DETERMINATION OF NORMS AND STANDARDS FOR BIOMASS FAST PYROLYSIS LIQUIDS AS AN ALTERNATIVE RENEWABLE FUEL FOR ELECTRICITY AND HEAT PRODUCTION

CONTENTS

SUMMARY

The uptake of biomass-derived pyrolysis liquids for use in heat and power applications depends on the ease of use and acceptability of the fuel by the end user and equipment providers. One of the aims in Task 2 is to derive standards for biomass derived pyrolysis liquids, based on a consensus between equipment providers (boilers, engines and turbines) and the liquids producers. Five basic properties (homogeneity, water content, solids content, stability, flash point) for the liquids are used as the primary criteria for pyrolysis liquid evaluation. Specific values are proposed to ensure that pyrolysis liquids meet a minimum grade acceptable for use as a fuel oil ("premium" grade) in boilers and engines. Data on emissions from boilers, engines and turbines are presented. At present, there is not enough long duration data available to allow further more detailed specifications on secondary properties to be made, or define standards for liquids in turbines. The aim is to ensure that a realistic set of specifications are determined to allow the introduction into existing fuel infrastructures and markets, initially perceived as the domestic heating fuel oil markets in Scandinavia.

Keywords: biomass pyrolysis, pyrolysis liquids, specifications, physical properties, standardisation, environmental compliance, production costs

INTRODUCTION

The overall objective of the work is to derive norms and standards for biomass derived fast pyrolysis liquids to enable their acceptance in the marketplace as a renewable, alternative fuel. To achieve this, the following five tasks were completed within the project.

1. Review fast pyrolysis technologies and describe processes at pre-commercial and commercial scale, suitable for heat and power production in the near [1-4 years] to medium term [5-10 years]. Review incentives to develop pyrolysis technologies at national and EU level.
2. Derive norms and standards for biomass fast pyrolysis liquids. The project will review end user requirements and specifications for biomass fast pyrolysis liquids to obtain specifications and standards in liquid fuel quality.
3. Sector and market strategies for the production of heat and power from pyrolysis liquids.
4. Long-term cost/benefit analyses comparing biomass fast pyrolysis to traditional forms of energy and other alternative renewable energy sources and comparing the overall conversion efficiencies to electricity.
5. Quantification of benefits obtained in improving the producer-converter-user interface and improvement of the energy/environmental balance in pyrolysis liquids production.

This project was clustered with another ALTENER II project - Competitivity of a variety of biomass pyrolysis applications in the EU, which is reported elsewhere.

TASK 1 REVIEW EU PYROLYSIS TECHNOLOGIES AND INCENTIVES AT NATIONAL LEVEL

1.1 Review biomass pyrolysis at pilot [> 20 kg/h], demonstration and commercial scale in the EU.

Europe has only relatively recently become involved in direct production of liquid fuels from biomass. Up to 1989, the only European plant was a conventional (slow) pyrolysis demonstration plant of 500 kg/h operating in Italy for liquid and char production with approximately 25% yield of each (1). Around the same time, Bio-Alternative in Switzerland was operating a fixed bed carbonisation pilot plant fed with wood, waste and MSW for charcoal production with secondary liquids as a low yielding by-product at up to 20 wt% yield (2). Tests were carried out on combustion of these oils (3). Both these activities served to foster interest in direct production of liquids from biomass in atmospheric processes as well as creating concerns over poor liquid quality and low yields that still linger.

Subsequently, a 200-250 kg/h fast pyrolysis pilot plant based on the fluid bed design of the University of Waterloo [Canada] was constructed in Spain by Union Fenosa, which started up in mid 1993 (4, 5). Egemin in Belgium built and operated a 200 kg/h capacity entrained downflow pilot plant to their own design which started up in July 1991 and operated until late 1992 with limited success (6). ENEL purchased a 15 t/d Ensyn RTP3 pilot plant to produce bio-oils for testing which was installed at Bastardo in Italy in mid 1996 (7). These processes are described in more detail below with other process above 20 kg/h, as listed in Table 1. The inclusion of fast pyrolysis in the 4th Non Fossil Fuel Obligation (NFFO) tranche in the UK in 1996 served to heighten awareness of the technology and caused a considerable increase in interest in Europe, but has led to no significant technological development.

In North America a number of commercial and demonstration plants for fast pyrolysis have been operating in North America at a scale of up to 2000 kg/h. Ensyn (Canada) are marketing commercial fast pyrolysis plants of up to 10 t/h throughput which are offered with a performance guarantee and a number of conditional sales have been concluded, namely for the food additives/flavourings industry (8). Two plants of around 1 t/h capacity are operated regularly in the USA for food flavourings production which is still the only commercial application for fast pyrolysis (9). Castle Capital have acquired the Continuous Ablative Reaction (CAR) process developed by BBC and until 1996 were operating a 1-2 t/h plant near Halifax, Nova Scotia, Canada (10). The second generation 1360 kg/h Interchem demonstration plant in Kansas based on the NREL vortex ablative pyrolysis process (11, 12) was abandoned in the early 1990's.

PYROLYSIS PROCESSES

The significant research, demonstration and commercial processes that are based on pyrolysis for production of liquids are listed in Table 1, arranged in size order. Dormant or dismantled or abandoned processes are only included if there is useful information available. Both fast and slow pyrolysis processes are included in Table 2 as slow pyrolysis processes for liquids contain some technical parallels and the expertise and related support is closely related to fast pyrolysis.

Table 1 Pyrolysis Liquids Production Processes, 2002

Host organisation	Country	Technology	kg/h	Status
BTG	Netherlands	Rotating cone	2000	Planned 2002
BTG/KARA	Netherlands	Rotating cone	200	Operational
Dynamotive	UK	fluid bed	1000	construction
ENEL/Ensyn	Italy	Circulating transported bed	625	Operational
Enervision	Norway	ablative tube	??	not known
Fortum Oy	Finland	own	500	Commissioning
Pasquali / ENEL	Italy	Circulating fluid bed [CIRO]	150	Shut down
Union Fenosa/Waterloo	Spain	Fluid bed	200	Operational
Univ. Hamburg	Germany	Fluid bed	50	Operational
VTT / Ensyn	Finland	Circulating transported bed	20	Operational
Wellman Proc. Eng. Ltd.	UK	Fluid bed	250	Commissioning

Table 2 Organisations with Pyrolysis Processes for Liquids

Organisation	Country	Origin	Technology	Status
BTG	Netherlands	Twente	Rotating cone	Operational
Dynamotive UK	UK	RTI	fluid bed	Operational
ENEL	Italy	own	Circulating fluid bed	see Pasquali
ENEL	Italy	Ensyn	transported bed	See Ensyn
Fortum Oy	Finland	own	own	Operational
Pasquali	Italy	Own	Circulating fluid bed	Dormant
Union Fenosa	Spain	Waterloo	Fluid bed	Dormant
VTT	Finland	Ensyn	transported bed	see Ensyn
Wellman	UK	own	fluid bed	Commissioning

BTG - Biomass Technology Group B.V., the Netherlands

Introduction

The Biomass Technology Group B.V. is an independent private firm of consultants, researchers and engineers, which has its origin in the Chemical Engineering Department of the University of Twente. Their experience covers a wide range of biomass energy technologies including pyrolysis, carbonisation, gasification, and combustion.

Description

The development of the rotating cone technology started in 1989 with a PhD research project at the University of Twente (q.v.) and resulted in a 10 kg/h prototype reactor (13). It was continued in 1994 with another PhD. project aimed at the development of a fully heat integrated laboratory plant and since 1996 with a subsequent project aimed at catalytic pyrolysis (14). These activities have been described (15). BTG owns the patents rights of the pyrolysis technology (16). A 50 kg/h test unit has been delivered to the Shenyang Agricultural University in China where co-operative research has been carried out for two years.

The development, construction and operation of another 50 kg/h bio-oil production unit has recently been contracted. This unit will be operational from July 1998 with an availability of 5000 h/y. Finally, a pilot plant with a throughput of 200 kg biomass per hour is being developed in an EC-FAIR programme. BTG is involved in a range of EC and nationally funded projects to develop the technology for biomass, plastics and solid waste applications.

Castle Capital

<u>Introduction</u>

Castle Capital has spent several years developing the Continuous Ablative Reactor for processing a range of waste materials including MSW, scrap tyres and plastics. Initial work was carried out on a 15 kg/h unit operating on tyre crumb.

<u>Description</u>

Waste feedstock is processed to the desired size and is sent to a feed bin. The material is then fed into the CAR where it is heated in contact with the wall of a coiled heated tube, where the material pyrolyses and the vapours and residual solids are passed through a cyclone. The recovered material drops into a coarse carbon hopper and the vapours are cooled and condensed in two stages: a heavy oil condenser followed by a light oil condenser. Oil then drains into a common oil tank. Residual gases can then be flared, fired in an engine or recycled to the regenerator to provide process heat.

<u>Product and Yields</u>

Products are oil for use in an engine, or as a chemical feedstock.

<u>Applications</u>

The char may be used as a filter media in gas cleaning.

<u>Future Plans</u>

There appear to have been plans to build a CAR in Norway, but no further details have emerged (10).

Dynamotive, Canada

<u>Introduction</u>

Dynamotive was incorporated in 1991 and is currently located at BC research in Vancouver The company is engaged in a variety of innovative technologies, notably fast pyrolysis for production of value added products derived from bio-oil including an emissions control sorbent known as calcium enriched bio-oil.

Description

A 20 kg/h fluidised bed fast pyrolyser known as BioTherm™, has been designed and constructed with assistance from RTI, and began operation in 1997 (17). The unit operated on mixed sawdust feedstock, which is dried to 15% moisture or less and its operational capacity has been increased up to 80 kg/h (18). The heat required to operate the pyrolyser can come from by-product pyrolysis gas or char, or other biomass products. The pyrolysis off gas is utilised as fluidising gas to the pyrolyser or it can be incinerated to produce heat input to the pyrolyser. Over 2000 operational hours have been obtained on this unit (19). A 400 kg/h unit was constructed and operated also in Vancouver. This has performed to its operational capacity and achieved over 10 t/d wood throughput (20). The units have now been dismantled and mothballed.

Product and Yields

Typical yields are 70wt% liquids, 15wt% char and 15wt% gas on an as fed basis. No data is reported on a dry feed basis. Detailed chemical analyses have been carried out on various product liquids (18).

Applications

The pyrolysis liquid product provides material for producing a variety of Biomass Refinery products including value added chemicals and calcium enriched bio-oil which is the reaction product of whole or fractionated pyrolysis liquids and slaked lime (calcium hydroxide suspension). It is used for control of SOx and NOx in coal combustion systems. Work on calcium-enriched bio-oil has been suspended.

Dynamotive is focussing on commercialising the biomass refinery concept through partnerships with industry leaders including Lockheed Martin/INEEL, Usina Santa Helena SA and Stone and Webster.

Future plans

Dynamotive are concentrating on the North American market and have withdrawn from the UK.

ENEL, Italy

Introduction

ENEL and Agency ARUSIA of Umbria Region have carried out a project to assess the use of fast pyrolysis for the production of electricity as a demonstration project to be fed with different feedstocks. The technology was supplied by Ensyn Technologies Inc. Canada in 1996.

Description

The pyrolysis plant supplied by Ensyn is described as an RTP III plant [see Figure 1 below] and is described below. The reactor system is an entrained bed, with sand recycle and separate char combustion.

Product and Yields

Some data on the initial operation of the fast pyrolysis plant are given in Table 3.

Table 3 Mass balances for the ENEL Bastardo Plant

Biomass type	Oak	Tropical Hardwoods
Reactor temperature [ºC]	525	527
Residence Time [s]	0.6	0.6
Char yield	NK	NK
Organics + water	74-76	73
Gas yields	NK	NK
Closure	NK	NK

The plant has had numerous operational difficulties, which are still being resolved. The use of mixed hardwoods led to problems in the collection system, the extra char produced overloaded the heat exchange train, which the system was not designed to handle. The heat exchangers used to recover heat were replaced with thermal oxidisers, although what purpose this serves is not explained. Approximately 70 hours operation has been carried out.

Future Plans

At present, the plant is undergoing extensive re-design and modification, to overcome various operational problems.

Ensyn, North America

Introduction

Ensyn's RTP™ technology evolved from the research on fast pyrolysis carried out at the University of Western Ontario in the late 1970s and early 1980s. This had the main objective of employing fast pyrolysis to produce both gaseous and liquid fuels and chemicals although most of the publications from this work relate to ethylene and propylene production (eg 21, 22). The process was commercialised in 1989 (23). The work on liquid products resulted in a commercial plant being sold to Red Arrow in the USA for recovery of food flavourings and additives (23, 24). There are currently eight operational plants: 30 dry t/d, 25 dry t/d and 3 dry t/d units at Red Arrow in Wisconsin, a 15 t/d demonstration plant at ENEL in Italy, a 100 kg/h unit, 40 kg/h unit and 10 kg/h R&D units at Ensyn in Ottawa, and a 20 kg/h unit at VTT in Finland.

Description

At least four reactor configurations have been developed referred to as RTP-I, RTP-II (25), RTP-III and RTP-IV, some of which have variations. Figure 1 shows the RTP-III configuration as designed for the ENEL plant.

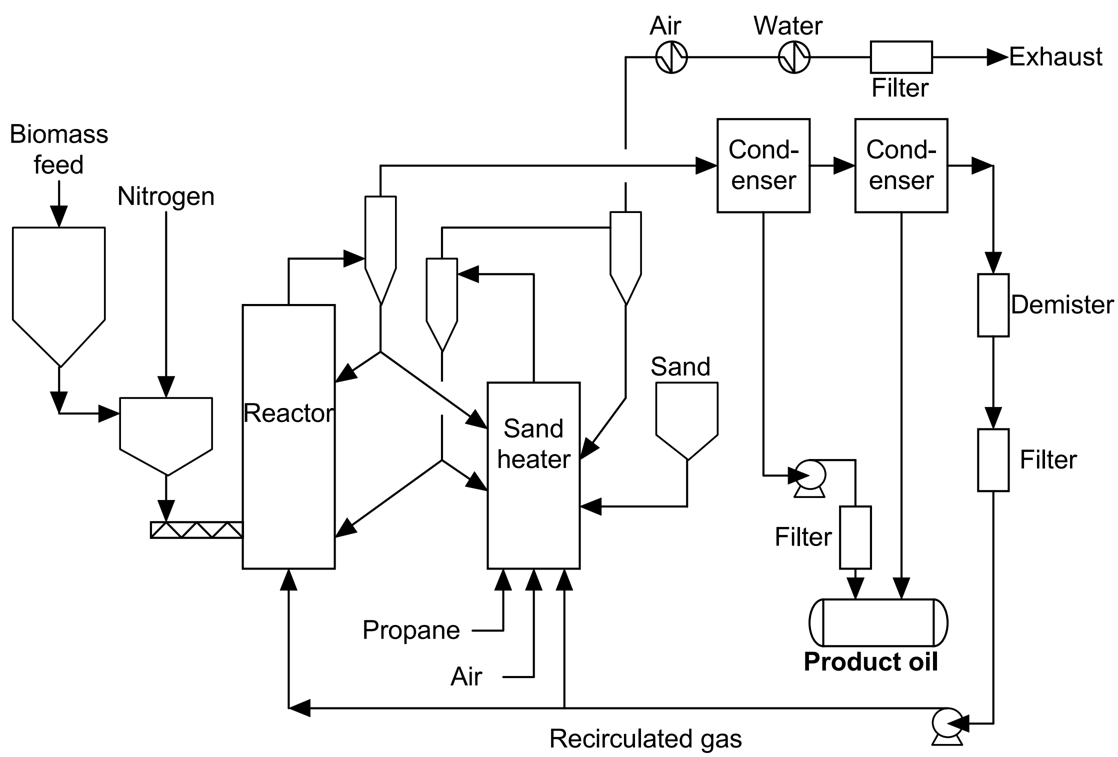


Figure 1 Ensyn RTP III Process Flowsheet of the ENEL Bastardo plant (26)

The heart of the system is a transported bed reactor which contacts hot recirculated sand with biomass in an upflowing reactor. In all the systems, biomass is comminuted to minus 6 mm and dried to not more than 10% moisture before feeding to the reactor. The products are passed through two cyclones to separate solids, then the vapour is rapidly quenched and cooled in a multiple stage system. The total residence time for the hot vapours can be controlled down to a hundred milliseconds that "freezes" the thermally unstable liquid intermediates of pyrolysis. These very low residence times are used for chemicals production, while longer residence times are used for liquid fuels in order to more completely crack the lignin. R&D is currently underway to reduce the char and ash levels in the liquid by hot vapour filtration and oil filtration (27), as shown in Figure 1.

A variety of feeds have been processed including cellulose on which much early work was carried out (28), wood, lignin, cellulose, sludges, agricultural residues, heavy oils, heavy distillates, asphalt and bitumen, and tyre crumb.

Product and yields

Characteristics of bio-oils can vary according to feed, reactor configuration (29) and process parameters (30). From woody biomass feeds, the overall liquid yield is up to 83% by weight on a dry feed basis (31, 32).

Applications

The first commercial application of the Ensyn Technology was at Red Arrow Products in Wisconsin, USA that produce chemicals with the residual oil used as a boiler fuel (24). Preliminary combustion tests performed showed that fast pyrolysis bio-oils could be used in place of heavy and light fuels oils in industrial boiler applications (27, 32) where bio-oil was shown to have a similar heat release rate and flame length as Number 6 fuel oil. More recent tests at CANMET (33) and at MIT (34) have shown that the liquid oil is more similar to light fuel oil in its combustion characteristics. Special combustion chambers would, therefore, not be required and a fossil fuel fired boiler or furnace could be easily converted to use this oil. Special attention has been paid to emissions, and one conclusion, for example, was that carbon monoxide emissions would be comparable to those from fossil fuel oil combustion, particulate emissions might be greater depending on the extent of char removal from the oil and NO_X emissions would be lower. SO_2 emissions from bio-oil combustion are less than 2% of those from the combustion of Number 6 oil. Bio-oil at Red Arrow is routinely burned in boilers for heat production (23) and has met local emissions requirements.

Currently Ensyn is working with a number of companies to test fire bio-oil in an internal combustion engine and is involved in a large project with a gas turbine manufacturer to test fire bio-oil in a gas turbine (23). Some costs and economics of the process have been published (27, 35).

Fortum Oy, Finland

Introduction

Fortum Oy has recently announced that a 500 kg/h biomass fast pyrolysis plant is under construction (36).

Description

No details are available on the technology. The only statement is that proprietary technology is being used.

Product and Yields

Plant is presently under commissioning - no results are available.

<u>Applications</u>

Liquids are for use in small domestic boilers in co-operation with Vapo Oy in Scandinavia. .

<u>Future Plans</u>

Fortum Oy plans to produce commercial units of 5 t/h by mid-2004.

Pasquali-ENEL, Italy

Within the context of an EC sponsored project, Pasquali and ENEL are collaborating on the development of a circulating fluid bed fast pyrolysis system with a nominal capacity of 150 kg/h, referred to as CIRO (37). This is based on modification of a CFB combustor and includes integral char combustion at the base of the pyrolysis riser.

<u>Applications</u>

The aim of this plant is to utilise the CFB for theoretical and experimental investigation of the fluid dynamic regimes (38).

<u>Future Plans</u>

No further work has been carried out on the plant to date.

University of Twente, Netherlands

<u>Introduction</u>

Gas-solids reactors, such as fluidised bed processes, have been studied for a long time within the Chemical Reaction Engineering group. One direction focuses on the development of new reactor types including the rotating cone reactor. Several projects have aimed at further development of the rotating cone technology for pyrolysis.

This work was instigated to develop a new intensive reactor technology for the pyrolysis of biomass by sliding and pressing the particles on a heated surface. The original aim was to achieve ablative pyrolysis where the particles "slide" across a heated metal surface in a rotating cone, but subsequent development of the initial ideas led to a type of transported bed pyrolyser.

The development of the rotating cone pyrolysis reactor took place in two European sponsored research projects from 1989 to 2001 (39, 40, 41, 42, 43). Current research is concerned with the development and testing of the new concept in the framework of a European Joule-project on catalytic pyrolysis. Special attention will be paid to the in-bed catalytic upgrading of the bio-oil and the first experimental results were recently obtained in this new concept.

<u>Description of Concept 1</u>

The rotating cone is a novel type of reactor, applicable to fast pyrolysis of solid materials. The concept is that biomass particles are fed onto an impeller, which is mounted at the base of the heated rotating cone together with an excess flow of inert (or catalytically active particles). These are then flung on to the heated surface to be pyrolysed while being transported spirally upwards along the hot cone wall. The concept is depicted in Figure 2. The final char and ash residue is ejected from the top of the cone. No carrier gas is needed, which reduces the size and costs of the secondary oil-collection system considerably. The reactor is very compact and has a very high solids transport capacity of up to 3 kg/s solids.

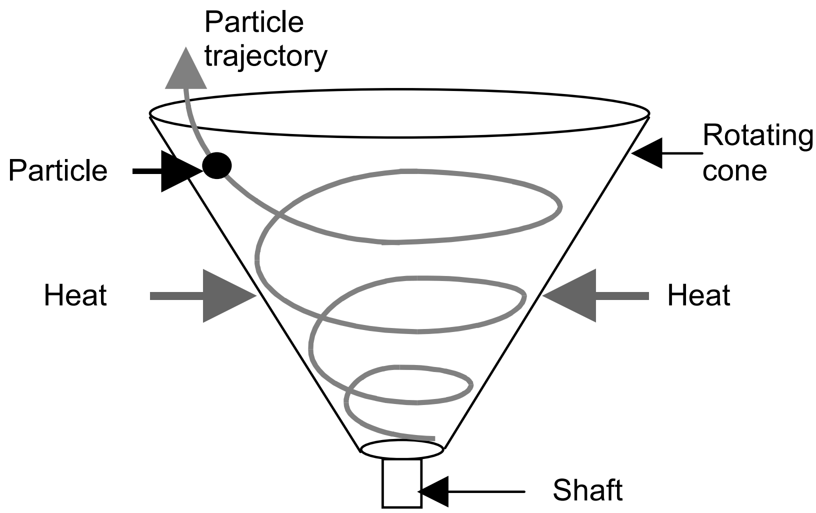


Figure 2 University of Twente Rotating Cone principle

Initial experiments were carried out mainly with a cone temperature of 600°C and a cone rotational speed of 900 rpm. The reactor interior was subsequently modified as shown in Figure 3 to reduce the operational volume from 0.25 m^3 to 0.003 m^3, otherwise the gas/vapour residence time would be around 80 s giving significant vapour cracking. The reactor outside the cone quickly becomes filled with sand and char, restricting experimental runs to 10 minutes. The liquids are collected in a condenser/quench system (44). The reactor was subsequently modified to permit internal sand recycle as shown in Figure 4.

The reactor has been further modified so that the sand is removed from the reactor with the char, the char combusted and the hot sand re-fed to the reactor, i.e. an internal sand recycle. A cold model was constructed at the beginning of 1995 and has subsequently been tested as a hot system. The latest arrangement is shown Figure 4.

Another project is aimed at the recycling of plastic waste by flash pyrolysis in another bench-scale unit, also based on the prototype rotating-cone concept by Wagenaar (45). In this project the 'back to monomer' concept is experimentally studied on pilot plant scale, and the aim is to produce high value monomers from short heating-up times and rapid quenching conditions. Technical and economic evaluation of the entire process have indicated that the rotating cone reactor is very competitive with other types of gas-solids reactors such as bubbling fluid bed and riser systems.

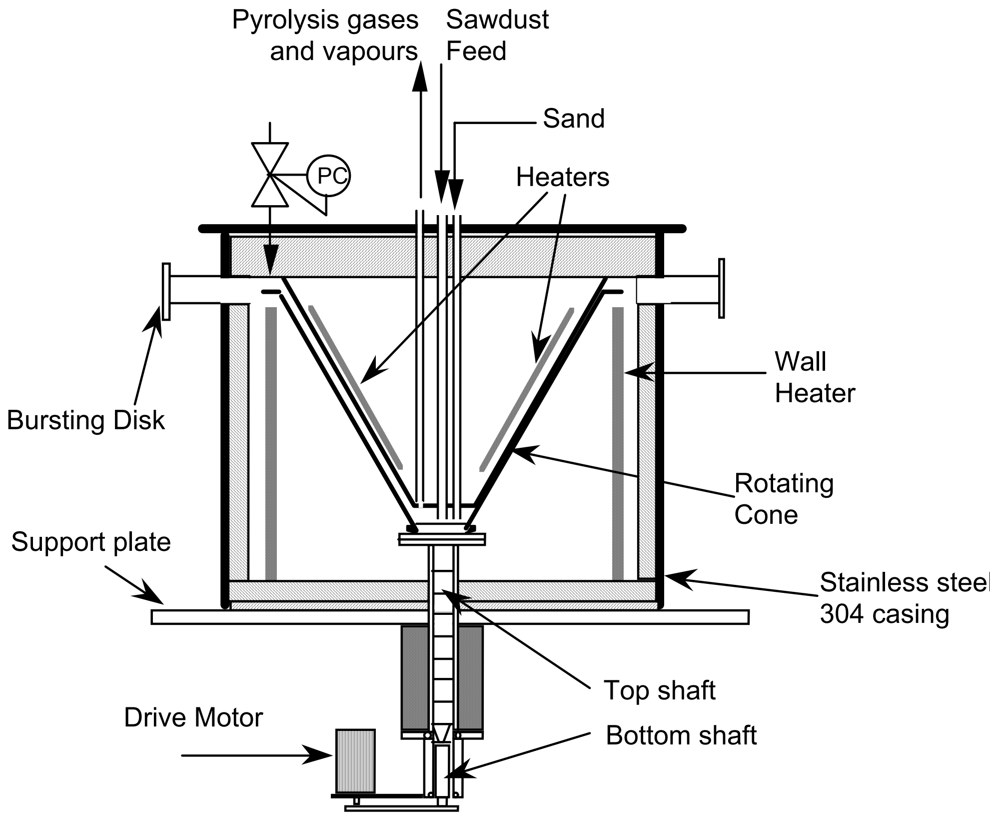


Figure 3 University of Twente Rotating Cone Flash Pyrolysis Reactor

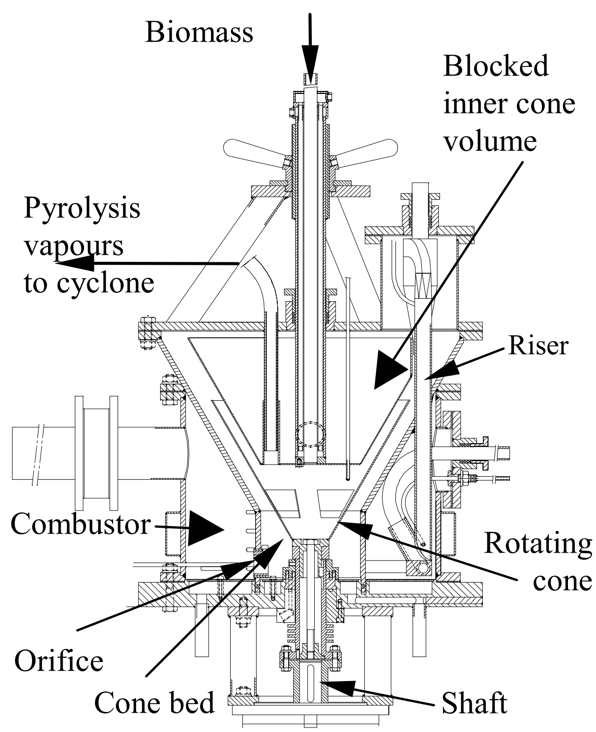


Figure 4 Energy Integrated Rotating Cone Pyrolysis Reactor

Products

Isothermal reactor operation leads to significant cracking of the product vapours. Typical yields at 1 s residence time and a heated surface temperature of 600°C are: 60 wt% liquids, 25 wt% gases and 15 wt% char. The mass balance closure is generally around 90 %. Work is also in progress to devise tests for measurement and prediction of bio-oil thermal stability.

Results

Some data has been presented on the various systems and these are summarised in Table 4 and in Table 5 below.

Table 4. Mass balances for the first rotating cone reactor [yields in wt%] (39)

Biomass type	mixed softwoods
Reactor temperature [ºC]	500
Char yield	
Organics + water	70
Gas yields	15
Closure	85
Gas Composition	
CO	
CO_2	
CH_4	

Table 5 Mass balances for the integrated rotating cone reactor [yields in wt%] (46)

Reactor temperature [ºC]	450	510	520
Char yield	4.67	5.71	3.96
Organics + water	49.9	65.3	64.3
Gas yields	11.1	9.65	13.9
Closure	65.7	80.7	82.2
Gas Composition			
CO	4.95	3.74	6.08
CO_2	5.77	5.51	7.08
CH_4	0.34	0.40	0.70

Future plans

Scale up to 200 kg/h biomass feed has been implemented by BTG (q.v.) and a THERMIE grant has been obtained for scale-up to 2 t/h, with operation planned in 2003 at a local wood processing plant.

Wellman Process Engineering Ltd., UK

Introduction

Wellman Process Engineering Ltd. are developing a 250 kg/h fast pyrolysis process under the framework of an EU funded project (47). Wellman Process Engineering Ltd.'s aim is to design, construct and commission and operate an integrated fluidised bed fast pyrolysis reactor system for the optimal production of liquids. The development of a reliable fast pyrolysis system, capable of continuous operation is essential for subsequent commercialisation. To this end, a fully integrated system has been designed which minimises dependence on external fuel sources by utilising the by-product char and non-condensable gas into the process to provide process heat, fluidising and inert gases.

Description

The design biomass feed rate is 250 kg/hr softwood [dry basis] with anticipated pyrolysis liquids of 75% at a reactor temperature of around 500°C. The pyrolysis char and gas yields are expected to be 12-14 wt% each. The energy provided by the by-products is more than sufficient to provide the heat required for the pyrolysis process, based on detailed mass and energy balances over the system.

Wood will be fed continuously through a water-cooled screw conveyor into the reactor via a lock-hopper system. The pyrolysis reactor will consist of an inner sand bed reactor fluidised using recycled pyrolysis gases, which have been oxidised using air over a catalyst bed. Char is removed from the pyrolysis vapours and gases in a primary cyclone where the majority of the char is recovered. A secondary cyclone removes the remaining char.

The char combustor is a separate sand bed reactor, located in the annulus surrounding the pyrolysis reactor. This arrangement allows the pyrolysis process and char combustion to be controlled independently allowing more flexibility when dealing with different feedstocks. Approximately 75% of the process heat is supplied indirectly by the char combustor and the hot fluidising gases to the pyrolysis reactor provide the remaining heat.

After char removal, residual pyrolysis vapours and gases enter a two-stage quench column where approximately 70 wt% of the liquids will be recovered. The total residence time of pyrolysis vapours will be less than 2 seconds from production through to quenching. An electrostatic precipitator is used to collect remaining organics and water.

The pyrolysis char is collected by two cyclones and used to provide 75% of the energy for the pyrolysis process. A proportion of the non-condensable gas, consisting mainly of CO, CO_2, CH_4 and H_2, will be recycled for use as fluidising gas in the pyrolysis reactor after catalytic oxidation. Excess gas is vented after catalytic oxidation. The process was granted IPC authorisation in November 2000 - the first plant in the UK to gain authorisation for liquids production.

Process Flowsheet

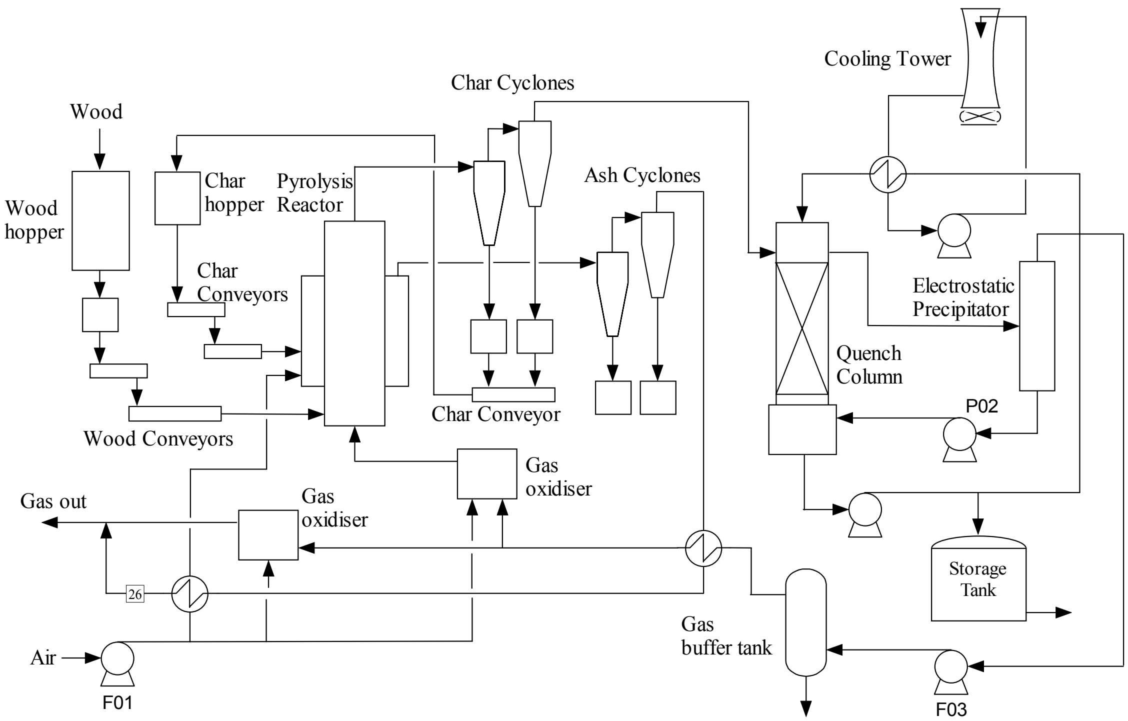


Figure 5 Wellman Process Engineering Ltd. fast pyrolysis process

Product and yields

No product yields are available yet.

Future Plans

At present, the plant has stopped commissioning, due to a lack of funds to obtain IPPC authorisation. IPC authorisation had been granted in 2000, but with the changeover to IPPC, the regulatory regime was not accounted for and a new application is required. IPPC is an important environmental compliance issue for all fast pyrolysis technologies. To date, IPPC authorisation has not been applied for, due to excessive costs and the plant has not been commissioned.

1.2 INCENTIVES FOR BIOMASS PYROLYSIS IN THE EU MEMBER STATES

Each of the member states in the EU has its own particular incentives for the promotion of biomass fast pyrolysis, in this case for power generation. Each of the member states is reviewed below. The basis for this was taken from recent IEA publications and direct inputs from the partners where appropriate.

1.2.1 Austria

An Ordinance of the Federal Minister for Foreign Affairs in force since 1st August 1995 guarantees minimum prices for electricity that is traded between provinces and has been produced from CHP stations and renewable electricity plants. For plants up to 2 MW these prices range from €0.03/kWh to €0.07/kWh [100-125% of the prices charged by the Verbundgesellschaft], depending on the time of delivery. For plants over 2 MW, the rates are 100% of the prices charged by the Verbundgesellschaft, or € 0.03-0.07/kWh.

Both direct and indirect information measures to support renewable energy are in place. Federal support for third party energy information and advice [consulting firms] was made available in 1993 and has resulted in estimated energy savings of 1.25 PJ per year at a cost of €0.38M. Support for smaller energy users was introduced in 1993.

1.2.2 Belgium

Renewable energy plays only a minor role in Belgium, due to its relatively limited potential. Promotional activities for renewable energy are limited at a national level to setting electricity buy-back rates and to federal R&D activities, as the progressive rationalisation of Belgian energy policy has transferred responsibility and promotion of renewables to Belgium's three regional administrations [Flanders, Wallonia and Brussels].

Regional renewable energy R, D & D and promotion programmes such as economic or fiscal incentives, regulation, information and training are in place, although the renewable energies targeted vary between regions. Flanders has a renewable energy target of doubling renewable energy use over the period 1996-2000, and achieving a use of 5% of energy consumption from renewable sources by the year 2020. Wallonia's 1995 Environment Plan for Sustainable Development includes an aim to increase renewable energy use to 3% of energy consumption by 2000 and 5% by 2010.

Renewable energy promotion programmes are the basis of one of 14 measures cited in the Belgian National Plan to reduce CO_2 emissions. The plan states that each authority [federal or regional] will seek to promote renewables within the current system of grants, subsidies or agreements. For the federal government, this has meant granting conditions that are more favourable for auto produced renewable electricity. The regional governments continue to rely on financial incentives, mainly grants for R&D projects. The Plan explicitly quantifies renewables' contribution to CO_2 mitigation in the industrial sector at 0.2 Mt of CO_2 [or 2.6% of total emission reductions envisaged in the plan]. Potential export markets are an important driver for the country's renewable manufacturing capability in biomass and wastes. The Belgian Control Committee for Electricity and Gas [CCEG] increased the financial incentives available for renewable electricity in 1995. There is now a payment of €0.03/kWh produced.

The 1995-2005 Electric Equipment Plan was approved by the government in January 1996 and includes measures aiming to increase the production of electricity from renewable energy resources, including biomass. However, a guaranteed market for renewable electricity does not exist in Belgium. The Belgian CO_2 reduction programme cites strengthening of Electric Equipment Plan as part of the climate change response strategy and the government has asked the CCEG to continue its study of tariffs that would be favourable to increased use of renewable electricity.

Renewable energy technologies are eligible for a range of existing financial support instruments for "new technologies". Up to 100% of research costs and 50% of demonstration, costs are to be made available for renewable projects and investments in non-R&D systems benefit from grants and tax allowances. Information that is more detailed is shown in Table 6 [Flanders region] and Table 6 [Walloon region]. Further regional support for renewables includes use of information programmes to raise awareness. The measures to promote renewable energy that are summarised in Table 7 are those for which the Wallonia region Direction Générale des Technologies, de la Recherché et de l'Energie [DGTRE] is responsible.

Table 6. **Renewable energy support measures in the Flanders Region, Belgium**

Name	Description of Incentive	Budget
Investment grants [ecology support]	15% investment support for renewables	Unlimited [part of general investment support budgets]
Demonstration projects	35% investment support for renewables	€0.5M
Tax allowances	14% of renewable investments can be deducted from company profits	
Research and development projects	A range of projects executed by research organisations, universities and agencies	€1.0M

Table 7. **Renewable energy promotion in Wallonia, Belgium**

Measures	Description of Incentive	Beneficiaries
Decree of the Walloon Region in the field of RD&D of 5 July 1990	Financial support for RD&D projects: - Subsidies for basic industrial research: up to 50% of the Eligible Cost [E.C.] [general provision]; up to 80% of the E.C. for SME's; and up to 100% of the E.C. for universities and research centres	Firms [including SME's] groups of firms, research centres, universities
	- Subsidies for the preparation of RD&D projects for accompanying measures: up to 80% of the eligible costs for SME's	Small and Medium Firms [SMEs]
	- Recoverable advances for applied research, development and demonstration projects: up to 50% [general provision]; up to 80% of the eligible costs for SME's or for projects meeting specific conditions	Firms including [including SME's] groups of firms, research centres, universities
Tax Allowances [Fiscal incentives]	13.5% [1997] of the allowable costs for renewable energy investments can be deducted from the profits of enterprises	Firms
Royal Decree 10.2.83"ECHOP"	Subsidies [20%] of the eligible costs for renewable energy investments	Schools and hospitals

1.2.3 Denmark

Denmark aims to almost double the contribution of renewable energy to primary energy supply from its 1988 value by 2005. This will be achieved by co-ordinated energy/environment initiatives prominently featuring renewable energy beginning with the Government's original Energy 2000 Plan [published 1990], the Energy 2000 Follow-Up Plan [published 1993] and Energy 21 [Spring 1996]. The 1993 Follow-Up plan proposes a series of additional measures to be taken in the energy sector [excluding transport], to ensure the original 2000 targets will be met. Additional measures to promote biomass energy applications in Energy 21 include:

- Ensuring that the energy supply to small communities be met by biomass-based district heating of CHP [rather than natural gas] [this has, however, restricted the expansion of gas networks and of growth in gas use for other purposes];
- Increasing the flexibility of regulations governing the quantities of wood chips and straw to be used in electricity generation;

A package of new initiatives for the promotion of renewables was launched by the Danish Energy Agency [DEA] in November 1995 focusing on wind energy, but also including actions in the areas of biomass. Efforts to promote renewables in Denmark continue to include regulations; economic and fiscal incentives, targets, information dissemination and R&D. Extensive evaluations of the potential for different renewable energy sources have also been carried out. These were strengthened in the 1980s and 1990s by targeted regulatory mandates, market stimulation measures via output subsidies and guaranteed markets for renewable electricity. Other financial incentives include reduced taxation rates for profits from the sale of renewable electricity.

Output credits [payments/kWh] were first introduced in 1983 for wind electricity and extended in 1992 to electricity from renewable CHP plants. A more favourable and extensive system of output credits for wind and other renewables including biogas and hydro, biomass and municipal waste in some circumstances, was introduced in 1992 with lower credits for small-scale biomass. Different renewable technologies receive state aid in the form of output subsidies per kWh produced. These vary between €0.01-0.04, depending on the renewable energy source and producer [most utility producers receiving the lower rate and self producers the higher rate]. The funds to run this subsidy scheme come from the revenues from the CO_2 tax, from which renewable energy is exempt. However, the total buy-back rate for renewable electricity is significantly higher than the subsidies, as utilities have an obligation to pay private operators 85% of the total generation and distribution costs for renewable electricity. Buy-back rates for privately generated wind electricity in 1996-averaged € 0.08 [including the €0.04 subsidy].

Measures first introduced in the 1988 Heat Supply Act to encourage district heating using renewables by prohibiting installation of electric heating in specified residential areas are still in force. The mandatory programme launched in 1990 to convert all local district-heating plants to CHP based on natural gas or biomass was to be completed by end 2000, although this has now been extended. The ban on in field burning of straw imposed in 1990 has resulted in this being used for energy purposes. In 1992, a parliament resolution required utilities to undertake fuel substitutions, including uptake of biomass. Utilities are obliged to purchase power from wind turbine operators and providers of other types of renewable electricity at a set price. The Government has also required municipalities to elaborate plans for future wind turbine siting. In addition, from 1996, all waste must be recycled or burned in CHP plants.

The types of economic instruments employed to promote renewables have included both capital and output credits. A construction subsidy of up to 30% of approved installation costs can be given to renewable energy projects [although this was phased out in 1989 for wind]. Subsidies of up to 50% for CHP plants using biomass can be obtained from a pool of €3.4M/year up to 2000.

The two Danish utilities, ELSAM and ELKRAFT, implemented a bioenergy development programme in 1992. The 1993 Biomass Agreement requires the utilities to use 1.2 mt of straw and 0.2 mt of wood chips annually by 2000 [about 0.4 Mtoe], either in biomass-only power stations or co-fired with coal, although this approach was relaxed slightly in Energy 21, which allows greater flexibility in how the total biomass target is met. The Biomass Agreement was amended in July 1997 leaving the utilities greater choice in the type of biomass procured. The requirements are now at least 1m tons straw, 0.2mt wood chips and 0.2 mt of either straw, wood chips or willow: this should minimise the need for expensive imports of straw from neighbouring countries. Another part of the plan allows individual towns and communities to adopt, if they wish, biomass technologies on their own initiative.

Plans for development and demonstration of advanced biofuel technologies, in particular biomass gasification, are a major priority area within the biomass sector. Seven pilot plants are presently under construction or in operation. Two further inter-Ministry groups in the areas of solid biomass and liquid biofuels have also been set up.

Trends in renewable energy R&D expenditure have shifted from wind [42% in 1990 down to 37% in 1996] and solar [from 18% in 1990 to 13% in 1996] towards biomass applications [rising from 28% in 1990 to 49% in 1996] producing electricity and heat.

1.2.4 Finland

There are no targets for total renewable energy use in Finland, however, the Finnish government decided on 7 April 1994 upon an action programme for the promotion of bio-energy that aims to increase the use of bio-energy at least 25% by year 2005. The programme aims to increase use of bio-energy by 30% in 2005 [compared with 1993]. This is equivalent to an increase in bio-energy production of around 1.5 Mtoe per annum. The Government's approach to bio-energy subsidies, taxation and exemptions is explicitly linked to regional employment and social issues. The government also aims to have 100 MWe of wind capacity installed by 2005. Energy policy is the responsibility of the Energy Department in the Ministry of Trade and Industry [MTI]. The Finnish Technical Development Centre [TEKES], part of the MTI, aims to strengthen R&D activities and improve project management and cross-fertilisation with non-energy activities. Fiscal measures and R&D are the two central policy approaches used to support market deployment and commercialisation of renewable energy in Finland. There are no regulatory measures or other related commitments. The Electricity Market Act, which entered into force in June 1995, allows all electricity producers to seek customers throughout the Nordic electricity market. This could allow interested parties to opt for "green power", if available. In Scandinavia, the incentive for electricity production is low, as the pool price for electricity in

Finland and Sweden is very low at € 0.01/kWh. There is a higher incentive to target CHP schemes, where the heat product may command a similar value as the electricity.

Reduced fiscal incentives towards renewable energy, notably the removal of special VAT exemptions on bio-energy sources, came into effect from 1 January 1995 following requirements to harmonise with EU policy. This, and the 1997 energy tax system reform, has resulted in the favourable tax treatment of biomass inputs to electricity generation being removed: from 1997, tax has been levied on electricity output [irrespective of the fuel used for generation] rather than on the fuel inputs. However, a refund system was also introduced to compensate electricity generation for the reduced tax advantages: a tax refund equal to the electricity tax is available for electricity from wind, wood, wood-based or small hydro. The need for further significant electricity supply capacity [estimated at 4800 MW above 1994 capacity by 2005] provides significant potential for the development of renewables, particularly biomass-based electricity generation.

However, the 1997 tax reform maintained the incentives for biomass-based heat generation, as taxes on heat are based on the net carbon emissions from input fuels, and are zero for renewable energy sources. Previously, the carbon/energy tax was based 60% on the carbon content of the fuel and 40% on the energy content. In addition, renewable energy sources are still subject to favourable tax treatment and direct bio-energy investment support to assist deployment and commercialisation. For investments in biomass based energy technologies, maximum subsidies are 30% of eligible cost. For energy technology studies, the maximum rate of subsidy is 50% of the amount of eligible cost.

The development of bio-energy technologies is also given a high priority within energy R&D. Public expenditure on R&D is normally about €10M per year. R&D finance is channelled mainly through the Research Programme for Bioenergy. A set of eight national energy technology programmes was launched in 1993 by TEKES. Four programmes - Liekki 2, Bioenergia, NEMO 2 and SIHTI 2 - are directly related or have strong links with the promotion of renewable energy. Around one sixth or €336M per year of total R&D expenditure is directed towards TEKES activities, of which €33.6M supports the energy sector. The funds for renewables are about €10M.

1.2.5 France

Although long-term emphasis on nuclear power continues, a 1994 Government-initiated national debate and consultation exercise on future plans for energy policy emphasised among other things the need to stimulate EDF's actions to promote renewable electricity supply. Following the recommendations from this "Souviron Report", the government initiated EOLE, a plan to promote grid-connected wind electricity, in 1996. Promotion of wood energy for heating is also being strengthened via a Wood Energy Plan.

Renewable energy policy is formulated by the Ministry of Industry and implemented through the Agence de l'Environnement et de la Maîtrise de l'Energie [ADEME]. Government supports renewable energy in several ways, including direct funding of local and regional projects, joint EDF/ADEME agreements, financial incentives [such as favourable tax treatment for renewable energy investments, reduced VAT on renewable energy equipment, and premium buy-back rates for successful projects under the EOLE programme] and information/education programmes. ADEME is co-directed by the Ministries of Industry, Research and Technology, and Environment gaining financial support mainly from earmarked taxes and, to a lesser extent, directly from Government. ADEME supports several renewable R&D activities including: energy production from municipal waste; biomass [mainly the supply and distribution of wood]; regional development plans; and PV standardisation. A tax on municipal waste was introduced in 1993 to encourage energy recuperation from waste. It stands at €4.6/ton in 1996, increasing to €5.4/t in 1997 and €6.2/t in 1998.

Increased use of biomass, especially for heating apartment blocks, is supported by the Wood Energy Plan, initiated by the Ministry of Industry. Under the EOLE programme, projects have to be between 1.5-8 MW capacity: the legal limit for independent power producers. A market for power from the successful bids is guaranteed, and will be bought for the rate determined at the time of bidding for 15 years. A further round of bidding for 100 MW [of which 25 MW is to be in France's overseas territories and departments] was initiated in early 1998. A similar policy to encourage installation of 10 MW of biomass electricity capacity and 10 MW of biogas electricity plants was also announced in February 1998.

Biofuels benefit from excise tax exemption of up to €0.35/l for RME and €0.5F/l for ethanol. The Government estimates that this subsidy will cost €0.25 billion per year in lost tax receipts, although it will only result in limited reductions in CO_2 emissions. This programme is followed for agricultural reasons, as it is not cost-effective in terms of CO_2 reduction alone. Tax credits are available for investments in renewable energy technologies in overseas department for small hydro, wind, biomass photovoltaic and solar thermal power schemes, whereby renewable energy investments by a company can be deducted against taxable profits.

National government expenditure on renewables accounted for 1% of total energy R&D budget in 1996 [€5.8M]. This was the lowest reported proportion of any OECD country's energy R&D budget that is spent on renewable energy. The majority is spent on biomass, photovoltaics and geothermal. A scientific agricultural group of chemistry and energy [AGRICE] has been set up to co-ordinate different research paths for increased use of energy crops, notably biofuels for transport and heating.

1.2.6 Germany

German energy policy continues to be characterised by efforts to reconcile political, economic and environmental objectives. The Chancellor's declaration in April 1995 to reduce CO_2 emissions by 25% by the year 2005 relative to 1990 has resulted in a range of policies and measures for renewable energy promotion being been put forward. Perhaps the most effective renewable energy promotional policy to date has been the Electricity Feed Law [EFL], which is at the heart of renewables promotion and guarantees a market for renewable electricity at very favourable buy-back rates. Other government promotional policies include economic incentives for increased use of solar and biofuels, R&D programmes, favourable treatment of renewables in building codes and information and training. Green pricing [a private initiative] is available in some parts of Germany. Renewables are also promoted at the Länder level. Responsibility for biomass promotion rests with the Federal Ministry of Consumer Protection, Food and Agriculture.

The drafting, financing and implementation of programmes to promote renewable energies in Germany are strongly influenced by the federal structure of the country. This can have the disadvantage that measures to promote renewable energies are not always co-ordinated in an optimal manner and that information that is of relevance for private interests is not always available to the extent desired. On the other hand, regional corporations have significant flexibility in promoting renewable energies. There are no plans to strengthen co-ordination of renewable energy technologies on the Federal level or among the Länder.

Despite a number of attempts by some German utilities to block or overturn the EFL, it is still in place and creates a guaranteed market and favourable prices for renewable electricity generated by non-utilities. These prices are set at a percentage of final user prices, depending on the type of renewable: small hydro facilities and biomass/waste are paid 80%. For 1998, the price is €0.08/kWh. These prices are approximately 2% lower than those paid in 1997 because electricity prices have been decreasing in Germany.

The EFL has been revised in order to distribute the cost of renewable electricity production, as it currently places a significant, although unequal, financial burden on some utilities [especially those near the coast where the majority of wind turbines are situated]. The April 1998 Energy Law caps at 5% [of total electricity distributed] the amount of renewable electricity that has to be distributed by an individual [municipal] utility. Once this 5% threshold is surpassed, the cost of supporting additional renewable generation is passed on to the higher level [regional] utility. If a regional utility also crosses the 5% threshold, the obligation to pay for the renewable electricity passes to the supra-regional utility, and once this is surpassed, the obligation to pay will end. The EFL has been modified and new law was passed in 2000 the Renewable Energy Sources Act, 25 February 2000.which offers premium prices for biomass-derived electricity.

< 500 kWe: €0.10/kWh
501-5000 kWe: €0.09/kWh
> 5000 kWe: €0.085/kWh

The Deutsche Ausgleichsbank [DtA], a public bank, grants low-interest loans to specified projects. About €2.1 billion of loans was granted between 1990 and December 1997, mostly for wind energy [€1.77 billion] followed by hydropower [€154M] and biomass [€136M] in the framework of the ERP-Environment and Energy-Saving Programme.

A range of other smaller programmes support renewable energy. From 1 January 1995, amendments to the Ordinance on the Fee Schedule for Architects and Engineers provide new incentives for architects and engineers to incorporate the use of renewable energies in dwellings. Land set-aside bonuses are available if biomass crops are grown on set-aside land. Subsidies for renewable energy also exist at the Länder level.

1.2.7 Greece

Promotion of renewable energy in Greece is based on four types of measure at the national level: economic incentives [in the form of both capital subsidies and favourable buy-back rates]; targets for future renewable energy use; information dissemination, and R&D. Policies used to promote renewable energy development are described in the Greek National Communication [Climate Change: The Greek Action Plan, Ministry for Environment, Physical Planning and Public Works, February 1995, Athens], which estimates annual CO_2 savings of 3.1 Mt from increased use of renewables.

Specific measures promoting renewable energy sources [RES] are provided by relatively recent legislation [Law 2244/1994, Ministerial Decision 8295/1995]. The main provisions of these are to:

- Remove restrictions and liberate regulations for electricity production from RES, with a maximum capacity of 50 MW for independent producers;
- Allow auto-[self] producers the possibility of compensating on equal terms their own production of electricity from RES and their consumption [net metering];
- Limit the amount of bureaucracy involved in the issuing of the licenses required;
- Define all basic elements of the new improved pricing system.

National policy is formulated by co-operation between the Ministry's Directorates for Energy Policy, Renewable Energy Sources and Energy Conservation, the General Secretariat of Research and Technology, the PPC [the State power company] and the Centre for Renewable Energy Sources [CRES]. PPC have also established a company that will manage its renewable electricity production schemes. CRES is the National Centre for the Promotion of Renewable Energy and the Rational Use of Energy [RUE] and it carries out R&D activities in the sector. CRES operates mainly under the auspices of the General Secretariat of Research and Technology, but also under the General Secretariat of the Ministry, responsible for the energy sector. There are four forms of Government financial support available for renewables [with the emphasis on renewable electricity production]:

- Law 2244/1994 set up a new pricing policy between PPC and independent or auto [self] producers, whose installations are connected either with the PPC's isolated grids on islands or with the PPC's interconnected system in the mainland.
- Law 1892/1990 provides economic incentives [a subsidy of up to 45% reaching 55% in certain cases, according to location] for the promotion of various investments including renewable energy production.
- Law 2364/1995 allows for 75% of renewable appliances for households, such as solar water heating systems, to be deducted from a person's taxable income.
- The Operational Energy Programme of the Ministry of Industry, Energy and Technology, which runs to 1999, allocates €20M of public funds in addition to the €120 M of EU and private funds for the development of renewable energy sources.

Under Law 2244/1994, the PPC is required to purchase all electricity from private renewable electricity plants for a period of 10 years [after which an extension may be possible]. For self-producers selling electricity to isolated grids, all excess renewable electricity supplied to the PPC's network is purchased by PPC at 70% of the low voltage tariff. When renewable electricity is fed into an interconnected system, the excess kWh produced is purchased at 70% of the tariff corresponding to low, medium or high voltage. For independent producers, the PPC's purchase price for the excess kWh is set at 90% of the low voltage and of the low, medium or high voltage tariffs, for the island's isolated grids and for the mainland connections, respectively.

In accordance with the relevant provisions of the Law 1892/1990 and 2244/1994, there is no difference between the subsidies for private investors for small hydro, solar, wind or biofuel electricity projects. However, as the uptake of the different energy sources will vary, so will the extent of public support. The National Communication estimates that €60M of €230Mfor biomass promotion will be met from public funds. To date, there has been very little development in the exploitation of biomass, with only one small-scale pyrolysis activity hosted at the Agricultural University of Athens, which has since been dismantled.

1.2.8 Ireland

The 1993 Irish National CO_2 Abatement Strategy and the Irish National Communication refer to the role that wind, solar energies and energy crops could play in mitigating CO_2 emissions, and the proposals contained in the National Communication for a renewables tranche of electricity capacity have been carried out through the Alternative Energy Requirement [AER] programme.

The AER bids have encouraged the development of renewables: less than 8 MWe of renewable energy generating capacity was in place prior to the start of the AER, and bids for more than 140 MWe of renewable electricity plant were successful in AERs I and II. AER I was supported by a 15 M IR£ fund for grant assistance for project capital costs from the European Regional Development Fund and €89M for long-term price support for successful projects. This latter sum will be passed on to the consumers by the Electricity Supply Board [ESB]. The successful renewable electricity projects were chosen via a competitive bidding procedure, where like technologies compete with like [as in the UK's NFFO]. There have been three AERs to date, the results of which are outlined below.

In AER I, prospective generators were invited to bid to sell electricity to the ESB under purchase power agreements [PPAs] for up to 15 years. All renewable energy projects under AER I were paid a "standard" price [~€0.08p/kWh during weekdays, and €0.03/kWh at nights and weekends] that is indexed annually based on the Consumer Price Index. Prospective producers could also bid for a capital grant to ensure the recovery of project costs and a return on investment where the tariff revenue alone did not ensure this. However, not all capacity bids submitted a grant request, as the developers estimated that they could recover their costs through the purchase power agreements and the target renewable capacity was in fact exceeded without needing to disburse any capital subsidies.

In AERs II, III and IV [AER IV is exclusively for CHP projects], PPAs are also available for up to 15 years, but the prices paid will reflect the bid price of successful projects. A cap was set of for AER II [biomass/wastes] and €0.05/kWh for AER III. The actual price paid for electricity will be adjusted by season and time of day so that electricity produced at peak time will be paid more than electricity produced during off-peak hours. Successful bids from AERs II and III were expected to be operational by the end of 1999; however there have been delays primarily due to planning.

AER II resulted in one successful bid of a 30 MWe waste-to-energy plant, although this is still the subject of public debate. The target capacities for AER III are 90 MWe wind [made up of 25 MWe for wind farms under 5 MWe and the remainder for wind farms of 5-15 MW], 7 MWe biomass/waste and 3 MWe small hydro. These were all surpassed, with successful bids of 137 MWe wind, 17 MWe biomass/waste [mainly landfill] and 4.4 MWe small hydro.

Following the successful completion of the bidding and allocation procedure under AER I, a review of alternative energy strategy was initiated. This process included consultation with all interested parties, and a number of studies for the review were commissioned by the Department. The Government concluded that the AER was a significant step towards using Ireland's renewable energy resource and that the bids received for AER I indicated a willingness to invest in alternative energies. However, the government acknowledge that several players are involved in the development of renewable energy in Ireland, and that the concerns of each of these players will need to be addressed in the development of a successful renewable energy industry. Following this review of renewable energy policy, government targets for future renewable energy development have been announced. These will be supported through the funds remaining from AER-1, and all projects will receive a grant of €83,000/MWe installed.

The Government's general policy document "An Action Programme for the Millennium" commits the government to promote pilot alternative energy projects and to publishing a Green Paper on environmentally sustainable energy sources. The AER programme will continue after 2000, with annual competitions expected.

The restructuring of the electricity utility ESB to create a competitive electricity market could impact the future viability of renewable projects not covered under the AER. Other regulatory measures that could influence renewables include the production of guidelines [from the Department of the Environment] for planning authorities on the development of wind farms. In December 1997, the government indicated that tax relief would be introduced for private investment in approved wind energy and biomass projects: this relief will apply to up to 50% of a project's cost [capped at €9.6M per project and €12.7M p.a. per company]. AER V was launched in 2002, with the aim of attracting over 600MWe in new generating capacity.

1.2.9 Italy

Encouragement of renewable energy started in earnest in 1991, with Laws 9 and 10 liberalising the electricity industry and facilitating access by independent renewable electricity producers. A subsequent Directive CIP6/92, introduced in 1992, allocated premium buy-back rates for independently generated renewable electricity [paid for via a levy on electricity bills], and resulted in increased interest in grid-connected renewable electricity, especially biomass, wind and PV. However, the directive CIP6/92 was abolished in 1997, and the new Regulatory Authority sets new rules for payment of renewable electricity for Electricity and Gas.

Law 9 partially deregulates independent electricity generation and allows independent power producers to sell renewable electricity to the electricity utility ENEL. Law 10 provided for subsidies of 30-80% of the capital cost of a renewable energy plant. However, financial constraints have meant that few capital subsidies have in fact been disbursed and both Laws have now been repealed. The new Regulatory Authority for Electricity and Gas has not yet established specific rules regarding future incentives for renewable electricity generation. There are very few incentives now for biomass in Italy since Law 10 expired, which has been reflected in the slow uptake of large-scale biomass projects.

1.2.10 Luxembourg

Luxembourg is almost entirely dependent on energy imports and its energy policy pursues energy security through diversification, energy efficiency and environmental protection. Luxembourg has only limited renewable energy potential, as it is a small and landlocked country. Renewable energy is however being encouraged by a number of measures including guaranteed electricity markets at favourable rates, and grants for renewable energy technologies.

Key policy developments that relate to renewables include the Energy Efficiency Law adopted in 1993, which in turn led to, a 1994 Grand Ducal regulation on purchase price regulations for surplus electricity produced by CHP and renewable energy sources. A subsequent ministerial regulation in 1994 established a government programme for new CHP projects and renewable energy sources. Since December 1996, expenditure on certain technologies, including renewable energy systems, is tax deductible. Information and education measures relating to renewables are not followed. No public funding is allocated to renewable [or other] energy R&D. Renewable energy policy is overseen by the government's Energy Agency, which was created in 1991.

For installations based on biomass, the December 1994 ministerial regulation allocates various grants according to the capacity of the installation or the end-user. Non-residential uses of solar, biomass and heat pumps also benefit from a 25% subsidy [capped at €38,000]. The Grand Ducal regulation of 30 May 1994 sets the remuneration system for electricity produced from CHP and renewable energy sources. The price paid for surplus electricity produced by renewable installations with a capacity up to 500 kW averages €0.074/kWh; for installations from 501 kW to 1 500 kW, the price paid is €0.06 /kWh for day supplies and €0.03/kWh for night supplies. There is also a possible annual premium of €113/kWe installed used for peak power, on the condition of electricity deliveries during the network's peak load. This system corresponds to a bonus of about 20%.

1.2.11 The Netherlands

Available resources of wind, waste and biomass mean that continued growth in renewable energy use is feasible: the short-term objective is to produce 3% of energy from renewables by 2000. The longer-term target is for renewables to supply 10% of energy by 2020: this would be mainly met from renewable-generated electricity, but to a lesser extent the use of solar water heating, ambient heat and geothermal energy.

The current policy framework to encourage renewable energy is laid out in the 1997 White Paper Renewable Energy - Advancing Power. Although this action programme includes voluntary agreements with the electricity distribution companies and industry, other measures [such as tax exemptions and other fiscal instruments, increased funding for renewables R&D] aiming to increase the market penetration of renewable energy are also included. The White Paper also laid the foundations to amend the 1989 Electricity Act. The revised 1998 Electricity Act includes an option for requiring electricity distributors to distribute a certain amount of "sustainable" electricity at a future date. In addition, seven electricity producers offer the possibility of buying "green power".

The Ministry of Economic Affairs, EZ, is responsible for promoting renewable sources of energy. Voluntary agreements with utilities are an important component, but may become less so with the introduction of "green certificates" [above]. Economic and fiscal incentives, regulations, information and R&D are also used widely. The Ministry of Housing, Physical Planning and Environmental Management, VROM, is also involved in some renewable energy policy issues, and works with EZ on planning and siting problems for wind turbines and the joint energy-from-biomass programme. Recent policies and legislation that impact renewable energy development are outlined below.

Renewable Energy - Advancing Power outlines the measures needed to increase renewable energy supply in the Netherlands, and restates the expected supply of each renewable energy source to 2020. This White Paper is predominantly a "technology push" programme that aims to improve the price-performance ratio, to promote market penetration of renewables, and to reduce administrative bottlenecks. While the programme includes voluntary actions, such as agreements between government and utilities, it also sets out a number of different economic and fiscal incentives used in the promotion of renewable energy. For example, there are many types of tax exemptions including corporation tax exoneration for investments in renewable energy technology and income tax exoneration for investments in "green" investment funds. The programme also doubled renewable R&D funding. The manner in which renewable energy is promoted is therefore changing from a system emphasising voluntary agreements and capital subsidies, to one that is more market-based and that gives a more prominent role to fiscal incentives.

Table 8. Summary of recent policies relevant to renewable energy promotion in the Netherlands

The Dutch Electricity Act, 1998	Includes provisions for "green certificates" for renewable electricity and the possibility to set an obligation for consumers to buy an amount of renewable electricity.
Renewable Energy-Advancing Power: Action Programme 1997-2000, 1997	Government white paper on renewable energy
CO_2 reduction plan, 1996	€700M, of which €470M for CO_2-limiting projects and €230M for Joint Implementation, energy conservation and R&D.
Regulatory energy tax, 1996	Renewable energy is exempt from this tax, which has significantly increased the costs of small-scale energy consumption from other sources.
Environmental Action Plan, MAP 2000, 1997 [follow-on from 1994 plan]	This agreement between the government and the energy distributors lists actions the latter will take to reduce CO_2 emissions.
Energy Investment Relief, 1997	Tax relief in renewable energy technology and energy conservation technologies. Investments may be offset against taxable profits at a rate varying between 40-52%.
"Green electricity"	A regional, voluntary policy whereby consumers can opt to pay more for electricity produced from renewables.

Renewable Energy Project Bureau	Project bureau for the promotion of and information about renewable energy.

The 1998 Electricity Act contains provisions that explicitly aim to promote the amount of "sustainable electricity", defined as electricity from mini [<15 MWe] hydro, wind, solar or biomass sources, and are classified as "green" by the government. Currently, individual distribution companies have undertaken commitments to either buy or produce 1.7 TWh of sustainable electricity ["green labels"] by 2000. This will result in a developing market for renewable electricity as producers work towards meeting their commitments.

In 1998, the Dutch government's target for the contribution of renewable power to the total Dutch supplies is 3.2% in 2003, rising to 17% in 2020. Foreign producers will be also allowed to apply for green certificates, although, as for Dutch producers, they will have to contract with suppliers or consumers within the Netherlands so that they are not eligible for "green" incentives where they are situated as well as in the Netherlands.

The Third White Paper on Energy Policy set targets for individual renewable energy contributions to Dutch TPES for the years 2000, 2007 and 2020, and outlined the policies that will be undertaken to achieve these targets. The Paper's renewable energy targets for 2000 are unchanged from those established in 1993 [in the Second Memorandum on Energy Conservation, SMEC], although longer-term targets have been brought forward [in general, targets for 2010 laid out in the SMEC now apply to 2007] and, in some cases, strengthened.

The energy distribution sector's Environmental Action Plan, MAP, was produced in consultation with central Government and includes information on measures that will be undertaken to stimulate the uptake of renewable electricity from wind power, hydro, biomass, PV, solar thermal power and waste incineration. These actions aim to reduce emissions by 2.7 Mt CO_2 by the year 2000, by producing 3.1% of electricity sales and 0.1% of gas sales from renewable sources. The additional costs of increasing renewable energy use will be paid for from the "MAP supplement", contributed to by the distribution companies and the Government. The distribution companies [EnergieNed] will fund their contribution from an environmental surcharge [capped at 2.5%] levied on their customers.

Waste policy is the responsibility of VROM, and the priority is to minimise waste formation by reusing and recycling as much as possible. Landfilling of combustible waste was banned in 1997. Waste policy is important as regards renewable energy potential as incineration of waste produces the majority of the Netherlands' renewable energy [either via electricity production or from heat production]. The Energy Recovery from Waste and Biomass programme aims to improve the gasification, combustion and digestion of biomass and thereby facilitate its market introduction. Current promotional measures emphasise competition within renewable energy supply, and favourable tax treatment for renewable energy investments and expenditure. The rate of VAT on Green Electricity is charged at 6% instead of the normal 17.5%.

The Dutch Government set up an investment scheme at the beginning of 1995 aimed at increasing funds available for nature and environment-related projects [including renewable energy] in the Netherlands. Seven banks have responded, setting up "Green Funds", 50-60% of interest and dividends from which is exempt from income tax. The projects, which are considered for green funding, have to be recognised as "green" by the Ministry of the Environment.

1.2.12 Portugal

Portugal's Energy Programme was defined most recently in 1994 in the Decree number 195/94. This programme was designed to achieve a number of objectives, including a reduced dependence on energy [and especially oil] imports; a reliable energy supply at a reasonable cost; increased energy conservation and reduced environmental impacts of energy use. Part of the Energy Programme is devoted to encouraging the increasing use of renewable energies [mainly renewable electricity] not only to increase energy self-sufficiency from its currently low level, but because of the positive effects that increased renewable energy use has on the environment and on regional development. The short-term target for renewable energy includes 10 MWe biomass capacity in place by 2000. Portugal uses a range of measures to promote renewable energy including:

- Measures to encourage renewable electricity production [guaranteed markets and favourable prices for renewable electricity and CHP];
- Direct capital investment subsidies;
- Other market stimulation incentives, e.g. no-interest loans;
- Information/education campaigns; and
- R&D.

The renewable part of the Energy Programme is run by the General Directorate of Energy under the Ministry of Economics, with almost a third of the total estimated financial requirements of €0.925M provided by the EU programme FEDER. The form of support for renewable energy projects under the Energy Programme depends on the nature of individual projects:

- Projects benefiting from a grant of up to 60% of eligible costs if they are demonstration projects,
- Up to 50% if they are dissemination [commercialisation] projects,
- Loans [that could possibly be transformed into grants if the project is considered "excellent"] up to 40% for projects aiming to increase the deployment of mature technology.

The subsidies per project are capped at €0.3M except for CHP systems, where the cap is €0.8M. The exact level of support for an individual project varies depending on its size [projects under 10 MWe receive most help], and its regional and environmental impacts.

In addition to the capital subsidies described above, the Government encourages independent renewable power generation allowing any organisation [but not individual households] to qualify as an independent producer with the right to supply the grid up to 10 MWe at regulated prices [set out in Law 313 in 1995]. The prices vary depending on when the electricity is produced, with a premium for peak or shoulder rate electricity. Average prices paid were estimated at €0.05/kWh in 1996. For systems larger than 10 MWe, incremental electricity production [i.e. from all but the first 10MWe capacity] will be paid for at "avoided cost" rates for 15 years. The purchase power obligation and technical conditions for installing connections to the national grid are set out under Decree Law 189 [1988], and include provisions for a guaranteed market for renewable electricity at favourable prices.

Public energy R&D is managed through the Institute for Industrial Engineering and Technology [INETI]. Significant reorientation of support away from energy conservation and fossil fuels towards renewable R&D took place in 1993-94 with renewable sources receiving a rapidly growing portion of the overall energy R&D budget. Overall spending on renewable energy was increased by 44% in 1994 [€2M] while total energy R&D spending remained roughly the same. The main thrust of R&D was solar [mainly PV] accounting for over half the total renewable R&D. Biomass received the next largest share of funds [22%] with the remainder spent on small hydro, geothermal, wind and ocean energy.

1.2.13 Spain

The relative lack of indigenous energy reserves has shaped Spain's energy policy, which has security of low cost energy supply from a diverse range of domestic resources as its key objective. The country is completing its latest National Energy Plan [PEN], which runs from 1991-2000.

A number of national plans and sub-plans for renewable energy have been drawn up during the last decade. Promotion of renewable energy in Spain has been supported by the Spanish government under the PEN, through two Renewable Energy plans [PER 86-88 and PER 89-90] and currently under the Renewable Energy Programme, which is one of four sub-plans under the PAEE, itself included in the National Energy Plan. The government's strategy to promote increased use of renewables rests on two main approaches: favourable buy-back rates for electricity produced from facilities under 100 MWe; and financial support via capital subsidies and loans for third party financing under the PAEE plan.

Responsibility for the promotion of renewable energy lies with the Institute for Energy Diversification and Conservation [IDAE], a state 'mid-autonomous' organisation under the supervision of the Ministry for Industry and Energy. Renewable energy is also promoted at the regional and local levels, e.g. the Andalusian government launched a 3 year programme for solar heating systems with a budget of €7.5M. IDAE has also launched renewable programmes with the regions of Canarias, Aragon, Valencia and Murcia.

The emphasis of the renewables programme of the PAEE is on new electricity generating technologies, which reduce dependence on fossil fuels, although use of renewable-based heat is also included. Biofuels for transport are excluded from the plan. The overall objective of the PAEE is to increase renewable energy production to 1.1 Mtoe/year by 2000, increasing renewable electricity production to 4.2 TWh/y and thermal energy to 0.5 Mtoe, comprising 85% increase from biomass, 9% from small hydro.

The government estimates that the renewables section of the PAEE programme, including projects currently under construction, place Spain almost 60% of the way towards its 2000 target for total electricity generated from renewables, see Table 9.

Table 9. Renewable Electricity Targets

		PAEE Target	Completed [end 1996]	% target met
Small Hydro	Capacity [MW]	779	408	52.4
	Generation [GWh/y]	2474	1469	59.4
MSW	Capacity [MW]	239	67	28.2
	Generation [GWh/y]	1298	502	38.7
Wind	Capacity [MW]	168	205	122
	Generation [GWh/y]	403	502	125
Solar PV	Capacity [MW]	2.5	3.8	152
	Generation [GWh/y]	4.5	6.4	142
Total	Capacity [MW]	1188	684	57.5
	Generation [GWh/y]	4179	2479	59.3

Until 1995, IDAE concentrated its efforts on small hydro, but has since 1996 been investing more heavily in wind energy because the purchase price of electricity makes these projects more attractive. The IDAE can finance up to 100% of the eligible cost [directly linked to the cost of energy-producing equipment, but also including "energy audits"] of a project, and is developing financing through joint ventures. State and regional subsidies finance less economically attractive projects. Every year a Decree sets the share of eligible costs that can be subsidised [see Table 10]. This amount varies by project type as well as varying over time: for example, capital subsidies for wind systems are now only available in certain regions, while those for biomass, projects have been strengthened.

There is an obligation for utilities to buy excess electricity from producers at a price set by the Administration. A December 1994 Decree on electricity produced by generators from hydro, co-generation and renewables, overturned a previous decree that pegged buy-back rates to the cost of small hydro generation. The new decree only applies to plants with a capacity lower than 100 MWe and sets rates for both capacity and output credits [buy-back rates]. Capacity credits are highest for waste incineration plants, whereas output credits are highest for wind and solar plants: €0.07/kWh over a five-year period. Output credits for waste-generated electricity vary, depending on the size of the plant and the relative importance of any co-fired fossil fuel, but are lower than those for wind and solar electricity, and decrease yearly. Buyback rates for such plants vary from €0.0575-0.0612/kWh in the first year - still significantly higher than the estimated average production cost from producers of €0.05/kWh. The buyback rate levels are also dependent on continuity of supply to avoid periodic surges in power sold to the grid.

Table 10. Maximum subsidies for renewable energy systems under the PAEE

		Subsidy [maximum percentage of eligible cost]	
	1997-1999*	1996	1995
Biomass and wastes	- up to 30% for fuel production** and electricity	- up to 30% for projects substituting fossil or electricity use with the	- up to 20%

	generation	use of wastes	
[Only available for plants firing up to 10% of "conventional" fuel].	- up to 25%** for use of municipal solid waste- up to 20%** for biogas	- up to 15% for electricity generating projects - up to 15% for other projects [e.g. biogas]	- up to 15%

* Only certain regions of Spain are eligible for grants from 1997.
** Small and medium businesses ["PYMES"] can obtain subsidies up to 10 percentage points higher.

1.2.14 Sweden

The Parliamentary decision on energy policy in June 1997 Toward a Sustainable Energy Supply included a strategy for reducing the energy sector's impact on climate. The strategy is based on the view that successful international co-operation requires an equitable distribution of commitments and mitigation costs, and that national circumstances [e.g. mitigation measures already undertaken] should be taken into account when determining environmental commitments. Under the EU's burden sharing agreement, the EU's emission reduction commitment agreed to in Kyoto translates into a 4% increase in greenhouse gas emissions in Sweden for 2008-2012 compared to 1990 levels.

In January 1998, the Swedish National Energy Administration was set up. This body has the main responsibility for running the newly introduced energy programmes described below. A seven-year programme aiming at an ecologically sustainable energy system was initiated in January 1998. Total programme funds of €600M are available over the seven-year period, including €314M on energy research in Sweden. This reverses the previous downward trend in government R&D expenditure. An additional €185MK is dedicated to the support of commercial electricity production from renewables.

Another government programme set up to encourage increased use of renewables has been running since July 1997. This programme supports renewable energy investments in order to encourage increased production of renewable electricity, particularly from biomass and wind. Grants available since July 1997 are:

- 25% for investments in CHP plants based on biomass [up to €345/kWe], with a 5-year budget of €50M,
- 15% for wind turbines over 200 kWe, with a 5-year budget of €34M,
- 15% for environmentally friendly, small-scale [<1.5 MWe] hydro plants, with a 5-year budget of €17M.

In addition to the 1997 investment support programme, the government set up a 5-year technology procurement programme for renewable electricity production from January 1998. Total funds for the procurement programme are €11.5M.

Holders of so-called supply concessions [i.e. electricity utilities] are obliged by the Electric Law to buy power from small power producers [< 1500 kWe]. The price for this electricity should be "fair", and this is defined as being the average sales revenues of the distributor, with deduction for reasonable costs of administration and a profit margin. In addition, small generators will obtain discounts on the network tariff and are exempt from the NOx levy, which only applies to plants with a production of over 25 GWh/year. The Government has provided for favourable buy-back rates for renewable-generated electricity from small producers further augmented by an "environmental bonus" [equal to the excise tax on electricity] paid for by the Government, when generation is by wind power. The exact amount of this tax varies within Sweden. "Green power" is also an available option for some consumers, e.g. wind power from Vattenfall.

Table 11. Energy and Environmental Tax rates from 1 January 1998 [SEK/unit]

	Residential/commercial rate	Industrial rate
Gas-oil [per m^3]	207	61
Heavy fuel oil [per m^3]	219	73
Coal [per ton]	159	70
LPG [per ton]	144	41
Natural gas [per 1000 m^3]	119	46
Petrol, leaded & unleaded [per litre]	0.51	-
Diesel [per litre]	0.31	-

Biofuels are not subject to energy taxes, i.e. they are exempt from the energy tax, CO_2 tax and sulphur tax. Because of this exemption, a number of coal-fired CHP and district heating plants have changed to firing solid biomass. Since 1993, industrial users pay no energy tax and the carbon tax is applied at the lower rate of the rate applicable to other sectors. Although fuel used in electricity production is exempt from tax, the carbon and energy taxes have helped to change the economics of new power generation options, making coal-fired district heating plants more expensive than any other option.

The main purpose of the R&D programme is to reduce renewable energy's costs to make them a more economically viable alternative to fossil fuels. Short and medium-term measures are directed primarily towards an increased use of biomass, but also wind, hydro and heat storage. Longer-term priorities include fuel cells and solar heating, and focus on sustainable exploitation of renewable energy sources and increased efficiencies in the conversion technologies for heat and electricity production. These include many biomass-related projects, including one aiming to develop a new production process for ethanol based on cellulosic raw materials. Wind energy research was allocated 8 M SEK in FY 1995 by the Wind Power Consortium [VKK], created in 1994. An R&D programme on thin-layer PV cells is also supported with €1.7M for a 3-year period.

1.2.15 United Kingdom

The UK Government is seeking to increase the use of renewable energy resources by giving them the opportunity to compete equitably in a self-sustaining market. Measures in the following five complementary areas are in place to achieve renewable goals:

- Stimulating market conditions for renewable electricity production via the Non-Fossil Fuel Obligation NFFO [now expired];
- Continuing R&D in promising areas;

- Ensuring an adequate flow of information on renewable energy;
- Removing market barriers that inhibit the uptake of renewable energy; and
- Encouraging internationally competitive industries to develop.

The UK Department of Trade and Industry is responsible for administering policies and programmes to promote renewables. Local government planning authorities and the Environment Agency are responsible for some regulatory aspects of renewables. The development of renewables is also affected by environmental legislation and regulations, planning legislation and regulations and agricultural policy and support initiatives. Other areas of policy having indirect effects are usually related to the above three in some way [e.g. the application of the UK building regulations] or are not thought to influence developments greatly.

The promotion of renewable energy in the UK has as one of its aims reduction in emissions of pollutants, including gases that may contribute to climate change. The UK Government has calculated that by 2000, renewables could contribute up to 2 million tonnes of carbon savings annually [7.3 mt CO_2], 100,000 tonnes of SOx, and 30,000 tonnes of NOx.

NFFO operated through the Electricity Act [1989], which empowered the Secretary of State to make orders requiring the public electricity suppliers to secure specified amounts of renewable energy generation capacity from specified renewable energy sources. The public electricity suppliers meet these obligations by contracting with renewable energy generators at prices that provide a guaranteed market. Renewable energy suppliers bid in a competitive process to supply electricity at the lowest bid price. The regional electricity companies [RECs], who are responsible for distributing electricity to consumers, are required to ensure the distribution of a certain amount of renewable generated electricity. The RECs collaborate collectively through a Non-Fossil Purchasing Agency to meet these obligations, and sign contracts with renewables-based generators for their electricity. The integral role played by the RECs in the NFFO contractual process has helped focus their attention on renewable energy, in some cases to the extent that the RECs have become active in supporting renewable energy bids in particular areas [wind] under NFFO.

The NFFO originated in 1989 as a mechanism for protecting nuclear power during the privatisation of the electricity supply industry. The measure was extended to include renewables in 1990. Since 1990, there have been four renewable Orders under the NFFO [referred to as NFFO-1, 2, 3and 4 respectively] in England and Wales, two Scottish Renewables Orders [SRO] and two Orders in Northern Ireland [NI-NFFO].

NFFO orders are financed through the "Fossil Fuel Levy" on electricity bills, which originally ran to December 1998 for NFFO-1 and NFFO-2. Following agreement from the European Commission, the levy for renewables has been separated from that of nuclear power and for NFFO-3, 4 and 5 is not constrained by the 1998 deadline. The contractual timescale for NFFO now runs for 15 years within a 20-year time span, a period related in part to plant lifetime. NFFO support for 1997/98 was around 120M GBP.

NFFOs 1, 2, 3 and 4, together with the Orders in Scotland and Northern Ireland, have brought 506 MWe of new renewable energy generating capacity on stream [as at December 1997]. The capacity of bids approved under the NFFO orders to date is significantly higher than that actually constructed [Table 12] due to delays in construction or failure to obtain planning permission.

The price paid for electricity from the different renewables has again declined [as illustrated in the above table] between NFFO-3 in 1994 and NFFO-4 in 1997. The NFFO-3 prices were also lower than the "strike prices" paid under NFFO-2. This increased renewables capacity and generation may help the government achieve some of its aims regarding energy security and diversity, and contributes to lowering energy-related greenhouse gas emissions.

Table 12. Renewable Orders in the United Kingdom

	Number of projects	Approved capacity [MW]	Installed capacity [end 1997, MW]
NFFO-1 [1990]	75	152	144.5
NFFO-2 [1992]	122	472	181.5
NFFO-3 [1994]	141	627	138.1
NFFO-4 [1997]	195	843	0.7
SRO-1 [1994]	30	77	1.6
SRO-2 [1997]	26	114	27.1
NI-NFFO-1 [1994]	20	16	14.6
NI-NFFO-2 [1996]	10	16	0.1

Government R&D expenditure for FY 1996/97 declined by around 20% compared with 1995/96 to 14.7 M GBP. From late 1994 onwards the UK R&D programme has seen the creation of a task force to assist the transfer of UK new and renewable energy expertise to overseas markets, and now employs two dedicated Renewable Energy Trade Promoters.

Short-rotation coppicing and other aspects of biomass exploitation are believed to be a promising area, and over six years from FY 1990/91 to 1996/97, this R&D budget has increased from about €0.6 M to €1.7 M per year. Activities within the UK's biomass R&D programme area come under three main headings including: agricultural and forestry residues; crops; and advanced conversion technologies. The intentions behind the programme area's activities are to drive down fuel production and utilisation costs, increase the efficiency of fuel production and use, and provide support to domestic industry to diversify into the biomass to energy market. Coppice crops are eligible for financial support under the Set-Aside and Forestry Authority Woodland Grants Scheme. The level of grant available depends on whether the land is designated as eligible for set-aside payments. For set aside land €250 /ha/yr [up to a maximum of 1250 ha/yr] is available and €375/ha/yr [up to a maximum of 1000 ha/yr] is available for non-set aside land.

The UK Environmental Protection Act [1990] set the framework for an improvement in landfill standards by instituting a system of landfill regulation and licensing to be administered locally and leading to greater scrutiny and control of all land filling operations. A levy on landfill was introduced in 1996. Even after the imposition of such a levy, landfill will remain the least cost option for many areas in UK, currently £11/t. This has now be superseded by Integrated Pollution and Prevention Control [IPPC], which means that all pyrolysis technologies for the production of a liquid fuel are required to obtain authorisation for the process.

The replacement to NFFO is a renewables order obligation on the RECs to allow customers to opt for non fossil fuel derived electricity. This mechanism will force the RECs to contract "green" electricity, but at the pool price + €0.3/kWh, thereby giving a limited stimulus for renewables. There is an ongoing debate to attempt to improve the incentives for biomass thermal conversion. The recent launch of the "Green Challenge" is hoped to improve the uptake of liquid fuels. The latest legislation to support renewables is the Renewables Obligation order [2001] which pays an inflation linked price of €44/MWh on top of the base price for renewables, however no distinction is made between technologies, therefore all receive the same income.

Table 13. Incentives for biomass pyrolysis in the EU

Country	Scheme/legislation	Price offered for renewable electricity	Comments
Austria		€0.03/kWh to €0.07/kWh	
Belgium Flanders region	Investment grants [15%] Demonstration projects [35%] Tax allowances [14% of renewable investment offset against profits]	€0.03/kWh produced	No uptake for pyrolysis yet.
Belgium Walloon region	Subsidies [50% of eligible cost, 80% for SMEs] Various R&D subsidies [up to 80%] Tax allowances [13.5% of renewable investment offset against profits]		
Denmark	CO_2 tax; Buy-back price Subsidy [50% for biomass CHP - ended in 2000] High landfill tax	€0.01-0.04/kWh basic subsidy Depends on renewable energy	
Finland	Subsidy [30% maximum of eligible cost] Tax refund ≡ electricity tax		Little stimulus for biomass projects
France	Wood Energy Plan [1.5-8 MWe projects only] Energy Tax [due 2001]		Renewables will be tax-free
Germany	Renewable Energy Sources Act, 25 February 2000.	< 500 kWe: € 0.10/kWh 501-5000 kWe: € 0.09/kWh > 5000 kWe: € 0.085/kWh	Expected to be a major stimulus for biomass
	TASI Regulation [ban landfilling of material with > 5% TOC after 2005]		Incentive to dispose of carbonaceous material by other means
	Low interest loans		
Greece	Subsidies [45-55%] New pricing policy for isolated grids	10 year contract	
Ireland	Alternative Energy Requirement [AER]	[6.1-6.4p/kWh during weekdays, and	AER IV now gives projects a

	Programme	€0.03p/kWh for AER I €0.046/kWh for AER II [biomass/wastes] €0.05/kWh for AER III	grant of €83,000/MW installed
Italy	Law 10 [now lapsed]	Increased price of € 0.1/kWh for electricity from biomass	Limited stimulus for biomass pyrolysis, although gave highest electricity prices.
Luxembourg	Capital subsidy [25% capped at €38,000]	500 kW averages €0.074/kWh; 501-1500 kW, €0.06 /kWh for day supplies; €0.03/kWh for night supplies	Also possible annual premium of €113/kWe peak power delivered during peak load
Netherlands	Tax exemption from Regulatory Energy Tax, 1996 Tax relief on profits of 40-52% for renewable energy/energy conservation technology Reduced VAT [from 17.5% to 6%]		No direct payment to electricity producer
Portugal	Capital subsidies	€0.3M €0.8M for CHP systems	
	Regulated prices for renewables	€0.05/kWh in 1996	
Spain	Buyback rates	€0.0575-0.0612/kWh	
	Subsidies [in certain areas]	30% for electricity production	
Sweden	15% investment grant		
	Tax on NOx emissions		
UK	Non Fossil Fuel Obligation [NFFO] [now lapsed]	NFFO-3: € 0.14/kWh NFFO-4: € 0.095/kWh	Premium price for electricity from biomass fast pyrolysis
	Renewables Obligation Order	Offers £0.03/kWh on base price, inflation linked	Follow-up to NFFO
	Landfill tax	€20/t in 2003, increasing by €1.5/t/y until 2005	Stimulus to avoid landfilling carbonaceous materials

1.3 Obtain details on planned scale-ups and commercial ventures in the EU from technology providers and developers, licensees and other agents

There has been a significant drop in new ventures in fast pyrolysis as Dynamotive have withdrawn from the UK market and unfortunately several projects have been put on hold. Fortum Oy are presently operating a 500 kg/h unit and BTG are in detailed assessment of a 2 t/h rotating cone reactor. Fortum Oy are producing fuel, known as Forestera™ for the domestic heating oil market and within the next few years would be looking to scale up to 5 t/h. 8 t have been burnt in a boiler in Finland. The Wellman Process Engineering Ltd., UK 250 kg/h pilot plant has not finished commissioning, due to the excessive costs of authorisation under IPPC.

1.4 Review end user technology for power generation [engines, turbines and boilers] and summarise who is co-operating with the technology providers

1.4.1 Boiler/flame tunnel test work

Boiler work has been carried out predominantly in the EU by Fortum Oy and VTT/Oilon and Birka Energi (48), as noted in Table 14. Other work has been performed by the University of Rostock on flame tunnel combustion [300kWth coupled with Low NOx burner] (49). Fortum Oy view the market as being in domestic heating fuel up to capacities of 500 kWth.

Extensive work has been carried out in Canada, but limited results are available (50). The only good degree of interfacing between liquids producers and end users is the ongoing work of Fortum Oy and VTT/Oilon in Finland for the development of a technology and domestic boiler system. Emissions data have been reported [see Table 22]. Fortum and VTT are therefore co-operating with the end users as the technology developers.

1.4.2 Engines

Limited engine test work has been done in the EU, with only Ormrod Diesels having any significant experience on pyrolysis liquids from several sources since 1993 using a 250 kWe modified dual fuel diesel engine (55). Details of engine test work are given in Table 14. Ormrod have tested liquids from Union Fenosa, BTG, Dynamotive and VTT.

Other test work has been at laboratory scale, e.g. University of Rostock on raw liquids and also in conjunction with Allbau GmbH using 5% methanol [80 kWe engine]; VTT carried out early test work on a 55kWe Valmet engine with limited success, due to nozzle erosion by particulates in the liquids (51). At present there is almost no engine development ongoing, primarily due to a lack of high quality liquids.

1.4.3 Turbines

There has been very little turbine development work in the EU. Dynamotive/Border Biofuels had planned to build a 1 MWe demonstration plant in the UK, with a turbine to provide the power generation, however, this project has now been shelved indefinitely. The University of Rostock has tested pyrolysis liquids in a small commercial gas turbine type T 216 (Klöckner-Humboldt-Deutz AG, Germany) with a rated electric power output of 75 kW. Pre-treatment of the liquids was required to remove all solids. The gas turbine combustion behaviour was examined in numerous tests during 1999 and 2000. The emissions were measured for both bio-oil and diesel fuel operation. When compared to diesel fuel, characteristically, the emissions of CO and NOx were higher for bio-oil at part load operation [0.56 g/kWh CO compared to 0.13 g/kWh for diesel fuel and 0.37 g/kWh NOx compared to 0.18 g/kWh for diesel].

Other limited test work on a laboratory combustor has also been carried out using a blend of pyrolysis liquids and ethanol (52). Dynamotive have recently announced plans to use an Orenda gas turbine in projects located in Canada up to 2.5 MWe (53).

1.5 Assess the degree of interfacing between power generators and technology providers

At present, there is limited interfacing between power generators and the technology providers.

The key technology providers who are supplying oil and their end users are summarised in Table 14 overleaf:

Table 14. Associations between producers and end users

Producer	Quantity	End user/ developer/partner	Purpose	Comments	Ref.
BTG, the Netherlands	1 t	EU supported research	100 kWth flame tunnel	Operational on pre-filtered liquids	54
	1 t	Universität Rostock, Germany	Turbine combustor	Laboratory scale	49,
	6 t	Ormrod Diesels, UK	250 kWe dual fuel diesel engine]	Operating at 50% capacity	55
DynaMotive Europe Ltd.		100 kWth combustor	Production of calcium enriched bio-oil for SO_x and NO_x reduction	Limited development - now mothballed	56
		Orenda Aerospace, Canada	2.5 MWe Mashproekt gas turbine	No results available	
		Border Biofuels	1 MWe demonstration	On hold	57
		Ormrod Diesels, UK	250 kWe dual fuel diesel engine]	No results available	
		Fortum Oy, Finland	Boiler trials	Emissions data for notable gases	58
Ensyn Tech. Inc., USA		VTT Energy	55kWe dual fuel diesel engine trials	Injector erosion due to particulates in liquids	59
		Wartsila Diesels Oy, Finland	1.4 MWe dual fuel diesel engine	Limited operation – no data available	
		ENEL, Italy	0.5 MWth test furnace		60
		Fortum Oy, Finland	0.2 MWth LFO boiler 2.5 MWth LFO boiler		61 62
		Orenda Aerospace, Canada	2.5 MWe Mashproekt gas turbine	Limited trials for 6 hours	63
	1 t	Veba Oel, Germany	Catalytic hydrotreating for transport fuel		64
		Oilon Oy, Finland	4 MWth boiler, > 350 kWth Boiler testing	Data available	
	40 t	Birka Energi [formerly Stockholm Energi Ab], Sweden	9 MWth boiler trials	No results available	48 65
		CANMET	Bio-emulsions development	Laboratory scale	66

Union Fenosa, Spain	3-5 t	Ormrod Diesels, UK	250 kWe dual fuel diesel engine	Operating at 50% capacity and on solvent/pyrolysis liquid blends	67
		Fochi S.E.T., Italy	Hydrotreating pilot plant	Not completed	
		Neste Oy, Finland [now Fortum Oy]	0.2 MWth LFO boiler 2.5 MWth LFO boiler		58, 61
	1 t	VTT Energy, Finland	55 kWe dual fuel diesel engine		51
	1 t	VEBA OEL AG	Thermal hydrotreating for transport fuel	Pilot plant	64
		Wärtsila Diesel International Ltd. Oy, Finland	1.4 MWe dual fuel diesel engine	Limited testing due to lack of liquids	
Wellman, UK	30 t	Ormrod Diesels, UK	250 kWe dual fuel diesel engine	Liquids not yet supplied	68
Other - Small					
CRES, Greece	< 0.05	ZSW, Germany	Stirling engine testing [6 kWe net]	Bench scale	69
		CPERI, Greece	Catalytic upgrading [0.1 kg/h]	Bench scale	
ENEL, Italy		Instituto Motori, Italy	Dual fuel diesel engine testing	Small-scale 30 kWe	
Ensyn Tech. Inc., USA		Universitá di Pisa	Catalytic upgrading to transport fuel	Laboratory scale	70
Union Fenosa Spain	< 0.1	Universidad Politécnica de Madrid	Turbine combustor [100 kg/h pyrolysis liquids]	Some operations 80:20 pyrolysis liquids & ethanol	52
BTG, Netherlands	< 0.1	Universitá di Firenze, Italy	Emulsions for engine trials 5kWe	Laboratory scale	71

It can be seen that the link between a technology provider and an end user, i.e. a power generator or developer of a power generation system is very limited and often with poor results. Problems have arisen primarily due to inconsistent liquids quality and in some cases; the liquids were not "pure" raw pyrolysis liquids, but blends of recovered fractions. The blending of fractions does not give a liquid with the same properties as raw pyrolysis liquids and this has led to various problems.

The majority of efforts have been on pyrolysis liquids produced by Union Fenosa and Ensyn, as these have been the only companies producing significant [tonne] quantities for supply. Dynamotive have recently entered the market and hope to exploit the present poor producer-end user interface. There is improving co-operation in this area, with Ensyn claiming that they can supply a guaranteed turbine or engine to run on biomass-derived pyrolysis liquids. To date, there are no ongoing commercial developments using pyrolysis liquids for power generation, due to slow technological developments and no demonstration plants.

It is expected that increasing the availability of liquids in significant quantities will lead to more engine and turbine manufacturers offering to test liquids for combustion applications. The first expected commercial development for a liquids producer and a power generation system was the NFFO-4 contract of Dynamotive UK/Border Biofuels, operated in the UK, however, Dynamotive have withdrawn from the UK market and the project has been delayed indefinitely.

The entry of Fortum Oy into the market with a 500 kg/h pyrolysis plant is a significant endorsement of fast pyrolysis. Fortum Oy plan to scale up their technology to 5 t/h by mid 2004, primarily for boiler applications. Vapo Oy is also involved in the initial development of the 500 kg/h unit. Fortum have started testing the liquids in boilers and at present is the only significant activity in the development of a technology provider and end user in Europe.

The link up within Finnish industry to establish a market for small-scale boilers is a significant development and should lead to a development phase for the technology with reducing costs. This should lead to more rapid engine and turbine developments as liquid quality improves. Over 8t of liquids have recently been tested in boilers in Finland [June 2003].

TASK 2 DERIVE NORMS AND STANDARDS FOR BIOMASS FAST PYROLYSIS LIQUIDS.

Before commercial, standards for pyrolysis liquid have to be established. This work includes:

- Collecting feedback from liquid producers and end-users on fuel oil quality of pyrolysis liquids
- Defining fuel oil quality and fuel oil specifications for pyrolysis liquids
- Defining norms and standards for sampling and test methods
- Standardisation of pyrolysis liquid as a fuel

2.1 End-users requirements

Pyrolysis technologies are slowly emerging from pilot to demonstration scale to provide bio-oil for heat and power applications. One of the challenges facing the industry is that pyrolysis liquids will have to compete with conventional fuel oils, which are well established and known to the end-user (utility, local grid, on-site use for heat and power, etc.). Some of the main problems in the large-scale application of pyrolysis liquids have been:

- Irregular supply
- Lack of handling and pumping instructions
- Variable moisture content (and heating value)
- High solids (and method for accurate determination of its components)
- Chemical instability (inherent in all liquids)
- Inconsistent physical properties
- Material corrosion
- Lack of quality specifications. Poor fuel quality (relative to conventional fuel oils)
- Lack of co-ordination between producers and end-users/developers

Moses and Bernstein have provided an in-depth summary of the potential impact of using pyrolysis liquids in gas turbine systems for power generation (72). They emphasised that developing fuel specification for pyrolysis liquids is necessary to assure fuel quality and price so that engine development costs can be minimised and satisfactory performance and durability guaranteed. The major performance and durability parameters in gas turbine application are: ignition, lean stability or turndown ratio, combustion efficiency, liner temperatures, exhaust particulates, exhaust CO, NOx, and hydrocarbons, corrosion, erosion, and deposition, thermal stability, and materials compatibility. Of greatest concern are:

- Effects of physical properties of biomass pyrolysis liquids on atomisation, combustion efficiency, and gaseous emissions.
- Effects of physical and chemical properties of pyrolysis liquids on soot formation and hence on flame radiation, liner temperature, and particulate emissions.
- Effects of chemical composition of biomass liquids on the composition of the exhaust organics/hydrocarbons.
- Effects of high alkali content in the presence of chlorine and/or low sulphur in biomass fuels on corrosion of turbine blades.
- Fuel thermal stability and the ability to heat the fuel to reduce the viscosity and improve atomisation.
- Compatibility with metals and non-metallic elastomers and seal used in fuel systems because of the acidic nature and the unusual organic compounds in pyrolysis liquids.

The end-users for pyrolysis liquids need to know certain properties of the liquids and their behaviour in boilers, engines, and turbines. A summary of the prioritised properties defined by the industry (73, 74, 75) is shown in Table 15. Stability, homogeneity, water, solids, and ignition are the most important properties. Stability is necessary for proper adjustment of pumps, nozzles, burners and other equipment. Slight phase-separation may results in poor combustion. High [above 30 wt%] water content yields high particulate emissions (76). These emissions can be decreased to certain extent by using a support fuel and optimising the atomisation viscosity. High solids content in pyrolysis liquid is detrimental for the equipment, especially for injectors and turbine blades, also results in high particulate emissions. The limit for flash point is defined according to legislation for transportation and storage.

Table 15. Critical properties of pyrolysis liquids defined by industry, April 2003.

Property	**Boiler Fortum Oy**	**Gas turbine Orenda**	**Diesel Engine Wärtsilä**	**Diesel Engine Ormrod**
Homogeneity	Single phase 6 months			
Stability	Single phase 6 months			
Water, wt%	Max. 27	15-25	Max. 26	
Solids, wt%	Max. 0.05	Max. 0.25	0	
Flash point, °C	Min. 40	Min. 55		
LHV, MJ/kg			Min 16	
Viscosity @40°C, cSt				12-17

During 2003 Orenda [Orenda Aerospace Corporation, Canada] will carry out long-duration turbine tests with three various pyrolysis liquids from large producers. Orenda (74) has set up preliminary specifications, through which they evaluate the suitability of pyrolysis liquid for the gas turbine. Fortum has initiated field tests with their product Forestera™ in 200 kW_{th} LFO-boilers. The preliminary results are promising (77). The goal is to combust 10-20 m^3 of Forestera™, perform hundreds of cycles to test critical components, and determine the required fuel quality. To date 8t of Forestera™ have been burnt in 1500 cycles. Further details on this work are given in Appendix II.

2.2 Fuel oil specifications

An important issue in commercialisation of fast pyrolysis for the production of heat and power is the need for pyrolysis liquid specifications. ASTM and similar organisations in respective countries have established the specifications for standard fuel oils. They define property ranges for different classes of fuels marketed for different applications. Standards are required also for fast pyrolysis liquids to assist in their uptake into fuel infrastructure. At present, there are no nationally or internationally recognised standards of fuel specifications for biomass-derived fast pyrolysis liquids. Progress is being made in this area, but due to the lack of consistent quality pyrolysis liquids, coupled with ongoing developments in the methods for fast pyrolysis liquid analysis, standards are not expected for some time yet.

Elliott has assessed the specification standards for various pyrolysis liquids in IEA BLTF (Biomass Liquefaction Test Facility) project (78). The classification was based on ASTM standards D-396 for fuel oils, D-975 for diesel fuels, and D-2880 for gas turbine fuels. The IEA PYRA group suggested (79) specifications shown in Table 16. These specifications were based on the requirements for conventional fuel oils (ASTM Nos. 2-6). Diebold did not define "limits" for the range of properties quoted - only viscosity and some other properties were specified. Several developments since then allow more specific values to be added to the table. Potential end-users (Fortum/Oilon, Wärtsilä, Ormrod) commented that:

- Specifications should be tighter.
- Water should be lower, because of poor ignition properties and high emissions of high-water content pyrolysis liquids.
- Solids test method should be specified to include also forest residue liquid.
- Viscosity should be determined at two temperatures, 20 and 40°C.
- The meaning of flash point should be clarified. It does not correlate with the ignition properties of pyrolysis liquids.
- Liquids must be of consistent and reliable quality and with long "shelf-life".

Table 16. Proposed specifications for biomass pyrolysis liquids (79)

Property	**Light FPL [~ASTM #2]**	**Light MFPL [~ASTM #4]**	**Medium FPL [~ASTM #5]**	**Heavy FPL [~ASTM #6]**
Viscosity [cSt]	1.9-3.4 FO 1.9-4.1 D 1.9-4.1 GT @ 40ºC	5.5-24 @ 40ºC	17-100 @ 50ºC	100-638 @ 50ºC
Ash [wt%]	0.05 FO 0.01 D 0.01 GT	0.05 FO 0.10 D	0.10 FO	0.01FO
Pour point [ºC]	Report	Report	Report	Report
Conradson Carbon Residue [wt%]	Report	Report	Report	Report
Max 0.1 µm filtered ethanol solids [wt%]	0.01 FO	0.05	0.10	0.25
Accelerated aging at 90ºC [cSt/h]	Report	Report	Report	Report
Water [wt%, wet liquid basis]	32	32	32	32
LHV [MJ/kg min, wet liquids]	18	18	18	Report
C	Report	Report	Report	Report
H	Report	Report	Report	Report
O	Report	Report	Report	Report
S	0.1 max.	0.1 max.	0.2 max.	0.4 max.
N	0.2 max.	0.2 max.	0.3 max.	0.4 max.
K + Na [ppm]	Report 0.5 GT	Report	Report	Report
Phase Stability [at	Single phase	Single phase	Single phase	Single phase

20ºC after 8 h at 90ºC]				
Flash point [ºC]	52	55	60	60
Density [kg/m^3]	Report	Report	Report	Report

Another approach is to specify only the properties, which can be influenced, for example, by choice of feedstock or by product condensation temperature [see Table 17]. These include homogeneity, water and solids contents, stability, and flash point. Decreasing the feedstock moisture or increasing the condensation temperature can decrease the water content of the product. Some properties (density, viscosity and heating value) can be influenced indirectly by changing the water content. By fixing maximum water, the minimum density, viscosity, and heating value will be defined [see Figure 6]. Solids can be decreased down to 10-µm particle size by efficient cyclones and/or hot-vapour filtration. A decrease in solids decreases the ash and alkali metal content of pyrolysis liquids. Some properties are inherent to the pyrolysis liquid itself and are more difficult to influence. These properties include pH and the content of N, O, Cl, and S.

The properties, which are critical for use of pyrolysis liquid, are marked as "specified". These properties have to be met before liquid producer distributes the liquid to end-user. Other important properties for end-users are included to Fuel Data Sheet marked as 'FDS'. An example of a ‘typical’ pyrolysis liquid is included in Table 18. Water content 27 wt% is the maximum allowed water content for a fresh pyrolysis liquid. It allows about 2-3 wt% increase in water during 6 months ageing. From end-users perspective the feedstock of the fuel has no significance, only the fuel quality. In addition, there is not enough data on fuel quality generated from other feedstocks than wood. These are the reasons why the specifications in this report are tailored for wood liquids.

Table 17. Fuel oil specifications for fresh wood-based pyrolysis liquid – boiler use

Property	**Method****	**Premium**
		Boilers < 1 MW*
Homogeneity	Water distribution	Max 3 wt%
Water, wt%	E 203	Max 27
Solids, wt%	MeOH:DCM, 1:2	Max 0.1
Stability, %	80°C/24h, viscosity change	Max 100
Flash point, °C	ASTM D 93	Min 40

* Fuel specified to meet the limits in small boilers but are suitable to boilers of various sizes
** (82, 83)

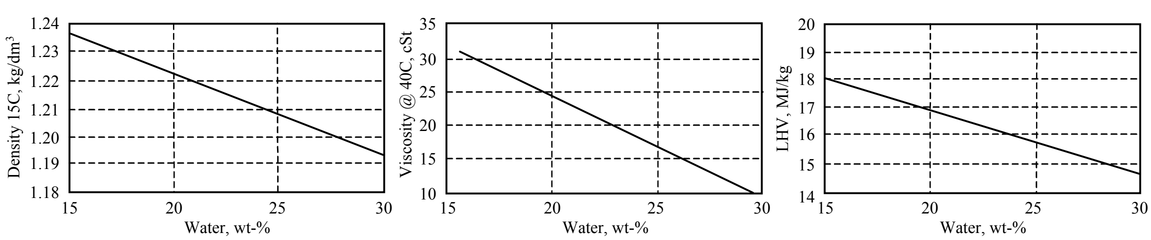


Figure 6. Approximate correlation of water to density, viscosity, and heating value (80).

Table 18. Fuel oil properties of wood pyrolysis liquid containing maximum allowed water content

Property	Method (80, 82)	Pyrolysis liquid Fresh	Pyrolysis liquid 6 months	Specification
Homogeneity	Water distribution	25.4-28.4	27.4-30.4	Specified
Water, wt%	E 203	27	30	Specified
Solids, wt%	Methanol:CH_2Cl_2, 1:2	0.1	0.1	Specified
Stability, %	80°C/24h, viscosity change	Max 100	Max 100	Specified
Flash point, °C	ASTM D 93	Min 40	Min 40	Specified
Ash, wt%	EN 7	0.01	0.01	FDS
Na,K, Mg,Ca, ppm	AAS	20	20	FDS
Viscosity @20°C, cSt	ASTM D 445	100	150	FDS
Viscosity @40°C, cSt	ASTM D 445	30	45	FDS
LHV, MJ/kg	DIN 51900	15.5	15	FDS
LHV, MJ/l	DIN 51900, ASTM D 4052	18.5	18	FDS
Density (15°C), kg/dm^3	ASTM D 4052	1.20	1.20	FDS
N	ASTM D5373	< 0.1	< 0.1	FDS
pH		2.6	2.7	FDS
Pour point, °C	ASTM D 97	19	19	FDS

2.3 Analytical methods

Reliable analytical methods are needed to determine specifications (80, 81, 82).

2.3.1 Homogeneity

Homogeneity of pyrolysis liquid has to be ensured by liquid manufacture before shipping the liquid. A test method based on water distribution is suggested.

2.3.2 Stability

Pyrolysis liquids are chemically and sometimes physically unstable. During storage the properties of liquids change ('ageing'). The viscosity increases, because of an increase in molecular weight due to condensation/polymerisation reactions (83). The viscosity increase can result in larger droplets leading to higher emissions from combustion.

Water is formed in ageing reactions and the original water content increases gradually. This increase in water has only minor impact on viscosity. When water content approaches 30 wt% an aqueous layer starts to separate out from lignin-rich phase.

During storage, for example lignin fragments interact with each other and with other components of pyrolysis liquids (78, 83). Sometimes these high-molecular-weight products form sludge that are hard to remove from storage tanks and that can interfere with pumping etc. For these reasons stability has to be included in the specification.

The stability of pyrolysis liquid can be measured by an accelerated ageing test, for example, the viscosity increase of pyrolysis liquid after 24 hours at 80°C correlates to the viscosity increase in one-year storage at room temperature. In IEA-EU PyNe Round Robin (75) it was reported that more study and clearer instructions to stability tests are needed.

Stability of the liquid can be improved after production by the addition of polar solvent, E.G. methanol, ethanol, acetone.

<u>2.3.3 Water</u>

Water content can be affected mainly by feedstock moisture and liquid condensation efficiency. Density, heating value, and viscosity are a function of water content of pyrolysis liquids. Increase in water decreases the density and viscosity of the liquid, but also lowers its heating value.

At about 30wt% water, equilibrium in pyrolysis liquid shifts resulting in two liquid phases. This phase separation has to be avoided and hence 30wt% can be regarded as the maximum allowed water content of pyrolysis liquid. In ageing reactions the water content can increase 2-3 wt% in 6 months. In order to quarantine 6 months storage stability to customers, the maximum allowed water content for fresh liquid would be 27 wt%. Higher water concentrations also increase the relative stability, but its addition to pyrolysis liquids is not recommended.

<u>2.3.4 Viscosity</u>

Viscosity can be considered as a secondary property that is defined by the water content and type of feedstock. However, it should be reported because the viscosity is what normally differentiates a light fuel oil from a heavy fuel oil. Especially the low temperature viscosity needs to be clearly defined so that fuel delivery systems and minimum fuel temperature during storage can be adjusted. It is suggested to determine viscosity at 20 and 40°C in Fuel Data Sheet. Pre-heating up to about 80°C can reduce viscosity if no liquid recycle is used. Viscosity can also be influenced after production by the addition of solvents, like alcohol. However, because the addition of alcohol decreases the flash point the amount of added solvent should be low [preferably below 5 wt%].

<u>2.3.5 Solids</u>

Solids [char] are important due to the combustion system requirements in different applications with respect to clogging of nozzles, valves and filters. Solids can block small capillaries in injection needles or cause erosion in pumps or other equipment. Solids content is influenced by the particle size and particle size distribution of the feedstock. High-molecular-weight polymerisation products can be formed around solids and these cause sludge formation in storage tanks.

The amount of allowed solids depends on application. Large heavy fuel oil [HFO] boilers can tolerate solids up to 1 wt% and they even improve the combustion by raising the heating value and by stabilising the combustion. Small light fuel oil [LFO] boilers cannot tolerate solids content above 0.1 wt%. Solids content below 0.5 wt% can be obtained, and even below 0.1 wt% is technically feasible.

2.3.6 Ash

Most of ash can is removed by improving the solids removal. Typically ash content is about 10 wt% in solids. Alkali metals of the liquid are mainly found in the ash. It is suggested to measure total amount of alkali metals [Na, K, Mg, Ca] and include this to Fuel Data Sheet.

2.3.7 Flash point

Flash point of petroleum oil is measured to indicate the maximum temperature, at which it can be stored and handled without fire hazard. In case of pyrolysis liquids flash point does not correlate to ignition properties of the liquid. However, the flash point has to be specified due to safety regulations. Flash point of pyrolysis liquid can be influenced by liquid condensation system and by alcohol addition.

2.3.8 Heating value, density

Heating value is important for all applications because it defines how much fuel must be delivered to the combustion process to produce heat or power. Density is of little significance as an indication of burning characteristics, but is important in calculating volume-based heating value. Heating value and density correlate to water content similar to the viscosity (Figure 6) and can be adjusted indirectly by reducing the water in feed, increasing the temperature at which vapours are condensed or by adding an alcohol.

2.3.9 Nitrogen

Elemental analyses of pyrolysis liquid are related to the feedstock composition. Nitrogen has an impact to NOx-emissions and should be measured and included to Fuel Data Sheet. There is no literature data on reducing nitrogen content of the feedstock or during pyrolysis.

2.3.10 pH

The pH of pyrolysis liquids ranges typically from 2 to 3. If the pH is raised using additives, such as KOH or NaOH, lignin material starts to sediment close to pH 4. This is an example of the complex solubility behaviour of pyrolysis liquids. Because pH cannot be significantly raised there is no need to include pH in specifications. However, pH is easy to measure and reminds the user about the acidity of the fuel, it is included to Fuel Data Sheet.

2.3.11 Conradson carbon residue

Conradson carbon is important for soot formation during combustion but cannot be controlled. Conradson carbon residue is related to the lignin content of the biomass feedstock. It is lower for straw and grasses having lower amount of lignin, but there is no clear method for affecting it. It is not included on the liquid fuel specifications.

2.3.12 Pour point

Cold properties are important especially in northern countries and hence it should be included on the Fuel Data Sheet. Pour point is affected only by condensation conditions or by additives. High amounts of light solvents lowers the pour point and removal of the original liquids light fraction increases it.

2.4 Standardisation of biomass fast pyrolysis liquids

For introducing pyrolysis liquids into markets, standards and norms are needed. There are no national or internationally recognized standards of fuel specifications for biomass-derived fast pyrolysis liquids. The reasons for the lack of uniform specifications include the lack of large quantities of pyrolysis liquid for long-duration field-tests and variation in fuel oil quality of pyrolysis liquids.

Standardization work under CEN is ongoing for biomass feedstocks [CEN/TC 343/W63]. CEN has approved [CEN www-pages] the proposal made by SIS, Sweden (84) for the initiation of the standardization of alternative fuels, including pyrolysis liquid, but as yet, there is insufficient data to allow a full specification to be made. The aim of this working group is to provide CEN with a proposal on how to proceed with the standardization of alternative fuels. The final report of the BT/WG 149 Alternative Fuels will be given to CEN/BT by mid-2004. The participants in this project will make some contributions to the CEN activity.

2.5 Summary

The work on standards and norms will be continued in PyNe Network. Based on the study in the ALTENER project following objectives are proposed for PyNe:

1. Propose standard methods for characterisation of the most important (for fuel applications) properties of pyrolysis liquids,
2. Collect data for pyrolysis liquid (from large plants) properties that will serve as a base for specifications,
3. Update fuel oil specifications based on field tests, continuation of ALTENER No. 4.1030/C/00-015/2000,
4. Define fuel oil specifications for boilers and engines,
5. Initiate the standardisation of pyrolysis liquid in CEN/BT working group 149 of Alternative fuels.

TASK 3 SECTOR AND MARKET STRATEGIES FOR THE PRODUCTION OF HEAT AND POWER FROM PYROLYSIS.

3.1 Assess market opportunities for biomass fast pyrolysis in the EU in terms of possible market size and location

It is difficult to quantify the actual market size for biomass fast pyrolysis, except in terms of the incentives offered to stimulate uptake of the technology. The other opportunity that can be identified relates to the availability of suitable biomass residues in sufficient quantities to support a large-scale pyrolysis plant. With recent delays in the implementation and development of the technology towards a commercial product, the initial market for pyrolysis liquids is viewed as the LFO market, for domestic and industrial boilers of small-scale [< 10 MWth]

The aim of this part is to establish the nature and the size of the markets both within Europe and within the developing countries for pyrolysis liquids, heat and power through a range of options [turbine, diesel engine and boiler]. Pyrolysis liquids can be used as a fuel for compression ignition engines in dual fuel mode, as a fuel for gas turbines and as a fuel for raising heat in boilers and combustors.

A review of the available data on land use within the EU and the production of crop residues and agricultural wastes in SE Asia and Indo-China was made, giving the potential markets for fast pyrolysis to make an impact. Non-energy uses for the pyrolysis liquids are also a possibility, i.e. charcoal production, speciality chemicals [fertilisers, adhesive, resins etc.].

3.1.1 Biomass Availability in the EU

The most comprehensive data on biomass availability in the EU comes from the IEA Bio-Energy Agreement, which has published an extensive survey of biomass resources in the EU and world-wide. Other data sources have also been used. The FAO is rated to provide a fairly accurate assessment of biomass in the EU-15. Some data on the principal resources is given in Table 19.

Table 19. Principal Biomass resources in the EU (85)

	Current Resource [Mt/y]	Future [Mt/y]
Wood energy	5	75
Wood wastes	50	70
Energy crops	<1	250
Agricultural wastes	250	250
MSW/Refuse	60	75
Industrial wastes	90	100

Additional data focusing on the relatively untouched area of agricultural residues is given in Table 20. There is significant potential for biomass pyrolysis and this would also suggest that the reduction in land use for agricultural purposes could lead to an increase in demand for bio-energy.

Table 20. Yields and potential production of residues from agricultural crops (86)

Crop	Residue	Residues yield (dry tonnes per hectare)	Potential production (M dry tonnes per year)
Wheat (M)	Straw	3.5	34.2
Maize (M)	Cobs, corn stover	9.4	20.7
Rape (M)	Straw	3.0	7.4
Sunflower (M)	Straw, heads	6.0	6.2
Sugar beet (M)	Tops and leaves	4.1	6.3
Sugar beet (S)	Tops and leaves	3.7	1.9
		Total	76.7

M, Middle Europe; S, South Europe.

Typical estimates of the land available for energy crops in the EU-12 are ~22.3 Mha, with Italy, Germany and the UK having the largest land areas suitable [9.98, 5.6 and 2.6 Mha respectively] (87). There is significant potential for biomass fast pyrolysis to use some of these agricultural crops as feedstocks, although little work has been carried out in the EU on such materials. Other crops, which may also be of interest, from the aspect of available residues, are miscanthus and sorghum bagasse.

3.1.2 Biomass Cost

The cost of biomass, assumed to be a wood derived biomass, is highly variable across the EU, ranging from €0-100 /t delivered, or more in some cases. The cost of the biomass is strongly influenced by other markets, e.g. pulp and paper, fibreboard [MDF, OSB] and other fuel applications which do not have a stringent specification on the material.

3.1.3 Fiscal and Legislative Incentives

Since the beginning of this contract, there have been several legislative changes at EU level for the development of renewables, including biomass pyrolysis. The range of fiscal incentives in the EU-15 have been previously reviewed [see Table 8].

3.1.3.1 CO_2 trading

With the implementation of the Kyoto Protocol, setting a reduction in CO_2 emissions, biomass pyrolysis systems offer the possibility for trading of CO_2 credits to other countries and companies. As the net CO_2 emissions for renewable energy fuelled pyrolysis systems are very low [based on life cycle analysis, less than 25 g CO_2/kWh], then this is a niche that needs to be further exploited.

3.1.3.2 Environmental Incentives

Biomass fast pyrolysis offers particular environment advantages over other thermal conversion technologies and can comply with the following environmental legislation and Directives within the EU.

1. Compliance with the EU White paper on renewables to reduce dependence on fossil fuels and improve the supply from renewables, especially for remote and niche applications (88).
2. Contribution towards the EU Green Paper [com (2000) 769, November 2000] to reduce the structural dependence on fossil fuels and increase internal EU consumption of renewable resources, in particular in isolated communities.
3. Utilisation of biomass and wood pallet wastes which may otherwise be landfilled or combusted at lower energy efficiency [EU Waste Directive [article 7.1 of 94/67]].
4. Reduction in CO_2 emissions [1997 Kyoto Protocol, agreed limits Marrakech, 2001].
5. Avoidance of wastewater generation in compliance with the EU Wastewater Directive [91/271/EEC],
6. Compliance with IPPC in terms of lower emissions, improved energy efficiency and more advanced technology [EC Directive 96/61/EC on IPPC].
7. Minimal NOx emissions [in compliance with EC Combustion Directive (89)].
8. Utilising wood wastes [furniture or pallet manufacturing residues] that other wise may be landfilled or burned. This complies with the EC Landfill Directive [1999/31/EC, OJ L18, 16.7.99].

Fast pyrolysis processes are recognised as having little or no wastewater emissions, very low NOx, SOx emissions and can comply with strict EU environmental legislation.

3.2 Assess costs of pyrolysis liquids relevant to other liquid fuels in order to assess possible market niches

There is little commercial data available on the actual production costs of pyrolysis liquids. Most work has been based on studies of conceptual flowsheets and pilot scale plants, which gives disproportionately high costs, although these do give a basis for capital cost estimation techniques to be used to estimate costs for scaled up plants.

3.2.1 Cost of pyrolysis liquids and other fuels – energy basis

As noted, one of the initial markets for pyrolysis liquids may be the domestic heating fuel market. Based on prior work carried out on an EU funded contract, the energy cost of pyrolysis liquids from the Wellman Process Engineering Ltd. and BTG fast pyrolysis processes were averaged and presented in Figure 7 (47).

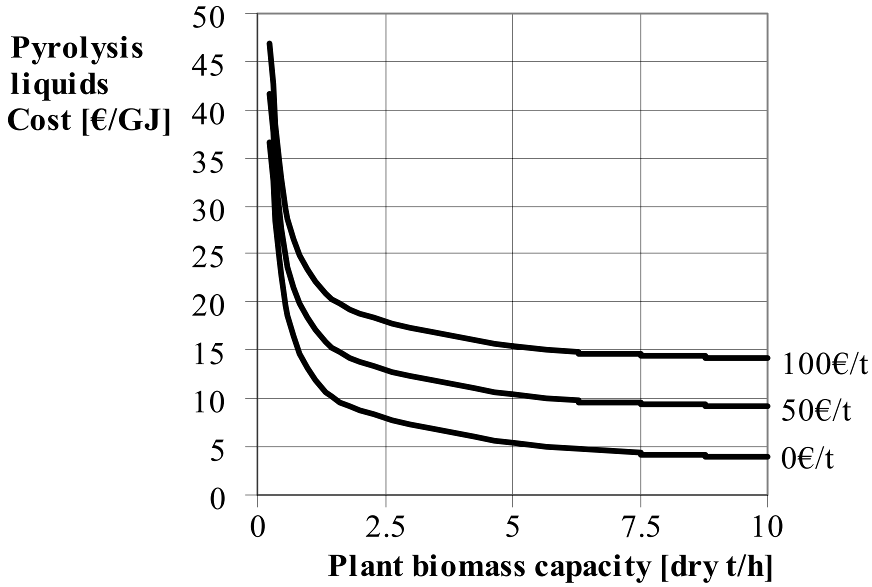


Figure 7. Production costs of pyrolysis liquids v's biomass input v's feedstock cost–energy basis [averaged for two pyrolysis processes]

Details of liquid fuel prices for different fuels in European countries are given in a recent report by EUBIONET, highlighting the significant variation in availability of renewable liquid fuels and costs of production (90). A detailed report on the development of liquid biofuels in the EU has recently been published, although pyrolysis liquids are only mentioned in the Greece activity report (91). There is considerable data on energy statistics available from the IEA (92) and the UK DTI (93). Prices for some renewable and non-renewable liquid fuels are given in Table 21.

Table 21. Comparison of fuel prices for renewable and non-renewable liquid fuels

Fuel	LHV MJ/kg	Density kg/m^3	LHV GJ/m^3	Cost €/GJ [Low]	Cost €/GJ [High]
Pyrolysis liquids	16	1.21	13.2	4.0	43.8
Rape Methyl Ester	37.2	0.85	43.8	5.5	28.5
Biodiesel [from waste vegetable oils]	37.2	0.88	42.3	0.9	16.1
Bio-ethanol	27.2	0.79	34.3	20.8	22.0
Methanol	19.9	0.80	25.1	7.5	12.5
No. 2 Fuel oil	41.1	0.93	44.2	2.4	3.0
No. 4 Fuel oil	40.8	0.95	42.9	3.7	4.4
Diesel - conventional	42.9	0.84	51.1	20.8	NK
Petrol	43.2	0.82	53.0	1.8	NK
Beef Tallow	40	0.92	43.5	7.5	10.0

The calculated costs for alternative liquid fuels have been published of 0.13-0.14 €/l for ETBE from wheat, sugarbeet and RME (e.g. 94). Pyrolysis liquids mat therefore have the potential to compete with some fuels, however, it would appear from Figure 8 that there is an opportunity in some countries to compete with the domestic heating fuel market, as taxes and other additional costs vary from country to country. Markets for pyrolysis liquids in where domestic heating oil cost are very high [> 12 €/GJ] include Denmark, Hungary, Italy, the Netherlands, Norway and Sweden – these would appear to be promising opportunities.

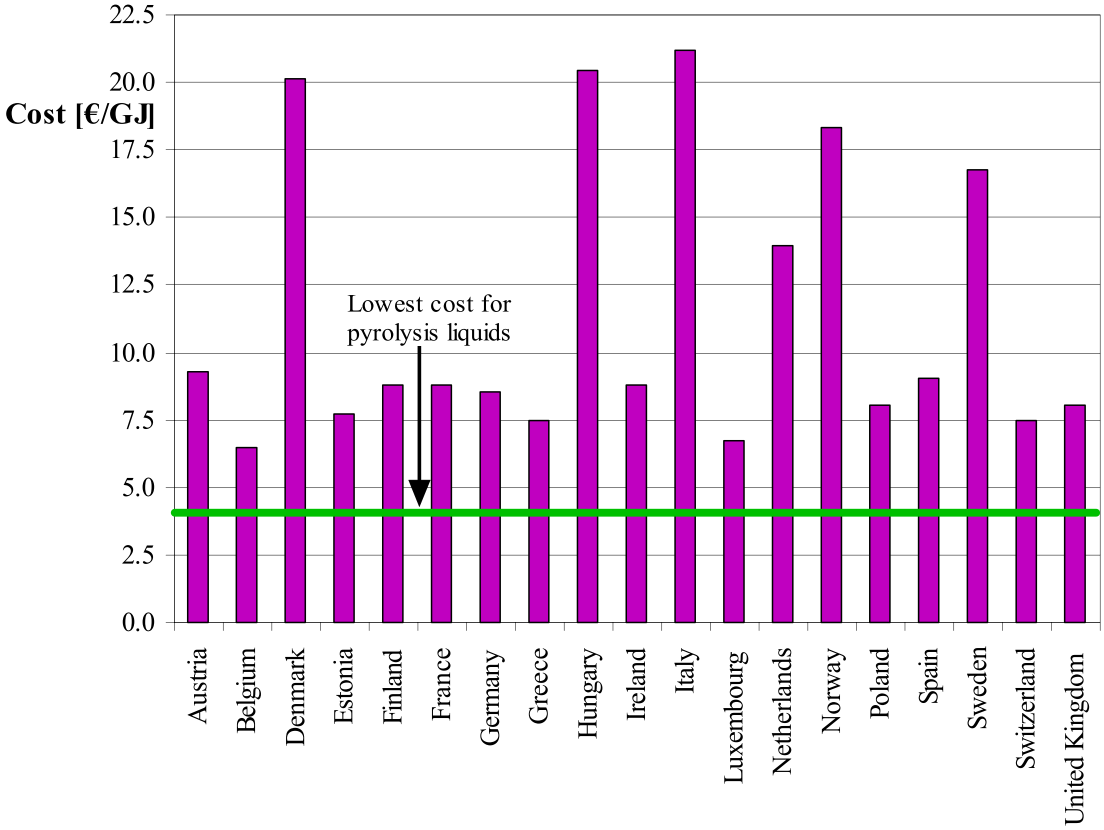


Figure 8. Domestic heating oil costs in selected countries [2002].

<u>3.2.2 Cost of pyrolysis liquids and other fuels – electricity basis</u>

Costs were requested from companies active in fast pyrolysis and asked to provide quotes for commercial systems, either based on direct experience, or projected from pilot plant work. The data was requested from the feeding of biomass to the reactor, pyrolysis, products recovery and storage. The cost is also to include the civils, instrumentation and controls, and installation. Unfortunately, there has been very little data provided from the few active companies in the industry, due primarily to project specific costs and a desire not to provide "generic" plant costs.

Peacocke has recently estimated costs for the Wellman Process Engineering Ltd. and BTG fast pyrolysis processes, which is one of the few current studies in this area (95). Electricity production costs [averaged between the two technologies] were calculated at €¢15/kWh at 2 MWe electrical output [zero feedstock cost] to €¢ 12.5 at 10 MWe output. Some data for zero feedstock cost is given in Figure 9.

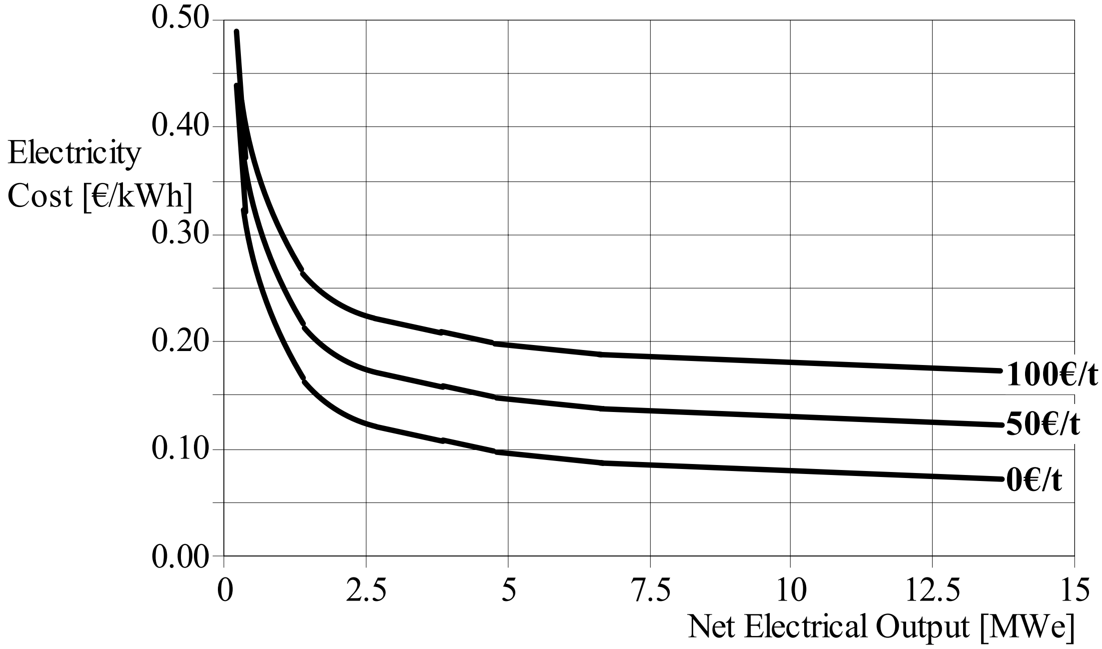


Figure 9. Electricity Productions Cost v's Net Electrical Output [MWe], v's feedstock cost [averaged for BTG and Wellman Process Engineering Ltd. fast pyrolysis systems]

Bridgwater et al. have also applied a similar methodology in their cost estimations for thermal conversion technologies (96). Electricity production costs varied from €¢12/kWh at 2 MWe net electrical output to €¢7.3/kWh at 20 MWe net electrical output. The cost of producing electricity from pyrolysis liquids at this time appear to be high compared to other conventional methods.

The prices for electricity within the EU vary significantly, due to differences in taxation and the end-user [domestic or industrial]. With changes in environmental legislation, carbon taxes on fossil fuels and CO_2 credits for renewables, then there may be a market for electricity produced via pyrolysis. Domestic consumer prices are given in Figure 10 (97).

Industrial prices are given in Figure 11 (98). It can be seen that there is no opportunity for fast pyrolysis to compete in the industrial supply market, as prices are not favourable for pyrolysis. There is the opportunity of direct replacement for domestic consumers in niche locations, where there is not a suitable grid connection and there is a supply of suitable biomass in countries such as Denmark, the Netherlands, Italy and Austria. Out of a total energy consumption of 1453 Mtoe in the EU for year 2000, only 53.3 Mtoe was from biomass (99). There is potential to significantly increase the contribution from renewables such as biomass fast pyrolysis.

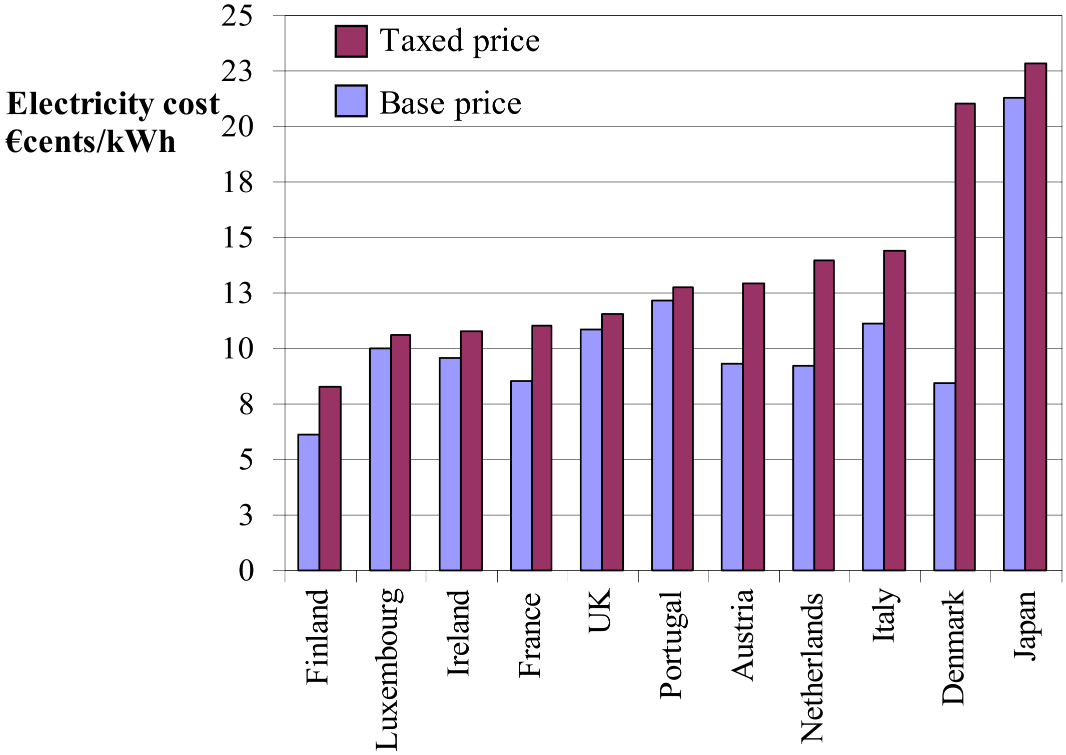
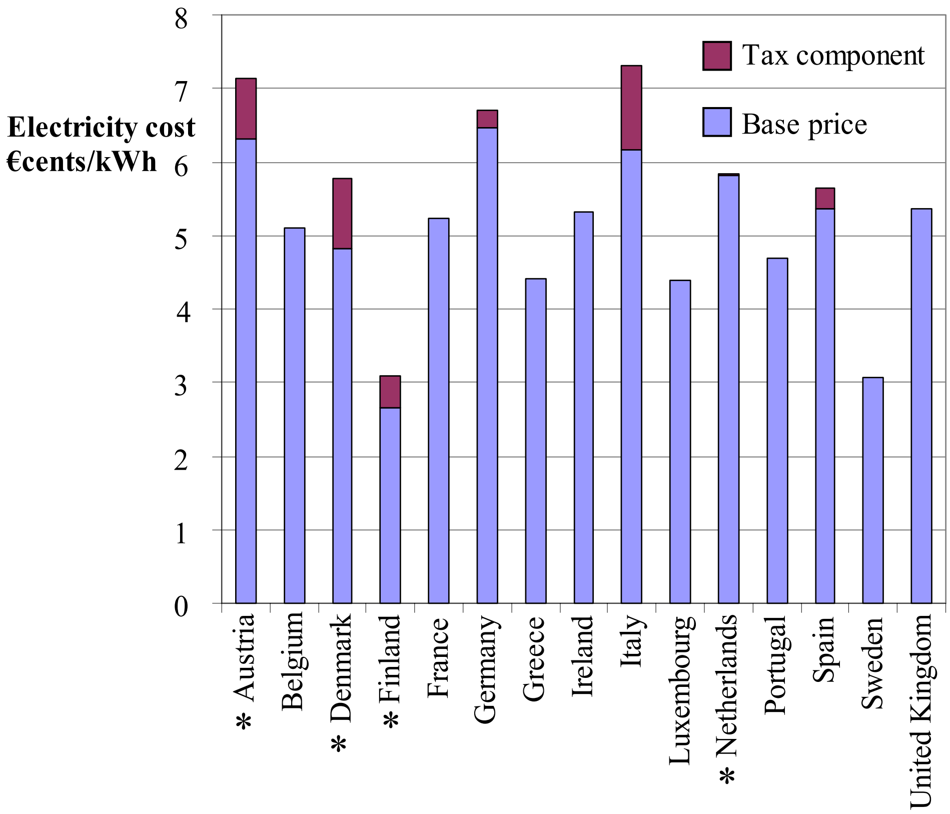


Figure 10. Domestic Electricity prices in selected countries [year 2000]



Notes: Prices taken for 2000, except where indicated [*], then data for mid 1999. Consuming 50GWh per annum with a maximum demand of 10MW.

Figure 11. EU industrial electricity Prices [10MWe peak user] (98)

There are limited opportunities for biomass fast pyrolysis liquids to produce electricity at an economically competitive price for industrial applications, as shown in Figure 11. Only where the pyrolysis plant is above ~ 10 MWe and with a zero cost feedstock, then there are possible opportunities in countries like Austria, Denmark, Germany and Italy, the rest being marginal in terms of price differentials.

The initial market for fast pyrolysis liquids may therefore be as a domestic heating fuel oil replacement, but only in certain locations. For the production of electricity, this would appear to be viable only in areas where there is no grid connection, waste disposal and transportation costs are significant and indigenous fuel supplies are expensive.

TASK 4 LONG TERM COST/BENEFIT ANALYSES COMPARING BIOMASS FAST PYROLYSIS TO ALTERNATIVE RENEWABLE ENERGY SOURCES.

4.1 Collate data on emissions from heat and power generation equipment

There have been several small-scale attempts to combust pyrolysis liquids in flame tunnels, boilers and engines, but no experience yet on turbines in the EU. Limited data is available on the emissions, but the summary of what is available is shown below in Table 22. Emissions work on boilers in Canada has been published on boilers (100) given in Table 22 and some preliminary work in a flame tunnel for a turbine application (63).

4.1.1 Boiler emissions

Some of the first work on combustion of pyrolysis liquids was carried out in boilers and flame tunnels. Some examples of work in the EU and North America are presented in Table 22.

Table 22. Boiler emissions - some examples

Liquid Source	Ensyn		Union Fenosa [1]		Ensyn			CFB [2]	BFB [2]	BFB [2]
Feedstock	Hardwood		Eucalyptus		Hardwood			Hardwood	Pine	Pine
Solids	0.5		0.7					~0.4	0.17	0.03
Boiler	Arimax Eetta 200 kW boiler		Arimax Eetta 200 kW boiler		Water-wall utility boiler 10 MWth			Oilon Lenox GRT-5L	Oilon Lenox GRT-5L	
O_2 [vol%]	4	6	5	6	--	--	--	3.3-3.6	3.3-3.4	3.4-3.7
CO [ppm]	32	28	40	20	32	32	67	1-2	10-25	2-4
NOx [ppm]	142	137	170	150	195	198	208	159-164	108	88-105
THC	--	--	--	--	0.8	1.0	1.4			
Particulate [mg/MJ]	--	--	--	--	105	144	161	15	92	98
Bacharach No.	5	5	2.5	2.8	--	--	--	2	2.8	5.9
Reference	61		61		100			101	101	101

Notes:

1 with additional 3wt% ethanol and 3wt% water, modified refractory in boiler to ensure complete combustion, BFB

2 CFB - circulating fluidised bed, BFB - bubbling fluidised bed

More recent work by Fortum and VTT has given more consistent emissions data, as shown in Figure 12. Using liquid fuel such as pyrolysis oil [PO] instead of solid biomass fuel in a boiler has potential in reducing emissions. It is well known (102) that using solid biomass in small-scale boilers yields high CO, NOx, tar and other emissions. Emissions from PO combustion in a 300 kWth boiler is compared to a case, where wood chips are fired in a similar boiler [see Figure 12] (103). Using PO instead of solid wood would potentially reduce boiler emissions in this size class. The Austrian emission standard is currently the strictest in EU.

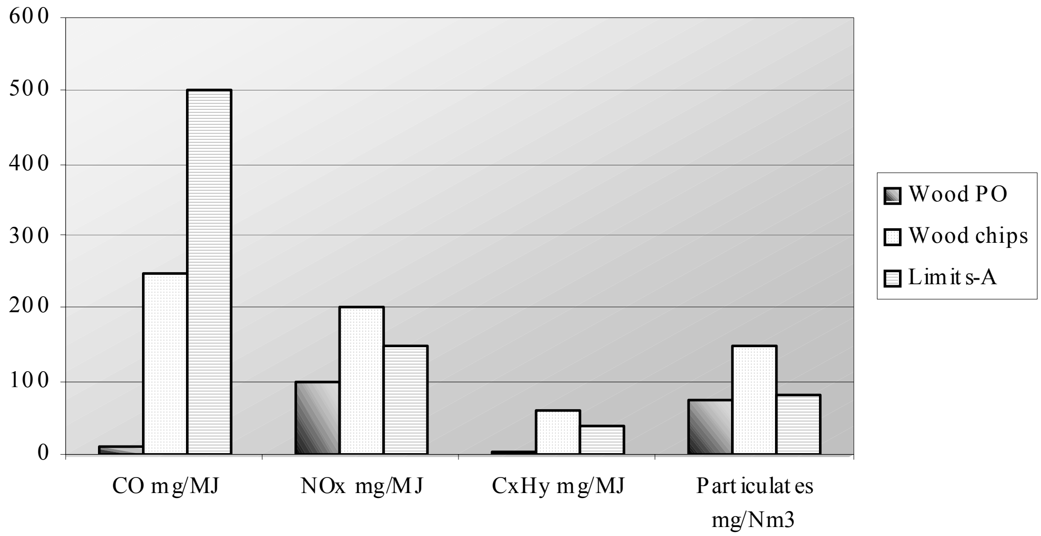


Figure 12. Typical wood chip and PO boiler emissions compared to Austrian emission limits (104) for automatic fed wood fired boilers at 300 kW_{th}.

In Figure 12, the CxHy emissions are for unburned hydrocarbons. In the experiences of Fortum / Oilon, these concentrations must be very low in order to eliminate all odours since the compounds have very low detection limits. In order to get these emissions to an acceptable level, the combustion process must be very efficient and this will give also very low emissions of carbon monoxide. The NOx emissions are to a large extent determined by the fuel nitrogen levels which are higher in biofuels than in heating oils but similar to that of heavy fuel oil.

4.1.2 Engine emissions

Work on engines has been particularly limited, primarily due to a lack of consistent, stable and realiable supplies of liquids. Early work was carried out by VTT on liquids in a small engine and the results are presented in Table 23.

Table 23. Valmet 420 DS 84kW diesel engine emissions (105)

Main fuel	NOx	CO before cat.	CO after cat.	THC before cat.	THC after cat.	Smoke number[1]
	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	
Diesel	7.1	1.8	0.1	1.7	< 0.1	2.7
Ethanol	4.6		0.1		< 0.1	0.5
Pyrolysis oil	3.2	9.9	0.1	1.3	0.4	0.7

[1] Bosch-units NOx = Nitrogen oxides, CO = Carbon monoxide, THC = Total hydrocarbons

Several potential problems were identified in the preliminary tests. Wear and corrosion were detected in injection needle and pump elements during both bench tests and engine operation. Relatively high CO emissions were analysed in the engine exhaust gas during the test. However, the commercial catalyst installed in the unit removed most of CO and hydrocarbons.

The only long term commitment to engine testing using a variety of pyrolysis liquids has been by Ormeod Diesels, who have operated a 250 kWe engine for 9 years. Some results are presented in Table 24. Further longer term work on consistent liquids is required for robust performance and emissions data and allow the determination of standards for engines.

Table 24. Engine and burner emissions

Liquid Source	BTG (106)			BTG (69)
Solids [wt%]				0.35
Pilot fuel	Diesel			
Engine and User	250 kWe Mirrlees 6 cylinder Ormrod Diesels, UK			Stirling Engine FLOX® burner ZSW, Germany
Pilot fuel [wt%]	7	17	100	
O_2	15	15	15.8	6-10
CO [ppm]	3475	2057	270.5	<35-125
CO_2 [vol%]	4.36	4.55	3.88	
NO [ppm]	240.4	313	509.8	
NO_2 [ppm]	40.5	76.5	76	
NOx [ppm]	384	266	585.8	20-95
SOx [ppm]	0	32.5	86.25	
THC [mg/m^3]	--	--	--	20-40
Bacharach No.	--	--	--	2

4.1.3 Turbine Emissions

There has been work performed only on one turbine in Canada (63) and a small turbine combustor in Germany (49, 54). Only 6 continuous hours have been obtained on the Orenda Aerospace gas turbine using Ensyn liquids in 1997. Work by the University of Rostock on a 300 kWth turbine combustor test facility and a 75 kWe gas turbine give relative values for CO_2, CO, NOx and hydrocarbons of 105, 780, 45 and 981% respectively compared to operation of the turbine on 100% diesel (49). These values are given in Table 25.

Table 25. Turbine Combustor emissions (107)

Liquid Source	BTG
O_2	5

CO [ppm]	3434
CO_2 [vol%]	10.5
NO [ppm]	30
NO_2 [ppm]	42
NOx [ppm]	72

4.1.4 Other burners and additives

Some work has also been carried out on a 6 kWe Stirling engine with a modified burner system (69) giving acceptable emissions below German standards for diesel engines. There is no other work on Stirling engines for pyrolysis liquids. Work has also been carried out on emulsions to allow minimal retrofitting of an engine (e.g. 108, 109, 110).

4.2 Compare emissions and performance with other renewable liquid fuels

The liquids, which are useable for fuels, are listed below and are all classified as renewable liquid fuels. Typically these renewable liquids are used in transport fuel applications and not in base load or power production in stationary applications, therefore a true comparison between pyrolysis liquids and other renewable fuels is not possible. The only liquids for which data could be found on stationary power applications were beef tallow, RME and biodiesel and these presented in Table 21, highlighting that pyrolysis liquids are significantly more expensive than other fuels such as biodiesel.

4.3 Assess cost benefits and compare with other liquid fuels

It is difficult to assess the cost benefits of other renewable liquids with pyrolysis liquids, as most are used as transport fuels and not for stationary power applications, as would be the case for pyrolysis liquids.

The costs for several liquid fuels were previously presented in Table 21 and Figure 8. The data for pyrolysis liquids is very limited at this time and only tallow and biodiesel may be considered useable for power generation, based on their cost and actual commercial experiences. At this time, the cost benefits of pyrolysis liquids have not been clearly demonstrated and further development work is required.

This part of the project was transferred to the other part of the cluster as per the contract amendment of 2001. Some data on emissions for inclusion with the competitivity part of the cluster are enclosed in Appendix 1.

4.4 Assess biodegradability of fast pyrolysis liquids and compare with conventional liquid fuels

Very little work has been carried out on the biodegradability of biomass pyrolysis liquids. The only published work has been by RTI Ltd., Canada, who demonstrated that the liquids are biodegradable, but no further work has been carried out to develop the preliminary findings (111). More extensive work on a range of liquids is required to satisfy ends user requirements for transport, storage and handling.

This is an area which will become more significant, as transportation and extensive handling of pyrolysis liquids will lead to increased spill risks and therefore, in some cases, additional action may be required to remediate spills.

The biodegradability of other renewable liquid fuels has been extensively characterised and most of the vegetable oil derivatives are highly biodegradable and have low toxicity and hazard levels. Biodegradation rates expressed as a value of original sample and the quantity remaining after a set time. There are different measures to assess the rates of biodegradability, therefore relative methods need to be evaluated carefully.

Table 26. Respirometric biokinetic studies on Oak-ENEL, Poplar-RTI and diesel liquids. Estimation of biokinetic parameters

Liquid used	Medium	Rate of Biodegradation [per day]
Oak - ENEL		
Neutralised	Water	0.216
Raw	Water	0.116
	Soil	0.195
Poplar - RTI		
Neutralised	Water	0.18
Raw	Water	0.122
	Soil	0.188
Diesel-Shell		
	Water	0.072
	Soil	0.071

Comparison of these results with other results is difficult, but the reference material used in most studies is conventional diesel, so a relative comparison with it can be made. Some other data on comparison of degradation rates is given in Table 27.

Table 27. Biodegradation rates for pyrolysis liquids, biodiesel and diesel

Liquid fuel	Relative rate	Comments
Pyrolysis liquids	Twice as fast as diesel	Rate enhanced by neutralisation
Biodiesel	over 95% in three weeks	
Diesel	up to 72% in three weeks	

Pyrolysis liquids appear to degrade at a rate similar to that of other renewable liquid fuels. Further work is required in this area to optimise conditions of degradation and assess environmental effects on the rates of biodegradation. All of these liquids have been shown to have extremely low toxicity in the environment and some liquids are used as adsorbents, due to the extreme biodegradability. Data is available for these other fuels and unfortunately; there is insufficient data available on pyrolysis liquids for a proper objective comparison.

TASK 5 QUANTIFICATION OF BENEFITS OBTAINED IN IMPROVING THE PRODUCER-CONVERTER-USER INTERFACE AND IMPROVEMENT OF THE ENERGY/ENVIRONMENTAL BALANCE IN PYROLYSIS LIQUIDS PRODUCTION

5.1 Technology provider –end user interface

In previous sections of this report, Fortum has provided information on the progress made in the Fortum / Vapo pilot plant and on the field trials using Forestera fuel in a commercial heating oil boiler utilising a prototype burner provided by Oilon of Finland.

In the course of this work it became apparent that in order to achieve rapid development of both the pyrolysis production process and the burner, a direct and constant communication was very important. Since it is clear that during the operating of a test plant, operating conditions will change as the process window is enlarged to allow the testing of various feedstocks and process conditions, the final fuel quality will vary from batch to batch. Some properties, such as water content and thus viscosity and heating value can vary to a fairly large extent while others such as acidity and maximum solids will vary to a smaller extent.

The goal of the Fortum / Vapo pilot plant has been to prove that the adopted technology is robust and reliable and that the grades of fuel that are being produced are superior to those that have been tested and caused problems in the past. The main problems that have been noted in the past are those of phase separation producing a liquid that is totally not useable and that of very high solids concentration, on the order of 0.5 to 1 weight percent that have been found to settle in tanks, clog nozzles and valves and cause poor combustion and high emissions.

5.2 Energy/Environmental Balance in Pyrolysis Liquids Production

5.2.1 Pyrolysis Energy Balance

Based on empirical data, and a detailed flowsheet comprising the mass and energy balances, taking into account data given in Table 28, the net energy efficiency of a fast pyrolysis process can be calculated. The calculation takes into account process heat losses, the variability in product compositions with temperature and varying proportions of char and pyrolysis gas to heat the process. The net energy efficiency is shown in Figure 13.with the char % increasing to 100% at 560ºC, with the contribution of energy required to heat the process moving over that provided by the pyrolysis gas above 600ºC.

Table 28. Data used to determine net energy balance for a fluidised bed fast pyrolysis process

Energy content of 1 kg of dry wood HHV	19.9 MJ/kg
Energy content of 1 kg of wet wood at 15wt% water HHV	16.9 MJ/kg
Energy content of 1 kg of wet wood at 15wt% water LHV	16.5 MJ/kg
Energy required to vaporise water [at 15wt% dry basis]	0.486 MJ/kg of dry wood
Energy required for pyrolysis [dry wood]	1.244 MJ/kg
Total energy required for pyrolysis and water	1.73 MJ/kg wood

Energy requirement for pyrolysis [% of wet wood HHV]	10.2 %

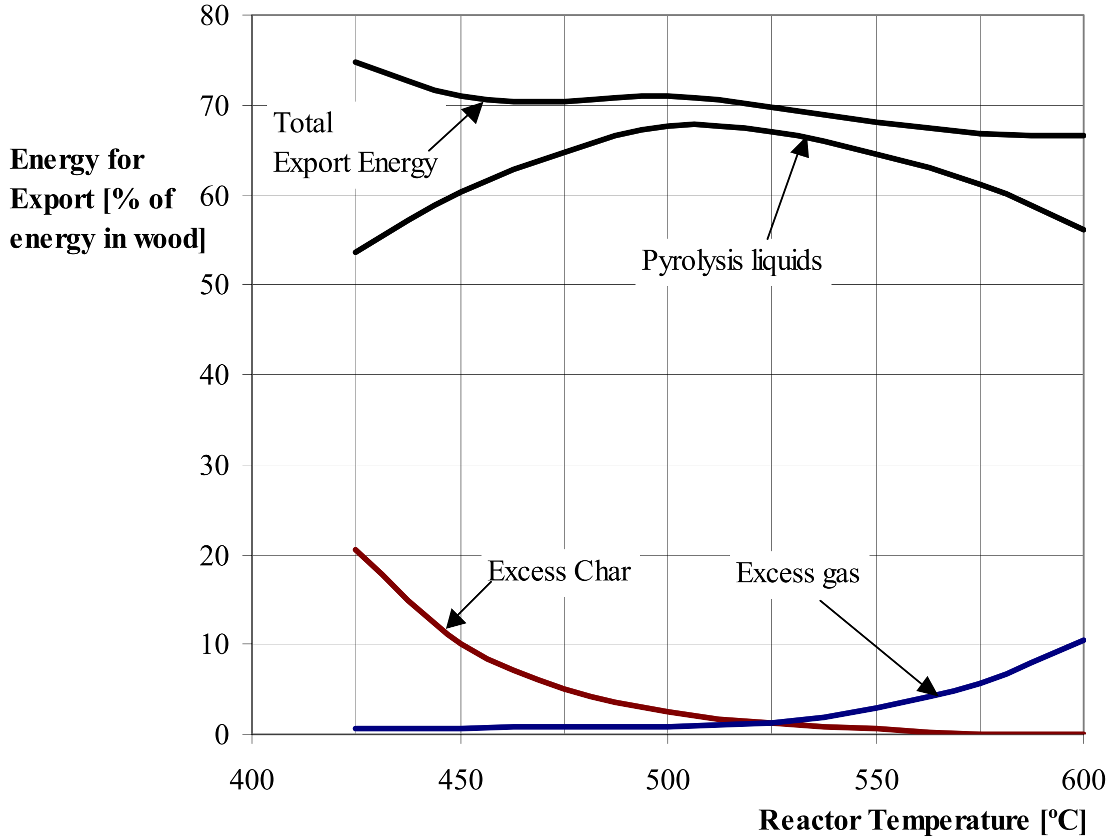


Figure 13. Net energy balance – fast pyrolysis – energy efficiency for the three products [allows for char and gas recycle to process for process heat]

The pyrolysis process is therefore energy self-sustaining and does not require input of fossil fuels during operation. The process can also be started up on surplus char, depending on the feedstock and operational conditions for the process. The overall energy efficiency of the process, related to the energy content of the product liquids was made, showing that the energy conversion of wood to liquid fuel is ~70% in the pyrolysis liquids. 8-10% of the energy content of the wood is required to effect the pyrolysis reactions, with the rest retained in the product char and gases.

5.2.2 Environmental aspects of fast pyrolysis processes

Due to the limited operational data from pyrolysis plants, the assessment of the energy/environmental balance has not been possible. The only data, which gives a comprehensive overview of the pyrolysis process, its emission and environmental impact, has been published in the IPC authorisation of Wellman Process Engineering Ltd., UK, who were one of the first plants in Europe to be awarded IPC authorisation for their pilot plant (112). Part of the IPC application is an assessment of the process emissions to ensure environmental compliance, at local, national and international level. For the IPC application, calculated values for the process were used and are given in Table 29. using clean biomass feedstocks, the primary emissions relate to combustion of the byproduct char and gas for process heat, followed by the pyrolysis liquids as the primary product.

Table 29. Calculated Inputs and Outputs for the Process

Inputs	Flowrate [kg/hr]	Net outputs	Flowrate [kg/hr]
Air	496.4	Flue gas	586.6
Wood	281.3	Pyrolysis oil	222.6
Char	24.3	Char	8.5
Spray Water	36.0	Ash	0.9
Purge Nitrogen	2.8	Cooling water purge	1000
Cooling make-up	1000	Pyrolysis vapours	0.1

Although the pilot plant did not operate, the data presented is based on empirical data from laboratory scale work, and used in a full chemical and process design of a 250 kg/h [dry feed basis] fast pyrolysis plant. As part of the IPC authorisation, evidence had to be presented to show that the process would meet emissions legislation as shown in Table 30. The only emission to air, which would require abatement, but would be initially monitored to determine the exact value, was the dust emission of 64 mg/Nm^3. The limit in the UK is 50 mg/Nm^3 [3 hours limit value], with the EU limit being 30 mg/Nm^3 for combustion processes. As there are no NOx, or SOx emissions from the process for clean biomass types, fast pyrolysis technologies are viewed as being more environmentally complaint than other technologies.

Table 30. Operational, fugitive and uncontrolled emissions to air

Air Releases	Normal Flow	Concentration	Normal Flow	Maximum hourly flow	Yearly mass [1]
	kg/h	g/m^3	m^3/s	m^3/s	t
CO_2	100.9	227.9	1.8E-5	3.6E-5	100.9
H_2O	58.8	132.8	2E-5	4E-5	58.8
N_2	384.9	869.2	8.6E-5	1.7E-4	384.9
O_2	41.0	92.5	9.0E-6	1.8E-5	41.0
Ash Dust	0.03	.068			0.03
Velocity [m/s]	14		14	19.8	
Fugitive Char	0.001				0.001
Fugitive Ash	0.0001				0.0001
Fugitive Organics [2]	0.007	35943			0.007
Uncontrolled [kg] [3]	7.3				0.007

Notes:
1 assuming operation in first year of 1000 hours at 250 kg/h
2 uncontrolled release assumed to be 1 a year. 3 from storage tank for the pyrolysis liquids

Biomass fast pyrolysis therefore has significant advantages over incineration in terms of emissions and this should be one of the major incentives for its continued development for renewable liquids as fuels for heat and power applications.

6 CONCLUSIONS

Biomass fast pyrolysis technologies have seen a slow growth over the past 4 years, primarily due to low oil costs and low base electricity prices throughout most of Europe. The demand for a renewable liquid fuel for heat and power generation has therefore been reduced and other competing technologies have come to the fore, namely for transport fuels, which have a higher market value.

There are a range of incentives in the EU for renewable energy technologies, although the level and form of support vary significantly and in some cases do not make any distinction in the level of technological development in renewable energy technologies, with all being classed as commercially available. Some harmonisation in support measures is required.

Due to the limited deployment and development of the technology, there is not enough empirical data to allow full norms and standards for biomass derived fast pyrolysis liquids to be determined. There is a real need for bulk quantities of liquids to be supplied to boiler and power generation equipment developers to enable standards for liquids to be fully assessed and specified.

The initial market for biomass derived fast pyrolysis liquids may be in the replacement of domestic heating fuel. There is the opportunity for liquids to enter the power generation market for domestic applications, but only in selected countries. Further long-term test work is required to establish performance and operability data for engines and turbines on pyrolysis liquids. Pyrolysis liquids can compete on cost terms with other renewable fuels, but only in certain niche applications.

The overall energy balance of biomass fast pyrolysis can give 70% efficiency to liquids, with low environmental emissions. This is one of the major advantages of biomass fast pyrolysis and means that abatement costs for such systems are low.

In conclusion, opportunities exist for pyrolysis liquids, however, further work is required to establish long term performance in engines and turbines.

APPENDIX I

Data LCA emissions from alternative liquid fuels are shown below in Table 31. No data on the LCA for pyrolysis liquids has been made to date.

Table 31. LCA emissions for alternative liquid fuels.

Emission	LSD	Renewable				Renewable		Non-Renewable			
		Ethanol		Biodiesel		Hydrogen		CNG		FT Diesel	
	g/km	g/km	%	g/km	%	g/km	%	g/km	%	g/km	%
CO_2	925	315	34	74	8	897	97	787	85	1234	133
Total HC	1.51	0.83	55	0.61	40	0.36	24	0.32	21	1.06	70
NOx	11.25	8.83	78	11.81	105	0.57	5	1.67	15	10.92	97
CO	2.72	10.55	387	1.45	53	0.13	5	0.15	6	1.46	54
PM_{10}	438	287	66	274	63	7	2	13	3	275	63

Emissions for RME in Valmet 611 CSBH diesel engine: CO 8.8 g/kWh, HC 0.9 g/kWh, NOx 17.8 g/kWh (for diesel oil: CO 9.1, HC 1.1, NOx 16.5 g/kWh) (113). The study dealt with methylester of rape oil (RME), and its suitability as fuel for used diesel engine without any changes. The suitability was researched with diesel engine tests and with 6000 km long field tests. As a result, it was found out that RME is very suitable as a replacement for diesel oil. RME features closely diesel oil, also with emissions. Data for other fuel combinations is available (e.g. 114).

APPENDIX II

Paper presented at the Pyrolysis and Gasification of Biomass and Waste The future for pyrolysis and gasification of biomass and waste: status, opportunities and policies for Europe 30 September – 1 October 2002, proceedings published by CPL Press June 2003.

Development of Combustors for Pyrolysis Liquids

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Abstract
Flash pyrolysis has been identified as an economic method to convert solid biomass into a liquid fuel which can be shipped, stored and combusted more economically than solid biofuels. This liquid differs significantly from existing liquid fuels and a combustion system specifically designed for this fuel is required. The long term use of this fuel in practical systems has not yet been demonstrated and there remain questions concerning the type of combustion technology that will be required, the level of emissions and long term storage. Oilon , a burner manufacturer, together with Fortum, an energy company have embarked on a development programme where the liquids produced in the Fortum/Vapo 500 kg/hour pilot plant will be test combusted in a Oilon prototype combustion system during the fall of 2002. Results of these tests will be used to design and construct commercial systems.

Background

Although flash pyrolysis liquids have been combusted in a large number of laboratories and test programmes over the past ten years and the special features of combustion have been documented /1-7/ there does still not yet exist commercial combustors. The main reasons for this is the lack of commercial production and variability of fuel qualities produced to date.

With the decision taken by Fortum and Vapo of Finland in 1999 to develop and scale up pyrolysis production technology to commercial sizes, Oilon, a burner manufacturer in Finland, has embarked on the task of developing commercial combustion sytems. As the properties and quality of pyrolysis liquids have been known to vary in the past and since there does not yet exist a fuel specification, it was further agreed that the pyrolysis liquid producers would take an active role in the development work.

The main goals of the development work were to find clean and economic ways to burn pyrolysis liquids. This report presents results gained with in this work. As the development work and the required technology has not yet been decided, the technical solutions are not presented here. This will be verified with further measurements and combustion tests were performed in Porvoo and Lahti and at slected customer sites.

Modifications Required To Commercial Burners

Existing burner equipment that is normally used with light fuel oils has been optimized with a much higher heating value fuel than pyrolysis liquid (roughly double). This means that to achieve an adequate fuel / air mixtures and velocities with pyrolysis liquids, much less air is required for combustion. This causes the flame to expand in size and to extend to the end of the combustion chamber. It was observed that this type of flame is such that internal heating is not adequate to combust particulates and high molecular tars which increases emissions. This required that a new burner retention head be developed. Also it was observed that since pyrolysis viscosity is higher than light fuel oils, a higher pressure for atomisation is required to achieve the small drop size required for efficient combustion. One drawback of this high pressure is large droplet blow through which is caused by a small fraction of the drops being larger than the average size and leaving the flame centre before they are combusted. This leads to high emissions. The low pH due to the high concentration of formic and acetic acids has meant also that normal carbon steets cannot be used in pumps and fuel lines. Stainless steel pumps are available but they are considerably more expensive than normal fuel pumps. Since pyrolysis liquids contain significant amounts of water and have a low heating value, it has also been found that they are difficult to ignite. This has meant that the combustion chamber must first be warmed up to ignition temperatures by a separate fuel. This temperature was found to depend on the type of burner head solution that was adopted. In practise this is possible in less than 30 seconds. Finally, it was found that after burner shut-down, pyrolysis liquids must be rinsed our of nozzles to prevent clogging.

Results - Emissions

The results of combustion tests are shown in Figure 1 and Tables 1 and 2. In Figure 1 it is seen that good combustion, as seen by carbon monoxide levels around 60-70 ppm, can be obtained with oxygen content in the flue gas at around 5% levels. Clean combustion was also determined by measuring tar and PAH emissions as shown in Table 1. Here the influence of improvements into the burner retention head are illustrated. Especially the PAH emissions have been reduced to very low levels. This was done while at the same time reducing the amount of excess air required for good combustion. The amount of excess air has very strong influence on the type of boiler heat exchange surface that is required. We started with 10-8 vol-% and now we are in 4 vol-%.

Table 1. Tar and polyaromatic emissions for pyrolysis liquid combustion.

Emission	Unit	1998	2000	2002
Tar	mg/MJ	-	3	*
PAH	mg/MJ	1000	50	15
CO	mg/MJ	200	100	20
NO_x	mg/MJ	50-200	50-200	50-200
O_2	%	8	6	4

* differense betveen content and background is too small
Method used SP-1686

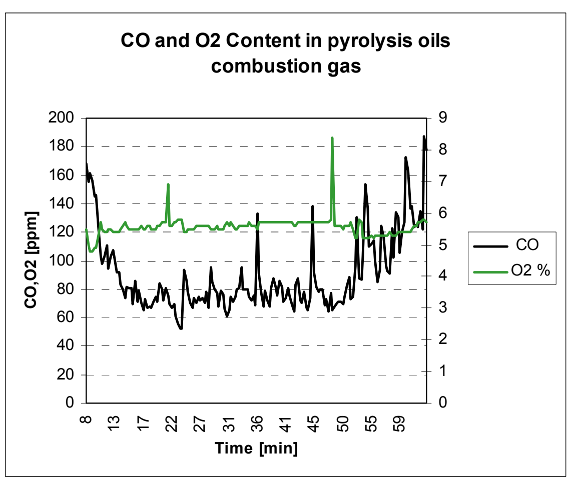

Figure 1. Typical carbon monoxide emissions when combusting VTT produced samples

Finally in Table 2, the combustion emissions of pyrolysis liquids using our improved burner retention head are compared to those of typical mineral oils and to those of pellets and woodchips. Tempera 15 is a typical light fuel oil used in intermediate size boilers while POR L 180 is a typical heavy fuel oil containing 1% sulphur. Here it is seen that combusting wood in the form of this pyrolysis liquid is much cleaner than that in a solid form but still not as clean as for light fuel oil.

Other emissions of interest are sulphur dioxide, nitrogen oxides and particulates. Sulphur dioxide is not measured because wood contains very small amounts of sulphur. Nitrogen oxides come primarily from the nitrogen content of the fuel and so attempts to reduce NOx emissions by changing combustion conditions have very little effect. Particulate emissions continue however to be one of the problems with this fuel. This is seen by a higher smoke number or Bacharach number than for light fuel oils. Whereas LFO has a Bacharach number less than 1, pyrolysis liquids have smoke numbers in the range of 2 to 4 depending on the fuel quality. With our emission testing results taken from Table 2 it can be seen that the emissions are mainly inorganic. They are a combination of ash that is found in the residual char and some sand from the process. The reduction of these emissions will be determined by producing pyrolysis liquids with very low levels of solids, at or below the 0.1 weight percent range.

Table 2. Pyrolysis emissions compared to other fuels

	Tempera 15	Pyrolysis Oils	POR L 180	Pellet	Wood Chips	Fire Wood
HHV (MJ/kg)	42	15	39	17	5	13
Water wt-%	-	28	-	8	50	25
Typical Boiler Size	~ 500 kW	~ 300 kW	> 1 MW	~ 20 kW	> 1 MW	~ 20 kW
Excess air %	4	4	4	8 - 12	5 - 10	10 - 20
CO (mg/MJ)	10	15	15	50-1000	100-5000	1000 - 10000
NO (mg/MJ)	30	***	100-150	***	***	***
SO (mg/MJ)						
Tar mg/MJ	-	*	-	< 10**	< 20 **	1000**
PAH µg/MJ	-	8****	1	1000*****	2000*****	8000*****

*	Method used SP-1686. Difference Between measured value and background were too less. Background ~1 mg / MJ
**	Measuring method used. Not known
***	NO Content comes from the biomass nitrogen, typically 50 - 300 mg/MJ. In bigger boiler (10-300 MW) one can use NO reduction technology
****	Method used SP-1686, Analysis EPA 610
*****	Informations from 1986

Prototype Development

With the more than 5 years of experiences of Fortum and Oilon from various combustion tests and the scale up of Fortum / Vapo Forestera technology to 500 kg/hour, a prototype combustion system utilising these experiences has been developed. The platform for the prototype is a standard burner that has been modified to combust pyrolysis liquids. This is a fully automated combustion system that will be installed at a location in Finland in the fall of

2002 to begin long term testing of both the burner, possible deposit formation in the boiler and test qualities of different fuels.

References to Appendix 2

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