CASE STUDY ON
LAHDEN LAMPOVOIMA GASIFICATION PROJECT
KYMIJARVI POWER STATION, LAHTI, FINLAND

For

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By

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BACKGROUND

Lahden Lämpövoima Oy (LLV) is a Finnish power company (established 1971) producing power and district heat for the city of Lahti. LLV was originally owned by the city of Lahti and Imatran Voima Oy (now Fortum). Since 2000, however, LLV has been owned by Lahti Energia Oy. Because of the high availability of biomass/waste fuels within 50 km of most power plants in northern Europe/Scandinavia--typically up to 150 MW--the owners of this plant decided to construct a circulating fluidized bed (CFB) gasifier to utilize some of this renewable resource, while reducing fuel costs at the plant.

With assistance (25%) from the EU-THERMIE programme (BM 15/96), the CFB gasifier was constructed in 1997, and provided low-Btu gas to the coal boiler in January 1998. Commercial demonstration of the gasifier started in March 1998. The goal of the project was to demonstrate on a commercial scale the direct gasification of wet biofuel/waste, and combustion of hot raw product gas (low calorific value) in the existing conventional pulverized coal-fired power plant. Project partners included:

- Lahden Lämpövoima Oy, Finland, as the project coordinator and plant operator;
- Foster Wheeler Energy Oy, Finland, for design and construction of the CFB gasifier;
- Plibrico Ab, Sweden, for supply/installation of refractories;
- Elkraft, Denmark, for project monitoring and dissemination; and
- VTT Energy, Finland, for project monitoring and dissemination.

In addition, Roxon Oy (Sandvik) supplied/erected the feed preparation and handling system.

TECHNOLOGICAL DETAILS

Kymijärvi Power Station

The Kymijärvi power plant was originally commissioned in 1976, as a heavy oil-fired unit. In 1982 the unit was modified for pulverized coal firing. The boiler is a once-through Benson-type unit. Steam production is 125 kg/s at 540ºC/170 bar and 540ºC/40 bar, and the plant produces district heat for the city of Lahti and electric power for the owners. Maximum output is 167 MWe/240 MWth. The unit operates about 7 000 h/a, and is usually shut down in the summer when demand is low. In spring and autumn the plant is operated at low capacity using natural gas as the main fuel.

In 1986 a gas turbine/generator set was installed, producing a maximum of 49 MWe at an outside temperature of -25ºC. Exhaust heat from this unit is used via a heat recovery boiler preheat the boiler feed water. In summer, when the main boiler does not operate, turbine exhaust heat is transferred from the heat recovery boiler into district heating water through a separate district heat exchanger.

The boiler uses about 1 200 GWh/a (180 000 t/a) of coal and about 800 GWh/a of natural gas. The boiler is equipped with an electrostatic precipitator, but not with a sulphur removal system; however, the sulphur content of the coal used varies between only 0.3 to 0.5%. Flue gas recirculation/staged combustion are provided to lower NOx emissions.

Circulating Fluidized Bed Gasifier

The gasifier concept employed at Lahti is quite simple. The circulating fluidized bed gasification system consists of a steel reactor, a uniflow cyclone and a return pipe, all refractory lined. Preheated gasification air, blown with a high-pressure air fan, enters the gasifier vessel at the bottom via an air distribution grid. Velocity of this air is sufficient to fluidize solid particles making up the bed. The bed expands and individual particles move rapidly, some conveyed out of the reactor into the uniflow cyclone. In the uniflow cyclone, gas and circulating solids flow downwards, with solids flowing down the return pipe, and gases going into the air preheater.

In normal operation, the fuel feed rate defines the capacity of the gasifier, while the air feed rate controls the gasifier temperature. Fuel is fed to the gasifier above the air distribution grid. This fuel is less than 5 cm in major dimension, and typically contains 20-60% moisture, 40-80% combustibles, and 1-2% ash.

Typically, the gasifier operating temperature is in the range of 800ºC-1000ºC, dependent on the fuel. As fuel particles enter the gasifier, rapid drying takes place, and the primary phase of reaction, pyrolysis, occurs. This involves driving off of volatiles and conversion of fuel particles into gas, char and tars. Some of the char falls to the bottom of the bed, where it is combusted, generating CO, CO_2 and heat. These products flow up the reactor, where secondary reactions occur: heterogeneous (char and gas); and homogeneous (gas only) reactions. These reactions result in production of a combustible product gas which enters the uniflow cyclone, and leaves with a small percentage of fine dust.

Solids (mainly char) are separated in the cyclone and return to the gasifier bed near the bottom. Combustion of this char in the oxygen-rich fluidizing air stream produces the heat required for the previously mentioned pyrolysis, heterogeneous and homogeneous reactions to occur. Coarse ash accumulates at the bottom of the gasifier, and is removed with a water-cooled bottom ash screw.

The produced combustible gas enters a heat exchanger, lowering its temperature somewhat while preheating the fluidization air. The gas is then transported through a duct to two burners located below the coal burners in the main boiler. These burners are of a unique design developed through pilot-scale combustion tests and CFD modelling. Originally, it was envisioned that the burners would be placed above the coal burners, in the reburning mode, to control NOx; however, pilot testing showed that maximum heat and residence time for impurity destruction were produced with the gas burners below the coal burners. Figures 1-3 illustrate the gasifier and its connection to the boiler.

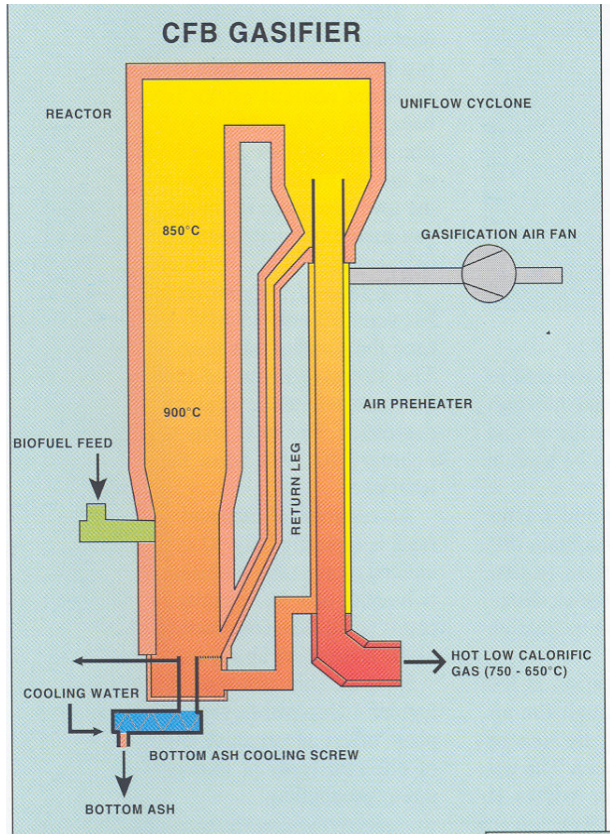

Figure 1. Cross-section of Lahti Gasifier

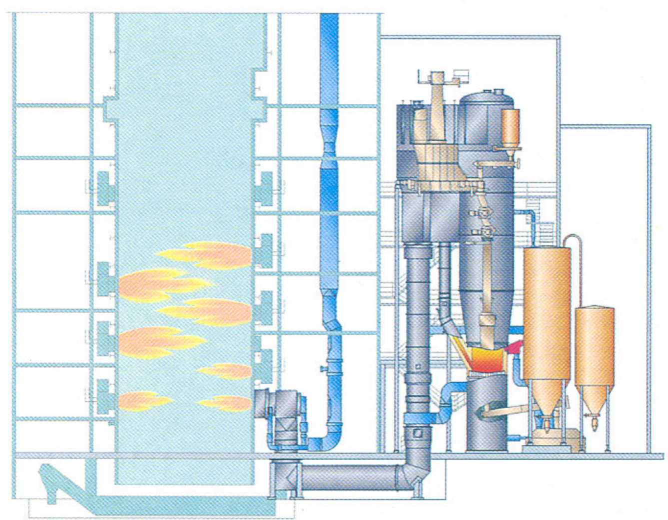

Figure 2. Gasifier Connection to Lahti Boiler

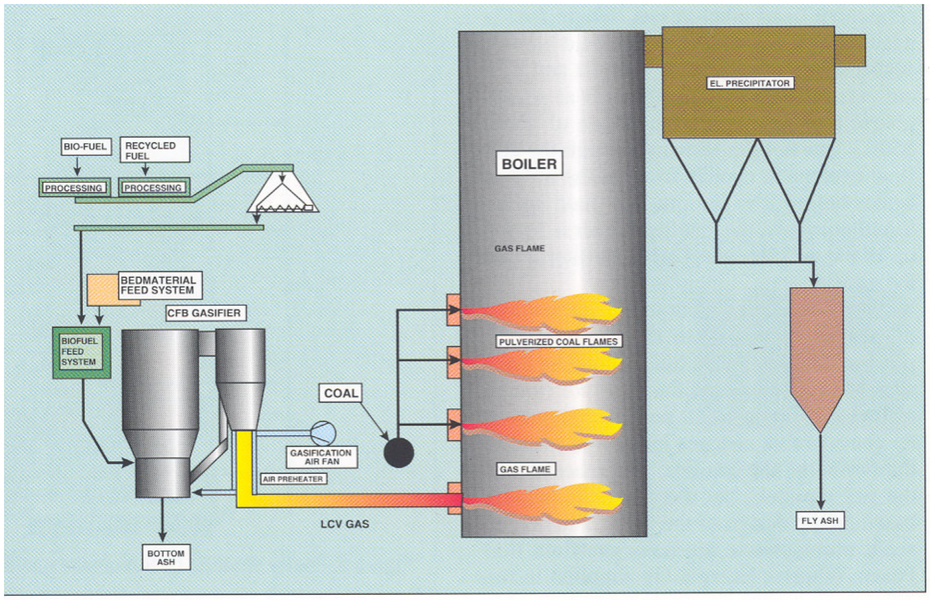

Figure 3. Simplified Plant Schematic

Fuel Preparation and Handling

The entire fuel preparation and handling system at the Lahti plant was supplied in 1997-early 1998 by Roxon Oy (a Sandvik company). The system handles two types of fuel—recycled energy fuel (REF) and biofuel—and blends the two prior to the gasifier. REF processing from source-separated waste was begun in 1997 by the municipally-owned waste management company Päijät-Hämeen Jätehuolto Oy. Components and operation of the fuel preparation/handling system are as follows:

- REF and biofuel are received in two separate receiving stations, specifically designed for rear unloading transport vehicles.
- REF is tipped onto the floor of the receiving station from where it is pushed via a bucket loader onto an apron conveyor feeding the primary shredder. The primary shredder (Roxon MNR) is hydraulically driven, and has a capacity of 150 m^3/h of REF and 50 m^3/h of wood waste.
- Biofuel is discharged from its own receiving station through a disc screen onto a conveyor starting below the primary shredder in the REF receiving station. The conveyor takes this material and the precrushed REF through magnetic

separation, screening and secondary shredding. The secondary shredder (Roxon MNL) is electric motor-driven, with a capacity of 50 m^3/h.

- From secondary shredding, material at the final product size is conveyed to the intermediate storage building.
- A traveling screw reclaimer at the floor of the intermediate storage building discharges material, along the full length of the building, onto a belt conveyor, and further onto chain conveyors to the gasifier feed bins. Material flow from intermediate storage to the gasifier bins is completely automated. Bin level indicators control operation of the discharging screw reclaimer and subsequent conveyors, while speed is adjusted with a frequency converter. The reclaimer operates in such a way that the fuel is optimally homogenized for downstream gasification.

Figures 4 and 5 illustrate salient features of the preparation/handling system.

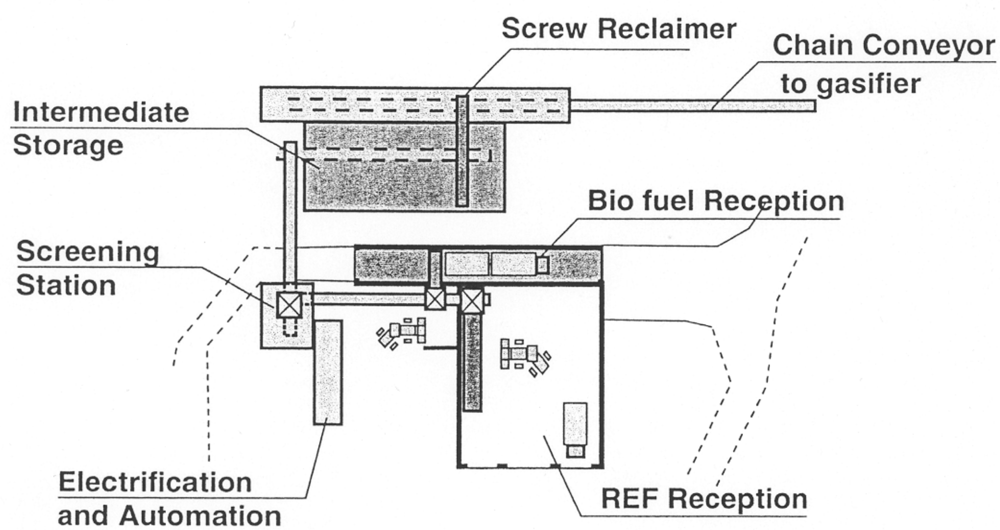

Figure 4. Reception/Handling System at Lahti

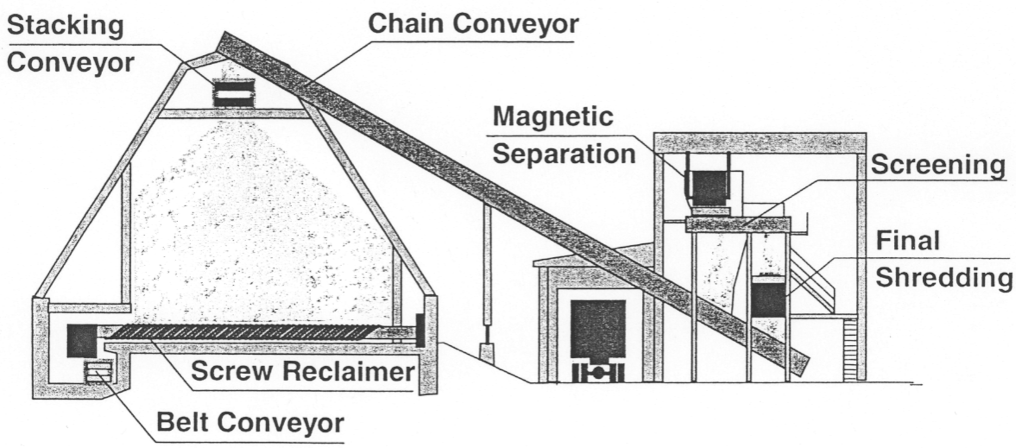

Figure 5. Lahti Fuel Preparation System

FUEL CHARACTERISTICS

It is estimated that about 300 GWh of biofuels and REF are available annually within easy transportation distance of the Lahti plant. Transportation distance is of prime importance, as the energy density of fresh biofuel is less than 1/10 that of coal (2.5 GJ/m^3 vs 30 GJ/m^3), requiring that more than ten times the volume be transported to supply the same heat content. The approximate biofuel split for the Lahti plant is as follows:

Table 1. Current Lahti Fuel Quality/Mix

Fuel	Weight % of Total	Weight % Moisture
Sawdust	10	45-55
Bark, wood chips, etc.	40	45-55
Woodworking wastes (plywood, particle board, etc.	30	10-20
REF	20	10-30

REF, processed by municipally-owned Päijät-Hämeen Jätehuolto Oy, is composed approximately of the following components:

Table 2. REF Composition

Component	Weight %
Plastics	5-15
Paper	20-40
Cardboard	10-30
Wood	30-60

Other fuels such as peat, demolition wood waste and shredded tires have also been used occasionally as gasifier feed. Boiler fuels typically comprise 1 200 GWh/a (180 000 t/a) coal and 800 GWh/a natural gas, on a thermal basis. Thus, on an annual basis, biofuels substitute for about 15% of total boiler input fuel, and can equal up to 30% of the coal used. The gasifier itself is designed for a capacity of 45-70 MWth, depending on the composition and moisture content of the feedstock. Produced gas has a typical heating value of 2.0-3.5 MJ/Nm^3. This can rise to as high as 4.5 MJ/Nm^3 when moisture is low and the proportion of plastics is high.

Since commercial operation began in March 1998 to the end of 2001, the gasifier has operated for 22 000 h, gasified 394 000 t of biofuel, and produced 1310 GWh (on a thermal basis. Availability, energy production and fuel components used are summarized in the following table:

Table 3. Operating Record of the Lahti Gasifier

	1998	**1999**	**2000**	**2001**
Operating hours	4730	5460	4727	7089
Availability, %	81.8 (99.3)*	98.9	97.1	96.1
Energy production, GWh	223	343	295	449
Fuel, wt%				
Biomass	71	57	63	61
Plastics	--	13	7.4	12
Paper	--	6.0	0.1	0.3
Railway ties	5.5	0.1	0.2	--
Shredded tires	1.5	0.9	--	--
REF	22	23	29	26
Total, t/a	79 900	106 200	91 800	116 100

PERFORMANCE

Environmental

Table 4 summarizes the changes in environmental emissions from the main boiler at Lahti as a result of cofiring gas produced in the gasifier. The fact that CO emissions did not change, indicates that there has been no degradation in combustion caused by cofiring the produced gas. Reductions in NOx and particulates can be attributed to moisture in the product gas. Moisture content slightly lowers the flame temperature in the boiler, reducing NOx while moisture in flue gas enhances performance of the electrostatic precipitator, reducing particulates emissions. Other changes result from increases (e.g., Cl) or decreases (e.g., S) of a particular element in the biomass/waste feedstock compared to the coal/natural gas used.

Table 4. Effect of the Gasifier on Main Boiler Emissions

Emission	Change Caused by Gasifier
NOx	Decrease by 10 mg/MJ (5-10%) [current limit - 240 mg/MJ]
SOx	Decrease by 20-25 mg/MJ [current limit - 240 mg/MJ]
HCl	Increase by 5 mg/MJ (base level low)
CO	No change
Particulates	Decrease by 15 mg/Nm^3
Heavy metals	Slight increase in some elements (base level low)
Dioxins/furans	No change
PAHs	No change
Benzenes	No change
Phenols	No change

Table 5 lists typical trace pollutant concentrations in the product gas when gasifying non-contaminated feedstocks. Contaminated fuels generally increase concentrations of ammonia, hydrogen cyanide and alkalis. For example, gasification of gluelam can increase ammonia to 3 000-5 000 mg/m^3, HCN to 200-300 mg/m^3 and total alkaline content to 0.3 ppmw.

Table 5. Typical Trace Pollutant Concentration of Product Gas

Gas Component	Concentration Range (mg/m^3, dry)
NH_3	800-1 000
HCN	25-45
HCl	30-90
H_2S	50-80
benzene	7-12
tars	7-12
alkalis	<0.1
particulates	6-10

Bottom ash from the gasifier consisted mainly of bed sand and limestone plus small amounts of metal chunks and concrete, etc. Carbon content was typically less than 0.5%, and chlorine levels were negligible. The ash also contained trace amounts of certain heavy metals; however, leachability was low.

Gasifier ash makes up only a small proportion (3-5%) of total main boiler ash and, therefore, has little effect on quality. Unburned carbon and alkali levels were unchanged, but some heavy metal levels increased slightly, depending on the type of feedstock. For example, zinc content increased when shredded tires were gasified. No changes in trace organics, such as dioxins, were detected. Leachability test results were satisfactory, and the plant is permitted to use boiler ash as before.

Energy Balance

Efficiency of biomass/waste conversion to electricity is very nearly equivalent to that of the coal-fired unit itself. Based on a 15% fuel substitution by waste/biomass gas, it has been reported that net thermal efficiency for electricity production was reduced only from 31.3% to 31.1% and, for district heating, from 49.9% to 49.4% (on a HHV basis). One reason this occurs (despite the increased product gas moisture content and flue gas nitrogen content) is increased flame radiation in the furnace, and an improvement in the effectiveness of the convective heating surfaces through the back passes of the boiler and the superheater. Other explanations are, of course, possible.

During the site visit, the following operating data were recorded for the gasifier:

Input:

- 5.09 kg/s feed at 10.3 MJ/kg and 32.8% moisture (52.4 MWth)
- 3.45 Nm^3/s air at 365ºC (heat-exchanged with product gas)

Output:

- 19.2 Nm^3/s product gas at 2.48 MJ/Nm^3, 6 mbar and 810ºC (47.6 MWth)

Product gas enters the boiler, in equal streams, through two bottom burners at 712ºC, after heat-exchange with the input air stream. This gas has the following composition:

- CO – 9.6%
- CO_2 – 12.3%
- CH_4 – 3.3%
- H_2 – 6.7%
- H_2O – 35.0%
- Balance N_2

The overall energy balance (52.4/47.6) is 90.8%. The operator reported that the usual gasification efficiency is approximately 92%.

Problems and Successes

While the product gas has been reported (Table 5) to contain dust and tar, alkali, ammonia, and HCN, performance has not been adversely affected. In corrosion probe monitoring tests of the boiler, no indication of abnormal deposit formation, fouling or corrosion could be seen. Inspection of the boiler heat transfer surfaces (furnace walls, superheater, economizer and air preheater) showed no abnormal deposit formation or high-temperature corrosion.

Stability of the steam cycle, coal burners and product gas burners has been excellent. The large openings made to accommodate the product gas burners have caused no disturbance in the water circulation. Operation of these burners has been good: combustion of the low-Btu, high-water content product gas has been stable. Operating temperatures, pressures, flows and gas compositions were very close to design values.

Because of the excellent process behaviour of the gasifier and low impact on emissions, Finnish authorities have set no limitations on applicable feedstocks or utilization of ash (very low trace metal leachability). All fuel fractions that have been tested in the gasifier are currently permitted by the Finnish regulators to be used at the plant.

Due to fuel shortages and problems in the fuel preparation plant at times during the first year of operation, the gasifier was occasionally operated in the combustion mode. In this mode, normal temperatures (840-850ºC) are maintained in the gasifier while the fuel feed rate is minimized to 5-7 MWth.

Use of shredded tires as gasifier fuel has caused operational problems. Because there is no magnetic separation after the shredder, accumulation of tire wire occasionally blocked the ash extraction system, resulting in gasifier shutdowns. Other problems have included faults in fuel reception, fuel feeding, automation, and fuel quality and particle size. These have all been corrected satisfactorily.

CAPITAL, OPERATING AND MAINTENANCE COSTS

Total capital cost of the Lahti gasification project was about 12 MEUR. This figure included fuel preparation, civil works, the gasifier, instrumentation and control, electrification, and modifications to the main boiler. Of this amount, 3 MEUR (25%) was received under the EU THERMIE Programme. It has been reported that Foster Wheeler would charge a higher price for a second unit. This would suggest that FW had a vested interest in seeing the first-of-a-kind plant succeed both technically and economically.

A number of studies, comparing projections for plant costs and other factors for different cofiring options, have been undertaken. Two of the more interesting studies are presented below. In Table 6, a base case plant of 600 MWe and 40% efficiency (LHV) is considered, with 10% substitution of coal by biomass.

Table 6 indicates that thermodynamic projections and economics favour direct co-combustion in the coal boiler. This is not always possible for logistical/operational reasons (adequate feed supply at reasonable cost, ash marketability, etc.). Economic calculations at this scale (60 MWe) show that the Foster Wheeler concept used at Lahti is the next best method of cofiring.

Table 6. Cofiring Predictions for Base Case Coal-fired Power Plant

Concept	Net Electrical Efficiency (%LHV)	Specific Additional Investment Cost (EUR/kWe)
Direct co-combustion	39.5	40
Upstream gasification (FW)	38	455
Upstream slow pyrolysis	32.5	1240
Upstream separate combustion with steam-side integration	38.5	940

Table 7 compares capital and operating cost projections for a 20 MWe biomass plant. In this analysis, the following assumptions have been made:

- Cost of capital – 10.3%
- Cost of biomass – zero
- Operating cost – 0.36 MEUR/a
- Maintenance cost – 2.5% of investment cost/a
- Overhead – 40% of O & M costs
- Coal cost – 50 EUR/t
- O & M and depreciation of existing coal-fired plant – 0.018 EUR/kWh
- Operation – 7 500 h/a

Table 7. Capital and Operating Costs for 20 MWe Biomass Plant

Concept	Specific Investment (EUR/kWe)	Total Cost (MEUR)	Annual Cost (MEUR/a)	Electricity Cost (EUR/kWh)
Direct cofiring	680	14	0.45	0.021
Upstream gasification	1270	25	1.7	0.029
Upstream combustion (steam-side integration)	1360	27	1.8	0.030

Once again, direct cofiring (if feasible) is the cheapest option, with upstream gasification rating second. Table 7 costs are higher than projections in Table 6 because of the smaller plant scale.

Note in Tables 6 and 7 that all cost projections are based on economic factors and estimates specific to their study authors, and are inserted here to represent trends rather than firm quotes.

For the same 20 MWe biomass plant as outlined in Table 7, the following capital, operating and maintenance breakdown has been developed (MEUR/a, unless otherwise indicated):

- Capital charge – 2.7
- Personnel – 0.36
- Maintenance – 0.68
- Overhead – 0.41
- O & M sub-total – 1.5
- Biomass – 0.0
- Avoided coal – (2.5)
- Fuel sub-total – (2.5)
- Total costs – 1.7
- Electricity cost (gasifier contribution) – 0.011 EUR/kWh
- Electricity cost (coal boiler contribution) – 0.018 EUR/kWh
- Total electricity cost – 0.029 EUR/kWh

Fuel costs at Lahti depend on the type and quality. Forest residue is purchased for 7 EUR/MWh (LHV), while REF costs 2-3 EUR/MWh. Feedstocks are tested for chlorine content, and payment is on a sliding scale, with a tipping fee (also varying) applicable when chlorine content exceeds 0.5%. Coal currently consumed at the plant costs about 12 EUR/MWh.

Four employees currently operate the plant. With a modern computer control system, three employees would suffice. One operator is in charge of the gasifier and boiler, and sits in a combined control room. Thus with no dedicated personnel, and fuel cost savings, operating costs approach zero.

FUTURE PLANS

As the plant now stands (biomass and REF gasification), it cannot meet the EU Directive. It is understood that regulations (WID) will lower allowable NOx emissions from the current 400 to 200 mg/Nm^3 when cofiring with waste-derived gas. While the gas lowers NOx somewhat, that level cannot be met (even by the boiler burning coal only). Gasifying biomass only will meet the Directive. Therefore, one option for the future is to discontinue the use of REF. A green power initiative currently pays a bonus of 0.4 EUR cents/kWh for biomass electricity (district heating does not qualify). Under current operation, Lahti does not receive the green power bonus – a disincentive to continue gasification of REF.

A second option, with REF gasification included, is to clean the gas prior to its injection into the boiler. A NOx removal scheme is required. Lahti and VTT are currently investigating various methods, including additives, process units and operating conditions to achieve gas clean-up economically. The incentive for this is the cost differential of 9-10 EUR/MWh between REF and coal, but it is unclear at this time how much of an effect the de-NOx method will have on plant economics. Because of the sensitive nature of this work, and the potential value of intellectual property aspects, these investigations are proceeding under a secrecy agreement, and no further details have been published.

CONCLUSION

"The gasification concept offers an efficient use of biofuels and recycled refuse fuels, with low investment and operation costs, and the utilization of the existing power plant capacity. Furthermore, only small modifications are required in the boiler and possible disturbances in the gasifier do not shut down the whole power plant." [Palonen and Nieminen, Foster Wheeler Review, Summer 1999].

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