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Application of the hydrothermal carbonization technology to produce electricity by using rice-straw as a renewable energy resource

Introducing a Concept for South-East Asia to install a renewable energy project with the focus of improving the fuel quality of rice straw for co-firing purposes in existing coal-fired power plants

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Abstract

The proposed concept incorporates the usage of rice straw as a renewable energy resource. Rice straw typically has low energy density which limits it's economic transportation over short distances. To master this challenge, a transportable mezzanine product with high energy density and the same quality as lignite is produced by the process of hydrothermal carbonization (HTC). The HTC-sites generating the synthetic lignite are located in rural areas and contribute to an economic transportation over longer distances to conventional coal-fired power plants. In addition the synthetic lignite to be used for co-firing purposes is a substitute for the import of expensive hard coal.

Keywords

Rural electrification, village development, renewable energies, biomass, hydrothermal carbonization technology, HTC technology, co-firing of rice residuals, rice husk, rice straw

JEL - Classification

O13, Q42, Q54, Q57, R11

1 Introduction

Rice grows in many regions of Asia with an average yield of 5.0 tons/ha. The by-products are rice husk, which accounts for 20% by weight of the rice and rice straw with 2.5 tons/ha on average. Especially countries such as the Philippines, Thailand, Vietnam and Myanmar are well endowed with renewable energy resources based on these by-products of rice.

For the time being rice husk is used in widespread applications. Typically it is used as fuel for heating purposes in smaller enterprises (Figure 1) or for gasification units for electrification purposes used in decentralized mini-grids [see for more Ahiduzzaman, M. (Rice Husk Energy, 2007) and the Indian company Husk Power Systems www.huskpowersystems.com]. These outcomes show a promising opportunity in employing rice husk as a renewable energy resource. Meanwhile there is a functioning fuel market for rice husks in many countries of Asia (Figure 2). In the case of the Philippines the current price for rice husk is 1.15 Phil pesos per kg.

Figure 1. Usage of rice husk for heating purposes in a small manufacturing enterprise (Fact Finding Mission (2013))

Figure 2. Rice husk delivery (Fact Finding Mission (2013))

A large amount of rice straw, however, is burned or dumped in the fields resulting in waste disposal challenges and methane emissions [see for more Fung, V.; Jenkins, B. (Biomass Power Development, 2003)]. For example, in the Philippines 60% of the rice straw is burned in the fields. That means that there is a large potential to use rice straw as a renewable energy resource. Many attempts have been made in the past to use rice straw as a resource to generate electricity in an effective, economic and environmentally friendly way. For the time being, however, it is challenging to find a sound possibility. Direct combustion is generally hazardous to the environment and human health due to the non-avoidable large amounts of ash and dust. Fermentation is not applicable due to the high content of cellulose. Gasification typically fails due to the low melting temperature of the ash [see for more Jain, A. (Rice Husk Throatless Gasifier, 2006)].

As a result, carbonization of rice straw seems to be the only viable alternative. But the capital-intensive process of carbonization with the aim to produce briquettes or charcoal with a high calorific value and use it later as an alternative to the direct combustion is typically connected to prohibitively high transportation costs and subsequent storage costs [Ghosh, S.; Mahapatra, S; Deka D. (Techno-Economic Analysis of Biomass, 2002)]. This disadvantage comes especially into play as the produced synthetic charcoal can only substitute similar products on a local range and in small scale. Thus producing charcoal or briquettes by a conventional carbonization process provides typically disappointing results in terms of high complexity and high inefficiency. Consequently most of the applied carbonization procedures failed or were not appreciated by the users (Figure 3).

The failure of the carbonization attempts so far does not necessarily mean that this way is not effective, i.e. meaning the wrong direction. Because the other alternatives mentioned are not feasible, it makes sense to think about possibilities to improve the carbonization process to achieve a higher quality. To develop a sound business model based on carbonization, it is necessary to achieve an end-product which can be used in large scale deployment outside rural areas. The rice straw should be converted into a useful form of energy to meet the thermal and mechanical energy requirements of already existing power plants. Thus a co-firing approach achieves an end-product with the properties of at least lignite quality. This helps to reduce the dependency from imported hard coal.

2 Carbonization by the hydrothermal carbonization (HTC)

Many conventional carbonization projects suffer from suboptimal target setting. The typical aim is to produce a synthetic charcoal on a small “household” scale to replace the original material, i.e. rice husk or rice straw, rather than generate a valuable large scale product with high energy density to replace fossil fuels. One practical conclusion is to improve the carbonization process aiming at a “better charcoal” with the properties and the quality of at least lignite. Such an improved carbonization process provides a high energy product to reduce the transportation costs per energy unit and enables rural people to generate additional income by selling this product as a high-quality fuel source.

Value added in terms of scale effects and a tailor-made end-product promises HTC technology (hydrothermal carbonization) with following features:

- The efficiency of this carbonization process is 80%, meaning roughly 80% of the original energy remains [ICU – Ingenieurconsulting (Verwertung von Mähgut (2011)]. In addition the density is increased considerably. Rice straw as a raw material has a low density of 120 kg/m³, whereas, after the HTC carbonization the density increases to 850 kg/m³. The higher density ensures easier handling, storing and transportability.
- Any biomass material can be converted to humus, lignite and hard coal as well as nutrient water within a few hours. The wet biomass material is compressed and heated in a reactor under high pressure of 12 bar and temperatures of 200 degrees (figure 3). Synthetic lignite is generated after 12 hours.
- The HTC technology can be applied to dry as well wet biomass. Thus the energy intensive drying process of all other carbonization procedures is not necessary.

The end product of the HTC procedure is a liquid suspension containing the lignite. Typically a drying process has to be included by re-feeding the surplus energy caused by the exothermical process which takes place in the HTC reactor.

Figure 3: Unused carbonization reactor for producing synthetic charcoal [Fact Finding Mission (2013)]

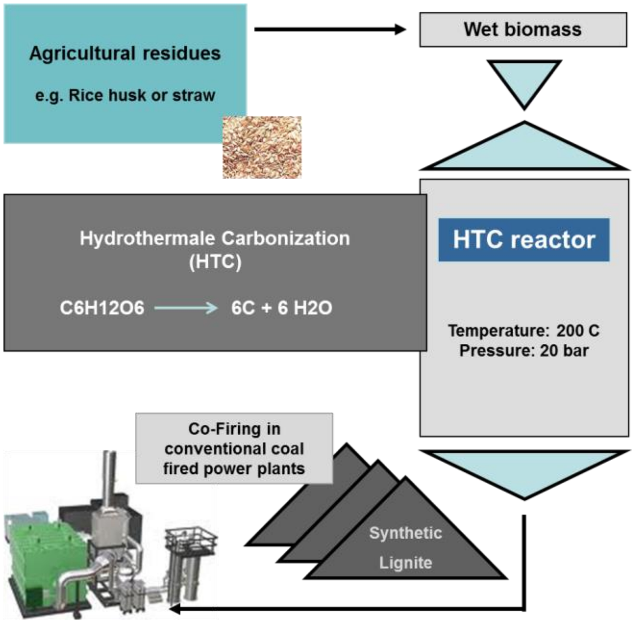

Figure 4: HTC carbonization scheme

Currently the HTC technology is provided by following three German companies:

- SunCoal Industries GmbH, Ludwigsfelde (http://www.suncoal.de/en/technology/carboren-technology)
- CS Carbon Solutions GmbH, Kleinmachnow (http://www.suncoal.de/en/technology/carboren-technology)
- Grenol GmbH, Wülfrath, Germany (http://www.grenol.org)

SunCoal and Carbon Solutions (CS) operate pilot sites in Ludwigsfelde and Teltow, respectively. The HTC site of SunCoal in Ludwigsfelde is based on their CarboRen technology and has a capacity of handling 60,000 tons of wet biomass yearly. Released investment costs for this site were 12 Mio EUR corresponding to roughly 15 Mio USD [FTD (Kohle, 2011)]. The CS site in Ludwigsfelde has a lower capacity of processing, 10,000 tons wet biomass per year. According to a company statement the plant works reliably on a continuing basis to convert greenery of the public parks of the city of Berlin. Their experience has shown that a minimum size of 3,000 tons per year should be planned for a HTC site in order to maintain a reliable process and high product quality. Common agreement is that these sites can operate economically if there are no material costs for biomass. This is typically the case for biomass residuals such as leaves or grass in parks. The city of Berlin conducted an analytical study in which the HTC technology performs best compared to other procedures, i.e. fermentation or composting [Verwertung von Mähgut (2011)].

3 Co-firing of the HTC product

Due to its key features – usage of wet biomass and generation of a high-value end product on a large scale - the HTC-carbonization of rice straw is considered for a co-firing approach, which consists of two components:

- On a decentralized stage in rural areas synthetic lignite is produced by the hydrothermal carbonization process (HTC technology) in sites with a capacity of 4,000 tons per year to achieve a competitive product with high energy density.

- On a centralized stage the produced synthetic lignite will be utilized to produce electricity in a conventional coal fired power plant.

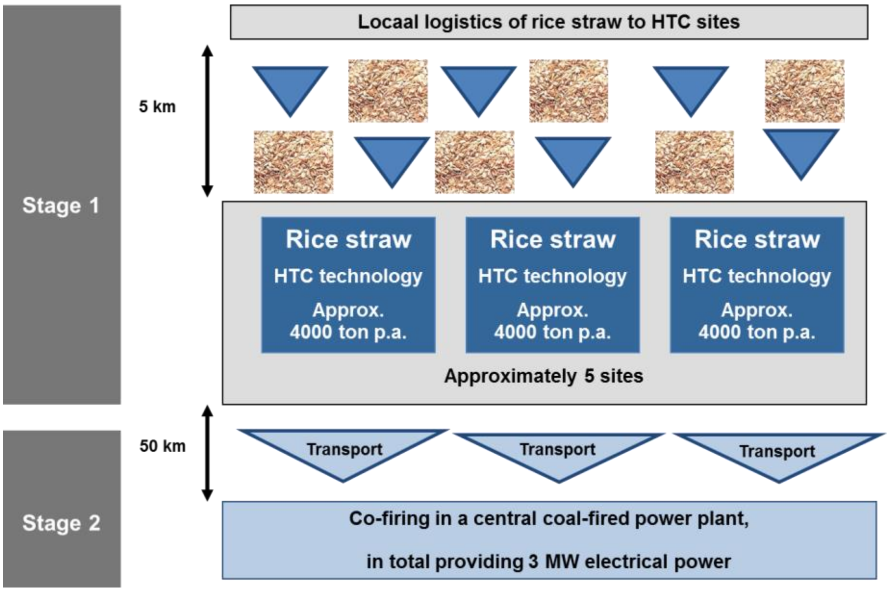

Figure 5: Two-stage-concept for HTC carbonization of rice straw

In such a way the quality of the rice straw as a renewable energy resource is improved to meet the demand of already existing coal fired power plants. This is the core idea of the proposed two-stage approach utilizing rice straw as a renewable energy resource (Figure 5). Rice straw transportation is done decentralized on the conventional way to supply the HTC carbonization units. The transportation of the produced synthetic lignite to the central power plant decreases transportation costs substantially. Along with that goes a clear reduction of dust pollution and fuel oil consumption in comparison to a direct rice straw combustion, as it is already done, e.g. the Roi-et Green power plant located in the north-eastern part of Thailand [Chungsangunsit, T., Shabbir H., Patumsawad S. (Environmental Profile, 2004)].

4 Business valuation

The economic rationale can be achieved by co-firing the produced synthetic lignite in an already existing coal fired power plant based on the following assumptions as in the Philippines (Table 1):

- Investment costs of USD 0.8 Mio. for a HTC site with a capacity of 4000 tons of rice straw yearly (16 tons daily). The investment costs are based on the above mentioned published investment costs of the SunCoal pilot site and a discount of 20% due to learning effects.
- Linear depreciation of the investment costs over 20 years.
- Yield of 500 tons rice and 250 tons rice straw per km^2, meaning that an area of 16 km^2 is necessary to provide the required 4000 tons rice straw.
- Transportation costs for rice straw of 6 USD per ton.
- Labor costs of 14 USD (700 peso) daily for one worker in the HTC site. The required work force is assumed to be three.
- Transportation costs for the produced synthetic lignite of 1 USD per km by assuming a distance of 50 km from the HTC site to the coal fired power plant and 18 tons vehicle transport.

- Pricing of the produced synthetic lignite based on the average price of hard coal in the last 3 years of roughly 100 USD/ton (ARA hard coal future, see for more https://www.eex.com/de/Marktdaten/Handelsdaten/Kohle).

Business assessment	HTC site
Investment costs USD	**800.000**
Capacity Rice Straw ton/p.a.	**4.000**
Caloric value Rice Straw (kWh/kg)	3,6
Yield ton/km²	250
Area requirement (km²)	**16**
Trasnports rice straw daily, small trucks	5
Transports synthetic lignite yearly, 18 tons trucks	105
Efficiency HTC procedure	80%
Produced synthetic lignite ton/p.a.	**1.900**
Caloric value synthetic lignite (kWh/kg)	6,1
Hard coal equivalent ton/p.a.	**1.450**
Price Hard Coal ARA USD/ton	**100**
Revenues per year (Mio. USD)	**145.000**
Transportation Costs Rice straw USD p.a.	24.000
Labour and storage costs US p.a.	11.000
Transportation Costs Lignite USD p.a.	5.000
Total costs incl. depreciation USD p.a.	**80.000**
Earnings per year (Mio. USD)	**65.000**
Return on investment (ROI)	**5%**

Table 1: Business assessment: Rice straw carbonization by the HTC technology

Taken together of the 4,000 tons of HTC that the site produces roughly 1,900 tons synthetic lignite can replace the import of 1,450 tons hard coal. As a practical consequence the increase of the density by the factor of 7 by converting rice straw to synthetic lignite results in an increase of the caloric value of 70% and finally in transport cost savings per ton of more than 50%. In the case of co-firing in a coal fired power plant with an efficiency of 37% the produced synthetic lignite generates 4.3 GWh electrical energy per year corresponding to a power of 0.6 MW assuming 7000 hours of usage per year. The assumptions lead to total costs of roughly 80,000 USD, whereas depreciation takes the half with 40,000 USD remaining. The high fraction of this non-cash item leads to a significant difference between earnings as EBIT of roughly 65,000 USD and the cash flow as EBITDA amounting to 105,000 USD.

At first the return on investment (ROI) seems to be low with 5%. The HTC concept, however, should not only be considered by analyzing issues of cost and earnings. This concept requires a more holistic assessment of the quality of energy supply delivered as it achieves long term sustainability in three dimensions:

- **Economical sustainability**:
  The profitability calculation depicts clearly the dependence on the price of hard coal substituted by the synthetic lignite. An increase of only 20% in the price of hard coal would double the ROI to 10%. Thus the HTC provides an effective hedge against rising prices of fossil energy resources.
- **Ecological sustainability:**
  From a climate approach the substitution of 1,450 tons hard coal avoids a CO2-emission of 3,200 tons CO2 yearly if the hard coal is used to generate electricity in a power plant with 37% efficiency and corresponding CO2 emissions of 0.75 g CO2 per 1 kWh produced electrical energy. If these emission rights can be valued under the

classical CDM scheme with prices of emission rights of 10 USD per ton and more the business case would become very sound, not to say extremely profitable (Gonzales, A.D.; Mathias, A.J. [Market implementation of bio-energy, 2004)].

- **Social sustainability:**
  The two-stage concept of rice straw carbonization by the HTC technology requires an area of roughly 16 km^2 for each HTC site. This is equivalent to a circle of only 2.3 km radius underlying the concept of a local network in a rural area. Thus every HTC site is able to create employment in rural areas, not only by the assumed 3 man work force for logistics and maintenance purposes but rather more in a considerable size to generate entrepreneurship for local logistics requirements.

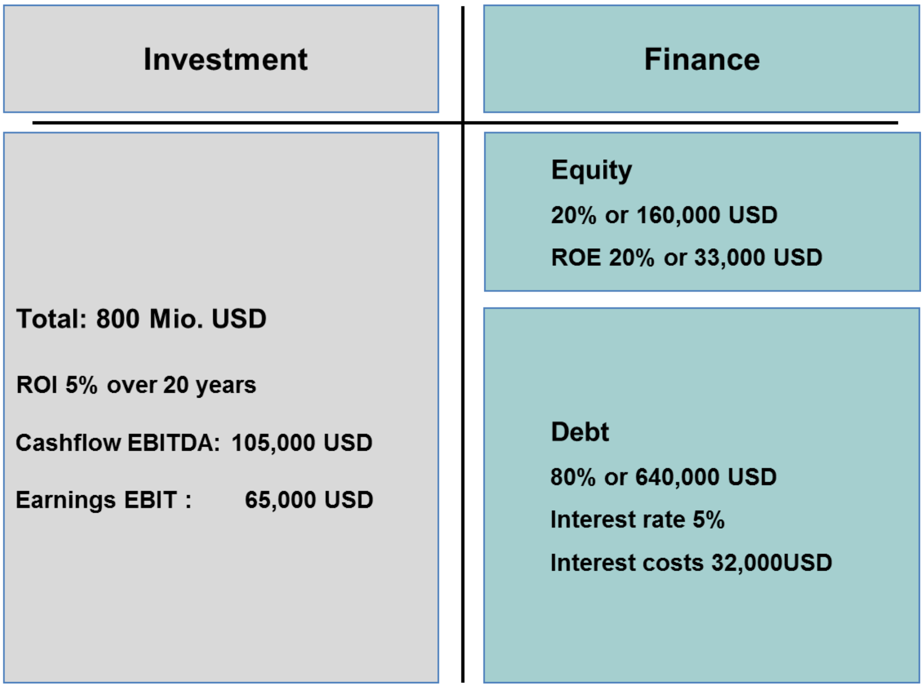

Figure 6: Finance concept for one HTC site

Although long term sustainable elements are provided, a subsidized loan should still be sought. Given the valuable elements of long-term sustainability, however, a subsidized loan arranged by a non-profit orientated organization (NGO) with long term targets should be aimed for. In addition the shown sound cash flow picture should support considerations to come up with a credit facility provided by a NGO. If the investment costs are covered by 80% of such a subsidized loan the profitability will increase substantially. In this case a sound return on equity (ROE) of 20% with an amortization of 5 years is achieved (Figure 6). In the end this HTC concept makes sense from a business perspective.

5 Introduction of the concept

A possible introduction of this concept looks as follows:

Phase I: Conducting a feasibility study
It appears prudent to follow a step-by-step approach. Efforts should be undertaken to carry out a study in partnership with a non-governmental organization (NGO) or a government institution. Furthermore one test unit should be set up.

Phase II: Setting up one or more HTC carbonization production entities
After sufficient information has been gathered, policies should be defined as how to proceed further. Phase II is characterized by optimizing the HTC carbonization concept and by an ongoing intensifying of cooperation possibilities into the network of existing power plants.

Phase III: Integration of the synthetic lignite production for co-firing purposes
This is the ultimate overall objective of this initiative. Proceeding in steps allows for better management of the risks involved. Again, it would be advisable to share some of the risks with a NGO and/or a government institution.

After completion the production sites are owned and managed by a local technology company as service provider closely connected to the national utilities.

6 Conclusion

This paper introduces a concept to use rice straw for electrical power generation by applying the hydrothermal carbonization (HTC) technology. The proposed two-step approach takes into account the dispersed availability of biomass and its low energy density as well as the necessity of an economic generation of electricity. The HTC-technology makes it possible to replace fossil resources of energy. Unused biomass like rice straw can be used effectively and environmental friendly. In addition this technology should be recognized as having a far greater potential impact on energy access and economic activity, especially as they are also capable of providing high quality, surplus supply as opposed to simply substituting the local supply by briquetting or conventional carbonization procedures. Furthermore applying the HTC carbonization on a local level avoids negative environmental effects in terms of transportation efforts and dust pollution of a large scale carbonization. In addition employment for rural people is created.

By co-firing the produced synthetic lignite in existing coal fired power plants, the HTC technology would increase the overall energy efficiency of these conventional power plants and also their environmental profile by reducing their fossil CO2 emissions. The application as a co-firing material creates value for the end-product in a way that a large scale usage of the rice straw would finally be achieved. Accordingly there is social and economic benefit using this concept for countries such as the Philippines, Thailand and Vietnam. However, credit for capital investment is necessary to achieve a sound economic business profile. This could be a severe challenge in introducing this concept. To overcome this constraint non-governmental-organizations (NGO's) could play an important role in the build-up process and in arranging a loan facility.

Literature

Ahiduzzaman, M. (Rice Husk Energy, 2007): Rice Husk Energy Technologies in Bangladesh, Agricultural Engineering International: the CIGR Ejournal. Invited Overview No. 1. Vol. IX. January, 2007

Chungsangunsit, T., Shabbir H., Patumsawad S. (Environmental Profile, 2004): Environmental Profile of Power Generation from Rice Husk in Thailand, The Joint International Conference on Sustainable Energy and Environment (SEE), 1-3 December 2004, Hua Hin, Thailand

Fact Finding Mission (2013): Fact Finding Mission of HNU to the University of the Philippines Diliman, Manila; Excursion to Jennie's Pork Chicharon production site located in Sta. Maria, Province Bulacan August 2013

FTD (Kohle, 2011): Kohle aus dem Kessel, Financial Times Deutschland 17.02.2011, download 01 October, 2013
http://www.suncoal.de/uploads/downloads/FTD_GrueneTechnik_17022011.pdf

Fung, V.; Jenkins, B. (Biomass Power Development, 2003): Biomass Power Development for the Philippines, Agricultural Engineering International: the CIGR Journal of Scientific Research and Development, Vol. V. Invited Overview Paper. Presented at the Forum on Bioproduction in East Asia: Technology Development & Opportunities. ASAE Annual meeting, Las Vegas. 27 July 2003.

Ghosh, S.; Mahapatra, S; Deka D. (Techno-Economic Analysis of Biomass, 2002): Techno-Economic Analysis of Biomass briquetting Technology for Rural Entrepreneurship: A Case Study, Proceedings of the International Conference on Renewable Energy for Rural Development. 19-21 January 2002, Dhaka, Bangladesh. pp.255-257.

Gonzales, A.D.; Mathias, A.J. (Market implementation of bio-energy, 2004): Demonstration and market implementation of bio-energy for heat and electricity in Southeast Asia: Financing Issues and CDM potential, download 18 October, 2004.
http://www.cogen3.net/doc/articles/DemonstrationMarketImplementBio-Energy.pdf

ICU – Ingenieurconsulting (Verwertung von Mähgut, 2011): Konzept zur klimaschonenden Verwertung von Mähgut und Laub in Berlin, Senatsverwaltung für Gesundheit, Umwelt und Verbraucherschutz, Referat Abfallwirtschaft, ICU – Ingenieurconsulting Umwelt und Bau, Dr. Wiegel, März und Partner Ingenieure, Wexstraße 21, 10715 Berlin, 2011, download 01 October, 2013
http://www.stadtentwicklung.berlin.de/umwelt/abfallwirtschaft/downloads/biomasse/studie_maehgut.pdf

Jain, A. (Rice Husk Throatless Gasifier, 2006): Design Parameters for a Rice Husk Throatless Gasifier,. Agricultural Engineering International: the CIGR Ejournal, Manuscript EE 05 012. Vol VIII., 2006