The full citation of the published article is as follows:

Kusch-Brandt, Sigrid: Charcoal from alternative materials for use as energy carrier or reducing agent: a review of key findings in Europe and the Americas. SGEM 2018 Conference Proceedings (18th International Multidisciplinary Scientific Geoconference SGEM 2018, 2 July - 8 July 2018), Vol. 18, Energy and Clean Technologies, Issue 4.1, 2018, pp. 203-2010

DOI: 10.5593/sgem2018/4.1/S17.027

ISBN 978-619-7408-44-7 / ISSN 1314-2704

https://sgemworld.at/sgemlib/spip.php?article12151

CHARCOAL FROM ALTERNATIVE MATERIALS FOR USE AS ENERGY CARRIER OR REDUCING AGENT: A REVIEW OF KEY FINDINGS IN EUROPE AND THE AMERICAS

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ABSTRACT

According to FAO, the Food and Agriculture Organization of the United Nations, global annual charcoal production amounts to 52 million metric tons. Around half of the population in South America depends on forest-sourced resources (firewood, charcoal) to cover their basic energy needs, and in some countries large-scale industrial charcoal usage is further common, e.g. in Brazil in the production of pig iron for steel. To limit adverse impacts on forest health, sustainability of charcoal production merits high attention. One approach is to focus on usage of alternative materials such as organic wastes and residues.

A desktop study was implemented to explore experiences with charcoal production with alternative materials in Europe and the Americas, primarily under the lens of potential usage of such charcoal as energy carrier or reducing agent in iron and steel making or similar applications.

Research findings illustrate that a large variety of biomass types can today be converted into charcoal. However, this does not necessarily mean that the obtained output indeed represents a product that can easily substitute conventional energy carriers. One challenge is that charcoal production with alternative materials (biomass other than wood) typically yields an output characterized by a high number of single particles. When substituting coal in steel making, charcoal shows a different performance in the process, which requires attention.

Key differences can be identified when comparing charcoal supply chains and charcoal utilization patterns in South America to the situation in Europe and Northern America. Informal activities are more common in South America. Charcoal markets and their dynamics are less transparent, and documentation is less complete. Usage of wood residues to produce charcoal is more widespread than commonly assumed. One issue in this context is that charcoal statistics do not usually disclose the quality of the used raw material, and charcoal produced from wood might refer to raw wood, but it might also include charcoal made from wood residues.

Keywords: charcoal, biochar, organic wastes and residues, wood residues, iron and steel making

INTRODUCTION

Charcoal production amounted to 52 million metric tons in 2015 [1], showing an increasing trend and uneven distribution across regions worldwide (Figure 1). South America is one of the three main charcoal producing (and charcoal consuming) regions, and most of the production occurs in Brazil, where usage of charcoal as energy carrier and reducing agent in iron and steel making is very common [2]. In contrast to Brazil, where more than 90% of charcoal is used by the industrial sector [2], in other countries of the region charcoal is mainly used in the food sector and in households. About half of the population in South America depends on forest-sourced resources (firewood, charcoal) to meet individual basic energy needs [2]. Charcoal production with wood causes pressures on forest resources, with implications under both environmental and economic perspectives. Depletion of forest resources jeopardizes future economic welfare in the region (and other regions alike). One approach to increase sustainability of charcoal production is to focus on alternative materials such as organic wastes and residues or other low-grade biomasses.

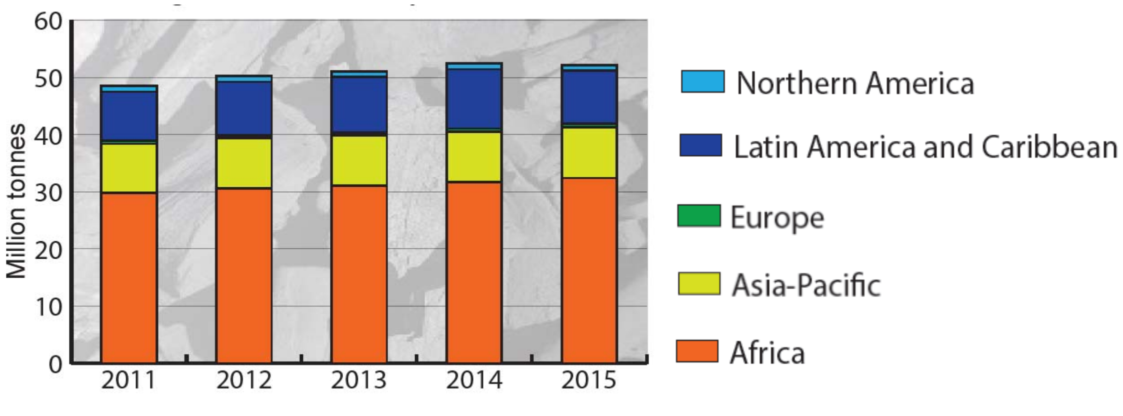

Figure 1: Global charcoal production [1]

Research on charcoal production with alternative materials was carried out as part of the Siderurgia Sustentável Project (Sustainable Iron and Steel Industry), a project implemented by United Nations Development Programme UNDP Brazil to encourage sustainable production of charcoal and its use in the Brazilian iron, steel and ferroalloys industry in order to reduce greenhouse gases emissions. Parts of research tasks were carried out within the UN Volunteering programme. This work reviews experiences with charcoal production with alternative materials made in Europe and the Americas (excluding Brazil), primarily under the lens of potential usage of such charcoal in iron and steel making or similar applications. A desktop study focusing on Europe and the Americas (excluding Brazil) was implemented (other regions were studied as separate tasks, they are not considered here). Results were compiled in a research report [3], and this paper draws from the research report and highlights key findings.

CARBONIZATION TECHNIQUES

Charcoal is traditionally achieved via pyrolysis at temperatures of typically between 400 and 800°C in the absence of oxygen and holding times that range from few minutes to several hours. Charcoal production via pyrolysis is known since long times (several thousand years) for delivering a key energy carrier that burns cleaner and slower than wood, and which has higher energy density compared to the original biomass, which makes transport more viable.

More than pyrolysis exists today. Another way to convert biomass is hydrothermal carbonization (HTC), which occurs in the presence of liquid water and at temperatures of 160-300°C, at pressures of 2 to 70 bar. Solid biogenic material is exposed to a humid environment, whose liquid state is maintained by operating the process in high-pressure reactors, thus enabling the pressure to rise to a favourable level. HTC enables direct use of wet and liquid feedstock, while pyrolysis requires a solid feedstock with limited water content (usually up to 50%). HTC is primarily a development of modern times, with major progress made in the last two decades. The energy balance is more favourable than that of pyrolysis, and loss of carbon is significantly lower, but the process is more complex. There is some inconsistency in whether the solid product of HTC is included when reference is made to charcoal, or whether charcoal is considered to comprise solely the output of pyrolysis. The products of pyrolysis and HTC both are carbon-enriched solid materials, but they differ chemically and in their burning performance. HTC delivers a solid output that resembles to brown coal (lignite). It is often referred to as hydrochar.

The solid output of HTC is also commonly referred to as biochar. However, there is no consistent usage of the term biochar either. Biochar usually might include all types of chars obtained from biomass, or sometimes only some types, whether obtained via pyrolysis, HTC or other processes.

In addition to pyrolysis and HTC, two further char production processes exist, although they remain less common: vapothermal carbonization (VTC) and torrefaction. Vapothermal carbonization resembles hydrothermal carbonization, but the process is operated in a steam environment, which allows for higher solid content (biomass mass) in the reactor, thus resulting in a process that proceeds faster and generates less wastewater compared to hydrothermal carbonization, however, the solid output has a lower carbon content compared to HTC outputs [4].

Torrefaction is a mild form of pyrolysis, operated in an oxygen-free environment with slow heating of biomass at temperatures of typically 200-350°C. This achieves char-like structures of the remaining material, after moisture and oxygen-rich and hydrogen-rich functional groups are driven off. Torrefaction was developed some 200 years ago to improve the fuel properties of solid biomass: the solid output is more uniform than unprocessed biomass, regardless of the origin of the biomass, and has higher energy content than the original biomass. Torrefaction therefore represents a good biomass pre-treatment option when supplying biomass as energy carrier. Compared to pyrolysis, loss of carbon is lower, but also the general conversion degree of biomass is lower. Compared to hydrothermal, and also to vapothermal carbonization, torrefaction as a water-free (dry) process achieves a solid output that has a lower carbon content, making it less attractive under this aspect [4], but its application is less complex, and the resulting output usually requires little precaution and expert knowledge in its handling.

BIOMASS RESOURCES FOR CHARCOAL PRODUCTION

Based on their origin and their occurrence in value chains, seven groups of biogenic materials for charcoal production can be identified [3]:

- Raw wood after harvesting
- Other wood biomass, occurring as residual materials during felling and initial handling of trees (e.g. bark waste, wood pieces) or during processing of wood (e.g. sawmill residues)
- Biomass resource purposely cultivated as energy crops (or for other bioeconomy applications) through agricultural activity
- Residual biogenic material occurring in agriculture and landscape maintenance (e.g. crop harvest residues such as straw, manures, grasses and green cut from parks)
- Materials originating from individual human settlements (e.g. the biogenic fraction of municipal solid wastes, yard trimmings)
- Residues from industrial productions, in particular biogenic residues occurring in the food and beverage sector (e.g. nut shells, spent coffee grounds, distillers' grains, pomaces)
- Other biomasses, such as algal biomass

In Europe and Northern America, carbonization of biomass is researched primarily under the aspect to valorise low-value biogenic residues into a high-value target product (other than a fuel). Such a target product can be a highly reactive char to serve catalytic applications in the pharmaceutical industry or in other industries, or which can be used for purification of water or air. Another target application is the supply of biochar to be used as soil amendment, which can increase soil productivity and discourage deforestation [5]. Applying biochar to soil also means that the contained carbon will be sequestered for many centuries. As a means to combat climate change, this carbon sequestration pathway has boosted research around biomass carbonization mainly in the last two decades, and research and development in this field remain vibrant in particular throughout Europe, Northern America, and also Asia. Desired properties of such biochars differ from desired properties of carbonized materials that are to be used as fuels, therefore, findings are not generally transferable to the area of production of charcoal to be used in iron and steel making, or other applications as a fuel.

Although research findings illustrate that all kinds of biomasses can today be converted into charcoal, this does not necessarily mean that the obtained output indeed represents a product that is successfully marketable as a fuel. In Europe and Northern America, much of the used charcoal is used in speciality cookery such as barbecuing, and the demand is for a specific quality or even a specific type of charcoal. Such demand for a specific type of charcoal was also observed in South America in urban areas of Peru [6].

Charcoal production with alternative materials (biomass other than wood) yields an output that is characterised by a high number of single particles, which can be rather fine or rather lumped, depending on the input material and the processes applied. Pyrolysis of sawdust for example, which is one biomass extensively used for charcoal production in all three regions studied in this work (Europe, Northern America, South America), delivers a fine powder. Such powder will usually be processed into briquettes. At an industrial scale, it was found that char from pyrolysis, in fact, needs to be compressed into briquettes in order to obtain a material able to resist to handling operations inside a factory, such as a steel making plant, avoiding the dispersion of very reactive powders during charging operation [7]. Briquetted charcoal also shows more homogeneous burning properties and less occurrence of anomalous flame emissions, as was demonstrated in European full scale industrial steel making factories during experimental campaigns [7, 8]. Briquetting is usually done with mixtures of charcoal particles, water and binders, and applying elevated pressure [9]. Typical binders are wood tar, starch, molasses, clay and gum Arabic. Briquetting of torrefied biomass is much simpler than briquetting of pyrolyzed biomass [7]. However, especially for industrial applications it should be considered that torrefied biomass is generally less homogeneous and less predictable compared to pyrolyzed biomass.

KEY LESSONS LEARNED FROM EUROPE AND NORTHERN AMERICA

In Europe and Northern America, targeted sourcing of materials other than wood for the production of charcoal is not a key focus. Rather it is the inverse case, where an underutilised biomass is identified, in particular biogenic wastes and residues, that charcoal production – whether as a fuel or for other applications – is considered as one possible valorisation strategy to make use of such biomass. Iron and steel making in Europe and Northern America are based on fossil fuels, and do not use charcoal. Nevertheless, substitution of coal by charcoal obtained via pyrolysis of locally sourced low-value biomass (forest residues, agricultural residues) was tested in Europe at industrial scale in conventional steel making factories (electric arc furnace) [8]. Technical feasibility and economic viability were assessed. Briquetted pyrolysis charcoal showed generally good technical performance, although attention is required to the fact that the charcoal differs from coal in its application, and in some cases technical modifications might be required [8]. This highlights that, where substitution of conventional fuels at industrial level is considered, extensive testing should be implemented before indeed deciding in favour of such changes. One interesting aspect observed during steelmaking was that usage of charcoal reduced the melting time by some 30-50% [10]. Substitution of coal by charcoal did not affect quality of the steel in a negative way, although the composition of the produced steel showed some differences with view to its carbon content [8, 10]. With view to economic viability, in Europe substitution of coal by pyrolysis charcoal is difficult to be cost-competitive; however, if additional benefits are obtained, e.g. via emission trading schemes, economic viability appears achievable [8]. Torrefied biomass is more cost-competitive compared to pyrolyzed biomass [7], but state of knowledge about usage of torrefied biomass is more limited. Generally, material obtained via pyrolysis, hydrothermal carbonization and torrefaction was all assessed to be successfully applicable in existing European steel making plants, however, most experiences are with pyrolyzed biomass.

In Europe and Northern America, charcoal production today is subject to strict emission standards, which had major impacts on progress in the existing state of the art and on implementation of advanced technologies. Efficient technologies are one element to drastically reduce adverse environmental impacts of charcoal production. Case studies from Europe [3] reveal that technically advanced charcoal production facilities reduce the associated emission of greenhouse gases by at least a factor of 2 to 3, and most likely by even higher factors [11]. This further improves the environmental balance of charcoal production and usage. More generally, Life-Cycle Analysis (LCA, assessing environmental impacts) revealed that most existing biochar production systems indeed represent negative carbon processes, with favourable performance regarding climate change mitigation [12]. LCA implemented by Moreira et al. [12] furthermore showed that materials based on lignocellulosic waste achieve the highest environmental benefits in charcoal production, mainly due to the large energy potential of lignocellulosic biomass in comparison with other feedstocks. Lignocellulosic biomass comprises for example straw, forest harvest residues, nut shells. Looking at usage of charcoal in cement production in Canada, thus substituting fossil fuel, LCA implemented by Ayer & Dias [13] demonstrated that achieving considerable environmental benefits is linked to sufficient availability of locally sourced low-quality biomass, such as forest harvest residues. These findings highlight that good environmental performance of charcoal systems depends both on efficient technologies and on usage of responsibly sourced biomass. This is applicable to all regions worldwide.

KEY LESSONS LEARNED FROM SOUTH AMERICA

Comparing charcoal supply chains and charcoal utilisation patterns in South America to the situation in Europe and Northern America, some key differences can be identified. South American charcoal supply chains constitute of formal and informal activities, and have manifold links between actors, and typically involve a high number of individuals, including small-scale actors whose livelihoods are fundamentally tied to charcoal production [2, 6, 14]. Much of the population directly depends on resources originating from forests, mostly firewood and charcoal, to cover basic energy needs [2], which further increases vulnerability of large population groups. This calls for highest attention to responsibly manage wood resources. It further highlights that in South

America, in contrast to Europe and Northern America, a strong effort to find alternative biomass resources to produce charcoal is to be considered a major priority.

Carbonization of wood residues, often in small-scale rural or urban pyrolysis kilns, is common in South America. Large quantities of sawmill waste are available. Valorisation of wood residues to charcoal might be more widespread throughout the region than commonly assumed. One issue in this context is that charcoal statistics do not usually disclose the precise nature of the used raw material, and charcoal produced from wood might refer to raw wood, but it might also include significant quantities of charcoal made from wood residues. This makes it difficult to fully understand the charcoal market and its dynamics, and it also makes it difficult to precisely assess the impact of charcoal production on forest health. A field study about the charcoal supply chain between the Amazonian zone in Ucayali and Peru’s capital city of Lima revealed that in the region the system of charcoal production is based almost entirely on the use of sawmill waste as scrap wood, and remnant wood in formerly cleared agricultural areas, while felling live trees for charcoal production is not common [6]. These results suggest that it creates a knowledge gap in the charcoal context if statistical data do not show whether wood charcoal is made from raw wood or from wood residues.

Another issue is that statistical data might be incomplete with documenting the total charcoal quantities produced and consumed. In Peru, charcoal production in Pucallpa, the capital city of the region of Ucayali, was found to be more than 80 times higher than official figures [6]. One factor in this context can be assumed to be the high number of actors involved in the charcoal sector and the high number of small-scale charcoal production units, as well as the highly decentralized usage of charcoal.

In addition, the study reveals that technical details about individual charcoal production processes and charcoal usage in South America are generally less well documented compared to Europe and Northern America. Overall, the level of transparency around charcoal production and usage, be it in traditional form or with innovative approaches, is significantly lower in South America than in Europe and Northern America. This makes it difficult to assess areas that should be subjected with priority to improvements, but it also makes it difficult to identify and explore innovations in the field, and to find and evaluate shining examples in South America that contribute to more efficient and responsible use of available resources. Making local knowledge better available could be a decisive factor to improve sustainability of charcoal production and usage throughout South America, and to achieve multiplier effects for innovative solutions.

Two alternative charcoal resources with very high potential for South America are bamboo, including residues from processing bamboo into high-value market products, and oil palm residues [3]. Most information about both types of biomass, their performance in charcoal production processes, and characteristics of obtained charcoals are available in Asia. Transferability of the knowledge derived in the Asian context about carbonization of bamboo and oil palm residues merits high attention and warrants increased efforts.

CONCLUSIONS

Pyrolysis, hydrothermal carbonization and torrefaction have been demonstrated to be able to generate a carbon-enriched output from a large variety of different biomasses. Most experiences exist with pyrolysis, which has the longest tradition and today remains the most common carbonization process, while hydrothermal carbonization and torrefaction are being deployed more recently. Although all kinds of biomasses can be transformed into chars using the different techniques, this does not mean that the obtained carbon-enriched products can easily be used to substitute conventional fossil fuels such as coal in iron and steel making or in similar applications. Biomass chars, due to the higher presence of volatile matter and the higher specific area compared to fossil coal, are much more reactive materials than coal.

Under environmental criteria, carbonization of lignocellulosic biomass, in particular wastes and residual biomasses, is most favourable, and availability of local materials is essential. Responsible sourcing of biomass and implementation of highly efficient carbonization technologies both have a major role to play in making the charcoal sector more sustainable. European practice shows that usage of advanced charcoal production facilities reduces emission of greenhouse gases by at least a factor of 2 to 3.

Usage of wood residues, e.g. from sawmills, might be more common than assumed, in particular throughout South America. While this is generally positive, it is a problematic issue that charcoal statistics do not usually disclose the precise nature of used raw materials. Charcoal from wood might refer to raw wood but also to wood residues. This makes it difficult to fully understand charcoal markets and the environmental impacts of charcoal production. In addition, statistical data might be incomplete with documenting the total charcoal quantities. Overall, the level of transparency around charcoal production and usage in South America requires improvement. Two alternative biomass types that warrant more attention are bamboo and oil palm residues.

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