ELSEVIER

Energy Policy 34 (2006) 2871–2880

ENERGY POLICY

www.elsevier.com/locate/enpol

Opportunities for biomass-derived "bio-oil" in European heat and power markets

J.G. Brammer[a,*], M. Lauer[b], A.V. Bridgwater[a]

[a]Bio-Energy Research Group, CEAC, Aston University, Birmingham B47ET, UK

[b]Joanneum Research, Elisabethstrasse 5, A-8010 Graz, Austria

Available online 23 June 2005

Abstract

Bio-oil (biomass fast pyrolysis) systems for heat, power or CHP production are nearing demonstration status. Their commercial attractiveness will depend on many factors, and will vary with the application, the scale, and importantly the location and its associated economic and logistical factors. The objective of this work, carried out as part of an EC-ALTENER project, was to evaluate the opportunities for bio-oil in the heat and power markets of Europe. Bio-oil applications were compared with conventional (fossil) alternatives for the same heat and power duty. The evaluation was carried out by a quantitative assessment of the economic competitiveness of standard applications in 14 European countries. Location-specific data were collected, and combined with technology-specific data obtained from earlier work. A competitiveness factor (c_F) was derived which represents the total annual cost of a conventional alternative relative to a bio-oil application. The results showed a wide variation across Europe. A total of six countries had at least one bio-oil application which was economically competitive. Heat-only applications were found to be the most economically competitive, followed by CHP applications, with electricity-only applications only very rarely competitive. For a given technology, the larger the scale, the better the competitiveness.

Keywords: Bio-oil; Pyrolysis; Competitiveness

1. Introduction

Bio-oil is a renewable liquid fuel produced by the fast pyrolysis of biomass, with a lower heating value of about 16 MJ/kg compared with 43 MJ/kg for diesel. It can be used as a fuel in boilers, diesel engines or gas turbines for the production of heat, power or combined heat and power (CHP). Compared to combustion and gasification of biomass, fast pyrolysis has the advantage that a liquid intermediate is produced (the bio-oil) which may be stored and transported economically. Thus bio-oil production and heat and/or power generation can be carried out independently at different locations and times, and at economically efficient scales.

Bio-oil systems for heat and power are on the boundary between development and demonstration (Bridgwater, 1999). Their attractiveness compared with alternatives will depend on many factors, and will vary with the application, the scale, and importantly the location and its associated economic and logistical factors, for example biomass availability and price, fossil energy prices, incentives, industrial traditions etc.

The objective of this work, part of a project funded by the EC ALTENER programme, is to evaluate the opportunities for bio-oil in the heat and power markets of Europe (Bridgwater et al., 2003). Bio-oil applications are compared with fossil energy applications for the same heat and power duty. Bio-oil is treated effectively as a commodity, and the production of the bio-oil is considered separately from its utilisation. An application is defined here as an installation for the conversion of bio-oil to energy, with a specific technology, purpose

*Corresponding author. Tel.: +44 121 204 3380; fax: +44 121 359 6814.

E-mail address: j.g.brammer@aston.ac.uk (J.G. Brammer).

0301-4215/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2005.05.005

(power, heat or CHP) and location, at a range of scales (rated output in MW).

The evaluation of opportunities is carried out by a quantitative assessment of the economic competitiveness of a set of standard applications in 14 European countries which are members of the PyNe biomass pyrolysis network (Lauer, 2002). Competitiveness in terms of economic superiority compared to other options for providing the same service is one of the most important issues for the implementation of new technologies. The assessment is conducted from the point of view of the investor who is deciding how to meet his specific energy requirements, and who makes a rational economic choice in so doing.

Economic competitiveness is a relative issue. The overall costs of a technology meeting a given duty should be at the same level or lower than the overall costs of a competing technology meeting the same duty. The relation of the overall costs of two competing technologies depend very much on the specific application and location, and it is necessary to consider items such as output, fuel prices, labour costs, taxes, incentives, availability and capacity factor.

The approach here is to use a competitiveness factor which represents the total annual cost of a bio-oil application relative to that of the conventional fossil-based alternative for the same heat and power duty. Calculation of the competitiveness factor requires knowledge of the costs associated with the bio-oil production process and with the bio-oil utilisation process, the latter being split into technology-related elements and location-related elements.

Local data necessary for the assessment have been gathered from the various countries. In terms of cost characteristics, those of the technology relate to the equipment only and are treated as not location-specific, whereas those of the application include both the technology costs and location-specific factors such as the cost of the fuel and the labour rate.

2. Standard applications

The complete set of standard bio-oil applications is given in Table 1. Rated heat output is given as MW_{th}, rated electrical (or power) output as MW_e. In heat or CHP cases, it is assumed that the heat is supplied as hot water, typically for space heating purposes. CHP applications include some rated by electrical output and some rated by heat output to assist comparisons, as heat to power ratios can vary widely between technologies.

Each of these standard applications was evaluated for the following countries: Austria, Belgium, Denmark, France, Finland, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, UK.

Table 1
Standard applications—bio-oil

Technology	Product	Rated output
Bio-oil boiler	heat	0.5, 1.0, 2.0 MW_{th}
Bio-oil IC engine (dual fuel diesel)	electricity	1.0, 5.0 MW_e
Bio-oil IC engine (dual fuel diesel)	CHP	1.0, 5.0 MW_e 2.0, 10.0 MW_{th}
Bio-oil gas turbine	electricity	5.0, 15.0 MW_e
Bio-oil gas turbine	CHP	5.0, 15.0 MW_e 10.0, 25.0 MW_{th}
Bio-oil gas turbine combined cycle	electricity	15.0 MW_e
Bio-oil gas turbine combined cycle	CHP	15.0 MW_e 25.0 MW_{th}
Bio-oil boiler (Rankine cycle)	CHP	15.0 MW_e 25.0 MW_{th}

3. Bio-oil production cost

One of the key advantages of bio-oil-based applications over other biomass applications lies in the storability and transportability of bio-oil. This allows bio-oil production to be quite independent of its utilisation. Although bio-oil does exhibit slow property changes over time, these are inconsequential for periods of 12 months or more provided the oil has met certain quality standards and correct handling and storage procedures are followed (Bridgwater and Grønli, 2003). Hence bio-oil could be a traded commodity in much the same way as fossil fuel oil.

Therefore it has been assumed that a single bio-oil production facility is located in a region of high biomass availability, and takes all the available biomass from an area of radius 100 km up to a maximum of 200,000 dt/a (the size of area has been limited to reflect the high transportation costs of raw biomass, and the maximum plant size has been capped to reflect current technology expectations). Bio-oil is then produced and stored, with an associated cost of production. The standard bio-oil applications (of which there may be numerous) are then assumed to purchase bio-oil at this cost.

The bio-oil production cost (€/MWh_{chem}) will vary from location to location. In each case, it will be a function of numerous parameters; however, it has been assumed here that all are common except for the following location-specific parameters:

- biomass annual availability (dt/a)
- biomass cost (€/dt, transport and handling included)
- biomass lower heating value (MJ/kg)
- biomass initial moisture (%, wet basis)
- real interest rate for capital (%)
- cost of electricity (€/MWh)
- labour rate (€/h)

Table 2
Common parameters for bio-oil production in all locations

Parameter Reference feedstock ultimate analysis:	Value	Unit
C	50.5	wt%
H	5.7	wt%
O	40.7	wt%
N	0.4	wt%
S	0.1	wt%
ash	2.6	wt%
Reference feedstock lower heating value—(dry basis)	17.3	GJ/t
Reference feedstock delivered moisture content (wet basis)	35	%
Bio-oil moisture content (wet basis)	25	%
Bio-oil yield (dry feed basis)	70	%
Bio-oil lower heating value—reference feedstock (dry basis)	20.4	GJ/t
Annual maintenance cost (% total investment cost)	4	%
Annual overhead cost (% total investment cost)	4	%
Capacity factor	0.9	
Labour requirement	5	persons

All European members of the PyNe biomass pyrolysis network were asked to act as country representatives and provide data-sets of these parameters for their country. The minimum requirement was a data-set corresponding to a standard feedstock of chipped wood, but countries could provide additional data-sets for other feedstocks if there was a specific local interest.

Key fixed parameters utilised to derive bio-oil cost in conjunction with these variable parameters are given in Table 2. A typical fluidised bed pyrolysis process is assumed. Other parameters and functions used may be found in Bridgwater et al. (2003). All costs are brought to a year 2000 basis. Reference data for the standard feedstock are also given in Table 2 if location-specific data are not provided.

Investment costs for the pyrolysis plant are taken to comprise reception, feed storage, drying, comminution, pyrolysis and oil storage. These are brought to a final plant cost basis (installed with ancillary equipment and fully commissioned, with a contingency of 10% included), assuming the 10th installation. Where investment cost data or functions correspond to pre-10th installation, they are corrected using a learning factor of 20% (the amount by which unit cost falls when number of units doubles). If they correspond to post-10th installation, they are unaltered. In order to calculate a bio-oil production cost, the investment costs are annualised using the specified interest rate for capital.

4. Technology cost and performance

With the exception of interest rate and labour rate, all parameters associated with plant and equipment providing a given heat and/or power output are assumed to be constant across Europe. Although this is unlikely to be the case for investment costs, variations would be a complex function of buying and sourcing policy and any attempt to apply fixed location factors could be highly misleading.

Parameters needed for the calculation of competitiveness factor are, for each application:

- total investment cost (€)
- operation and maintenance cost excluding labour and fuel (€/a)
- labour requirement (h/a)
- bio-oil input (MWh/a, lower heating value basis)
- heat output if applicable (MWh/a)
- electricity output if applicable (MWh/a)

Data have been obtained from manufacturers, previous studies and published literature, where necessary updated to reflect technology changes and cost inflation. All cost data are again brought to a year 2000 basis. Details of assumed values and performance functions are contained in Bridgwater et al. (2003).

Heat recovery for CHP applications will involve additional equipment (principally a gas-to-water heat exchanger) for all cases except Rankine and combined cycle, where it is assumed that the steam condenser acts as a water heater.

Operation and maintenance cost excluding labour and fuel is taken to be comprised of overhead and maintenance elements only. Electrical power consumption is assumed to be the only significant utility cost, and this is treated as parasitic power (taken as constant for all technologies) and so is deducted from gross power output.

Investment cost functions for major plant items are included in Bridgwater et al. (2003), together with the relevant source. As with bio-oil production, investment costs are brought to a final plant cost basis assuming the 10th installation, and annualised.

Capacity factor for each technology (actual energy delivered over a year divided by maximum energy deliverable if running continuously at full load over a year) was assumed as follows:

$\leq 1\ MW_e(\text{or}\ \leq 2\ \text{MW}_{\text{th}})\text{output}:\quad 0.45$

$> 1\ \text{MW}_{\text{e}}, \leq 5\ \text{MW}_{\text{e}}(\text{or}\ > 2\ \text{MW}_{\text{th}},\quad 0.55$
$\leq 10\ \text{MW}_{\text{th}})\text{output}$

$> 5\ \text{MW}_{\text{e}}(\text{or}\ > 10\ \text{MW}_{\text{th}})\text{output}:\quad 0.65$

Labour requirements for each technology are based on the assumption that automation will be maximised within reasonable limits, and that no labour is required when not running.

5. Competitiveness factor

In order to provide a measure of competitiveness, a non dimensional index c_F (competitiveness factor) is introduced. This is defined as the ratio of the total annual cost of meeting the required duty using conventional energy to that of meeting the same duty using a purpose-built bio-oil plant.

$$c_F = \frac{\text{total annual cost : conventional energy}}{\text{total annual cost : bio-oil plant}}$$

The value of c_F indicates the competitive situation of the bio-oil option in a specific application. If $c_F > 1$, the bio-oil option is economically superior to the conventional alternative. If the conventional alternative is standardised across all applications, then it is possible to compare options that are different in scale, location and service provided.

The conventional alternative is specified for all applications as:

Electricity: Supplied from the local electricity grid at the commercial tariff offered by local electricity supply companies. Where a premium price for "green" electricity is available, a rational investor who has built a new bio-oil plant to meet his electricity requirements would in fact sell his green electricity at the premium price and buy in electricity from the utility at the lowest tariff, rather than use his own green electricity directly. This "profit" must therefore either be subtracted from the total annual cost of the bio-oil option, or added to the total annual cost of the conventional alternative. The latter is done here, by using the green electricity tariff where one exists.

Heat: Supplied from a dedicated on-site boiler burning either natural gas or fuel oil (depending on local availability and tariffs).

The total annual cost for a bio-oil application is calculated by adding all investment and operating costs, following the guideline VDI 2067 prepared by the Association of German Engineers (VDI, 1983). The investment costs take full account of the construction phase of the project, although final decommissioning costs have not been included. No attempt is made to subtract any capital grants or subsidies which may be available in the various countries.

The total annual cost for the conventional alternative for electricity is simply the specified electricity price (using the value for green electricity if available) multiplied by the annual demand. That for the conventional alternative for heat is the specified natural gas or oil price multiplied by the annual demand divided by an assumed boiler efficiency of 90%, plus annual capital, operation and maintenance costs for the boiler. The latter are derived from current data obtained from boiler manufacturers.

Calculations of competitiveness factor were carried out for all applications in all countries, and in addition sensitivity analyses were performed for the key parameters.

6. Results

6.1. Location-specific data

The specified feedstocks and associated prices for each country may be obtained from Tables 3–16 (standard feedstock given first). Most of the countries claimed to have at least one area of 100 km radius capable of producing 200,000 dt/a of biomass feedstock, corresponding to the maximum allowable facility size. There were also however a number of much lower specified availabilities. Biomass feedstock prices varied widely, ranging from 1.4 €/MWh (Italy, furniture industry by-product) to 15.7 €/MWh (Denmark, hardwood residues from forestry). Most of the data were in the approximate range 8–0 €/MWh.

Similarly, fossil energy prices varied widely across Europe. The UK, Finland, France, the Netherlands, Belgium, Spain and Portugal all gave prices below 20 €/MWh for heating fuel, whereas prices exceeded 30 €/MWh in Denmark, Greece, Ireland and Norway. Electricity prices varied from 30 €/MWh to 124 €/MWh, although the higher values corresponded to the price paid by utilities for "green" electricity, where such tariffs existed.

Labour cost also showed large variations across Europe, ranging from 9 €/h in Portugal to 28 €/h in Denmark.

The real interest rate on capital paid by industry for low-risk projects varied between 5% and 8%.

6.2. Competitiveness

Large numbers of results for competitiveness were generated in this analysis, and the reader is referred to Bridgwater et al. (2003) for a complete set. Here a subset of indicative values is presented for each country together with a brief commentary, followed by some key findings for Europe as a whole.

Table 3
Results summary, Austria

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (sawmill residues), 10.0 €/MWh	31	All bio-oil heat boilers	0.76
		All bio-oil IC engine systems	0.99
		All bio-oil gas turbine systems	0.76
		All bio-oil Rankine cycle systems	0.80

Table 4
Results summary, Belgium

Feedstock and Price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (industry by-product), 10.6 €/MWh	32	All bio-oil heat boilers	0.50
		All bio-oil IC engine systems	0.66
		All bio-oil gas turbine systems	0.58
		All bio-oil Rankine cycle systems	0.64

Table 5
Results summary, Denmark

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (hardwood Forestry residues), 15.7 €/MWh	40	All bio-oil heat boilers	1.33
		All bio-oil IC engine systems	0.70
		All bio-oil gas turbine systems	0.67
		All bio-oil Rankine cycle systems	0.99
Wood (industry by-product), 13.5 €/MWh	34	All bio-oil heat boilers	1.51
		All bio-oil IC engine systems	0.76
		All bio-oil gas turbine systems	0.74
		All bio-oil Rankine cycle systems	1.10
Wood (softwood forestry residues), 14.8 €/MWh	37	All bio-oil heat boilers	1.43
		All bio-oil IC engine systems	0.73
		All bio-oil gas turbine systems	0.71
		All bio-oil Rankine cycle systems	1.05

Table 6
Results summary, Finland

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (forestry residues), 8.9 €/MWh	26	All bio-oil heat boilers	0.65
		All bio-oil IC engine systems	0.50
		All bio-oil gas turbine systems	0.42
		All bio-oil Rankine cycle systems	0.39

Table 7
Results summary, France

Feedstock and price	Bio-oil cost €/MWh	Application	c_F (avg.)
Wood (forestry residues), 11.8 €/MWh	31	All bio-oil heat boilers	0.51
		All bio-oil IC engine systems	0.37
		All bio-oil gas turbine systems	0.35
		All bio-oil Rankine cycle systems	0.42

Table 8
Results summary, Germany

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (industry by-product), 10.2 €/MWh	72	All bio-oil heat boilers	0.35
		All bio-oil IC engine systems	0.48
		All bio-oil gas turbine systems	0.39
		All bio-oil Rankine cycle systems	0.38

Table 9
Results summary, Greece

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (forestry residues), 10.1 €/MWh	31	All bio-oil heat boilers	1.35
		All bio-oil IC engine systems	0.70
		All bio-oil gas turbine systems	0.66
		All bio-oil Rankine cycle systems	0.98
Cereal straw, 13.2 €/MWh	36	All bio-oil heat boilers	1.20
		All bio-oil IC engine systems	0.65
		All bio-oil gas turbine systems	0.60
		All bio-oil Rankine cycle systems	0.89
Cotton stalks, 9.6 €/MWh	30	All bio-oil heat boilers	1.41
		All bio-oil IC engine systems	0.72
		All bio-oil gas turbine systems	0.68
		All bio-oil Rankine cycle systems	1.01
Olive tree prunings, 9.8 €/MWh	28	All bio-oil heat boilers	1.46
		All bio-oil IC engine systems	0.73
		All bio-oil gas turbine systems	0.70
		All bio-oil Rankine cycle systems	1.04

Table 10
Results summary, Ireland

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (forestry residues), 11.7 €/MWh	36	All bio-oil heat boilers	0.85
		All bio-oil IC engine systems	0.59
		All bio-oil gas turbine systems	0.58
		All bio-oil Rankine cycle systems	0.77
Wood (sawmill residues), 11.7 €/MWh	37	All bio-oil heat boilers	0.82
		All bio-oil IC engine systems	0.57
		All bio-oil gas turbine systems	0.56
		All bio-oil Rankine cycle systems	0.74
Wood (tree cuttings), 14.4 €/MWh	37	All bio-oil heat boilers	0.82
		All bio-oil IC engine systems	0.57
		All bio-oil gas turbine systems	0.56
		All bio-oil Rankine cycle systems	0.74

Table 11
Results summary, Italy

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (industry by-product), 1.4 €/MWh	15	All bio-oil heat boilers	1.14
		All bio-oil IC engine systems	0.95
		All bio-oil gas turbine systems	0.99
		All bio-oil Rankine cycle systems	1.17

6.2.1. Austria

Summary results for Austria are given in Table 3. The cost for bio-oil in Austria is slightly higher than the cost for conventional fuel. The competitiveness is quite good (c_F near 1) for bio-oil use in IC engines, due to the high electric efficiency and the special price paid for "green"

Table 12
Results summary, Netherlands

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (industry by-product), 5.4 €/MWh	24	All bio-oil heat boilers	0.48
		All bio-oil IC engine systems	1.03
		All bio-oil gas turbine systems	1.04
		All bio-oil Rankine cycle systems	1.06
Dried grass, 5.0 €/MWh	27	All bio-oil heat boilers	0.45
		All bio-oil IC engine systems	0.99
		All bio-oil gas turbine systems	0.98
		All bio-oil Rankine cycle systems	0.99

Table 13
Results summary, Norway

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (forestry residues), 13.9 €/MWh	39	All bio-oil heat boilers	0.82
		All bio-oil IC engine systems	0.36
		All bio-oil gas turbine systems	0.35
		All bio-oil Rankine cycle systems	0.55
Wood (industry by-product), 7.2 €/MWh	41	All bio-oil heat boilers	0.80
		All bio-oil IC engine systems	0.36
		All bio-oil gas turbine systems	0.35
		All bio-oil Rankine cycle systems	0.54

Table 14
Results summary, Portugal

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (forestry residues), 8.6 €/MWh	28	All bio-oil heat boilers	0.60
		All bio-oil IC engine systems	0.74
		All bio-oil gas turbine systems	0.68
		All bio-oil Rankine cycle systems	0.78

Table 15
Results summary, Spain

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (fruit tree prunings), 10.8 €/mwh	30	All bio-oil heat boilers	0.55
		All bio-oil IC engine systems	0.60
		All bio-oil gas turbine systems	0.57
		All bio-oil Rankine cycle systems	0.66
Orujillo, 2.9 €/MWh	16	All bio-oil heat boilers	1.21
		All bio-oil IC engine systems	0.88
		All bio-oil gas turbine systems	0.85
		All bio-oil Rankine cycle systems	0.94
Thistle, 6.2 €/MWh	42	All bio-oil heat boilers	0.95
		All bio-oil IC engine systems	0.77
		All bio-oil gas turbine systems	0.72
		All bio-oil Rankine cycle systems	0.79

electricity in Austria. Due to the relatively low prices for conventional fuels, the competitiveness for bio-oil boilers is poor.

6.2.2. Belgium

Summary results for Belgium are given in Table 4. The competitive situation in Belgium suffers from the

Table 16
Results summary, UK

Feedstock and price	Bio-oil cost (€/MWh)	Application	c_F (avg.)
Wood (forestry residues), 11.7 €/MWh	32	All bio-oil heat boilers	0.49
		All bio-oil IC engine systems	0.44
		All bio-oil gas turbine systems	0.40
		All bio-oil Rankine cycle systems	0.47

low prices for conventional fuels. The cost for bio-oil is 78% higher than for conventional fuels used for industrial boilers. CHP or electricity production applications are better than heat applications, but the overall competitiveness is poor.

6.2.3. Denmark

Summary results for Denmark are given in Table 5. Due to high biomass prices the cost of bio-oil in Denmark is comparatively high. This is however compensated by extremely high prices for conventional fuels, and bio-oil heat boilers in particular seem to be highly competitive with c_F values above 1.3. Producing electricity seems to be interesting in Denmark as well, especially with bio-oil Rankine cycle power plants (if CHP production is possible). The high prices for conventional fuels help to increase competitiveness for technologies with relatively low electrical efficiency.

6.2.4. Finland

Summary results for Finland are given in Table 6. In Finland the competitiveness of bio-oil applications is weak. Low prices (at least for industry) and moderate electricity cost make all options unattractive with c_F values below 0.7. The situation in Finland seems to be different in other market segments such as room heating etc. However in this project the focus lies on industrial energy use.

6.2.5. France

Summary results for France are given in Table 7. The situation is characterized by low prices for conventional fuel, low prices for electricity and high biomass prices. So competitiveness for bio-oil use is in general poor, with average c_F values of below 0.55 for all applications.

6.2.6. Germany

Summary results for Germany are given in Table 8. Germany has a special situation as far as the biomass feedstock is concerned. There seems to be no established market for biomass, so the information supplied was based on a single industrial source with limited availability (6000 dt/a). This results in a very high cost of bio-oil production. Even with high prices paid for "green" electricity, competitiveness for bio-oil applications is low ($c_F < 0.5$). However, if availability of biomass feedstock can be increased and biomass price reduced with an emerging biomass market, competitiveness of bio-oil production and use could be similar to, say, Austria.

6.2.7. Greece

Summary results for Greece are given in Table 9. Due to the moderate prices for the biomass and the high prices for conventional fuels, the competitiveness of bio-oil technology is quite high, especially for heat boilers. Due to the relatively low prices for electricity, electricity production using bio-oil is not as interesting except in the case of the bio-oil Rankine cycle plant.

6.2.8. Ireland

Summary results for Ireland are given in Table 10. The cost of producing bio-oil is in the same range as the cost of conventional fuels. As the use of bio-oil is more expensive than the use of conventional fuels, the competitiveness is quite low for all applications.

6.2.9. Italy

Summary results for Italy are given in Table 11. By-product from the furniture industry was specified as the standard source for bio-oil production. As Italy has a large furniture industry and the by-products are usually fine dry material, this would be an excellent option. As the feedstock is cheap with a high availability, bio-oil cost is as low as 15 €/MWh corresponding to only 60% of that of conventional fuel. Based on this situation, competitiveness of bio-oil applications in Italy is quite high. A variety of bio-oil applications both for heat production and for CHP seem to be economically viable.

6.2.10. Netherlands

Summary results for the Netherlands are given in Table 12. The situation in the Netherlands is characterized by a very low cost for conventional fuels (13.4 €/MWh) and very high prices for selling "green" electricity (124 €/MWh). Based on this situation many bio-oil applications seem to be economically viable, the only exception being use in heat boilers.

6.2.11. Norway

Summary results for Norway are given in Table 13. Both specified feedstocks were of limited availability. In Norway electricity prices are very low and the cost of bio-oil is similar to that of conventional fuels. Thus bio-oil applications are generally uncompetitive.

6.2.12. Portugal

Summary results for Portugal are given in Table 14. The situation in Portugal is characterised by very low prices for conventional fuel and moderate prices for electricity. This situation is reflected in the results, with all bio-oil applications uncompetitive. The competitiveness for co-generation using bio-oil is slightly better than that for combustion in heat boilers.

6.2.13. Spain

Summary results for Spain are given in Table 15. The situation in Spain is characterized by relatively low prices for conventional fuels and average prices for electricity. With the standard feedstock (fruit tree prunings) competitiveness is not demonstrated. However, both orujillo (a residue) and thistle (an energy crop) give better results, with orujillo giving a cost of bio-oil below that of conventional fuel. Particularly promising is the use of bio-oil in heat boilers.

6.2.14. United Kingdom

Summary results for the UK are given in Table 16. In the UK low prices for conventional fuel and moderate prices for electricity combined with relatively high prices for biomass result in poor competitiveness. All c_F values for bio-oil applications are below 0.52.

6.2.15. Europe-wide

Any identification of the most promising applications across Europe is only valid for the boundary conditions as specified by the country representatives as at August 2002. As these boundary conditions (conventional fuel prices, special rates for "green" electricity etc.) can change rapidly, the precise competitive situation can also change rapidly. For example the increase in fossil fuel prices that took place in Spring 2003 may have had a major influence. However, the results should indicate in general terms those regions of Europe and those bio-oil technologies where developmental emphasis should be placed.

The results show a wide variation across Europe, in both the levels of competitiveness and in the rankings of the various applications. A total of six countries had at least one bio-oil application which was economically competitive ($c_F \geqslant 1$). They are listed below, together with for each country the percentage of applications competitive, and the competitive technologies in descending order of competitiveness.

- *Italy*
  55% of applications competitive:
  gas turbine (CHP), Rankine (CHP), IC engine (CHP), boiler (heat), gas turbine combined cycle (CHP)
- *Netherlands*
  43% of applications competitive:
  gas turbine (CHP), IC engine (CHP), gas turbine combined cycle (CHP), gas turbine (electricity), IC engine (electricity), Rankine (CHP)
- *Denmark*
  32% of applications competitive:
  boiler (heat), Rankine (CHP), gas turbine (CHP), IC engine (CHP)
- *Greece*
  24% of applications competitive:
  boiler (heat), Rankine (CHP), gas turbine (CHP), IC engine (CHP)
- *Austria*
  15% of applications competitive:
  IC engine (CHP) only
- *Spain*
  15% of applications competitive:
  boiler (heat), IC engine (CHP), gas turbine (CHP)

In the remaining countries (Belgium, Finland, France, Germany, Ireland, Norway, Portugal, UK) the current market conditions are shown not to be favourable for the bio-oil applications investigated.

For specific applications and technologies, some general results are seen:

- Heat applications are the most economically competitive, followed by CHP applications, followed by electricity applications. Only one country (the Netherlands) showed any competitive electricity applications.
- Within a given technology, the larger the scale, the better the economic competitiveness.
- The boiler for heat applications showed on average the best economic competitiveness across Europe, followed by the IC engine for CHP and the Rankine cycle for CHP.

7. Conclusions

- Data was successfully collected from 14 European countries and combined with data from earlier studies to give measures of the economic competitiveness and environmental performance of a range of bio-oil applications.
- A wide variation was found across Europe in the levels of competitiveness, and in the ranking of the different applications.

- In a total of six countries, at least one of the standard bio-oil applications is shown to be economically competitive. These are (in decreasing order of number of applications) Italy, Netherlands, Denmark, Greece, Austria, Spain.
- In Belgium, Finland, France, Germany, Ireland, Norway, Portugal and the United Kingdom, none of the standard bio-oil applications is shown to be competitive.
- Heat applications are the most economically competitive, followed by CHP applications, with electricity applications generally uncompetitive.
- Within a given technology, the larger the scale, the better the economic competitiveness.
- The boiler for heat applications showed on average the best economic competitiveness across Europe, followed by the IC engine for CHP and the Rankine cycle for CHP.
- It is important to note that these conclusions are only valid for the situation prevailing in each country at the time of data collection (August 2002). However, the work provides a good basis for a preliminary identification of which countries and technologies are likely to respond well to developmental effort in bio-oil for heat and power, and which are not.

References

Bridgwater, A.V., 1999. An introduction to fast pyrolysis of biomass for fuels and chemicals. Fast Pyrolysis of Biomass: A Handbook. CPL Scientific Publishing Services Ltd., Newbury, pp. 1–13.

Bridgwater, A.V., et al., 2003. Opportunities for bio-oil in european heat and power markets. Final Report, EC-ALTENER Project AL-2000-305.

Bridgwater, A.V., Grønli, M., 2003. Strategies for development and implementation of fast pyrolysis of biomass. Pyrolysis and Gasification of Biomass and Waste. CPL Scientific Publishing Services Ltd., Newbury, pp. 675–679.

Lauer, M., 2002. Implementation Subject Group Fast Pyrolysis of Biomass: A Handbook, Volume 2. CPL Scientific Publishing Services Ltd., Newbury.

VDI, 1983. Richtlinie VDI 2067. VDI Gesellschft Technische Gebäudeausrüstung. Beuth Verlag, Berlin.