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THE JERUSALEM ARTICHOKE (*HELIANTHUS TUBEROSUS*) AS A POTENTIAL ENERGY SOURCE

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Key words: Jerusalem artichoke, alcohol industry, energy requirement.

The Jerusalem artichoke is a plant which has great potential as a crop food and forage, or as a raw material in alcohol industry. Energy requirement to produce ethanol from this crop is prepared for farm-size operation. It is one of the most efficient crops for ethanol production from a net energy viewpoint.

INTRODUCTION

The world population is expected to reach the six billion inhabitants by the end of this century, which will undoubtedly create severe strains on existing energy and food resources. According to an EXXON report [1] approximately 2/3 more energy will be required in 2000 than was needed in 1978. It is expected that new developments in biotechnology will play an important role in resolving part of energy and food problems that lie ahead. One important development which has stimulated worldwide interest is the utilization of renewable carbohydrate resources for the production of ethanol as an energy source or valuable feedstock for chemical industry and concomitant production of single cell protein (SCP).

The production of fermentation ethanol is a complex process. The proccess flow begins with a choice of raw material, substrate preparation, microbial conversion, ethanol recovery and the utilization of by-products. One of the strong arguments against the production of fuel ethanol is that ethanol production process is energy deficient. However, it can be shown that by selection of a high-yielding raw material and by utilizing the by-products a farm-scale plant producing alcohol can be a commercially viable operation from energy viewpoint.

RAW MATERIAL — JERUSALEM ARTICHOKE

A very wide variety of agricultural crops have been used for ethanol production (Tab. 1). Recently a great deal of research has been directed towards producing ethanol from highyielding crops.

Table 1. Ethanol and energy yields per cultivated area

Raw material	Crop, t/ha	Ethanol, t/ha	Ethanol, GJ/ha
Sugar cane	55-70	3.1-4.1	82.9-109.7
Sugar beet	30-55	2.3-3.9	61.5-104.3
Corn	4-7	1.1-1.9	29.4-50.8
Wheat	2-4	0.6-1.1	16.1-29.4
Cassava	10-15	1.4-2.1	37.4-55.6
Potato	20-30	1.6-2.4	42.8-64.2
J. artichoke improved	50-80	3.3-5.1	88.3-136.4
Fodder beet improved	50-120	2.8-6.7	74.9-179.2

The Jerusalem artichoke (*Helianthus tuberosus L.*) is a member of the Compositae family and is closely related to the sunflower (*Helianthus annous L.*) and contains a widespread root system that produces tubers. The plant, native to temperate North America was introduced to Europe in the 17-th century. The common Polish names for this plant are Bulwa or/and Topinambur. There are number of characteristics inherent to *J. artichoke* that make it a potentially valuable crop. It shows a higher tolerance to frost than conventional crops. The plant is very resistant to pests and common plant diseases. It does not demand either prime soil and heavy fertilizing, however, yields are below maximum potential on lower-quality soils. Several reviews have been written about this plant [3, 5, 7, 8, 13, 15, 16, 17].

The simplest and original use of the J. artichoke was as a foodstuff for animals and livestock. Either the fleshy tubers or the fibrous tops of the J. artichoke may be used as animal feed whereas human consumption is primarily limited to the tubers. However, since about the turn of the century many other industial uses have been suggested due to its favorable chemical composition (Tab. 2), but agronomic technology and economic structure at the time of investigation were generally restrictive and research was abandoned. The

Table 2. Proximate chemical composition of Jerusalem artichoke tubers and stalks [3], [7], [15].

Components	Tuber % of fresh weight	Stalk % of fresh weight
Dry matter	22.5	29.5
Moisture	77.5	70.5
Crude protein	2.3	2.2
Fat	0.1	0.4
Cellulose	1.9	10.9
Nitrogen-free extract including:	14.6	17.1
Sugar	16.9	4.0
Ash	1.1	1.4

commercial application of ethanol production from this crop has been reported in France [10], USSR [6], Germany [21], Poland [20], the U.S.A. [19] and Japan [18].

More recently, the J. artichoke has received renowned interest as potential biomass crop for ethanol production due to the improved varieties which have exhibited higher yields per hectare. According to Stauffer et al. [15], compared to the amount of ethanol obtainable per hectare of sugar beet, corn and wheat, J. artichoke would yield 1.7, 2.0, 3.7 times more alcohol, respectively. Among the many strains of J. artichoke mentioned by growers in America, the Mammoth French White, French White Improved and Columbia seem to be the most common. The latter one achieves high tuber production within the growing season of Western Canada. Tuber yields have ranged from 38 t/ha to 76 t/ha under drought and ideal growing conditions in Manitoba with mean sugar contents of 18—20% of fresh weight in the fall and 16% in the spring [2]. According to the J. artichoke growers, an average yield of tubers at 50 t/ha and stalks at about 30 t/ha with 30% dry matter are realistic for Ontario. A preliminary test of the growth Columbia strain conducted in small plots in 1985 showed that very similar yield would be achieved also in Poland.

The main sugar found in the J. artichoke is a homologous series of polyfructofuranose units which consist of linear chains of D-fructose molecules joined by β $(2 \rightarrow 1)$ linkages. This chain is terminated by a D-glucose molecule linked to fructose by an α $(1 \rightarrow 2)$ bound as in sucrose. The polimerization degree depends on the harvest and storage time.

ENERGY ANALYSIS

INTEGRATED MODEL ON FARM FOR ENERGY ANALYSIS

The integrated model of ethanol production on farm included the agricultural subsystem and the alcohol plant subsystem. Both of these are close to the livestock subsystem (Fig. 1).

In the agricultural subsystem, the J. artichoke is grown specyfically to make ethanol and produce the stalks to meet energy requirements of the alcohol plant. The extracted pulp from the alcohol plant is used as animal feed in the wet form. The CO_2 from the fermentation and distillery residues are not now considered for use.

The model includes energy inputs for:

a) producing the J. artichoke in the agricultural subsystem and transporting tubers and stalks from the field to the alcohol plant,

b) production of ethanol.

ENERGY REQUIREMENTS FOR GROWING J. ARTICHOKE

Energy requirements for production of agricultural products vary considerably depending upon climatic conditions, cultural and harvesting practices and

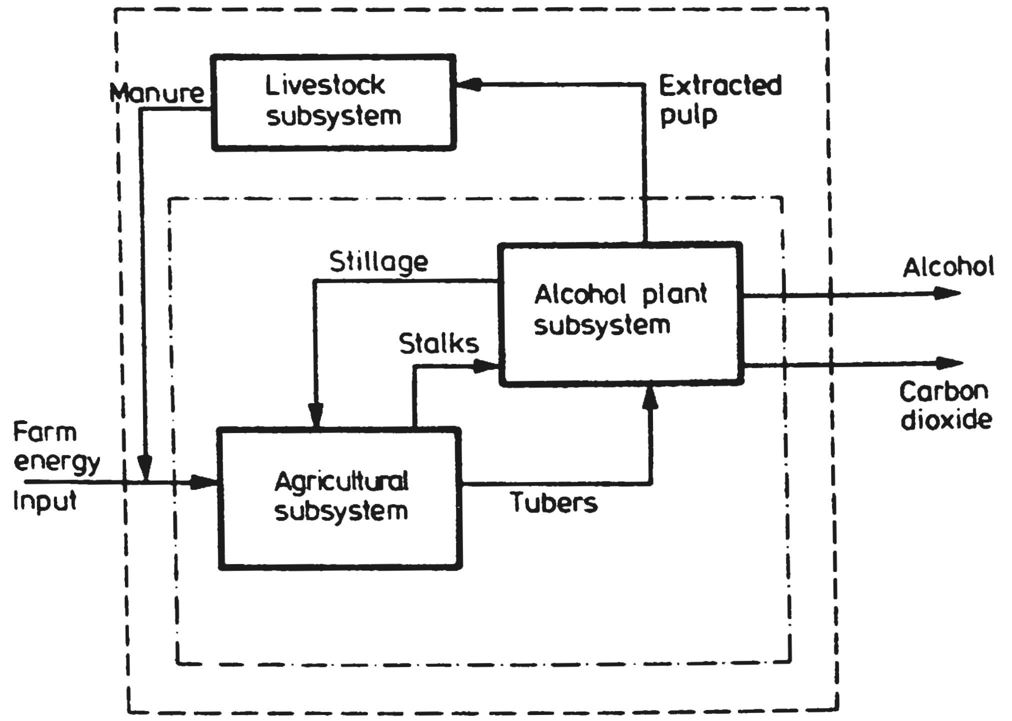

Fig. 1. Intergrated model of alcohol production on farm-scale operation

the agricultural crops. At present, there is information on the energy requirement for producing J. artichoke. For the modern agricultural process with high level of mechanization the estimated energy requirements for production of J. artichoke is shown in Table 3.

For comparison, energy requirements for production of sugar beet and potato given by ECC Report [4] are 7.94 MJ/kg of ethanol and 8.7 to 11.2 MJ/kg of ethanol, respectively.

Table 3. Estimated energy requirements for the production of J. artichoke

In terms of Total Resources Depletion*		
Energy inputs**	MJ/ha	MJ/kg of ethanol
Cultivation	350	0.098
Plating	350	0.203
Fertilizer***	10050	2.792
Inter-row cultivation (2)	610	0.169
Fungicide	810	0.225
Sprout inhibition	670	0.186
Harvesting: tops****	1330	0.369
tubers	3270	0.908
Hauling to alcohol (5 km) plant	3680	1.022
50 tonnes of manure*****	2220	0.617
(loading, transport, spreading)	5330	
Machinery amortization******	5330	1.481
Total	29050	8.070

* adapted from Stauffer [15],
** potato production energy requirements by category according to Southewell and Rothwell [14],
*** fertilizer rates in Manitoba, kg/ha: N—90, P_2O_5—56, K—50,
**** assumes values similar to corn silage,
***** adapted from Pasquier [12],
****** assumes values 750 kg of steel per ha and 10 years amortization.
Note: Ethanol yield 72 kg of ethanol/t of tuber, 3600 kg of ethanol/ha

It is also interesting to note that the energy produced by agricultural subsystem through combustion of tubers and stalks is about 186 700 MJ/ha and 148 680 MJ/ha for tubers and stalks, respectively.

ALCOHOL PLANT AND ENERGY INPUTS

This study is based on a farm-scale alcohol plant producing about 4.0×10^6 kg of ethanol per year. Farm size of about 1000 ha is needed to support an alcohol plant. Heat recovery and recycling are feasible for operation of this size. A general flowsheet of process is shown in Fig. 2.

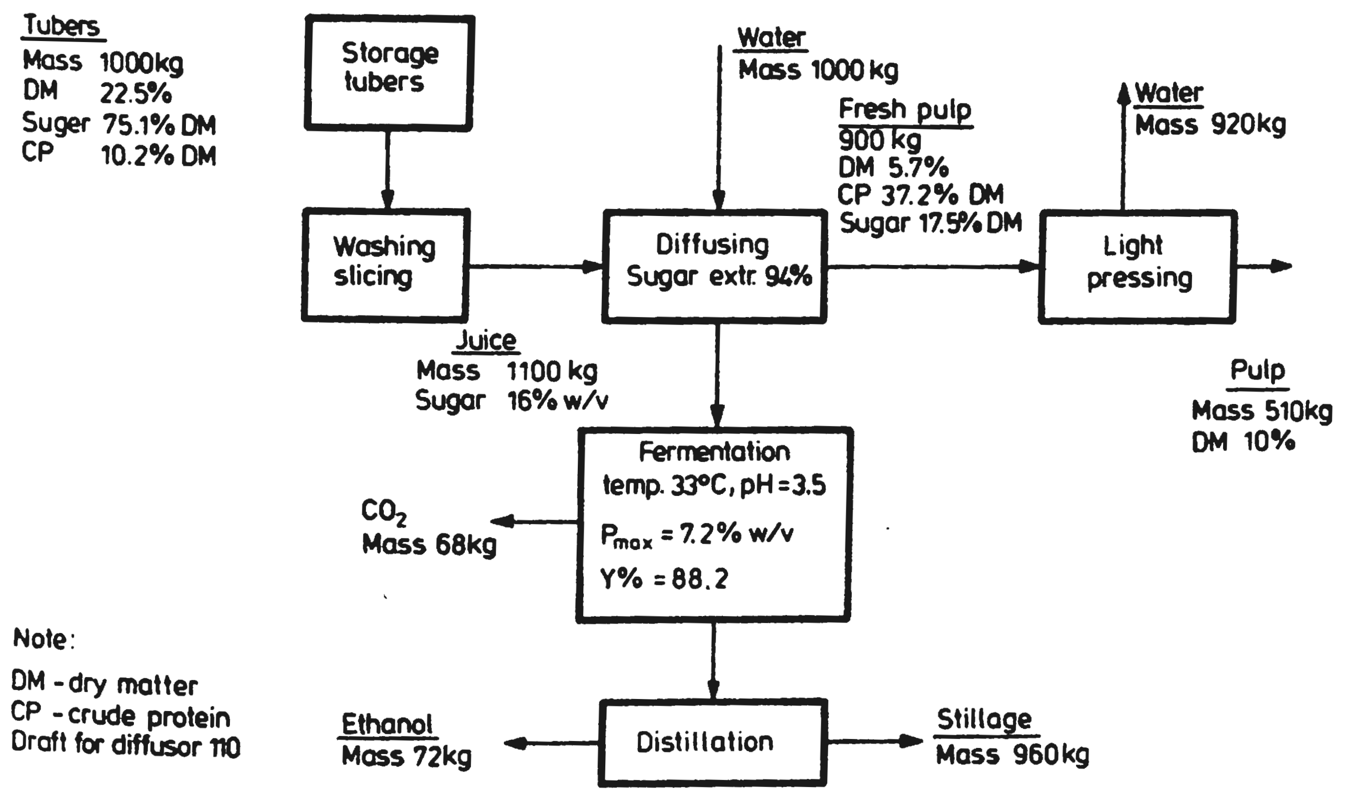

Fig. 2. A general flowsheed of ethanol production process mass balance based on one tone of tuber

Table 4. Kinetic parameters of the fermentation by *Kluyveromyces marxianus* [9].

Parameter		Value
S_o	% w/v	16.0
P_{max}	% w/v	7.2
X_m	g biomass dry wt/L	5.0
$Y_{x/s}$	g/g	0.034
$Y_{p/s}$	g/g	0.489
Y	% of theoretical	88.2
Pr	g ethanol/L h	3.4
%	of sugar utilized	0.92

The juice obtained is fermented by the yeast *Kluyveromyces marxianus* with inulase activity. The use of this strain allows a complete fermentation without prior hydrolysis or even without sterilization when carried out at pH = 3.5. This is particular energetic and economic interest. Kinetic parameters of the fermentation are given in Table 4.

The energy required for alcohol plant can be assumed to be about 13.36 MJ/kg of ethanol. This value includes: preparation of wort 3.16 MJ/kg of ethanol, fermentation 1.25 MJ/kg of ethanol, ethanol recovery 9.0 MJ/kg of ethanol. (Note: The indirect energy required to manufacture equipment at the alcohol plant is not included). Industries which manufacture distallation plants generally give values 8.0 to 12.0 MJ/kg of ethanol for broth from starchy materials without futher specification [11].

ENERGY OUTPUT—ENERGY CONTENT OF AGRICULTURE RESIDUES

The total energy that could be obtained through combustion of stalks is determined by adding the products of each component's weight and heat of combustion. This energy yield is 148 680 MJ/ha, i.e. 41.30 MJ/kg of ethanol. It is evident that only 50% of the stalks are required so produce the energy needed to operate the alcohol plant with a boiler efficiency of about 70%;the rest could be left on the field to prevent soil depletion. It is also possible to improve forage quality of the stalks through plant breeding and use them as animal feed.

ENERGY CONTENT OF EXTRACTED PULP

The pulp constitutes the most important by-product of the alcohol plant. Energy yield through combustion of the pulp is estimated to be about 17.26 MJ/kg of dry matter or 12.22 MJ/kg of ethanol. The pulp contains about 37% DM crude protein and the amount of metabolizable energy found in this pulp suggests that it has a good feeding value. It is reported that there is a high lysine and methonine content of this pulp and very good protein quality [15].

ENERGY CONTENT OF ETHANOL

The energy value of ethanol is taken as its heat of combustion at the low heating value. This is 26.64 MJ/kg of ethanol.

SUMMARY OF ENERGY ANALYSIS

The total energy analysis is shown in Table 5. From this analysis it is evident that the energy balance for ethanol production from the J. artichoke is positive. Utilization of the agricultural residues is very important since they represent about 56% of the total energy produced by the agricultural subsystem. The pulp produced in the alcohol plant represents about 33% of the total energy output in this subsystem.

Because this crop is not yet cultivated on a large scale in Poland the assumptions and data used allow only to present a crude estimate of the energy balance.

Table 5. Total energy analysis

	Overall MJ/kg of ethanol	For model MJ/kg of ethanol
1. INPUTS		
Agricultural subsystem	8.07	8.07
Alcohol plant subsystem	13.36	from stalks
TOTAL INPUTS	21.43	8.07
2. OUTPUTS		
Alcohol	26.64	26.64
Agricultural residues	41.30	for alcohol plant
Exstracted pulp	12.22	12.22
TOTAL OUTPUTS	80.16	38.86
Ratio: INPUT/OUTPUT	3.7	4.8

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BULWA (*HELIANTHUS TUBEROSUS*) JAKO POTENCJALNE ŹRÓDŁO ENERGII

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Streszczenie

Produkcja etanolu przez fermentację odnawialnych, bogatych w węglowodany surowców roślinnych jest ciągle przedmiotem badań na całym świecie. Etanol jest bowiem nie tylko alternatywnym zamiennikiem ropy naftowej w sensie energetycznym, ale również substratem do wielu syntez chemicznych. Powszechne stosowanie etanolu jest jednak ciągle kontrowersyjne, gdyż część badaczy twierdzi, iż jego produkcja jest energetycznie nieefektywna.

W niniejszej pracy wykazano, że użycie wysokoplennego surowca roślinnego do produkcji etanolu w gorzelniach rolniczych i wykorzystanie przy przerobie tego surowca wszystkich uzyskiwanych produktów zapewnia energetyczną opłacalność procesu.

Takim właśnie surowcem roślinnym jest bulwa, ze względu na jej wysoką plenność (tab. 1), jak i korzystny skład chemiczny (tab. 2). Dzięki uprawie bulwy z powierzchni uprawnej można uzyskać odpowiednio 1,7, 2,0 i 3,7 raza więcej etanolu niż z uprawy buraka cukrowego, kukurydzy bądź zbóż. Bulwa cechuje się relatywnie małymi wymaganiami w stosunku do siedliska, jest odporna na większość szkodników i zaraz, jak również na niską temperaturę.

Do analizy energetycznej procesu zastosowano zintegrowany model produkcji etanolu w skali gorzelni rolniczej (rys. 1). Model uwzględnia ilości energii wydatkowane w trakcie uprawy bulwy (tab. 3) i w trakcie jej przerobu na etanol (rys. 2 i tab. 4). Z przeprowadzonego bilansu energetycznego wynika (tab. 5), że uzyskuje się znaczny zysk energetyczny, gdyż stosunek ilości energii uzyskiwanej do ilości energii włożonej wynosi ok. 3,7.