



# An assessment of the torrefaction of North American pine and life cycle greenhouse gas emissions



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## ABSTRACT

Bioenergy is increasingly being used to meet EU objectives for renewable energy generation and reducing greenhouse gas (GHG) emissions. Problems with using biomass however include high moisture contents, lower calorific value and poor grindability when compared to fossil fuels. Torrefaction is a pre-treatment process that aims to address these issues. In this paper four torrefaction treatments of pine were performed and a mass–energy balance calculated. Using experimental data, a pellet production supply chain incorporating torrefaction was modelled and compared to an existing wood pellet system to determine life-cycle GHG emissions. Two utility fuels, wood chips and natural gas, were considered to provide process heat in addition to volatile gases released during torrefaction (torgas). Experimental results show that torrefaction reduces the moisture content and increases the calorific value of the fuels. Increasing torrefaction temperature and residence time results in lower mass and energy yields. GHG emissions reduce with increasing torrefaction severity. Emissions from drying & torrefaction and shipping are the highest GHG contributors to the supply chain. All 4 torrefaction conditions assessed outperformed traditional wood pellet supply chain emissions but more land is required which increases with temperature and residence time. Sensitivity analysis results show that emissions increase significantly where natural gas is used for utility fuel and no torgas is utilised.

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## 1. Introduction

Several EU countries are endeavouring to increase the use of renewable energy and reduce greenhouse gas emissions by 2020 with further targets set for 2030 [1,2]. In addition to the targets set out in the European Renewable Energy Directive, the UK is also bound by legal framework to reduce its GHG emissions by at least 80% relative to 1990 levels by 2050 in accordance with the Climate Change Act 2008 [3]. In fulfilling these emissions reduction targets, it is widely accepted that bioenergy will play a significant role as outlined in the UK bioenergy strategy [4] and as a result is being increasingly mobilised to help achieve these policy goals domestically as well as across several EU states.

The energy sector was responsible just under a third of UK GHG emissions in 2013 [5], therefore ways in which it can be reduced must be explored. The use of solid biomass for energy has undergone rapid expansion in the past few years owing to its relatively

easy and cost-effective incorporation in to existing solid fuel supply chains (e.g. coal supply chains). In addition, when compared with other sources of renewable energy, biomass is an attractive option being a carbon carrier that can be stored and brought on-line when required and so alleviates issues of intermittency associated with solar and wind technologies, for example. Owing to limited and competing land availability in the EU however, generous subsidies for renewable electricity and heat have led to a rapid increase in biomass imports to the UK and EU [6–8]. Despite this, there can be challenges associated with using biomass as a fuel [9] with issues including high moisture content (MC), low calorific value (CV), low bulk density, poor grindability and heterogeneity relative to fossil-based fuels which may cause problems with logistics, bulk handling and transportation [10,11]. Densification treatments are therefore normally implemented to ‘raw’ biomass to help alleviate these problems with conventional wood pellets currently the favoured form of biomass for transportation over long distances. Ofgem reported that in 2011–12 1.3 million tonnes of wood pellets were imported to the UK under the Renewables Obligation (RO), with over 90% coming from North America [12]. Demand for wood pellets has rapidly increased over

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the last decade and is projected to continue expanding due to incentives for bioenergy in the UK and EU [3,8]. Nevertheless, conventional wood pellets still retain some of the inherent problems associated with biomass such as absorption of moisture upon transportation and storage, which can cause pellets to become mouldy and disintegrate [13]. Additional treatments can therefore be considered in lieu or in combination with pelletisation. Torrefaction of biomass is one such treatment that goes some way to address these issues. Torrefaction, sometimes called 'mild pyrolysis' is a pre-treatment process where biomass is heated in the absence of oxygen at low heating rates (<50 °C/min) to temperatures between 200 and 300 °C to produce a darkened material with improved chemical and physical properties [14]. During torrefaction, moisture and oxygen-rich volatile materials with low calorific value are driven off resulting in a reduction in hydroxyl groups (that form hydrogen bonds with moisture) and a greater mass loss to energy loss producing a more energy dense fuel. The loss of these volatile compounds are mainly ascribed to decomposition of the hemicellulose fraction, which binds the cellulose fibrils in the cell wall providing structural integrity and so their partial or full decomposition results in a fuel with improved grindability characteristics [15–17]. It is suggested that torrefaction combined with pelletisation is thus preferable to untreated wood pellets as a result of lower moisture, higher heating value, improved bulk density and wider handling and transport benefits [9,18]. An additional benefit is the use of torrefied pellets in existing power plants. Torrefied pellets can be ground to a fine dust with relatively minor modifications in existing coal mills, whereas conventional pellets require specialised mills and higher amounts of energy for grinding [19]. A disadvantage however is the possibility of fine dust formation during handling, with associated explosion risk. Durability of pellets is therefore another important consideration.

While torrefaction improves the chemical and physical properties of raw biomass, as the process often requires drying of the fuel prior to torrefaction, the process is overall endothermic and so requires an energy input. Although most of the original energy content of the fuel is contained within the solid torrefied product, during torrefaction some energy will be lost in the volatile materials evolved which can be combusted to provide some of the heat requirements of the process. In the case where the gases produced do not meet the heat demand for drying and torrefaction, an additional source of heat is required. It must be determined therefore whether the benefits of torrefaction outweigh any potential energy penalties paid.

Utilising torrefied biomass will also have other implications along the bioenergy supply chain from the amount of feedstock required to its impact on pellet production and energy delivered to the end-user. These impacts become significant when considering life-cycle emissions and must remain within sustainability guidelines [7]. To assess the potential for torrefied wood being used as pellets, this paper combines experimental work on the torrefaction of North American pine with whole systems assessment of greenhouse gas (GHG) emissions from the supply chain. In this study, North American pine has been torrefied under 4 different conditions to determine the changes in fuel properties and a mass and energy balance for each process determined. Using these data, the energy requirements for the torrefaction processes have been modelled and incorporated in to a bioenergy supply chain in which the feedstock is harvested, torrefied and pelletised in the United States and transported to the UK to determine the life-cycle GHG emissions for electricity generation. The results are then compared with a conventional wood pellet supply chain and a sensitivity analysis performed to assess key assumptions and data uncertainties.

## 2. Methodology

The methodology described below is split into two main sections being the experimental work and the greenhouse gas emission assessment.

### 2.1. Experimental

#### 2.1.1. Samples

The fuel used in this study was pine wood (de-barked) grown in North America and sourced from a UK power station. The sample was in the form of wood chips in the size range 5–30 mm.

#### 2.1.2. Torrefaction of pine chips

The torrefaction experiments were conducted using a three zone electrically heated horizontal tube furnace with an internal diameter of 75 mm and 750 mm in length (Elite Thermal Systems). The heated zone, controlled by three PID controllers (Eurotherm, Schneider Electric), is approximately 575 mm in length. A full description of the experimental equipment can be found in [20]. The temperature in the furnace was monitored using three thermocouples at 20 cm intervals inside the reactor tube, measuring the temperature of both the inert gas and the sample with temperature profiles recorded for each experiment. In each torrefaction experiment, approximately 100 g of untreated sample was weighed and placed in a reactor tube 800 mm in length with an internal diameter 60 mm, with the sample positioned within the heating zone of the furnace. Each torrefaction experiment was performed under a flow of nitrogen (1.2 L/min) controlled using a valve and flow meter.

The samples were heated at a rate of 10 °C/min to 150 °C and held at this temperature for one hour to dry before heating at the same rate to the final temperature where the sample was then held for the desired residence time. The torrefaction conditions performed in these experiments are shown in Table 1.

The residence time in this instance begins when the gas temperature has reached the desired final temperature and held for the desired residence time after which the reactor tube was quickly removed from the furnace and quenched with an increased flow of N<sub>2</sub> to ensure rapid cooling. It must be noted that during some torrefaction experiments, the temperature recorded from the thermocouples was in some cases 15 °C higher than the set temperature indicating exothermic activity during torrefaction. Once cool, the torrefied sample was carefully removed from the reactor tube and weighed. The mass yields (dry basis) for each experiment were calculated using the following equation:

$$\eta_m = \left( \frac{m_{\text{treated,dry}}}{m_{\text{untreated,dry}}} \right) \times 100 \quad (1)$$

where  $m_{\text{treated,dry}}$  and  $m_{\text{untreated,dry}}$  correspond to the mass of the treated and untreated biomass (dry basis) before and after torrefaction respectively.

**Table 1**  
Summary of the torrefaction conditions used in torrefaction experiments.

Condition name	Temperature (°C)	Residence time (min)
250-30	250	30
270-30	270	30
270-60	270	60
290-30	290	30

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