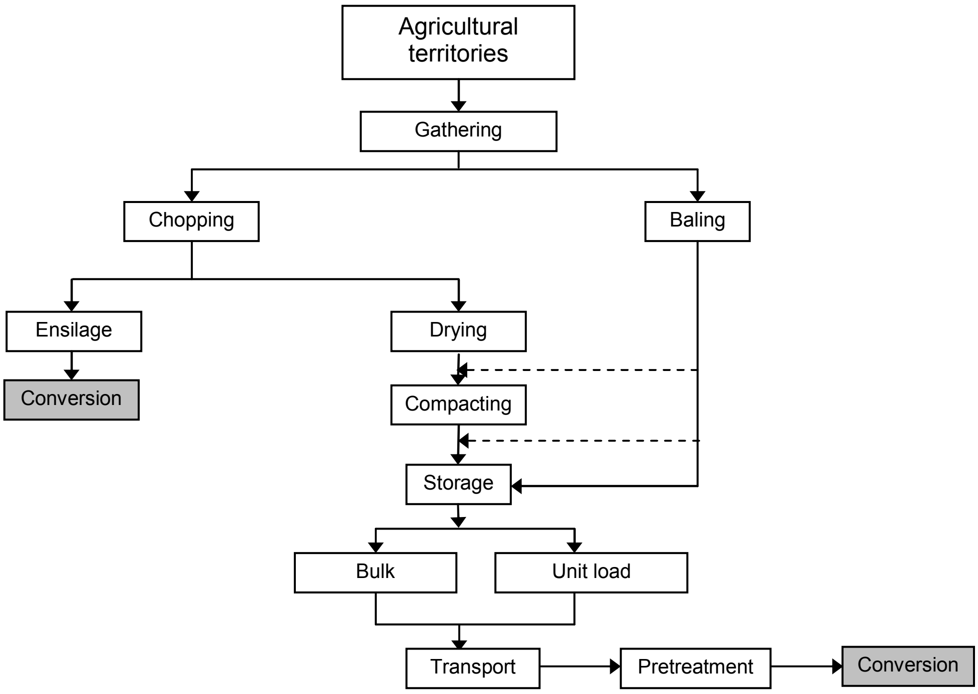

Figure 1: Logistical model of agrarian organic wastes (IBSAL)

(*Sokhansanj et al.* 2006)

Similar to the logistic model of the solid biomass can be made in case of bioreactors. That model does not contain the technological subsystem of drying and compression resulting from the processes of biogas production. During delivering the input materials into the bioreactors we can experience a lot of problems which do not appear at conventional utilization. Table 1 shows some special view points which do not show up at conventional procedures.

Table 1: Properties of the basic materials of renewable and conventional energies (*Narodowslawsky et al.* 2006)

Conventional (chemical) processes	**Processes based on renewable energy resources (biomass)**
Standardized	Different quality
Continuously available	Availability is limited
Centralized resources	Decentralized resources
Logistics has small role in the process structure	Logistics has a significant affect on the process structure

According to a wider explanation the whole process of biogas can be described as the sum of logistic processes (Figure 2).

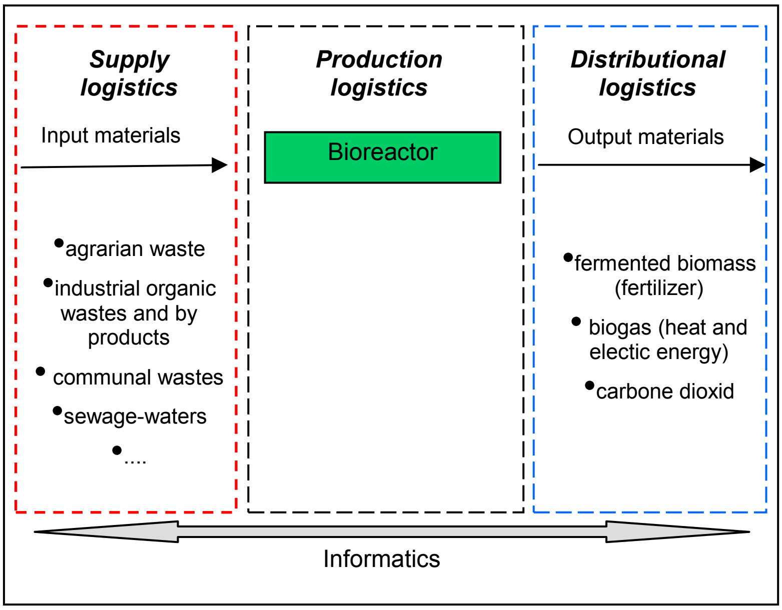

Figure 2: Logistical system of bioreactors (*Sinóros-Szabó, Jr.* 2007)

The figure above shows the classic logistic grouping. Being not able to separate the relations in the three logistic subsystems, the informatics functioning as a part system connects them with one another. Information supply is a cardinal issue at the field of biogas production because it is the base pillar of secure production and automation. In contradiction to the material flow he informational one is a two-way supply representing the diversity of the information flow in time and space. It can be stated that keeping the principles of 6R is very desirable.

Examining the aspect of logistics delivering and distribution would be the most effective if the sources and demands were in harmony with production. This can not be solved in practical life. Minimizing the costs and optimizing the production are the main tasks. It is important to note that the produced volume of biogas (and the profit) depends on the quality of the input material. As a result concentrating on delivering can prove that the quality, constitution and distribution in time and space of the basic material are meaningful factors of taking profitability into consideration. Experiences show that the rate of biological degradation using multicomponent mixture can be higher by 40% compared to single-component mixtures. (*Barótfi* 1998). All the three subsystems contain the upload of the databases indispensable for the part-system informatics which secures both the fast fixing of errors and the basis of monitoring and controlling systems (*Benkő* 2000; *Prezenszky* 2003).

The system-approach attitude of logistics is one of the most determining aspects of the corporate image (*Armbruster* 2006). A company with high-level logistics also represent high technology. Besides the classic logistic tasks (stock monitoring, acquisition strategy, distribution logistics, controlling, etc.) the information flow will have been prepared and determined the commodity movements by the year of 2010. Another important and considerable aspect is the forming of logistic centres. The establishment and installation of logistic centres have partially passed off but their development including the building of new ones is supported by the government at the same time. On the other hand: „ If the logistic grid is not built up by us then it is built up by someone else. After this the enterprise income is going to be less and we lose the further base of the emergence of the civic „middle" social section and we are going to be deprived of having influence on the national agrarian production and the level of national income will decrease." (*Kovács* 2003)

The treatment, storage of bio-comestibles is more difficult than that of the conventional ones. This fact may lead back to the primary materials „live" origin considering the lower rate of energy content than the substituted conventional (mostly fossil) ones. Furthermore it can be proved that it is not sufficient if the price of bioenergy resources is cheaper than the fossil ones. The difference is too significant (30-40%).

Usually the manure output of a breeder farm can be simulated as a punctual environmental load. Simultaneously shipping this manure mass from these farms is profitable in case of small distances. The same considerations typify the output of bioreactors

For instance the most important input material logistic data of the bioreactor in Nyírbátor (president: Dr. Petis Mihály) are the following: the total capacity is 6.409 m^3. Calculating with a 28-day-process time and 280 workdays a year, it is 64.090 m^3 in total, which means in volume-flow of 228,9 m^3/day or in mass-flow of 210,6 tons/day ($\rho=0{,}92\frac{kg}{m^3}$). The next table contains the input material data of the bioreactor in Nyírbátor.

Table 2: Absolute and relative division of the input materials of the bioreactor in Nyírbátor

(*Petis* 2004)

Waste kind	Quantity [tons/day]	Annual quantity [tons]	Relative division [%]
Cattle manure	19,4	5432	9,2
Poultry manure	1,5	420	0,7
Plant waste	11,4	3192	5,4
Sewage-water and sludge from the slaughter-house	110,1	30828	52,3
Food and culinary waste	2,3	644	1,1
Slaughter-house waste (giblets, crop and tripe containment, etc.)	57,3	16044	27,2
Sterilized fats	4,6	1288	2,2
Sterilized carcasses	4	1120	1,9
Total	**210,6**	**58968**	**100**

The rentability of a bioreactor based on input materials originated from mostly agricultural wastes is influenced by the distance of delivery. It is a fact that if the distance is longer than a certain unit (usually 10 km) than the profit of gas production is questionable. In certain cases the parameters can be calculated by deviation both in positive and negative directions. Using own products, the delivery distance can be longer if the purchase price of the input matter is at the minimum rate („free”) thus transportation may tolerate higher prices. In this case both positive (promotions, synergies, etc) and negative (stink, plant organization problems, decrease of costs for the elimination of hazardous wastes, etc.) external impacts have to be considered. Beyond all of the aboves, the profitable energy production is influenced by:

- up-to-date machine park (power, stability, service times and costs),
- large-scale production (low marginal costs),
- availability of technical skills.

2.2 Organic materials as primary products

Waste materials have to be categorized by their qualities. The recognition of these is especially important from the point of treatment, processing and disposal. Usually categorization is made by physical, chemical and biological parameters. Their arrangement is also possible by further aspects (e.g. condition, origin, dangerous character of them, etc.). One of the most general view points on the utilization of wastes is that the risen by-products have to be utilized by their originating forms in consideration of the minimizing the technological - manipulating costs. The annual arising agrarian and forestry by-products in Hungary (1998) are summarized in *Table 3*. It shows that the higher moisture content of a by-product has the less actually utilizable energy it contains.

Table 3: Annual arising agrarian and forestry by-products in Hungary

(*Vermes* 1998)

	Unit	Baled straw	Corn-stalk	Corncob	Sunflower-stalk	Trimmings, vine	Wood waste
Annual raised mass	million ton	4,5-7,5	1,0-1,2	10,0-13,0	0,4-1,0	1,0-1,2	1,0-1,5
Annual combustible mass	million ton	1,5-2,0	0,4-0,6	3,0-4,0	0,3-0,4	0,5-0,7	0,5-0,7
Moisture content after harvesting	%	10-20	30-40	40-65	30-35	30-45	20-45
Moisture content after storing	%	13-15	12-20	22-43	18-25	15-20	15-25
Heating value	MJ/kg	13,5	13,5	13,0	11,5	14,8	15,0

From the biogas production point of view, another important raw material group can be derived from the output of food industry. Almost entirely, these basic materials are the by-products of food-processing technologies.

The most important physical and chemical features of organic wastes from the treatment process are summarized in Table 4.

Table 4: Most important features of organic wastes (*Vermes* 1998)

Physical-chemical features	Complex features	Biological features		
		Eco-toxicological	**Toxicological**	**Virulence**
Physical condition Chemical reaction Structure and concentrations - humid content - organic content - element analysis - cations and anions Heating value Reaction with water, acid, base Solubility in water, organic solvent Corrosivity etc.	Degradability - biological- - photo- - chemical Accumulation - terrestrial creatures - human body - aquatic creatures	Vegetal Animal Micro organisms	Acute Sub-acute Sub-chronic Mutagenity Teratognity Carcinogenetic	Bacteriological Virological Parasitological

The complex estimation of the environmental damages of organic wastes needs expensive investigations which are regulated by statutory decree 102/1996. (VII.12.). The managing of the organic waste is shown by Figure 3.

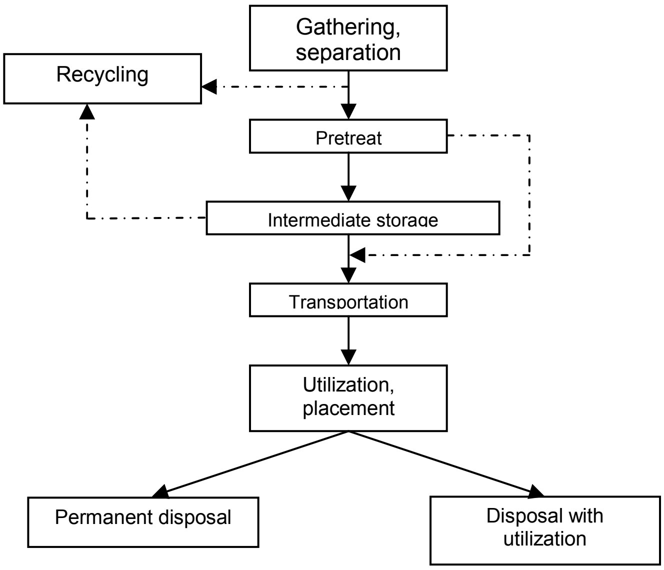

Figure 3: Logistical model of agrarian waste-management (*Vermes* 1998)

Pretreatment and intermediate storage can swap place, even can stay out of the technological order. In case of intermediate storage and permanent disposal, pretreatment is the process right before disposal. Transportation can be realized among each technological step frequently on different demands. Recycling wastes is possible after gathering or pretreatment. Gathering is executed, mixed or separated and its planning and organization is realized in accordance with waste management/ waste utilization process. Filtering the hazardous, toxic matters can be executed in this process by using the so-called source-control. During biogas production the directives for the transportation of hazardous wastes has to aspire to respect.

(Transportation of hazardous wastes is regulated by the 94/55/EC directive which has been modified several times (by the decision of 2005/263/EC last time)).

Pretreatment is necessary for the sake of storing, transportation, placement or quality improvement and it contains physical, chemical and biological methods of which the most often used ones are (*Vermes* 1998):

- chopping and sieving of wastes, filtering liquids,
- mixing humid substances with dry or absorbent materials,
- homogenization by mixing,
- dehydration of large water-content materials by drying or mechanically,
- separation of fluid and solid stages,
- neutralizing highly acidic and basic materials,
- heat-treatment of organic or other combustible matters,
- composting wastes mostly containing plants.

Pretreatments are specific processes thus the input material and mode of reclamation considerably determine their technology. Pretreatments usually serve as deactivation but it has to be considered that submitting the input materials just to the procedures is definitely needed by the technology because each action reduces the obtainable income and profit.

Sometimes if the gathered wastes can not be shipped to the site of consuming or permanent disposal or the used technology requires, then „pre-storages" have to be built and the temporary storage has to be done there. The storage can be located on the site meeting the requirements. The shipping of wastes is imminent and an activity with high risk. During the transfer these goods can be dispersed or got to places controlled with difficulty or not at all. Shipping can be executed via road, railway, water or pipe-systems in case of bulk liquid materials. Shipping is regulated by international agreements emphasizing the transfer of hazardous goods.

Shipping hazardous material via road is regulated by ADR (Accord européen relatif au transport international des marchandises dangereuses par route) in Europe. This agreement places the shipped materials into 7 divisions. In this each material has a four-letter identifier, a so-called UN-number. During shipping or forwarding the UN-numbers must be displayed on the labels. For example, in case of biogas production (shipping materials with animal origin – animal carcasses): UN2814, ADR subdivision ranging: 6.2.

The member countries of ADR – beside certain restrictions – can depart from this code-system. The inland differences can be divided in two groups by their registration:
1. Road transportations – relating to small quantities (RO-SQ: Road - Small Quantity)
2. Road transportations – relating to local transports (RO-LT: Road – Local Transport).

The biogas supply and output material handling are at a lower level compared to the small goods transfer (Table 6). The tonnage utilization factor indicates the rate of the maximum net load and the actual load considering the exploitable net volume. (*Kassai* 2005).

Table 5: Load-weight utilization of some material derived from agriculture and forestry

(Kassai 2003)

Material	Moisture content [%]	Heat value [kWh/kg]	Density [kg/m^3]	Load-weight utilization referred to fuel oil [%]
Straw	15	4,17	100-135	**4,92%**
Wheat	15	4,17	670-750	**29,72%**
Rape seed	9	6,83	700	**47,99%**
Wood shavings	40	2,89	235	**6,82%**
Wooden planks (beech)	20	4,08	400-450	**17,41%**
Wood pellet	6	4,9	660	**32,46%**
Fuel oil	-	11,86	840	**100,00%**

The specific energy consumption of each traffic sector is basically different. If the energy consumption referring to ton-kilometre (tkm) of water transport is considered 1, then railway transport is at ~10, road transport is at~100 and aerial transport is at ~1000. Beside of these the efficiency of the internal combustion engines has to be considered, which value is between 30-35%. But if the efficiency of energy consumption of the transportation has to be given, then we should consider other factors like energy consumption of producing a unit of crude oil or the consumption of aero-resistance, etc.). In this case the efficiency would be approx. 10%. Another decreasing factor comes from the unloaded run of the vehicles. In this case the efficiency of the transportation is about 5 % (*Glatz* 2000).

Making transportation more effective is equal to the reduction of its energy consumption. This augmentation of effectiveness can be placed in three groups (*Glatz* 2000):

- primary savings: by efficiency augmentation of the power source (engine),
- secondary savings: by development of the vehicle,
- tertiary savings: by organization of the shipping (logistics).

The base of this grouping is in the diversity of the experts dealing with it. Primary and secondary opportunities are the tasks of engine and vehicle constructors. Characteristic of both saving methods is getting into development late compared to practical life. The secondary methods (development of drive train, climatization) are faster regarding their spread but the increase of total efficiency is smaller than in case of the primary ones.

In goods and passenger transportation the tertiary savings result the fastest efficiency increase by the smallest specific expenditure. This saving method contains among others accurate freight organization and route planning, forming the gathered and distributional transport systems. Energy consumption can also be reduced by the development of a satellite-based controlling and monitoring system, TCM service, or the improvement of freight managing and optimizing.

3. Results

3.1 Determination of transportation capacity

At the determination of transportation that fact has to be considered which proves beside the growing input material demand the distances and thus transportation capacities are expanding at the same time. Although usually not just energy plants are used for biogas production solely but by-products (cornstalk, infected plants, etc.). It has to be mentioned that for the sake of technological/biotechnological development, the government supports it in the near future.

The results obtained at determining transportation capacities of biogas production in-put materials can be used in connection with bioethanol and biodiesel production. Beside the similarities there are significant differences as well resulting from the type of technology. The parameters of plant based biogas production have to be completed to suit animal originated ones, too. In the followings I consider the utilization possibility of both in-put materials.

In case of plant biomass utilization the area from where the given plant is delivered, grows proportionately with the delivery capacity. The weight of in-put material produced in “f” and “g” sided tables of a given bioreactor (production site biomass), which is of “w” km distance from the production site (Figure 4):

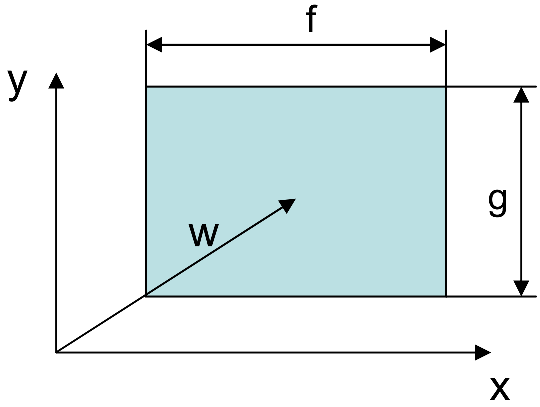

Figure 4: Notations of bioreactor in-put material capacity

$$dM = Y \cdot a \cdot dx \cdot dy \text{ (t)} \qquad [1]$$

where
Y – average yield (tons/hectare),
a – proportion of the utilizable cropland,
$\vec{x}$ and $\vec{y}$ - unit vectors (m).

The total production quantity (considering that both “y” and “x” have distance dimensions (“s”)):

$$M = \int_0^g \int_0^f Y \cdot a \cdot dx \cdot dy = Y \cdot a \cdot f \cdot g \cong Y \cdot a \cdot s^2 \text{ (t)} \qquad [2]$$

The transportation costs of the vegetal input material can be originated from the mass-functions:

$$dc_{1i} = dx \cdot dy \cdot Y \cdot a \cdot k \cdot b \cdot dx, \text{ (Ft)} \qquad [3]$$

where
k – specific transportation costs (Ft/tons)
b – constant taking the rate of the bee-line between the site and the plant in consideration

The total transportation costs of one kind of material are given by integrating the cost-functions:

$$c_{1i} = \int_0^w \int_0^g \int_0^f Y \cdot a \cdot k \cdot b \cdot dx \cdot dy \cdot dx = Y \cdot a \cdot k \cdot b \cdot x \cdot y \cdot x \cong Y \cdot a \cdot k \cdot b \cdot x^3 = K_n \cdot x^3 \text{ (Ft)} \qquad [4]$$

The input material transportation is done from different places thus:
$c_1 = \sum_{i=1}^{n} c_{1i}$, where i=1,2,3…,n

So the transportation cost of the biogas produced from vegetal:

$$c_{1i} = K_n \cdot x^3$$

In other words the transportation costs of a certain vegetal are proportional to the transportation distance on the third power. If the territory grows by 10% then the costs of transportation increase by 33%.

The logistic costs of the wastes from animal origin can be determined more easily because these input materials proceed form a certain place which size has not any influence on the transportation costs. The input materials from animal origins rise almost in the same quantity and season independently while the vegetal ones just periodically. Thus the determination of the transportation costs:

$$dc_{2i} = M_{2i} \cdot k \cdot b \cdot \eta \cdot dx$$

where
M_{2i} – the mass of input material with animal origin rise from the “i”-th term (tons),
η - load volume utilization factor (≥ 0,8 - for the matters of agriculture).

The rate of the delivery does not increase directly the transportation distance but the number of daily turns (Figure 5) which:

$$n_f = \eta_m \cdot \frac{M}{M_{\max}} + 1$$

η_m – load tonnage utilization factor
M_{max} – maximum load (tons)

Illustrating the by Figure 5:

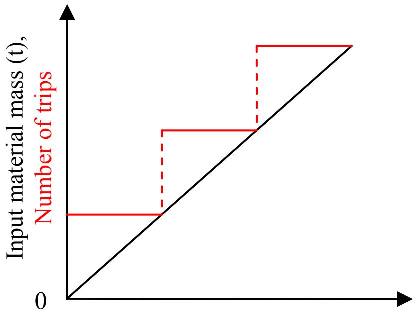

Figure 5: Connection between the mass of input material and the number of trips

The acquisition of new vehicles is also a possible way but it results extra costs too. Similar to the plant origin input materials:

$$c_{2i} = \int_0^{x_2} M_{2i} \cdot k \cdot b \cdot dx = M_{2i} \cdot k \cdot b \cdot x_2 = K_2 \cdot x \qquad [7]$$

and

$$M_2 = \sum_{i=1}^{n} M_{2i} \qquad [8]$$

Delivering more input material with animal origin:

$$c_2 = \sum_{i=1}^{n} c_{2i} \qquad [9]$$

For the sake of the minimizing the transportation costs the bioreactors has to be settled near the sources of the input materials from animal origin (e.g. breeder farms, slaughter-houses, etc.). Moreover has to be noticed that the transportation of liquid materials (with low dry matter content) can be solved via pipelines. The cost-function is in case of this:

$$c_3 = \eta_{sz} \cdot P_w \cdot t \cdot k_{sz}$$

where

η_{sz} – pump efficiency,

P_W – effective power of the engine operating the pump (kW),

t- time of pumping (h),

k_{sz} – unit price of the used energy (Ft/kWh).

If there is no vertical obstacles are inessential and the rate of the flow in pipe is below 2 m/s (for avoiding turbulences) then the energy of the pumps transfers to pressure energy and work to overcome losses.

Taking the pressure to constant (*Szendrő* 2003):

$$c_3 = \eta_{sz} \cdot P_w \cdot t \cdot k_{sz} = P_h \cdot t \cdot k_{sz} = \lambda \cdot \frac{l_e}{2d} \cdot c_s^2 \cdot \rho \cdot \dot{V} \cdot t \cdot k_{sz} \qquad [10]$$

where
λ - pipe-frictional factor,
l_e – equal pipe length (m),
k_e – constant of equal pipe-length,
d – diameter of the pipe (m),
$\dot{V}$ - (constant) volume flow (m^3/s),
P_h – hydraulic power (W),
ρ - density of the transferred material (kg/m^3),
c_s – flow velocity in the pipeline (m/s).

In case of liquid manure the density (*Sitkei* 1997):

$$\rho = 1000{,}58 + 3{,}67 \cdot SZT \text{ (kg/m}^3\text{)}, \qquad [11]$$

where SZT symbolizes the dry matter content. The rightness of the equation is true if SZ>3%. The dry matter content of the input materials of the bioreactors between 8 and 10% and it is important to execute the transportation under these circumstances.

In the first and second case the costs are in direct ratio to the delivery distances. (In case of the transportation via pipelines the delivery cost depends on the diameter and length of the pipes mostly).

Expressing c_3 by M:

$$c_3 = \lambda \cdot \frac{k_e \cdot x}{2d} \cdot c_s^2 \cdot \rho \cdot V \cdot k_{sz} = K_3 \cdot M \cdot x \text{ (Ft)} \qquad [12]$$

So the sum of the transportation costs of the previously described input material groups regarding the [5], [7], [9] and [10] correlations:

$$c = \sum_{i=1}^{3} c_i = K_n \cdot x^3 + K_2 \cdot x + K_3 \cdot x = K_n \cdot x^3 + K'' \cdot x \qquad [13]$$

The product of bioreactors is the biogas which consists of methane, carbon-dioxide and bio-manure mostly. The methane-content of the biogas is usually utilized by gas-engine or turbine units. The generator is shaft-coupled with the shaft of the power machine. The waste-heat of the power machine (engine) is also used. (Nowadays bioreactors producing electric and heat energy are licensed exclusively in Hungary). The efficiency of the power machine is 75-80% and the ratio of produced electric and heat energy is 1:2.

On the other hand if we would like to increase the electric production of a bioreactor without switching in new energy producer units then what is the relation between transportation costs and the growth of capacity?

Considering the electric production of the plant and marked with P_v and the energy production with P then:

$$\mathrm{P_v} = (0{,}75 - 0{,}8) \cdot 0{,}33 \cdot \mathrm{P} \ \ (\mathrm{kWh})$$

Let in our case be:

$$\mathrm{P_v} = 0{,}25 \cdot \mathrm{P} \ \ (\mathrm{kWh})$$

Considering the heating value of biogas is approx. 23 MJ/nm^3, the produced electric energy is:

$$P_v = \frac{M}{y} = 0{,}25 \cdot \frac{23}{3{,}6} \cdot V_h \cdot 10^{-3} \cdot M \approx 1{,}6 \cdot V_h \cdot M = Kg \cdot M \ \ (\mathrm{kWh/kg}) \qquad [14]$$

y – mass of input material for the production of unity output (tons/kWh),
V_h – volume of usable biogas (litre/kg),
Kg – constant influencing the rate of the fermentation.

Considering V_h given, then the capacity is the function of the delivered input material mass. This can be done for the heat utilization but being analog with the electric utilization I do not deal with that.

As it could see the volume of the vegetal biomass is proportional only to the distance.

So using vegetal biomass as input material the transportation distance derived from capacity:

$$P_{vn} = Kg \cdot K_{n \cdot} x^2 = K_{gn} \cdot x^2 \Rightarrow x = \sqrt{\frac{P_{vn}}{K_{gn}}} \qquad [15]$$

Considering the other input material that $P_{vö}$ is the sum of P_{vn} (vegetal) and P_{vt} (other) capacity.

$$P_{vt} = P_{vö} \cdot (1 - P_{vn}) \cdot \frac{M}{y}$$

and because M is not functionally related to x therefore P_{vt} and M are in direct proportion.

Thus the transportation costs regarding [12] and [13]:

$$c = K_n \cdot x^3 + K'' \cdot x = K_n \cdot \left(\sqrt{\frac{P_{vö}}{K_{gn}}} \right)^3 + K^* \cdot P_{vö} \qquad [16]$$

K_n, K^* are constants. This means that the costs of transportation is proportionate to the increase of capacity on the 3/2 power in the case of plant-biomass and linear in the case of biomass from animal origin utilization and materials transferred by pipe systems.

According to this if both the rate of the input of vegetal biomass is increased by 10% and also the one from animals then the transportation costs: $1{,}1^{3/2}+1{,}1=1{,}15+1{,}1=1{,}25$. That means 25% increase in prices. (Supposing the same conditions in both cases). If just one certain input material is utilized by the bioreactor then the part of the absent kind of input material became 0 in the polynomial.

3.2 Determination of the optimal transport cost

The total costs (TC) of an enterprise consist of fix (FC) and variable (VC) costs:

TC=FC+VC

Otherwise:

$TC = A \cdot P^m + B \cdot P^n + k^{'} \cdot P$ (Ft)

where
A – factor of the transport costs,
m – power index creating the correlation between transportation and capacity costs,
B – factor of the production costs
n – power index creating the correlation between production and capacity (usually 0,7)
k' – factor in direct proportion to the output units (for example general expanses.)

this equation in the case of biogas utilization:

$TC = A \cdot P^m + A^{'} \cdot P + B \cdot P^n + k^{'} \cdot P$ (Ft)

considering the transport of materials with animal origin and via pipe-system. Formally k'·P and A'·P are the same and for this reason this two can be merged in k**·P form.

The specific cost referring to the unity mass of the input material:

$$C = TC / P = A \cdot P^{m-1} + B \cdot P^{n-1} + k^{**} \text{ (Ft/t)}$$

I bring the mark M=m-1, N=1 in.

Costs are minimized, if

$$\frac{dC(P)}{dP} = 0,$$

condition realized:

$$\frac{dC}{dP} = \frac{d}{dp} A \cdot P^M + B \cdot P^{-N} + k^{'} =$$
$$A \cdot M \cdot P^{M-1} + B \cdot (-N) \cdot P^{-N-1} = 0$$
$$A \cdot M \cdot P^{M-1} - B \cdot N \cdot P^{(-N-1)} = 0 \qquad [17]$$
$$A \cdot M \cdot P^{(M+N)} = B \cdot N$$
$$P^{(M+N)} = \frac{B \cdot N}{A \cdot M}$$

The relationship of transportation costs as the function of the production costs:

$$R = \frac{A \cdot P^{M}}{B \cdot P^{-N}} = \frac{A}{B} \cdot P^{(M+N)} \qquad [18]$$

Substituting in [17]:

$$R = \frac{A}{B} \cdot \frac{B \cdot N}{A \cdot M} = \frac{N}{M}. \qquad [19]$$

in this case N=1-0,7=0,3, M=1,5-1,0=0,5. Thus under these circumstances at the 60 percentage of the transport cost is minimal the total costs.

According to the aboves the relation between the capacity and transportation as well as the capacity and production depend on just the power index.

If the transportation is realized by via road or pipes the relationship alters. In this case there is no minimum but the trivial solving of the function. The effort for income maximum is decisive in this case.

On the other hand it has to be considered that the usually the basic material are from foreign sources. The work of the complex bioreactors have only just benefits for the ones whom concerned directly, especially:

- Reduces the load of the rural sewage farms and dumps and opens the door for any surplus-investment. One portion of the transportation costs can be saved by the suppliers.
- The foreign base material utilization means double income for the operator company of the biogas plant. In one respect it does not result base material cost but income in other respect the diversity increases the output of biogas production.
- Settling large-scale energy demanding enterprises in the neighbourhood of bioreactors means selling the redundant waste-heat at a reduced rate and increase in the savings for the enterprises. Because of the biogas plant decreases the unemployment rate as well.

All of the aboves have further effects on the costs of input material logistics.

4. CONCLUSIONS, SUGGESTIONS

Conclusions:

- According to the international status analysis and the national environment-evaluation of bioreactors, it can be stated that the applied technologies have different effects under different circumstances, many times-seemingly-contradictory ones.

- As a result of complex analysis and synthesis an obvious attempt can be documented to transfer today's industrial and well operating plant technologies into a wider environment. Moreover, there is a more and more general professional requirement to examine, evaluate and analyze complexly the forming and operation of bioreactors. All these mean the production, supply and preparation for fermentation of bioreactor raw material, gas production and the utilization of fumigated materials.

- My analyses state that the biomass material-processes of bioreactors and the connecting energy processes are determined by time and natural-geographical structural changes. These changes have an effect not only economic, natural-environmental, but also on social-human environmental specifications and they can be well described by the characteristics of the above mentioned biomass material- and the connecting energy processes.

- I analyzed and summarized the general correspondences of bioreactors and their adaptable effects in Hungary reviewing their material- and energy processes, their complex relationships and process and system changes.

- The research objective and the applied methods are built on the principles of logistics. At the same time it gives a new, unique interpretation of the origin, transformation and utilization of organic materials that are used as raw materials in bioreactors.

- The special characteristics, temporal material changes of biomass production and the possibilities and conditions of its transformation in the bioreactor show such new correspondences with logistic methods that enable the analysis of certain partial processes as well. On the other hand they also make the determination of system correspondences possible.

- The transportation distance affects the costs of biogas production from agricultural biomass. The rate of this effect depends on the way of transportation, the type and quality of the transported material and the distance of transportation.

- At capacity increase of biogas production, the rate of transportation costs and the profit must be considered in the planning phase. Practice shows the chosen parameters of optimal transportation costs. I consider of great importance to research and determine appropriately it-taking notice of domestic relations.

- The system analysis and the determination and research of the technological and environmental characteristics of bioreactors could be realized by a new logistic method and the connecting description applied by me.

Suggestions:

Suggestions to education

- In frames of MSc education I suggest teaching the synthesis of the results of my thesis and the material-, energy- and cost relationships of bioreactors.

- Besides I suggest applying and presenting softwares during the education that contains modules and methods which consider my results.

Suggestion to research and development

- I suggest considering the costs and relative optimum correspondences stated by me at planning and operating of bioreactors to preplan efficiency and cost-saving.

- I suggest verifying the mathematic connections worked out in the results topic in more-independently operating-bioreactors. Independent tests promote the refinement of the method a lot. Practical testing can help to find the mistakes in the method and to define practical costs.

- I suggest determining the logistic connections of the origin and utilization of the produced out-put materials in the bioreactors. When considering the mathematic model, it would be practical if the model formed a coherent system with the connections having prepared by me.

5. NEW AND NOVEL SCIENTIFIC RESULTS

1. I have researched the complex Hungarian circumstances of bioreactor foundation, putting a special emphasis on global and local problems in Hungary and the decrease and termination of them. I have stated considering more view points that Hungary's facilities and opportunities are outstanding in the EU.

2. It was my research objective and I have analyzed bioreactors in different technological variations by applying the chosen methods under different circumstances. After the evaluation of all these, I have identified groups by synthesizing the results of the complex system based on corresponding factors, characteristics and processes. The characteristics of the groups defined by me were differentiated and they gave the principles of bioreactor planning and operation.

3. I have found a connection between field biomass area-increase and the logistic costs of biogas production. When determining functions I have considered the main characteristics –from a logistic point of view- of in-put materials, ways of transport and the possibilities and circumstances of utilization.

4. I have determined -according to the objective, method and syllabus of logistic correspondences- the raw material delivery system to bioreactors. According to this the plant and animal raw materials form different groups and this appears in logistic costs as well.

5. I have given a mathematic description and process determination of raw material delivery of bioreactors. I have recognized that the logistic costs of delivery increases linearly by applying animal raw materials, and according to the cube if applying in-put materials coming from plant production: ($c = K_n \cdot x^3 + K'' \cdot x = K_n \cdot \left(\sqrt{\frac{P_{vö}}{K_{gn}}} \right)^3 + K^* \cdot P_{vö}$, where K_n, K'', K^*, K_{gn} - is constant, $P_{vö}$ - total capacity).

6. I have prepared a complex cost-index to show the symmetry-changes of plant- and animal-raw material groups. During the delivery of in-put materials I have considered the variable and constant costs. I have determined the function-connection of the minimal total cost and the belonging optimal delivery amount by function analyzing methods.

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