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Elucidation of the potential of high yielding energy crops

Sustainable Bioenergy Solutions for Tomorrow

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Preface

This report is a part of the Sustainable Bioenergy Solutions for Tomorrow (BEST) research program, which is joint research program by FIBIC Ltd, and CLEEN Ltd. BEST program is funded by the Finnish Funding Agency for Technology and Innovation, Tekes.

The report belongs to BEST research program's Working Package 2 (WP2) "Radical improvement of bioenergy supply chains", and it's Task 2.1 "Raw materials". This report is an elucidation of the potential of high yielding energy crops.

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Name of the report: Elucidation of the potential of high yielding energy crops

Key words: bioenergy, biomass, Igniscum, Giant knotweed, *Fallopia sachalinensis* , Virginia mallow, *Sida hermaphrodita*

Summary

Igniscum® and Virginia mallow *(Sida hermaphrodita)* are high yielding perennial plants, which maintain productivity for decades after being established. Igniscum® and Virginia mallow could be utilised as fresh biomass for biogas or as spring-harvested dry biomass for burning in district heating or CHP plants. Spring-harvested biomass contains low quantities of detrimental elements for burning processes, because nutrients are removed from stems and leaves to roots outside the growing season. Virginia mallow could be established by seeds or planting seedlings. Igniscum® is a self mutated *Fallopia japanese* and *Fallopia sachalinensis* (Giant knotweed) hybrid, which doesn't produce seeds and is less invasive in character than Giant knotweed. Cultivation for increase of Igniscum® plants is made by micro-propagated seedlings or root- and stem cuttings. A Giant knotweed trial was established in MTT Agrifood Research Finland experimental farm in Piikkiö in 2006. An Igniscum® population was established in 2010 and a population of Virginia mallow in 2011. Measured dry weight yields of Giant knotweed spring harvests were15-31 tons/ha. The yields of Igniscum® were over 20 tons/ha in autumn, but below 8 tons in spring. The dry matter yields of Virginia mallow were ca 15 tons/ha in autumn and 8 tons/ha in spring, when harvested in MTT Piikkiö experimental farm.

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1 Igniscum® cultivation

1.1 Introduction

Igniscum® is a fast-growing perennial plant. Itis a hybrid breed by natural mutations of *Fallopia japanese* and *Fallopia sachalinensis. F. japanese* originates from East Asia; China, Japan and Korea. *F. sachalinensis* (Giant knotweed) originates from the Sakhalin Island and the islands belonging to the group of Kuril Islands. Both parents of Igniscum®, *F. Japanese* and *F. sachalinensis* are at present widespread and invasive species. The self generated mutation variety Igniscum® was discovered for the first time in 1987, in the North-Rhine-Westphalia Germany (United States Plant patent publication). Its features include that it is not forming sprouts or seeds, which makes it less invasive than its parents, and it is sustainable and produces abundant biomass. Cultivation for increase of Igniscum® is made by micro-propagated seedlings (meristem cultivation), division of roots, or by root- and stem cuttings. Because of its high biomass yield it can be used for bioenergy, but also for medical use, as it contains stilbenes, catechins and quercetins (Nadezda Vrchotová, Bozena Será and Eva Dadáková 2009). Igniscum® was cultivated on a practical farming area of 393 ha in the year 2012, mainly in Germany, but also on experimental fields in Finland, Spain, Ireland and Italy.

1.2 The establishment of the crop

The cultivation conditions where Igniscum® is planned for are not demanding. It thrives on weaker than average value of soils. The soil type can vary from light sand to rigid clay, as long as the growth substrate goes down to a depth of at least 70 cm. The plant does not thrive well in flooded conditions. The moisture conditions of soil can vary from dry to wet, but the plant needs at least 450 mm of precipitation, divided evenly throughout the growing period. Cultivation on steep slopes in the vicinity of watercourses is not desirable because of possibility of heavy rainfalls to wash away parts of roots and the plant can spread to new areas along the water ways.

Igniscum® can grow in areas which are not suitable for the most demanding crops. The pH of the soil can vary from slightly acidic (pH 5.5) to mildly alkaline (pH 8). As a warmth favoring plant, growth might set up of the inclined slopes, whose altitude is less than 750 m. The stands ripen and the leaves wither in winter. The roots can overwinter under the snow even at -23°C air temperatures.

The establishment of the crop starts in the autumn by ploughing or tilling the field. Manure used as fertilizer should be ploughed in the soil in the preceding year before planting. In the spring, before planting, the soil should be power harrowed. Planting takes place in the spring after the frosts, earliest in May to June, unless very dry periods are anticipated. Irrigation of the plantlets may be necessary, if it is very dry after planting. In any case, the transplanted seedlings need good moisture conditions (either by rain or by artificial irrigation) after planting, in order to ensure reliable rooting.

1.3 Preceding crops in rotation

Preceding crops in rotation for Igniscum® are ideally deep pile root plants, such as sunflower and oil radish, or green manuring legumes such as Lupins, which bring nitrogen to the soil. The perennial weeds need to be treated the year preceding planting with glyphosate, or at least two weeks before tilling and planting.

1.4 Planting

Best suited planting equipment for Igniscum® is e.g. a cabbage planting machine. Row spacing should be 1.3 meters and plant spacing 1 meter in a row, with resulting planting density of about 7500 plants/ha. Seedlings should be 5 to15 cm high and the root ball diameter 4 cm. It should be noted that the root ball should be completely covered with soil, as otherwise a turf of root ball could dry off, which can lead to drying of the roots and seedling death. The planting depth should be about 1 cm deeper than the height of the root ball.

Seedlings root easier, when the soil is well prepared before planting. Tilling should be made when the soil is moderately moist, and it should be made quite deep before finalizing the surface, to ensure capillary movement of water from the moister deep layers to the plantlets. In clay soils basic cultivation should be done already in previous fall, in fine sands, basic cultivation can be done in spring, which promotes soil warming. After ploughing, finishing tilling is made by power harrow or rotary hoe. The better the soil cultivating, the better the planting output and seedling growth. After planting in a loose tilled soil, it is worthwhile to roll, in order to achieve a better soil capillary humidity. The best suited equipment for rolling is a Cambridge-type smooth roller, which compresses and adapts to the ground shapes better than a skeleton-type roller. The rolling is necessary in dry weather conditions and in particular if tillage layer has been left coarse. Favorable time for planting is from May to August, when the last frosts in the spring are over and the first autumn frosts are still to come.

1.5 Weed control

In the planting year and the following one, the weeds have to be removed from the growth by harrowing, because Igniscum® plants are still too weak to compete against weeds. Harrowing can be started three weeks after planting, when the plants are rooted well. Two or three harrowings is a sufficient amount if pre emergent herbicides are not used. Harrowing is possible until Igniscum® plants begin to form lateral shoots between the planting rows. Small weeds in the planting rows can be harrowed by using a finger cultivator, with plates with rubber fingers that uproot or bury in the ground the smallest weeds. In the spring after the planting year it is possible to use glyphosate before Igniscum® emerges. Herbisides Fusilade Max 1-1.5 l/ha and Select 240 EC 0.5 l/ha with fixative in oil 1 l/ha are suitable for grass-type weed control. By the second year after planting, the competitiveness of the Igniscum® plants is adequate, as they make large number of shoots, now also covering the spaces between rows. Plant growth is rapid after soil warming in the spring, offshoot grows approx. 10-15 cm per day and the beginning of June stand is already more than 2 m in height and very shady.

Figure 1. Liming after the harvest before shooting reduces leaf yellowing and stunting

1.6 The fertilization in harvest years

Fertilization is based on the data of the soil fertility analysis. The need for fertilizers per harvested dry matter ton is shown in Table 1.

Table 1. Nutrients needed to produce one metric ton of dry matter of Igniscum® (Fechner 2012).

Nutrient	N	P	K	Ca	Mg
Kg/yield DM ton	5.2	0.5	6.2	9.7	1.0

Mineral fertilizers, manure and urine are suitable for nitrogen fertilization. At the stage of crop establishment, mineral fertilizers and liquid organic fertilizers can be located between rows. In later years, fertilizing on the plant leaves should be avoided and nutrients given as soon as possible in the spring after harvest and before plants produce shoots. Sludge fertilizer can be led to vegetation by hoses from slurry wagons. Solid biogas reactor digestate can be spread as well as composts and manures. Acid soils need liming to maintain an adequate level of pH, even if the plant comfortable pH level is 5.5 to 6.5. According to the German experience (Fechner 2012), liming after harvest prevents plant leaves from yellowing and stunting in the spring (Figure 1).

1.7 Harvest

The first full yield can be harvested in the third year after establishment. The full potential yield can be achieved only when there are more than 40 shoots/m^2. Suitable machines for harvesting are row spacing -independent self propelled silage choppers such as Claas Jaguar, New Holland and John Deere. The row spacing independent header manufacturers are, among others, German Kemper and Krone. Beside the self propelled silage choppers a tractor is required for hauling a trailer. In the spring harvested Igniscun Basic®-knotweed, appropriate chip length is between 23 to 35 mm. For Igniscum Candy® used in the manufacturing of biogas, appropriate chip length is between 6 and 8 mm. Moisture of chips in the spring harvest should be less than 20%, in order to the storage not being a problem. In good weather conditions, frost and spring sun dry the stems to below 11% humidity, so they could be pelleted without extra drying. Harvesting is good to do in the spring before ground frost has melted, to avoid soil compression because of the heavy machinery. If the ground frost melts before harvest, there is also a risk that new growth begins before soil is dry enough to carry harvesting machines. Bulk specific gravity of the spring harvested sun-dry Igniscum Basic® is 130-150 kg/m^3, when the chip length is 30 mm. For longer journeys, chopped biomass could be baled before transport because volume weight of a bale goes up to 400 kg/m^3. As a raw material for biogas, Igniscum Candy® is suitable for harvesting, when the dry matter content is between 28 to 35 %. It can be harvested during the growing season every 4 to 6 weeks. When harvested for silage type storage (e.g. bales wrapped in plastic), specific gravity for Igniscum Candy® is 300-500 kg/m^3, when cutting length is between 6 to 8 mm (Fechner 2012).

1.8 Transportation

Tractor-trailer -combinations can be used for short-haul transports directly from fields to storage areas. For longer distance transports, biomass needs to be compressed to roller bales or large square bales. The loading efficiency of large square bales is better than roller bales in vehicles, which makes the transportation more profitable, and also increases the size of the transport unit. Tractor bale wagon dimensions are 2.5 m x 9 m, which loaded by large square bales gives more than 40 m^3 in volume and 20 t of payload mass. In short transport distances, about 15 km from the field directly to the storage, a transport tractor is fast enough, but in longer distances it is easier to arrange the transport by a truck. The bulk dry mass transportation over long distances could be intensified by using efficient transferable pellet machines to add transport capacity. In this case the material moisture content has to be about or under 11 %.

1.9 Storage

If the biomass humidity is below 20 % in spring harvest, no post-harvest drying is necessary. Storing dry biomass can take place either in an aerated large-bay building or on solid field, covered by e.g. TOPTEX ® coating material, like e.g. sugar beet clamps. Storing height must not exceed 7 m in order to avoid spontaneous combustion of the clamps. In clamps Igniscum® bulk density is 160 kg/m^3 (Fechner 2012).

Ensiled harvested Igniscum® can be stored in horizontal silos compressed by narrow type tractor tires, so that surface pressure is high and air escapes from the preservation process. After compaction, horizontal silos are covered with hermetically sealed plastic sheet in order to prevent silage warming and deterioration in silos. Alternatively the silage could be stored in low oxygen tower silos, where compressing happens through air flow and masses own gravity.

1.10 Utilization of Igniscum®

Igniscum Basic ® dry chaff (Figure 2) is suitable for burning, just like wood chips in district heating and CHP power plants. It can be pelleted or compressed into briquettes without assistance of binders, because of the high lignin content (22 %) of the biomass. Pelleting increases the mass volume weight of dry biomass 4.7 fold, to 760 kg/m^3, which will help reduce the need for storage volume and facilitate the product transportation. Briquetted products can be used in all kind of wood-burning stoves. Table 2 presents the Igniscum Basic® fuel analyses, according to German research, as well as Giant knotweed fuel analyses cultivated in Piikkiö.

Figure 2. The spring harvested lignin rich chopped Igniscum® stems, chip length about 2 cm.

Table 2 Igniscum® and Giant knotweed fuel values and detrimental elements.

		Igniscum Basic® Germany	Giant knotweed Piikkiö
Calorimetric value	MJ/kg	18,288	19,24
Ash content at 815 °C	%	2,128	2
Ash melting temperature	°C	1170-1500	
Cl	%	0,01542	0,028
S	%	0,05286	0,03
N	%	0,546	<0,3
Ca	ppm	8901	6700
Na	ppm	198	89
K	ppm	5648	4800
Mg	ppm	994	
Cu	ppm	8,025	
Cr	ppm	1,45	
As	ppm	< 0,5	
Cd	ppm	≤ 0,5	
Hg	ppm	< 0,05	
Pb	ppm	< 10	
Ni	ppm	4,25	
Zn	ppm	30	

1.11 Giant knotweed varieties and Igniscum® in growing trials in Finland

A trial of Giant knotweed varieties was established in MTT Piikkiö in the year 2006. The first harvest measurements of Giant knotweed were made in spring 2011 and 2012. Giant knotweed populations had been acquired from various nurseries. Planting area was 6 m^2 and isolated for between corridors. The whole plot was harvested, and thus corridors have side effect on every plot yield, but level could not be verified (Figure 3.). The yields of harvested plots in 2011 and 2012 are presented in Table 3 and Igniscum® harvested biomass in growing seasons 2012-2014 in Table 4. The first growing season's growth of Igniscum® is presented in Figures 4-7.

Figure 3. Spring harvested Giant knotweed populations in spring 2011 in Piikkiö. The trial was established in 2006.

Table 3. Giant knotweed varieties, number of stems/m^2 and the dry matter yields in spring harvest in MTT Piikkiö in 2011 and 2012. The trial was established in 2006.

	2011			2012		
Giant knotweed variety number	Stem number/ m^2	Dry matter g/stem	Dry matter yield kg/ha	Stem number/ m^2	Dry matter g/stem	Dry matter yield kg/ha
193401	38	55,1	20769	40	69,6	29081
193402	31	83,3	26086	33	98,1	31163
193403	18	83,7	14927	29	74,4	22019
193404	21	94,7	20053	37	79,8	30328
193405	28	99,6	27386	35	86,2	31436

Table 4. The yields of Igniscum® in growing seasons 2012-2014 in Piikkiö. The trial was established in the year 2010.

Fertilization N-P-K kg/ ha	Harvest time	Dry matter content %	Fresh weight yield kg/ha	Dry matter yield kg/ha	Harvested part of growth
370 -11 -11	3.7.2012	20.8	70200	14640	stems and leaves
370 -11 -11	3.8.2012	27.2	88720	24150	stems and leaves
370 -11 -11	25.9.2012	36.6	75500	27670	stems and leaves
370 -11 -11	15.11.2012	31.6	41670	15265	stems
370 -11 -11	30.4.2013	87.3	8833	7713	stems
0-0-0	6.5.2014	64.3	8415	5413	stems
370 -11 -11	17.6.2014	15.9	109700	17500	stems and leaves
370 -11 -11	15.9.2014	37.9	59440	22570	stems and leaves

1.12 Production costs of Igniscum®

Igniscum® seems to be very suitable as a short-term cultivation plant. Cultivation willingness will, however, be restricted by the high cost of establishment. Cost of micropropagated planting material was 1.5 €/plant in 2011. Additional costs were caused by tillage, planting, fertilization and plant protection (Table 5).

Table 5. The Annual cultivation costs of Igniscum® in Germany in 2011. North Rhine Westphalia Landwirtschaftskammer

		€/ha
Establishment 6700 pcs/ha	tilling	250
	plants	10000
	planting	800
	fertilisation and plant protection	321
	alternative yield value loss	300
		11636
Annual cost 2nd year	fertilisation and plant protection	232
	harrowing	60
	alternative yield value loss	300
		592
Annual costs	plant cost/year	839
	clearance of the crop and field recultivation	17
	fertilisation	273
	harvest and field transportation	635
		1772

Figure 4. The first growing season 2011 growth of Igniscum® in Piikkiö 12.4.2012.

Figure 5. After the spring harvest Igniscum® crop starts forming new shoots, also between planting rows 23.5.2012 Piikkiö.

Figure 6. The Igniscum® growth in Piikkiö 26.7.2012.

Figure 7. In the second year's growth stems are 25-30 mm in diameter, light passes weakly through the dense green foliage, and the lowest leaves turn yellow and come off due to lack of light.

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2 Cultivation of Virginia mallow (*Sida hermaphrodita*)

2.1 Introduction

Virginia mallow is a perennial plant belonging to the Mallow family. The plant is native in the Appalachian Mountains, where it thrives in sunny and sandy beaches of half shady and cobbly river banks or wetlands, which are covered with water throughout the year. Rail lines and road sides are also possible plant habitats. Today, the plant has become rare in its original habitats. Virginia Mallow is, in particular in Poland, studied as a bioenergy plant. Suitability of the plant as a soil stabilizer, for forage or for fiber and pulp industry has been studied in Ukraine (Spooner et al. 1985). In addition to the use as bioenergy plant, it is suitable for forage because of its high protein content during flowering time (almost 30 %) (Styk B. 1984). As a nectar plant for bees it has yielded honey up to 120 kg/ha (Borkowska H., Styk B. 1997, 2006). In the spring harvest, the plant dry matter can be used as insulation material and as fiber cellulose like that of pine trees. The green biomass can be used in medicine, forage and biogas production. As a short rotation bio-energy plant it is utilized, among other things, as pellets or briquettes for burning, biomass for biomethanol and biogas, and as substrate for cellulose based ethanol in power and heating plants (Borkowska H., Styk B. 1997, 2006).

Even though cold and dry weather conditions in the spring would inhibit the germination of Virginia mallow seeds and stop the growth of the shoot, the plant can survive extreme cold conditions up to -35°C and extreme drought because of its strong root system. In the spring every plant produces from 20 to 40 shoots that overwintered in dormant buds. In autumn, the stems and leaves dry up and the nutrients are returned to the roots to be used for the next year's new growth.

2.2 Establishment of Virginia mallow stands

The establishment of the crop starts with preparing the soil well, like with other perennial crops. Perennial weeds should be treated before the establishment of the crop. The plant benefits from good soil fertility values, such as phosphorus, potassium and magnesium, as well as from neutral or a little sour soil pH value. The crop can be established from seed sown directly in the field in early spring, or by planting seedlings. The crop does not produce harvestable yield the year after establishing. Due to the slow development of the crop, it is susceptible to weed competition in its early phases. The seed requirement for establishment of the crop is one kg/hectare, when the weight of a thousand seed is 4-4.5 g, which makes around 25 plants/m^2. Sowing is carried out on the rows with a pneumatic precision drilling machine. Row spacing can vary from 0.5-0.75 m. Large spacing is a prerequisite for weed harrowing and later harvests with self propelled silage choppers.

Recycled fertilizers as compost, sewage sludge or manure can used for fertilizing. Mineral fertilizers are easy to broadcast, but it isn’t meaningful to use them because of their high price and higher greenhouse gas emissions caused by them, compared with nutrients derived from waste.

Well established vegetation produces little biomass in the establishing year, but in the following years the growth is fast, depending on the weather conditions and habitat. The stems can reach 3-4 meters height each year (Figure 8).

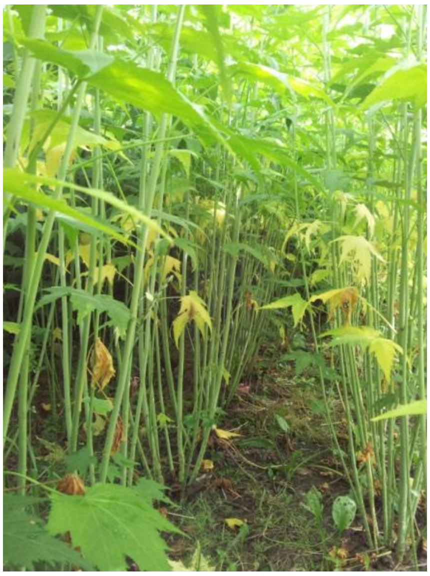

Figure 8. The second year growth needs no longer harrowing; weeds will be outcompeted by the crop.

The most part of the root growth takes place in the uppermost soil layers, where roots can get the fastest access to water and nutrients. The development of the crop during the growing season 2012 has been described in Figures 9-12. The trial was established in 2011.

Figure 9. The growth of Virginia mallow, 23 May 2012

Figure 10. The growth of Virginia mallow, 14 June 2012

Figure 11. The growth of Virginia mallow, 5 July 2012

Figure 12. The growth of Virginia mallow 26 July 2012

2.3 Harvest

Harvesting is done in the spring before new growth begins and when the stalks are driest. In Poland, the crop is be harvested during the winter, between December and March, when the crop moisture is between 15 to 30 %, and burnt directly in district heating or CHP power plants. The energy value of biomass should reach 10 to 15 kJ/kg (Wardzinska K. 2000).

Self propelled silage choppers are the most appropriate machinery for dry crop harvest. Harvesting can also be done by mowing machines and self loading silage wagons. As a raw material for biogas, crop could be harvested in the autumn when the plants still have green leaves. The biggest fresh weight yield is achieved when harvest is made twice in the growing season. In Poland, the biggest fresh weight yield that has been harvested, has been 100 tons per hectare, with dry matter content of 40-60%. This, however, substantially reduced the yield of next year's harvest (Borkowska H., Styk B., Molas R.2007).

For the burning or pelleting immediately, moisture content of crop biomass should be less than 20%. In this case, there is no need for drying processing before storing, pelleting, baling or burning in a district heating or CHP plant. In the autumn at the end of the growing season, the moisture content of the crop is between 28 and 55 %, in the winter the moisture content is between 23 and 37 %, and in the spring from 16 to 25 % (Borkowska H., Styk B., Molas R.2007).

The yields of Virginia mallow depend on growing conditions, in addition to farming technology. Fertilizing by the waste water sludge, the dry matter yields were 9–11 tons/ha, while on well established plantations in the sand-clay soil the dry matter yields have risen up to 20 tons per hectare. The growth can be established in farmland, fallow and almost sandy soil, the most crucial factor being soil moisture (Borowska, H. and Wardzińska, K. 2003). Yield levels of the trials established in 2011 in Piikkiö are presented in Table 6.

Table 6. The yields of Virginia mallow in growing seasons 2013 and 2014 in MTT Piikkiö. The trial was established in 2011.

Fertilization NPK	Harvest time	Dry matter content %	Fresh weight yield kg/ha	Dry matter yield kg/ha	Harvested part of growth
370-11-11	30.4.2013	84	7693	6720	stems
0-0-0	6.5.2014	81	10100	8200	stems
370-11-11	15.9.2014	37	45240	16720	stems and leaves

2.4 Storage and utilization of Virginia mallow

The biomass may be stored in the open air, because it does not absorb moisture during storage as a result of the woody cellulose-like structure. Only a thin surface layer of the plant can be wetted, which is however a small part of the plant mass. Dry, spring harvested Virginia mallow is suitable for burning without adding another fuel. To increase the energy content, fine charcoal has been added to the biomass in Poland. The mixture has the advantage of reducing carbon and nitrogen emissions as well as sulphur emissions compared to pure coal burning. The advantage of Virginia mallow is a low ash content, approximately 2 %, and the fact that spring harvested dry mass contains only little fertilizer nutrients, just like other spring harvested perennials (Agricultural farm Ostrowąs).

Virginia mallow has also been used for removal of soil heavy metals and it can be fertilized by using sewage sludge. As particularly haulms take cobalt, iron and nickel from the soil, these heavy metals can safely be harvested and dealt with in the burning plants (Borowska, H. and Wardzińska K. 2003, Wardzińska K. 2000).

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