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https://doi.org/10.1177/0734242X20938438 Waste Management & Research 1–12 © The Author(s) 2020 Article reuse guidelines: sagepub.com/journals-permissions DOI: 10.1177/0734242X20938438 journals.sagepub.com/home/wmr Introduction The topic of possible fossil fuel replacement by environmentally friendly alternative biofuels has been was investigated, proved and published widely in recent years. The reasons for this are many: the dwindling supplies [2]of fossil fuels and their increasing prices; efforts to reduce environmental pollution caused by fossil fuels; and increasing of renewable energy using or spreading the knowledge about proper waste management. Nowadays, both scientific research and the commercial sector, focus on utilization of green and clean renewable energy sources in order to generate different kinds of biofuel (solid, liquid, and gaseous) by valorization of various waste biomass (WB) (Adarme [2]et al., 2019; Hawkes et al., 2002; Logan and Regan, 2006; Niju and Swathika, 2019; Soto et al., 2019; Vats et al., 2019; Yusuf, 2017). Currently, WB (originating prevalently from the agricultural sector) is considered as the largest source of renewable energy in the world (Niu et al., 2019). The amount of WB has increased significantly and represents a threat in the form of environmental pollution, if not properly processed, recovered or stored (Flores-Jiménez et al., 2019; Yusuf, 2017). In response, various sustainable technologies for proper waste management combined with biofuel generation have been already put into practice or are under development. [5]One of the promising sustainable technologies used for WB effective Briquetting of sugarcane bagasse as a proper waste management technology in Vietnam Anna Brunerová1 , Hynek Roubík2 , Milan Brožek1, Dinh Van Dung3, Le Dinh Phung3, Udin Hasanudin4, Dewi Agustina Iryani5 and David Herák6 Abstract [1]The present research describes an application of high-pressure briquetting technology to the waste management of sugarcane processing in Vietnam. The amount of generated sugarcane bagasse was monitored during sugarcane processing within the street juice production in Hue city, Vietnam. [23]Generated sugarcane bagasse was subjected to fuel parameters analysis within its suitability for direct combustion. The obtained sugarcane bagasse [11]was converted into bio-briquette fuel by a high-pressure briquetting press and its mechanical quality was determined. Results proved that the proportion of generated sugarcane bagasse from whole sugarcane stem mass was equal to 35.45%. This indicated generation of an abundant amount of sugarcane bagasse worldwide in general. Fuel parameters analysis proved high quality level of low ash content = 0.97% and high calorific values (gross calorific value = 18.35 MJ·kg-1, net calorific value = 17.06 MJ·kg-1), which indicated good suitability for direct combustion processes. Indicators of mechanical quality proved the following observations: mechanical durability = 99.29%, compressive strength = 150.82 N·mm-1 and bulk density = 1022.44 kg·m-3, with all these indicators representing positive results. In general, the observed results indicated suitability of sugarcane bagasse valorization within the production of bio-briquette fuel by using high-pressure briquetting technology. Finally, analysis of such waste biomass proved its great potential for energy recovery, thus, the advantage of its valorization within the sustainable technologies. Keywords Bio-briquette, waste biomass, mechanical durability, calorific value, sugarcane bagasse, renewable energy Received 24th January 2020, accepted 2nd June 2020 by Associate Editor Rodrigo Navia. 1 Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic 2 Department of Sustainable Technologies, Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, Prague, Czech Republic 3 Department of Animal Nutrition and Biochemistry, Faculty of Animal Sciences & Veterinary Medicine, Hue University, Hue University of Agriculture & Forestry, Hue City, Vietnam 4 Department of Agro-industrial Technology, Faculty of Agriculture, University of Lampung, Bandar Lampung, Republic of Indonesia 5 Department of Chemical Engineering, Engineering Faculty, University of Lampung, Bandar Lampung, Republic of Indonesia 6 Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic Corresponding author: Anna Brunerová, Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Prague, 165 00, Czech Republic. Email: brunerova@tf.czu.cz 938438WMR0010.1177/0734242X20938438Waste Management & ResearchBrunerová et al. research-article2020 Original Article 2 Waste Management &

 utilization (valorization) is briquette processing technology. It works with heavy machinery (high-pressure briquetting press) and a process of densification applied to bulk feedstock material, while bio-briquette fuel intended for direct combustion represents the final products. A suitable feedstock for briquetting technology can be found between various WB, prevalently generated as a wide range of agriculture residues. Densification (briquetting) of bulk feedstock into the bio-briquette form (solid biofuel) increases its fuel efficiency and improves its characteristics, specifically: less smoke and more heat is produced during combustion; easier handling and storage of the biofuel; and practical feeding of fur naces (Eissa and Alghannam, 2013; Werther et al., 2000). To increase the level of WB fuel parameters even more, it is possible to use the subsequent process of torrefaction (at 200–300°C in inert atmosphere) (Niu et al., 2019). One of the agriculture sectors producing a great amount of WB (potential feedstock) is the sugar industry. Sugarcane plant represents a major crop within sugar production worldwide. The sugar industry generates various WB during the harvesting of crops and milling, thus, extensively contributing to worldwide waste management or to environmental pollution eventually (Marin et al., 2019; Souza et al., 2008). Sugarcane bagasse together with sugar cane top leaves are the main waste material generated during such crops processing as cleaning, skinning, peeling or pressing operations. If sugarcane bagasse is properly processed and subsequently re-utilized, it has great potential for further valorization and it represents a valuable commodity. Valorization of sugarcane bagasse can be achieved by its conversion into feedstock materials or by extraction of specific components, both for certain purposes. Sugarcane bagasse can be utilized for extraction of lignin, hemicellulose, and cellulose or can be used as a source of dietary fibres due to its nutritional values (Batalha et al., 2015; Gil-López et al., 2019; Yu et al., 2015), as well as being utilized as a fodder for livestock (Ullah et al., 2019). In addition, so-called bioelectricity can be generated from sugarcane molasses by using microbial fuel cell technologies, which isolate specific bacterial strains (Hassan et al., 2019). Sugarcane bagasse suitability for liquid biofuel production was also proved, namely in bioethanol and biodiesel production by fermentation due to its high content of cellulosic fibres (Niju and Swathika 2019; Soto et al., 2019). In the case of gaseous biofuel, sugarcane bagasse proved its potential for biogas generation by anaerobic digestion, which takes place in biogas plant stations (Adarme et al., 2019; Vats et al., 2019). Therefore, the spectrum of sugarcane bagasse sustainable reuse is very wide. However, sugar producers can also reduce their costs by application of proper sugarcane bagasse waste management into their industry life cycle (Ullah et al., 2019). Indeed, generated sugarcane bagasse can be burned directly in the industry in order to improve (electrical) energy demands of the production (Teixeira et al., 2010). Sugarcane represents one of the important agriculture crops cultivated in Vietnam. Despite Vietnam not belonging to group of major countries within the sugarcane cultivation worldwide (i.e., Brazil, India, China, and Thailand), its contribution to worldwide sugarcane production is not negligible (Food and Agriculture Organization of the United Nations, 2019), as can be seen in Table 1. Regionally, 80% of Vietnamese sugarcane production is cultivated in the Mekong Delta and Red River Delta areas. All production operations (including harvesting) of sugarcane cultivation are still performed manually by the farmers. A similar situation can be found in sugarcane processing; approximately 30% of cultivated crops are processed in large-scale factories, while the remaining 70% are processed by small-scale processing plants. Processed sugarcane stems from such small-scale plants are subsequently sold to small businesses and local markets. Unfortunately, such small-scale plants are often highly inefficient and incur major material losses, which is also associated with improper waste management (Food and Agriculture Organization of the United Nations, 2019). Figure 1 shows amounts and examples of various kinds of WB (bagasse, skins, peels, leaves, and stems parts) generated in small-scale sugarcane processing plants located in Hue city, central Vietnam, within one working day, and subsequent improper waste management in practice, such as collection by municipal mixed waste garbage trucks. Despite a relatively large amount of sugarcane bagasse generation in Vietnam, the number of scientific local studies monitoring its sustainable utilization within biofuel production, etc. is very limited and deficient. The majority of available studies deal with briquetting of sugarcane bagasse ash, thus, with sugarcane bagasse charcoal bio-briquette fuel production (Teixeira et al., 2010; Zandersons et al., 1999). Those studies indicate that sugar cane bagasse is being used for combustion processes, but in bulk form, which is inefficient in terms of its potential. Therefore, the main objective of this study is to investigate, analyse and evaluate the whole process of sugarcane bagasse generation in specific parts of Vietnam and its suitability for production of Table 1. Analysis of sugarcane production in Vietnam and in the World (in total) (Food and Agriculture Organization of the United Nations, 1997). Year Area harvested Average yield Production (ha) (kg·ha-1) (tons) Vietnam World Vietnam World Vietnam World 2014 304,969 27,051,024 65,000 69,609 19,822,851 1,883,001,244 2015 284,262 26,598,926 64,509 70,378 18,337,227 1,871,966,995 2016 256,322 26,537,470 63,643 70,134 16,313,145 1,861,183,072 2017 281,149 25,976,939 65,291 70,891 18,356,398 1,841,528,386 Brunerová et al. 3 bio-briquette fuel by using high-pressure briquetting technology. To achieve the stated main objective, we focused on several other specific objectives. In order, the first specific objective was to monitor the procedure and amount of sugarcane bagasse generation within small-scale crop processing at local markets in Vietnam and related waste management in practice. The second objective was to investigate the viability of raw sugarcane bagasse utilization as a feedstock for production of bio-briquette fuel by using a high-pressure briquetting press and its practical implementation. The third objective represented experimental measurements focused on detailed analysis of bio-briquette fuel parameters such as chemical and mechanical quality. Methodology This section contains the complete process of sugarcane bagasse utilization within bio-briquette fuel production. Description begins at the process of sugarcane bagasse generation during juice production, while its mass ratio from pressed stems was determined. This is followed by the process of sugarcane bagasse conversion into suitable feedstock and utilization for bio-briquette fuel production by using of a high-pressure briquetting press. Finally, the sugarcane bagasse chemical fuel parameters and energy potential were determined, as well as the mechanical quality of produced bio-briquette fuel samples. Materials and samples collection We investigated WB, the sugarcane bagasse, originating from sugarcane crops cultivated and harvested in Phú Yen Province, central Vietnam. Mentioned crops represented a Miá duong species, which is characterized by 11high content of sugar. In consequence, local street sellers commonly use this specific species 3for production of sugarcane juice by manual or electrical pressing machines (see Figure 2(d)). The initial observations and measurements 7related to the sugarcane bagasse generation and its amount (in percentage from pressed stem), as well as the samples collection, were performed in May 2019 at a smallscale sugarcane processing plant named Lam Mong Quang, located in Hue city, central Vietnam. The whole process of performed investigations, which 10at the same time includes the procedure of raw sugarcane cleaning, processing and pressing for juice production in practice, was captured by the photo-documentation and is displayed and described 6in Figure 2. In practice, harvested sugarcane stems were manually stripped of leaves and roots, skinned and peeled by an electric peeling machine, chopped into three pieces, packed and then sold to local street sellers for juice production. Waste to biomass ratio Sugarcane treatment for juice production includes several differ ent processes and each one generates a specific kind 10and amount of waste, while all together, they equalize to overall amounts of generated WB. Initial treatment processes are performed directly at the plantations during plants harvesting (top leaves and stem bottoms stripping). Following this, processes are 3performed in a target processing plant (skinning, peeling, and cutting) and the final process of stem pressing within juice production is performed in small street shops. In the present study, the main topic of interest was 7the amount of generated sugarcane bagasse during small-scale sugarcane juice production and the mass ratio (in percentage) of produced sugarcane bagasse from the pressed stems. Experimental measurement per formed in juice producing street shops was sugarcane stems (investigated samples) prepared for juice pressing (shown in Figure 2(c)) that were weighted each separately before and after juice pressing. Whereas, stem samples after juice pressing represented investigated sugarcane bagasse. The obtained data were used for calculating the final amount of sugarcane bagasse, which was expressed as a per centage from each stem separately; subsequently, an average value was calculated from all investigated stems. The following formula was used for the performed calculation (see equation (1)): WB m m = · 2 1 100 (1) where: m1, mass of unprocessed sample (g); m2, mass of processed sample; and WB, amount of waste biomass (%). Figure 1. Waste generation at sugarcane processing small-scale plant: (a) various kinds of generated waste biomass; and (b) collection by garbage truck. 4 Waste Management & Research 00(0) Data used for such simple calculations were collected in street juice selling shops in Hue city, central Vietnam, which use common types of electric sugarcane juice press machines equipped with three rotary cylinders (pressing rollers) as a pressing unit (see Figure 2(d)). As additional information, the amount of WB (peels) gener ated during sugarcane stem peeling (shown in Figure 2(b)) was monitored in order to extend the overall picture of sugarcane WB generation. Measurements were performed directly at the investigated target small-scale processing plant, where raw unprocessed sugarcane stems (samples) were collectively weighted before and after the peeling procedure performed by an electric sugarcane peeler (shown in Figure 2(b)). The mass ratio of cleaned stems (final product) and sugarcane peels (waste product) was monitored and the amount of generated WB was calculated and expressed as a percentage by using identical formula as in the case of sugarcane bagasse amount calculation in equation (1). Experimental measurements All procedures described were performed according to mandatory technical standards officially stated by the European Committee for Standardization in an effort to ensure proper procedures of solid biofuels (specifically, bio-briquettes) production and achievement of their high quality level within its commercial production. The list of followed standards is noted in Table 2. Investigated sugarcane bagasse samples, generated during the juice pressing, were collected, processed and used for subsequent experimental measurements within their utilization as a feedstock for bio-briquette fuel production. First, visual obser vation indicated that samples occurred in an unsuitable form Figure 2.   Steps of sugarcane bagasse generation and data collection in the processing plant: (a) stems storage in processing plant; (b) stems peeling

10by heavy machinery; (c) cleaned chopped stems prepared for juice production; (d) juice pressing– generation of sugarcane bagasse; and (e) sugarcane bagasse samples. Brunerová et al. 5 (see Figure 3(a)) for testing, 9as well as for process of densification, that is, production of solid biofuel, in the present case the bio-briquette fuel. Thus, samples were firstly dried and ground to a suitable level. The drying process (24 hours, 105°C) was performed using a laboratory dryer LAC, type S100/03 (Rajhrad, 3Czech Republic) and grinding was done using a grinding hammer mill Taurus, Type VM 7,5 (Chrudim, Czech Republic). The hammer mill used, worked with eight free-swinging hammers placed on a vertical shaft and a sieve with 8 mm diameter holes. 10The form of samples before and after the preparation process is displayed in Figure 3. Fuel parameters Dried and ground sugarcane bagasse samples were subjected to the set of laboratory experiments, 25which resulted in determination of their basic chemical parameters, energy potential and elemental composition. Such measurements were performed in an effort to reveal and state the suitability of such WB for 3the process of direct combustion within its potential utilization as a feedstock for bio-briquette fuel production. Specifically, the moisture content (Mc) (%) and ash content (Ac) (%) are interesting parameters. Preparation of samples consisted of grinding into powder (particle size <0.1 mm) followed by subsequent analysis. A thermogravimetric analyser LECO, type TGA 701 (Saint Joseph, United States) was used; the temperature of 107°C was selected 2due to the Mc (%) determination and 550°C due to the Ac (%). Applied procedures originated from technical standards EN 18134-2 (2015) and EN ISO 18122 (2015). The elemental composition contained carbon (C) (%), hydrogen (H) (%), nitrogen (N) (%), sulphur (S) (%) and oxygen (O) (%) contents for determination. Experimental measurements were performed using laboratory instrument LECO CHN628+S (Saint Joseph, United States), whereas helium 3was used as a carrier gas. Sugarcane bagasse samples were burned at 950°C (for C, H, and N) and 1350°C (for S) in presence of O and subsequent analyses of resulting flue gases were performed. Described experimental measurements followed technical standards EN ISO 16948 (2016) and ISO 16994 (2016), while O (%) content was calculated 4according to the technical standard EN

ISO 16993 (2016). All measurements were performed repeatedly until three proper results of each element were obtained. Table 2. List of mandatory technical standards followed within present research. Code Name Year EN ISO 16559 Solid Biofuels – Terminology, Definitions and Descriptions 2014 EN 15234-1 Solid Biofuels – Fuel Quality Assurance – Part 1: General requirements 2011 EN ISO 17225-1 Solid Biofuels – Fuel Specifications and Classes – Part 1: General Requirements 2015 EN 14918 Solid Biofuels – Determination of Calorific Value 2010 ISO 1928 Solid Mineral Fuels –Determination of Gross Calorific Value by the Bomb Calorimetric Method, and Calculation of Net Calorific Value 2010 EN ISO 18122 Solid Biofuels – Determination of Ash Content 2015 EN ISO 16948 Solid Biofuels – Determination of Total Content of Carbon, Hydrogen and Nitrogen 2016 ISO 16994 Solid biofuels – Determination of Total Content of Sulfur and Chlorine 2016 EN ISO 16993 Solid biofuels – Conversion of Analytical Results from One Basis to Another 2016 EN ISO 18134–1 Solid biofuels – Determination of Moisture Content – Oven Dry Method - Part 1: Total Moisture - Reference Method 2015 EN ISO 18134-2 Solid Biofuels – Determination of Moisture Content – Oven Dry Method – Part 2: Total Moisture – Simplified Method 2015 EN ISO 17831-2 Solid Biofuels – Determination of Mechanical Durability of Pellets and Briquettes – Part 2: Briquettes 2015 Figure 3. Investigated sugarcane bagasse samples: (a) initial form; and (b) processed form. 6 Waste Management & Research 00(0) The main indicator of the samples' energy potential was their calorific value. Both, gross calorific value (GCV) (MJ·kg-1) and net calorific value (NCV) (MJ·kg-1), were determined by using an isoperibol calorimeter LECO, type AC 600 (Saint Joseph, United States) in accordance to technical standards EN 14918 (2010) and ISO 1928 (2010). Samples were pressed into the form of pellets and burned in the mentioned calorimeter. Obtained result values represented GCV (MJ·kg-1), while NCV (MJ·kg-1) was calculated by using the following formula (equation (2)): NCV GCV M H c = − · + · ( ) 24 42 8 9 4 . . (2) where: NCV, net calorific value (MJ·kg-1); GCV, gross calorific value (MJ·kg-1), 24.42: coefficient of 1% of water in the sample at 25°C (MJ·kg-1); Mc, moisture content in analytical sample (%); 8.94, coefficient of hydrogen to water conversion; and H, hydrogen content in analytical sample

(%). Bio-briquette fuel production For production of sugarcane bio-briquette samples a hydraulic high-pressure briquetting press Briklis, type BrikStar 30-12 (Malšice city, Czech Republic) was used (see Figure 4(a)). The mentioned heavy machinery equipment works with a piston as a pressing unit and contains a mechanism, which [12]is commonly used in large-scale briquetting plants within commercial bio-briquette fuel production; such plants contain also equipment for feedstock drying, grinding, transportation or final products packaging. The final produced sugarcane bio-briquette samples are shown in Figure 4(b) and their basic physical parameters are described in Table 3. Mechanical quality indicators Directly after high-pressure bio-briquetting, the produced samples were subjected to a set of experimental tests, designed to determine their overall final mechanical quality, reflecting the efficiency of the performed densification [7]process and the suitability of the used feedstock materials. [27]Bulk density (ρ) (kg·m–3). The effectiveness of the densification process, thus, decreasing of volume and increasing of density of feedstock, can be expressed by ρ (kg·m-3) of produced briquette fuel. This parameter belongs to the basic success indicators of a briquetting [7]process and the suitability of pressed feedstock, where higher ρ (kg·m-3) represents better results. Calculation of the investigated bio-briquette samples ρ (kg·m-3) was performed by using their previously measured basic dimension properties added into following simple formula (equation (3)): ρ = m V (3) where: ρ, bulk density (kg·m–3); V, bio-briquette samples volume (m3); and m, bio-briquette samples mass (kg). Compressive strength (σ) (N·mm-1).   The physical strengths of produced bio-briquette samples were tested by [9]determination of their σ (N·mm-1). [12]The level of this indicator simulates the compressive stress applied to bio-briquette fuel in practice, when bio-briquettes are stored above each other, thus, their weight is applied to the lower layers. In consequence, the [4]increasing load was applied to each bio-briquette sample until it disintegrated, then the maximum increasing load Fmax (N) was reported. [10]The source of power and pressing unit was represented by a universal hydraulic testing machine WPM, type ZDM 5 (Leipzig, Germany) working with the pressing speed vp of 20 mm·min-1. Further calculation of σ (N·mm-1) worked with the resulting values of maximum increasing load Fmax (N) and bio-pellet samples length (m), which were added into 4the following formula (equation (4)). Figure 4. Bio-briquette samples production: (a) used hydraulic high-pressure piston briquetting press; and (b) produced biobriquette samples. Table 3. Initial physical parameters of produced bio-briquette samples. Length Diameter Mass (mm) (mm) (g) 54.08 ± 2.05 52.33 ± 0.28 118.80 ± 3.98 Note: ±, standard deviation. Brunerová et al. 7 σ = F L max (4) where: σ: compressive strength in cleft (N·mm-1), Fmax: maximal load (N), L: bio-pellet samples length (m). Mechanical durability (DU) (%). As a most 27important indicator of bio-briquette fuel mechanical quality, DU (%) is considered. The methodology 12of the experiment, as well as samples preparation and result values evaluation were performed within the specific mandatory instruction of a related standard, namely EN ISO 17831-2 (2015). Bio-briquette samples were placed into a specific dustproof rotary drum, where they were subjected to a precise number of impacts, when the drum rotated. Each bio-briquette sample was weighted 4before and after such destruction testing, and measured values were used for final calculation by using the following formula (equation (5)): DU m m a e = · 100 (5) where: DU, mechanical durability (%); me, samples mass before testing (g); and ma, samples mass after testing (g). Results and discussion Corresponding to the applied methodology, 7the results achieved are divided into several subsections to answer the questions related to the specific experimental observations and measurements. Waste to biomass ratio As 3the methodology section reported, treatment of sugarcane for juice production includes several different processes, starting with its cleaning and ending up with its pressing. Each specific treatment process generates a specific kind 10and amount of waste. Together, all those different kinds of waste are equal to an overall amount of WB generated within sugarcane juice production. Sugarcane bagasse 2is one of the mentioned waste kinds, thus, its amount represents a certain ratio of total sugarcane waste to biomass amount. Generation 4of sugarcane bagasse and its waste management was monitored at the street shops directly during sugarcane juice pressing. Obtained data proved a high amount of generated WB, as noted in Table 4. Achieved results of generated sugarcane bagasse amount proved, that WB generated during local sugarcane processing occurs at least at 2the level of about 35% from whole plant and more. However, such value is related only to generation of sugarcane bagasse from already peeled and cleaned stems, whereby other forms of sugarcane WB 3(not included in the discussed value) are generated too. As was mentioned, sugarcane stems are stripped of top leaves and stems' bottoms during their harvesting, thus, 2it can be concluded, that the final overall amount of WB originating from their processing is certainly higher than the mentioned 35%. Another investigated kind of sugarcane WB were the peelings (process shown at Figure 2(b)); specific data are noted in Table 5. 12In contrast to the sugarcane bagasse generation measurements, the measurement of sugarcane peelings' generation was per formed collectively, – that is, raw unprocessed stems were weighted together in one specific bundle (sample). As Table 5 indicates, 2the amount of generated sugarcane peelings occurred at approximately 8% level. Together with the observed amount of generated sugarcane bagasse from initial unpeeled stems, which was equal to ± 32.55%, this indicates that 6the amount of generated WB within the sugarcane crops treatment in small-scale processing plants with subsequent utilization for juice production is equal to ± 40.73% from whole harvested crop. Considering the observed data and the reported amount of produced sugarcane in Vietnam in 2017 to be equal to more than 18 million tons (as reported 4in Table 1), this suggests that the amount of generated WB from the sugarcane industry plays an important role in waste 2management of the country. Therefore, the reported amount of WB represents a commodity with great potential for further valorization and its sustainable utilization 4as a source of renewable energy may provide an ecologically friendly alternative to fossil fuels. Previously published research focused on the WB proportion (%) of various tropical fruits also resulted in high values of produced WB, 2as noted in Table 6. Fuel parameters If considering utilization of sugarcane bagasse 3as a feedstock for bio-briquette fuel production, its suitability within the fuel parameters and energy potential must be proved. The performed analyses of basic chemical parameters provided the resulting values 6shown in Table 7 with: wet matter basis (w.b.) – analytical sample, dry matter basis (d.b.) – after Mccorrection and on dry ash free state– without the presence of ash. 7In general, a low level of Mc (%) is required for bio-briquette feedstock, as its high level causes serious complications within the Table 4. Analysis of sugarcane bagasse generation during juice pressing. Sugarcane stem weight Sugarcane bagasse weight Waste ratio (g) (g) (%) 390.27 ± 96.38 138.34 ± 33.34 35.45 Table 5. Analysis of sugarcane peelings generation during the peeling process. Initial samples weight Peeled samples weight Peelings weight Waste ratio (g) (g) (g) (%) 22,000.00 20,200.00 1800.00 8.18 8 Waste Management & Research 00(0) high-pressure densification process and issues related to the final quality of the products. Mandatory technical standards EN 18134-2 (2015) and EN 18134-2 (2015), which need to be followed in the case of commercial bio-briquette fuel production, state a maximal level Mc < 10%. The operational conditions of the high-pressure briquetting press used, strictly recommend a used feedstock material with Mc < 15% without exception. Using of feedstock with higher Mc (%) can cause serious damage of the machine or results in an unsuccessful densification process. Moreover, production of bio-briquette fuel with higher Mc (%) in practice also results in products' disruption and cracks caused by the evaporation of the moisture (Matúš et al., 2015), thus, there is direct product degradation. Another serious issue related to feedstock high Mc (%) is the related low energy potential of subsequently produced bio-briquette fuel; specifically, its low level of GCV (MJ·kg-1). A direct relation between Mc (%) increasing and GCV (MJ·kg-1) decreasing was reported. Moisture vaporizing during combustion consumes concurrently generated energy, thus, decreasing the amount of energy release. In practice, longer and more demanding vapor izing consumes more energy and lowers the fuel energy potential (Lestari et al., 2015; Waweru and Chirchir, 2017). The Mc (%) of investigated samples was equal to 7.02% on average, which represents a satisfactory result, as well as corresponding to the mentioned mandatory requirements for feedstock Mc (%). Simultaneously, such a result represents a feedstock advantage due to its lower energy requirements for drying, which is also not necessary in the present case. Nevertheless, investigated samples were collected from local street shops using highly efficient electric pressing machines, but many sellers still use manual pressing machines with lower efficiency. It can be assumed, that Mc

(%) of sugarcane bagasse generated by such simple manual machines would be higher. Determination of Ac (%) proved outstanding results of this parameter (Ac = 0.90%), which is comparable with firewood Ac (%). Such positive evaluation is supported by comparison with other studies dealing with bio-briquette production using differ ent feedstock materials, as shown in Table 8. Low level of Ac (%) is required for bio-briquette fuel 2due to the negative impact of high Ac (%) on its combustion efficiency, as well as an insufficient air flow, low burning rate, and GCV (MJ·kg-1) (Onukak et al., 2017). Optimal level of Ac (%) for bio-briquette fuel is < 4%, while higher Ac (%) 6is considered as a limitation (Grover and Mishra, 1995). Energy potential expressed as GCV (MJ·kg-1) and NCV (MJ·kg-1) proved their satisfactory level as well, as shown in Table 7. Result of GCV on w.b., which corresponds to the reality of sugarcane bagasse burning in practice, was equal to 17.06 MJ·kg-1, 3which, in turn, corresponds to a satisfactory level of this fuel parameter. This evaluation 25is supported by the results of other studies, which reported sugarcane bagasse GCVs (MJ·kg-1) ranging from 17.33 to 18.20 MJ·kg-1 (Guar and Reed, 1998; Phichai et al., 2013). The energy potential of other parts 7of sugarcane and various tropical WB, used for solid biofuel production, is noted in Table 8 for clear comparison with our observed values. Analyses 9of elemental composition describe the suitability of sugarcane bagasse for direct combustion regarding emissions, production, and burning behaviour. In general, WB burning represents an essential process, which mobilizes specific elements such as C and N from the biosphere to the atmosphere (Crutzen and Andreae, 1990). However biomass 3burning has a significant influence on air pollution. Releasing of C species 2emissions in the form of greenhouse gases into the atmosphere contributes to climate changes (Chen et al., 2010), while N content can be directly connected to nitrogen oxides' emissions (Erisman et al., 2010), thus, high N (%) content is undesirable (Hu et al., 2000). These mentioned effects depend 6on the amount of released C and N, which differs in the case of each type of biomass and combustion conditions (Chen et al., 2010). 9Elemental composition of investigated sugarcane bagasse biomass, which belongs to the herbaceous biomass group, is noted in Table 9. Content of C (%) in the biomass should range between 45 and 50% (on d.b.), whereas stems (43.60%–49.70%) represent a higher level than leaves (43.40%–47.43%) (Heya et al., 2019; Northup at al., 2005). Content of biomass N (%) also differs depending on what part of the plant is investigated; higher content of N (%) was observed for leaves (2.56%–4.00%) than for stems (0.15%–0.28%) or branches (0.21%–0.52%) (Heya et al., 2019; Northup at al., 2005). In consequence, data noted Table 6. Comparison of different fruit species waste biomass proportions (Brunerová et al., 2017b) Fruit species Waste mass of total fruit sample weight (%) Durian 62.57 ± 4.15 Coconut 56.83 ± 11.47 Cacao 83.83 ± 8.99 Coffee 43.44 ± 9.89 Banana 39.43 ± 8.82 Rambutan 41.16 ± 4.45 Note: ±, standard deviation. Table 7. Fuel parameters and energy potential of sugarcane bagasse samples (on average). Moisture content Ash content Gross calorific value Net calorific value (%) (%) (MJ·kg-1) (MJ·kg-1) Wet matter basis 7.02 0.90 17.06 15.69 Dry matter basis - 0.97 18.35 17.06 Dry ash free state - - 18.53 17.22 Brunerová et al. 9 in Table 9 proved to be average, but satisfactory quality levels of the discussed elements within their role in biomass and solid biofuel burning. Overall evaluation of chemical analyses proved a satisfactory level of all investigated parameters, thus, demonstrating the suitability of sugarcane bagasse for green and clean energy generation by direct combustion processes, and its high potential to become feedstock for production of bio-briquette samples. Mechanical quality indicators After positive evaluation of sugarcane bagasse suitability for processing of direct combustion feedstock, high-pressure briquetting technology has been used for bio-briquette production. The production of bio-briquette samples itself and the viability of such production are represented by the first observed positive results, which indicated feedstock's suitability for the densification process. Furthermore, produced bio-briquette samples showed a satisfactory low level of Mc (%) at high level of ρ (kg·m-3), as reported in Table 10. The observed value (ρ = 1022.44 kg·m-3) corresponds to its highest level, which indicates that sugarcane bagasse bio-briquettes represent high quality solid biofuel. The high level of this quality indicator implies longer burning time, resulting in a greater amount of released heat. ρ (kg·m-3) of sugarcane bagasse in a raw undensified form ranges around 100–120 kg·m-3 only (Teixeira et al., 2010); if compared with our observed results, the volume of initial raw feedstock material decreased approximately ten times. In practice, this implies that sugarcane bagasse is suitable and an advantageous feedstock for the densification process. Thus, high efficiency of this process and bio-briquette fuel production by high-pressure briquetting technology were proved. Within the performed experimental measurements, the unusual low mass of produced bio-briquette samples was observed; reported as m (g) in Table 3. Such results can be considered as an advantage, due to bio-briquette biofuel stor age in layers on top of each other. Combination of bio-briquettes' low mass m (g) and high ρ (kg·m-3) is quite rare and positively evaluated, which contributes to the opinion that sugarcane bagasse bio-briquettes are characterized by a high level of mechanical quality. Destruction experimental testing provided results regarding σ (N·mm-1) and DU (%) values. The state of bio-briquette samples after testing is displayed in Figure 5; in both cases external and internal damages are visible. Ruptures and cracks are observed in the case of σ (N·mm-1) testing, while DU (%) testing caused prevalently abraded edges. Determination of σ (N·mm-1) is important within the bio-briquette fuel handling, storage and transportation, while its high level is required. Obtained result values were equal to 150.82 N·mm-1 on average. Measurement and evaluation of σ (N·mm-1) is not stated or requested by any mandatory standard, thus, there are no official limits or recommendations for a required level. Therefore, evaluation of the observed result was performed solely by comparison and discussion with previously published studies using this method. Previously published researches proved σ of bio-briquette fuel from bamboo fibre and sugarcane skin to be equal to 143.3 N·mm-1 and 46.5 N·mm-1, respectively (Brunerová et al., 2018). Other studies proved the following results of σ biobriquette fuel produced from different WB: "Jatoba" (Hymenaea courbaril) tropical hardwood - 47.05 3 N·mm-1 (Chiteculo et al., 2018); empty poppy pods – 58.73 N·mm-1; wheat husk – 44.18 N·mm-1 (Brunerová et al., 2017a); plane tree chips – 176.1 N·mm-1 (Brožek, 2016); waste paper – 32 N·mm-1; and waste cardboard Table 8. Comparison of fuel parameters of various bio-briquette samples. Feedstock Ash content Gross calorific value Reference (%) (MJ·kg-1) Sugarcane leaves 7.84 17.83 Jittabut (2015)

Bamboo fiber 1.16 18.15 Brunerová et al. (2018) Rice straw 29.51 15.07 Phichai et al. (2013) Pine sawdust 0.40 18.14 Stolarski et al. (2013) Oil palm empty fruit bunch 6.43 17.66 Nasrin et al. (2011) Corncob 1.36 18.77 Guar and Reed (1998) Coconut shell 0.90 19.42 Srihirun and Chayasakulviwat (2010) Table 9. Elemental compositions of investigated sugarcane bagasse (in average). Carbon Hydrogen Nitrogen Oxygen (%) (%) (%) (%) Wet matter basis 44.35 5.52 0.35 41.87 Dry matter basis 47.70 5.93 0.38 45.02 Dry ash free state 48.16 5.99 0.38 45.46 Table 10. Mechanical quality indicators 4of sugarcane bagasse bio-briquette samples. Moisture content Bulk density Compressive strength Mechanical durability (%) (kg·m-3) (N·mm-1) (%) 7.54 ± 0.51 1022.44 ± 15.59 150.82 ± 15.86 99.29 ± 0.59 Note: ±, standard deviation. 10 Waste Management & Research 00(0) – 153 N·mm-1 (Brožek, 2015). It is notable, that the observed level of σ (150.82 N·mm-1 for bagasse bio-briquettes) occurs 4at a high level, thus, it can be positively evaluated as a successful result which proves the high mechanical quality of sugarcane bagasse bio-briquette fuel. Experimental testing of DU (%) of sugarcane bagasse bio-briquette samples proved its extremely high-quality level, namely DU = 99.29%, thus, providing favourable conditions for high quality production. Such obtained results correspond to the highest level of mechanical quality indicators (DU > 95%) and prove 9the suitability of sugarcane bagasse bio-briquettes for commercial sale. Comparison of our obtained data with other studies (noted 6in Table 11), shows that sugarcane bagasse belongs to the highly advantageous group of feedstock materials suitable for bio-briquette fuel production. The selected reference literature, as noted in Table 11 was chosen, because of the similarity of tested bio-briquette samples within their dimensions, mainly the similar diameter of 50 mm plays a critical role in the relevance of the results comparison. Conclusion This study aimed to evaluate the suitability 5of sugarcane bagasse for bio-briquette fuel production by using high-pressure briquetting technology. All obtained observations, values and related data showed positive results for the reported investigations of fuel parameters. At first, a high mass ratio of about 36% of generated sugarcane bagasse during juice pressing from total mass of sugarcane stem was proved. Such an outcome confirms 2the necessity for proper waste management of sugarcane bagasse by its utilization as solid biofuel. High calorific values (NCV = 15.69 MJ·kg-1) as well as low moisture (7.02%) and ash (0.90%) contents were positively evaluated within the investigation of sugarcane bagasse suitability for energy generation by the process of direct combustion. Thus, the investigated material proved its suitability to be a favourable feedstock for solid biofuel production. Equally, the physical and mechanical properties of the investigated bagasse material corresponded to the needs of bio-briquette fuel production by using a high-pressure briquetting press. This was demonstrated by production of high-quality bio-briquette samples, which fulfilled mandatory requirements for commercial sale. In conclusion, all investigated aspects proved the significance of worldwide sugar cane bagasse generation, and the necessity for its proper waste management to ensure environmentally friendly treatment and utilization of such significant amounts of WB. Additionally, the combination of sugarcane bagasse with high-pressure briquetting technology proved its advantage and efficiency within the green and clean energy generation by bio-briquette fuel. Declaration of conflicting interests The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. Funding The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The performed research work was primarily funded by the European Union Figure 5. Produced bio-briquette samples after experimental tests of: (a) mechanical durability (DU); and (b) compressive strength (σ). Table 11. Comparison of various bio-briquette fuel mechanical quality indicators (on average). Feedstock Bulk density Mechanical durability Reference (kg·m-3) (%) Bamboo fibre 986.37 97.80 Brunerová et al. (2018) Rice husk 1061.00 77.90 Singh and Kashyap (1985) Coconut husk 605.00 91.70 Dziedzic et al. (2018) Cup plant 913.20 87.62 Wrobel et al. (2013) Tropical hard wood 896.34 77.60 Chiteculo et al. (2018) Waste paper 837.80 98.20 Brožek (2015) Brunerová et al. 11 (EU), managing authority of the Czech Operational Programme Research, Development and Education within the project “Supporting the development of international mobility of research staff at CULS Prague”, reg. no. CZ.02.2.69/0.0/0.0/16_027/0008366. Further, research was

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