



IEA Bioenergy
Technology Collaboration Programme

Industrial Process Heat: case study 3

Process steam in a dairy factory via fast pyrolysis bio-oil

Contribution of Task 34 to the intertask project on industrial heat

September 2020





IEA Bioenergy

Technology Collaboration Programme

Industrial Process Heat: case study 3

Process steam in a dairy factory via fast pyrolysis bio-oil

L. van de Beld - BTG Biomass Technology Group BV

A. Toussaint - BTG Bioliquids BV

Contribution of Task 34 to the intertask project on industrial heat

September 2020

Copyright © 2020 IEA Bioenergy. All rights Reserved

ISBN 978-1-910154-82-3

Published by IEA Bioenergy

Preface

The role that bioenergy plays in the global energy mix has expanded over the last decades, from predominantly domestic space heating and industrial heat until the 1990's to increased use in the electricity sector and more recently also large scale production of transportation fuels. According to the IEA SDS scenario, the use of biomass to produce high temperature heat in industry will not decrease, but quadruple from 8 EJ today to about 24 EJ in 2060.

Traditionally, the application of bioenergy in industry was performed in industries that can use their own biomass process residues to cover (some of) their own heat demand, e.g. sugar, palm oil, wood processing, pulp and paper, etc. With the increasing motivation in industry to reduce CO₂ emissions, several other industry sectors are also shifting towards biomass based heat generation in cases where there are suitable biomass resources and technologies available nearby.

While there is a large potential to displace fossil fuels with biomass fuels in the large and energy intensive industries (steel, cement, etc), there are also many small and medium sized process industries such as food industries, paper industries, etc. In contrast to the larger energy intensive industries where these cases typically require that large volumes of biomass are shipped to an individual site, the heat demand in these smaller industries can often be better matched with the biomass resources that may be locally available, resulting in smaller transportation distances.

This case study is part of a series of reports on the use of bioenergy in industry to supply process heat. In the framework of an intertask project, five of the tasks involved in the IEA Bioenergy Technology Collaboration Programme collaborated to produce four case studies and a policy synthesis report on biomass based industrial heat. The cases were selected carefully to illustrate that a wide diversity of bioenergy conversion technologies is readily available for market application, the optimum configuration depending on local availability of biomass resources, characteristics of the heat demand, availability of space, capital, etc. The cases are:

1. Combustion of wood chips and composting residues for process steam generation in a potato processing industry
2. Gasification of paper reject to displace natural gas usage in a pulp and paper process
3. Process steam in a dairy factory via fast pyrolysis bio-oil
4. Waste-to-Energy for production of steam for paper production

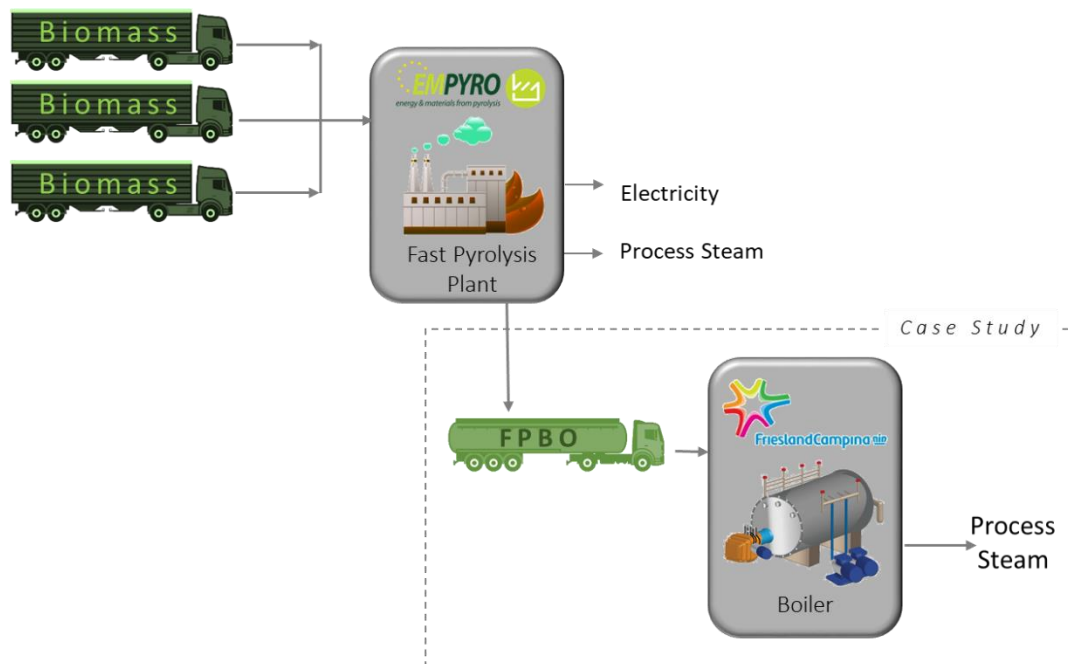
Early in 2021, a policy synthesis report will also be published that provides strategic information on market opportunities/potential and effective ways to address technical and non-technical barriers to implement bioenergy based process heat. The report builds upon the lessons learned in the cases, but also provides a more generic analysis of the market potential, and how its implementation can be supported, in order to unlock the enormous potential already mentioned above. All reports are available on the project website <http://itp-hightemperatureheat.ieabioenergy.com/>

Summary

Fast pyrolysis is a process in which organic materials are heated rapidly to 450 - 600 °C in the absence of air. Under these conditions, organic vapours, non-condensable gases (NCG) and char are produced ('thermal depolymerisation'). The vapours are then condensed to a liquid called Fast Pyrolysis Bio Oil (FPBO). Typically, 50-75 wt% of the dry biomass can be converted to FPBO. The char and NCGs are used to generate steam and produce electricity, partly for internal use, partly available for external use/export.

Nowadays, clean wood-based FPBO is commercially utilized to replace fossil heavy fuel oils and natural gas. Full-scale fast pyrolysis plants (> 10 MW_{th}) are in operation or under construction in Joensuu (Fortum-Finland), Lieska (GFN-Finland), Gävle (Pyrocell-Sweden), Renfrew (Ensyn-Canada), Cote Nord (Ensyn-Canada) and in Hengelo (Empyro-the Netherlands).

The case study -illustrated in the figure below- concerns the use of the fast pyrolysis oil produced by Empyro in the industrial size steam boiler of FrieslandCampina (FC). FrieslandCampina is a worldwide dairy company headquartered in Amersfoort, the Netherlands.



A new natural gas fired boiler was designed and constructed for FrieslandCampina suitable to co-fire pyrolysis oil. In the boiler, process steam is produced (40 t/hr at 20 bar) for the milk powder drying process. The boiler normally operates with 70 % of pyrolysis oil and 30 % natural gas (heating value basis), but 100% back-up of natural gas is always available guaranteeing continuous steam supply to the core processes of FrieslandCampina. The FPBO is transported from Empyro (Hengelo) to FrieslandCampina (Borculo) by tank truck, a distance of about 30 km. An on-site small storage facility of about 100 m³ is available. The boiler has been commissioned late 2015 and -to date- the use of FPBO has saved the company about 30 million m³ of natural gas and reduced their CO₂ emissions with some 60,000 ton. This case study report will describe the application, design and operation of the boiler in more detail.

Index

Preface	1
Summary.....	2
Background information	4
Drivers	4
Production of FPBO - Driver from BTL point of view	4
Use of FPBO - Driver from FrieslandCampina point of view	4
Empyro Production Plant	5
Fast pyrolysis.....	5
Fast pyrolysis process	5
EMPYRO [1]	5
Fast Pyrolysis Oil properties.....	9
Reach registration [2]	9
Fuel sourcing and logistics	10
Biomass feedstock for fast pyrolysis	10
Temporary storage of FPBO	12
FPBO transport	12
Implementation.....	13
Technical Implementation.....	13
General system description	13
FPBO delivery, storage and handling	13
FPBO combustion system	14
Footprint (steam boiler & storage).....	15
Operation & Operational issues.....	16
Emissions.....	18
Economical aspects	20
Environmental aspects	20
Organisational aspects	21
Project financing.....	22
Social and marketing aspects	22
Lessons learned / policy recommendations	24
References.....	25
Acknowledgements	25

Background information

The case study concerns the use of fast pyrolysis oil by FrieslandCampina in an industrial steam boiler. However, fast pyrolysis oil is not (yet) a commodity and production capacity needed to be established. Therefore, some information is included in this document on the development of the whole value chain from biomass to the end-use of fast pyrolysis bio-oil (FPBO).

In fact, one can't be developed without the other: a fast pyrolysis plant will only be built if the off-take of the oil can be guaranteed, and a dedicated oil boiler will only be built if the required fuel can be guaranteed. This has been a crucial part in the development of the Empyro value chain to have both in place at the same time.

DRIVERS

Production of FPBO - Driver from BTL point of view

BTG Bioliquids BV (BTL) developed their own biomass fast pyrolysis process, and aims to supply this technology to the market (Technology supplier). A nearby full-scale demonstration plant was highly desired, and a plan was developed to establish such plant (Empyro) in Hengelo, the Netherlands. Investment subsidies were available on regional, national and European level. Overall, nearly 40% of the investment could be covered by subsidies, the remaining part by investors and debts. More details on Empyro are given in § 1.2. However, financial close could only be reached if a long offtake agreement of the FPBO was guaranteed. A significant advantage of the application at FrieslandCampina is the continuous demand for process steam throughout the year (24/7, 365 days a year), and therefore a continuous and stable FPBO demand.

Use of FPBO - Driver from FrieslandCampina point of view

FrieslandCampina (FC) is a dairy company and produces and sells consumer products such as dairy-based beverages, infant nutrition, cheese and desserts in many European countries, in Asia and in Africa via its own subsidiaries. FrieslandCampina has offices in 36 countries, and the central office is in Amersfoort, the Netherlands.

Sustainability is an important aspect and besides the sustainable production of food, also the reduction of their carbon footprint is of importance. The production site in Borculo (the Netherlands) was reconstructed including the need to modernise the utilities. Traditionally, the process steam was generated in natural gas fired boilers. A CHP installation near the site was shut down and the remaining FC-boiler house was outdated and needed to be replaced. Furthermore, (partly) replacing natural gas with renewable fuels would contribute to the reduction of the carbon footprint. Biogas from the FC's waste-water treatment facility was already available, and FPBO produced from sustainable biomass was added as a new fuel. Direct use of biomass is not an option in this case due to i) space limitations, ii) undesired handling of biomass on site (close to food production), and iii) co-firing with natural gas is not possible.

The main advantage of FPBO is its high volumetric energy density. It is about twice as high as wood pellets and 6 times higher than for instance fresh wood chips (by volume). This means that far less truck transport is required when using FPBO. As the site of FC at Borculo is located near the centre of the village, this was also an important issue.

For FC, handling and storing solid biomass was unwanted as solid biomass involves emissions of dust during off-loading and handling. Also, biomass contains bacteria and fungi and -for a dairy company producing a.o. food for infants- this is highly undesired. FPBO does not produce dust and also contains no bacteria or fungi as a result of the properties, chemical composition of FPBO and the production process (elevated temperature).

FPBO as a liquid makes storage and handling easier compared to a solid biomass. A liquid storage tank is flexible with respect to diameter and height. By selecting a relatively high tank the footprint for the storage is relatively small. This was also an important aspect as limited free space was available on site.

Importantly, at that time (2012) a new support scheme was introduced by the Dutch government called SDE+ providing financial incentives for renewable heat. Basically, it covers the difference in price between the fossil and renewable fuel, and it is valid for a period of 12 years. Based on the above a long-term off-take agreement was signed between Empyro and FrieslandCampina for the supply of FPBO.

EMPYRO PRODUCTION PLANT

The actual case study concerns the use of FPBO as fuel for the generation of process steam. However, FPBO is not an existing commodity, and therefore the production of FPBO is also briefly discussed here.

Fast pyrolysis

Fast pyrolysis is a process in which organic materials are rapidly heated to 450 - 600 °C in absence of air. Under these conditions, organic vapours, permanent gases and charcoal are produced. The vapours are then condensed quickly to pyrolysis oil. Typically, 50-75 wt.% of the feedstock can be converted into fast pyrolysis bio-oil (FPBO). Pyrolysis enables the transformation of difficult-to-handle biomass of different nature into a clean and uniform liquid. Its energy density is four to five times higher than that of the original solid material, which offers important logistic advantages.

Fast pyrolysis process

BTG-BTL's patented fast pyrolysis technology includes fast heating of biomass followed by rapid condensation of the vapours produced. The original reactor concept is based on the so-called rotating cone. In this reactor biomass particles at room temperature and hot sand particles are intensively mixed in the reactor resulting in rapid heating and a quick release of organic vapours. The produced vapours pass through several cyclones before entering the condenser, in which the vapours are quenched by re-circulated oil. The pyrolysis reactor is integrated in a circulating sand system composed of a riser, a fluidized bed char combustor, the pyrolysis reactor, and a down-comer. In this concept, char is burned with air to provide the heat required for the pyrolysis process. Oil is the main product; non-condensable pyrolysis gases are combusted and can be used e.g. to generate additional steam.

EMPYRO [1]

Empyro is the acronym of the former European project as well as the name of the company who implemented the process in Hengelo. In this section the different aspects of the realization of the project are further described.

The main objective was to build and operate a 25 MW_{th} polygeneration pyrolysis plant for the production of electricity, process steam and fuel oil from woody biomass. The process steam and electricity is used locally, whereas the pyrolysis will be transported to an external customer replacing natural gas. The overall balance is illustrated in Fig. 1.

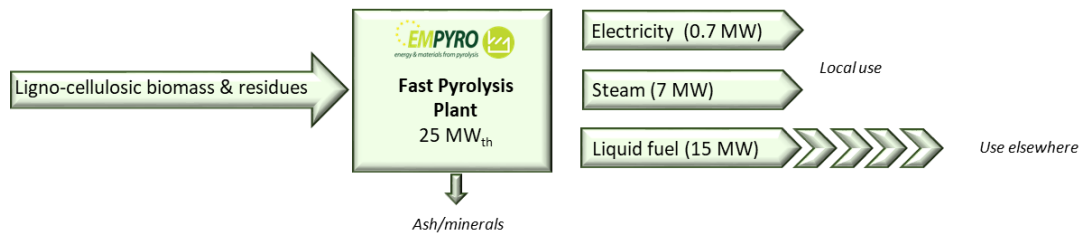


Fig. 1: Overall balance fast pyrolysis oil production

The plant will be used by BTL as a reference plant to demonstrate the suitability of their pyrolysis technology as well as the application of the pyrolysis liquid on a commercial feasible scale.

Empyro process

A simplified process scheme of the Empyro plant is depicted in Fig. 2. Woody biomass is stored in two vessels of 200 m³ each; more details on the biomass are given in Chapter 2. From the storage vessel the biomass is fed to a dryer to achieve a moisture content of around 5 wt%, and subsequently introduced in the pyrolysis reactor at a rate of up to 5 ton/hr. In the reactor the biomass is mixed with hot sand, and pyrolysis reactions will take place. The vapour is led to a spray condenser collecting the main liquid product. Sand and char are sent to a fluidized bed combustor where all char is combusted to reheat sand (char is therefore not a separate product). In the freeboard of the combustor the permanent gases from the oil condenser are added and combusted. Excess heat is used to generate steam in the heat recovery boiler. Minerals are removed from the bottom of this unit. A steam turbine is included in the plant to generate electricity. Optionally, pyrolysis oil can be filtrated and/or partly dewatered if needed for the application of the liquid. At site a maximum of 250 m³ can be stored.

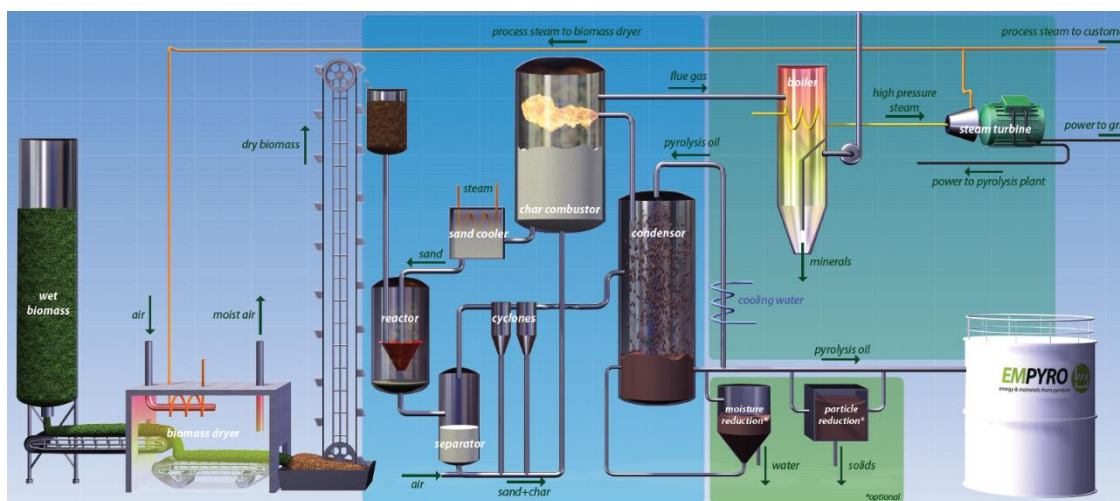


Fig. 2: Simplified process flow diagram of the Empyro Plant

The implementation started in 2014 and mechanically completed early 2015. The first oil was produced in March 2015. The Empyro plant can be considered as a polygeneration unit as it produces three different products simultaneously. Besides the main product FPBO also process steam and electricity are generated. The latter two products are partly used internally to run the process. Excess process steam is delivered to the nearby site of AkzoNobel, whereas the electricity is delivered to the grid. An overall energy efficiency of 85% is achieved in this way. In Fig. 3 the cumulative production and operational hours are shown till the end of 2019. Twence -a regional waste company)- acquired the Empyro plant by the end of 2018, and is officially the owner and operator of the plant since January 1, 2019.

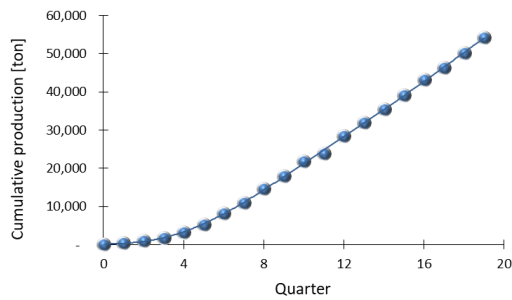


Fig. 3^A: Cumulative production

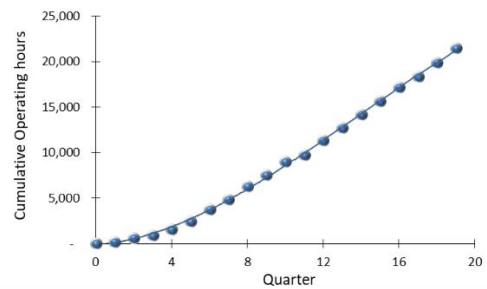


Fig 3^B: Cumulative operation hours

Similar plants as Empyro have been sold to GFN (Finland) and Pyrocell (Sweden). Expected start-up of these plants is in 2021 & 2022, respectively.



Fig. 4: Pictures of the Empyro fast pyrolysis plant

Fast Pyrolysis Oil properties

FPBO is recognized as a 2nd generation or advanced biofuel/intermediate energy carrier. However, it is completely different from conventional fossil fuels both in its physical properties and chemical composition. Due to large amounts of oxygenated components present, the FPBO has a polar nature and does not mix readily with hydrocarbons. Its energy density is four to five times higher than that of the original solid material, which offers important advantages for logistic and storage compared to the original biomass. FPBO can become unstable or separate in two phases when the water content becomes too high, typically above 25 wt%. A European standard exists for the use of FPBO in industrial boilers (EN 16900:2017). Some typical properties of FPBO and fuel oil are given in Table 1.

Table 1: Typical properties of FPBO and fuel oil

Physical property	FPBO	Fuel Oil
Water content [wt.%]	25	~ 0
pH [-]	2.5	-
Density [kg/L (15 °C)]	1.1 - 1.3	0.82 - 0.85
Nitrogen content [wt.%]	0 - 1 ^a	0.005 - 0.05
Lower Heating Value (LHV) [MJ/kg]	16.3	42.6
[MJ/L]	19.1	37.0
Kinematic Viscosity [cSt] (40 °C)	20 - 100	2.0 - 4.5
Solids [wt.%]	0.02 - 0.25	Water + sediment < 0.02
Surface tension [mN/m]	30	26
Acid Number [mg KOH/g]	80 - 100	< 0,08

^a strongly depends on biomass resource the FPBO is originating from

Reach registration [2]

REACH is the abbreviation for Registration, Evaluation, Authorization and restriction of Chemicals, and it was introduced in 2007 to combine various European regulations and directives. In 2018 all substances should be REACH registered. In the REACH registration a producer should indicate if a substance is toxic (and to what extent) and how this substance should be handled safely by the user. All substances produced or imported in the European Union in quantities above 1 t/y will be obligated for the REACH registration.

In 2013 a FPBO REACH consortium -led by Fortum- was established, with the goal of obtaining REACH registration for FPBO at the ECHA (European Chemicals Agency). FPBO is a so-called UVCB substance (substance of Unknown or Variable composition, Complex reaction products or Biological materials). Late 2013, the consortium submitted a Joint Dossier including a Substance Identity Profile (SIP). Empyro was not part of the core consortium and bought a so-called "Letter of Access".

Fuel sourcing and logistics

The sustainability of FPBO is to a large extent determined by the biomass source used in the fast pyrolysis production process. In the Dutch support scheme (SDE+) the sustainability must be proven for the actual value chain.

Biomass feedstock for fast pyrolysis

The primary biomass source was selected by Empyro and for initial start-up of the plant the crumbles from wood pellets were chosen. The crumbles are a byproduct/waste from pellet logistics, and available in the Rotterdam Harbour. The crumbles are transported by truck from Rotterdam to Hengelo (~150 km). Advantage for Empyro is that the crumbles are rather clean, well defined, relatively dry and particle size is small (all are advantages to fast pyrolysis). Furthermore, it simplifies the biomass storage & pre-treatment section (i.e. less investment).

To allow for SDE+ incentives a NTA8080 approval is required in the Netherlands.

The use of the pellet crumbles, with their good flow characteristics, made it possible to start Empyro with relatively simple silos as also used in the agricultural sector. These silos have conical outlets with motovibrators installed on them. Using these “standard” solution helped to reduce the initial investment cost. Also, the biomass feeding system turned out to be very reliable. The downtime caused by the feeding system has been very limited also because two silos were installed. The silos however result in restrictions on the physical characteristics of the biomass that can be fed to and taken out of the silo. For using the silo system, the biomass should be more or less free flowing. In other words, its tendency to bridge formation should be limited. In general, this rules out fibrous and low density biomass (like sawdust) feedstocks which tend to easily bridge.

Recently, Twence -the new owner of Empyro- started the construction of a new biomass storage and feeding system to enable other biomass feedstocks. Twence is actively sourcing other regional biomass types suitable for the Empyro plant.

This system consists of a dump pit with extraction screws making it possible to use dump trucks or walking floor trailers to deliver the biomass. From the high capacity dump pit (200 m³/h), the biomass is taken to a 800 m³ biomass silo. This silo is very different from the original one. The new silo has a flat bottom with a rotating extraction screw taking the biomass to a central outlet. From there the biomass is taken via conveyor screws to the inlet of the existing dryer. The original silos will also remain functional.





Fig. 5^A: Silos for storing wood crumbles; volume is 2x200 m³ sufficient for 2 days.



Fig. 5^B: New biomass storage; storage capacity 1 – 2 days



Fig. 5^C: FPBO storage 250 m³ (~ 3 days)

Temporary storage of FPBO

Unexpectedly, Empyro was already producing FPBO before the construction of the boiler system (see chapter 3) was completed. For this reason FPBO was temporary stored at a tank terminal in Nijmegen. This terminal has several tanks made of stainless steel which are used for storage of fuels and chemicals for third parties. FPBO was stored for more than a year in a 635 m³ gross storage tank and during the year transported to FrieslandCampina where it was successfully combusted (together with freshly produced FPBO).

FPBO transport

The FPBO produced at Empyro is transported on daily basis to FrieslandCampina (FC) by tank truck (31 ton/delivery, 30 km distance). Limited intermediate storage capacity is available at Empyro (~250 m³) and FrieslandCampina (~100 m³). FPBO is not qualified as ADR-good which makes transport easier and cheaper. The tank is made of stainless steel, and the actual transport is outsourced to a local transport company.

The amount of FPBO is determined by a weight bridge at the site of FC. The FPBO is charged based on the total GJ's (LHV) delivered. For this reason, a sample of FPBO is taken every time the tank truck is filled at Empyro. The samples of one week are combined and one average sample is prepared. The latter sample is used to calculate the LHV on basis of elemental composition and water content. After analysis the samples are stored in a fridge for at least 10 weeks enabling to do a re-analysis if needed.



Fig. 6: FPBO transport by tank truck

For FrieslandCampina it is important that the FPBO can be co-fired trouble-free on their boiler. Furthermore, to qualify for the SDE+ incentive scheme also the FPBO application should comply with the NTA8080 sustainability criteria. An overall GHG emission reduction of 96% is achieved, which is well above the required minimum of 70%. Both Empyro and FrieslandCampina received the NTA8080 certificate.

Implementation

TECHNICAL IMPLEMENTATION

In this chapter the design, implementation and operation of the pyrolysis oil boiler will be described. First a general overview will be presented and subsequently each part will be described in some more detail.

General system description

Due to the unusual properties of pyrolysis oils the application in boilers needs careful consideration. Stork Thermeq extensively tested different grades of fast pyrolysis oil in their test boiler (9 MW_{th}) in Hengelo [3]. It was demonstrated that co-firing with natural gas leads to stable combustion and low emissions.

A simplified flow scheme of the boiler set-up at FrieslandCampina is given in Fig. 7. The natural gas boiler -with a maximum thermal capacity of 29 MW_{th} and an efficiency of 95.5%- was designed by Stork and besides natural gas it can accept pyrolysis oil as a fuel. In the boiler, process steam will be produced (40 t/hr at 20 bar) for the milk powder process. The boiler can accept up to 70 % (based on LHV) of pyrolysis oil (max 4 t FPBO/h), exceeding the full capacity of Empro), but 100% back-up of natural gas is always available guaranteeing continuous steam supply to the core processes of FrieslandCampina. To comply with strict Dutch emission regulation a dust filter has been installed. The boiler was installed and has been commissioned in Q3 - 2015.

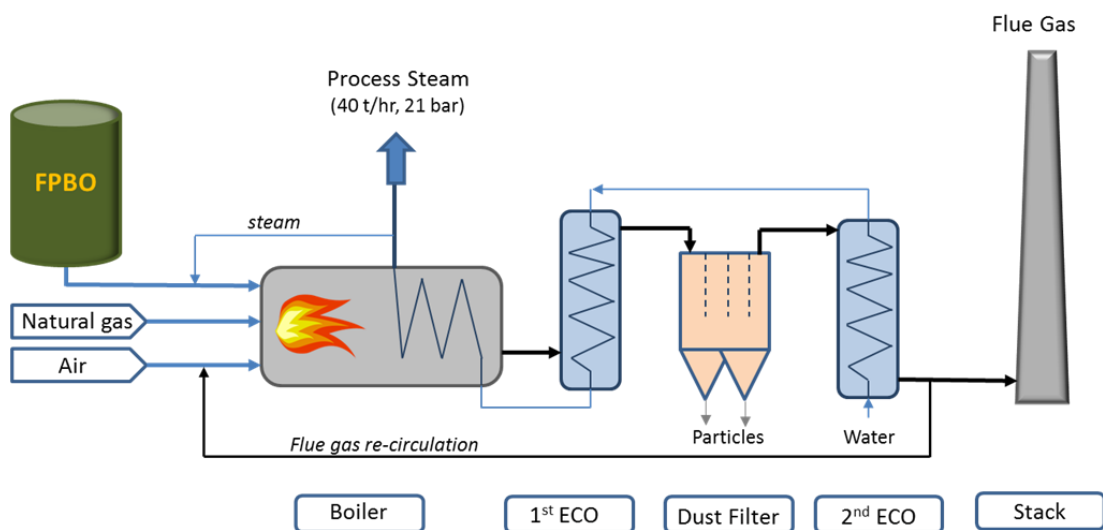


Fig. 7: Schematic overview boiler system

FPBO delivery, storage and handling

A FPBO storage tank has been installed at site of FrieslandCampina (FC). Due to the acidic nature of FPBO the material selection is important to avoid corrosion or attack of materials. Therefore, stainless steel materials like SS304 or SS316 are typically used for the storage tank, piping and equipment like pumps. In case of FC the storage tank is made of SS304 and has a gross capacity of 100 m³ (around 90 m³ nett). Alternatively, the storage tank can be made of glass fibre reinforced plastic (GRP) as was done at Empro. Piping was made in SS304 while valves and fittings were mostly made of SS316. There haven't been any signs of corrosion of these materials after almost 5 years of operation.

For the off-loading and circulating of the FPBO a centrifugal pump is used. It should be equipped with a double mechanical seal with a proper barrier liquid. When properly done, the pumps will run for several years without problems.

The FPBO is delivered to site by a tank truck (see chapter 2). Unloading of FPBO can be managed by the truck driver without involvement of FC personnel. Prior to unloading, the driver needs to install an earthing connection to the tank truck as well as a high level switch on the tank preventing overfilling of the tank truck. Potentially, this can happen when FPBO flows back when the fuel pump stops and the one-way valve fails. The fuel pump can't be started unless both connections are made. A hose with a dry-break coupling is used for connecting the storage tank to the tank truck. The dry-break coupling prevents spillage of FPBO during coupling and decoupling. Finally, a vapour return line is connected to the tank truck, which is used to maintain a "closed" system when filling the storage tank in order to prevent annoyance by odour. Via this vapour return line, air from the storage tanks is led to the tank truck. Furthermore, an active coal filter is installed on the tank venting nozzle on top of the tank. By taking these measures the distinct odour of pyrolysis oil can be properly managed.

The unloading process takes about 45 minutes and then the driver can disconnect the hoses and connectors. The hoses should be returned to their original position on the rack otherwise the gate can't be opened. This way it is prevented that the truck driver will accidentally drive away with the hoses still connected.

The FPBO unloading pump is also used for circulating the FPBO over the storage tank when it is not used for unloading. It avoids that more viscous oil fractions are settling on the bottom of the tank over time.

To pump the FPBO from the storage tank to the burner/boiler a progressive cavity pump is used. It works properly when selecting the proper stator rubber (Super Viton) and seal for the driving shaft. Rubbers for gaskets and O-rings are also a point of attention. For static, closed applications EPDM (a type of synthetic rubber) may be used but should be replaced after opening. For gaskets in plate heat exchangers Viton is advised. O-rings in dynamic seals should be of the high quality. Spiral wound gaskets are very suitable for flanges in the FPBO piping.

FPBO combustion system

As part of the FPBO delivery contract, Empyro was responsible for coordinating the design, implementation and commissioning of the multi-fuel steam boiler. The main boiler and burner characteristics are summarized in Table 2.

Table 2: Boiler design

	Value	Unit
Boiler capacity	27.6	MW _{th}
Steam production	40	t/h
Steam pressure	20	barg
Capacity natural gas	6-29	MW _{th}
Capacity FPBO	5-18	MW _{th}
Feedwater inlet temperature	80	°C
Flue gas temperature	100	°C
Boiler efficiency	95	%
Dust emission	< 5	mg/Nm ³

Stork Thermeq BV was selected for supplying the boiler and the dual fuel burner. Previously, Stork and BTL cooperated in R&D projects concerning FPBO combustion. Based on the results from these projects a boiler with a large furnace was selected allowing enough volume for complete combustion and low NO_x operation.

The steam boiler is a water-tube boiler with a furnace made from cooled membrane walls. A steam drum is located on top of the boiler allowing the boiler to operate on natural circulation. A dual fuel Stork double register burner is installed allowing the boiler to operate on a combination of FPBO and natural gas, and on natural gas only. The FPBO is injected in the centre of the burner via an oil lance. Steam is used for atomization of the FPBO. The oil lance and nozzle are further discussed under operational issues.

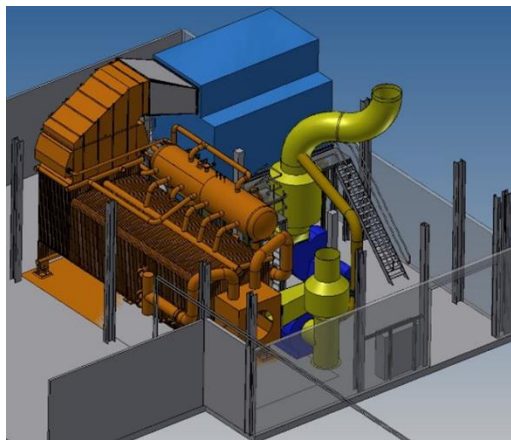


Fig. 8^A: Boiler design



Fig. 8^B: Photo of the boiler

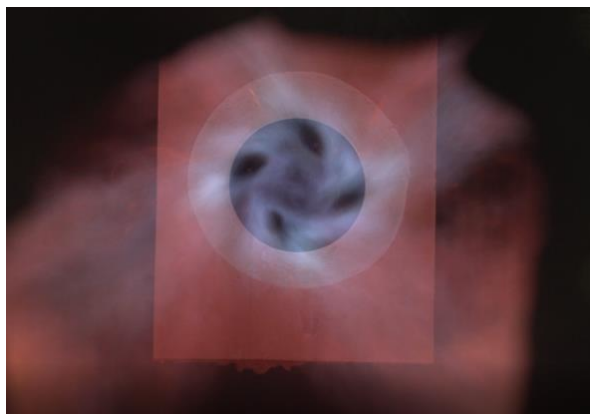


Fig. 9^A: typical natural gas flame

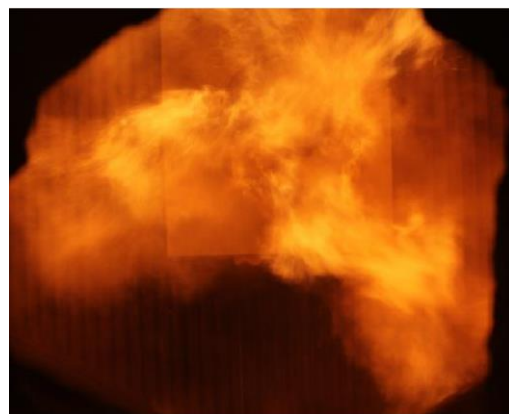


Fig. 9^B: co-firing FPBO with natural gas

Footprint (steam boiler & storage)

One of the reasons to choose for a FPBO fired boiler instead of a direct biomass is the limited space required on site. The primary biomass conversion is taking place elsewhere. Some distance between boiler and fuel storage is also not problematic as liquids can be easily transported via a pipeline. In Fig. 10^A a schematic drawing is given of the actual situation at FrieslandCampina. The distance between fuel tank and boiler is approximately 50 m; the area needed for the tank is about 25 m². Fig. 10^B shows a top view of the steam boiler; it is built on an area of 14 x 12 m (168 m²). Total area is less than 200 m² or $\sim 7 \text{ m}^2/\text{MW}_{\text{th}}$.

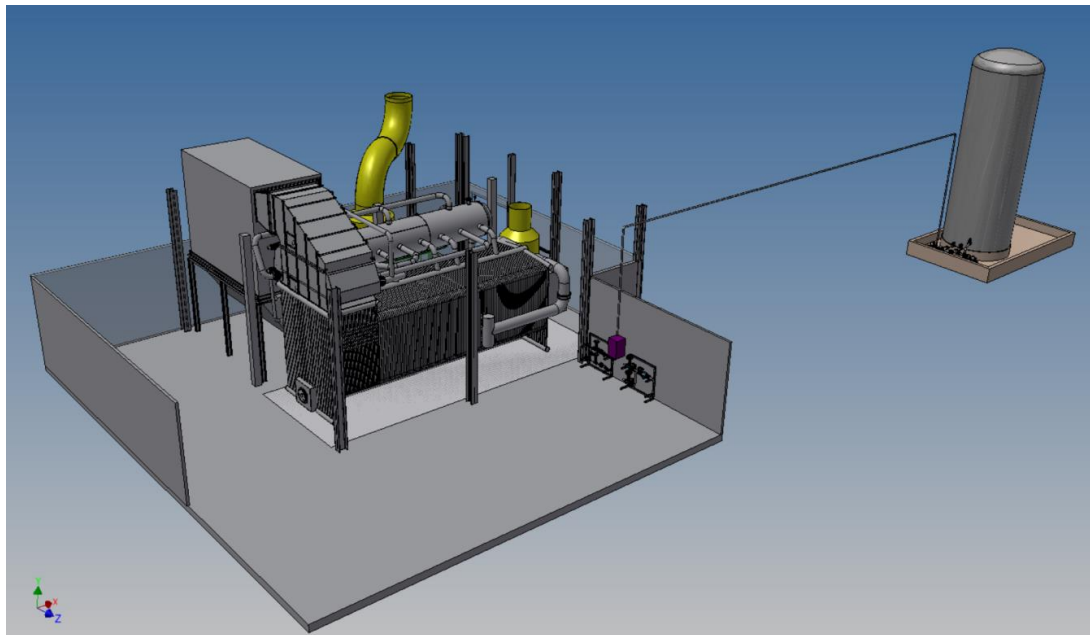


Fig. 10^A (above): Steam boiler and fuel storage

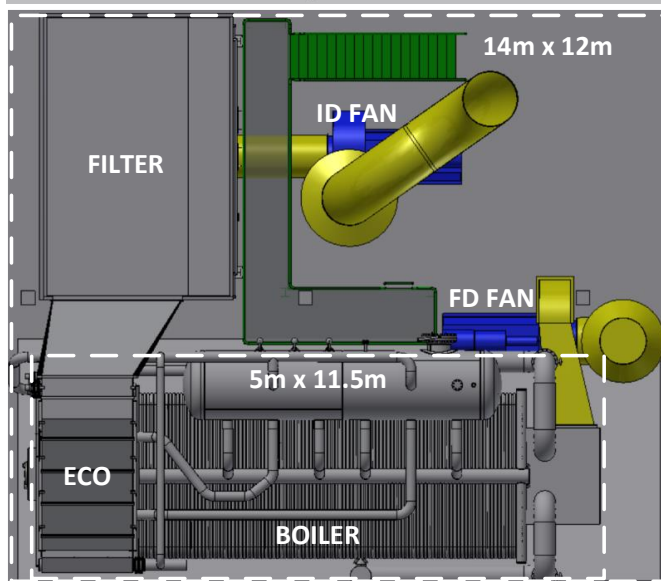


Fig. 10^B (left): Topview of the steam boiler

Operation & Operational issues

The system was constructed in 2014/15 and commissioned in Q3-2015. The oil feeding rate ranges from 1.5 t/h up to 4 t/h with a normal operating case of 3 t/h at 70% boiler load. Roughly, by feeding one ton of FPBO around 500 m³ natural gas is saved.

Overall, the combustion of FPBO at FC has been very successful. Nearly all FPBO produced by Emyro (>99%) has been combusted by FC and no oil was rejected. The remaining part was used by Emyro, BTL or clients for other purposes like the webshop, RTD and demonstrations.

The most relevant operational issues that were encountered during commissioning and operation are discussed below.

Oil lance atomizer clogging

The oil lance is used for atomization of the fuel in the centre of the burner. The original oil lance was equipped with a so called Y-type steam assisted atomizer. A typical example of such an atomizer is shown in the fig. 11.

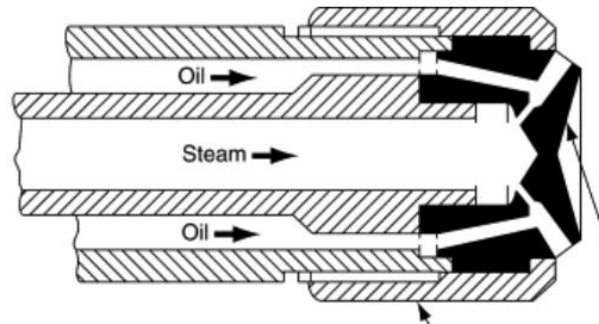


Fig. 11: Typical spray nozzle

The first atomizer tip was made of high temperature steel as normally used for (heavy) fuel oil applications. This resulted in rapid wear out of the holes by corrosion. After replacing the atomizer tip with stainless steel parts the life time of the atomizer was acceptable.

Two oil lances were constructed: the first one for use on the boiler, the second one as spare. During continuous operation of the boiler on FPBO it was found that the atomizer was getting blocked requiring a frequent replacement (every 3-5 days) of the oil lance with the spare one. Replacement of a lance took about 30 minutes. The replaced oil lance then needed to be cleaned so it could be reused. It was observed that the built up of deposits and clogging took place in the holes of the atomizer. Fortunately, these could be quite easily removed using a small drill. More challenging was a steady built up of deposits in the “oil chamber” just before the atomizer tip. This chamber was not accessible as it was a welded construction. A hole had to be cut in the side of the chamber, the deposits removed and then close the chamber again. At some point this cleaning was needed every few weeks, and obviously this is not acceptable and practical.

Therefore, alternative atomizers were evaluated which resulted in the selection of an ultrasonic atomizer as designed and delivered by Dumag (Austria). The main advantages of this atomizer is that it does not have small holes and it has just one straight tube with a deflector head. After successful testing with the new oil lance and atomizer it was decided to replace the original Y-type atomizer with the ultrasonic type, and it turned out to be a great improvement. Clogging is now reduced to a very low and acceptable level. Every two months, the oil lance is replaced by the spare one and only an easy and quick cleaning of the pipe to the nozzle tip is required.

Besides reduced maintenance the new oil lance also showed increased combustion stability, probably related to a better atomization and improved distribution of the droplets compared to the Y-type atomizer.

Boiler fouling

FPBO may contain small amount of ashes, but even a small amount will eventually lead to a thin layer of deposits on the membrane wall of the furnace. This layer is brittle and easily removable and does not influence the overall boiler performance. At the outlet of the furnace, the flue gases flow upwards passing a few rows of bare evaporator pipes prior to entering the first economizer. This economizer is constructed using welded square fin tubes; the tubes are

in-line and the fin spacing is 3 mm. Over time, the space between the fins at the flue gas inlet (hot) side is filled with ash deposits. Over a period of approximately 6 - 8 weeks the fouling is such that the flue gas temperature upstream the bag house filter becomes too high for the filter. Consequently, the boiler automatically switches to 100% natural gas firing preventing further built up of deposits. At a suitable moment the boiler is shut down for cleaning. The deposits can be easily removed by compressed air. The total shut down time is about 1 day. In the meantime, RFC has implemented off-line explosive cleaning. By doing this the shut down time has been reduced to 3 hours.

For a next boiler system, this issue can be prevented by the installation of an in-line cleaning system (eg soot blowers) or a modified economizer and fin design.

Corrosion of the second economizer

In order to achieve a high thermal efficiency an economizer is installed downstream the baghouse filter. The inlet temperature is relatively low (80 °C) and the economizer is constructed of carbon steel with serrated spirally wound fins welded to the tube. After some months of operation, it was discovered that the fins of the first rows (in contact with the coldest water) were corroded, see Fig. 12. With dew-point related corrosion one expects corrosion on the coldest part which is the tube; strangely enough only the fins were corroded. Further inspection revealed that the corrosion started at the foot of the fin, and eventually causing the fins to fall off (Fig. 13).

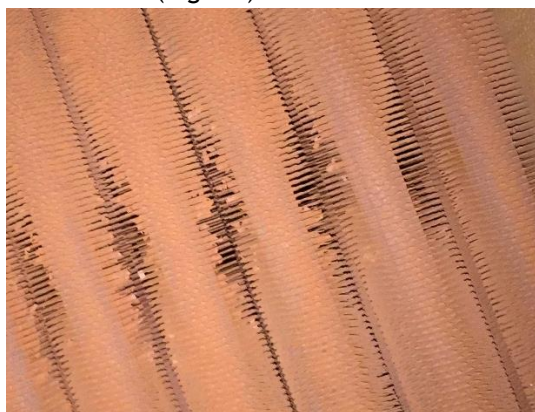


Fig. 12: Corroded fins of economizer



Fig. 13: Fins fallen off the economizer

It is thought that micropores in the weld of the fin on the tube have started this corrosion by collecting e.g. small amounts of sulphur and chlorine by condensation. Over time, some more fins were lost, but finally an equilibrium was reached where further fins are no longer attacked because the water is heated up enough in the bare tubes upstream.

For future projects, this problem can be avoided by using a higher feed water inlet temperature for the economizer or constructing at least the “cold end” of the economizer in stainless steel.

Emissions

In the Netherlands, a directive (“Activiteitenbesluit milieubeheer”) is in place describing the required permits and emissions limits for all kind of energy systems (different units, capacities, and fuels (solid, liquid and gaseous fuels)). Biomass fired systems are a separate category, but pyrolysis oil does not count as ‘biomass’ or ‘liquid biomass’. The latter category only concerns liquids like used cooking oil and vegetable oils. Also torrefied biomass or gasified biomass does

not qualify for the 'biomass category'. Regretfully, it can make the permit procedure more complicated and/or more strict emission limits must be met.

For the FrieslandCampina boiler the following emissions limits are applicable:

- Dust: 5 mg/Nm³ at 3% O₂
- NO_x: 145 mg/Nm³ at 3% O₂

For comparison, the same numbers apply to solid biomass but at 6% O₂ (i.e absolute emissions can be somewhat higher).

Dust

FPBO only contains a small amount of ash (< 0.05 wt%), but the dust emission without post treatment would be too high to comply with Dutch emission limits. For that reason a baghouse filter was installed downstream the first economizer. At this point the temperature of the flue gas is around 200 °C which is allowed for a baghouse filter. A second economizer is installed behind the filter to further cool down the flue gas. This second economizer is relatively small as tubes with serrated fins can be used in the clean environment. With the help of the filter the dust emission limit can be reached. A similar filter is in use at Empyro showing very good performance.

Approximately 1 m³ of fly ash is collected by the baghouse filter every two weeks and via a screw conveyor stored in a big bag. Fly ash is considered as waste in the Netherlands, and the ashes are sent to the landfill for disposal. Based on the amount of fly ash collected and the flue gas flows it can be estimated that before the baghouse filter the dust content is around 50 mg/Nm³, and the filter reduced the dust emissions with more than 90%.

NO_x emissions

The combustion system -i.e. the combination of burner and boiler- was designed to meet the NO_x emission limit by optimizing the combustion for low NO_x. For this reason the double register Low-NO_x burner was combined with flue gas recirculation and air staging in the furnace. Air staging is a well-known method to reduce the NO_x emissions for fuels containing nitrogen. For FPBO the nitrogen content is around 0.1-0.15 wt% when clean wood is used as a feedstock. Air staging is achieved by introducing part of the combustion air at about 1/3 of the furnace length behind the burner. This way a under stoichiometric zone is created in the first part of the furnace. These "lean" conditions cause the nitrogen to react to N₂ instead of NO_x. Despite the positive results in a test boiler, this method was found to be ineffective with FPBO on full scale. Extensive testing was done to optimize this system in a variety of ways. Burner parameters like swirl, FPBO spray angle and atomizing medium were varied, and the air staging nozzles were moved further downstream the furnace. The latter one was most effective, but overall the combination of all these measures was insufficient.

Increasing the flue gas recirculation reduced NO_x when firing natural gas only. When firing on FPBO the effect was less than 5%. This indicates that the contribution of thermal NO_x when combusting FPBO is limited. This is also something that might be expected when looking at the relatively low heating value and high water content of FPBO.

It was thought that the main reason for the staged air principle not working properly was back flow of the staged air to the primary, under-stoichiometric zone. In order to prevent this a physical barrier was created between the primary and secondary zone by installing a checker wall made of refractory. The principle of this is show in Fig. 14.

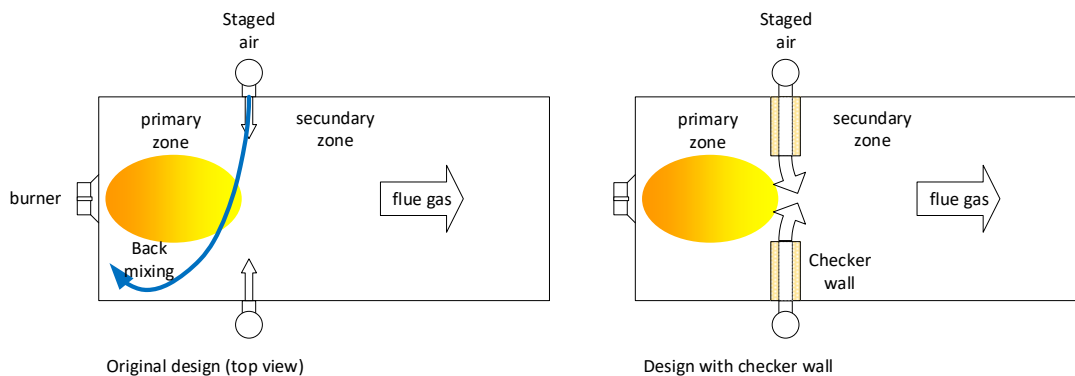


Fig. 14: Schematic view of boiler furnace (top view), original and modified design with checker wall

This modification also gave a limited reduction in NO_x emission. One theory why this doesn't work is related to the FPBO combustion mechanism. A droplet of FPBO will only partially evaporate after which a solid sphere is left. This solid sphere takes longer to combust and most probably ends up in the secondary zone before it burns. The nitrogen contained in the sphere will therefore not see the reducing conditions and will predominantly form NO_x.

Subsequently, SNCR and SCR options were investigated and tests were done with injection of ammonia and urea in the furnace (SNCR). This resulted in lower NO_x but still not enough to comply with the emission limit. Therefore, it was decided to install a low temperature SCR system downstream the bag house filter to ensure low emissions, and be more tolerant towards fuel bound nitrogen. Work on this is ongoing.

ECONOMICAL ASPECTS

The total investment in the multi-fuel boiler including FPBO storage was around 2.5 - 3 M€. Empyro was responsible for the design and delivery of the boiler to FC. The investment was primarily taken care of by FC. Investment support (~30%) was obtained from the Dutch TKI, because it is a first-of-its-kind installation and it contributes to a reduction of fossil fuel.

Obviously by feeding FPBO to the boiler a reduction in natural gas consumption is realized. Roughly, each ton of FPBO co-fired saves 500 m³ of natural gas, and to-date the overall saving in natural gas is close to 30 million Nm³.

In the Netherlands a financial support program called SDE+ is in place since 2012 supporting all kinds of renewable energy. It is an operational support and funding is obtained for real delivered and certified renewable energy. Basically, it pays the difference of the renewable option compared to a reference case. Once approved, the support is guaranteed for a period of 12 years. Specifically for the co-firing of FPBO described in this case study, the difference between the price of FPBO and natural gas is financed. A ballpark figure for the FPBO produced at Empyro is 300 €/ton ~18 €/GJ; more details on the cost breakdown have been published by Van de Beld & Muggen [1].

ENVIRONMENTAL ASPECTS

Several certification schemes have been evaluated for the production process (Empyro) and the pyrolysis oil application (FrieslandCampina). For both cases, the so-called NTA8080 scheme has been adopted [4]. This scheme requires a GHG emission reduction of at least 70% compared to

the fossil reference case. Calculation of the emission reduction is also of utmost importance to qualify for the SDE+ support scheme (see § 1.4) the sustainability of the chain must be proven. The evaluation includes the transport of biomass to the Empyro site, processing of the biomass, transport of the pyrolysis liquid to Borculo, and the use in the steam boiler [5]. The result from the calculations is summarized in Table 3. For this specific case, an overall GHG emission reduction of 96% is achieved, which is well above the required minimum of 70%. Both Empyro and FrieslandCampina received the NTA8080 certificate.

Item	Value	Unit
Biomass supply (360 km two-way)	2.2	g CO ₂ -eq/MJ _{FPBO}
Fast Pyrolysis Process	1.1	g CO ₂ -eq/MJ _{FPBO}
Total emission Empyro	3.3	g CO ₂ -eq/MJ _{FPBO}
Allocated to FPBO (energy basis)	70%	
Total emission PO-production	2.3	g CO₂-eq/MJ_{FPBO}
Transport FPBO to Borculo (60 km two-way)	0.4	g CO ₂ -eq/MJ _{FPBO}
FPBO combustion	0.5	g CO ₂ -eq/MJ _{FPBO}
Total FPBO application	0.9	g CO₂-eq/MJ_{FPBO}
Total emissions FPBO production & application	3.1	g CO₂-eq/MJ_{FPBO}
Emission per MJ of Heat (95% efficiency)	3.3	g CO ₂ -eq/MJ _{HEAT}
Fossil reference case	77	g CO ₂ -eq/MJ _{HEAT}
GHG emission reduction	96%	

Table 3: GHG emission reduction for the production and use of FPBO

Per ton of FPBO combusted about one ton of CO₂ is saved. It means that due to the implementation of the steam boiler around 60 kton of CO₂ has been saved by FC since its start late 2015.

The amount of ash is limited and about 1 big bag of fly ash is collected every two weeks, see §1.3; on annual basis it corresponds to ~24 big bags or around 20 ton.

No waste water is produced and there are no emissions to the (surface) water.

ORGANISATIONAL ASPECTS

The FPBO fired steam boiler operates fully automated and is suitable for unsupervised operation. The boiler is part of the utility centre and as such managed by a small number of operators. No additional operators are required for the operation of the FPBO boiler system. Especially after installation of the new oil lance, the boiler needs limited additional attention besides the 2 weekly replacement of the big bag under the bag house filter and changing of the oil lances every 3 to 4 months.

However, the periodic cleaning of the economizers in the boiler means additional work. The cleaning is done by an external company and can be done within a couple of hours. Also, compared to a gas fired boiler additional maintenance and inspections are required for the flue gas filter, FPBO pumps and oil storage as normally associated with this type of equipment.

During maintenance of the milk factory itself, the steam demand is very low or even zero. In that case the FPBO boiler is shut down. As FrieslandCampina is the only or major off-taker of the FPBO it is important that maintenance is aligned with the planned maintenance of Empyro or vice versa. The total FPBO storage capacity (Empyro + FC) is limited and can only balance

short-term disruptions (hours - day). However, practice has shown/learned that this can be very well arranged.

Normally, the Empyro plant manager communicates with one of the operators of FrieslandCampina. In most cases, it concerns FPBO transport and their timing.

Of all tank trucks leaving the Empyro site a sample is taken. All samples of a single week are collected and mixed to a “single week sample”. The sample is analysed by BTG on elemental composition and water content, and from this data the heating value (LHV) is calculated. The data is introduced in a common computer data base. On basis of this analysis and the total amount of FPBO delivered to FC, Empyro prepares a weekly invoice.

PROJECT FINANCING

FC provided the project investment and it fully owned by FC, see also § 1.4. Some investment support was obtained from the Dutch TKI programme.

SOCIAL AND MARKETING ASPECTS

BTG-BTL has been very active in the marketing & sales of the concept. Especially when the space is limited and a solution is needed where co-firing and redundancy is important the choice for pyrolysis oil on a boiler is excellent. From the beginning there was a close communication with the neighborhood in Hengelo (location of the pyrolysis plant). With respect to firing pyrolysis oil compared to firing biomass the amount of transport movements is considerably less. The pyrolysis oil boiler was officially opened by the Dutch minister and in this event the sustainability certificate from Better Biomass (NTA 8080) was presented.



Opening Empyro Production Plant



Empyro symposium on fast pyrolysis



Dutch minister Henk Kamp at the symposium on renewable energy supply at FrieslandCampina

PYROLYSE SPIN-OFF UT

Moderne alchemie: 'goud' uit zaagsel

De pyrolysetechniek van BTG-BTL gaat een grote vlucht nemen. Uiteindelijk moet het fossiele olie helemaal vervangen, zegt directeur Gerard Muggen.

De pyrolysetechniek van BTG-BTL gaat een grote vlucht nemen. Uiteindelijk moet het fossiele olie helemaal vervangen, zegt directeur Gerard Muggen.

Pyrolyse

De techniek voor de productie van pyrolyseolie uit hout is nu goed genoeg om te worden toegevoegd aan de fossiele brandstoffen. Het is nu mogelijk om te rijden op houtolie. Dit is een belangrijke stap op weg naar een duurzame energievoorziening.

Het is hard werken. Er in blijven geloven, ja, maar sloten, maar toch weer verdergaan.

-Gerard Muggen

Pyrolysis oil from wood in the news

PARIS PROCESS ON MOBILITY AND CLIMATE (PPMC) | About PPMC | News | 80 Days | Partners | Sponsors | Search

MESSAGES ON MOBILITY & CLIMATE | KNOWLEDGE PRODUCTS | NATIONAL & REGIONAL DIALOGUES | EVENTS | UNEP CCC & TRANSPORT

Using Pyrolysis Oil, a 2nd Generation Biomass to Liquid Advanced Biofuel, for Transport in the Netherlands

Context of Transport Climate Action

CO₂-emissions reduction from transport can be sustainably addressed by using pyrolysis oil for transport. This 2nd generation advanced biofuel can be utilized in heavy-duty transport vehicles (HDV), shipping and as jet fuel.

Description

Pyrolysis oil can be produced from residue biomass (non food related feedstock). Crude pyrolysis oil can be co-fed in existing oil refineries to green the production of present transport fuels. Upgraded pyrolysis oil can be used directly as transport fuels (road, shipping, air).

The typical production from a plant is 20 million liters of crude pyrolysis per year, the CO₂ reduction compared to fossil fuels is 29,000 tonnes CO₂-eq/year.

PROJECT INFORMATION

Location: Europe, Hengelo, The Netherlands

Start: 2015

End:

Lessons learned / policy recommendations

Generally, sustainability (CO₂-footprint) is considered very important by many end-users, and it will trigger an interest in sustainable technologies and/or renewable fuels. However, for the actual implementation and/or investment decision the business plan is leading, and economic operation must be guaranteed. Preferably, extra income is even generated to cover the additional technical risks compared to the standard. In case of fast pyrolysis, both the production process as well as the product (FPBO) were new on commercial scale. Enabling 100% back-up by natural gas was crucial to guarantee the availability of process steam at all time independent from the actual FPBO production ('technical de-risking').

Stable policy support and long-term commitment is of utmost importance for the introduction of new value chains. At the time Empyro was developed also a new incentive system was introduced in the Netherlands called SDE+ [7]. It provided financial support to produce renewable heat, and -maybe even more importantly- support was given for a period of 12 years. In the case study presented in this report SDE+-support is received by Empyro and FrieslandCampina. Empyro is a polygeneration plant: it is not only producing pyrolysis oil to be used at FrieslandCampina, but on-site also process steam and electricity are generated. The process steam is delivered to neighboring company Nouryon (chemical company). In fact, Empyro is just another example of producing *Industrial Process Heat* and could have been a case study as such.

A crucial aspect in the development of the fast pyrolysis value chain was to have both the production and application of FPBO in place at the same time. One can't be developed without the other: a fast pyrolysis plant will only be built if the off-take of the oil can be guaranteed, and a dedicated oil boiler will only be built if the required fuel can be guaranteed. Obviously, for any new process it is virtually impossible to guarantee the availability of the new fuel at any time in sufficient quantities. This issue could be overcome by providing 100% redundancy on natural gas, which was very supportive to convince the end-user to invest in the boiler.

The importance of having a full-scale, commercial demo-plant was clearly experienced to bring the technology to the next level and enable the roll-out of the technology. However, during the implementation of new technologies or processes many technical and non-technical issues will be encountered. Sufficient time should be allocated/reserved (also from financial point of view) to solve all issues. It is not unusual that troubleshooting and optimization take a few years. Running the full-scale plant provided new insight in the process and initiated dedicated research and technology development (RTD). It also means that direct access to RTD facilities is highly desired. Moreover, a running demonstration plant appeared to be more convincing than a lot of paperwork and glossy presentations.

Furthermore, the continuous operation of the pyrolysis plant led to the availability of large quantities of FPBO; to date over 50 million liters have been produced at Empyro. The majority has been sold to FrieslandCampina, but significant amounts have also been made available for dedicated RTD as well as large scale demo tests around the world boosting new applications of FPBO.

The case study concerns the production of industrial heat from pyrolysis oil, and the obvious alternative is burning biomass directly. Drivers for FrieslandCampina to choose pyrolysis oil were given on page 3, but eventually the preferred choice depends on the actual case. Reasons to select pyrolysis oil are a.o.:

- *Limited space available.* A FPBO based boiler requires much less space than a biomass boiler of similar capacity (including biomass storage).
- *Local transport.* The volumetric energy density of FPBO is higher than the original biomass, which leads to less traffic. It depends on the location whether that is an issue to consider.
- *Hygienic aspects.* In certain industries (e.g. food) the on-site biomass storage is unwanted due the presence of dust, bacteria and fungi. FPBO does not produce dust and contains no bacteria & fungi as a result of the properties, chemical composition of FPBO and the production process at elevated temperature.
- *Low CAPEX.* The investment in a FPBO boiler is much lower than for a biomass boiler. On the other hand, the fuel is more expensive (shift in OPEX-CAPEX). There is some analogy with choosing between natural gas and coal.
- *Peak load.* Decoupling of fuel production and utilization in time, capacity, and location. Pyrolysis oil can be used as peak fuel as e.g. demonstrated by Fortum in Joensuu, Finland [8].
- *Redundancy.* Possibility to cofire with gaseous and liquid fuels, and 100% redundancy can be achieved with existing fuels. In principle, it is possible to co-fire with coal, but in such case direct biomass cofiring makes more sense. Existing or lacking on-site experience/facilities to handle solid biomass can also make a difference.

References

- [1] L. van de Beld, G. Muggen, EMPYRO: Implementation of a commercial scale fast pyrolysis plant in the Netherlands, EUBCE Vienna
- [2] PyroKnown, http://pyrowiki.pyroknown.eu/index.php?title=REACH_registration
- [3] Maarten Rinket, Ardy Toussaint, Experience with firing pyrolysis oil on industrial scale, PyNe newsletter No. 31, pp 3-4
- [4] www.nta8080.org / www.betterbiomass.com (internet assessed on July 2020)
- [5] Martijn Vis, Guidelines for sustainability certification of pyrolysis oil, BTG report 1574/DBIO2002, available via www.btgworld.com or <http://pyrowiki.pyroknown.eu>
- [6] <http://pyromovies.pyroknown.eu> (internet assessed on July 2020)
- [7] <https://english.rvo.nl/subsidies-programmes/sde> (internet assessed on July 2020)
- [8] <https://www.biopad.eu/wp-content/uploads/Case-study-of-Fortum-in-Joensuu.pdf> (internet assessed on July 2020)

Acknowledgements

Financial support from the European Commission (No TREN/FP7EN/239357/"EMPYRO"), the Ministry of Economic Affairs via the Topsector Energie TKI-BBE programme, the province of Overijssel, and the Energy Fund of Overijssel (EFO) is gratefully acknowledged.



Further Information

IEA Bioenergy Website
www.ieabioenergy.com

Contact us:
www.ieabioenergy.com/contact-us/