# Grassservice

Alternative use of biomass for maintenance of grassland biodiversity and ecosystem services

LIFE12 BIO/LV/001130

# Testing alternatives for the use of grass biomass: experience from the GRASSSERVICE project

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**Testing alternatives for the use of grass biomass: experience from the LIFE GRASSSERVICE project**

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# Introduction

Human overdependence on fossil resources for energy production have caused serious environmental problems, the global climate change being the most significant, and people are constantly searching for viable alternatives. Biomass has a huge potential to, at least partly, replace fossil fuels. Mostly, biomass renewability and a climate change neutral $CO_2$ balance are cited as the most important advantages. However, biofuel production is also a controversial issue – it is often accused of requiring more energy inputs and producing more greenhouse gas emissions than their fossil counterparts, as well as causing erosion, deterioration of soil health, depletion of aquifers and water quality, and losses in biodiversity[1]. $CO_2$ absorption capacity is only one aspect that shall be considered when calculating sustainability of biomass use for energy needs. Energy inputs required to grow, harvest, transport, process, and distribute fuels, and the release of $CO_2$ from burning the biofuel must be included to calculate net energy balance (energy output vs energy input) over the life cycle of the biofuel[2].

Wood is traditionally one of the most popular alternative energy resources in Europe, particularly in the Nordic and Baltic countries, where forest occupies large areas. Lots of woody biomass residues area generated during timber cutting and wood processing and may be used for energy production. However, woody biomass resources from forestry are exhausted in several countries, which leads to looking at other resources, also in agriculture[3].

To date, three generations of biofuels have been developed. The first generation biofuels are made from edible feedstock like corn, soybean, sugarcane, and rapeseed. Despite wide applicability, these resources are often, rightfully or not, blamed for a surge of food prices and decrease in arable land availability for food production[4]. Consequently, requirements to minimise the amount of land used for production of energy crops is now legally regulated[5]. One of the alternatives to energy crops is green biomass, including grass, which is as an alternative raw material for biogas and biofuel production, regarded as the second generation of biofuels, coming from non-food biomass, but still competing with food production for land use (the third generation biofuels compete neither with food nor land use). Approximately 90% of the dry weight of most plant materials consists of cellulose, hemicellulose and lignin where the first two can be converted to fermentable sugars usable for alcohol-fuel fermentation[6]. Various biofuels can be obtained from biomass by additional processing: bioethanol, biobutanol, biodiesel, biogas, biohydrogen, glycerine. At present, bioethanol and biogas are most produced biofuels.

Using grass biomass for bioenergy production is not a new idea – already in the late 1800s, grasses were widely used as a heating fuel in simple stoves in the prairie regions of the United States with scarce wood resources[7].

Nowadays, mostly three species of cultivated grasses are used in the World for energy production needs: switchgrass (*Panicum virgatum*), miscanthus (*Miscanthus giganteus*), and reed canarygrass (*Phylaris*

[1] Jenkins, R., Alles, C., 2011. Field to fuel: developing sustainable biorefineries. Ecological Applications, 21(4), pp. 1096-1104
[2] Groom, M. J., Gray, E.M., Townsend, P. A., 2008. Biofuels and Biodiversity: Principles for Creating Better Policies for Biofuel Production. Conservation Biology, Vol. 22, No. 3 (Jun., 2008), pp. 602-609
[3] Heinsoo, K., Melts, I., Sammul, M., Holm, B., 2010. The potential of Estonian semi-natural grasslands for bioenergy production. Agriculture, Ecosystems and Environment 137, pp. 86–92
[4] Gupta, V.K., Tuohy, M.G. (Eds.), 2013. Biofuel Technologies, Springer-Verlag Berlin Heidelberg, pp. 397-441
[5] http://eur-lex.europa.eu/legal-content/LV/TXT/?uri=CELEX%3A32015L1513
[6] Mood, S.H., Golfeshan A.H., Tabatabaei M., Jouzani G. S., Najafi G. H., Gholami M., Ardjmand M., 2013. Lignocellulosic biomass to bioethanol, a comprehensive review with a focus on pre-treatment. Renewable and Sustainable Energy Reviews, 27(6), pp. 77-93
[7] Biomass Energy Resource Center, 2009. A Basic Discussion on Grass Energy

*arundinacea*)[8]. The energetic value of the switchgrass and read canary grass reaches 19 kJ/g[9,10]. Studies in Estonia show that that the energetic value of perennial grass from seminatural grassland is similar - 18.1-18.6 kJ/g[11]. The highest biomass production and energy potential per area (115 GJ/ha) was found in alluvial meadows[12]. Although being far from the values for gas, petroleum and coal, they are compatible to wooden biomass (20.3 kJ/g) [13].

In Europe, energy production from biomass is regulated by Directive 2009/28/EC on the promotion of the use of energy from renewable sources. The Directive mandates that 20% of all energy usage in the EU shall be produced from renewable sources by 2020. EU Directive 2015/1513 relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC states that at least 10% of the final transport-sector energy consumption in each Member State should come from renewable resources. In 2012, the share of biofuels within transport energy demand by source and mode reached 3.7%[14].

Blending of biofuels is one of the methods available for the Member States to meet this target. Bioethanol and biodiesel are currently the dominant bio-based fuels in transportation. However, new alternative fuels have been suggested over the years.

The target of 10% by 2020 is also included in Latvian legislation - the draft Law on Transport Energy to be adopted in 2018. Besides, the Law states that the national target limits the proportion of biofuels obtained from agricultural crops to 7%; accordingly, there is potential for the use of grass biomass from seminatural grasslands within the remaining 3%. In April 2017, the Cabinet of Ministers of Latvia adopted the Plan for the Development of Alternative Fuels for 2017-2020[15].

The aim of this publication is to reflect findings of the project “Alternative use of biomass for maintenance of grassland biodiversity and ecosystem services” in relation to the production of biogas, biobutanol and pellets from grass biomass covering technological processes and construction of pilot facilities developed within the project.

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[8] Krzyżaniak, M., Stolarski, M.J., 2017. Perennial Grasses for Energy. Reference Module in Earth Systems and Environmental Sciences, Encyclopedia of Sustainable Technologies, pp. 131–140

[9] Jannasch, R., Samson, R., de Maio, A., Adams, T., Lem, C. H., 2001. Changing the energy climate: clean and green heat from grass biofuel pellets. Presented at “Climate Change 2: Canadian Technology Development Conference”

[10] Nilsson, D., Bernesson, S., Hansson, P.-A., 2011. Pellet production from agricultural raw materials - A systems study. Biomass and bioenergy 35, pp. 679-689

[11] Heinsoo, K., Melts, I., Sammul, M., Holm, B., 2010. The potential of Estonian semi-natural grasslands for bioenergy production. Agriculture, Ecosystems and Environment 137, pp. 86–92

[12] Indrek, M., Heinsoo, K., Ivask, M., 2014. Herbage production and chemical characteristics for bioenergy production by plant functional groups from semi-natural grasslands. Biomass and bioenergy 67, pp. 160-166

[13] Nilsson, D., Bernesson, S., Hansson, P.-A., 2011. Pellet production from agricultural raw materials - A systems study. Biomass and bioenergy 35, pp. 679-689

[14] European Commission, 2015. State of the Art on Alternative Fuels Transport Systems in the European Union. Final Report, p 128

[15] https://likumi.lv/doc.php?id=290393

# 1. Biogas production

## 1.1. Technological process of biogas production from grass biomass

Biogas is produced in biogas plants by the bacterial degradation of biomass under anaerobic conditions. Main elements or biogas production facility would be – a reactor where substrate is converted to biogas, methanogenic (methane producing) bacteria, a biogas holder, a substrate holder, supplementary parts such as substrate input and output channels, a biogas to electricity conversion unit and others (Figure 1).

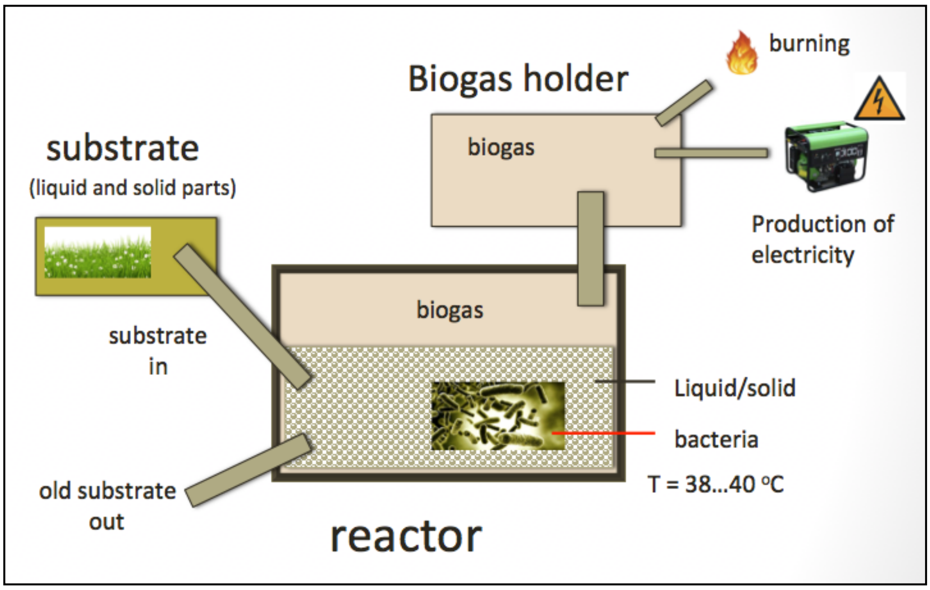


***Figure 1: The overall scheme of a facility to produce biogas from waste/grass***

Three most popular categories of biomass are used for biogas production:

- Substrate of farm origin, such as liquid manure, feed waste, harvest waste and energy crops.
- Waste from private households and municipalities, such as separately collected organic waste (in organic waste containers), market waste, expired food or food waste.
- Industrial by-products, such as glycerine, by-products of food processing or waste from fat separators.

Organic substance is converted to biogas in airtight digesters by bacteria in several steps – hydrolysis, acidogenesis, acetogenesis and methanogenesis (Figure 2). The bacteria are similar to those found in the prestomachs of ruminants.

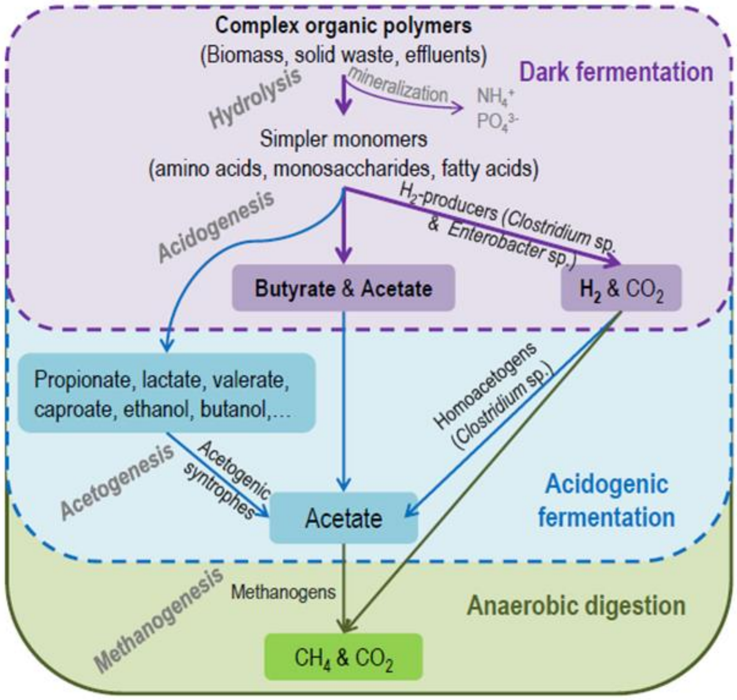


***Figure 2: An overview of hydrogenotrophic methanogenesis process[16]***

After simple desulfurization and drying, biogas can be converted to electricity and heat in cogeneration (combined heat and power - CHP) units, or the biogas can be burnt to produce heat. After treatment to natural gas grade, the so-called biomethane can be used in all applications commonly known for natural gas. Thus, biogas and biomethane produced from biogas are flexible renewable fuels that can be stored. Motor fuel, electricity and heat can be produced from these biofuels, which facilitate their role in the context of sustainable energy supply. Besides, biogas can also replace carbon compounds in plastic products.

As with fossil natural gas, the main component of biogas that determines the energy content of gas is flammable methane ($CH_4$). Depending on the substrate digested in the biogas plant, the methane content of biogas fluctuates between 50% and 75%. The second main component of biogas is carbon dioxide ($CO_2$) with a share between 25% and 50%. Other components of biogas are water ($H_2O$), oxygen ($O_2$) and traces of sulphur (S) and hydrogen sulphide ($H_2S$). If biogas is upgraded to biomethane with approximately 98% concentration in a biogas treatment plant, it has the same properties as natural gas.

Sustainable feedstock for dark fermentation (DF - fermentative conversion of organic substrate to biohydrogen) and anaerobic fermentation (AF - microbiological conversion of organic substrate to biomethane in anoxic conditions) should be abundant, readily available, cheap and highly biodegradable[17]. A wide range of waste types can be used as substrates for biogas production using anaerobic digestion (AD - a number of processes when microorganisms break down biodegradable material in the absence of oxygen.). Large quantities of lignocellulosic and cellulose waste are collected from agricultural, municipal, and other activities. The most typical forms of waste used in the European energy industry are animal manure and slurry, waste water treatment sludge, solid waste from municipalities and food waste[18].

[16] Turona, V., Trably, E., Fouilland, E., Steyer, J.-P., 2016. Potentialities of dark fermentation effluent as substrates for microalgae growth: A review. Process Biochemistry, November 2016, 51(11), pp 1843-1854

[17] Guo, X.M., Trably, E., Latrille, E., Carrère, H., Steyer, J.-P., 2010. Hydrogen production from agricultural waste by dark fermentation: A review. Int J Hydrogen Energy 2010, 35:106, pp 60–73

[18] Achinas, S., Achinas, V., Eurewink, G.J.W., 2017. A Technological Overview of Biogas Production from Biowaste, 2017, Engineering 3 (3), pp 299-307

As there are problems to use agricultural waste as primary feed stock due plant cell wall resistance to microbial attacks in hydrolyzation process, a number of different pre-treatment techniques are being used to replace microbial hydrolysis – hydrothermal, freezing and super shredding methods, chemical pre-treatment by alkaline, peroxides or acid pre-treatment, biological pre-treatment with hydrolysing aerobic fungi or hydrolase containing enzyme preparation and combined pre-treatment with microwave irradiation and chemical approaches. By using advanced hydrolysis process, it is possible to gain biogas with about 50-70 mol% of $CH_4$ in biogas composition by using rice straws as primary substrate[19].

Even more lignin and hemicellulose rich substrate can be used as AD substrate at the right pre-treatment conditions. After pine soft wood pre-treatment with 8.0 w/w% NaOH for 10 min in 100°C, methane increases for 181%; using the same concentration NaOH in 0°C for 60 min showed 118.6 % increase in $CH_4$ [20].

Grassland biomass is promising feedstock for AD due to its low water consumption, and it can efficiently grow in non-arable lands thus avoiding direct competition with food crops. As other agricultural side products, grass has to be hydrolysed by advanced hydrolysation process before undergoing AD. Comparison of different pre-treatment methods is presented in Table 1.

***Table 1: Comparison of different pre-treatment methods[21]***

| Pre-treatment | Conditions | Feedstock | Result in AD |
|---|---|---|---|
| Thermal | Autoclave | *Pennisetum hybrid* | +4% $CH_4$ yield |
| | Steam explosion 160-220°C | Hay | +16%$CH_4$ yield |
| | Oil bath 80°C | *Eleusine indica* | +46% $CH_4$ yield |
| Chemical | $Ca(OH)_2$ | Grass | +37%$CH_4$ production |
| | Fenton's reagent | *Miscanthus giganteus* | 13.6Ndm$^3$/kgTS (biogas) |
| | Fenton's reagent | *Sorghum Moensch* | 25.2Ndm$^3$/kgTS (biogas) |
| | Fenton's reagent | *Sida hermaphrodita* | 26.1Ndm$^3$/kgTS (biogas) |
| Biological | Microbial Consortium: MC1 | Napier grass | +39% $CH_4$ yield |
| | Microbial Consortium: WSD-5 | Napier grass | +49% $CH_4$ yield |
| | Microbial Consortium: XDC-2 | Napier grass | +32% $CH_4$ yield |
| | Ensiling | *Festulolium Hykor* | +40% CC |
| | Fungus: *P. flavido-alb* | Grass of verge | No effect |

Energy recovery from waste or any agricultural organic matter is an environmentally sensitive mean to generate energy and reduce greenhouse gas emissions. Biogas is a combustible gas that is produced in anaerobic fermentation of organic matter. Biogas composition gained in anaerobic digestion (AD) usually contains 50-60 mol% of $CH_4$ and 40-50 mol% of $CO_2$. $CH_4$ heating value is 34 MJ/m$^3$, but heating value of biogas is only approximately 20.8-23.6 MJ/m$^3$ because it contains a large quantity of $CO_2$.

There are several techniques of biogas enrichment with different metal catalysts[22] after biological processes, but there are also possibilities to enrich methane straight in the digestion process. Dark fermentation (DF) is recently studied technology where biohydrogen is produced by the help of obligate anaerobe bacteria *Clostridium sp.* and *Enterobacter sp.* and can be further used in methane production either through homoacetogenesis or through hydrogenotrophic methanogenesis process (Figure 2)[16].

Mono-digestion (using single substrate) is sometimes unstable and has tendency to decrease in biogas conversion efficiency over the bacteria unifosing rmity effect. Anaerobic co-digestion allows for greater

[19] Sari, K., Soeprobowati, T.r., Hariyati, R., 2014. Phycoremediation of waste water from a plastic manufacturing industry with *Chlorella pyrenoidosa* H. Chick in laboratory study. Waste Technology 2(1), pp. 17-25

[20] Salehina, P., Karimi, K., Zilouei, H., Jeinhanipour, A., 2013. Improvement of biogas production from pine wood by alkali pretreatment. Fuel, Vol. 106, pp. 484-489

[21] Rodriguez, C., Alaswad, A., Benyounis, K.Y., Olabi, A.G., 2017. Pretreatment techniques used in biogas production from grass. Renewable and Sustainable Energy Reviews, Vol. 68, Part 2, pp. 1193-1204

[22] Tan, Z., Ai, P., 2017. $CO_2$ reforming of biogas to obtain synthesis gas using non-thermal plasma. Journal of the Energy Institute, Vol. 90, Issue 6, pp. 864-874

resource recovery from organic substrates and provides opportunities for more stable and generally higher total solid removal. Adoption of co-digestion (using two or more substrates) is increasing operational complexity and suffers from some of the same challenges as mono-digestion – nutrient imbalance, ammonia inhibition and C/N ratio changes[23]. Popular agricultural co-digestion substrates are animal manure and some lignin rich substrate, such as e.g. swine manure and corn straw (SM/CS). Research shows that the maximum methane yield and methane production rate were obtained at pH 7.5 and 70:30 SM/CS ratio[24]. Grass and wheat straw substrate is used as co-digestion material for C/N ratio stabilization in poultry dropping co-digestion. A relatively high C/N ratio means fast nitrogen degradation by microbes and results in low biogas yields and vice versa. A low C/N ratio can result in inhibition of methanogens. By fermenting 90 days at 35.0°C grass with Poultry dropping in co-digestion with mass ratio 50:50 respectively and C/N ratio 30-35 after shows 33.4% increase in methane yield over mono-digestion[25]. Anaerobic co-digestion of NaOH pre-treated corn stove and goose manure was carried out in the C/N ratio between 20 and 30 and showed even 92.1% process enhancement over the best conditions[26]. In co-digestion process, more than two substrates can be used to reach the nutrient balance and ensure bacterial diversity. Biogas production from co-digestion of inoculum from AD brewery wastewater treatment digitate, hydrolysed napier grass and slaughterhouse wastewater using anaerobic mixed cultures was conducted under pH 7and C/N ratio 3.42; in this case, methane yield was 1.79 times greater than digestate alone[27].

## 1.2. Construction of the biogas pilot facility

The biogas production pilot facility developed and constructed (Figure 3) within the LIFE GRASSSERVICE project is using grass biomass for biogas production. Grass biomass includes fresh grass or/and haylage. Fine fraction of hay (up to 0.5 mm in diameter) obtained from dust filters in hay grinding machines are also an appropriate grass source for biogas production. Typically, grass used in the prototype was cut in pieces of a 30-50 mm length.

The first phase is **hydrolyses**. In hydrolyses equipment (Figure 4), the grass biomass undergoes mechanical and microbiological treatment with the aim to achieve high hydrolyses of cellulose, hemicellulose, proteins, and lipids within biomass. End products are mono-saccharides, aminoacids, long-molecular organic acids and volatile organic fatty acids (VFA). Progressive cavity pumps (PCP) are installed for mechanical grinding of biomass. Pumps provide the mixing and heating of the substrate, as they are installed outside the hydrolyses equipment. Additive enzymes and micro-elements accelerate microbiological processes in hydrolyses. The biomass left after the hydrolyses is removed from the system by a snail transporter and mechanical press. This mass mainly consists of lignin constituents of grass fibres and bacteria.

[23] Cook, S.M., Skerlos, S.J., Raskin, L., Love, N.G., 2017. A stability assessment tool for anaerobic codigestion. Water Research, Vol. 112, pp. 19-28

[24] Chunlan, M., Tong, Z., Xiaojiao, W., Yongzhong, F., Guangxin, R., Gaihe, Y., 2017. Process performance and methane production optimizing of anaerobic co-digestion of swine manure and corn straw. Scientific Reports, 9379

[25] Rahman, A., Møller, H.B., Saha, C.K., Alam, M., Wahid, R,. Fenga, L., 2017. Optimal ratio for anaerobic co-digestion of poultry droppings and lignocellulosic-rich substrates for enhanced biogas production. Energy for Sustainable Development, Vol. 39, pp. 59-66

[26] Muhammad, H., Weimin, D., Muhammad, U., Kunlun, H., Jinhua, B., Zhendan, S., 2017. Methane enhancement and asynchronism minimization through co-digestion of goose manure and NaOH solubilized corn stover with waste activated sludge. Energy, Vol. 118, pp. 1256-1263

[27] Sittijunda, S., 2015. Biogas production from hydrolysate napier grass by co-digestion with slaughterhouse wastewater using anaerobic mixed cultures, KKU Res.j., 20(3), pp. 323-336

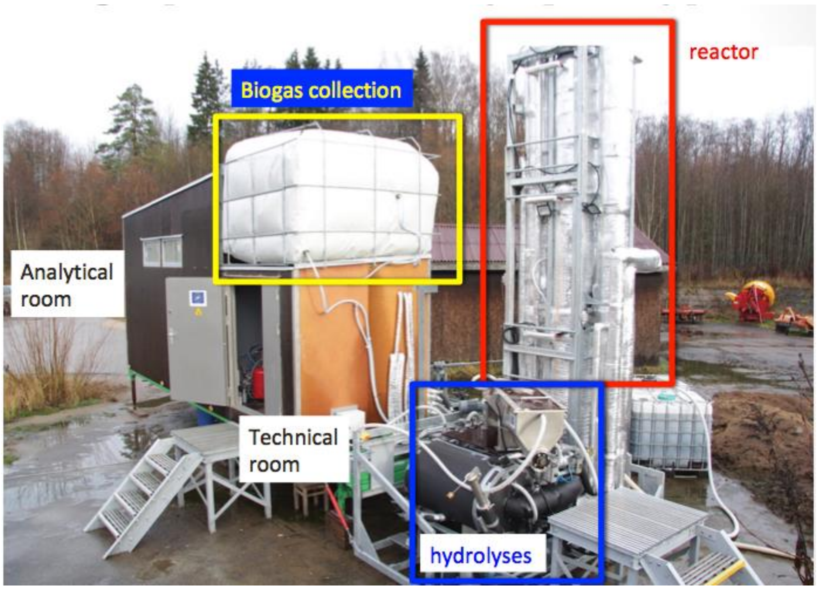


***Figure 3: An overview of the biogas production pilot facility (prototype)***

Biomass is loaded in the hydrolyses equipment manually. Grass is loaded twice a day in a basin above the hydrolyses equipment. This basin has a hermetic cover. Then snail transporter moves the biomass to the first basin of the hydrolyses equipment. This process is stimulated by a substrate pump within the hydrolyses equipment. The work of the snail transporter and substrate pump is managed and coordinated according to the algorithm loaded in the automatic control system of the prototype. Control elements in this system are pH and temperature sensors. Periodically, samples are taken to visually evaluate the degradation level of the biomass. Titration is used to detect fatty volatile acids. When the substrate has reached the required level of degradation with a certain level of pH, it is transported to the second basin of the hydrolyses equipment, where hydrolyses processes continue, as well as the acidogenic phase of anaerobic fermentation is takes place. Maximal hydraulic retention time in the hydrolyses equipment is 14 days.

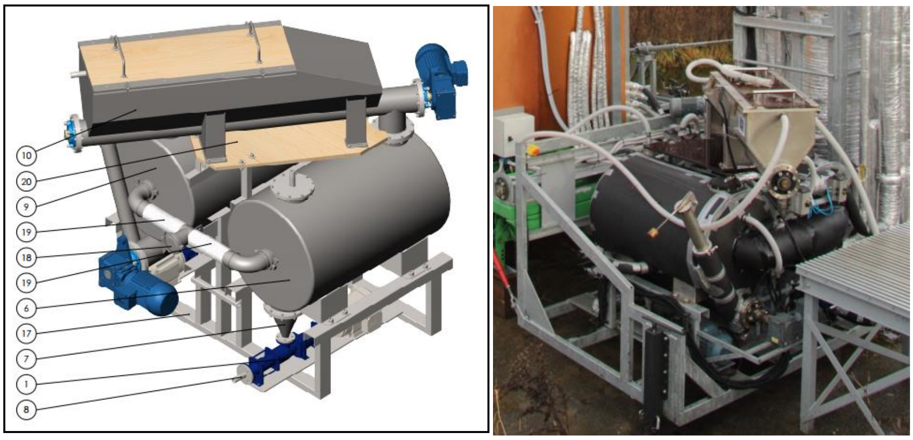


***Figure 4: An overview of the hydrolysis equipment within the biogas production pilot facility***

The hydrolysed biomass is pumped to one of the other side section of the reactor (Figure 5). Special valves open and close periodically and create paths to these sections. These valves control the amount of hydrolysed biomass to be fed in the reactor. Acidogenic, partially, methanogenic phases are realized in the side sections of the reactor.  According to a special algorithm, the substrate is fed into the central section of the reactor, where mainly the methanogenic phase of anaerobic processes is realized. Mass exchange occurs in the gas mixing system in each section of the reactor.

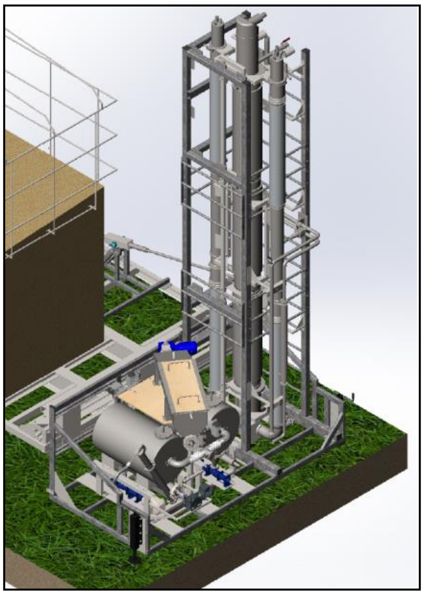 

***Figure 5: The design and actual appearance of the reactor within the biogas production pilot facility***

Control of the anaerobic fermentation process is based on the control of pH, temperature, and the liquid level in each section of the reactor. Periodically, samples are taken to obtain FOS/TAC analyses (the ratio of volatile organic acids FOS to alkaline buffer capacity TAC). The hydraulic retention time of the reactor is 14 days. During the demonstration of biogas production pilot facility, the aim was to achieve a 100 $Nm^3$ biogas yield from 1 tonne of fresh grass. In laboratory conditions, 1 tonne of fresh grass with a 32% dry matter (TS – total solids) provides a biogas potential of 135 $Nm^3/t$.

Biogas flows from the reactor to technical room where, at first, it is cooling below the dew point (+9-+12°C) to separate water vapour. Then a filter comes with active coal filling for the absorption of volatile organic compounds (VOCs) and hydrogen sulphide ($H_2S$). The purified gas is counted in an FMA 5400 Mass Flow Meter (OEMGA) and transported to a gasholder by the biogas pump. The Gasholder is made of an antistatic PVC membrane. When the pressure of gas in the gasholder reaches the set value, a Micro CHP is switched on. In this process, electricity ($Q_{el}$=2kW) and heat ($Q_{silt}$=4 KW) is produced, which is used for the needs of the pilot facility. When the Micro CHP is not switched on, heat energy is obtained from an electric boiler with a capacity of 300 l. When biogas pressure drops below the atmospheric pressure, the Micro CHP is switched off. Then the process of biogas collection in the gasholder is continued.

In the gas chromatograph (GC), components of biogas - $CH_4$, $CO_2$, $N_2$, $O_2$, $H_2S$, $H_2$ - are periodically measured in an automated regime. There is a possibility to measure gas components also from hydrolyses.

## 1.3. Characteristics and challenges of the biogas pilot facility

Main parameters of the developed biogas production pilot facility are as follows:

- Volume of the reactor – 600 litres.
- Volume of the hydrolyses equipment – 500 litres.
- Work temperature of the reactor - + 37.5°C.
- Hydraulic retention time (HRT) for the reactor - 14 days.
- Maximal hydraulic retention time (HRT) for the hydrolyses equipment – 14 days.
- Consumption of grass biomass – 50 kg/day.
- Biogas output - 100 $m^3$/tonne, 5 $m^3$/day.
- Dual-fuel engine cogeneration unit (equipment) (biogas + diesel).
- Power of the cogeneration equipment (CHP) – 2 kW (electric power) and 4.0 kW (heat power).

After long term operation of this facility, the correction of some of these parameters may take place, for example, the hydraulic retention time and biogas yield.

Advantages of the biogas production pilot facility:

- Partially separated phases of anaerobic fermentation enhance the stability of microbiological processes.
- Excess pressures in the side section of the reactor decrease the release of $CO_2$ from the substrate and provide a higher average methane concentration in the exit biogas (60-65%) at a fixed organic loading rate (OLR), compared to other operating biogas facilities.
- The facility is mobile.
- The hydrolysis phase is performed with a high hydraulic retention time (HRT) in anaerobic conditions and is supported by a high organic loading rate (OLR).
- Hydrolyses gas is integrated in the common biogas production system and reduces losses of the produced energy in the hydrolyses process.
- The biomass not degraded during the hydrolyses process is removed from the system – the biogas reactor works only with liquid products of hydrolyses.

The biogas production pilot facility was operated during demonstration activities from 19 September till 28 December 2017. In the given period, operation had breaks due to transportation of the facility from one demonstration place to the other, as well as due to optimization and correction procedures in anaerobic processes. The pilot facility was constructed to be operated at average day temperatures above $0^oC$ (when $H_2O$ is liquid). Accordingly, the pilot facility had to be stopped in the winter period.

Results obtained during the operation of biogas production pilot facility reveal potential directions for improvements:

- The improvement of mechanical degradation of grass biomass in the first receiving tank of the hydrolyses equipment by installing another type of the pump – chopper.
- The change of the reactors side section heads to reduce possibility for intrusion of the substrate into the gas mixing system.
- Alternative technical solutions for the gas mixing pumps to enhance the effectiveness of mixing.

Aims for the improvement of technological processes:

- To obtain stable operation of the hydrolyses equipment with grass biomass by optimizing operating temperature, pH, OLR, HRT.
- To evaluate the long-time effectiveness of technical solutions for the biogas reactor.
- To improve the software of the Automatic Control System of the prototype.
- To develop a simple control system of process parameters that is applicable for an industrial scale biogas facility.
- To develop separate hydrolyses process with hydrogen enrichment for biogas formation improvement by using hydrogenotrophic methanogenis processes in current pilot plant set up.

Biogas production facility prepared by "Bio RE", Ltd. is intended for the segment of low power (up to Qel=50 kW) biogas stations. It's relatively small size is an advantage for mobile application. The facility works with various substrates (grass and other).

Technical principles of the biogas production facility help to achieve the outcome of obtained energy from 1 tonne of biomass, which is about 13-15% higher than standard solutions available in the market. Hydraulic retention time (HRT) of the pilot facility is on average 6 times shorter than of standard biogas stations that are available in the market. It allows to reduce the size of the reactor to obtain the same yield of biogas.

# 2. Biobutanol production

## 2.1. Technological process of biobutanol production from grass biomass

Butanol, a 4-carbon alcohol (butyl alcohol), is generally used as an industrial solvent in products, such as lacquers and enamels or raw material for textile, plasticizer and butylamine production. However, it can also be blended with gasoline and used as a transportation fuel. Butanol is commonly produced using fossil fuels via catalytic process, however, it can also be produced from biomass, and then it is called biobutanol. Traditionally, it is produced from the same feedstocks as ethanol - corn, sugar beets, and other types of biomass.

The benefits of biobutanol include:

- **Higher energy content**. Biobutanol's energy density is 10%–20% lower than gasoline's energy density. However, biobutanol's energy content is relatively high among various gasoline alternatives. Fuel economy (km/l) is better than with ethanol.
- **Lower reid vapour pressure.** When compared with ethanol, biobutanol has a lower vapour pressure, which means lower volatility and evaporative emissions.
- **Distribution.** Biobutanol is less corrosive and has lower water solubility than ethanol. It can be distributed via existing pipelines and distribution stations.
- **Blending ability**. Blending is possible at higher concentrations than for ethanol without retrofitting the vehicle.
- **Safety.** Safer to use than ethanol. Lower amounts of volatile organic compounds (VOC) are generated in internal combustion engines[28,29].

The main steps commonly found in the process of the 2nd generation biobutanol production are feedstock processing (pre-treatment/hydrolysis), fermentation and collection/purification (Figure 6).

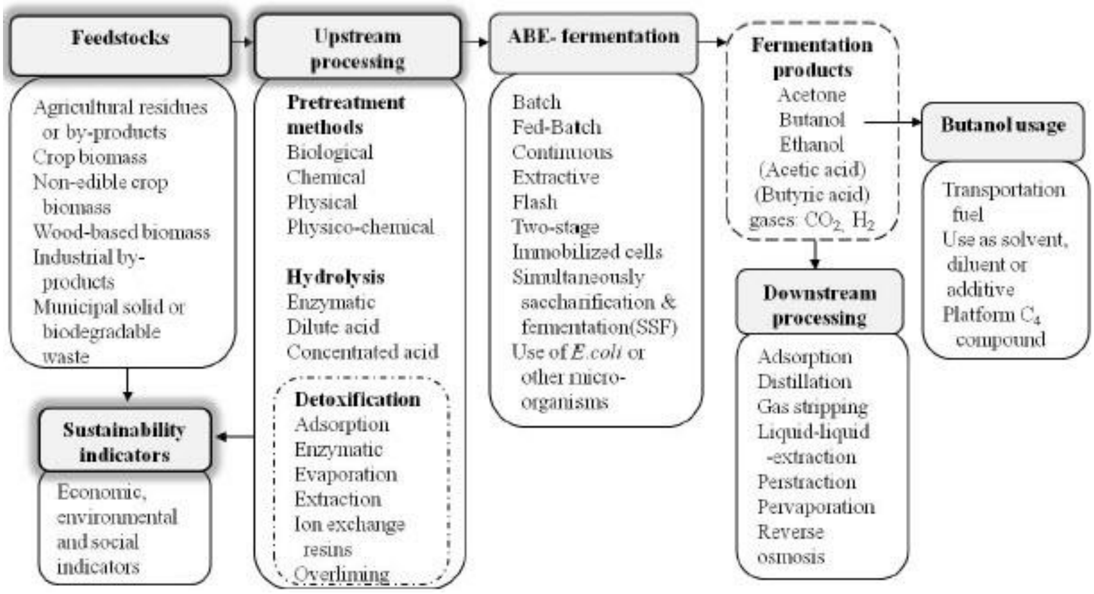


***Figure 6: Biobutanol production process[30]***

[28] Gupta, V.K., Tuohy, M.G. (Eds.), 2013. Biofuel Technologies, Springer-Verlag Berlin Heidelberg, pp. 397-441
[29] https://www.afdc.energy.gov/fuels/emerging_biobutanol.html
[30] Niemistö, J., Saavalainen, P., Isomäki, R., Kolli, T., Huuhtanen, M., Keiski, R.L., 2013. Biobutanol production from biomass. In: Gupta, V. K., Tuohy, M.G. (Eds.), Biofuel Technologies-Recent Developments, Springer-Verlag, Berlin-Heidelberg, pp 443-470

Feedstock processing is essential to disrupt the recalcitrant material of the biomass to increase the cellulose and hemicellulose reaction sites for enzymes[31] (Figure 7). The expected/desired characteristics of a suitable pre-treatment method are[32]:

- The more the pre-treatment system is able to process biomass pieces of large dimension, the better the energy balance and the overall process efficiency.
- Pre-treatment is a major energy-consuming step. Energy demand should be kept at the lowest possible level, while maintaining high process performances.
- The use of expensive materials should be avoided (this is also dependent on process operating conditions, such as temperature and pressure). Optimum design is a compromise between performances and costs.
- Pre-treatment process conditions should minimize sugar losses.

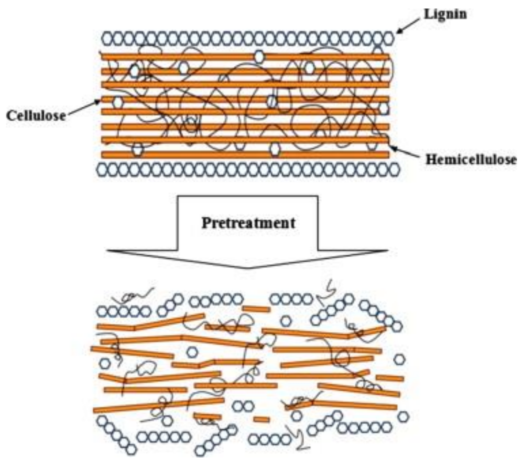


***Figure 7: Schematic pre-treatment of lignocellulosic material[33]***

The fermentation step is commonly called as Acetone-Butanol-Ethanol (ABE) fermentation, based on the main products formed. This anaerobic fermentation consists of two stages: first the acidogenic phase where Clostridial bacteria produce acetic and butyric acids, carbon dioxide ($CO_2$) and hydrogen ($H_2$) from sugars, followed by the solventogenic phase where acids are converted into acetone, butanol and ethanol, typically in the ratio of 3:6:1.[34]. Typically, *Clostridium* can utilize a wide range of carbohydrates, like, glucose, fructose, xylose, arabinose, lactose, saccharose, starch, pectin, inulin and other, however, a single strain is not capable of utilizing all above mentioned substrates[35]. Nevertheless, their ability to convert both pentoses and hexoses is regarded as a superior feature over ethanol-yeasts that can convert only hexose-carbohydrates.

After the fermentation, final products are recovered and purified in downstream processing to obtain firstly a mix of alcohols and then separate with the necessary purity. Adsorption, gas stripping, liquid-liquid extraction, pervaporation, perstraction and reverse osmosis are the most used separation methods integrated within the ABE fermentation[36].

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[31] Limayem, A., Ricke, S. C., 2012. Lignocellulosic biomass for bioethanol production: Current perspectives, potential issues and future prospects. Progress in Energy and Combustion Science, Vol. 38, Issue 4, pp 449-467

[32] Chiaramonti, D., Prussi, M., Ferrero, S., Oriani, L., Ottonello, P., Torre, P., Cherchi, F., 2012. Review of pre-treatmentprocesses for lignocellulosic ethanol production, and development of an innovative method. Biomass and Energy, Vol. 46, pp. 25-35

[33] Chiaramonti, D., Prussi, M., Ferrero, S., Oriani, L., Ottonello, P., Torre, P., Cherchi, F., 2012. Review of pre-treatmentprocesses for lignocellulosic ethanol production, and development of an innovative method. Biomass and Energy, Vol. 46, pp. 25-35

[34] Niemistö, J., Saavalainen, P., Pongrácz, E., Keiski, R.L, 2013. Biobutanol as a potential sustainable biofuel - assessment of lignocellulosic and waste-based feedstocks. Journal of Sustainable Development of Energy, Water and Environment System, Vol. 1, Issue 2, pp. 58-77

[35] Patakova, P., Maxa, D., Rychtera, M., Linhova, M., Fribert, P., Muzikova, Z., Lipovsky, J., Paulova, L., Pospisil, M., Sebor, G., Melzoch, K., 2011. Perspectives of Biobutanol Production and Use. In: Dos Santos Bernardes, M.A. (Ed.), Biofuel's Engineering Process Technology, ISBN: 978-953-307-480-1

[36] Groot, W.J., Van der Lans, R.G.J.M., Luyben, K.C.A.M., 1992. Technologies for butanol recovery integrated with fermentations. Process Biochemistry, Vol. 27, Issue 2, pp. 61-75

Despite the well-defined technologies for biomass conversion, fermentation and downstream processing, problems with high production costs, efficient re-use of chemicals and water is still an issue.

## 2.2. Overall construction of the biobutanol pilot facility (scheme)

Within EDF project "The production of a new generation of biofuel – biobutanol from agricultural waste" a specific biobutanol production pilot was constructed at Riga Technical University (RTU) (Figure 8). Initially the technology involved all classical steps for biomass conversion, fermentation and alcohol recovery.

***Figure 8: Biobutanol production pilot located at Riga Technical University (constructed in 2013)***

As a part of optimisation and adjustment, several modifications have been made during the LIFE Grassservice project. These include adjustments of membrane separation processes for sugar concentration, enzyme recovery and water re-use.

Membrane separation processes such as ultrafiltration (UF) and nanofiltration (NF) have gained much attention in biotechnology industry due to their simplicity, high selectivity, low energy cost and reduced chemical usage[37,38]. UF membranes can selectively remove proteins, viruses, and microorganisms. However, the permeates after UF membrane system are, in general, very diluted and vast in volume. Therefore, NF membranes can be introduced to concentrate the small molecules, like carbohydrates.

The overall technology designed at RTU consist of 8 main operation units– milling system, hydrolysis reactor, microfilters, ultrafiltration system, nanofiltration system, fermentation reactor, gas stripping system and condensation system (Figure 9).

[37] Cho, Y.H., Lee, H.D., Park, H.B., 2012. Integrated membrane processes for separation and purification of organic acid from a biomass fermentation process. Ind. Eng. Chem. Res., Vol. 51 (30), pp. 10207-12219

[38] Gryta, M., Szczupak, M. A., Bastrzyk, J., Tomczak, W., 2013. The study of membrane distillation used for separation of fermenting glycerol solution. Journal of Membrane Science, Vol. 431, pp. 1-8

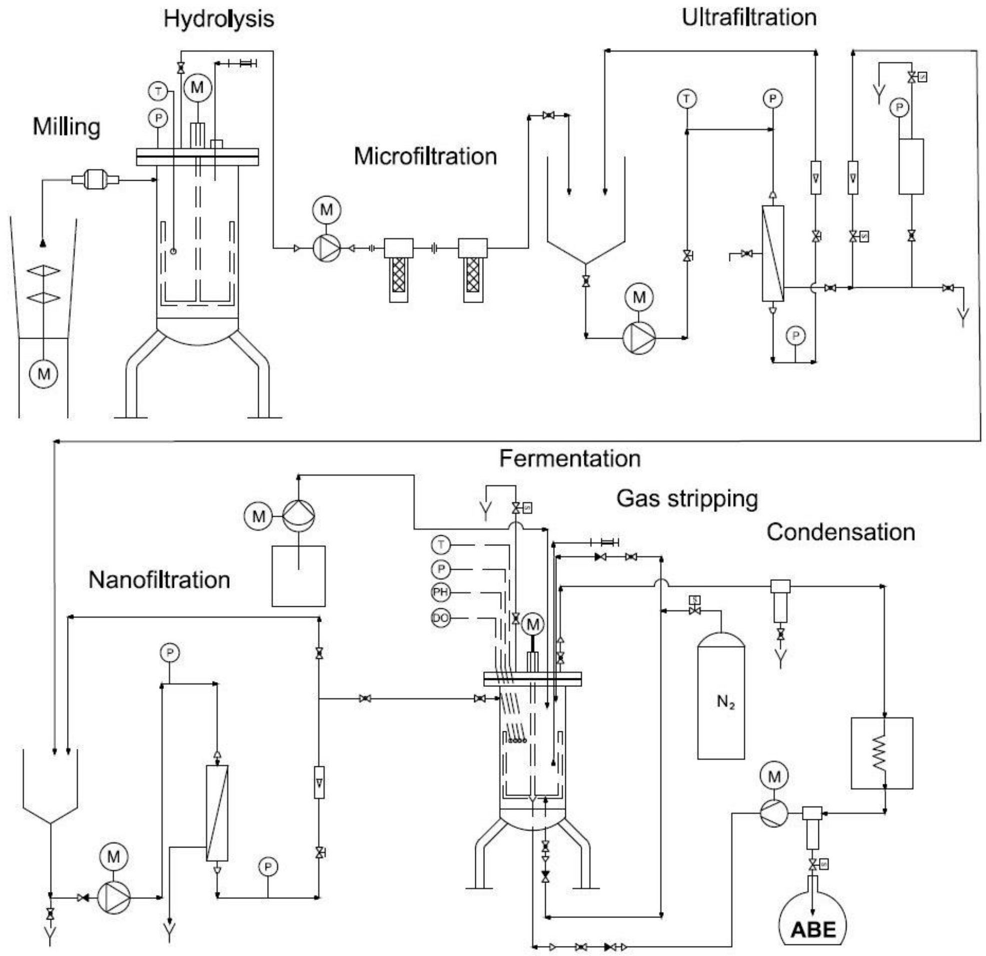


***Figure 9: Biobutanol production technology principal scheme***

Mechanical milling is performed to control particle size at fractions below 1 mm. Further the material is transferred to hydrolysis unit where the biomass is wetted with water and heated to 120°C for 5 min to remove indigenous microorganisms. Research has shown that heating at 100°C for 5 min (1 atm) is also sufficient[39], however, this might be problematic in closed systems. After heating the system is cooled down to the temperature suitable for hydrolysis (usually 30-55°C depending on the type of enzyme used). After hydrolysis (24-48 h or as defined by the enzyme manufacturer) the material is pumped through microfiltration unit to remove rough biomass particles.

UF is performed under pressure conditions (2-10 bar) with centrifugal pump drive through a membrane. Within this process carbohydrates are transferred to NF and enzymes are pumped back to the hydrolysis reactor.

NF is driven by pressure pump with frequency converter, where dissolved chemicals from UF are concentrated and water is removed. The produced water can be further used for biomass wetting at hydrolysis unit. The produced sugar concentrate is pumped into the bioreactor.
Process control of fermentation is dependent on the type of strain used. Generally, it involves adjustment of mixing, temperature, pH, oxygen level and permitted ABE concentration in the system. Microbial biomass and sugar concentration in the system can be controlled via regular sampling.

For alcohol collection gas stripping with anaerobic gas ($N_2$ or $CO_2$) has been selected. Flow circulation, through the fermentation solution in bioreactor and then through condensation system (temperature - 4 to - 2°C), is performed with an air pump to remove ABE from fermentation solution.

[39] Mezule, L., Tihomirova K., Nescerecka A., Juhna T., 2013. Biobutanol production from agricultural waste: a simple approach for pre-treatment and hydrolysis. Latvian Journal of Chemistry, Vol. 51(4), pp. 407-414

# 3. Grass pellet production

## 3.1. Technological process of pellet production from grass biomass

Production of compacted grass products is well known use of grass biomass. The biggest advantages of compacted grass products are easier handling, storage, transportation, and control over the use processes[40]. The classification of compacted grass products includes three types of goods depending on the size.

**Bales** are the largest ones; grass is not shredded but just compacted in a larger size by using special machinery on field. Round bales are most used for agricultural purposes; however, also square shaped bales are being produced. Square bales are very good for transportation, as can be packed very tightly. This product is particularly good for large scale handling with appropriate machinery. Bales can be made up with a material density up to 450 kg/m$^3$ [41].

Two other products are much smaller. **Briquettes** are usually round or square shaped much smaller sized compacted product usually 50-150 mm in size. The production process involves shredding grass or cutting in smaller particles – the process, which is not needed for bale production.

**Pellets** are the smallest by size product, typically a cylinder shape with a diameter of 2-8 mm. Pelletisation of biomass ensures great mass and energy densification. E.g., switchgrass pellets may reach six times higher density than that of raw grass (from 57 to 370 kg/m$^3$)[42].

The production of pellets includes milling, which is not needed for the bales and briquettes (Figure 10).

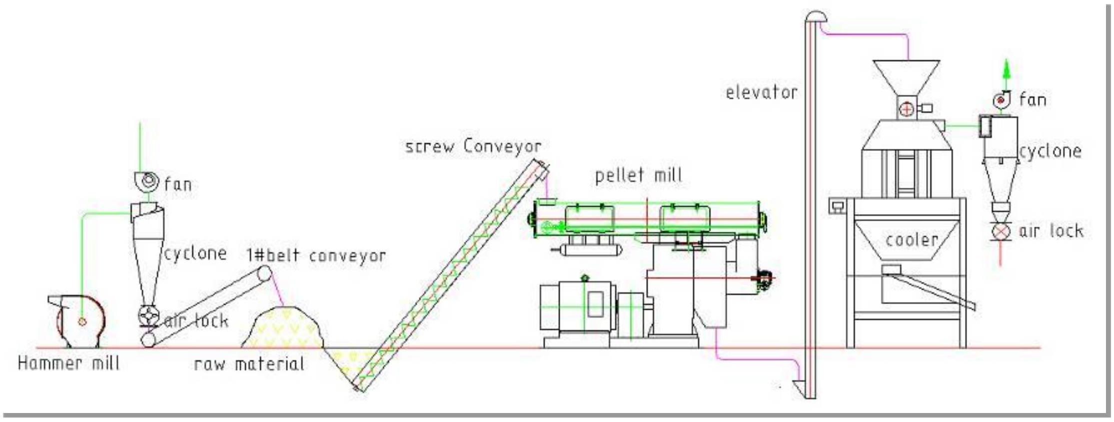


***Figure 10: Technological design of a pellet production facility[43]***

There are advantages and disadvantages during the production of the three products (see Table 2), which should be carefully evaluated before deciding, which is the right product. The production of grass pellets is most expensive because of the most complicated technological process and highest requirements in energy supply.

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[40] Cornell University Cooperative Extention, 2016. Bioenergy Information Sheet #7

[41] Data by Kronbergs, A., presentation in seminar „Sustainable grassland management: biodiversity conservation and alternative uses of grassland biomass", 5-6.11.2014, Sigulda, Latvia

[42] Gilbert, P., Ryu, C., Sharifi, V., Swithenbank, J., 2009. Effect of process parameters on pelletisation of herbaceous crops. Fuel, Vol. 88 (8), pp. 1491–1497

[43] Nicety Ltd.

*Table 2: The assessment of compacted grass products*[44]

| Product | | Process | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cutting | Drying on field | Prymary compacting | Transporting to workshop or storage | Shredding | Drying | Milling | Compacting |
| Pellets | Energy | YES | YES | YES | YES | YES | Yes, if needed | YES | YES |
| Pellets | Animal feeding | YES | Not recomended | Material is with high density | YES | YES | YES | Depending of pelleting machine | YES |
| Briquettes | Energy | YES | YES | YES | YES | YES | Yes, if needed | Yes, if particles are too long | YES |
| Briquettes | Animal feeding | YES | Not recomended | Material is with high density | YES | YES | YES | Yes, if particles are too long | YES |
| Bales | Energy | YES | YES | YES | YES | | | | |
| Bales | Animal feeding | YES | | | YES | | YES | | YES |

## 3.2. Use of grass pellets and other compacted grass products in the world

In general, there are three main applications of pellets. **Fodder** is the most traditional application of grass pellets and can be used for feeding agricultural animals (horses, cattle, sheep, goats, swine) and pets (rabbits, hamsters, Guinea pigs). Grass pellets have some advantages over non-processed hay – they are easier transportable in longer distances and easy dosing. During production process, essential minerals, vitamins and other active substances may be added depending on the species or breed of domestic animals. Dangers of poisonous plant species, like from the *Ranunculaceae* family, occurring in harvested grass biomass are constantly being discussed; however, concentrations of those are usually so small that they do not influence the health of fed animals. Grass pellets are also being recommended when animals possess problems with digestion, e.g. tooth wear, because it is already "chewed" into small particles.

Grass pellets can be used for **bedding** for both agricultural animals and pets. It is still not very widely used, as usually other type of bedding material is available.

**Production of heat and energy** from burning grass biomass is getting more and more popular on the world. There largest advantage of grass biomass is its renewability in opposite to fossil fuel sources that form during many millions of years.

Also, the lifecycle of biomass in grasslands is rather quick, and yields can be obtained each vegetation season in one site. At present, mostly wooden products are used for biomass burning, but tree based biomass production requires at least several years in energy plantations and tens of years in the traditional forest life cycle, where mostly only residues of timber industry are used for energy production.

The combustion of biomass might be near as effective as combustion of wood. In general, the heat capacity of grass biomass is just a little bit smaller compared to wood biomass and reaches up to 96% of it[45].

[44] Kronbergs, A., 2014. presentation "Production and use of compacted biomass: peculiarities and aspects to consider", seminar „Sustainable grassland management: biodiversity conservation and alternative uses of grassland biomass", 5-6.11.2014, Sigulda, Latvia

[45] Valsts SIA Vides projekti, 2009. Biomasas izmantošanas ilgtspējības kritēriju pielietošana un pasākumu izstrāde

For energy production, late mown grass can be used, which is not suitable any more as fodder for domestic animals. In certain cases, this is very essential to maintain grassland bird populations during nesting period, which often overlaps with optimal fodder grass harvesting.

In addition, the aspects mention for all compacted grass products, pellets have more advantages for burning: constant moisture, higher mass fluidity favourable for automatic feeding in small-scale boilers. Smaller fuel particles provide more even boiler feeding, leading to lower emissions and better possibilities to fire at lower loads, resulting in longer boiler utilisation times[46].

However, the energy production from grass biomass has one major problem – specific chemical contents of grass require specially adopted technologies and boilers. Grass contains a high level of chlorine (0.01-1.0%), nitrogen (0.30-1.8%), alkali metals (0.2-3.0%), sulphur (0.01-0.40%), and, particularly, silica (1-4%). Various studies confirm that dicotyledonous plants have an ability to accumulate greater quantities of minerals compared with monocotyledonous plants[47]. The corrosive chlorine in association with alkali metals sodium and potassium cause melting silica in lower temperatures and following development of clinker on the surface of the furnace[48]. While wooden ash melts in temperature of 1340-1700°C, for grass ash the melting temperature is much lower – 1100-1330 °C[49]. In no way, grass biomass should be used in wood biomass boilers, as it may quickly lead to damages of the facility.

Also, it shall be noted that significant efforts are needed to remove large amounts of ash. In Latvia, research shows that ash in grass biomass usually accounts for 6-8%[50] depending on grassland type and soil conditions, while in wooden pellets – 1% on average[51].

High contents of chlorine and nitrogen require strict control due to possibly forming harmful emission gases, especially, if bioenergy is produced on a larger scale.

There are many examples on the World when grass biomass is used for energy production needs. In the Baltic Region, a good example is Lihula Municipality in Estonia, where 1/3 of the mown grass is burned in the local boiler house, thus highly helping to maintain coastal grasslands of the Matsalu National Park[52].

## 3.3. Challenges in grass pellet production based on the LIFE Grassservice project experience

Although production of grass pellets seems quite optimistic when considering experience from other countries, the LIFE Grassservice project failed to launch planned pellet production in Sigulda Municipality. The following risk factors arouse during the execution of the project, which should be taken into account before starting grass pellet production:

**No real consumer market established in the country.** This is the most critical factor, both for pellets as fuel or fodder. There is a small local market for organic grass pellets as fodder for pets); most of the pellet products are being exported. Grass pellets are not yet considered in the local farmer community as a superior product in comparison to grass or hay, and it is also more expensive. The existing pellet furnaces use wood for energy production, which is still abundant in Latvia. As described above, these wood furnaces are not suitable for burning grass pellets. Therefore, introduction of grass for energy production would mean lots of efforts from the consumer side to either adjust the existing facilities by installing new burners

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[46] Nilsson, D., Bernesson, S., Hansson, P.-A., 2011. Pellet production from agricultural raw materials - A systems study. Biomass and bioenergy, Vol. 35, pp. 679-689

[47] Indrek, M., Heinsoo, K., Ivask, M., 2014. Herbage production and chemical characteristics for bioenergy production by plant functional groups from semi-natural grasslands. Biomass and bioenergy, Vol. 67, pp. 160-166

[48] Cornell University Cooperative Extention, 2014. Bioenergy Information Sheet #5

[49] Seminar materials, http://www.srcplus.eu/images/Seminars/Woodchips/Latvia/4_Cieta_kurinama_kvalitate.pdf

[50] Platače, R., Adamovičs, A., 2014. The evaluation of ash content in grass biomass used for energy production. In: Energy Production and Management in the 21st Century, Vol. 2, pp. 1057-1065

[51] Seminar materials http://www.srcplus.eu/images/Seminars/Woodchips/Latvia/4_Cieta_kurinama_kvalitate.pdf

[52] Kask, L., Kask, Ü., 2014. Presentation "Energy production from biomass of Matsalu Natural Park, Estonia", seminar „Sustainable grassland management: biodiversity conservation and alternative uses of grassland biomass", 5-6.11.2014, Sigulda, Latvia

or buying new stoves, which seem not grounded under current conditions when plenty of wood is available. On the other hand, recent trends show a shortage of wood pellets on the local market and even import from other countries, like Poland and Ukraine. One reason is switching heating from fossil fuels to more environmentally friendly wood in many households, as well as centralised heating systems in municipality centres. Also, wood pellets are easier to manipulate in furnaces compared to firewood. Another reason is that woody resources in overgrowing for several decades Latvian fields are gradually exhausted, because the overgrown areas are cleaned and restored in a good agricultural quality, and no wood surplus from these lands can be obtained anymore, and only residues from timber felling and wood processing industry remain a stable source for wood pellets. The increased demand also caused recent increase in pellet prices - from a bit above 2 EUR to 3.50 EUR per a package of 15 kg[53]. Thus, in future compacted grass products could be become a good alternative to wood resources for energy production, particularly in individual households.

The production of grass pellets was tested in Lithuania within another LIFE financed Project „Securing Sustainable Farming to Ensure Conservation of Globally Threated Bird Species in Agrarian Landscape" („Baltic Aquatic Warbler") where the main aim was to restore grasslands for the need of a threatened bird species – the Aquatic Warbler. A production line with a production capacity of 5 kg/hour was installed in 2013. Although the pelleting facility highly helped in fulfilling the conservation objectives of the project, the operation of the facility was not successful as a business model. Rather low production capacity and comparatively small amount of available biomass was the main reason for high production costs. In addition, prices for biofuel pellets had significantly decreased in Poland – the main potential market - during the implementation of the project. Company ABZUVINTAS tried to find a new market in Finland and sell pellets for animal bedding; however, the installed facility was not capable to produce pellets with client's required criteria. At the end, it was decided to buy a special heating boiler operating on grass pellets and use the produced pellets for heating the administration and visitor centre of the Žuvintas Biosphere Reserve, thus ensuring relatively low-cost heat supply from the local resources.

The decrease of market price for grass pellets was also the main reason why the beneficiary responsible for the production of pellets in the LIFE Grassservice project decided not launching the planned activity.

**Few existing grass pelleting facilities.** The LIFE GRASSSERVICE project was not successful in finding a suitable grass pelting facility for demonstration of the grass pellet production within the project. The overwhelming majority of the existing pelleting facilities in Latvia operate on woody biomass. Few use straw for pelleting, and even fewer – grass. The grass pelleting companies have their market niches (e.g. organic grass pellets for pets, alfalfa pellets for export) and do not possess additional production capacity. Accordingly, a company willing to start grass pelleting business must invest in purchasing pelleting facilities and establishing production lines. This is quite an obstacle for local entrepreneurs taking into account the weak market. However, there are possibilities to obtain the needed financing from several sources in Latvia (Rural Support Service, state-owned development finance institution ALTUM) after submitting a grounded business plan.

**Shortage of grass resources.** Until the beginning of the project in 2012, there were lots of not used grass resources in the project areas and the country in general. However, increase in the number of agricultural animals (e.g. sheep in the project areas Sigulda and Ludza municipalities), as well as few years with not favourable meteorological conditions (either draught or excessive rainfall) in the vegetation season led to the shortage in grass. In combination with the lack of grass pelleting facilities in the project areas, this led to failure to demonstrate grass pellet production even in a reduced amount. Thus, weather conditions have a huge impact on grass production in each certain year, and this may cause competition for grass between energy sector and agriculture - a very dynamic and changing sector.

[53] http://laukos.la.lv/specialisti-iesaka-granulas-japerk-vasara/

# 4. Future perspectives

Currently, biomass is the most realistic alternative to fossil sources for producing energy. It accounts for ca 14%[54] of the final energy consumption of the World.

Grass possesses a high potential among other biomass substrates and can successfully be used to produce bioenergy. The virtue of grasslands compared to other agricultural land is that they do require less input (soil processing, seeding and planting, fertilisation, application of pesticides) compared to arable land. Cultivated grasslands produce the largest amounts of grass biomass but they need periodical intervention by processing the soil and reseeding. Usually, natural and semi-natural grasslands have less productivity; however, also inputs are very minor, and the grasslands mostly can be self-sustaining.

At present, the development of the technologies for grass pellet, biogas and biobutanol production is on comparatively various levels. The technologies for pellets and other compacted grass products are well developed. Biogas production has long historical traditions, but grass as the feedstock has not been so popular compared to other resources, particularly specially cultivated crops, manure and agricultural wastes. Appearing availability of grass as a resource is a driver that facilitates development of related technologies. However, the economic competitiveness without a targeted public support in the current market conditions is questionable. Biobutanol is the youngest among the three products, and it is very difficult to speak about economic competitiveness of the product, as the production costs are still rather high for a larger scale production.

All three products have already their place on the market. However, the production of most of them at the current market conditions is not economically feasible without additional support and cannot compete with the extensively used products made of fossil resources, like petroleum or coal, which have to be only extracted, transported and processed, in opposite to biomass, which has to be grown, harvested and usually must undergo more stages during the processing to obtain the final product.

On the other hand, grass pellets could have economic competitiveness on the market in certain conditions. Canadian economic studies have shown pelleted grass to be competitive with conventional wood pellets and willow biomass[55]. A study in Canada says that the production cost of switchgrass pellets was $146/tonne for a plant with a capacity of 53 000 tonnes year that is slightly higher than for wooden pellets[56]. In Ontario Province, Canada, heating an average house with a 90 GJ heat demand with switchgrass pellets cost $1213 a year, which was notably lower compared to heating with electricity ($2234), heating oil ($1664), and propane ($2302). Natural gas was the only exception within fossil fuels costing 882 USD[57]. In Lihula Municipality in Estonia, the price of heat produced from grass biomass cost about 58 €/MWh, while the price from shale oil reached on average 70-80 €/MWh (without VAT)[58].

Also, pellets as fodder for animal can be economically viable. On European market, the price for pellets made of naturally grown meadow grass can be 0.54 EUR/kg[59].

The advantage of compacted grass products is that they require just special mechanical processing, while biogas and biobutanol production needs also biochemical treatment, which is more complicated and costly.

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[54] World Energy Council, 2016. World energy resources. Bioenergy, p 60
[55] Cairns, A., Gallagher, J., Hatch, R., Humphreys, M., 2007. A future for UK grassland in energy production?
[56] Sultana, A., Kumar, A., 2012. Ranking of biomass pellets by integration of economic, environmental and technical factors. Biomass and bioenergy, Vol. 39, pp. 344-355
[57] Jannasch, R., Samson, R., de Maio, A., Adams, T., Lem, C. H., 2001. Changing the energy climate: clean and green heat from grass biofuel pellets. Presented at "Climate Change 2: Canadian Technology Development Conference"
[58] Kask, L., Kask, Ü., 2014. Presentation "Energy production from biomass of Matsalu Natural Park, Estonia", seminar „Sustainable grassland management: biodiversity conservation and alternative uses of grassland biomass", 5-6.11.2014, Sigulda, Latvia
[59] https://www.dengie.com/horse-feeds/grass-range/grass-pellets/

However, although industrial scale biogas and biobutanol production could hardly be fully competitive with fossil fuels, it must be assessed from a wider perspective.

**Synergies with the existing policies.** Natural and semi-natural grasslands is a pool of biodiversity, and seizing their management due to reduced need in grass fodder for domestic animals leads to the disappearance of valuable habitats. Using grass for local energy supply is a good alternative option for continuing maintenance of grassland habitats, facilitate local production and provide work places. Lihula Municipality in Estonia mentioned above is good example that helps to bring together **nature protection** and **sustainable energy policies**.

**Synergies between various products.** Even if the production of biogas and biobutanol cannot sustain itself without public support, the picture may be different, if various processes and products are combined. Here, the concept of biorefinery comes in. **Biorefinery** is the sustainable processing of biomass into a spectrum of marketable products and energy. The products include food, feed, materials, and chemicals; energy includes fuels, power, and heat[60]. In relation to grass biomass, an example would be a facility that produces grass pellets for fodder, and the grass not corresponding to the quality for feeding animals are used for biogas production.

Materials that are considered as waste in conventional thinking can be used as resource. Animal farms face the problem of continuous accumulation of manure and slurry they have to deal with. Production of biogas is a good option to get rid of *wastes*. However, if manure is mixed with grass, it significantly increases the yield of biogas compared to using the both mentioned feedstocks separately. For any industry that has organic matter as leftovers from the processing, bioenergy production is a way to save costs on waste removal, transportation and deposition, and even obtain some financial profit, or at least significantly reduce losses.

**Local energy supply.** Economic issues play less importance, if a biofuel production facility is installed for local energy production needs, e.g., a countryside living house or a farm. If the market price for small-scale facilities reaches the value affordable for local people, they can operate them for energy self-supply using own renewable resources. Natural grasslands that are not used for agricultural production provide biomass resources for energy production either as pellets for heating, or biogas for heating and electricity production, or biobutanol for transport fuel; many countryside houses have few or more hectares of land not used for agriculture, and the produced biomass becomes waste. In Latvia, it's is a compulsory condition to remove the mown grass from the field, which is additional burden for the landowner. Production technologies are usually flexible, also other substrates can be used as the feedstock, if there is a shortage of grass in certain months or years. E.g., biogas production facilities also can process organic waste generated in the countryside. Even more, local residents can cooperate with each other by optimising biomass flow, production and sharing the final product.

[60] De Jong, E., Jungmeier, G., 2015. Biorefinery concepts in comparison to petrochemical refineries. Industrial Biorefineries & White Biotechnology, pp 3-33