

BIO FUEL OIL FOR POWER PLANTS AND BOILERS

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3. Abstract

To address the critical aspects in the utilisation chain biomass - fast pyrolysis liquid production - utilisation, the following objectives have been defined:

- Generating performance, emission and cost data for bio fuel oil utilisation schemes focusing on the market quality of the liquid,
- Developing downstream units of liquid production, improving the liquid quality, and establishing fundamental understanding of biomass pyrolysis, and
- Establishing a network of potential liquid producers and users.

Applications developed include pyrolysis liquid (bio fuel oil, BFO) as a fuel for oil boilers and diesel power plants, the emphasis being in the first application.

Four work packages were identified:

1. Pyrolysis liquid production and utilisation
2. Handling, storage, and transport of BFO
3. Quality improvement
4. BFO markets.

Market quality of BFO is critical for utilisation. BFO specifications were outlined for two applications:

- Use of BFO in boilers replacing heavy fuel oil
- Use of BFO as diesel power plant fuel.

Total of about 70 tonnes of BFO were produced within the project.

Combustion tests in a 200 kW and a 4 MW boilers were successfully carried out. Performance and emissions were comparable to those when fired with light and heavy fuel oils, respectively. In addition, fundamental combustion data was generated, which may be used in comparing combustion characteristics of different BFOs. Fundamental data generated is applicable to all BFO combustion applications (boilers, engines, combustion turbines).

A quick stability test (24 hours at 80 °C) has been developed for a comparison of the stability of different pyrolysis liquids. A change in viscosity is observed. This test corresponds roughly the viscosity change of a pyrolysis liquid in a year storage at ambient temperature.

BFO treatment and handling in industrial scale is reported for the first time within a European project. Properties of BFO are not at all similar to the properties of mineral oils, and corresponding measures have to be taken.

Two approaches were used in BFO quality improvement:

- Hot vapour filtration (HVF) in pyrolysis
- Chemical modification of BFO.

HVF will be continued in larger scale. Chemical modification was not successful. The failure in upgrading of BFO is primarily due to the lack of understanding of pyrolysis chemistry. It is

advisable, before continuing any research on catalytic upgrading, to study the chemistry of the pyrolysis vapour alone and the chemical changes involved in the oil ageing.

It was shown that improving the present BFO fuel quality is necessary. Markets, where BFO might be competitive, were identified in Sweden, Finland, and Italy. However, producing transportation fuels is not competitive, because of the low yield and high processing costs.

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5. Objectives

The work aims at developing alternative energy uses for biomass. Production and utilisation of fast pyrolysis liquid (bio fuel oil, BFO) is studied. Applications developed include BFO as a fuel for oil boilers and diesel power plants, the emphasis being in the first application.

The project is aimed at:

- Generating performance, emission and cost data for bio fuel oil utilisation schemes focusing on the market quality of the liquid,
- Developing downstream units of liquid production, improving the liquid quality, and establishing fundamental understanding of biomass pyrolysis, and
- Establishing a network of potential liquid producers and users.

To address the critical aspects of the utilisation chain the following specific objectives have been defined:

1. Establishing utilisation technology and market quality for bio fuel oil.

- To generate performance and emission data for bio fuel oil utilisation schemes focusing on the market quality of the liquid: a) as stationary medium-speed diesel engine power-plant fuel, b) as a fuel in medium scale oil boilers.
- To determine basic health and safety procedures in handling and storage of bio fuel oils to support further demonstration in Europe.
- To determine key material requirements of handling and storage equipment for bio fuel oils.

2. Developing downstream unit operations of liquid production, improving the liquid quality.

- To improve fast pyrolysis liquid fuel quality (solids content, viscosity, storability) in order: to ease the use of liquid in applications specified above, and to increase the value of the end-product.
- To produce at the pilot scale pyrolysis liquid in high-yield from eucalyptus and pine sawdust for utilisation tests.

3. Generating data on liquid property requirements for different applications.

4. Establishing a network of liquid producers and users.

The last objective is critical as bio oil is not used in Europe at present time. It is necessary to develop applications so that enough key players are contributing from the very beginning of the development work. The interaction between organisations dealing with BFO production and utilisation is critical for the further development of industrial applications.

The potential number of bio fuel oil users in European markets is highly dependent on cost and availability of biomass in each country. Markets and potential number of applications are studied as part of the work. Both electricity and heat production are assessed as end products.

6. Technical description

The proposed bioenergy utilisation chain may be divided into three areas: biomass production and delivery, biomass conversion, and utilisation of bio fuel oil. Main emphasis of the participants are shown in Table 1 and Figure 1 related to these areas.

Table 1. Biomass utilisation chain and emphasis of project participants

	Production	Conversion	Utilisation
VTT		X	X
ARUSIA	X		
Neste			X
UCL		X	
IWC		X	
Union Fenosa		X	X
Wärtsilä			X
Finesport			X
ENEL		X	X
Istituto Motori			X
Stockholm Energi			X

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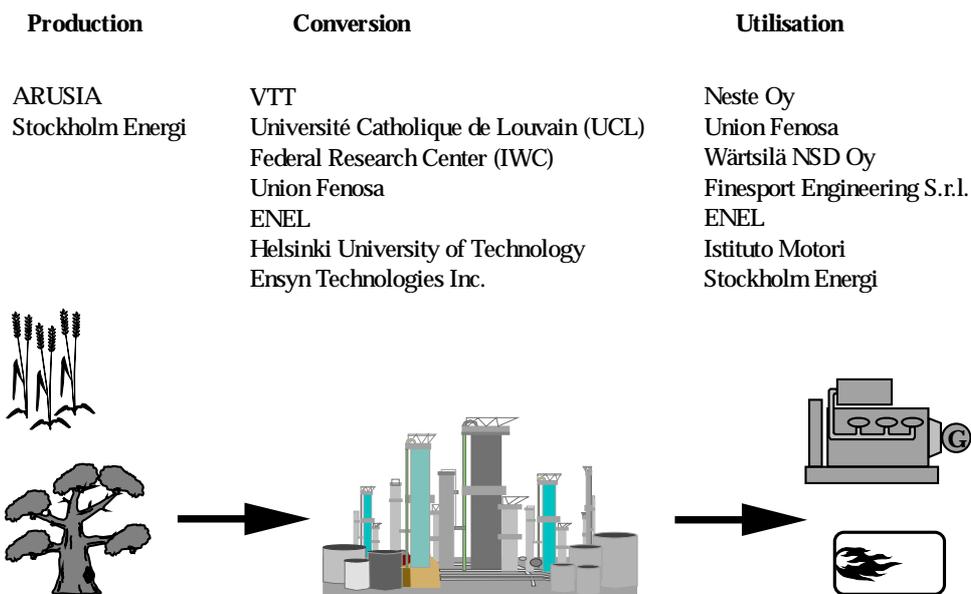


Figure 1. Project participants and applications

In the project, ARUSIA is interested in creating an agro-industrial centre for renewable energy production in the Umbria region. Logistic and management aspects of biomass delivery system are believed by ARUSIA to be essential for successful applications.

There are several industrial participants in the project. The two utilities involved, Union Fenosa and ENEL, are both carrying out R&D work related to both biomass pyrolysis and utilisation of bio fuel oil. Neste is interested of applying bio fuel oil in boilers for space heating. Stockholm Energi is studying the use of bio fuel oil within city limits as an alternative for mineral heating oil. Wärtsilä has been working on the diesel engine application. Finesport will study bio fuel oil applications in Italy.

R&D organisations and universities are working both on conversion and utilisation aspects. VTT is developing fast pyrolysis, and together with UCL and IWC, improving the product quality. Istituto Motori is studying combustion behavior of bio fuel oils.

An overview of the project work packages is presented in Figure 2.

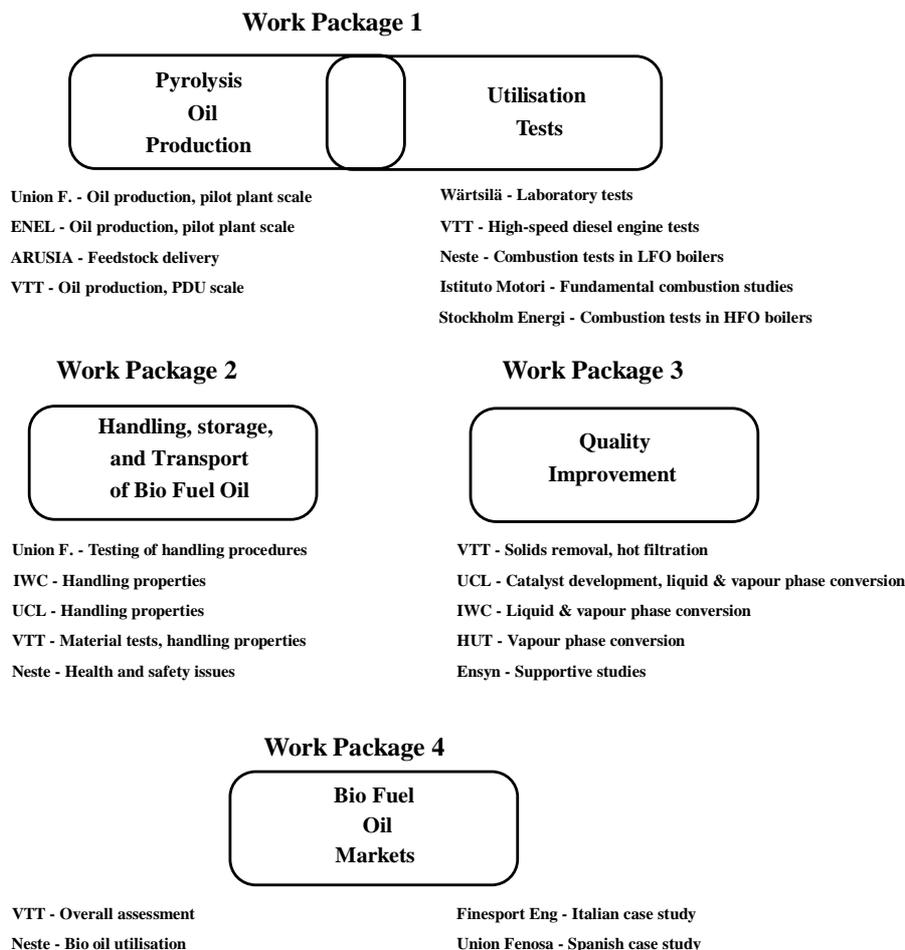


Figure 2. Work packages in the project JOR3-CT95-0025

7 Results

The activities within work package 1 are summarised in Table 2.

Table 2. Work package 1.

Activity
1.1 BFO characterisation for diesel engines
1.2 Utilisation of bio fuel oil in oil boilers
1.3 Characterisation of oil-droplet combustion
1.4 Liquid production for utilisation tests
1.5 Pyrolysis char combustion characteristics

Task 1.1. One test was carried out in the single cylinder test engine at VTT. The total time run on pyrolysis liquid was 24 minutes. During the test about 5 kg pyrolysis liquid was consumed. The test was stopped when a fuel line broke, but obviously the piston was damaged after only 8 minutes of running. The probable reason for the piston failure was wrong timing of the pilot/main injection, and a too high fuel delivery. Therefore the problems in the test cannot be attributed to any properties of BFO. Wärtsilä has characterised BFO and other bio oil samples in a fuel ignition analyser.

Within **task 1.2**, Neste has carried out boiler combustion work in a 200 kW test boiler (Figure 3).

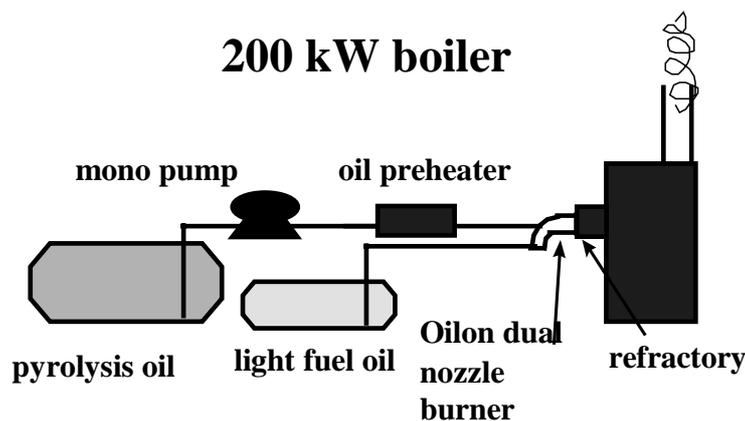


Figure 3. Test boiler at Neste

The main objective of the tests is to acquire knowledge and experience concerning the level and control of emissions from a variety of different fast pyrolysis samples. Secondary objectives are to determine the extent of special handling requirements, and combustion system modifications due to the particular physical properties of pyrolysis liquids.

The best emission results were obtained with fresh (< 4 weeks old) VTT Energy pine sawdust samples. These had carbon monoxide (CO) emissions of 30-50 ppm, nitrogen oxides (NO_x)

120-150 ppm and particulates Bacharach 2-3. The liquid produced a clear flame and was very stable. Compared to light fuel oils, these results are acceptable except for particulates.

After 6 months in storage, emissions increased for CO to > 100 ppm and particulates to > 4 Bacharach which could not be explained by the small (20%) rise in viscosity. The aged sample also caused problems with rapid blocking of filters.

Table 3. A summary of emissions from a 200 kW boiler

	O ₂ vol %	CO ppm	NO _x ppm	Bach. value	Pressure bar	Liquid T °C
Tempera 15	3-6	14-10	130-100	0.8-0.5	10	22
Ensyn 6/23	4-8	40-30	150-130	2-3	15-20	80-90
VTT 7/19 2,3,4	5-8	30-100	120-160	2-5	17-22	75-85
UEF 6/26 pine + 5 % IPA	8	300	140-160	5-6	17-22	85-90

Initially, combustion tests in a 9 MW district heat boiler were scheduled at Stockholm Energi. However, because of lack of time the coordinator made a decision to carry out combust tests at Oilon Oy, Lahti, Finland. A 4 MW well-instrumentated boiler was used. Performance and emissions were measured using all relevant PL samples available (two ENEL liquids, UEF, Ensyn, and Dynamotive). Total of about 20 m³ were combusted.

Combustion tests were performed to investigate the effect of furnace refractometers and insulation, burner performance and settings, atomisation, co-firing, load and different types and qualities of pyrolysis oils. Shape of the flame and temperatures, coatings, soot, dust, CO, HC, NO_x, were observed and measured.

In task 1.3, Istituto Motori (IM) has characterised BFO droplet combustion. The main results obtained in the task are summarised in the following.

The investigation on the *heating/vaporisation* phase of pyrolysis oil droplets evidenced the formation of two different morphologies of residual particles: a) compact and mechanically resistant spheres with much smaller diameter b) fragile, glasslike cenospheres with thin walls and menisci, with an overall dimension even twice the initial diameter.

This solid residual is the final result of a series of swellings and explosions with expulsion of large fragments; the sequence getting slower and less vigorous as the time elapses. The slow-down of such a pulsating process ends with a residual particle, which is hollow inside, with a thin glassy surface.

The mechanism is always present also in a complete *combustion* event: the main difference is due to the overlap of the cenosphere formation process with the burning process, which may well start during the swelling phase. The burn out of the hollow particle completes the process, leaving no trace of unburned matter.

The mechanism, which leads to the formation of glasslike cenosphere, appears characteristic of bio oils, regardless of the drop dimensions or the feedstock origin.

By means high-speed cinematography, the thermal history of droplet suspended to a thermocouple was related to the different phases undergone by the droplets: vaporisation, swelling, matter eruption, ignition, etc.

Four different stages characterised by well-defined droplet temperature were identified as typical of the combustion process of pyrolysis oil. The temperatures of the stages were around 120°C, 300°C, 500°C and 1200°C, respectively. The duration of the first three stages (vaporisation of the light and heavy compounds and liquid phase pyrolysis: "cooking stage") showed a marked dependence on the droplet size while the last stage duration was less sensitive to the droplet diameter. The overall effect is that the total burning time increases almost linearly with the droplet diameter.

The analysis of the stage duration permitted a deeper comprehension of the role played by the different classes of compounds in the oils: the overall thermal behaviour of different samples can be related directly to their composition in terms of classes of compounds. This approach should permit a great simplification in the modelling of the combustion of pyrolysis oil droplet.

The effect of dilution with alcohol was thoroughly investigated: no differences were observed in the overall combustion behaviour of pure pine oil and mixtures up to 10% of ethanol when small droplets composed of fresh mixtures were studied. On the contrary, differences were observed in case of aged mixtures. However, aged mixtures formed largest droplet respect to the fresh ones. Thus the role of alcohol addition was not completely assessed being not definitively understood the relative role of the aging respect to the effects due to different droplets size.

In task 1.4, Union Electrica Fenosa (UEF), ENEL, VTT produce liquid in their pilot, demonstration, and PDU-units, respectively, for analysis and utilisation tests. Amounts produced and BFO quality is summarised below. More BFO analysis results are shown in Task 3.4.

ARUSIA and SEAB supplied dried biomass to ENEL for pyrolysis liquid production. 180 tonnes of beech wood was supplied to the Bastardo plant. 32 tonnes of Swedish pine was also delivered.

During the first half of 1998, modifications were carried out for the ENEL pyrolysis plant (Figure 4). During September 1998 and April 1999, 67 tonnes of BFO were produced by ENEL.

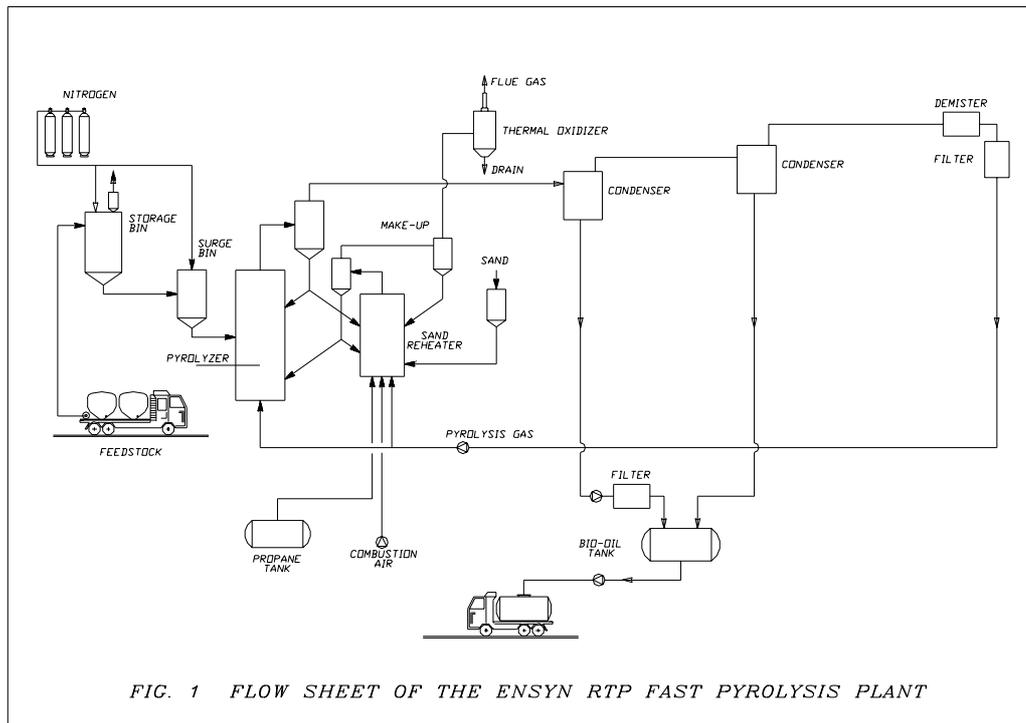


Figure 4. The ENEL Bastardo pyrolysis plant

After extensive modifications at the UEF plant were carried out, the pilot plant was operated in order to deliver BFO to the other partners (Figure 5). The first part of the production was focused to the starting-up of the plant processing with a Spanish biomass (pine). After the Spanish pine the 4 tonnes of Swedish biomass (pine) sent by Stockholm Energi was processed. About 3 tonnes of BFO were produced.

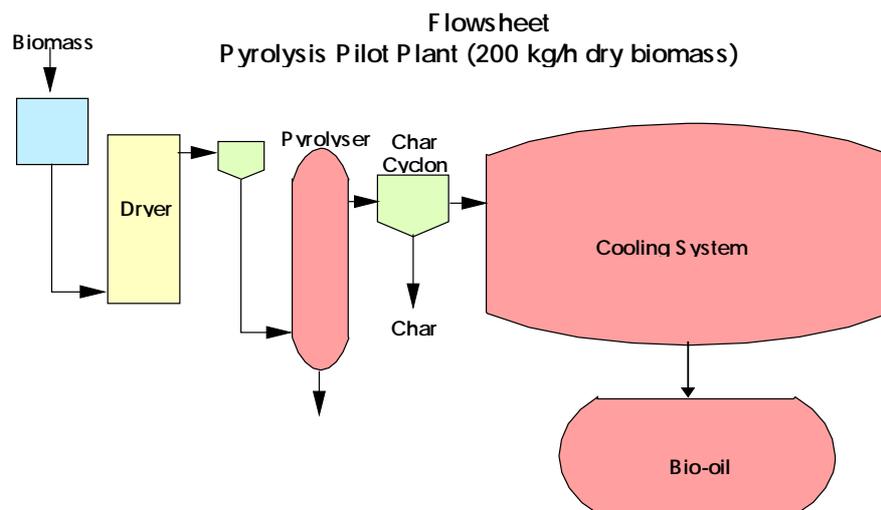


Figure 5. Flowsheet of the UEF pyrolysis pilot plant

BFO production was also carried out with a PDU (20 kg/h) at VTT Energy (Figure 6). The raw material used in these experiments was pine saw dust. BFO has been produced for utilisation tests (boiler tests at Neste), for quality improvement work at VTT, and for other partners (IM, UCL, IWC). About 2 tonnes were produced and used within the project.



Figure 6. Flowsheet of the VTT pyrolysis PDU

Task 1.5. VTT studied combustion of straw char, as that will be an essential step in straw pyrolysis. Straw ash properties set stern requirements for combustion conditions.

In biomass ashes, in which both silicon and potassium (also sodium) contents are high, the silicate formation can bind potassium and prevent volatilisation. In biomass ashes, in which silicon content is low, the formation of those potassium compounds which volatilise easy is more probable. Such compounds are e.g. chlorides; these compounds can also exist in small particles (carry over). The volatilising alkaline metal compounds are harmful, especially, in the combustion processes in which steam is produced. These compounds can deposit by condensation on heat exchanger surfaces. Silicate formation can then enhance bed agglomeration due to the low melting temperature of silicates (potassium silicate 740°C).

5.3 Work package 2

Work package 2 tasks are shown in Table 4 below.

Table 4. Work package 2.

Activity
2.1 Material testing
2.2 Health and safety issues
2.3 Stability, storage, and handling of pyrolysis liquids

Task 2.1. SEAB and VTT have carried out test with different materials with BFO. VTT carried out laboratory tests with several materials early in the project. SEAB continued material testing (as part of WP2.3) in large scale towards the end of the project.

The pH of pyrolysis liquids is low (2 - 3) due to high amounts (8 - 10 wt%) of volatile acids, mainly acetic and formic acids. These acids with water are claimed to be the main reasons for the corrosiveness of pyrolysis liquids especially at elevated temperatures. When processing pyrolysis liquids an even black coating is formed on the steel surface of the process equipment. This “coating”, analysed by ESCA (Electron Spectroscopy for Chemical Analysis), contained metals from pyrolysis liquid, mainly silica, potassium, and calcium.

The copper corrosion test ASTM D 130 is the standard corrosion test for mineral oils. In the test (at 40 °C) no corrosion or weight loss on copper stem (99.9% electrolytic copper) was observed for different pyrolysis liquids (hardwood, softwood, straw) from different processes (sand-circulation, fluidised-bed). Copper is a noble metal and hence has generally a good corrosion resistance to non-oxidising acids. However, if connected with other metals, there is a possibility of electrochemical corrosion. Copper and its alloys (brass, bronze, cupronickel) are widely used in piping applications (tubes, valves, etc.) mostly because of the excellent availability of different components. However, it should be borne in mind that copper and brasses are subject to erosion and corrosion, when high fluid velocities are used or abrasive particles are present especially at higher temperatures. It should also be pointed out that brasses with 15 % Zn or more cannot be used with pyrolysis liquids due to dezincification.

In the standard corrosion test (ASTM D 665 A) no rust was formed but a clear weight loss in carbon steel (AISI 01) was observed. No corrosion for carbon steel at ambient temperature in low acid (3.6%) and water (4.4%) concentrations has been reported, but clear corrosion has been observed at elevated temperature (45 °C) in high acid (17.5%) and high water (55.7%) contents. The acid-resistant steel AISI 316 (17 % Cr, 11 % Ni, 2.2 % Mo, 0.05 % C) is resistant at least at temperatures below 50 °C. One reason why the AISI 316 is better than AISI 304 is a small amount of Mo that serves to make the steel more resistant to general corrosion in non-oxidising acids, stress corrosion and especially localised corrosion (pitting and crevice corrosion) caused by aggressive components like halogens.

Nickel and nickel-based materials are not resistant to pyrolysis liquids even at room temperature. On the other hand, cobalt-based HAYNES 188 (39.4 % Co, 22 % Cr, 22.9 % Ni, 14.5 % W, 1.2 % Fe) shows no corrosion up to 80 °C.

Many plastics like PTFE (polytetrafluoroethylene), PP (polypropylene), and HDPE (high density polyethylene) are very resistant to pyrolysis liquids. They are excellent materials for containers in storing, transportation and sampling of pyrolysis liquids. Their use could possibly be extended to replacing copper or, in special cases also AISI 316.

Task 2.2. Neste has reviewed relevant issues related to safety and handling of BFO. Environment, health and safety (EHS) issues include emissions from combustion, material safety data sheets (MSDS), exposure limits to workers during production, spill procedures etc. Since there is not yet a commercial pyrolysis product available, work on EHS issues is preliminary in nature. At this phase it is important to clarify what are the most important health related issues and as the product is developed to quantify these. From the analyses performed to date, it is clear that both the feedstock and the process conditions will have an effect on the type and concentration of various toxic, mutagenic and carcinogenic compounds. During combustion, emissions are strongly influenced by both the fuel properties and the combustion conditions. It is therefore not possible to give definitive precise maximum or minimum values as to the level of particular pollutants.

The available literature has been reviewed in order to clarify the current level of knowledge. Toxic compounds & PAHs and their health effects have been reviewed by Diebold, Elliot and Gratson. Analyses of the liquid itself has shown the possibility of hundreds of different chemicals. From these it is possible to identify certain compounds which could pose a health risk. The most important of these are used in determining exposure limits to workers and are: acrolein and formaldehyde and phenolics such as guaiacol. Upgrading of pyrolysis liquids using zeolite catalysts can lead to very high increases of PAHs.

UEF has also studied toxicity of BFO, and has carried out a HS evaluation for their pilot plant.

Task 2.3. Stability of pyrolysis liquids can be monitored by several methods. At VTT a quick stability test (24 hours at 80 °C) has been developed for a comparison of the stability of different pyrolysis liquids. A change in viscosity (and water) is observed and samples with weight losses over 0.1 wt% are abandoned. This test corresponds roughly the viscosity change of a pyrolysis liquid in a year storage at ambient temperature. The increase in viscosity is directly related to the increase in average molecular weight of pyrolysis liquid.

Because the amount of reactive carbonyl groups in pyrolysis liquids is quite high FTIR runs were conducted and the change in these groups was monitored. Similar system than that at IWC was used.

Following observations can be drawn based on the results:

- The amount of carbonyl groups decreases slowly by heating at 80 °C (stability tests for 72 hours at 80 °C).

- The amount of carbonyl groups is lower for pine than for birch liquid (same process conditions)
- Concentration of birch pyrolysis liquids causes some evaporation of carbonyl-containing compounds (e.g. small acids)
- The mixed hardwood liquid was very low in volatiles which can be seen as a low ratio of carbonyl/aromatic band compared to the other hardwood liquid sample (birch)

Task 2.3 at SEAB. SEAB carried out large scale tests with BFO samples. The tests were related to use of BFO in industrial scale boilers. Not much relevant results have been so far published on this critical issue.

By adding alcohol (e.g. methanol) or alcohol-water mixtures it is possible to treat even old, phase-separated, high viscosity pyrolysis liquids to meet handling and burner viscosity demand.

The BFO temperature is recommended to be kept below 40 °C. Exposure to air must be prevented by several reasons; e.g. loss of light compounds and oxygen causes polymerisation reactions with consequent fall out of heavy compounds, strong odour in the environment. Storage, handling and transport hence must be done in airtight, non-ventilated containers and transfer from storage tank to transport vehicle and reverse must be done with a simultaneous exchange of gas to prevent air inlet and exhaust to ambient air.

Storing has to be done in tight, non-ventilated tanks. Storage under a separation layer of paraffin oil failed due to penetration and evaporation of the lighter compounds and that the paraffin was pushed away and collected in the vortex of the slow rotating mixing axes.

New fuel classification and tank storage regulations have to be considered. E.g. flame tests at 60 °C is not relevant. Pyrolysis oil shall not be stored above 25 °C and shall not be heated by hot surfaces; flammable, light components have a low concentration and are dissolved in water; by stepwise evaporation – condensation high concentration of light flammable components can be concentrated in the gas phase, reaching LEL (lower explosion limit) also at low temperatures; etc.

5.4 Work package 3

Work package 3 tasks are shown in Table 5.

Table 5. Work package 3.

Activity
3.1 Solids removal
3.2 Thermal stabilisation
3.3 Vapour phase upgrading
3.4 Characterization of bio fuel oils

Task 3.1 at VTT. Pine saw dust was pyrolysed at 525 °C in the 1 kg/h pyrolyser equipped with a hot-vapour filtration (HVF) unit. In addition to shorter tests with several process variables, two longer time experiments (57 and 71.5 hours) were conducted. It was concluded that HVF should be continued in a slip-stream unit connected to the PDU unit.

Both barrier filter and centrifuge were tested in liquid phase filtration. Pressure (barrier) filter gave mixed results: due to high loading of solids, the system was not practical at the ENEL pilot plant. However, at smaller scale, where solids loading is less, VTT was using a pressure filter successfully in the PDU. Ensyn tested centrifuges, and concluded that solids content may be successfully reduced with a centrifuge. However, it should be noted that neither of the liquid phase systems yields a solids content comparable to HVF.

Task 3.2 at UCL. The main activity done by UCL within the «Thermal stabilisation» task concerns the development of catalysts suitable for hydrodeoxygenation reactions.

The results obtained are promising but the advances done during the present contract do not allow the immediately industrial application. The testing of these new catalysts using the best reaction conditions (all these points have been studied during this contract at the laboratory/small bench scale) must obligatory be confirmed using real feedstocks and, later, in pilot scale.

Other role played by UCL during the project was to produce and/or select, characterise and provide hydrotreating catalysts to IWC. Different types of carbon supported catalysts, most of them containing noble metals such as Pd have been tested with real oils at IWC and characterised after test at UCL. No sensible quality increase was noted in the oils after reaction, this is probably due to the fact that the reaction conditions (closer to hydrogenation than hydrotreating) were not suitable for the catalysts developed at UCL.

Task 3.2 at IWC. The most important results of this investigation were the carbonyl group measurements and the rheological study. All samples showed a remarkable decrease of the number of carbonyl groups with storage time. Interestingly, a smaller decrease of number of carbonyl groups was observed for samples stored at -20 °C than for samples stored at 80 °C. Remarkably, hydrogenated oils showed a smaller increase of the number of carbonyl groups than the crude VTT pyrolysis oil. This observed increase of carbonyl groups substantiates the assumption about polymerization with time.

Task 3.3. at UCL. For this subject, UCL was to develop new catalysts and to characterise the catalysts used in IWC and VTT facilities. 25 catalysts were delivered to the partners. 40 used catalysts in total were received from IWC and VTT. Two main subject were treated:

- 1) As suggested in the technical annex, try to improve the process involving ZSM-5 (full upgrading)
- 2) Attempt to transform the oil so that it can be fired in a modified diesel engine (minimal upgrading)

The conclusions are that:

- Full vapour phase upgrading (production of hydrocarbon from the pyrolysis vapours) might be improved but the final upgraded product will still be very expensive. Indeed, the yield experimentally obtained may be raised. However, the yield in hydrocarbon will remain stoichiometrically limited by the very important oxygen content of pyrolysis products.
- Minimal vapour phase upgrading (production of a stable pyrolysis liquid) needs to be better defined before any further study. Encouraging results were obtained. But catalyst development cannot be performed without a clear idea of the chemical change to be obtained.
- Summarising, many catalysts have been tested. Most of these catalysts have not been envisioned previously in the literature. However no real breakthrough was obtained. This is mainly due to the lack of understanding of pyrolysis vapour chemistry. It is thus advisable, before continuing any research on catalytic upgrading, to study the chemistry of the pyrolysis vapour alone and the chemical changes involved in the oil ageing.

Task 3.3 at HUT. The catalytic conversion of pyrolysis vapours of pine sawdust was studied in micro- and bench-scales. Several catalysts, i.e., acidic zeolites and basic oxide catalysts were screened in a novel micro-scale system developed during the project. The zeolites were effective in the removal of oxygen. However, the liquid yields were low. Oxide catalysts had lower activities and the products remained mainly qualitatively unchanged. Therefore, higher liquid yields were achieved. The most promising results were achieved with zinc oxide which was chosen to be used in the bench-scale unit. In this unit the oil amounts were high enough for the stability tests. The oil without the catalyst reactor was used as the reference. The pyrolysis liquids processed were homogeneous, one-phase oils. The ZnO proved to be a mild catalyst and the liquid yields were not substantially reduced that agreed with the micro-scale results. Some indications of catalyst deactivation were observed. The oil samples were aged thermally and the viscosity and water content were determined. The increase in the viscosity was noticeably lower for the ZnO treated oil than for the reference oil thus indicating an improvement in the stability for the ZnO treated oil.

Task 3.3 at IWC. IWC decided to work within another project (JOR3-CT95-0081) on this topic. The most promising catalyst found was thermally expanded slate, an inexpensive highly porous material. It has a moderate catalytic effect in such a way that it enhances stability of the oil without major changes of yield and oil composition. The problem with slate is the lower density and smaller heat capacity resulting in difficulties with the fluidized bed reactor at pilot plant scale. More work is needed in this respect to optimize fluidization conditions for the new bed material.

Task 3.4. Quality requirements have been developed for BFO in two applications: fuel for diesel power plant and as a heavy fuel oil boiler (Table 6). These specifications are important, as this is the first time potential users of BFO have worked together with developers of BFO production technology to define quality requirements. The specifications were developed together with both Wärtsilä and Stockholm Energi. These specifications will evolve once more experimental data becomes available.

Table 6. Quality requirements for boilers and diesel engines using pyrolysis liquid

	Diesel engine tests by Wärtsilä		Combustion tests by SEAB
	Specifications	Allowable variation (10 %) for a tote (surface/bottom)	Specifications
Homogeneity	7-day storage	no phase-separation	-
Water, wt-%	max 26	max 10 % difference, max 26	max 25
HHV, MJ/kg	min 18	max 10 % difference,	min 19
LHV, MJ/kg	min 16	min 18 and 16	min 17
Ash, wt-%	max 0.1	0 - 0.1	max 0.1
Solids, wt-%	max 1	0 - 1	max 1
<50 µm	100	-	-
<25 µm	min 90	-	-

BFO quality follow-up was organised related to large scale production. Some analytic results concerning the BFO produced within the project are shown in Table 7. The liquids have been produced from pine and beech.

Table 7. BFO samples produced within the project

	UEF	ENEL	VTT
Biomass	Swedish pine	Italian beech	Swedish pine
Feed moisture wt%	5.5	3.0	2.5
Water wt%	35.4	20.5	16.3
Viscosity @50°C, cSt	5.8	19	32
Solids wt%	0.02	4.8	0.28
Ash wt%		0.5	0.05
Carbon wt%	32.8	43.1	46.6
Hydrogen wt%	8.2	7.4	6.7
Nitrogen wt%	>0.1	0.2	0.1
LHV MJ/kg	*	15.7	17.5

* Cannot be measured due to high water

5.5 Work package 4

Work package 4 tasks are shown in Table 8. The distinctive nature of this project was that BFO production was carried out in a reasonable large scale. The techno-economic

assessments are therefore based on more reliable mass and energy balances than other comparable studies.

BFO treatment and handling in industrial scale is reported for the first time within a European project. Large scale experimental data was also generated, which made it possible to verify some of the process parameters initially with large uncertainties.

Also because of the large scale, technical uncertainties in industrial applications are better understood. This makes it possible to take into account all relevant cost items, which may easily be left out, when assessments are based on laboratory scale results.

Table 8. Work package 4.

Activity
4.1 Technoeconomic assessment (TEA) of upgrading alternatives for the proposed applications
4.2 TEA of the feasibility of diesel power plants in Italy, Spain, and Finland
4.3 Bio fuel oil in Finland and Italy

Task 4.1 at VTT. Use of bio fuel oil (BFO) in three applications was compared:

- Use of BFO to replace heavy fuel oil (HFO)
- Use of BFO to replace light fuel oil (LFO)
- Use of BFO as refinery feed in the production of transportation fuels.

It was shown that improving the fuel oil quality of BFO is necessary. This can be accomplished for example by hot vapour filtration. However, producing transportation fuels is not competitive, because of the low yield and high processing costs (Figure 7).

Replacing Fuel Oils and Transportation Fuel with Bio Fuel Oil Competitiveness of Different Applications

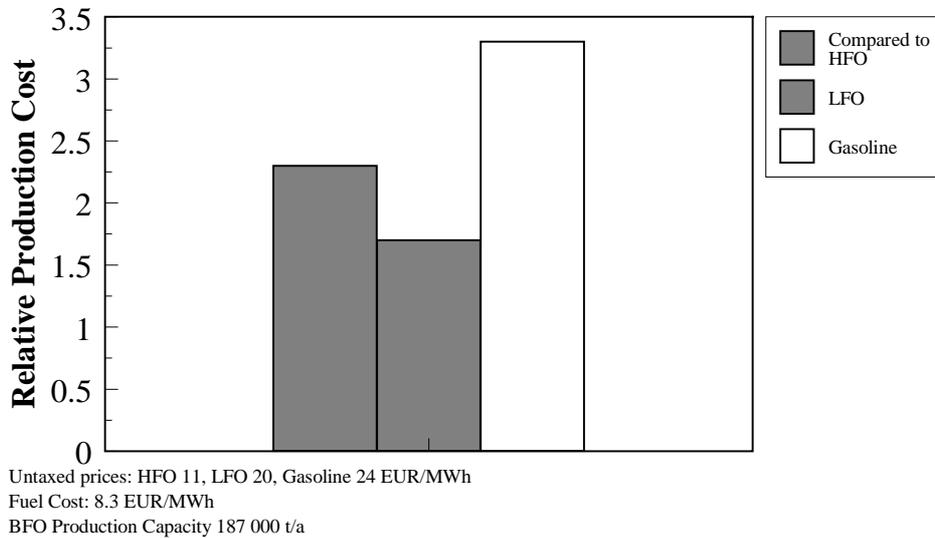


Figure 7. Relative competitiveness of BFO applications

Tasks 4.2. - 4.3. UEF has carried out an assessment of BFO use as diesel power plant fuel in Spain. The economic analysis indicated that production cost of BFO is fairly high. The conclusion is that without subsidies the concept is not competitive.

The economic assessment in Italy suggests that there is a market for BFO, provided that it could be used to fire a diesel engine power plant.

Neste has analysed the market potential of BFO in Finland. According to the analysis, pyrolysis liquid must replace light fuel oils in Finland to be economic. Tests at Neste have indicated that in order to ensure trouble free and clean combustion, burners and boilers must be larger than what is normally used in private homes (20 kW). The upper limit to light fuel oil burners in Finland is considered to be 1 MW. The range of boilers was then estimated to be roughly 0.1-1MWth such as used in schools, hospitals, greenhouses, small industry etc. Of the total light fuel volume of roughly 2.5 Mtonnes it is estimated that around 30-35% or 600 - 800 k toe could use pyrolysis liquid. Considering the fact that pyrolysis liquid has a heating value of 50% of fuel oil, this gives an upper limit to a production volume of 1.2 M tonnes.

8. Conclusions

The main objective, to generating performance, emission and cost data for bio fuel oil utilisation schemes focusing on the market quality of the liquid, was fulfilled.

For the first time in Europe, large amount of BFO was produced (about 70 tonnes) and utilised (about 20 tonnes). This called for a considerable amount of biomass to be produced

and dried. For the production of this BFO, a total of about 128 tonnes of pine and beech was processed.

The importance of the BFO quality was emphasised. Several factors improving the fuel quality were identified, and some tests were carried out to improve stability. It was shown that improving the fuel oil quality of BFO is necessary. This can be accomplished for example by hot vapour filtration. However, producing transportation fuels is not competitive, because of the low yield and high processing costs.

Preliminary BFO specifications for boilers and diesel engines were defined. It was found out that there remains considerable challenges, before industrial scale production of BFO according to specifications is possible. The high amount of water and solids remained as the largest problems.

Some market opportunities were defined:

- BFO production in Sweden to replace heavy fuel oil
- BFO production in Finland to replace light fuel oil
- Electricity production with a diesel power plant using BFO as fuel in Italy.

It should be noted that the first application requires a limited amount of R&D before commercial operation, provided the economics remain encouraging. However, the two other applications require R&D on both production and utilisation of BFO.

9. Exploitation

Enel in Italy and Union Fenosa in Spain are analysing when and how they could exploit the results for additional operation periods for the existing pilot units and scale up of the technologies, in details in the final report. Boiler tests were successful and Fortum (Neste) in Finland and Birka Energi (Stockholm Energi) in Sweden are looking for long term combustion tests in future projects, and even larger scale demonstration tests with several boilers. Birka Energi is planning to start commercial scale combustion of bio oils in Stockholm with 10-20 boilers as soon as reliable experiences are available. Another company, originated from Canada, in co-operation with Swedish forest organisations would produce the pyrolysis oil. Wärtsilä is ready to restart the diesel engine test as soon as long term successful boiler tests have been carried out and there will be guarantees for pyrolysis oil specifications by the market producers. VTT is planning to build a pilot plant of 5 MW in Finland with the local industrial consortium, where long term combustion tests in 200, 1000 and 4000 kW boilers with dual fuel nozzles would be carried out. Additional 1.5 MW diesel tests are planned with quality controlled and filtered oils.