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Solid biomass fuels for cooking

– beyond firewood and charcoal

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– beyond firewood and charcoal

Spotlight on energy products, cook stove technologies and projects of solid biomass fuels beyond firewood or charcoal

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Acknowledgements

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This work sheds light on the many opportunities and challenges associated with the use of solid biomass fuels, beyond firewood and charcoal, for daily cooking. Christa Roth was integral to gathering illustrative data and information on current initiatives that further the discussion. She also provided substantial support for this publication, which complements the GIZ-HERA booklet *"Micro-gasification: Cooking with Gas from Dry Biomass."*

A special thanks to those who provided reports on activities from the field, including Stefano Bechis, Asellah David, Frank Gschwender, Suzanna Huber, Per Loefberg, Chistian Goenner, Eric Reynolds and all the other project managers and executives who contributed data and information. It has been a joy to collaborate and reflect on your experiences and lessons learned during implementation of fuel processing and clean cooking initiatives.

I hope you find this brochure enjoyable and worthwhile. Please feel free to share your opinions, feedback, and findings with me at mail@frankhelbig.com.

Frank Helbig,
Berlin on May 5th, 2017

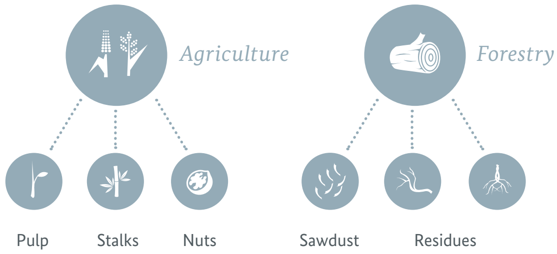
Please note:

This brochure does not intend to favor any company or specific product. The provided examples highlight the existence and the source of a particular technology for reference. Any links to commercial websites are not-for-profit to the authors and references are by no means exhaustive.

* end of sector programme Basic Energy Services – HERA (February 2017)

Chapter 1

Origins of solid biomass fuels



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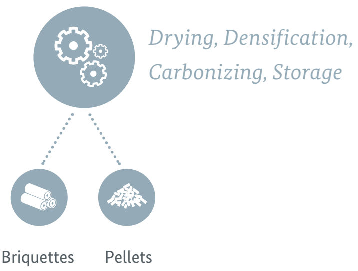

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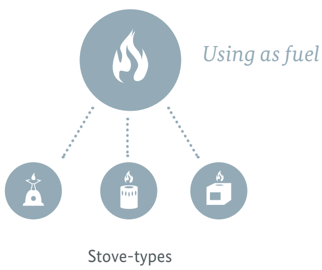

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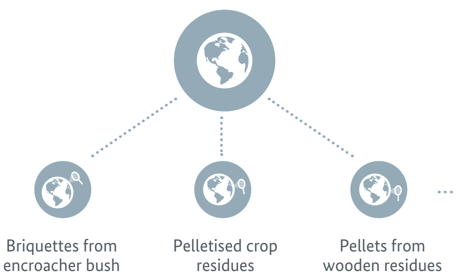

Amazing! Show me some examples!

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References

Introduction: Solid Biomass Fuels for Cooking

Approximately 2.9 billion people worldwide rely on solid biomass for daily cooking. Solid biomass is utilized for cooking in North America and in Europe, especially in rural eastern and southeastern regions. The practice is far more common in Africa, particularly in the sub-Saharan region, as well as in South America and Asia. In some countries, woody biomass and agricultural residues account for more than 90% of total household energy consumption[1].

Most solid biomass comes in the form of woody biomass derived directly from forests, of which some is converted into charcoal to serve as a cooking fuel. However, there is a much larger variety of solid biomass suitable for cooking. Solid biomass fuels beyond firewood and charcoal can be derived from by-products of agricultural production and forest residues, and are becoming increasingly important. For instance, an estimated 140 billion tons of residual biomass is generated every year from agriculture, representing an enormous amount of renewable energy — equivalent to 50 billion tons of oil[2]. To use these forms of biomass that go beyond firewood and charcoal is to make use of organic residues, establish value chains, contribute to climate protection, and thus to contribute to a circular economy[3].

In order to strive towards the internationally set goals resulting from the Paris Agreement and the UN's Sustainable Development agenda, a healthier and more resource-efficient way of generating cooking energy is urgently needed. For the most part, the current combustion of solid biomass fuels beyond firewood and charcoal happens inefficiently and with polluting effects, constituting a major source of air pollution and threats to human health. Despite improved energy accessibility and economic development, the annual death toll from indoor air pollution is estimated at over 4.3 million people — a higher rate than that from both malaria and tuberculosis[4].

The diversity of solid biomass fuels beyond firewood and charcoal is far reaching. This publication highlights the most common forms of these solid biomass compounds, the options regarding their production, and how they can be used for daily cooking. It also presents cook stove technologies that efficiently transfer the energy contained in solid biomass fuels to pots and pans. A selection of projects from international colleagues illustrate marketing approaches and the practical implications of utilizing solid biomass beyond firewood and charcoal for cooking.

1 International Energy Agency (IEA) and the World Bank. 2015. "Sustainable Energy for All 2015—Progress Toward Sustainable Energy" (June), World Bank, Washington, DC.

2 United Nations Environmental Programme, 2009: Converting Waste Agricultural Biomass into a Resource – Compendium of Technologies, Oct 2009.

3 Ellen Mac Arthur Foundation, retrieved at *https://www.ellenmacarthurfoundation.org/circular-economy* in August 2016.

4 World Health Organization 2016: Factsheet N°292, retrieved at *http://www.who.int/mediacentre/factsheets/fs292/en/* in August 2016.

The goal of this publication is to provide an overview of solid biomass fuels suitable for cooking other than firewood or charcoal. Which solid biomass is suitable for cooking; what forms of solid biomass exist; and how can they be processed? Furthermore, we will offer guidance on the vast opportunities related to cooking with solid biomass fuels. A sample of initiatives and projects that have made use of solid biomass that would have otherwise been discarded as waste are highlighted, and project staff share valuable lessons learned during project implementation.

Above all, this publication is addressed to policymakers, project developers and other interested individuals who seek to address one of the major challenges of this century with actionable solutions — by finding healthy and resource-efficient ways to use solid biomass fuels for the preparation of cooked food all around the world.

1.0

Origins of solid biomass fuels

1.0 Origins of solid biomass fuels

Solid biomass fuels are commonly derived from two sources – forests and agricultural land. Forest based biomass is nearly always woody biomass derived either directly from forest ecosystems and forest management activities. This may happen by thinning or logging in forests, or indirectly by making use of the residues of the wood processing industry. End-use materials, such as wood recycled from previous uses constitute a third category of forest based biomass. This can be poles from scaffolding or electricity lines, or even recycled carpentry wood such as old furniture and palettes *(see Table 1.1)*.

Table 1.1 **Bioenergy Terminology**

		Forest based solid biomass	Agriculture based solid biomass	
		Woody biomass	Herbaceous biomass	Biomass from fruits, seeds, stalks etc.
Energy crop	direct	Trees	Energy grass Energy whole Cereal crops	Energy grains Nuts and seeds
Byproducts	direct	Byproducts from thinning or logging	Straw Bamboo	Husks, hulls, nut shells, stones, fruit pits/stones, woody stalks
Byproducts	indirect	Wood processing	Fibre crop processing byproducts	Food processing industry byproducts
End use materials	recovered	Used wood	Used fibre products	Used products of fruits and seeds (e.g. bagasse, press cake)

Adapted from FAO 2004: Unified Bioenergy Terminology.

Solid biomass from the agricultural sector comprises herbaceous or 'grassy' biomass, and biomass from fruits and seeds, including roots, stems and stalks of agricultural production. Herbaceous biomass comprises straw, grass, cereal and fiber crops. Biomass from fruits, seeds etc. covers grains grown for energy, woody stalks (e.g. of cotton), residues from nut production, and more importantly, by-products from animal husbandry, landscape management and waste of the food industry.

Woody biomass is the most common form of solid biomass used for cooking. However, given the global challenges related to forest degradation, deforestation and climate change, the processing of agricultural residues to solid biomass fuels is becoming an increasingly important path for moving towards circular economies and cascading use of biomass. The main difference between biomass from the two origins lies in the supply chain and processing of the biomass.

There is a need to differentiate between 'substance' (referring to the chemical composition and ash content of the original biomass) and the 'shape' (which determines the physical characteristics such as density and surface-to-mass ratio) of the processed solid biomass fuel. Both substance and shape impact the efficiency of the thermochemical conversion during combustion to generate thermal energy for cooking (or heating) purposes.

Figure 1.1 Examples of solid biomass fuels: beech wood residues, cotton stalk trimmings, saw dust and stems from maize cultivation.

Forest and forest industry residues for cooking

Figure 1.2 illustrates the diversity of forest based residues and an approach to categorising the woody biomass that could potentially be used for cooking. Those that are derived directly from the forest can be grouped into thinning material, logging material and collected firewood (collected firewood is not addressed in this publication but listed for reasons of completeness).

Those that are derived from the forest industry are saw dust and cutting residues. Wooden residues of all kinds, such as old poles from telecommunication infrastructure, old furniture or scaffolding belong to the group of recovered wood. Wood of this group is used for cooking across the globe, albeit its potentially harmful emissions resulting of chemical treatment. Recovered wood cannot be recommended for use without special precautions, e.g. on good ventilation of the cooking space. Chemically untreated woody biomass is to be given preference – for wood from the forest industry and recovered wood (see *figure 1.3* for examples of woody biomass).

Figure 1.2 Categorisation of woody biomass for cooking.

Figure 1.3 Solid biomass fuels from the forest and forest industry. From top to bottom: seeds and cones, palettes, encroacher bush residues and wooden residues from firewood harvest in Georgia.

Agricultural residues for cooking

Agricultural residues are generated in large volumes every season, often being discarded as waste. Solid crop residues are the largest source of agriculture based solid biomass, comprising organic residues of straw, stems, stalks, leaves, husks, shells, peels, pits or seeds, pulp and the like from all sorts of crops. The greatest proportion is attributed to stalks of cereals (rice, wheat, maize, sorghum), cotton, and legumes (pigeon pea, bean, soya, groundnut), complemented with woody prunings from perennial plantations like coffee, tea, cacao and fruits or nuts (mango, banana, cocoa, cashew). Agriculture based biomass is particularly relevant for communities that live close to where the biomass is produced, or for enterprises that seek to increase the performance of their business by creating a value chain based on their agricultural residues.

Figure 1.4 Agricultural residues as cooking fuel: Pigeon pea in Malawi (left) and millet stalks in Ghana (right).

Box 1.1 Calorific values of agricultural residues.

Remark on the calorific value of agricultural residues

The section below highlights some of the most common agricultural residues that can be used as cooking fuel. Most of the biomass derived from agricultural residues has similar calorific values[5], ranging from 8-15 MJ per kg - this value being strongly dependent on the water content of the organic material at the time of combustion, bulk density and composition of the material. The more stability the plant material has to offer, the higher the silica content; as silica is not combustible, the calorific value decreases accordingly. Thus functional parts of a plant have a higher content of silica than the rest of the plant, e.g. stems that provide physcical strength to a plant or husks that are protecting a grain.

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5 The amount of energy produced by the complete combustion of a material or fuel. Measured in units of energy per amount of material, e.g. kJ/kg

Figure 1.5 shows a rough classification of selected bioenergy carriers that are relevant when considering energy for cooking. Four main groups comprise the diversity of agricultural residues:

- Nutshells, which can be used in their natural state or processed,
- husks and hulls, which can either be gasified directly in micro gasifiers or used for combustion after they have been pressed into a new shape like briquettes or pellets,
- raw material, which can be burned with or without further processing like plan stems, stalks or stovers etc, but also animal dung, and
- residues from agricultural industrial processes, such as the bagasse from sugar cane processing.

Most of these energy carriers have to be pressed into a shape that is applicable for the use as cooking fuel in household-size stoves.

Box 1.2 **Awareness for competing use of solid biomass from agricultural residues.**

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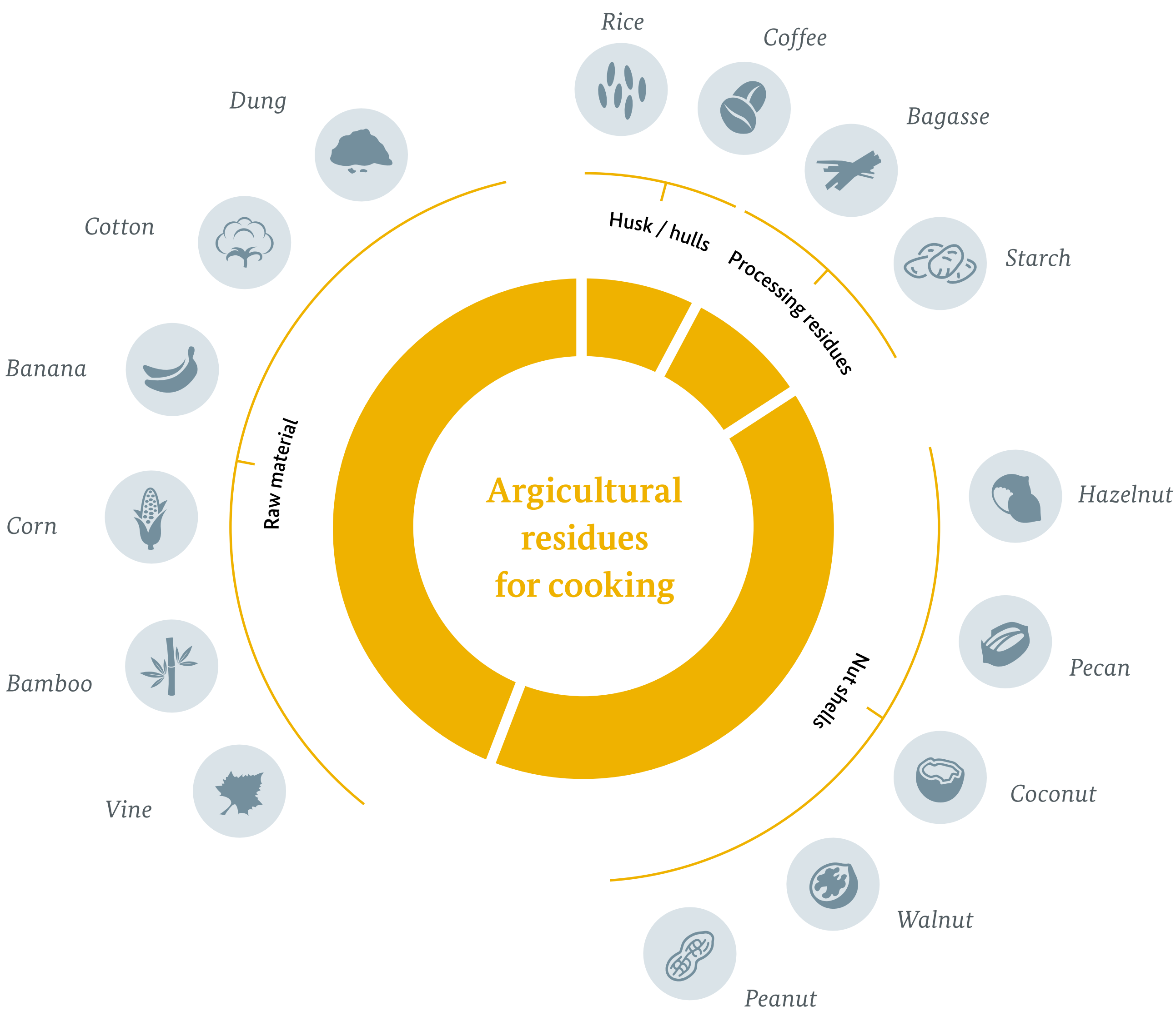
Attention for competing use of residues!

When making use of agriculture based solid biomass for cooking, it is important to be aware of the prevailing ecological effects and competing uses. Some energy carriers, such as corn cobs, accumulate after the corn is removed from the cobs, leading to no competing use. Whereas the cobs of the maize crops are usually left on the fields in order to reintroduce nutrients to the soil. Utilization of the cobs for cooking energy constitutes a competing use of the residue. This may be mitigated by taking the ashes with the minerals of the cooking fire back on the fields in order to close the nutrient cycle.

Box 1.2: adapted from Messinger (2011)

Figure 1.5 Categorisation of agricultural residues that comprise solid biomass fuels for cooking beyond firewood and charcoal.



Selected carriers of bioenergy from agricultural production

The following sections highlight some of the features of selected bioenergy carriers that could supply solid biomass fuels suitable for cooking and heating.

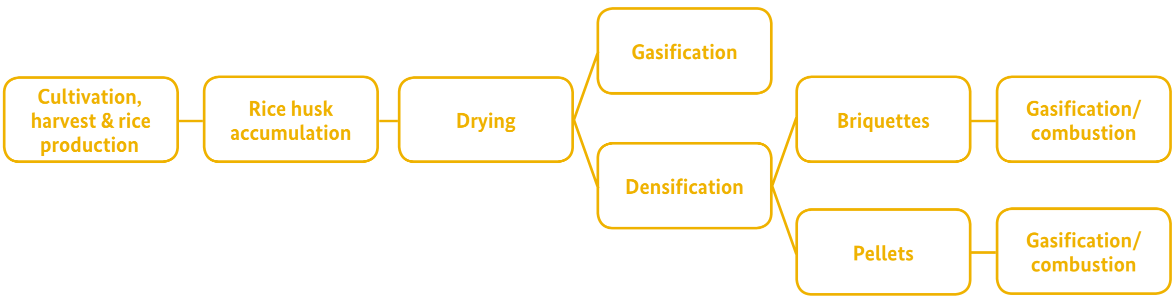
Rice husk

Rice forms a large part of the traditional diet for much of the world's population. 90% of the estimated 600 million tons of rice is produced in Asia, making it the single most important cereal grain with the largest potential as source of alternative fuels[6]. Rice husk is the hard protective cover of grains of rice. It is the major by-product from the rice-milling process, constituting about 20% of the grain yield weight e.g. 0.8 to 1.6 tons of rice per ha leaves 170-350 kg rice husk per ha. Consisting mainly of ligno-cellulose and silica, it can be used as energy carrier in cook stoves. However, rice husks are very bulky (<90 g/litre) with a high silica content reducing their energy content per weight.It is not efficient to transport rice husks. They are best utilised close to the source, normally the mill where the dehusking takes place.

The direct combustion of rice husks is challenging and tends to produce a lot of smoke. Batch-fed forced-draft micro-gasifiers can achieve a very clean combustion of dried rice husk. When in abundance, rice husks are often given away for free and can reduce expenditure on conventional fuel sources[7].

To press rice husk into pellets or briquettes, very high pressure is needed. With low pressure the elastic raw rice husk springs back into its original shape and the briquette crumbles, unless a binder is used or the rice husk is carbonised prior to being pressed into a new shape.

Figure 1.6 **Common value chain for cooking with rice husks.**



6 Abbas, A. & Ansumali, S.; 2010: Global Potential of Rice Husk as a Renewable Feedstock for Ethanol Biofuel Production.

7 Zafar S., 2015: Biomass Resources from Rice Industry. Retrieved from http://www.bioenergyconsult.com/tag/energy-potential-of-rice-husk in August 2016.

Figure 1.7 Rice husks being collected in Malawi.

Nutshells

Most nutshells are inedible and removed before the inner nut kernel can be eaten. Global production of tree nuts totalled 3.7 million tons in 2015, continuing the rising trend throughout the last decade. The USA is the world's largest producer, followed by Turkey, Iran and China.

On average, about 30% of the nut harvest by mass consists of shells, reaching up to 70% in the case of the pecan nut. Nutshells can be used in their natural state, or be ground and pressed into briquettes or pellets. Nutshells are a suitable firewood substitute across the globe, with a similar or even superior energy content, if the nutshells contain some oily residues[8].

Figure 1.8 Common value chain for cooking with biomass from nut shells.

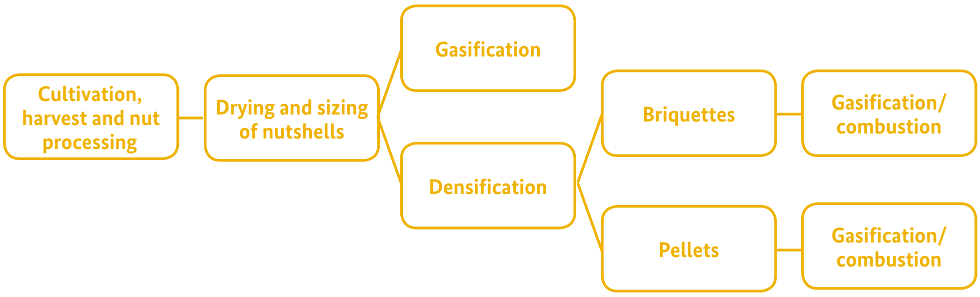


Figure 1.9
Macadamia nut shells.

8 Food and Agricultural Organization Statistics Division. Retrieved from http://faostat3.fao.org/home/E in August 2016

Corn cobs

Global maize production in 2015 was nearly 700 million tons, making it one of the largest agricultural products worldwide[9]. An estimated 2 tons of corn cobs can be extracted per season from one hectare of a maize field in developed countries. In developing countries, this can drop to well below 600 kg per ha. The biomass generally accumulates close to where the maize cobs are processed, commonly not on the field but close to the agricultural production premises.

A corn cob is the central core of a cob of maize after the grain has been removed. Compared to other bioenergy carriers, they have a relatively high calorific value of 18.9 MJ/kg, with low nitrate and sulphur contents. Yet they are light-weight but bulky and only availalbe after the maize harvest. Harvesting cobs has a low impact on soil residue, soil carbon, and the nutrients provided to subsequent crops.

Figure 1.10 Common value chain for cooking with corn cobs.

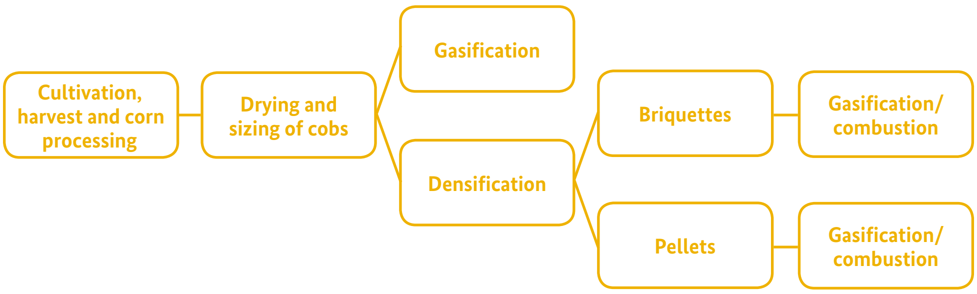


Figure 1.11 Corn cobs in a gasifier in Malawi.

[9] Brunner, T. et al., 2011: Combustion properties of maize cobs – results from lab and pilot scale tests. Retrieved from http://bios-bioenergy.at/uploads/media/Paper-Brunner-Combustion-properties-of-maize-cobs-2011-06.pdf on August 2016.

Banana skins & stems

The by-products of banana cultivation are leaves, stems and banana skins. Banana requires about one year from planting to harvest but bears fruit only once in a lifetime. As the fruit is harvested, the banana tree is cut, leaving the bottom part of the stem and rhizome untouched. For every ton of bananas, about 4 tons of fresh waste is generated. On plantations the fresh waste may reach up to 40 tons per hectare. In 2012, the volume of global gross banana exports reached a record high of 16.5 million tons.

Banana waste includes rotten fruit, peel, fruit-bunch-stem, leaves, pseudo-stem, and rhizome. The waste has a high moisture content and relatively low ash content when compared to other solid agriculture based biomass[10]. Most of this solid biomass can be used for the production of biomass fuels. The biggest challenge is a thorough drying of the fresh waste. Once the organic residues are dried, they can be ground and densified into briquettes or pellets. Their thermal combustion charactersitics are similar to other types of lignocellulosic biomass.

Figure 1.12 Common value chain for cooking with biomass from banana cultivation.

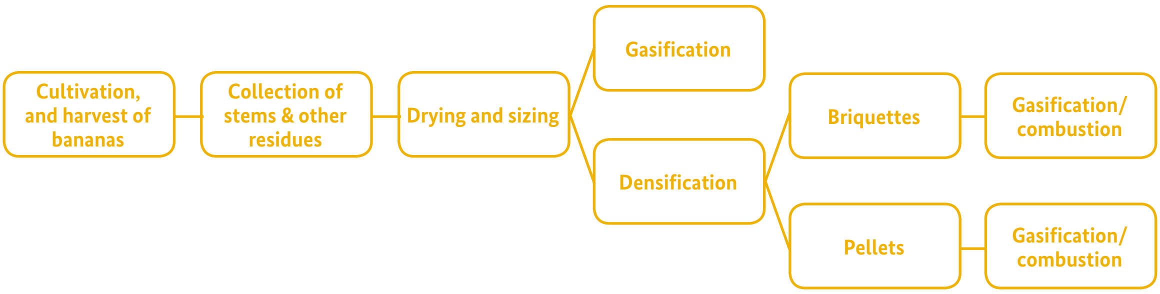


Figure 1.13
Green banana bunch on the plant.

10 Nurhayati, A. et al, 2014: Characterization of Banana (Musa spp.) Pseudo-Stem and Fruit-Bunch-Stem as a Potential Renewable Energy Resource in International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering Vol:8, No:8, 2014

Cotton waste

Most of the energy from the cotton plant is contained in the stalk. It has similar calorific values as other lignocellulosic feedstocks. Stalks are commonly removed from the fields after harvest. In Usbekistan, for example, about 10 tons of stalks were available per hectare of irrigated cotton. Cotton stalks are bulky and not easy to transport. They have limited alternative uses, apart from being used by farmers as cooking fuels directly e.g. to fire the tanoor ovens for bread baking (see *Figure 1.15*).

Briquette production from cotton stalks is a challenge as the quality largely varies across stalks. They are partially woody with hard root knobs (too hard for hammer mills and blades) but have spongy cores (too elastic to cut with rotating blades). They can be sized with grinders and subsequently pressed into pellets or briquettes.

Figure 1.14 Common value chain for cooking with biomass with biomass from cotton stalks.

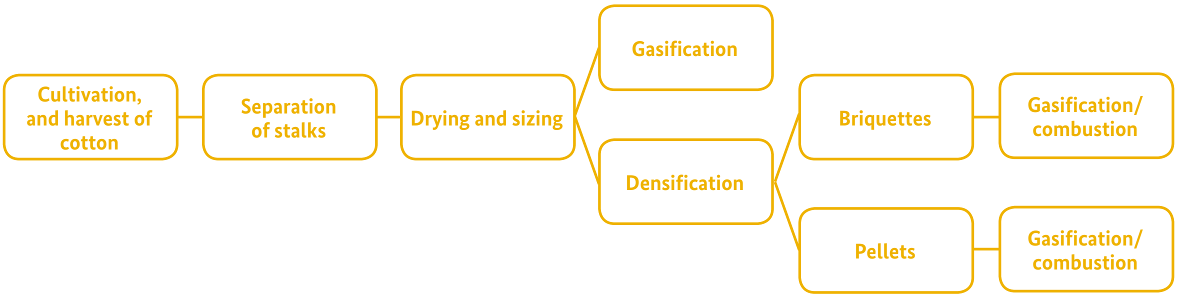


Figure 1.15
A farmer holding a bundle of cotton stalks.

Coffee husk

The husk and pulp of the coffee bean are common residues from the coffee-processing industry, representing 15% of the cherry weight when dried. In 2015, global coffee production consisted of roughly 144 million 60 Kg bags (almost 9 million tons); with Brazil, Vietnam and Colombia being the largest producers.

About 250-300 kg of residues can be extracted from the cultivation of one hectare of coffee. The husks accumulate near to the production facility for coffee and thus competing use is largely excluded.

Figure 1.16 Common value chain for cooking with solid biomass from coffee cultivation.

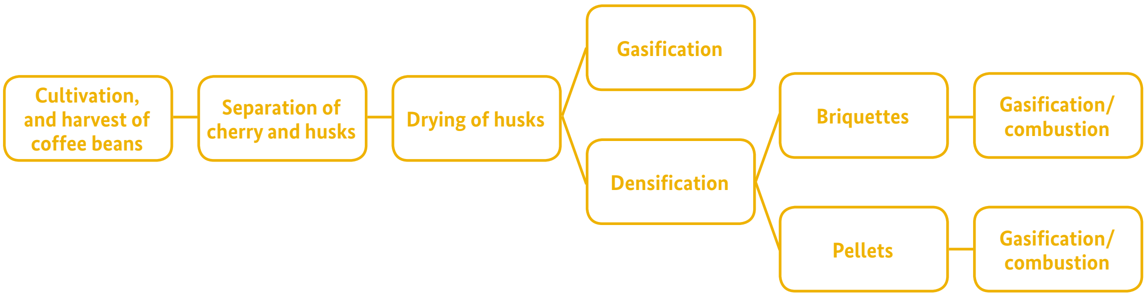


Figure 1.17
Coffee husks.

Bagasse and sugar cane

In 2015, the world sugar production amounted to approximately 175 million tons. During this period, Asia was the largest sugar-producing region in the world, yielding approximately 66 million tons of sugar. India, China and Thailand were the region's top sugar producers[11].

When sugarcane is squeezed to extract its juice, a fibrous pulp material is left over. This material is called bagasse. Approximately 300 kg of wet bagasse is extracted from one ton of sugar cane. The bagasse is usually accumulated near the sugar mills and is typically used to generate heat and electricity in sugar mills, but can also be used for the production of cooking fuels in the form of carbonised or uncarbonised briquettes. It can also be used in undensified form in gasifier stoves. Bagasse can be carbonised and crushed to a powder that is mixed with a binder (such as starch, clay, molasse, e.g.) to produce charcoal briquettes[12].

Figure 1.18 Common value chain for cooking with solid biomass from sugar cane cultivation.

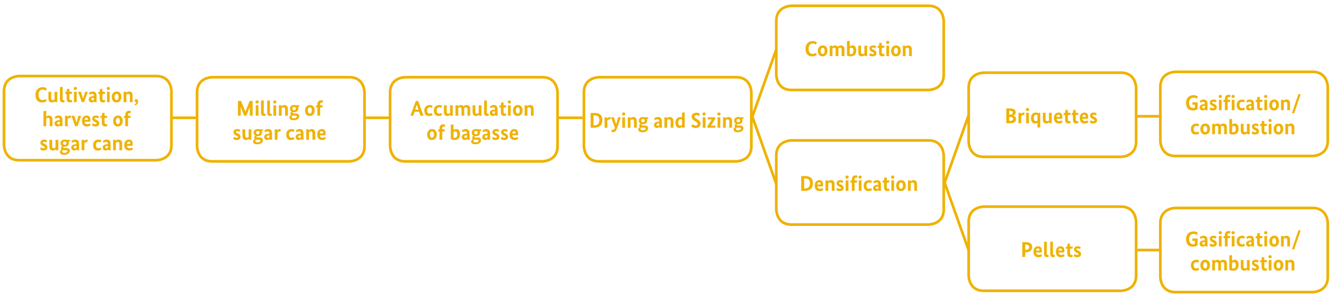


Figure 1.19 Freshly harvested sugar cane ready for transport

[11] Statista- The Statistics Portal, retrieved from http://www.statista.com/statistics/249679/total-production-of-sugar-worldwide/ in July 2016

[12] TED Talks: Amy Smith discusses charcoal from bagasse in Haiti and corncobs in Ghana. Retrieved from http://stoves.bioenergylists.org/taxonomy/term/706 in August 2016

Biomass from animal husbandry

More than 2 billion people across the planet burn dry animal dung for cooking meals[13]. Dung is a commonly used source of fuel where fuelwood is scarce, particularly in dry or cold areas like Tibet, Mongolia and high-altitude regions in the Andes above the treeline. Fresh dung needs to be dried before it can be used as an energy source. It is either left in in its natural shape or it is formed into round dung balls, flat dung cakes, or molded around a stick. In some regions, dung is mixed with other kinds of fuel, such as coal dust or agricultural residues, in order to increase the energy density and enhance burning performance. Combustion of dung is cumbersome and produces high emissions of carbon monoxide, hydrocarbons and particulate matter[14].

Figure 1.20 Common value chain for biomass from animal husbandry.

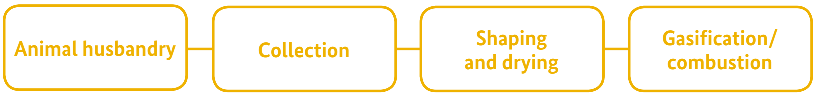
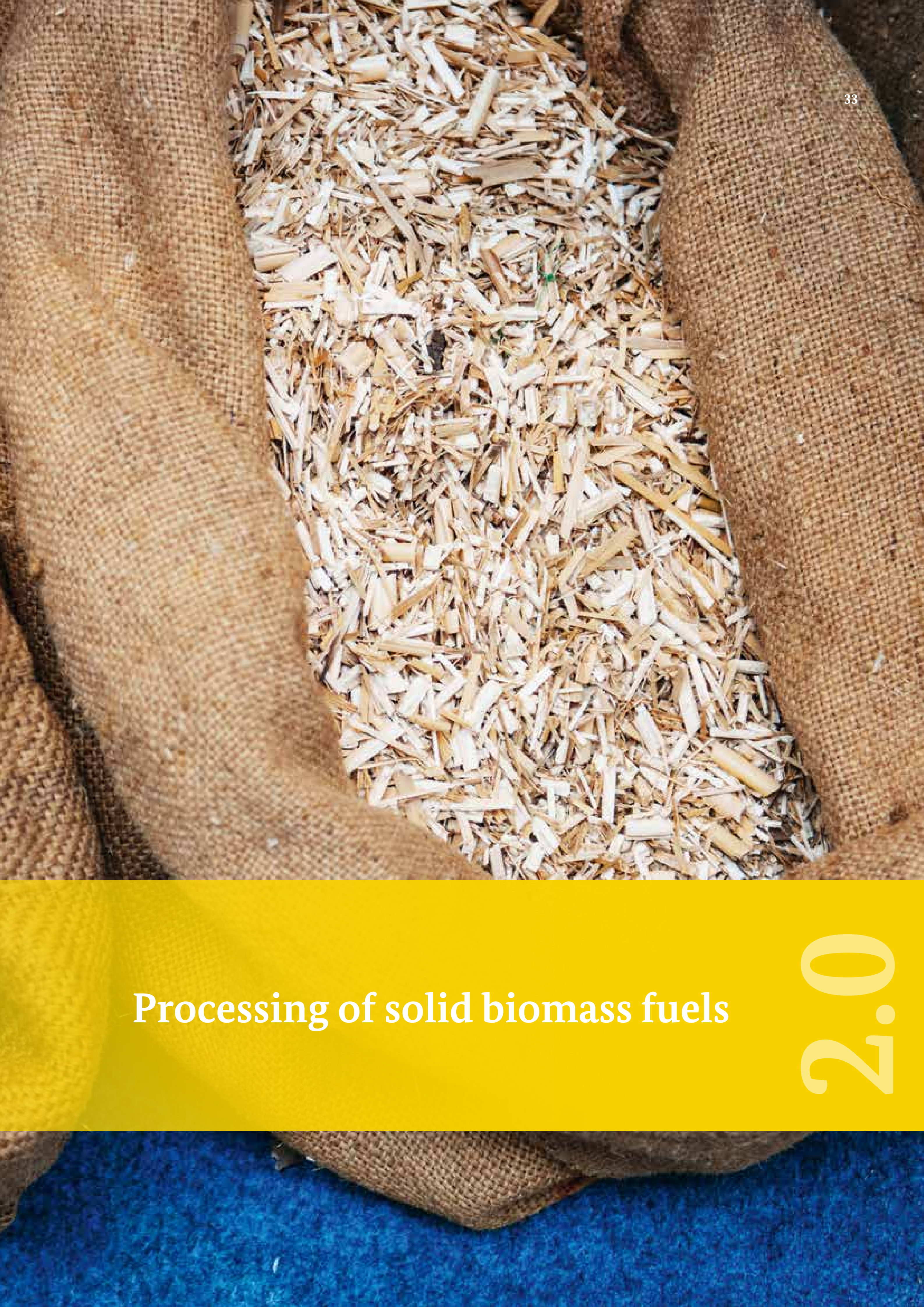


Figure 1.21 Left to right: Dung mixed with straw for sale in Nepal, cow dung cakes in Bangladesh (Tim Raabe) and storage of cow dung cakes in Tajikistan.

13 “Cooking with dung“ retrieved from www.energypedia.info in August 2016

14 Witt,M.; Weyer, K.,Manning, D., 2006: Designing a Clean-Burning, High-Efficiency, Dung-Burning Stove: Lessons in cooking with cow patties. Retrieved from https://www.iea.org/publications/freepublications/publication/cooking.pdf in August 2016



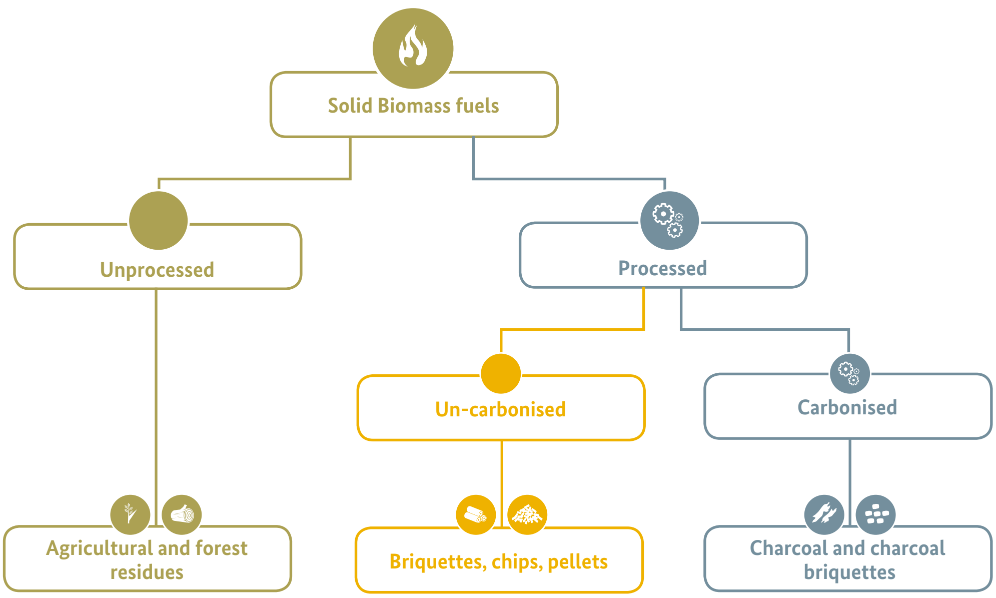
2.0 Processing of solid biomass fuels

2.0 Processing of solid biomass

Solid biomass fuels beyond firewood and charcoal can also be processed in various ways. *Figure 2.1* below illustrates the different categories of processes for solid biomass suitable for cooking.

Solid biomass fuels that are processed can either be carbonised or remain uncarbonised. If the effort of processing solid biomass fuels is made, one or more of the following processing steps are undergone. Size reduction, densification of smaller woody compounds (e.g. saw dust or wood chips) carbonised and, finally, storage. Briquettes, chips or pellets are the final products. Compared to unprocessed solid biomass fuels, densified solid biomass has a higher energy density and more homogenous physical properties, representing the main goals of its processing. The products of carbonised solid biomass fuels are charcoal and charcoal (or carbonized) briquettes, chips or pellets are the final products. Compared to unprocessed solid biomass fuels, densified solid biomass has a higher energy density and more homogenous physical properties, representing the main goals of its processing. The products of carbonized solid biomass fuels are charcoal and charcoal (or carbonised) briquettes.

Figure 2.1 **Categorisation of solid biomass fuels by different ways of processing.**



Processing needs for solid biomass fuels

Table 2.1 illustrates some of the processing needs for solid biomass when considering the use of solid biomass fuels for cooking with micro-gasifiers. For instance, if the particle size is too small the steady flow of wood gas through the gasifier is not guaranteed. If the solid biomass is produced in larger chunks or pieces, by means of densifying the fine particles, the gasification process can be improved. Again, densification can contribute to producing a solid biomass fuel that is suitable to supply a clean and constant gas for cooking. The table highlights how the processing needs align to the requirements of the cooking technology as well as the needs of the cook stove's user.

Table 2.1 **Processing needs for solid biomass fuels for use in micro gasifiers.**

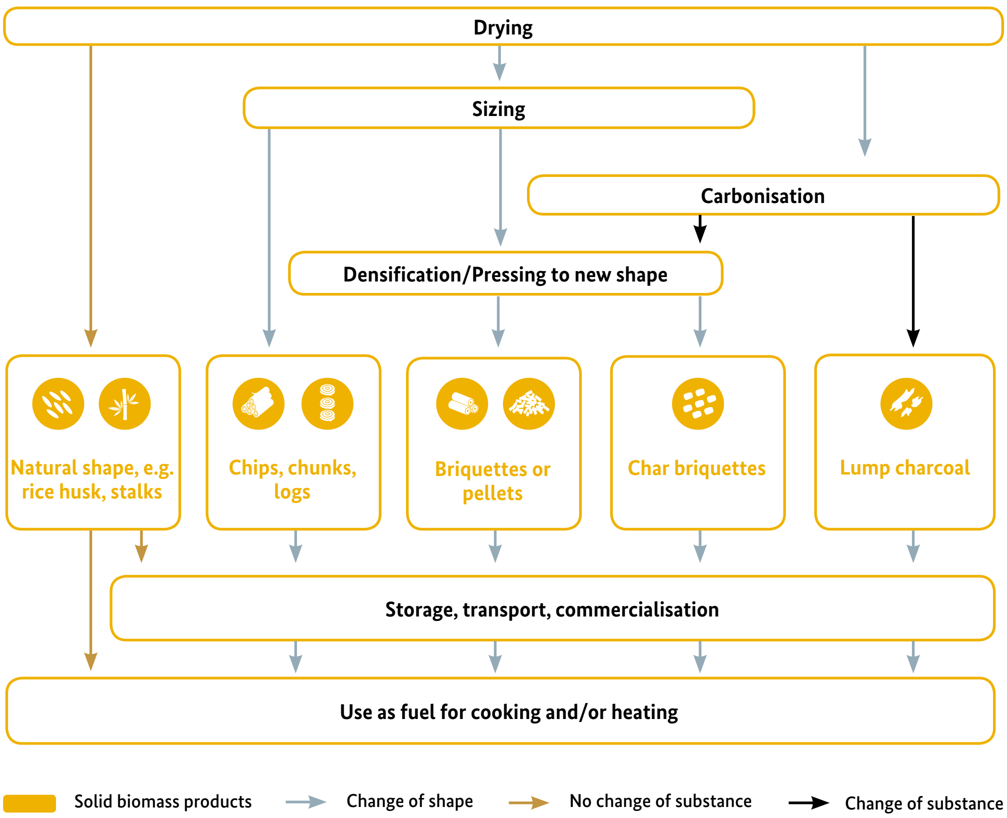
Size	Examples	Problem	Solution	Processing needs
Particles too small	Sawdust, rice husk	Small particles block gas flow	Produce larger chunks	Densification
Non-homogeneous particle size distribution	Wood shavings mixed with sawdust	Small particles block gas flow	Produce chunks with homogeneous sizes	Densification
Too bulky (high volume, low value)	Groundnut shells, straw, hay	Large combustion chamber needed, transport costs	Needs to be made more compact	Densification
Correctly sized	Anything that can be used directly in the fire chamber: wood shavings, twigs, nut shells, sheep dung, rabbit droppings, corn stoves			(drying)
Particles too large	Wood chunks, bamboo, coconut shells	Cannot fit into combustion chamber	Produce smaller chunks	Sizing: cutting, chopping, shredding, etc.

Common steps of processing solid biomass fuels

Figure 2.2 provides an overview to basic steps of processing. For efficient and clean use of solid biomass fuels the first step is drying. The moisture content of biomass has the most significant impact on the quality of a solid biomass fuel. Dried biomass has a lower weight than wet biomass, contains a higher calorific value and burns with less emissions. The production of pellets and briquettes works best, if the biomass has water contents of 8–12%[15].

Solid biomass fuels can then be left in their natural shape, be stored, commercialized and transported to the user to be used directly. Further processing after drying generally is sizing, whereas sizing may happen before drying as well. Sizing leads to chunks, wood chips or logs, if the biomass is carbonised the product can be carbonised to get lump charcoal. The next applicable process is densification of the dried and sized solid biomass to pellets or briquettes. These are the last possible steps of processing before all the likely solid biomass fuels are packed, stored or distributed to the users. Storage of solid biomass is not necessarily a step of processing but due to its strong impact on the quality of solid biomass it is listed as a step in the supply chain of the fuels. The efforts and costs for appropriate storage of processed solid biofuels should not be underestimated during project planning (see *figure 2.2*).

Figure 2.2 Scheme of possible processing steps in their likely sequence.



15 Kaltschmitt, M.; Hartmann,H.; Hofbauer, H., 2009: Energie aus Biomasse – Grundlagen, Techniken und Verfahren. Springer Science & Business Media.

Box 2.1 Aligning the three crucial factors for sustainable cooking energy.

Sustainable development of cooking energy on domestic level depends on aligning three factors:

1. Form and processing of the energy carrier must meet the requirements of the cook stove

2. Cooking technology must be adjusted to the energy carrier and needs of user

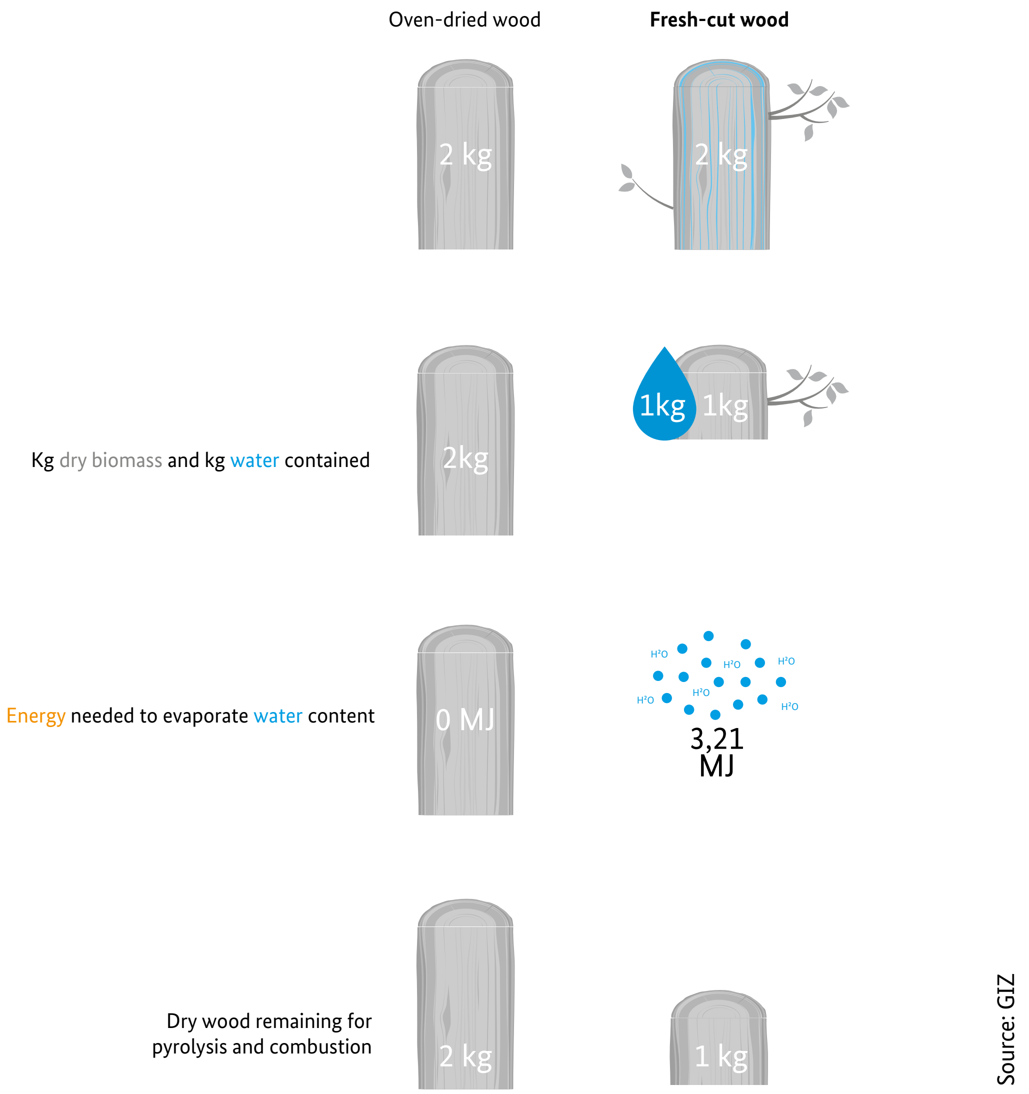
3. User awareness is essential for aligning the efforts of step one and step two

The following section describes the more steps of processing solid biomass fuels before making use of them in a cook stove.

Drying of solid biomass fuels

Optimal thermo-chemical conversion of the inherent energy of solid biomass is achieved at water contents of 10-15%. In fact, the available energy per kilogram of dry biomass is up to three times higher than that of fresh biomass[16]. The reason for this is illustrated in *figure 2.3*. In a dried piece of biomass, less heat, i.e. energy, is necessary to evaporate the containing water.

Figure 2.3 **Influence of water content on calorific value.**



16 Roth, C.; et al. 2014: Micro-gasification: Cooking with gas from dry biomass, GIZ, Eschborn, Germany.

Hence, solid biomass fuels must be dry before sizing and densifying. Industrial production of briquettes from woody biomass is achieved by the use of drying chambers that ventilate hot air.

Storage in a dry place exposed to sunlight and ventilation can lead to the required maximum moisture contents but takes more time. A fuel's interior moisture and surface moisture differ greatly in their required drying times: while surface moisture evaporates in a couple of hours, core moisture requires much longer – sometimes even months.

Box 2.2 **Drying of biomass in a household.**

A simple way of pre-heating biomass fuel to reduce its moisture is to keep the fuel close to the stove prior to use. Some stoves have special features, such as a warming drawer for fuel underneath the stove for this purpose.

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Sizing of solid biomass fuels

Sizing of biomass is necessary in most cases. Woody biomass, for instance, must be cut or chopped before it can be used in cook stoves. When briquetting or pelletizing, the optimal cohesion of the fibers is achieved at a low water content and maximal surface area amongst the particles of the compressed biomass. Hence, the finer the material, the better it will stick together after compression. For this purpose, woody biomass is often shredded or chipped using forest technology before it can be pressed. Agricultural residues, carbonized dust or husks and ground nutshells can be sufficiently homogenous to be pressed without prior sizing. The output of a downsizing process is sorted according to particle sizes; the division can either be carried out by hand, sieves or screens to separate suitable chunks from finer ones that have less beneficial combustion characteristics. In practice, the preparation of feedstock for the agglomeration processes is often more tedious and labor intensive than the actual densification.

Briquettes made of wood are best produced by mixing fine particles into the larger woody biomass particles (i.e. wood chips) before pressing. Mixing sawdust or finer particles with the raw material results in high quality briquettes that keep their shape and have high energy content.

Figure 2.4 Downsizing in a chipper (top left) and grinder (top right). Densified solid biomass fuels examples.

Carbonising solid biomass fuels

Carbonisation is the conversion of an organic substance into carbon or a carbon-containing residue through pyrolysis, meaning the decomposition of organic material without oxygen at elevated temperatures. The carbonisation of wood in an industrial setting usually requires a temperature above 280°C, and continues until only the carbonized residue – charcoal – remains[17].

The most common forms of carbonised fuels are either charcoal from woody biomass or charcoal briquettes, which can be comprised of smaller parts of biomass, such as forest industry and agricultural residues. Most organic residues can be dried, carbonised and subsequently pressed into briquettes. While nearly half of the energy contained in the original biomass is lost in the carbonisation process, carbonisation is still popular as the calorific value per mass can be substantially increased from 14-18 MJ/kg of dry mass to 24-26 MJ/kg for a charred briquette (depending on the binder) and up to 29 MJ/kg for lump charcoal.

This results in lower transport costs and cleaner combustion characteristics for this type of fuels, as the 'smoke'-creating volatiles have been lost in the carbonisation process. In theory, the released heat produced during the carbonisation process that turns biomass into charcoal can be used for cooking purposes as well. The practicality of this depends on the location and scale of the carbonisation. Any pyrolytic micro-gasifier with restricted primary air is basically a mini-kiln that produces charcoal while cooking[18].

Figure 2.5 **Carbonised briquettes, Senegal (left) and handmade charcoal briquettes from Uganda (right).**

[17] Kaltschmitt, M.; Hartmann,H.; Hofbauer, H., 2009: Energie aus Biomasse – Grundlagen, Techniken und Verfahren. Springer Science & Business Media.

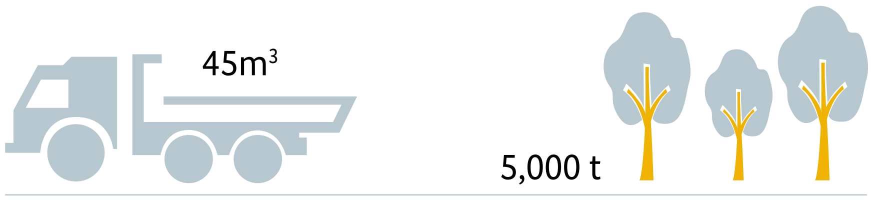
[18] For more details consult Roth, C.; et al. 2014: Micro-gasification: Cooking with gas from dry biomass, GIZ, Eschborn, Germany.

Densifying solid biomass fuels

Densification involves compacting the biomass with high pressure. This reduces its volume and agglomerates the material so that the final product remains in its desired form. This process also increases the energy density, i.e. the available energy per unit of volume, of the biomass energy carrier.

Table 2.2 lists the respective weight per cubic meter, resulting weight of the truck load and number of truck loads needed to transport the 5,000t of beech for different forms. The table lists theses values for chopped logs of 33cm length, wood chips, as well as briquettes and pellets. The chipped material would need 397 loads whilst the chopped and stacked wood pieces can be transported with 250 truck loads. Densified biomass in the form of pellets would need 170 loads and briquettes would result in only 124 truck loads for the transportation of the whole biomass less than half the truck loads that wood

Table 2.2 **Impact on load volume of different levels of densification.**



Form	Chipped	Chopped	Pelleted	Briquetted
kg/m³	280	445	650	900
Weight per load (tons)	12.6	20	29.3	40.5
No. of loads	397	250	170	124

Biomass quantity 5,000 tons. Each transport load has a volume of 45m³.
All of the values are approximations. Source: Kaltschmitt et al. 2009

chips would require. This clearly highlights one of the major benefits of densifying biomass. All values are estimates and vary significantly for different types of wood and respective water densities. Accordingly, the two forms of densified biomass that are most relevant for the sustainable supply of cooking energy are briquettes and pellets. The following sections describe the processing of solid biomass fuels to briquettes and pellets in more detail.

Densification to briquettes
Briquettes are made of dry, untreated and chipped/crushed solid biomass. They are pressed, and depending on the type of briquetting technique, a binder may be added. Pressing the biomass fuel reduces its volume, thereby increasing its bulk or energy density. As briquetting is performed in combination with drying of the biomass, the briquettes have a much higher calorific value than the raw material. Briquetting technology ranges from pressing the raw material in a mold by hands or roller presses to automated screw or piston presses that operate with pressures of up to 300 bar. Three different types of presses are displayed in *figure 2.7*. For more details on briquetting technology please refer to the publication *Micro-gasification: Cooking with gas from dry biomass.*

Box 2.3 Design of the solid biomass fuel.

Did you know that the design of the fuel shape has substantial impact on its combustion quality (combustion rate and smoke development) The two following pictures show briquettes that are shaped in a way that they burn in a clean and thorough way (see *figure 2.7*).

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Figure 2.6 Two charcoal briquettes with inherent design that supports low emission and complete combustion.

A binder is only necessary if the inherent binding forces of the biomass are insufficient to maintain its shape after being compressed. For uncarbonised biomass, paper or starchy materials are suitable binders. Charred biomass has lost all inherent binders in the carbonisation process, thus charcoal dust cannot be briquetted without a binder. Starch, molasses, gum arabic or even clay can be used as binder for charcoal briquettes. In the case of manual briquetting, for instance, more binding force, i.e. firmness or solidity, of the briquette can be achieved with a wide variety of materials, such as sawdust, rice husk, bagasse, coffee/peanut shells etc.

Figure 2.7 **Three different types of briquette presses. RUF press for wooden briquettes (left), roller press for carbonised pillow-shaped briquettes (center) and press for carbonised honeycomb briquettes (right).**

By compacting the biomass – under high pressure, it turns into a block or brick. Uncarbonised briquettes generally have two shapes depending on the technology applied for making the briquettes – they can either have a tubular (see *figure 2.8*) or a cuboid shape. Appropriately sized briquettes are suitable for the application in cook stoves that are fitted for this purpose. Log-shaped uncarbonised briquettes are the closest substitute for firewood and can be used in any stove technology suitable for firewood, even three stone fires or simple heating furnaces.

Figure 2.8 **Briquettes made from cotton stalks in Uzbekistan.**

Figure 2.9 Production of briquettes in Lilongwe, Malawi (left) and Bujumbura, Burundi (right).

Densification to pellets
Pellets normally refers to the shape of the compressed biomass pressed through a die hole under 20 mm diameter, like a spaghetti. Pelletising requires very high pressure, thus the resulting pellets are extremely dense. Pellets are produced with a very low moisture content (below 10%). Furthermore, their regular geometry and small size provide a predictable behavior in a furnace leading to a high combustion efficiency with possible low emissions. The engineering is in the fuel preparation!

Pellets can be made of any kind of solid biomass. Wood pellets of 6 mm are the most common type of pellet fuel and are made from sawdust, industrial residues from the milling of lumber, manufacture of wood products and furniture, and leftovers from construction. There are norms for pellets (e.g. DIN and ENPlus) to be used in high-end automatic space-heating furnaces, e.g. limiting the maximum permissible ash content to avoid clogging of the furnaces by ash melting at high temperatures. For micro-gasifiers any type of pellet can be used.

They can be used as fuels for power generation, heating and cooking. The shape of pellets allows for automatic feeding, even though this is only relevant for automated heating purposes only. Their high bulk density also permits compact storage and transport over long distance[19]. Pelletising is the process of compressing or molding a material into the shape of a pellet. This process is suitable for forest based as well as agriculture based material, including straws, grasses and energy crops[20].

[19] Cardellichio, P.; et al. 2010: Massachusetts Biomass Sustainability and Carbon Policy Study: Report to the Commonwealth of Massachusetts Department of Energy Resources.

[20] Kaltschmitt, M.; Hartmann, H.; Hofbauer, H., 2009: Energie aus Biomasse – Grundlagen, Techniken und Verfahren. Springer Science & Business Media.

Box 2.4 **Briquetting or pelletising.**

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Briquetting or pelletising?
This decision depends mainly on the local conditions: needs of the consumers regarding their cooking technology, quality and quantity of feedstocks, reliability and cost of the power supply, investment capital, intended scale, etc.

Low-density manual briquetting can be done without external power sources and on a small scale. Medium-density briquetting tends to have lower requirements for investment; maintenance and running costs but also lower production capacity, especially for briquettes with small diameters of 30-40 mm that are suitable for micro-gasifiers. Piston presses require little supervision and currently seem to provide the best ratio of power input, material output, supervision needs as well as wear and tear.

High-density pellets can only be produced with relatively high power input (<05 KW), easily exceeding 50 kW, which is often not available in the grid in developing countries. Pellet mills have higher throughputs, but also more wear and tear. Thus, greater requirements for maintenance and costly replacement parts like the rollers and dies ensue.
A pellet mill requires constant attention during operation as well as skilled and experienced operators.

Figure 2.10 **Pellets made from tobacco stalks (left), hay (center) and Miscanthus straw (right).**

Storage of solid biomass fuels

Storage of solid biomass, particularly after processing, is a key step in maintaining the high quality (calorific value, density, shape and texture) achieved by their previous treatment. For densified biomass, such as pellets and briquettes, proper storage is very important, since these highly densified and dried biomass products start to swell and decompose in humidity. Wood briquettes and pellets require airtight packaging to maintain their form and quality.

Figure 2.11 Stored and packaged briquettes.

3.0

Bioenergy carriers for cooking energy – concluding remarks

3.0 Bioenergy carriers for cooking energy – concluding remarks

A contribution to a circular economy

One of the key benefits of utilizing solid biomass fuels beyond firewood and charcoal for cooking is that these fuels can derive from either a residue or an endangered ecosystem. Agricultural and forest residues are natural resources that may benefit all those involved in their processing and utilization. Instead of being disposed without any other form of use, they can be the basis for locally adapted value chains, and generate employment. In addition, the supply of clean cooking fuels reduces indoor air pollution and thus threats to human wellbeing. If used with awareness, solid biomass fuels beyond firewood and charcoal can significantly contribute to a circular economy that enhances cascaded use of solid biomass.

Watch out for competing uses

Competing uses may strongly interfere with the production of cooking fuels from organic residues. Are the residues needed for cooking fuel truly of no other use? Or, would they, if left at the cultivated areas, contribute to renaturation of soils, for instance?

Distance between place of biomass collection and the kitchen

A determining factor in examining the economic and ecologic feasibility of solid biofuel production beyond firewood and charcoal is transport distance, i.e. the distance between the place of biomass collection and processing and the place of consumption. The projects reviewed in this publication show that the transport distance significantly influences economic feasibility. Large transportation distances reduce the profit margin so much so that projects cannot achieve economic sustainability.

Cooking technology: form of bioenergy carrier and user — an inseparable team

The best form of a bioenergy carrier in terms of combustion efficiency, emissions and state of technology for household cooking comes in the form of pellets. However, pellets are difficult to supply in terms of maturity of technology and markets, maintenance and complexity of production. Somewhat easier to produce are briquettes. However, each of these two forms of solid densified biomass has differing combustion characteristics and therefore requirements for cooking technology. All in all, the needs and preferences of the consumer, reliability, affordability, and availability are the deciding factors when weighing which fuel and cooking technology works best. The choice of the fuel MUST match the needs of the customer AND the cooking technology.

All of the aforementioned aspect make project planning and implementation a complex task. These factors should never be addressed in an isolated manner nor should they be underestimated. If all aspects are acknowledged, a profitable and sustainable business can be established to provide bioenergy carriers that allow for clean, healthy and affordable cooking, with the goal of working toward saving our climate.

Suitable cook stove technologies for alternative cooking fuels

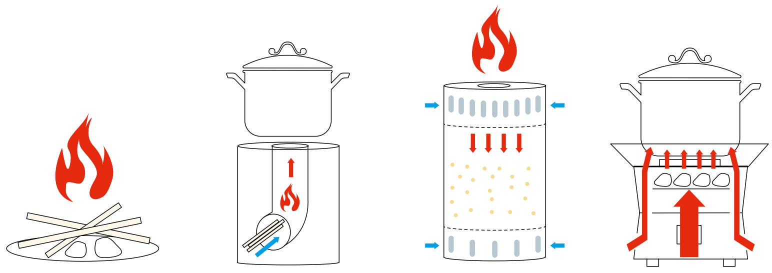
4.0

4.0 Suitable cook stove technologies for alternative cooking fuels

The term 'cook stove' refers to a device that directs heat generated from an energy carrier to an application crafted for the preparation of meals. Thus, a stove features the combination of heat generation and heat transfer to a cooking pot, griddle, cooking plate or any other device that is suitable for the preparation of food. The following section illustrates different types of cook stoves that are suitable for the use of solid biomass.

The vast majority of cook stoves can be attributed to four main types: traditional, side fed, batch fed or batch fed charcoal stoves. Each type of stove can further be differentiated according to its applicable fuel type, draft design and the process of energy conversion. *Table 4.1* on the right provides an approach as to how cook stoves may be categorized. For more information on the functioning principles of gasifiers please refer to the booklet *"Micro-gasification: Cooking with gas from dry biomass"*. In general, it can be stated that cook stoves can be grouped to those where the fuel is filled in a batch and those where fuel is continuously fed to the combustion zone from the side.

Table 4.1 **Stove types and an approach to a categorization of cook stoves.**



	Traditional	Side fed	Batch fed	Batch fed
Fuel type	All types of fuel work but best for firewood and chunky biomass	Best for firewood, chunky and ONLY uncarbonised biomass Pellets and wood chips are inconvenient	Best for pellets and wood chips Works well for chunky and carbonised biomass as well as firewood	Charcoal, i.e. carbonised biomass
Draft	Unregulated, natural draft principles	BBUD	TLUD BBUD	BBUD
Conversation	Combustion	Combustion Forced air / fan supported combustion	Gasification Combustion	Combustion

BBUD: Bottom-burning updraft, TLUD: Top-lit updraft

Improved cook stoves can reduce fuel consumption by up to 50% when compared to a traditional stove[21]. Furthermore, a more efficient combustion and effective redirection of emissions can improve indoor air quality substantially. Micro-gasifiers are nearly as clean as cooking with gas as the way of combustion in a gasifier stove happens after the biomass gasified. Hence, only the wood gases are burning and the user is cooking with gas. Gasifier stoves are gas-burners that produce their own gases from dry solid biomass.

[21] Ochieng, C. et al., 2013: A comparison of fuel use between a low cost, improved wood stove and traditional three-stone stove in rural Kenya, Biomass and Bioenergy 58 (2013), London, UK.

Box 4.1 **Definition of the term Micro-Gasification.**

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What is Micro-gasification?

As the term suggests, the solid biomass fuels do not combust but are rather gasified. Biomass gasification is the broad term used for the conversion of solid biomass fuels into inflammable "wood-gas". In a gasifier device, the stages of gas generation and subsequent combustion are deliberately separated in time and place. Micro-gasifiers are merely small gasification devices that create the gases and have their combustion fit directly under a cook-pot.

The evidence clearly indicates that solid biomass fuels is not the problem per se; rather, the problem lies in the way biomass is commonly used. Research, dissemination, and commercialization efforts over the past few decades have brought a range of improved cook stoves into use. Many types of cook stoves and development projects, as well as policies, have supported their commercialization. It is estimated that about 25 million households made use of improved cooking technologies globally in 2015. That is still a rather small share considering a total of roughly 570 million households that depend on the use of biomass as their primary source of cooking fuel[22].

Box 4.2 **Factors influencing the choice of cooking technology.**

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How to decide for the appropriate cooking technology?

Most important factors that influence the technology are:

1. Where does the biomass come from?

2. How can the biomass be processed (pellets, briquettes, carbonised or no processing)?

3. Which form does the biomass take?

[22] The World Bank Group, 2015: THE STATE OF THE GLOBAL CLEAN AND IMPROVED COOKING SECTOR (Technical Report), Washington D.C.,USA. Retrieved at *https://openknowledge.worldbank.org/bitstream/handle/10986/21878/96499.pdf* in August 2016.

Figure 4.1 From top to bottom: Selection of cook stoves: side-fed rocket stove for domestic use (top) and for institutional use, (bottom) a fan supported gasifier. (top right) and a charcoal stove for honeycomb briquettes.

5.0 Examples of solid biomass fuels for cooking from around the globe

Examples of solid biomass fuels for cooking from around the globe

The following section presents five projects that make use of residues from agriculture and the forest industry. Fifteen more projects were identified to provide the reader with guidance on where to find more examples and information.

Table 5.1 provides an overview as to what fuel types are produced and whether a cooking technology forms part of the initiatives. Nine out of the twenty projects combine the production of cooking technology and solid biomass fuel, already. This table does not claim to be exhaustive, it is much rather a random collection of solid biomass fuel initiatives that provide energy for cooking beyond firewood and charcoal.

Table 5.1 **Solid biomass fuels beyond fuelwood and charcoal for cooking projects and initiatives.**

Project lead	Fuel type	Country	Website
Filanthrop	Rice husk, coffee pulp, pine needles etc.	Vietnam, Laos, Cambodia, India, Indonesia	https://filanthrope.org
Appropriate Rural Technology Institute of India	Carbonised briquettes from sugar cane residues/bagasse and other agricultural residues	India	http://www.arti-india.org
Green BioEnergy Ltd.	Carbonised briquettes from banana skins, coffee pulps; bagasse	Uganda	http://www.greenbioenergy.org
Emerging Cooking Solutions – Zambia Ltd	Pellets from saw dust, pine, eucalyptus, peanut, elephant grass etc.	Zambia	http://supamoto.co.zm
Gogle Energy Saving Stoves and Engineering	Gogle Energy Saving Stoves and Engineering Honeycomb charcoal briquettes	Ethiopia	http://www.gogleenergy.et
Home Energy Ltd.	Biomass pellets (Ag. Residue, Processed Biomass, etc.), Crop residues	Zambia	http://www.aaaa.no/home-energy
Vutisha Technologies	Briquettes from saw dust, peat and straw	Ivory Coast South Africa	https://vuthisa.com

Project lead	Fuel type	Country	Website
Abellon Clean Energy Ghana Ltd	Pellets from short-rotation energy crops plantations	Ghana	http://www.abelloncleanenergy.com
Oko-baba Saw-dust Waste to Wealth Initia-tive	Briquettes from saw dust	Nigeria	http://www.sradev.org
Carbon Roots International	Carbonis ed bri-quettes from sugar cane bagasse	Haiti	http://carbonrootsinternational.com
GIZ Support to De-bushing/ Cheetah Con-servation Fund	Wood briquettes from shredded bio-mass of invasive bush carbonized bri-quettes	Namibia	https://www.giz.de/en/world-wide/28648.html
Katene Kadji	Pillow-shaped bri-quettes from char-coal dust	Mali	http://katenekadji.com
BRADES Ltd.	Hollow-core char-coal briquettes with clay binder	Senegal	
CarbonBrake Ltd.	Briquettes from peanut shells and waste millet stalks	Senegal	http://carbonbrake.com/senegal-pea-nut-shells
National Insti-tute for Scien-tific and Indus-trial Research	Briquettes from re-cycled coal waste and carbon dust	Zambia	http://www.nisir.org.zm
Sustainable Green Fuel Enterprise SGFE	Hollow-core char-coal briquettes with starch binder	Cambodia	http://www.sgfe-cambodia.com/
Chardust Kenya	Charcoal briquettes in various shapes (pillow, round balls)	Kenya	hhttp://chardust.com
National Forest Agency	Solid block bri-quettes from forest residues	Georgia	http://forestry.gov.ge/en
GreenTech Ltd.	Briquettes from groundnut shells	Gambia	http://www.greentechgambia.com

Project fact sheets
Five project fact sheets provide insights into the type of fuel that is produced and which technology is applied. Marketing of new energy carriers is a substantial part of a successful project implementation and therefore the marketing approach applied in the projects is described.

The key lessons learned as provided by the project managers showcase the various challenges and bottlenecks the projects were confronted with.

Pelletised sawdust from Eucalyptus and Pine trees

Lead	Emerging Cooking Solutions Ltd.
Region	Zambia
Partners	Total S.A.
Status	Ongoing

Fuel Type

Wood pellets are produced from the waste of the wood processing industry, mainly saw dust.

Technology & Production

The sawdust is delivered to the production site and, if necessary, dried in a flash drier. Other residues which must be reduced in size are processed with a hammer mill. Dried raw material is pelletized by a pelletiser imported from China. The pelletiser is the third machine of its kind as the first was destroyed during a devastating fire at the production site, and the second did not provide sufficient quality.

A selection of improved cook stoves, mostly fan supported TLUD gasifiers (Mimi Moto and Prime) are offered in combination with the pellets. The team is starting to produce institutional, large-scale stoves as well as own domestic stoves.

Marketing

A selection of customer groups is targeted – universities and schools with institutional kitchens, households and enterprises. The distribution is done via fuel stations. The project leader reached an agreement so that all fuel stations are supplied with pellets and stoves. A subscription to continuous fuel supply is currently being elaborated where customers receive a code via SMS after payment. The code entails to go to the next fuel station and retrieve pellets.

Lessons learned

- Be well funded before you start.
- Take small risks.
- Go step by step.
- Don’t get a fire in a factory.
- Be thorough and careful in selecting key staff.

FOR MORE: *http://supamoto.co.zm/* Remark: All pictures provided by Emerging Cooking Solutions.

Lesson 1

Be well funded before you start

To allocate funding for projects related to improving the cooking situation, generally in the form of loans or grants represents itself to be a rather challenging task. According to the experience we made in Zambia, it appeared to be impossible to find a regular bank loan (due to risk associated to investments in Zambia). Very few people, of those that are employed in banks, have heard of pellets and know of the complex topic of improving the way the people cook.

The project developers saw the huge potential that pellets and improved cook stoves could have and started from scratch, started without funding. As they were the first to try it out, it took a lot of time and resources to trial each step. The first pellet mill was purchased with less than 20,000 USD and didn't last long. During the first months, a lot of help and informal support helped to begin with production. Not even salaries could be paid to the involved people at start. Today, the third pellet mill has been installed after a devastating fire destroyed most of the pellet producing machinery.

Lesson 2

Take small risks and go step by step

Taking one step at a time is the recommended *modus operandi* for projects and expect disasters to happen! In October 2015, a fire destroyed all the acquired machinery, the team was facing tremendous difficulties. The saw mill had taken fire due to faulty electrical wiring. Twenty institutional kitchens and all the local suppliers throughout Zambia (all TOTAL fuel stations) that guaranteed pellets for the participating customers had to wait and thus return to other ways of cooking. The large-scale kitchens were offered wood chips but all in all the project team could hardly cope with the struggles of surpassing the time of not being able to produce solid biomass. In addition, the inventory, i.e. already produced pellets, was not insured so that the company had to face a huge financial and material loss.

Don't create large overhead costs and try to be as lean as possible in your planning. Start selling as soon as possible. Because as soon as you sell, you proof to investors that you can set out and then gain additional funding, for instance.

If everything could have been done again, the team would have imported the pellets first in contrary to producing by themselves. Setting up the production of both, the pellets and the cook stoves proved to be a very difficult task. Organizing and keeping up the whole supply chain took a lot of time and resources that could have been used more wisely. Market conditions, pricing of the pellets and overhead costs could have been explored as part of an iterative process. Not so with the presentation of the complete business plan where many assumptions had to be made that turned out not to reflect the real-life conditions.

Lesson 3

Be thorough and careful in selecting key staff

There were many issues with key staff as hiring reliable and responsible staff happened to be difficult. Furthermore during the initial phase a lot of commitment was required, yet long term employment remained uncertain. There were cases of missing items or incorrectly administered inventory in the first few years of the project.

Lesson 4

The customers like this approach

The price of pellets in Zambia is comparable to the prices of Western Europe. In the applied business model, the largest profit margins are derived from selling the fuel. And in spite the relatively high price of pellets, the customers can still achieve reducing expenses for cooking energy!

One customer bought a subscription for the pellets, a solar home system and an improved cook stove. Prior to using the system, she cooked for 15 people and used about 180 Kg of charcoal at a cost of US$30 per month. Since she started cooking with pellets she had reached a drastic reduction of energy expenses. She now uses 30 kg of pellets for only US$ 7! That 1,000 kg of firewood derived from local forests to produce charcoal could be replaced by 30 kg pelletized residues. Most people will need two bags in the same amount of time but the potential reduction of the demand for firewood is evident.

Pelletised crop residues

Lead	Terresolidali NGO
Region	Niger
Partners	Università degli Studi di Torino - Italy
	Action pour la Sécurité et la Souveraineté Alimentaires
Status	Completed

Fuel Type

Pellets are produced from agricultural residues (millet, cow peas, sorghum etc.) which are ground and then pelletized. Mango leaves and stalks are partially used together with residues from pruning and cuttings of agricultural production.

Technology & Production

Agricultural crops are collected independently by people who then go and shred it to small particle size before pelletising them. Two pelletisers have been set up that operate 8 months per year. Capacity to produce 240 tons per year in order to fuel 470 stoves and households. 370 Aaron stoves (see *picture*) were sold. Aaron stove is a TLUD gasifier. Changed from a diesel fuel pelletizer to an electric one of 22 kW power from China. This machine provides a production capacity of around 200 kg per hour, and 1200 kg per day.

Marketing

The Aaron stoves are sold to key persons in the community, such as for instance woman who are preparing food at the side of the road. In this way the community quickly sees and learns about the benefits of using the Aaron stove. The project planners have successfully distributed their cook stoves *via* this channel so far.

Lessons learned

- Ownership and project lead remains one of the main challenges in the implementation of the project.
- This was the first project of pellet production in Niger. Planners learned a lot about the challenges of it.
- Production capacity of pelletisers is much lower than initially expected if solid pellets of homogeneous quality are to be produced.

FOR MORE: *www.energiesdurablesniger.org*

Remark: All pictures provided by Terresolidali.

Lesson 1

Ownership and project lead remains one of the main challenges in the implementation of the project

A large variety of stakeholders were involved during the planning and implementation of the project. It was difficult to determine and announce the project leader over the whole lifecycle of the project (2011-2015). Changing responsibilities during the project administration and changing personnel turned out to be a one of the major hurdles for project implementation.

Lesson 2

This was the first project of pellet production in Niger. Planners learned a lot about the challenges of it

This was the first time that someone tried to install a production line for pellets and micro-gasifier cook stoves in Niger. Important steps of project implementation turned out to take much longer than initially anticipated. The importation of diesel machines caused delays, the construction of the facilities proved to be more expensive and the planned production capacities could not be achieved with the two first pelletizer bought in the framework of the project. The project planners based their business plan on these specifications and calculated an annual production capacity of approximately 400 tons. When the mill was installed, the labor force started to pick up the job and the team realised that the achievable production capacity was much lower than expected.

Lesson 3

Production capacity the Diesel pelletisers was much lower than initially expected if solid pellets of homogeneous quality are to be produced

To overcome this problem, around one year before the end of the project, a new electric pelletizer was bought in Benin, and connected to the local power grid, after a connection point was expressly set up in Niamey, Commune 5. The new electric unit is a 22 kW pellet mill of Chinese origin. This machine provides a production capacity of around 200 kg per hour, and 1,200 kg per day. The forecasted yearly working days under real conditions can be estimated to about 230 days per year, considering that during the wet season the production of pellets must be stopped as the raw material does not stick together if the moisture content does not fall below 10%. The management of the pellet production was taken by to a cooperative that worked in a satisfactory way in the first months but then showed some problems of internal management organisation. The problem is not the cooperative form of management *per se*, but in this case problems arose due to the internal dynamics of this specific cooperative.

The organisation of work at the pellet making facility must be monitored closely and carefully. A new solution is to be found with respect to this.

The organisation is to provide for local manufacture of some spare parts such as rollers and dies. If there is the possibility to manufacture locally, the organization must provide for the regular supply of raw material. The same is true of ball bearings because, in a production as indicated, it takes at least 6 ball bearings a month, two for the mill and 4 for the pellet machine (in the pellet machine there are two ball bearings per roll). The presence of dust, often with silica, in the twigs, causes the parts to wear out quickly.

The Maintenance is also important. The mill, which must have mobile hammers (and not fixed hammers), must also have spare grids.

Pellets from wooden residues

Lead	Inyenyeri – A Social benefit company
Region	Rwanda
Partners	
Status	Ongoing

Fuel Type

Pellets from wooden residues, in particular collected firewood and saw dust . No split wood or agricultural residues is accepted as only collected branches or saw dust residues are suitable for the project's objectives.

Technology & Production

The solid biomass is collected in rural areas in clean, dry bundles and sorted by species. The sawdust is bought from saw mills. All biomass is dried and passed through a shredder to reduce the volume for transport to the pellet factory. The solid biomass ground to fine particles is then controlled for moisture and subsequently pelletized by the pelletizing mills. The MIMOTO fan supported gasifier cook stove is a batch-fed, TLUD type of cook stove, which is supported by an electric fan that can be charged using a solar panel.

Marketing

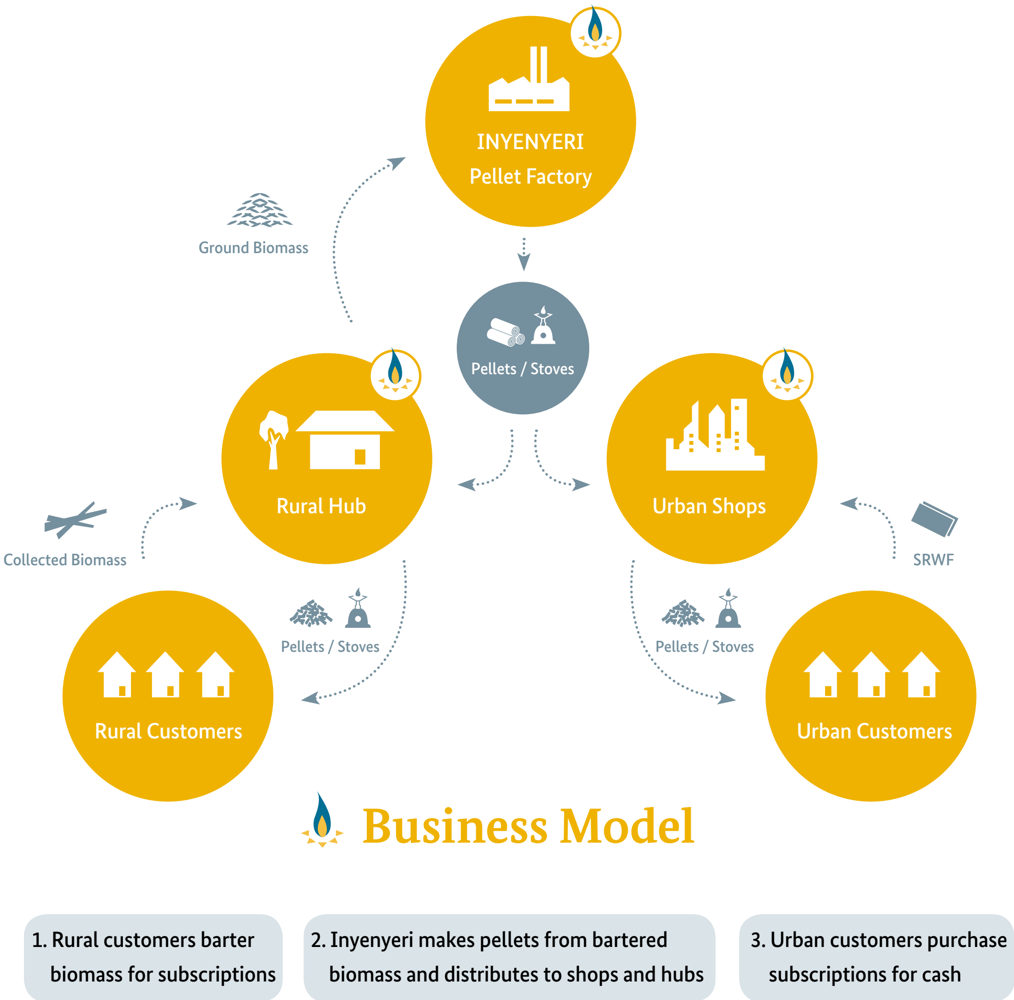
"People don't want a fridge; they want a cold beer". Inyenyeri owns the stoves and delivers the service of clean cooking to its customers. About 1,500 households participate, already. Monthly membership packages offer a stove and delivery of pellets. Maintenance of stove is part of the package. It is planned to Install new pellet facility with capacity to serve about 10,000 households and diversify retailing network through partner vendors and street team. Deployed SMS mobile wallet payment system to have an easier accounting for the customers. Customers receive service for the stove, regular biomass supply and are trained in appropriate use of stove and fuel.

Lessons learned

- People want a clean combustion process, such as LPG for cooking. The art is to deliver equally comfortable cooking solution.
- A reliable biomass supply chain is the most crucial aspect.
- You have to be able to cook with one batch.

FOR MORE: *www.inyenyieri.org*   Remark: All pictures provided by Inyenyeri.

Figure 5.1 **Business model of Inyenyeri.** Source: Inyenyeri.



Focus on the *Inyenyeri* Business Model
Inyenyeri provides a truly clean biomass Fuel+Stove solution affordable to all levels of households – extreme rural poor to urban middle income - through a fuel-based approach.

Inyenyeri operates with an innovative business model that decreases the hurdle of seed capital for the customers and empowers rural customers providing them with an opportunity for income. Customers merely purchase subscriptions to receive the cooking tools (pellets and stoves). Rural customers can barter biomass in addition to paying the subscription to receive the cook stove, pellets and maintenance service provided by Inyenyeri at a reduced rate. Inyenyeri then makes pellets from the bartered biomass and distributes the pellets to regional shops and hubs. The urban customers purchase the subscriptions for cash.

Lesson 1

Preparing food still is a dangerous activity!

Cooking with solid fuel is the leading risk factor to health in Rwanda - it kills over 5,500 Rwandans every year. Almost half of those deaths are children under the age of 5. Virtually all Rwandans (99.3%) cook with solid fuel (i.e. firewood, charcoal, agricultural residues etc.) releasing potentially lethal levels of household air pollution, causing respiratory and cardiologic diseases, leading to premature deaths and the loss of thousands of disability-adjusted life years (DALYs).

Lesson 2

You can't sell a cook stove or fuel to someone with no money

Household Air Pollution is still a problem in the developing world because no scalable solution for cooking has been developed that is accessible to ALL household demographics. The stoves and fuels that can save lives are unaffordable for the majority; LPG and electricity (being the cleanest cooking fuels) will not be economically viable in Rwanda for the next few decades. This sets solid biomass fuels as the main cooking fuel soon. Inyenyeri shows a solution with its innovative business model.

Lesson 3

One "clean" cook stove doesn't solve the problem

Even if a household can afford a single clean stove, one stove usually is not enough to meet all household cooking needs; stove stacking (or simultaneous use of traditional stoves with clean stoves) occurs. The potential health benefit of the clean stove is rendered null by the traditional stove(s). That's why Inyenyeri offers cook stoves in packages for as many as are necessary.

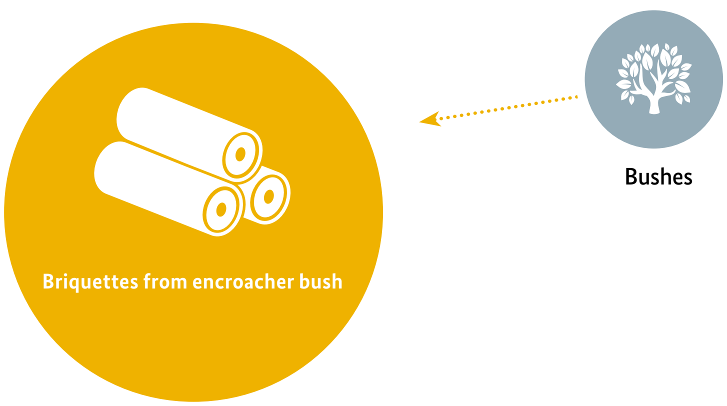
Lesson 4

Most solid fuel cooking solutions for the developing world lack appropriate design

Even when cook stoves are distributed for free, it has occurred that often they are not being used because they are less convenient than what people were cooking with beforehand. We have gained the impression that some improved cook stoves do not look like an innovative approach to cooking but rather one step back.

Briquettes from encroacher bush

Lead	GIZ Support to De-bushing
Region	Namibia
Partners	Ministry for Agriculture, Water and Forestry
Status	Ongoing



Fuel Type

Namibia is affected by bush encroachment on a massive scale. An estimated 45 million hectares of farmland experience the excessive growth of predominantly indigenous bush species at the expense of grass cover. This has severe negative consequences for the local ecosystems, reducing biodiversity, groundwater recharge as well as agricultural productivity. Despite the negative impacts, the bush constitutes an enormous biomass resource and its utilization creates win-win situations for farmers and businesses. Most Namibian bush species are slow-growing, high density species. The biomass is therefore characterized by a high energy content of 5.2–7.4 GJ/m^3 and is ideal for energetic use. The bush is harvested and processed into briquettes.

Technology & Production

Bush is harvested on Namibian farmland by means of semi-mechanised (axes, electric saws) and mechanised means (excavators). The material is immediately chipped, packed into bags and transported to a production facility. The chips are processed into briquettes utilising an extrusion press and have a hollow-core tubular shape. The *Zama Zama* cook stove is a side-fed rocket stove that is imported from South Africa. Its fuel inlet is just big enough to accommodate the briquettes. Air enters through the centre hole to provide oxygen to the tip of the briquette inside the combustion chamber. This is an inherent and important feature of the briquette shape to assist the burning process.

Marketing

The briquettes are marketed as a fuel of high energy content that reduces indoor air pollution and energy expenses. During the pilot project an awareness raising campaign informs customers about the advantages of the Zama Zama cook stove by individual consultation and leaflets. Part of the ongoing pilot project is the development of a business model, which includes the distribution of affordable stoves, which are refinanced through the sale of monthly packages of briquettes. Close to 100 households and 5 schools participate in the pilot. The average household can reduce fuel demand by up to 40% compared to using firewood on a 3-stone-fire. For large- scale institutional kitchens, where the Maxi Zama is used, the “Bush Blok” is offered. Therewith, a solid biomass fuel of homogenous quality is used in combination with adequate cooking technology.

Lessons learned

- Encroacher bush harvesting is difficult and expensive
- Supply of biomass is strictly limited by transportation costs
- Briquettes and cook stove have to be used jointly to reach anticipated savings
- Tubular briquettes have to be reduced in size to fit the ZamaZama rocket stove
- Cultural and socio-economical aspects of adaptation and adjustments to improved cooking technologies

Support to De-bushing Project: *www.giz.de/en/worldwide/28648.html*

Remark: All pictures provided by GIZ GmbH.

De-bushing Advisory Service: *www.dasnamibia.org*

Lesson 1

Encroacher bush harvesting is difficult and expensive

Manual and semi-mechanised harvesting, with axes or electric saws, is a cumbersome process, made difficult by the harsh climatic conditions of Namibia and the thorny nature of many encroacher bushes, among other factors. Fully mechanised bush harvesting, for example with excavators, is a cost intensive operation. Maintenance cost of machinery is high due to the extraordinary hardness and high mineral content of the wood. The same challenges apply for wood processing, such as chipping of the bushes, which typically takes place in conjunction with the harvesting process.

The local producers that continue to harvest encroacher bush, seek assistance from foreign forest machinery producers to supply machinery that can deal adequately with the wood characteristics and environmental factors.

Lesson 2

Supply of biomass fuel for cooking and heating is strictly limited by transportation costs

Namibia is a country with a low population density and vast unpopulated lands, Namib means "vast place". Hence, the long transportation distances add up to the cost of the arduously harvested woody biomass from the encroacher bush. Besides harvesting and processing, transportation is the second most determining cost factor. Under current market conditions a maximum transportation distance of 50 km was found to be economically feasible.

Lesson 3

Wood briquettes and cook stove have to be used jointly to reach anticipated savings on natural fuelwood consumption and cooking time

The awareness raising campaign, comprising of the distribution of flyers and demonstration workshops with participating households, emphasizes the crucial importance of (predominantly) using briquettes in the energy efficient cook stoves. The stoves lead to efficiency gains also when conventional firewood is used. The densified briquettes, however, bear the additional benefit of a high energy content per piece, which further increases the efficiency of the cooking process. Through the combined use of high energy biomass and efficient cook stoves, households can significantly reduce their fuel costs. This provides an opportunity for business models, centered around the combined marketing of the stoves and the briquettes.

Lesson 4

Cultural and socio-economical aspects of adaptation to improved cooking technologies have to be considered to sensitise the users.

Past experiences have shown that there is a reluctance of uptake due to the high capital costs to purchase the stove, lack of marketing, conflict between the stove design and cultural way of open fire cooking and the lack of continuous availability and accessibility of cook stoves. A supply chain is commendable for the success of the pilot.

Solid briquettes from forest residues for larger combustion chambers

Lead	National Forest Agency
Region	Akhmeta, Georgia
Partners	UNDP & GIZ
Status	Ongoing

Fuel Type

Wood briquette from forest residues, such as branches, trunks, roots that are left after thinning for firewood. The fuel is used in municipal buildings and households for heating and cooking.

Technology & Production

The residues are collected by forest entrepreneurs and delivered to the briquette production facility. Biomass is chipped with a single shaft shredder and transported to a modified shipping container that is used for drying. 80°C hot air is circulated in the container to dry 30 m^3 of wood chips in about 48h. The dried wood chips are pressed by a RUF 600 briquette press. 170 tons of wood briquettes are planned to be produced per month, leading to an annual production of approx. 2,000 tons.

Marketing

Marketing of the briquettes is done with support of NGOs. The pilot project supplies briquettes to schools in the region with corresponding media coverage. In addition, the *National Forest Agency* (NFA) promotes the advantages of the combustion of briquettes across the country by means of school visits, mobile exhibitions and demonstrations. Shops in Tbilisi are supplied with the briquettes where information leaflets inform the consumer about the advantages of energy dense and dry fuels, such as wood briquettes. By using briquettes (5,000 KWh/m^3) instead of fresh firewood (2,000 KWh/m^3) the consumption of natural resources for cooking and heating can be reduced by up to 50% in every day practice.

Lessons learned

- Assumptions for price of raw material and project implementation were too optimistic.
  Be conservative in calculating the business plan!
- Drying of the biomass is the most crucial production step.
- Not all partnerships could be kept as per the business plan. Reach agreements before handing in the project proposal!
- Machines overloaded regional power network.
  Be prepared that framework conditions can't cope with the new technology.

More info at: *http://nfa.gov.ge* via Natia Iordanishvili.

Remark: All pictures provided by Frank Helbig.

Lesson 1

Assumptions for price of raw material and project implementation were too optimistic. Be conservative in calculating the business plan!

There was one key lesson learned related to the production of briquettes from forest residues in Georgia. The raw material was calculated to have no price and freely available (neglecting the cost to harvest) to produce briquettes. The business plan was based on this assumption and funding was granted on the baseline calculations. As the production facility was finalised and production was scheduled to begin, the project leader realised that the price for the raw material had increased to such an extent that the initial cost-benefit analysis was invalid. Few of the actual costs corresponded to the anticipated expenses of the project proposal for example, costs for constructing the production facility and for building auxiliary machines such as a conveyor belt. This was partially related to the fact that the project proposal was written at a stage when the effort of identifying the actual costs of the project exceeded the available human resources of the project implementer.

Hence, it is better calcultate with extra margins to ease the project implementation albeit with the increase of risking not to win the tender for project funding. Requests for additional funding to the donor organisation were additional hurdles.

Lesson 2

Drying of the biomass is the most crucial production step

The test production showed that drying is the most difficult step of the production line of briquettes from forest residues. Drying involved the operation of a heating system with hot water cycle, a heat exchanger (water to air) and two ventilators that transport the heated air to the drying chamber. The drying chamber was built out of a used shipping container (to reduce costs) but was not air tight. The hot air escaped the drying chamber and the raw material could not be dried.

In addition, one container full of raw material needed to be heated for about 48 hours. During the test production, it showed to be very difficult to guarantee a continuous operation of the heating cycle, so that the raw material needed twice the time to dry compared to what calculations suggested.

Furthermore, the container planned to be lifted by a load bearing construction designed by a local blacksmith. The construction was built and installed. When it was meant to lift the container, the construction broke and was bent by the weight of the container leading to additional costs.

Lesson 3

Not all partnerships could be kept as in the business plan.
Reach agreements before handing in the project proposal!

During project planning it was anticipated to provide two schools with briquettes. For this purpose, the schools were supposed to be equipped with central heating systems from Germany. After the project proposal was accepted by the donor organisation the project leader reached out to the schools. Asked about cooperation the schools did not commit to trialing the new technology. This has reduced the awareness raising impact as well as the number of beneficiaries of the project.

Lesson 4

Machines overloaded regional power network.
Be prepared that frame work conditions can't cope with the new technology.

When the RUF 600 briquette press was connected to the local power grid a power cut was the result. The local utility exchanged the old transformer during subsequent days. The machines started operating again until the next power cut occurred a few moments later. Technical assessments showed that the wood chipper (4KW) and the press (22KW) were overloading the local grid again. This lead to further extra costs and time necessary for the repairs.

Marketing approaches for alternative cooking fuels

The following chapter provides some considerations to promote the use and uptake of solid biomass fuels products for cooking that go beyond firewood and charcoal.

The use of biomass for cooking is strongly interlinked with the socio-economic and cultural background of the local population. Fuel-efficient cook stoves and biomass that are produced and supplied on a more sustainable basis constitute two steps required for the successful modernisation of the process with which much of the global population generates energy for cooking its everyday meals. The most important part, however, is acceptance on the part of consumers. In the past, many international cooperation projects have not achieved a long-term impact due to a lack of suitable marketing approaches for cook stoves and biomass, and limited cultural awareness of project developers. Today, any cook stove initiative should first seek to assess the local cultural framework of cooking energy before implementing a supply chain and technology for sustainable cooking energy.

Any activity related to marketing seeks to raise sales and dissemination of the product, hence it is important to communicate the benefits and added value of a product to potential customers. The first step to successful marketing is a market-analysis. This allows to understand and group the market, into customer segments. The market can be segmented based on geographic, demographic, behavioral or cultural characteristics, for example.

Each customer segment needs to be addressed separately. Household income level and purchase power, who is the person that uses the cook stove on a regular basis, what are cultural backgrounds related to preparation of meals – these are just some of the aspects that influence how an enterprise can address its customers for successful marketing. Some of the key questions for deriving a marketing strategy for biomass are:

- What is the energy demand of the customers and how is cooking currently done?
- What is the socio-economic and cultural background of the customers?
- Why and how can the biofuel improve the situation for the customer?
- What does the regional market offer, and which fuels are easily accessible?
- Are most of the products for cooking traded on a formal or informal basis?
- What are the unique selling points of the biofuel compared to other available fuels?
- What is the purchase power of the customer?
- Which form of communication is the most promising when addressing potential customers?

Once the above questions are answered, the marketing approach can be derived. The following case study shall illustrate how this process was undertaken in Georgia.

Case study on marketing approaches: Briquettes from wood waste in Georgia

Let's take a closer look at how briquettes from forest residues in Georgia were marketed to schools and domestic consumers. By using this example, necessary considerations that need to be considered during the process of marketing can be demonstrated more clearly. This case study guides the reader through the development of a marketing approach in a step by step methodology.

The objective was to make use of wooden residues, which are currently left in forests in the proximity of Akhmeta. The high quantities of forest residues represent both a serious risk to forest health and a potential source of devastating forest fires. By turning a forest residue into a valuable energy carrier, the remaining forests would be spared and forest ecosystems would become more resistant. In addition, some regions of Georgia are far from forests, so currently the wood has to be transported. A higher energy density would enable more energy per load to be transported, thus improving the process from an economic perspective.

Annual production was planned to start at 1,000 tons and gradually increase to about 2,000 tons in the following years. In order to guarantee a steady demand a marketing campaign was developed and implemented in Georgia.

Market analysis
Once demand is quantified and the product designed, it is essential to have a clear understanding of the target group that your marketing efforts are directed to. Two customer groups are targeted in the pilot phase of marketing the briquettes in Georgia.

1. Municipal buildings

A few schools and nurseries in the area close to Akhmeta obtain briquettes from the production site for heating their premises. Their procurement is administered by the Ministry of Education, for this reason the demand is guaranteed during the pilot phase of the project. These purchase agreements were agreed before the actual production of briquettes started, for this reason the marketing focus for this consumer group and raises awareness about the benefits of using briquettes and multiplying the approach after successful demonstration.

2. Households

The households in the region of Akhmeta are the second consumer group, particularly the households that make regular use of firewood in the region, coming close to 80% of the total population. The marketing addresses issues like reduction of fuel expenses, lower fuel quantities to handle and less smoke during combustion. These three aspects were identified to be the most cumbersome aspects for households that make use of biomass for heating and cooking in the area.

Marketing approach – advantages of briquettes over firewood

The marketing campaign highlighted the following advantages of briquettes compared to firewood as it is commonly used in Georgia:

1. Wood briquettes with a moisture content of 8-12% have higher calorific value (5 kWh/kg) than fresh firewood of moisture content of 25-30%, which contains about 2.5 kWh/kg.

2. Looking at the volume makes the advantage of briquettes even more evident. 1 m^3 of fresh firewood has ca. 2,500 kWh, whereas 1 m^3 of briquette has ca. 5,500 kWh! Buying one cubic meter gives you much more energy than buying fresh firewood.

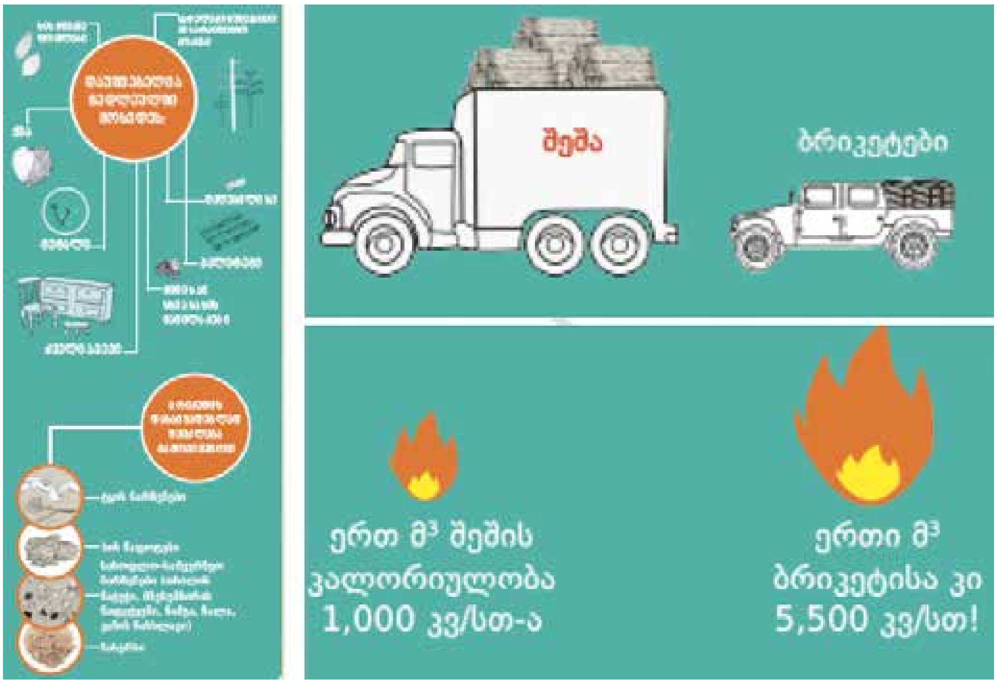
3. The high energy density of the briquettes leads to lower packaging volume and is easier to transport biomass than firewood.

4. The moisture content of the briquettes is about 8-12%, which leads to more efficient and cleaner combustion.

5. The carbon dioxide balance of the process of combustion is the same, as wood briquettes release the same quantity of CO_2 into the atmosphere as the trees captured during their growth during the process of photosynthesis.

For household consumers, pricing and energy content of the briquettes are the most important factors to consider. For public buildings, the ecologic and socio-economic benefits are more relevant. Accordingly, the marketing approach varies depending on the consumer group.

Figure 5.2 Images from the marketing campaign for briquettes in Georgia.
Source: Caucasus Environmental NGO Network.



Marketing approach – advantages of briquettes over firewood

A household that needs 10 m³ (≈10,000 kWh) of fresh firewood can sustain itself with half the volume by buying 3 m³ of firewood (3,000 kWh) and 2 m³ (8,000 kWh) of briquettes. 10 m³ of firewood cost €270, compared to 3 m³ of firewood for €80 + 2 m³ of briquettes for €140, resulting in a total cost of €220 and more energy available than with firewood (an extra 1,000kWh). A minimum cost reduction of €50 for an average household is achievable by having more energy available for heating and cooking at the same time!

The aspects from above were broadcasted on the radio and in the local newspapers in Georgia. Most of the relevant aspects are printed on the packaging of the briquettes (see *figure 5.2*) and showcased during fairs that are carried out in the region with support of regional stakeholders.

Lessons learned from marketing briquettes : The following conclusions and lessons can be observed from marketing approach implemented in Georgia.

- It is important to not only raise awareness in the consumer groups about the environment and climate benefits when using briquettes, but also benefits other than reduction of fuel expenses such as that briquettes burn hotter than firewood.
- As soon as the briquettes were produced and marketed, the suppliers of the raw material understood its 'non zero' value and increased the price of the raw material. It was nearly free during project planning. This is a major lesson learned from planning and implementing the project.
- The resource efficiency depends only to a minor extent on the fuel used. Consumer awareness regarding use of the fuel in combination with efficient conversion technology, i.e. stoves and furnaces, is the key influencing factor. For this reason, the consumers should be educated in the appropriate use of briquettes.
- Most of the marketing is printed on the packaging of the briquettes, making this an extremely important point of project design. For the project in Akhmeta, personnel of the National Forest Agency as well as the NGO Caucasus Environmental Network are dedicated to designing appropriate packaging for briquettes.
- Ideally, consumers use the briquettes in combination with an oven that can regulate the combustion rate by primary air inflow and has a certain heat storage capacity, either by means of firebricks or hot water buffer storage. The marketing campaign incorporates efforts to raise awareness on this matter.

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