Biomass and Bioenergy 89 (2016) 184–200

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Moving torrefaction towards market introduction – Technical improvements and economic-environmental assessment along the overall torrefaction supply chain through the SECTOR project

Daniela Thrän [a, b, *], Janet Witt [a], Kay Schaubach [a], Jaap Kiel [c], Michiel Carbo [c], Jörg Maier [d], Collins Ndibe [d], Jaap Koppejan [e], Eija Alakangas [f], Stefan Majer [a], Fabian Schipfer [g]

[a] DBFZ Deutsches Biomasseforschungszentrum gGmbH, Torgauer Straße 116, 04347 Leipzig, Germany
[b] UFZ Helmholtz–Zentrum für Umweltforschung GmbH, Permoserstraße 15, 04318 Leipzig, Germany
[c] ECN Energy Research Centre of the Netherlands, 1755 ZG Petten, The Netherlands
[d] Universität Stuttgart, Pfaffenwaldring 23, 70569 Stuttgart, Germany
[e] Procede Biomass BV, Vlierstraat 111, 7544GG Enschede, The Netherlands
[f] VTT Technical Research Centre of Finland Ltd., Koivurannantie 1, FI-40400 Jyväskylä, Finland
[g] Technische Universität Wien, Gusshausstrasse 25/370-3, A-1040 Wien, Austria

ARTICLE INFO

Article history:
Received 18 September 2015
Received in revised form
2 March 2016
Accepted 3 March 2016
Available online 30 March 2016

Keywords:
Torrefaction
Solid biofuel
Sustainability
Standardization
Densification
Market implementation

ABSTRACT

The large-scale implementation of bioenergy demands solid biofuels which can be transported, stored and used efficiently. Torrefaction as a form of pyrolysis converts biomass into biofuels with according improved properties such as energy density, grindability and hydrophobicity. Several initiatives advanced this development. The first pilot-scale and demonstration plants displayed the maturity and potential of the technology.

The European research project SECTOR intended to shorten the time-to-market. Within the project 158 Mg of biomass were torrefied through different technologies (rotary drum, toroidal reactor, moving bed). Their production led to process optimization of combined torrefaction-densification steps for various feedstocks through analysing changes in structure and composition. The torrefied pellets and briquettes were subjected to logistic tests (handling and storage) as well as to tests in small- and large-scale end-uses. This led to further improvement of the torrefied product meeting logistics/end-use requirements, e.g. durability, grindability, hydrophobicity, biodegradation and energy density. Durability exceeds now 95%.

With these test results also international standards of advanced solid biofuels were initiated (ISO standards) as a prerequisite for global trade of torrefied material. Accompanying economic and environmental assessment identified a broad range of scenarios in which torrefied biomass perform better in these areas than traditional solid biofuels (e.g. white pellets), depending e.g. on feedstock, plant size, transport distances, integration of torrefaction in existing industries and end use. The implementation of industrial plants is the next step for the technology development. Different end user markets within and outside Europe can open opportunities here.

1. Introduction

This paper is a condensed summary of final results from the project SECTOR (Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction), which was funded by the European Union's Seventh Programme for research, technological development and demonstration (GA no. 282826). The project aimed at shortening the time to market of torrefaction technology to provide high density bioenergy carriers, spanning the complete value chain, which it achieved successfully.

Large scale implementation of bioenergy is expected to increase [1–9], and high energy density commodities form the key to

* Corresponding author. DBFZ Deutsches Biomasseforschungszentrum gGmbH, Torgauer Straße 116, 04347 Leipzig, Germany.
E-mail addresses: daniela.thraen@dbfz.de (D. Thrän), kiel@ecn.nl (J. Kiel), Joerg.Maier@ifk.uni-stuttgart.de (J. Maier), JaapKoppejan@procede.nl (J. Koppejan), Eija.Alakangas@vtt.fi (E. Alakangas), schipfer@eeg.tuwien.ac.at (F. Schipfer).

http://dx.doi.org/10.1016/j.biombioe.2016.03.004
0961-9534/

establish this. In Europe, adapted biomass fuels for co-firing in coal power stations could significantly support the fulfilment of the political targets – the provision of 20% of the primary energy consumption through renewable fuels until 2020, and 27% until 2030 – with relatively minor technical adaptations and at acceptable costs [2,10].

This requires bioenergy carriers that behave similarly to coal during logistics, milling, combustion and gasification in order to use the existing infrastructure. Crucial properties are the net calorific value, required energy for milling, particle size distribution, mill capacity and pneumatic feeding. Another short term application is the use of bioenergy carriers in small and medium scale boilers. Here, an optimal alignment between boilers and bioenergy carriers regarding heating value, volatile matter and moisture, bulk density and fuel pellet dimensions has to be established [3,4]. In the long term, the use of bioenergy carriers to produce bio-chemicals and bio-fuels via gasification routes is expected.

One approach to provide these bioenergy carriers is the torrefaction of solid biomass, such as wood and herbaceous material [4,11]. During torrefaction, as a form of mild pyrolysis, water and part of the volatile matter are removed which results in a brittle and to a certain degree hydrophobic intermediate. By combining torrefaction with pelletization or briquetting, solid biomass materials can be converted into a high-energy-density commodity energy carrier with additional advantageous fuel properties compared with white wood pellets, such as improved grindability, higher water resistance and good biological stability. These torrefied biomass pellets can be provided in a constant, end-user specific quality [1,5]. This indicates that logistics, handling and conversion of torrefied biomass pellets may occur in a fashion that is more comparable to fossil solid fuels such as coal. Additional value could be created by reclaiming the volatile matter that is released during torrefaction, as wood vinegar or resin substitute [6,12].

Technical development of this pre-treatment of solid biofuels has been intensified during the last decade [7,8,13,14]. Technology development and implementation is currently pushed with different research and demonstration projects mostly in the European Union and North America (Fig. 1).

The main issues in torrefaction development at the start of the project (2012) have been process control, heat integration, process upscaling, ensuring product quality that allowed large scale handling, outdoor storage and end use as well as flexible input materials [15]. Torrefaction of non-woody biomass is an additional relevant issue as large biomass potentials especially from residues have been identified in several assessments [16,17]. Market implementation and integration are further important subjects for research.

The SECTOR project included these as major issues into its work program. The overall objective was to produce torrefied biomass pellets with properties similar to those of coal to enable its substitution without major adaptations of existing conversion installations. The project achieved continuous production ensuring the required properties and proved the applicability of torrefied material in major end uses.

The project included different torrefaction technologies, densification methods, logistic and storage testing, end use application in small-, medium- and large-scale combustion and gasification units. Furthermore assessments of the overall value chain were conducted and several standards of fuel characterisation were prepared. 21 partners from 9 countries contributed to this project. More than 150 Mg of torrefied biomass have been produced from 12 different raw materials. These have been tested in about 30 different setups with respect to behaviour during logistics and end use.

Two major framework conditions were set by analysing the global and European biomass potential (most interesting in EU: wood/wood residues (3.7 EJ a^{-1}) and straw (0.56–0.982 EJ a^{-1}) and by identifying the end user needs (application specific values for net calorific value, ash mass fraction, particle size distribution, moisture and price) [18]. The optimization work within SECTOR is based on these findings.

This paper will summarise the results in the different research areas of the SECTOR project and conclude the market readiness of torrefied solid biofuels. It will commence with the description of the results from torrefaction and densification test performed in the different facilities (chapter 2), followed by the results of the logistic, storage (chapter 3) and end use application tests (chapter 4). Based on these results we provide an assessment of the fuel quality, the environmental and economic aspects of torrefied biomass in comparison to other solid fuels (untreated woody biofuels and coal) and discuss proposals for appropriate fuel standards and declarations, including sustainability requirements (chapter 5). Finally, we discuss the market opportunities with regard to promising application fields (chapter 6) and conclude with suggested market implementation strategies and the remaining research demand (chapter 7).

2. Torrefaction and densification

The combination of biomass torrefaction and densification potentially results in superior properties for the use of biomass in many major end-use applications such as co-firing and co-gasification in coal fired power plants. Torrefaction and densification of biomass result in solid bioenergy carriers that display a high extent of homogeneity in comparison with the corresponding untreated feedstock. This offers several advantages, amongst others: it can be traded as a commodity, storage and handling does not need to be dedicated to a specific feedstock, and milling and feeding occurs in a steady manner. The combined optimization of torrefaction and densification is necessary in pursuit of high-quality solid bioenergy carriers.

During torrefaction, biomass is heated to temperatures between 250 and 350 °C in an oxygen depleted environment. In this temperature range hemicellulose is the most reactive component present in lignocellulosic biomass followed by lignin, while cellulose is the most thermally stable [19]. Due to the fact that the hemicellulose strength is severely weakened during torrefaction, the torrefied biomass becomes brittle, which eases comminution and subsequent densification into sustainable solid bioenergy carriers, such as pellets and briquettes. Upon moderate torrefaction temperatures lignin is typically only slightly affected and can serve as binder during the densification process. Therefore, different performance parameters need to be considered that affect both the pretreatment process (e.g. net energy efficiency and the resulting production costs) as well as the product quality. The most important product characteristics are the energy density (in order to avoid de-rating of the power plants), grindability (to use the existing mills also used for coal), mechanical durability (to prevent loss of mass during transport and avoid dust formation), hydrophobicity and biological stability (required for storage) [4,9,11,20]. Therefore, also storage and end use application of the torrefied biomass have been tested (see chapter 3 and 4).

Within SECTOR, about 12 different biomass feedstock have been torrefied (e.g. pine, spruce, poplar, forest residues, bamboo, straw, Paulownia), conditioned and densified at pilot- or demonstration scale. The composition of a large number of torrefied materials that are described in this paper can be found in the online Phyllis2 database [21]. This has resulted in further optimization of the torrefaction technologies under development by: 1. broadening the feedstock range, 2. allowing the production of solid sustainable