PROJECT N° : NNE5-CT-2001-00604

COMBIO- A New Competitive Liquid Biofuel for Heating

Work Package 5

TECHNO-ECONOMIC ASSESSMENT, THE FINNISH CASE STUDY

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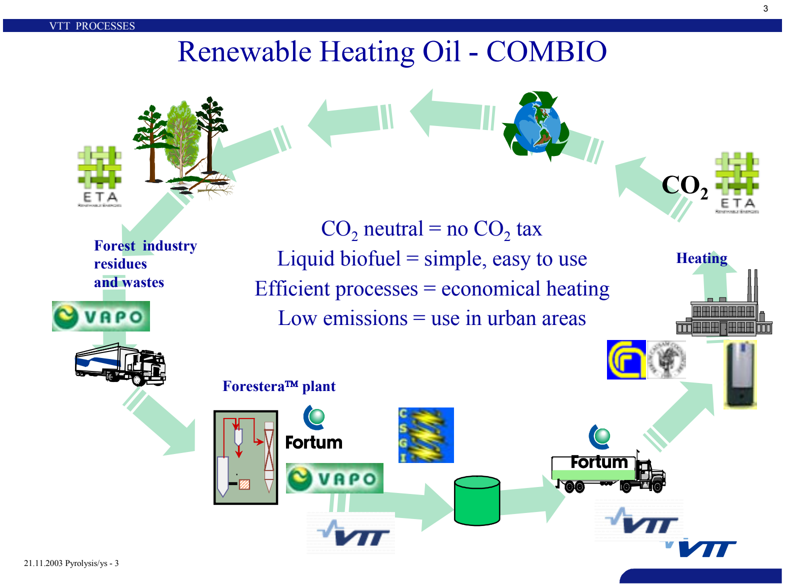
1 THE CHAIN CONSIDERED

The utilisation chain considered is schematically shown below in Figure 1. In Finland, woody biomass is converted to liquid bio-oil, which is used to replace mineral oil in heating boilers. Wood fuels are transported to the pyrolysis plant, which is preferably integrated to a CHP power plant. Road transportation is employed, as this is the current industrial practise. Bio-oil is transported to users with a tanker, much like mineral oils to large users today. The tanker has to be specially prepared for bio-oil transport because its properties are different from mineral oils.

A forest residue harvesting, collection and transportation chain is depicted in Figure 2. The chain is currently employed industrially in Finland.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Renewable Heating Oil - COMBIO

CO_2 neutral = no CO_2 tax
Liquid biofuel = simple, easy to use
Efficient processes = economical heating
Low emissions = use in urban areas

Forest industry residues and wastes

Heating

Forestera™ plant

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Figure 1. Bio-oil utilisation chain including project partners and their respective roles in the project

2 WOOD FUEL COSTS

Forest residue harvesting, collection and transportation chain is depicted in the Figure 2. The harvesting methods have improved during the recent years due to increased utilisation especially at forest products industry CHP-plants. Increased wood fuel utilisation has eventually caused also price increases, which is shown in Figure 3. Price of wood fuels were relatively steady at 8 €/MWh (including approximately 50 km transport) from 1997 to 2001. However, after 2001 price of wood fuels have increased from 8 to about 10 €/MWh. This will certainly affect the competitiveness of biofuel alternatives. An estimate for the price as a function of transportation distance is given in Figure 4. Increasing the transport from 50 km to 100 km will increase the price of wood fuel from 9 to about 11.5 €/MWh. This corresponds to an effective increase of available amount of biomass from about 20 to 70 MW_{th} per plant, which is a reasonable range of considered plant capacities.

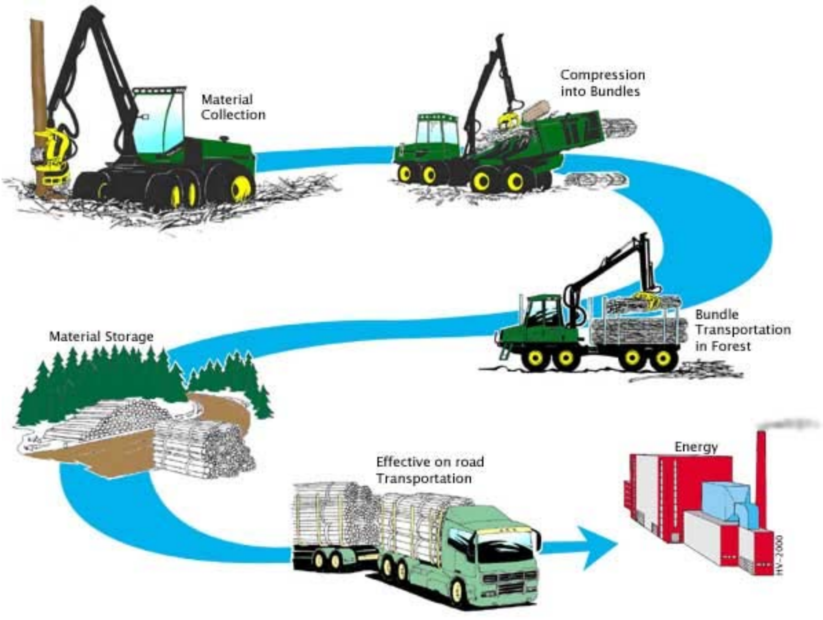
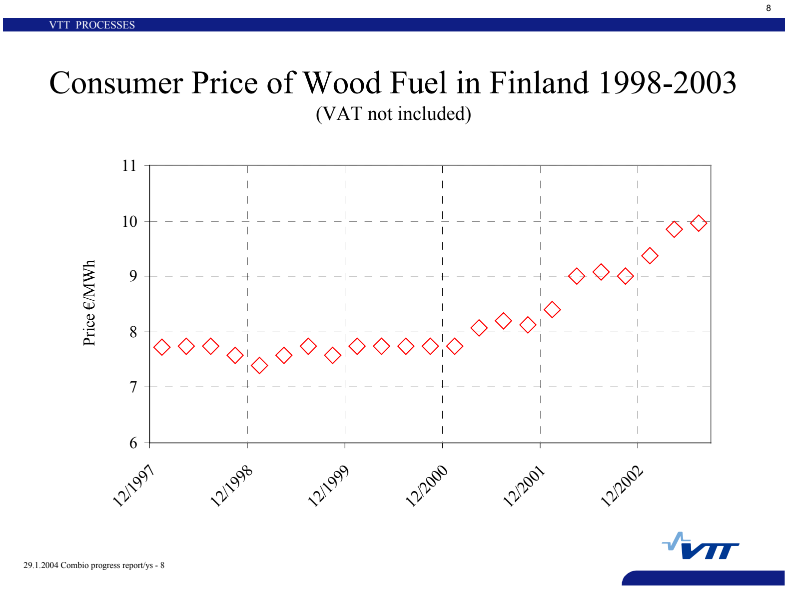


Figure 2. Forest residue harvesting, collection and transportation chain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Consumer Price of Wood Fuel in Finland 1998-2003

(VAT not included)

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Figure 3

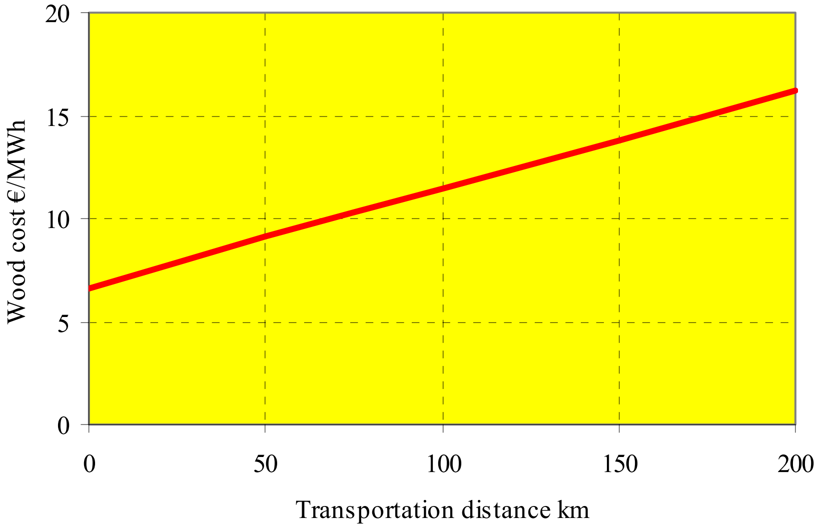


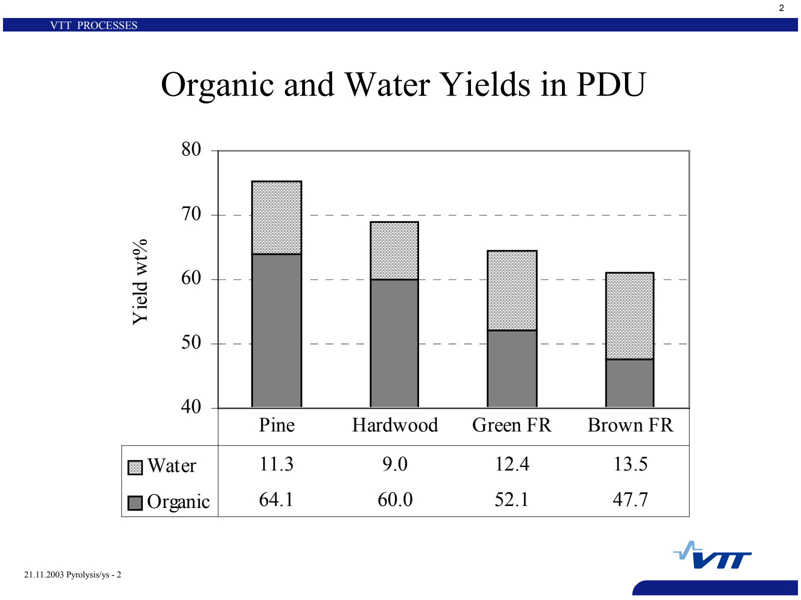
Figure 4. An estimate for the price as a function of transportation distance

3 PYROLYSIS PLANT PERFORMANCE

Plant mass and energy balances are currently based on experimental data from PDU-scale of operation. Therefore they will need to be verified in larger scale, and at least in part this will be done within this project.

The critical yield data, which has been employed in estimating the industrial plant performance, is given in Figure 5 below. Yields from four distinct wood fuels are shown: pine (corresponding to stem soft wood), hardwood, and two different forest residue qualities. These differ mainly in the storage time applied, where "brown" refers to a fuel which has been stored about 6 to 12 months in the forest before use. For this case study, green forest residues have been selected as fuel.

A preliminary performance balance has been calculated based on the assumptions given above. The flowsheet with the respective mass balances is shown in Figure 6. With the given bases the water content of the liquid product is 29 wt% with an LHV of 13.2 MJ/kg. The corresponding liquid production efficiency is about 67 % based on lower heating values. LHV for the 50 wt% moist feedstock is 7.2 MJ/kg.



Organic and Water Yields in PDU

	Pine	Hardwood	Green FR	Brown FR
▨ Water	11.3	9.0	12.4	13.5
■ Organic	64.1	60.0	52.1	47.7

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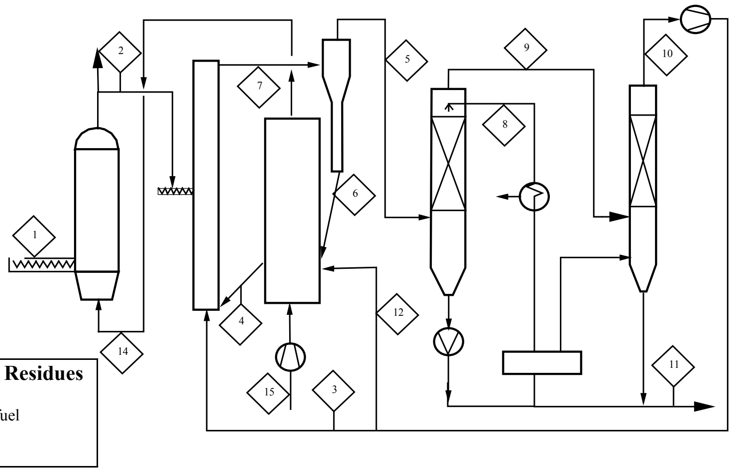
Figure 5



Fast Pyrolysis of Forest Residues
ENK5-CT-2002-00690
A New Competitive Liquid Biofuel
VTT Processes
January 15, 2003/ys

	1	2	3	4	5	6	7	8	9	10	11	12	14	15
	WOOD TO DRYER	WOOD TO PYROLYSIS	RECYCLE GAS TO REACTOR	HEATER SAND IN	PYROLYSIS VAPOURS	HEATER SAND OUT	CHAR TO COMBUSTOR	QUENCH LIQUID	QUENCH VAPOURS	DEMISTER VAPOURS	PRODUCT LIQUID	PURGE GAS	FLUE GASES TO DRYER	AIR TO COMBUSTOR
Temperature C	15	66	112	640	505	540	472	35	50	35	43	78	1062	15
Pressure bar	1.0	1.0	1.2	1.0	1.0	1.0	1.0	5.0	1.0	1.0	1.0	1.2	1.0	1.0
Total mass flow kg/s	5.47	2.96	4.44	59.18	6.68	59.18	0.45	58.62	4.43	4.82	2.01	0.38	5.63	3.75
Non-condensables			4.15		4.37			0.06	3.95	4.37		0.35	5.27	3.75
Water	2.74	0.22	0.11		0.69			14.68	0.19	0.11	0.59	0.01	0.36	
Organics			0.19		1.61			43.75	0.29	0.34	1.42	0.03		
Char					0.00		0.45	0.13						
Wood	2.74	2.74												
Sand				59.18		59.18								

Figure 6. Pyrolysis performance

4 INVESTMENT COSTS

A summary of various investment cost estimates are compared in Figures 7 and 8. These estimates are from three principal sources: Aston University (UK), VTT (FIN), and Kemiinformation AB (SE). The sources are to a large extent independent: Aston reports that data from manufacturers is used, VTT is using literature with in-house data, and Kemiinformation pyrolysis data is derived from related industrial data. The specific investment costs shown are calculated based on product liquid chemical energy (mass flow kg/s * LHV MJ/kg). All the estimates are corrected with the Chemical Engineering Plant Cost Index (CEPI) to 2003 US dollars. Dollars are employed because all the earlier estimates were done using this currency. No other corrections have been made to the original numbers.

It is seen that the general correlation is as expected (Figure 7). However, from about 40 to 60 MW_{th} the correlation is not as expected (Figure 8). It is seen that the spread within the numbers is larger than acceptable. The discrepancy is accepted here because very little industrial data is available to compare the published data.

In this work, the integrated production facility is selected. Pyrolysis plant is integrated to an existing CHP power plant. The power plant is based on fluidized-bed boiler. In principle power plant main fuel could be either bio- or fossil fuel. However, in this case a bio-fuel is assumed.

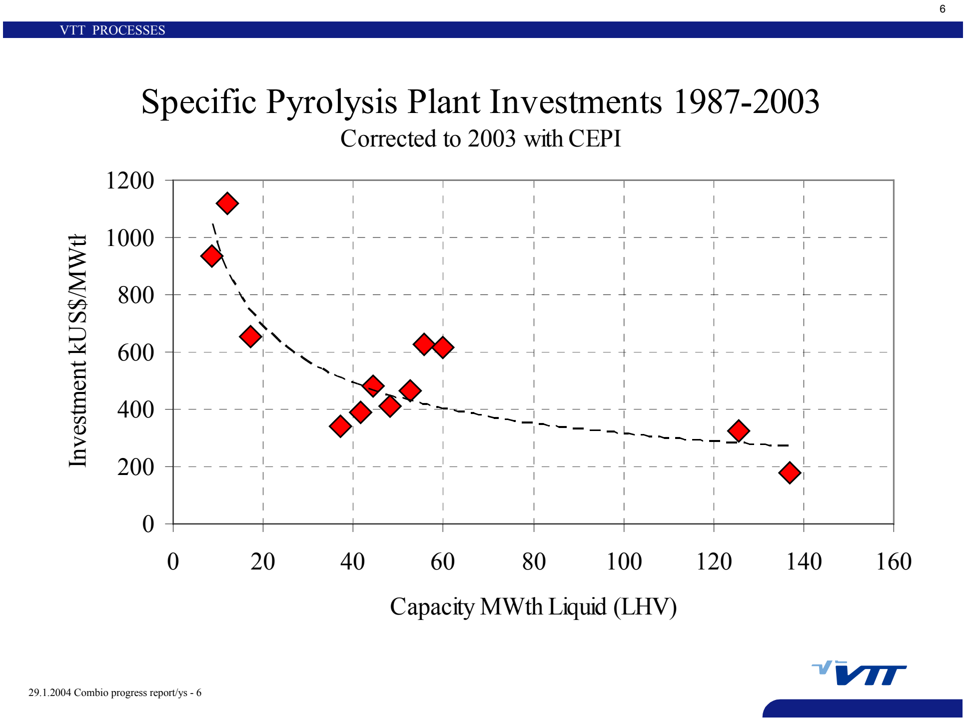


Figure 7

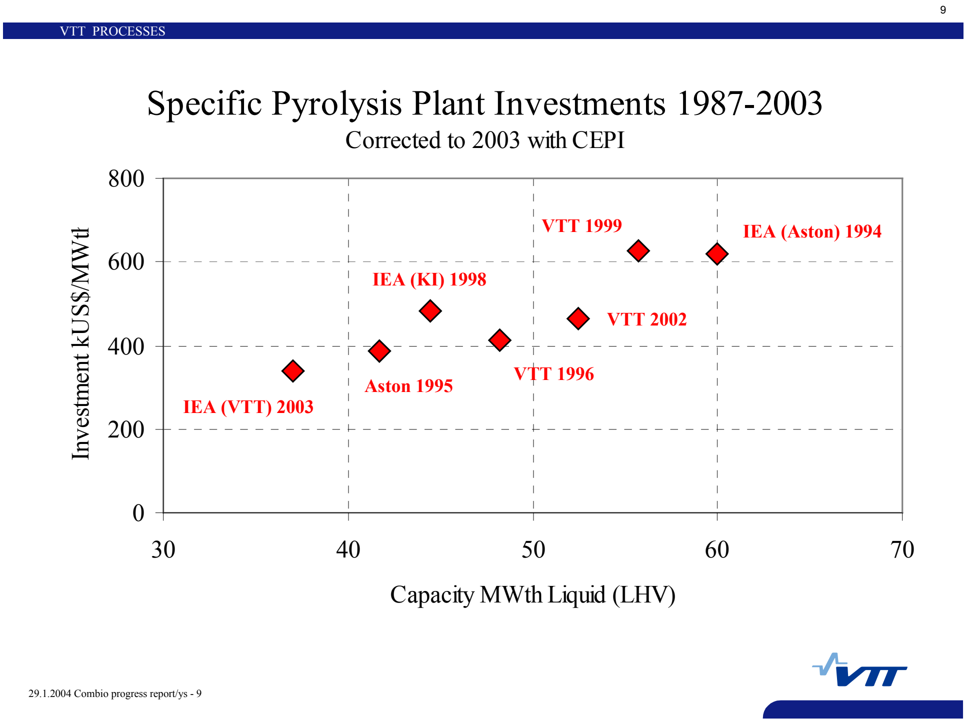


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Figure 8

5 PRODUCTION COSTS AND COMPETITIVENESS

Consumer prices for light (LFO) and heavy fuel oil (HFO) in Finland are used as reference prices. These are shown during 1998 -2003 in Figure 9 below. Consumer price for the LFO has varied between 30 and 40 euro/MWh during this time.

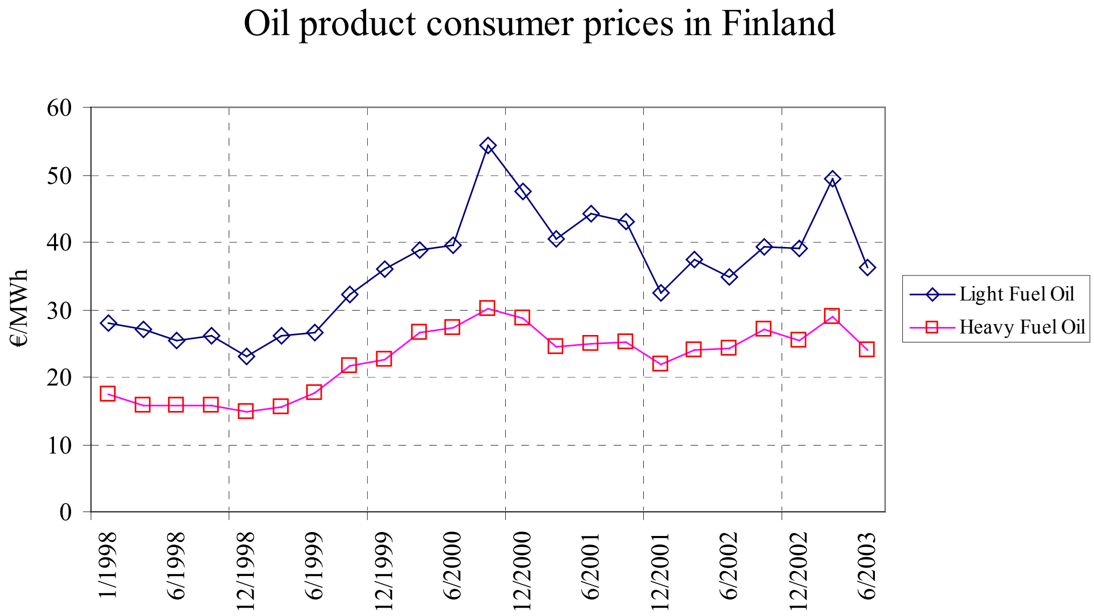

Figure 9

Two economic estimates are shown for pyrolysis oil:

- Production cost is estimated using the annuity method for valuating capital costs.
- Internal rate of return (IRR) is calculated assuming a lower price for pyrolysis liquid fuel to take into account higher transportation and increased utilisation costs compared to LFO.

Parameters used as bases in the assessment are summarised in Tables 2 - 4. Note that the efficiency for pyrolysis liquid production is defined for integrated operation, where pyrolysis char and gases are combusted in a CHP boiler, and reaction is heat is provided by boiler sand.

Table 2. Moisture contents and heating values of the feedstocks

HHV of dry feedstock	MJ/kg	20.2
Moisture content of as-received feedstock	%	50
LHV of as-received feedstock	MJ/kg	8.2
Moisture content of feed to pyrolysis reactor	%	8
LHV of feedstock	MJ/kg	17.2

Table 3. Mass balance for pyrolysis and heating values for products, base case. Note: efficiency defined for an integrated ITP-process.

FLOWS	WOOD FEED	PRIMARY OIL	TOP PHASE
WET t/h	16.28	5.99	0.67
DRY t/h	8.14	4.35	0.60
Moisture %	50.0	27.5	10.6
LHV MJ/kg	8.2	15.1	25.9
Efficiency % (LHV)	80		

Table 4. Bases for production cost estimates

Feedstock and energy costs	
- feedstock, €/MWh (LHV basis)	8.2
- electricity, €/MWh	35
Labour	
- requirements, persons	8
- costs, including payroll overheads, €/a	33 000
Cost factors	
- annual capital charges factor, (10 % interest, 20 a)	0.1175
- costs for startup, interest during construction, % of plant investment	21
- scale-up exponent	0.63
- maintenance, insurance, overheads, taxes, % of fixed investment	9
- tax rate 40 %	
Operational time, h/a	5000

Production cost estimate is shown in Table 5 using the annuity method to assess capital costs. Top phase of the oil is considered as a by-product, and its value is deducted in the production cost estimate. However, in the base case (Table 3), its value is specified similar to primary oil. The estimated production cost is 7.5 €/GJ (27 €/MWh).

Table 5. Bases for production cost estimates

	M €/a	**€/t**	**€/GJ**	**€/MWh**
FIXED OPERATING COST				
Operating labor	0.25	8.3	0.5	2.0
Maintenance labor	0.08	2.8	0.2	0.7
Overheads	0.17	5.6	0.4	1.3
Maintenance materials	0.25	8.4	0.6	2.0
Taxes, insurance	0.17	5.6	0.4	1.3
Others	0.08	2.8	0.2	0.7
	1.00	33.5	2.2	8.0
VARIABLE OPERATING COST				
Feedstock	1.52	50.6	3.4	12.1
Electricity	0.27	9.0	0.6	2.1
	1.79	59.6	3.9	14.2
CAPITAL CHARGES	1.24	41.3	2.7	9.8
BY-PRODUCT	-0.65	-21.6	-1.4	-5.2
PRODUCTION COST	3.38	112.8	7.5	26.9

Using 8.3 €/GJ (30 €/MWh) as a value for the liquid biofuel, and with the parameters listed above in Table 4, an internal rate of return of 10 % is calculated (pre-tax). IRR as a function of product price, liquid yield, and capital cost are presented in Figures 10 - 12. It is seen that IRR is especially sensitive for sales price and yield and to a lesser extent to investment cost.

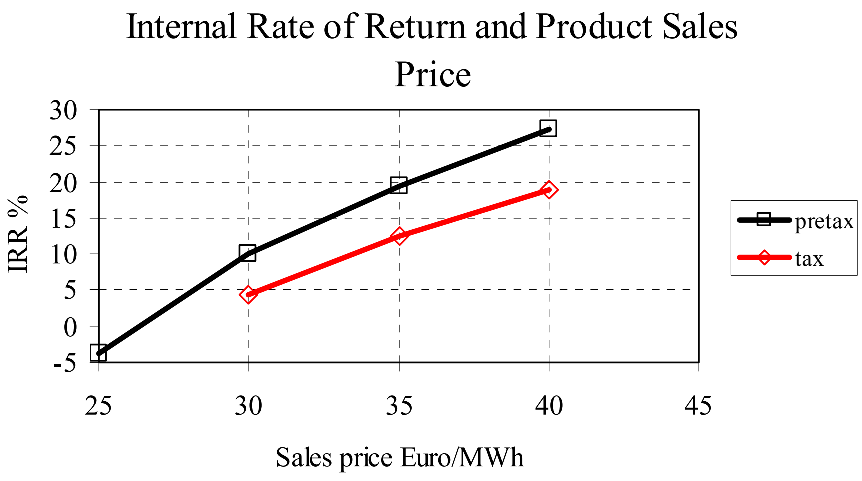

Figure 10

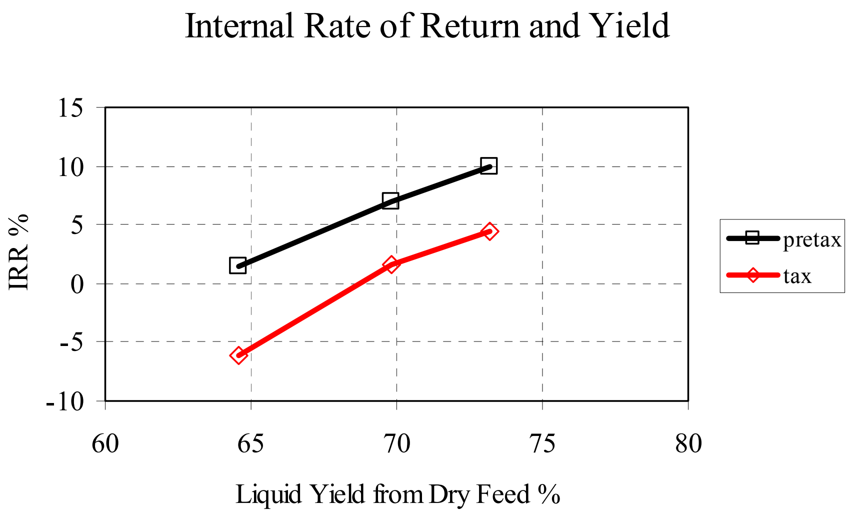

Figure 11

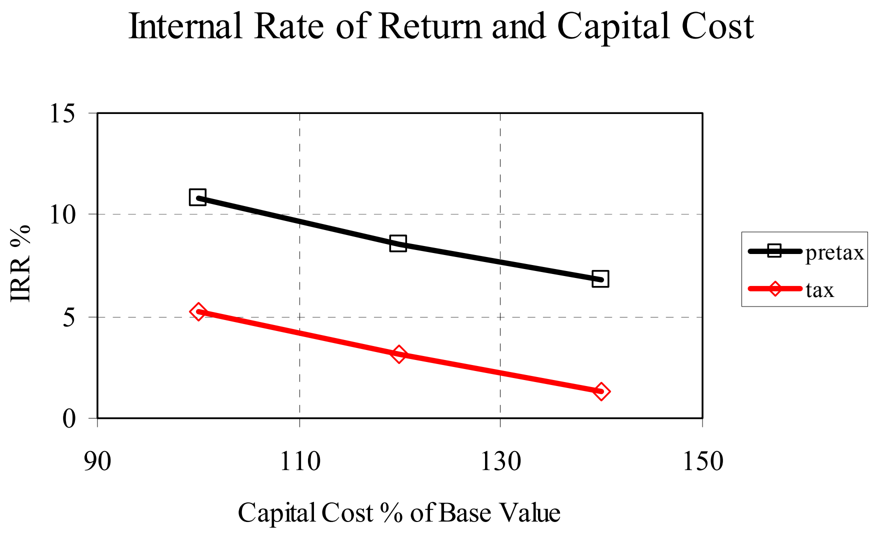

Figure 12

A summary of the economic and technical challenges for pyrolysis liquid utilisation is shown in Figure 13.

Forestera™ Challenges

Economics

- cost competitive with HFO in special markets only e.g.Sweden and Denmark, in other markets must compete with higher quality LFO
- requires special handling: acid resistance pumps, valves, fuel lines, storage tanks

New Fuel Unknown in Market Place

- associated with wood tars which have health and safety issues
- requires long term testing in heating applications
- due to rapid process conditions, fuel is not fully stable and requires special handling

Oil and Gas Oy/Oil R&T/Forestera

Fortum

Figure 13