Original Research Article

The Possibility of Biogas Production from Anaerobic Co-digestion of Hemp – A perspective in Germany

Comment [PM1]: Incomplete- Co-digestion of Hemp with what?

ABSTRACT

Replacement of fossil-based resources with renewable resources to offset the use for heating and electricity production are important for today's social and economic growth and energy security. Anaerobic fermentation and the production of biogas generates an alternative, carbon-neutral, renewable fuel that easily can be generated from local, low-cost organic waste materials.

The anaerobic digestion experiments ran~~run~~ for 240 hours at a temperature of 39°C ± 2°C for the duration of the experiment.

The combined biogas production ~~production~~ of hemp residues and hemp stems showed that the average reduced volatile solids content for hemp residue 1 and 2 was 0.98 g with a combined biogas production of 231.31 ml/g. For the hemp stems 1 and 2 the average reduced volatile solids content was 4.06 g and the combined biogas production was 64.90 ml/g respectively. Manure showed average reduced volatile solids content of 0.76 g and a combined biogas production of 305.69 ml/g respectively. The biogas content without CO_2 was 62% for the manure samples, 55% for the hemp stems, and 57% for the hemp residues. The application of co-digestion utilizing cow manure and hemp-based waste material, as feedstock could be an option, helping to increase energy security, biological diversity, and sustainability.

Comment [PM2]: Specify the aim/objectives of your research

Comment [PM3]: Revise the sentence.

Comment [PM4]: Avoid repetition

Comment [PM5]: Specify the type of manure

Keywords: Anaerobic digestion, biogas, co-digestion, energy production, fermentation, hemp

1. INTRODUCTION

Whether it's industrial fiber crops or intoxicating marijuana, the term hemp is polarizing. Experts from all over the world are arguing about what is probably the most controversial plant of all time. But industrial hemp is actually gaining approval - also in Germany. The federal and state governments are now also working to put the plant in a better light. Nevertheless, the debate remains controversial - while some see new possibilities and opportunities in the plant, others remain on the already established biomass resources. Both sides have hardly any difficulties in finding arguments. Ultimately, the question remains as to whether hemp was sent from heaven or sent from hell and, above all, one thing: a matter of interpretation.

In the fight against climate change, it is of great importance that we replace fossil energy resources with renewable, carbon dioxide-neutral and therefore sustainable resources. Germany is on the right track in this regard. Nevertheless, about 19.7% of the primary energy consumption in Germany in 2021 was based on renewable energy sources [1]. A positive trend can be observed here: Germany is increasingly relying on regenerative energy

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sources. In 2020 251 billion kilowatt hours of electricity were already generated from renewable energy sources a 4% increase to 2019.
Germany is very rich in resources for biogas production such as corn or wheat. Proportionally, most of the plants are grown for use in biogas plants. The main resource for biomass in Germany is still maize silage [3].
While these are undisputedly efficient for biogas production, other plant species need to be studied and considered more closely for a sustainable future. The aim here is to find new and sustainable approaches, on the one hand to make the resources for biogas production more diverse and on the other hand to take into account the increasing animal and nature conservation problems in Germany. Because not only must energy resources be found that are climate-neutral, i.e. their production is low in pollutants, but also those that offer endangered animal and insect species sufficient protection and food sources.
One don't have to look far to find sustainable and efficient energy resources, because they surround us in all areas of everyday life. The by-products of meat production that our schnitzel brings to our plates; the rye field we walk through in the afternoons and beyond that any organic waste we produce. Everything is about energy resources and not just any, but low-emission and environmentally friendly. The term “biomass” is used as a collective term for these resources – the sustainable energy of tomorrow that is already all around us today.
According to Peter Salje's commentary on the German Renewable Energy Priority Act, the term biomass means any form of plant material, animal residues, sewage sludge from sewage treatment plants and organic waste from human settlements. The material is independent of the state of aggregation. In addition, harvested plant material, residual wood and harvest residues, wood waste and residues from food production and animal husbandry are considered biomass [4].
Fossil fuels have evolved from biomass over time, and are no longer referred to as biomass [5]. To represent the production of biomass, the following general equation according to Quasching can be used:

$$H_2O + CO_2 + \text{Hilfsstoffe} + \Delta E \rightarrow \underbrace{C_kH_mO_n}_{\text{Biomass}} + H_2O + O_2 + \text{Stoffwechselprodukte [5]} \quad \textbf{(1)}$$

The formula indicates how water and carbon dioxide are split with the energy ΔE of visible sunlight. The products are the biomass $C_kH_mO_n$, as well as water, oxygen and other metabolic products. If the biomass is used further, CO_2 is produced again, but only as much as the plant previously absorbed from the air. This harmony is called zero balance. If only as much biomass is used as can grow back again, this is a climate-neutral and, above all, renewable energy source.
In order to use biomass as an energy source, there are various further processing methods. The energy carriers are either solid, liquid or gaseous [5]. These include: Biomass-to-Liquid (BtL), bio-alcohol, biodiesel and further processing into solid bio-energy carriers, such as pellets. However, the biomass can also be processed into biogas and fed into the gas system by anaerobic digestion (AD). The biogas can in turn be used to operate gas engines and thus generate kinetic energy and thermal energy [4]. Combined heat and power plants, in which electricity and heat are generated, serve as production facilities for biogas.
The gas produced is a mixture consisting mainly of methane (CH_4) with a concentration of 40% to 70% and carbon dioxide (CO_2). The mixture also contains traces of hydrogen sulfide (H_2S), ammonia (NH_3) and other gases. It is the hydrogen sulfide content that gives the biogas its distinctive rotten egg smell [5].
In fact, the generation of energy from biomass can also be illustrated in a simplified way by plugging a tiled stove in with pieces of wood. After all, wood is basically biomass. In this case, the substrate (the wood) is converted into thermal energy. Due to this triviality,

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biomass is still one of the most important energy sources in many developing countries today [5].

Today, many waste streams can be utilized for AD processes. AD is a sequence of biological processes used to degrade organic material and produce mainly biogas under anaerobic conditions [6]. Feedstock for AD can be farm-based including agricultural residues, crops, plant biomass, as well as sewage sludge from wastewater treatment operations or industry based organic waste residues. Each feedstock requires different reactors to achieve best operation results. For research application, mostly batch reactors are used [7].

One of these waste streams could be process residues from hemp oil production. The Cannabis plant. This plant is an annual herbaceous plant, and comes from the Cannabacae family and belongs to the C3 or Calvin plants. "C3 plants" is the collective term for most green plants in the middle and high latitudes, which form a compound with 3 carbon atoms and 3-phosphoglycerate as the first product of carbon dioxide fixation during photosynthesis and this directly into the Calvin cycle (the conversion of carbon dioxide to glucose) [8]. Corn, wheat, sugar cane, rye or millet are also among the C3 plants in addition to cannabis.

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In order to avoid confusion, the term "cannabis" must first be defined more precisely.

Of course, it cannot be denied that cannabis plants - provided they have been bred with high levels of ∆-9-tetra-hydro-cannabinol - lead to intoxication, changes in blood pressure, breathing and heart rate, dry mouth, high appetite, altered perception of time and a significant deterioration in concentration and learning ability [9]. Nevertheless, cannabis is not the controversial drug marijuana! A precise distinction must be made as to whether a particular plant is a fiber genus or a drug genus. This distinction is based on the concentration of ∆9-THC, the psychoactive compound delta-nine-tetrahydrocannabinol [10]. If the concentration of the substance in a plant is above the critical value of 0.3%, the plant is said to have intoxicating properties. In this case, the plants are processed into psychoactive hashish and marijuana. In contrast to those intoxicating plants such as C.Ruderalis or C.indica, the hemp plant of the genus C.Sativa only has higher values of ∆9-THC through specific breeding and is therefore referred to as a fiber genus [11]. The cultivation of industrial hemp, Cannabis Sativa L., with a very low concentration of ∆9-THC (<0.3%) but a higher concentration of CBD, cannabidiol, is not prohibited by law in Germany, but is subject to very strict regulations . According to the Federal Agency for Agriculture and Food, the cultivation of industrial hemp is only permitted for agricultural companies under Article 1 Paragraph 4 of the Law on Old-Age Insurance for Farmers [12]. According to Article 29 of the Narcotics Act, the cultivation, possession and trafficking of cannabis and cannabis products is otherwise prohibited by law.

The cultivation is very popular all over the world. In addition, industrial hemp, the oldest cereal crop in the world [13], has already become an integral part of agriculture in many countries [14-15]. Hemp is mainly cultivated for the cellulose found in the stem of the plant and for the robust fibers, which provide ideal basic conditions for paper and textile production. Hemp is also a source of food, and with the increasing popularity of CBD oil, the Calvin plant has even become a miracle plant for the cosmetics and pharmaceutical industries [16-17]. Despite all this, hemp is mainly grown for fiber production [18].

The renowned US American Popular Mechanics magazine for science and technology described the cannabis plant as the new "billion-dollar-plant" as early as 1938 [14]. With a monthly plant growth of up to 60 centimeters and great resilience to contaminated soil and pests, industrial hemp ultimately proves to be an ideal energy crop.

In Germany the energy crop maize accounted in 2021 for more than 56% of the cultivated renewable raw materials in Germany and is used as primary energy crop for biogas production [19].

The German Bundesministerium fuer Ernaehrung und Landwitschaft (BMEL) regulates with

Erneuerbare-Energien-Gesetz 2021 (EEG2021) (engl. Renewable energy law 2021) the bioenergy sector including biomass usage with focus on residues and waste and materials [20]
State specific legislature is in place such as in Bavaria, where the The Bavarian State Institute for Agriculture requires that various crops and energy crops be used in the cultivation of renewable raw materials so that substrate production can be made as sustainable as possible [21].
Hemp has a legitimate place among the new energy crops. With the support of the BMEL, the biogas mixture Veitshöchheimer Hanfmix NC 871 [22] developed by the Bayerische Landesanstalt für Weinbau und Gartenbau (LWG) (engl. Bavarian State Institute for Viticulture and Horticulture). According to the LWG this is a wild plant mixture of hemp seeds that has been specially developed by more than 15 institutions over a period of 10 years, which significantly promotes biodiversity in arable farming regions. However, it should be emphasized that the name is deceptive: the plant mix consists of a total of 30 plants, with hemp only serving as a nurse plant and mass carrier in the first year. Already in the third year the tansy takes over the place of the main mass carrier. The wild plant mix produces flowers from the end of May until harvest at the end of July. In its post-blooming period - the time 3-4 weeks after harvest - the wild plant mixture provides a vital source of food for insects such as honey bees, bumblebees and solitary wild bees. This fact is vital for the insects, because the food supply for flying insects has already been severely affected by climate change. In the short post-blooming period of comparable plants, bees usually get nothing. However, the Veitshöchheimer hemp mix is not only extremely attractive for flying insects, but also for small game, birds and bats. From 2020, the hemp mix will be funded via the Kulturlanschaftsprogram (KuLaP) program B43 for the sustainable protection of biodiversity in Bavaria [23].
Nevertheless, the flowering mixture has a major disadvantage: the yield of the biogas mixture is only 40% of the yield of corn. On the other hand, the wild plant mix requires very little work and contributes to reducing nitrate levels in the soil. A remediation of nitrate-polluted soils in water protection areas is therefore possible [22].
In general, hemp plants are also suitable for cultivation on and cleaning of heavily contaminated soil (Dölle et al. 2019). Ultimately, the "Hemp Mix" demonstrates an effective way to incorporate the benefits of hemp with the yield enhancement of traditional resources. The approach of initially only integrating alternative resources is common. Because a complete change in the use of certain resources cannot simply take place overnight.
The present work is therefore dedicated to explaining industrial hemp as such a potential energy resource for the sustainable production of biogas on the basis of in-depth research and a research study. In addition, it was specifically examined whether hemp waste products from CBD production are suitable for the production of biogas.
The following manuscript describes the laboratory scale batch fermentation research using wine grapes pomace after pressing as feedstock. The research is based on procedures established by Dölle and Hughes for co-digesting Hyacinth (*Eichhornia crassipes*) and Cow Manure [16].

Comment [PM15]: Source required

Comment [PM16]: Provide your research aim. You have defined co-digestion as a way for biogas optimization

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2. MATERIAL AND METHODS

With the various possible applications and the similar properties of hemp compared to conventional energy crops such as corn and rye, the question arises as to whether hemp is also suitable as an energy crop, explicitly as a biomass resource for biogas production. The comparability of hemp with other energy crops has already been confirmed several times (Sausserde et al.; Das et al.; Harper et al.). To determine if hemp waste products from CBD oil production could be used as a biogas resource, the biogas potential of industrial hemp

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was investigated and identified with a research study. The biogas was generated through the process of anaerobic fermentation.
Two systems were used to measure the biogas production of hemp samples: A laboratory system for anaerobic fermentation (Laboratory Benchtop Anaerobic Fermentation System; LBAF for short), see Figure 3 and a methane gas analysis system (Laboratory Benchtop Methane Analyzer; LBMA for short), see Figure 4. The LBAF was used to measure the raw biogas production. The pure methane content in the biogas without CO_2 was then determined with the LBMA.

2.1. Materials

2.1.1. Fermentation Materials

Cow Manure inoculate (CMI) was obtained from a nearby farm and hemp residue were collected from a nearby production facility.

Comment [PM19]: Quantify the inoculum

2.1.3. Barrier Fluid

Preparation of the barrier fluid was based on DIN 38414 [17]. First, 1000 ml of deionized water was heated under stirring in a 1500 ml glass beaker using Thermo Scientific brant stirring hotplate and a magnetic stir bar. After a temperature of 40°C was reached, 30 ml of sulfuric acid (H_2SO_4; ρ=1,84 g/ml). Then 200 g of sodium sulfate dehydrate (Na_2SO_4) was~~is~~ added slowly to the diluted sulfuric acid solution. The solution is stirred till all sodium sulfate dehydrate is dissolved in the solution.
Second, in a 150 ml glass beaker 0.1 Methyl orange sodium salt is dissolved in 100 ml of distilled water under constant stirring at a temperature of 20°C.
Third, a few drops of the Methyl orange solution are added to the barrier fluid to allow for easier visualization. The color can be adjusted to either a lighter or a darker orange by adding more or less drops to the barrier solution.
Forth, the barrier solution should be stored at room temperature to prohibit crystallization. If crystallization occurs, the crystallization can be reversed easily by heating and stirring the barrier solution to of 40°C.

Comment [PM20]: Specify the purose of each solution and correct the grammatical mistakes

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2.1.3. Absorbent Fluid

The Absorbent fluid was prepared using a 1000 ml glass beaker filled with 500 ml of deionized water with 20°C. The beaker was placed on a Thermo Scientific brand stirring hotplate, and under stirring using a magnetic stirrer. Sodium Hydroxide (NaOH) pellets were added till a final NaOH solution of 10% was achieved. The prepared adsorbent solution was filled in a clear PVC container and covered till used.

Comment [PM23]: State purpose of the fluid

2.2. Laboratory Benchtop Anaerobic Fermentation Systems

Both the Laboratory Benchtop Anaerobic Fermentation (LBAF) and Laboratory Benchtop Methane Anlalyzer (LBMA) systems were set up and used according to the guidance of Dölle and Hughs [24].

2.2.1. Laboratory Benchtop Anaerobic Fermentation System

The LBAF was set up according to Figure 1. The system consisted primarily of an 18.4 cm2 digital cooking plate (1). The hotplate was used to heat a 2.0 liter glass beaker (2) which was filled with deionized water (12). The glass beaker, in turn, served as a heating vessel; in this, a specific temperature of approx. 39°C for anaerobic fermentation was generated, in which the ferments could work ideally. A 500 ml Erlenmeyer flask was fitted with a 40 mm long magnetic stirrer and used as a vessel for anaerobic fermentation, or GAF for short (3). A rubber stopper (4) finally sealed the vessel. The rubber stopper contained a self-sealing tube fitting which was connected to polyvinyl chloride (PVC) tubing (5). The PVC hose was in turn fitted with a shut-off clamp (6) which enabled the GAF to be sealed. When opened, the generated biogas (13) could flow from the biomass suspension (11) through a PVC tee (7)

into an inverted 120 ml PVC cylinder (9). To do this, the valve (8) had to be closed. The PVC cylinder was also used as a displacement vessel (9) for the sealing liquid (14). At the beginning of the experiment, the barrier liquid was drawn from the reservoir (10) into the displacement vessel. The displacement vessel (9) was about 5 mm above the bottom of a transparent 500 ml beaker, the reservoir for the sealing liquid (10). When the valve (6) to the left of the PVC tee (7) was closed and the valve (8) on the PVC hose (5) was opened, the barrier fluid was able to flow back into the displacement vessel (9) using the connected 3-way rubber suction cup (15). In order to extract the resulting biogas for further measurements, the suction bell (15) was replaced by a 50 ml PVC syringe.

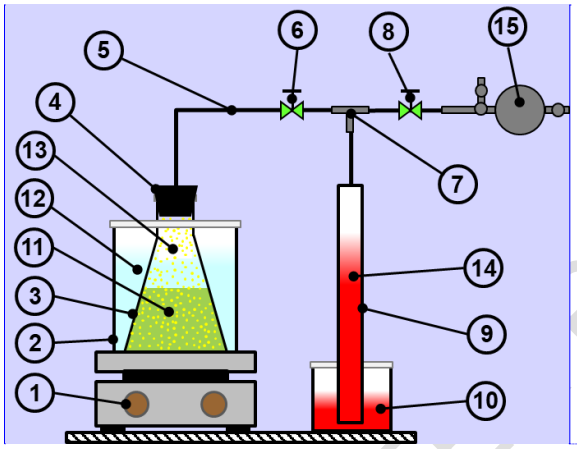

Fig. 1. Laboratory Benchtop Anaerobic Fermentation system: 1) Digital heating-stirring hot plate, 2) Heating vessel, 3) Fermentation vessel, 4) Rubber stopper, 5) PVC hose, 6) Shut-off valve, 7) Tee, 8) Shut-off valve, 9) Barrier fluid displacement vessel, 10) Barrier fluid reservoir, 11) Biomass suspension, 12) Heated water, 13) Biogas, 14) Barrier fluid, 15) 3-way rubber suction ball [24]

Comment [PM24]: Labelling not consistent

2.2.2. Laboratory Benchtop Methane Analyzer System

Comment [PM25]: What did the analyzer work? What gases were analysed?

The LBMA was set up according to Figure 2. The system consisted of a 500 ml clear PVC beaker (1) containing the solvent. A 120 ml inverted PVC cylinder was used as the displacement vessel (2) for the absorbed solvent (10) and was located approximately 5 mm above the bottom of the PVC beaker. The displacement vessel was also fitted with a self-sealing pipe fitting. Both ends of the tee (4) were connected to a PVC hose (3). This was provided with valves (5) and (6) on both the left and right side. A 3-way rubber suction cup (7) was attached to the right of the tee. In the last step, a 50 ml syringe (8) containing the biogas (9) was attached to the left side.

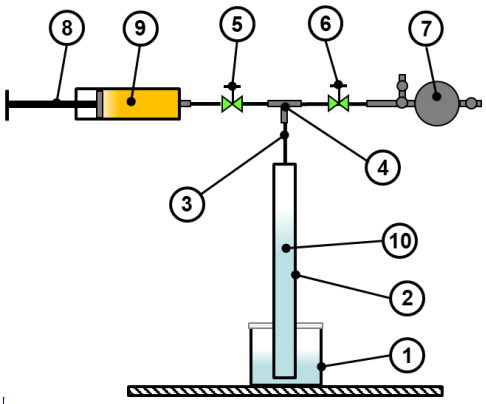

Fig. 2. Laboratory Benchtop Methane Analyses System: 1) Solvent reservoir 2) Sovent displacement vessel 3) PVC hose, 4) Tee, 5) Shut-off valve, 6) Shut-off valve, 7) 3-way rubber suction ball, 8) 50 ml syringe, 9) Biogas, 10) Solvent [24]

Comment [PM26]: The arrows shown on the diagram need to be consistent

2.2.3. Operation of the LBAF

In order to be able to interpret the results as practice-oriented as possible, the study determined the biogas production of different hemp samples as well as that of liquid manure and grass under the same basic conditions. The biogas production of the samples were ~~was~~ carried out twice in a row at an interval of three weeks under the same conditions. The hemp residue used in the experiments was waste products from CBD oil production. The waste was dried hemp stalk and mixed hemp residue. The raw materials hemp stalk, hemp residue and grass were mixed with liquid manure, having a 10% solids content at the beginning of the study. Approx. 300 ml of substrate and approx. 30 ml of liquid manure were always used. The liquid manure serves as an inoculum in biogas production – it contains the bacteria that enable the release of biogas a priori. During the anaerobic fermentation with the LBAF, constant pH values between pH 7 and pH 8.5 were maintained. At pH values below pH 6, the methane-producing bacteria would have died. Both analysis systems described above were used. First, the biogas production was measured with the LBAF and then the methane content with the LBMA.

Comment [PM27]: Not shown on results. What were the temperature ranges?

Comment [PM28]: Which waste?

Comment [PM29]: Complete word required

Comment [PM30]: Take it to results section

In the first step, approx. 300 ml of prepared biomass solution were filled into the pre-weighted fermentation vessel (3) together with a magnetic stirrer. Then the same (3) was closed with a rubber stopper (4) and sealed with several layers of parafilm in order to seal the vessel ideally. The fermentation vessel was incubated in the heating vessel (2) which was located on the digital heating plate (1). For the entire duration of the experiments, the heating vessel contained 1200 ml of distilled water at a temperature of 39 °C starting from the hot plate. The water was filled into the beaker up to the neck of the Erlenmeyer flask. The water is used here as a kind of "coat" to control the temperature in the fermentation vessel and keep it constant. The valve (6) was initially closed and a magnetic stirrer placed in the digester and adjusted so that the biomass solution (11) slowly rotated in the digester (2).

Next, the barrier liquid (14) was fed into the displacement vessel (9) via the 3-way rubber suction cup (15). Valve (8) was then closed and valve (6) opened. The biogas produced (13) was drawn from the headspace of the digester into the displacement tank (9). Biogas production was measured up to the point at which no new biogas was produced at all. Biogas production was usually measured at intervals of around nine to ten hours; However, irregularities in the measurement times do occur.

Comment [PM31]: Not under methodology but results.

Comment [PM32]: Mention them and state ways of minimizing them

In the next step, the pure methane content was measured using the LBMA. First the valve (5) was closed and the right valve (6) was opened. Then, with the attached 3-way rubber suction cup (7), the solvent was moved into the displacement tank (9) to a desired level.
Valve (6) was then closed and the syringe (8), which contained biogas (9), was attached. When valve (5) was opened, the biogas (9) was pressed into the displacement tank (2) and the solvent (10) was displaced. The solvent then adsorbed the CO2 contained in the biogas and forced the methane gas back into the displacement vessel. The difference between the volume of biogas pressed into the displacement vessel and the volume of solvent in the displacement vessel revealed the pure methane gas content without CO2

2.3. Testing Procedures

The following section describes the procedures used for each sample to determine the Total Solids Content (TSC), Ash content (AC) and Volatile Solids Content (VSC). All tests were run in duplicate. A Denver Instrument SI-234 analytical balance was used to determine the sample weight. TSC of each test sample was determined based on modified TAPPI test method T412 om-06 “Moisture in pulp, paper and paperboard” [18] using a 70.7 l (2.5 cuft) Thelco drying oven set to 105°C. AC was determined for each test mixture using TAPPI test method T 211 om-02, “Ash in wood, pulp, paper and paperboard: combustion at 525°C” [19] using a Fisher Scientific Thermolyne 1.3 l (0.04 cuft) Muffle furnace set to 525°C.
Voltaic Solids VS content in % was determine by ((TSC-AC)/TSC*100).
Temperature and pH measurements were conducted using a portable Accumet AP85 pH/temperature/Conductivity meter.

Comment [PM33]: Step by step procedure is required and purpose for each procedure should be well articulated.

Comment [PM34]: On your results and discussions section, state your pH and temperature results and finally discuss them.

2.3.1. Solids content, ash content measurement procedures

To evaluate the Solids Content (SC) of a given test sample 50 ml aluminum sample trays were marked and weighted accordingly. Then approximately 30 to 45 ml of the prepared biomass suspension or test sample was added to each of the corresponding aluminum sample trays prepared for the given test sample. Next these samples were weighed to obtain their wet sample weight measurements and then placed in a ~105°C oven to dry for 24 hours. After drying, the samples were weighed again to determine their dry weight measurements. The loss in mass was attributed to moisture. The remaining solids were the Total Solids Content (TSC) of the feedstock.
To determine the Ash Content (AC), 30 ml crucibles were labeled, weighed, and the remaining dried solids were scraped from their aluminum trays into their corresponding crucibles. The crucibles containing the samples were then weighed again and placed in a 525°C muffle furnace for approximately 6 hours for combustion. After combustion the crucibles with the remains were weighed to determine their ash weight measurements. The change in mass was attributed to the VS of the biomass material, which were ignited during the process. The remaining solids were the ash present in the sample.

Comment [PM35]: How did you calculate total solids, volatile solids, ash content?
Why was AC determined?
Why determining volatile solids?

Comment [PM36]: TS formula should be highlighted and numbered

2.3.2. Material preparation:

To prepare the hemp stems, hemp residues and manure with a solids content of 88.79%, 86.66%, and 11.20% respectively the following processing steps were done.
First, the hemp stems were cut into approximately 0.25 inch (6 mm) long pieces. The hemp processing residues did not need to be cut, because they had already a size of approximately 0.25 inch (6 mm). Second, a mixable solution was prepared of approximately 8% solids content from the hemp residues, hem stems and manure. Each solution was then blended for 2 minutes separately using a 1.5 l benchtop laboratory blender/mixer.
Third, from the blended manure solution 150 ml of inoculate were prepared for the hemp stem and hemp residue solution by filtering. The manure inoculate solution had a solids content of 6.39%.
After preparation, the suspensions were stored in a refrigerator at 41°F (5°C) prior to executing the anaerobic fermentation experiments.

Comment [PM37]: Clarify the 8% solid content

Comment [PM38]: Specify the manure type

2.3.3. Experimental procedure of the anaerobic fermentation experiment

A total of 8 AD experiments were conducted with hemp residues, hemp stems and manure using the LBAF system. First, the prior prepared biomass mixtures were diluted with tap water to a target solids content. The best solids content for stirring using a magnetic stirrer was evaluated prior to the experiments. Hemp stems were diluted to approximately 3.2%, hemp residues to 2.2%, and manure to 3% solids content. Second, the pH of the solution was adjusted to a pH of 8.0 with a 20% Calcium Hydroxide ($Ca(OH)_2$) solution. To the hemp stem and hemp residue solution, 10% manure inoculate with a solids content of 6.29% was added by volume.

From each solution, the AD experiment solution was prepared by filling approximately 330 g of the solution into a 500 ml Erlenmeyer flask that contained a 40 mm magnetic stirrer. The final solids content of the hemp residue, hemp stem solution was 3.59% and 2.61% respectively. The manure solution remained the same since no inoculant was added.

All 8 individual AD experiments with the LBAF system were run as described in section 2.2.1. with duplicate tests for 240 hours.

Measurements of the produced biogas volume and CH_4 gas content per experiment was done as described in section 2.2.2.

3. RESULTS AND DISCUSSION

Figures 3 shows the results of the study. Biogas production from hemp residues, hemp stems and manure were measured over a period of 240 hours. The x-axis of the diagram shows the time in hours and the y-axis shows the accumulated amount of biogas produced in milliliters. The maximum amount of biogas that could be produced from this raw material under the given conditions is achieved after 240 hours. However, small changes can still be observed even after the maximum value has been reached.

The Cumulative Biogas (CBG) production of hemp residues 1 and 2 after 240 hours were 276 ml and 180 ml respectively. The VS consumption (VSC) during anaerobic fermentation was 0.98 g and 0.98 g for hemp residue 1 and 2 respectively. The CBG per gVS (CBG/gVS) was 279.98 ml/g and 182.64 ml/g with an average VSC and CBG of 0.98 g and 231.31 ml/g respectively.

For the hemp stems 1, 247 ml and hemp stems 2, 192 ml of CBG was measured after 240 hours of anaerobic fermentation. The VS consumption (VSC) during anaerobic fermentation was 2.59 g and 5.53 g for hemp residue 1 and 2 respectively. The CBG per gVS (CBG/gVS) was 95.05 ml/g and 34.75 ml/g with an average VSC and CBG of 4.06 g and 64.90 ml/g respectively.

Manure as a control run gave 198 ml for manure 1 and 263 ml for manure 2 after a anaerobic fermentation time of 240 hours. The VS consumption (VSC) during anaerobic fermentation was 0.78 g and 0.74 g for manure 1 and 2 respectively. The CBG per gVS (CBG/gVS) was 357.42 ml/g and 253.94 ml/g with an average VSC and CBG of 0.76 g and 305.69 ml/g respectively.

Biogas sample of 50 ml was taken at the end of the study. The biogas composition without CO_2 showed a biogas content of 62% for the manure samples and a 55% for the hem p stems and 57% for the hemp residues.

Based on the results it can be concluded that that hemp processing residue waste can produce more biogas from a lesser amount of biomass. On the other hand hem stems can be easier broken down by anaerobic fermentation but a lesser biogas content can be produced based on the biomass amount.

Comment [PM39]: Remove irrelevant information.

Comment [PM40]: These results are not detailed are not analysed. Many questions come from this research as follows:
- What was the pH of the slurry?
- At what operating temperature was the optimum biogas produced?
- What was the mixing ratios of the co-substrates?
- What was the methane content of the maximum biogas produced?
- What was the loading rate?
- Why drawing cumulative graphs?
- What was the best mixing ratio of the co-substrates?
- How many experimental set ups?

The results are inadequate and not convincing at all.

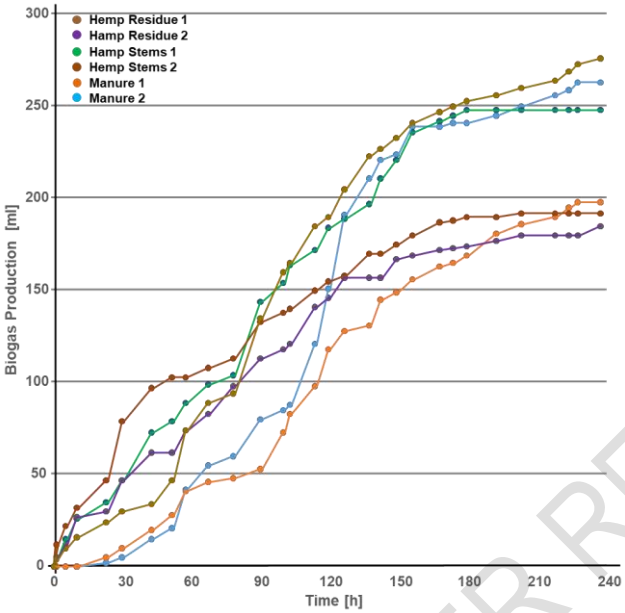

Fig. 3. Cumulative biogas production over time for Hamp Residue 1&2, Hamp Stems 1&2, and Manure 1&2

CONCLUSION

The cumulative biogas production by anaerobic co-digestion of

The CBG production of hemp residues and hemp stems showed that after 240 hours the average VSC reduction for hemp residue 1 and 2 during anaerobic fermentation was 0.98 g with an CBG of 231.31 ml/g. For the hemp stems 1 and 2 the average reduction of VSC by 4.06 g and the CBG was 64.90 ml/g respectively. Manure showed an average reduction of VSC of 0.76 g and CBG of 305.69 ml/g respectively. The biogas content without CO_2 was 62% for the manure samples, 55% for the hemp stems, and 57% for the hemp residues. Each AD test was run for 240 hours at a temperature of 39°C ± 2°C for the duration of the experimental.

Overall, the use of co-digestion utilizing hemp processing residues as waste biomass feedstock has some potential for energy production using AD technology, and therefore shows the potential of hemp as an energy crop.

The world must become greener in the future – possibly with alternative energy crops such as hemp. And it is precisely these that we need a lot of in times when glaciers are melting faster, summers are getting hotter and winters are getting shorter. Because only with them can we find alternatives to the harmful status quo, fossil fuels. And yet, it must be considered that the future must be green not only for us humans, but also for all living beings and animals. Our plants of the future must therefore be sustainable, renewable and ecologically valuable. As this work testifies, the hemp plant is an ideal raw material for these purposes. As the study carried out showed, hemp is quite impressive in comparison to conventional biogas resources. However, there will probably not be a pure cultivation of hemp in the

Comment [PM41]: Poorly presented. The horizontal lines should not appear.

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Comment [PM43]: Incomplete

Comment [PM44]: Which manure?

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Comment [PM47]: Substantiate your point

future, as with corn. Nevertheless, hemp cultivation is by no means frowned upon in Germany and some farmers are already using industrial hemp as a renewable energy resource for their biogas plants. Constantly new, adapted regulations and developments such as the Veitshöchheimer hemp mix also has the potential to show a positive trend. With such flowering mixtures the possibility of future energy generation is possible. However, more research is needed to improve and assess the potential of the new flowering mixtures.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly used ~~use p~~roducts in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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