Overview of international developments in torrefaction

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Abstract

Torrefaction is a thermal pre-treatment technology, which produces a solid biofuel product that has superior handling, milling and co-firing capabilities compared to other biofuels. Although the favourable properties of torrefied biomasss have been proven on lab and pilot scale, there are still many technical and business challenges that need to be taken up in order to realize torrefaction on a commercial scale.

Torrefaction technology is currently entering the commercial demonstration phase. Three 35 – 60 kton/a European torrefaction plants are starting up production in Q4 2010/ Q1 2011. In Northern America there are also some interesting initiatives under development, but the first commercial demonstration plant still has to be realized. The market potential of torrefied biomass is huge, because the product can potentially be applied in large-scale power production, industrial heating and residential/district heating. The market for torrefaction of biomass is currently mostly driven by utilities, which are looking for a cost effective and secure supply of biomass in order to reduce their CO_2 emissions or to increase their share of renewables. The current demand for torrefied biomass of utilities alone exceeds by far the production capacity that can be realized in the coming years. This puts a lot of pressure on the torrefaction developers, which need to scale up their technologies as soon as possible. However, the technology and the process still need to be optimized.

Most of the torrefaction technologies, which are currently available have been designed and tested on processing woody biomass. Pilot plant testing with different biomass types already showed that the feedstock flexibility of the current torrefaction technology generation is limited. Further R&D efforts are needed in order to torrefy agricultural biomass in a technically and economically feasible way. Operational experience with the commercial demonstration plants is needed to optimize the balance between particle size, temperature and retention time, which vary per biomass type. Furthermore, there is an economic optimum between energy yield (good process control and high efficiency), product quality and feedstock price.

Apart from technological development, product standardization and large-scale product validation are required to develop a commercial market for torrefaction. Utilities have difficulties with articulating their demand, because they have no experience with the product. There are still a lot of uncertainties about storage, transport, milling and combustion of torrefied biomass. To conclude, the market for torrefied biomass strongly depends on whether the first torrefaction plants in operation will be able to produce a product that lives up to the expectations.

Introduction

The utility sector in many countries is facing major changes in the energy value chain. Renewable energy targets/ obligations and CO_2 emission markets drive the transition to a cleaner and renewable energy production system. In this context, utilities are looking for cost effective options with a large impact. Co-firing biomass is, together with wind power and hydro power, the main contributor to meeting the world's renewable energy targets. It avoids the destruction of capital, by making coal-fired power plants cleaner without having to replace them. However, coal-fired power plants are not designed to co-fire large amounts of biomass. In practise, this means that not more than 5 – 10% (e/e) of biomass can be co-fired. In order to increase this amount, utilities have to make significant investments in dedicated biomass handling and processing equipment. Even when these investments are made, the co-firing percentage is often limited to 20 % e/e, because the chemical and physical properties of the state-of-the-art bio-fuels, like wood pellets, divert to much from coal. Co-firing torrefied biomass could increase the co-firing percentages much further to even 40% e/e, while saving investment and transport cost compared to state-of-the-art bio-fuels. However, torrefaction technology and torrefied biomass is not yet commercially available (> 100 kton/a). This paper will shortly discuss the technical and business challenges that lie ahead of commercial application of torrefied biomass.

Product characteristics

The torrefied product shows a large resemblance with charcoal. However, an important difference between torrefied biomass and charcoal can be found in the volatiles (evaporative organic components) that remain in the product. During the process of charcoal production, most of the volatiles will be lost, which also means an unnecessary loss of energy. Conversely, most of the volatiles will remain in the biomass, when torrefaction is applied efficiently. From a technical perspective, every form of carbonization must be avoided during torrefaction, because it leads to suboptimal efficiency. Table 1 compares some typical fuel properties of wood, wood pellets, torrefaction pellets, charcoal and coal and their effect on handling, milling and transport requirements.

Table 1 Indicative fuel properties

	Wood	Wood pellets	Torrefaction pellets	Charcoal	Coal
Moisture content (% wt)	30 – 45	7 – 10	1 – 5	1 – 5	10 – 15
Calorific value (MJ/kg)	9 – 12	15 – 16	20 – 24	30 – 32	23 – 28
Volatiles (% db)	70 – 75	70 – 75	55 – 65	10 – 12	15 – 30
Fixed carbon (% db)	20 – 25	20 – 25	28 – 35	85 – 87	50 – 55
Bulk density (kg/l)	0.2 – 0.25	0.55 – 0.75	0.75 – 0.85	~ 0.20	0.8 – 0.85
Volumetric energy density (GJ/m^3)	2.0 – 3.0	7.5 – 10.4	15.0 – 18.7	6 – 6.4	18.4 – 23.8
Dust	Average	Limited	Limited	High	Limited
Hydroscopic properties	Hydrophilic	Hydrophilic	hydrophobic	hydrophobic	hydrophobic
Biological degradation	Yes	Yes	No	No	No
Milling requirements	Special	Special	Classic	Classic	Classic
Handling properties	Special	Easy	Easy	Easy	Easy
Product consistency	Limited	High	High	High	High
Transport cost	High	Average	Low	Average	Low

Table 1 clearly shows that when biomass is torrefied and subsequently pelletized, the product will have quite similar handling, milling and transport requirements as coal, which implies significant cost savings over the bio-value chain. The added value of torrefied biomass compared to wood pellets can be found in the following:

- The physical and chemical properties of torrefied biomass allow higher co-firing percentages, up to 40% e/e.
- Significant cost savings in handling and processing of biomass at the site of the power plant. The capital expenditures are strongly reduced, because dedicated biomass equipment (e.g. hammer mills, silo storage, biomass feeding system, biomass burners) is not needed and because the dimensions of the equipment are smaller, which results from a higher volumetric energy density of torrefaction pellets.
- Significant cost savings in transport, especially when the biomass is also pelletized after torrefaction. This results in a volumetric energy density of 15.0 – 18.7 MJ/m^3, instead of 7.5 – 10.4 MJ/m^3 for wood pellets.
- Torrefied biomass is less sensitive to degradation, due to the hydrophobic nature.
- Research has shown that milling torrefied material results in a powder with a favourable size distribution and spherical particles, which allows torrefied powder to meet the smooth fluidization regime required for feeding it to an entrained flow processes (gasifier and pulverized coal boiler).

Torrefaction technology and process

An overview of reactor technologies that are applied for torrefaction is given in table 2. In general all reactor technologies are proven technology in other applications, such as combustion, drying and gasification.

Table 2 Overview of reactor technologies and associated suppliers

Reactor technologies	Torrefaction supplier
Rotary drum reactor	CDS (UK), Torr-Coal (NL), BIO3D (FR), EBES AG (AT), 4Energy Invest (BE), BioEndev/ ETPC (SWE), Atmosclear S.A. (CH)
Screw conveyor reactor	BTG (NL), Biolake (NL), FoxCoal (NL), Agri-tech producers (US)
Multiple Hearth Furnace (MHF)/ TurboDryer®	CMI-NESA (BE), Wyssmont (US)
Torbed reactor	Topell (NL)
Microwave reactor	Rotawave (UK)
Compact moving bed	ECN (NL), Thermya (FR), Buhler (US)
(Oscillating) Belt conveyor	Stramproy Green Investment (NL), NewEarth Eco Technology (US)

Further there are a number of innovative technologies in development such as torrefaction with thermal fluids of CNFBiofuels (US) and torrefaction combined with washing in the Torwash process of ECN.

Apart from the reactor technology, the performance of torrefaction strongly depends on the heat integration design. Although heat can be integrated in various ways, all torrefaction developers apply the same basic design in which the volatiles are combusted in an afterburner and the flue gas is used to directly or indirectly heat the pre-drying process and the torrefaction process. Pre-drying the biomass to a moisture content of 15% or lower is needed to efficiently torrefy the biomass and combust the volatile rich torrefaction gas. Higher moisture contents increase the residence time of torrefaction and result in inefficient combustion of the 'wet' torrefaction gas, which needs to be heated from 300 ºC to at least 900 ºC to achieve an adiabatic combustion process. This minimum combustion temperature is also needed to ensure all organic components are combusted before leaving the stack.

Although the basic concept of heat integration is the same for all torrefaction concepts, three heat integration options can be distinguished, which are depicted in Figure 1.

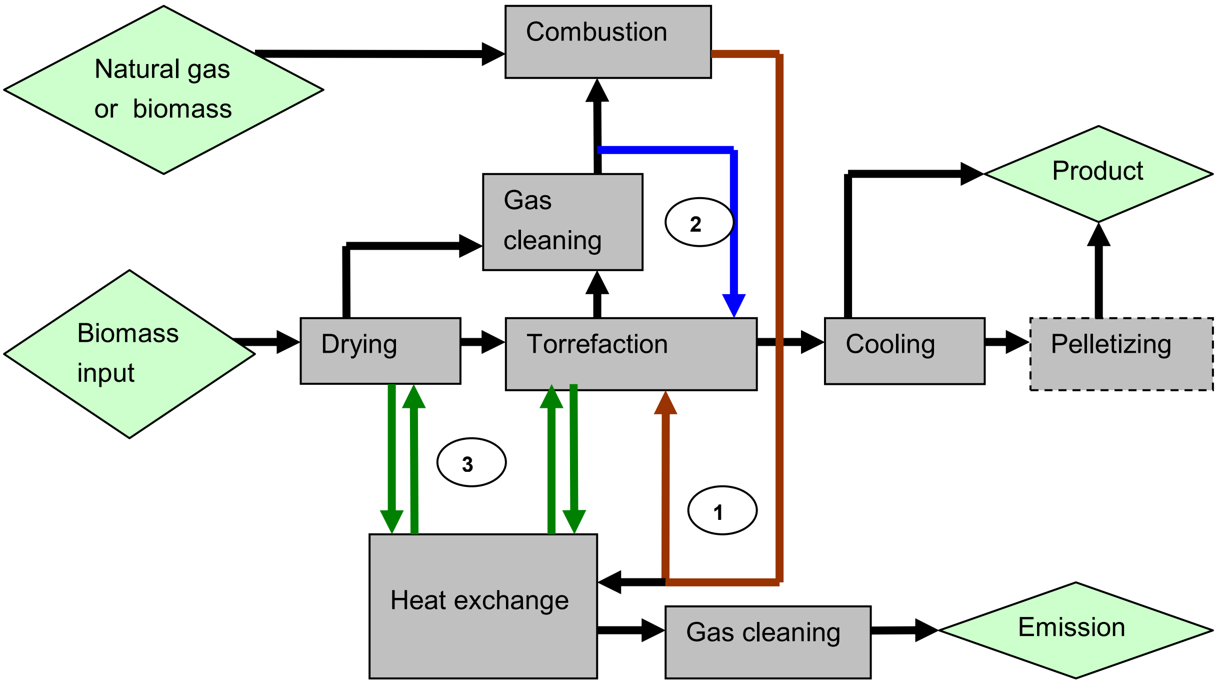

Figure 1 Heat integration options of torrefaction

1 Recirculation of the *flue gas* to directly heat the torrefaction process. In this option the heat is efficiently transferred from heating medium to biomass without losses in heat exchange. A disadvantage of this integration option is that the flue gas will contain a certain percentage of oxygen, which reduces the efficiency of torrefaction. Recycling large volumes of flue gas will require additional investments in ducts, fans and compressors and subsequently increase the electricity consumption cost.

2 Recirculation of the *torrefaction gas* to directly heat the torrefaction process. Just like the first integration option, heat is efficiently transferred between the heating medium and the biomass. Furthermore, the volume of torrefaction gas will be much smaller than the volume of flue gas, which makes the recycle more compact. A disadvantage of recycling torrefaction gas is that the concentration of organic acids and cyclic organic components will increase. As a result more tar is formed during torrefaction.

3 Recirculation of *(super critical) steam* to directly or indirectly heat the torrefaction process. When the biomass is directly heated with steam, the heat is transferred efficiently and the process is kept inert. However, the torrefaction gas will have a relatively low calorific value, because it is saturated with moisture. This will lead to inefficient combustion of the volatiles. Further, the recycled steam

flow will become contaminated by volatiles (acids) and tars, which can condensate at relatively cold spots in the recycle. When no countermeasures are taken (such as special materials), this will lead to corrosion and fouling of equipment. When the biomass is indirectly heated by steam, there is a risk on hot spots in the reactor, especially where the biomass is in contact with the reactor wall. The presence of hot spots increases the risk on carbonization and thus on loss of product. Furthermore, the heat is transferred less efficiently.

Torrefaction initiatives

World wide there are many torrefaction initiatives in development, but the initiatives which are furthest in development can be found in Europe and North America. An overview is given in Table 3. KEMA does not claim to give a complete overview, especially because more initiatives pop up almost monthly. The information on production capacity and starting date of operation is based on quotations and sometimes estimations of the torrefaction suppliers or developers.

Table 3 Overview of torrefaction initiatives

European torrefaction developers					
Developer	**Technology**	**Supplier**	**Location(s)**	**Production capacity (t/a)**	**Starting operation**
Topell Energy B.V. (NL)	Torbed	Torftech Inc (UK)	Duiven (NL)	60,000	Q4 2010
Stramproy Green Investment B.V. (NL)	Oscillating belt conveyor	Stramproy Green Technology (NL)	Steenwijk (NL),	45,000	Q3 2010
4Energy Invest (BE)	Unknown	Stramproy Green Technology (NL)	Amel (BE)	38,000	Q4 2010
Torr-Coal B.V. (NL)	Rotary Drum	Unknown	Dilsen-Stokkem (BE)	35,000	Q3 2010
Thermya (FR)	Moving bed	Lantec group (SP)	San Sebastian (SP)	20,000	2011
ECN (NL), Vattenfall (SWE))	Moving bed	Unknown	Unknown	Unknown	Unknown
FoxCoal B.V. (NL)	Screw conveyor	Unknown	Winschoten (NL)	35,000	2012
BioLake B.V. (NL)	Screw conveyor	Unknown	Eastern Europe	5,000 – 10,000	Q4 2010
EBES AG (AT)	Rotary drum	Andritz (AT)	Frohnleiten (AU)	10,000	2011
Atmosclear SA (CH)	Rotary drum	CDS (UK)	Latvia, New Zealand, US	50,000	Q4 2010
Bio Energy Development North AB (SWE)	Rotary drum	Unknown	Ö-vik (SWE)	25,000 – 30,000	2011 / 2012
Rotawave, Ltd. (UK)	Micro wave reactor	Group’s Vikoma	Terrace, British Columbia (CA)	110,000	Q4 2011

North American torrefaction developers					
Developer	**Technology**	**Supplier**	**Location(s)**	**Production capacity (t/a)**	**Starting operation**
Integro Earth Fuels, LLC (US/NC)	TurboDryer	Wyssmont (US/NC)	Roxboro, NC	50,000	2010
Agri-Tech Producers LLC (US/SC)	Belt reactor	Kusters Zima Corporation (US/SC)	Unknown	Unknown	2010
Torrefaction Systems Inc. (US)	Unknown	Bepex International (US/MN)	Unknown	Unknown	2013
New Earth Renewable Energy Fuels, Inc (US/WA)	Fixed bed/ Pyrovac	Pyrovac Group (CA/QU)	Unknown	Unknown	Unknown
Zilkha Biomass Energy (US)	Unknown	Unknown	Crockett, Texas (US)	40,000	Q4 2010
WPAC (CA)	Unknown	Unknown	Unknown	35,000	2011

The overview of torrefaction initiatives clearly shows that the project plans of North American torrefaction initiatives are less concrete. Most North American developers are still in the financing and engineering phase of realizing a commercial demonstration plant.

Technical challenges

Fuel flexibility

The fuel flexibility of the first generation torrefaction technology is limited to primarily woody biomass. The moisture content, bulk density and particle size distribution of the feed stream need to be accurately controlled in order to produce a high quality product with an efficient process. Pilot plant tests showed that torrefaction of other biomass types than wood is still a technical and economical challenge. Agricultural biomass for instance, tends to ignite or carbonize easily during torrefaction. Due to a relatively low bulk density of agricultural biomass, the volume of the feed stream needs to increase significantly to realize a similar energy yield, which could be achieved with woody biomass. Most reactor technologies have volume and biomass transport restrictions, which results in a lower throughput of biomass and thus in a lower economic performance. Operational experience with the first commercial demonstration plants is needed to find the technical and economical optimum of different biomass types. It is not unlikely that design modifications are needed to allow torrefaction of certain biomass types. A limited fuel flexibility of the first generation torrefaction technology is also the result from a very specific demand for wood based biomass, because most utilities do not want to co-fire waste streams, which are prone to negatively impact plant performance and which are subject to stricter emission norms than woody biomass. Furthermore, woody biomass is widely available the year around while some other more exotic biomass streams have limited availability.

Emissions

Torrefaction gas contains organic acids and primary tars, which need to be cracked in an afterburner. Although the tars that are formed during torrefaction will be cracked in the afterburner, tars can represent a serious problem when they condensate on the product or internals of the installation. When the torrefaction temperature increases the tar formation will increase exponentially. Therefore this issue should be managed carefully.

The operation of the afterburner strongly depends on the quality of the torrefaction gas. When the torrefaction gas contains a lot of moisture, the calorific value will reduce, leading to suboptimal combustion. Moreover, the moisture in the torrefaction gas will be heated up from about 300 ºC to at least 900 ºC, which will reduce the thermal efficiency of the torrefaction plant. Test results have shown that even after combustion, the flue gas will contain some organic compounds, such as hydrogen fluorides, sulphides and nitrates that need to be removed before emitting the flue gas. Therefore, additional flue gas cleaning is necessary. Torrefaction developers use bag filters and ceramic filters with an absorbent (e.g. activated coal) to control the emissions. Another possibility is condensation of torrefaction gas, but this results in a waste water stream, which needs to be taken care of.

The emissions of biomass torrefaction are restricted by the IPPC and in the near future also by sustainability criteria for biomass. The latter focuses on CO_2 emissions over the whole bio-value chain. This means that the CO_2 emissions during torrefaction should be kept as low as possible. The emissions of biomass torrefaction are not expected to be a major technical challenge, but should be addressed adequately.

Some torrefaction suppliers claim to significantly reduce the ash, chlorine, sulphur and sometimes even alkaline concentration by pre-treating biomass with torrefaction. However, under typical torrefaction conditions (260 - 300 ºC / 25 – 35 minutes) and with no additional cleaning measures this will not be the case. At these temperatures, only very small percentages of chlorine and sulphur will volatilize, while alkaline will remain in the biomass.

Up-scaling

The up-scaling steps that are undertaken by the developers are significant. In general, a pilot plant scale of about 20 to 600 kg/h will be scaled up to a 5 to 8 t/h commercial demonstration plant. This is a large up scaling step, even though the reactor is proven technology and has been scaled up to even bigger units in other applications. At this stage of development, the suppliers claim they can do it, but only when the first commercial demonstration plants start up, we will learn whether the scaled up design performs as expected. Some effects can occur in the commercial demonstration plant which have not been observed during the pilot plant tests. On the other hand some throughput and feed issues which were present in the pilot plant can be resolved be scaling up the dimensions. It will be a challenge for torrefaction developers to develop a full commercial torrefaction plant, which incorporates the necessary design and process modifications for good commercial performance.

Process validation

Although the torrefaction process has been proven in general, many torrefaction developers are still struggling with optimizing the process conditions. Experience learns that process control of the main parameters; temperature, residence time and feed particle size, which are interdependent, is extremely important for good performance. The challenge is to find the optimum between these three process parameters. The optimum can only be found by operational trial and error and accurate control of each of the process parameters. The optimum operating spectrum is different for each type of biomass, which limits the feedstock flexibility of torrefaction. Apart from the three main process parameters there are still many other technical issues that need to be solved for good process performance.

Product validation

Utilities indicate there are still a lot of uncertainties about the product quality and specifications. The operational experience with handling and co-firing torrefied product in a coal-fired power plant is still very limited. The first large-scale co-firing trials will most probably be performed in 2011, which will provide data about milling, handling, storage, transporting and combustion of large amounts of torrefied biomass. The challenge for torrefaction developers will be to produce large amounts of torrefied biomass, which has a consistent quality and corresponds with the specifications of the coal-fired power plant. So far, handling, milling and pelletizing has been less straightforward than anticipated. Torrefied biomass is extremely reactive in the form of powder, which already resulted in a fire accident at a torrefaction installation located in Amel, Belgium. After milling, torrefied biomass should be kept inert to avoid spontaneous combustion. Pelletization of torrefied biomass is also challenging, because the concentration of lignin, a natural binding agent of biomass, reduces when biomass is torrefied. Therefore, most torrefaction developers use biological additives to produce torrefaction pellets.

Business challenges

Economic optimization

In the end torrefaction developers optimize their torrefaction process according an economic optimum. In practise this means that a suboptimal efficiency or product yield will be accepted, when the business case can be improved by for example increasing the throughput. The economics of torrefaction depend strongly on the margin between biomass feedstock price and product price. The challenge for torrefaction developers will be to negotiate a good price for their biomass feedstock and product. Further, the production cost of torrefaction should be minimized by optimizing the efficiency and product yield of the process.

Product standardization

In order for the torrefaction market to develop, product standardization is crucial. When torrefaction suppliers produce product with different and fluctuating quality, the market for torrefaction will not develop optimally. When instead a product standard is developed, the torrefied product becomes a commodity, which will be traded in large volumes. Further, it will differentiate between the torrefaction suppliers which manage to commercially provide torrefied biomass according specifications and the torrefaction suppliers which perform poorly.

Cooperation between torrefaction suppliers and utilities or other consumers of the product is very important to develop a product standard. Consumers need to gain experience with the product and articulate their demands so that torrefaction suppliers can optimize and adapt their processes to meet these demands. Both parties will have to invest to achieve a satisfying product quality and product price, especially because both parties will benefit from a market which develops quickly to a commodity market.

Financing

The financing of torrefaction development is another important hurdle. Most torrefaction developers and suppliers are small companies with a limited financial base. As a result they are strongly dependent on bank loans, which in turn demand a long-term off take contract to grant the loan. A large consumer, like an utility, is not likely to sign a long-term commitment when the impact of the torrefied product on their own business process is uncertain. Therefore, it will require a large batch of torrefied material to perform a co-firing trial. This can lead to a deadlock situation where torrefaction suppliers need to produce a large batch of torrefied biomass in order to get more financing to scale-up their technology, but are not able to produce this batch because they need financing for the up-scaling step. This situation has been present in The Netherlands, but has been removed by a couple of launching customers, which were willing to take the risk. As a result, three Dutch torrefaction suppliers have scaled up their technology to a commercial demonstration plant. The performance of these plant will be crucial for further financing, which is needed to scale-up to a full commercial plant (> 100 kton/a), but also for torrefaction development in general.

Some conclusions

At the moment, torrefaction technology is making its first careful steps towards commercialization, while the technology and product quality are still surrounded by uncertainties. Nevertheless, some European utilities (Essent B.V., DELTA N.V.) have taken the risk by signing long-term off-take contracts with torrefaction suppliers and other utilities (RWE Innogy) are also participating in the development of torrefaction, which indicates torrefaction is gaining momentum.

European torrefaction developers, suppliers and utilities are leading the torrefaction development, with three commercial demonstration plants starting up in the beginning of 2011. The North American torrefaction initiatives are currently still in the pilot scale phase, where R&D efforts and financing are needed to make the up-scaling step towards commercial demonstration plants. However, the experience and lessons learned in Europe can accelerate the development of torrefaction in North America.

The first generation torrefaction technology has a limited feedstock flexibility and is optimized to process woody biomass. This is the result of biomass availability, technical limitations of the reactor technologies and economical optimization which favours woody biomass. Further, utilities prefer 'clean' woody biomass as co-firing fuel, because it minimizes the impact on plant performance. Torrefaction suppliers face the challenge to torrefy waste streams (like agricultural residues or RDF) in a technically and economically feasible way.

Torrefaction technologies which allow accurate control of the main process parameters (temperature, particle size and residence time) will have a higher efficiency and a better product quality. Heat integration options that directly heat the biomass generally result in better efficiency and product quality, because the heat is transferred more efficiently and there is a lower risk on carbonization.

The market for torrefaction is primarily driven by utilities that want to co-fire large amounts of biomass, but there is also market potential in the residential heating sector and in the industrial heating sector. These markets all have different demands and different conditions, which need to be matched by the supply side of the torrefaction innovation system in order to be exploited.