IEA Bioenergy Agreement

Task 33: Thermal Gasification of Biomass (2001-2003)

Technology Brief

Fuel gas co-firing

Prepared by KEMA by order of Novem

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Introduction and Background

This subtask describes the current status, the (non-)technical barriers and new development in the area of fuel gas co-firing in pulverised and gas-fired power plants. Figure 1 shows the different routes for fuel gas co-firing that are commercially operated or under development.

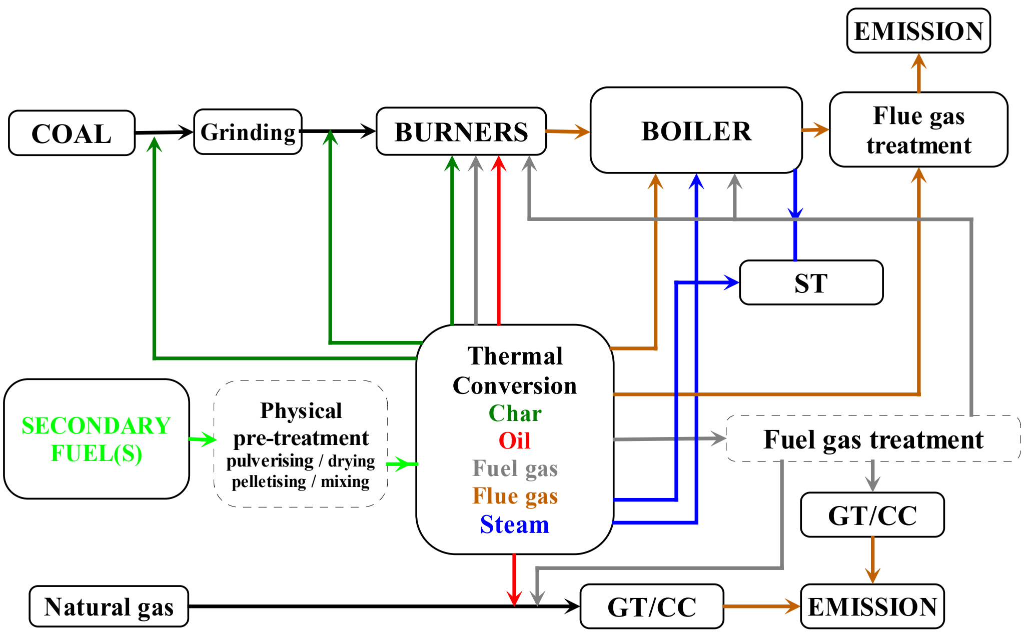


Figure 1 Routes for fuel gas co-firing in coal and gas-fired power plants

Fuel gas co-firing offers high efficiency utilisation of local fuels due to its connection with a large boiler operating at higher steam conditions, a reduction of the fossil fuel input, higher fuel flexibility, high plant availability and the utilisation of existing power plant utilities. However, in order to be economically feasible, up to this day fuel gas co-firing needs renewable energy incentives to be paid from the power generated from the fuel gas or tax advantages for the use of renewable fuel.

State-of-the-Art of Fuel Gas Co-firing

Fuel gas co-firing in pulverised coal-fired power plants is in commercial operation in the range of 10 to 100 MW_{th} fuel input at a number of full-scale coal-fired power plants (for example Lahti, Zeltweg, Vermont and Amer), with a wide variety of fuel input (bark, sawdust, REF, aluminous plastic waste, (waste) wood). The 50 MW_{th} input CFB gasifier at the power station in Ruien, Belgium was most recently added to the list presented in table 1. For more detailed information on these projects see the attached fact sheets. Varkaus burns the fuel gas not in combination with a PC fired boiler but is added to the list because it represents a development which is clearly of interest for fuel gas co-firing

Table 1 Fuel gas co-firing projects

unit	capacity (MW_e)	co-firing unit		
		fuel	**capacity MW_{th} input**	**status**
Amergas NL	600 + 350 th	Demolition wood	83	Operational
Lahti SF	167 + 240 th	Demolition wood, peat, REF, tyres	40 70	Operational
Ruien B	250	Clean wood chips	50	Operational
Varkaus SF		plastic waste	40	Operational
Vermont US	50	tree wood chips, waste wood	30	not in operation
Zeltweg A	137	bark, sawdust, wood	10	not in operation

Currently, the Vermont and Zeltweg gasifiers are not in operation. This is not related to the technical performance of the gasifiers but has to do with economic considerations.

Thus far, the big breakthrough of fuel gas co-firing has not been achieved. This is partly due to technical barriers but, most certainly, also to economic and political barriers. In many countries environmental and tax systems are undergoing review and changes, making the investment climate too unstable for new initiatives. From a technical point of view fuel gas cooling and cleaning has recently proven to be a hard technical barrier to overcome.

Fuel gas co-firing in gas-fired boilers is not yet in commercial operation. In the Netherlands fuel gas co-firing at the 1700 MW_e gas-fired Eems power station is still in the planning phase. Many studies are (or have been) conducted on the effect of co-firing fuel gas with natural gas and its effect on the combustion behaviour of the gas turbine. Furthermore, fuel gas reburning is receiving considerable attention. Although co-firing of fuel gas and natural gas is technically feasible, the major barrier for this application is the high level of gas cleaning that is required for this type of operation. Furthermore, the economic feasibility is uncertain due to the low gas prices and the high investments needed for this type of installation.

The Lahti concept - gasification with almost direct combustion of the raw fuel gas in the main boiler - has proven to be successful. Attempts to introduce more sophisticated fuel gas cleaning systems in the Amer project (and also in the stand-alone Arbre gasifier) have led to serious problems in the gas cooling section. This has led to a major reconstruction of the Amer fuel gas-cleaning concept to a system with only limited gas cooling and partial dedusting before the raw fuel gas is fed to the main boiler.

Table 2 Fuel gas quality and effect on boiler emissions (compared to coal)

	Fuel gas quality MJ.Nm^{-3}	**Effect on boiler emissions**
Lahti	1.6 – 2.4	NOx decrease by 10 mg/MJ SOx decrease by 20-25 mg/MJ Particulates decrease by 15 mg/Nm^3 HCl increase by 15 mg/Nm^3
Ruien	3 – 4	NOx no influence SOx decrease Particulates no influence HCl unknown at present
Varkaus	Not available	Not available
McNeil	17	Not available
Zeltweg	1.6	Small decrease in SOx Significant decrease in NOx (10-15 % less NH_3 required in SNCR to meet emission requirements)
Amer	Not yet available	Not yet available

Technical and Non-technical Barriers

The main technical and (non-)technical barriers specifically related to fuel gas co-firing in large pulverised coal or gas-fired boilers are listed below (for large-scale CFB gasification applications in general these barriers have already been listed in the technology brief of VTT).

Technical Barriers

- Fuel gas cooling and fuel gas cleaning. There have been serious problems with plugging and fouling the gas cooling and cleaning system with the ashes and tars produced in the gasification process.
- Application of the produced by-products. The ashes that are being separated before entering the main boiler (will) have to meet strict national and international (EURAL) standards in order to be used in certified applications. In spite of the limited fuel gas cleaning in place unacceptable contamination of the coal ash must be avoided. The wastewater produced in wet gas cleaning systems is very specific and has to be significantly cleaned before disposal. There is little experience on this matter.

- Due to the above-mentioned limitations, (future) emission legislation and the restrictions placed on the fuel gas quality before application in the main boiler, currently a limited fuel package can be gasified and co-fired when making use of this route.
- The effects on the main boiler when co-firing raw fuel gas (for instance slagging or fouling of biomass ash, corrosion by HCl or heavy metals, NO_x formation).
- Emissions and its effect on flue gas treatment system (SCR). New (future) EU directives on emissions, for example 200 mg/Nm^3 NO_x and SO_2.

Non-technical Barriers

- Permitting procedures. Seeking permits for power plants applying biomass or secondary fuels is, in many countries, a time-consuming task with many problems to be faced.
- Several economic factors play a role:
  - the availability and increasing price of clean biomass fuels
  - the reimbursement of green electricity price being too low or non-existing in some countries when making use of this route
  - the competition with (much) cheaper direct co-firing
  - the unstable investing climate due to national and international policy (changes).
  - how to determine and obtain CO_2 credits.

Recent/New Developments in Fuel Gas Co-firing

Due to the problems in the fuel gas cleaning, the Amer wood gasifier gas clean-up has been reconstructed. The raw fuel gas is cooled to 500 °C, partly dedusted in a cyclone and, subsequently, fired in the 600 MW_e coal-fired boiler. The reconstructed plant has been in operation since the beginning of 2003. The first results are positive.

In January 2003 Electrabel successfully put a Foster Wheeler built 50 MW_{th} input waste wood CFB gasifier into operation at its coal-fired power plant in Ruien, Belgium. FW is developing new gas cleaning concepts for more extensive fuel gas cleaning.

Principal Technology Developers with Contact Details

See country report September 2002 and www.gasifiers.org.

Subtask Co-ordinator Concluding Remarks

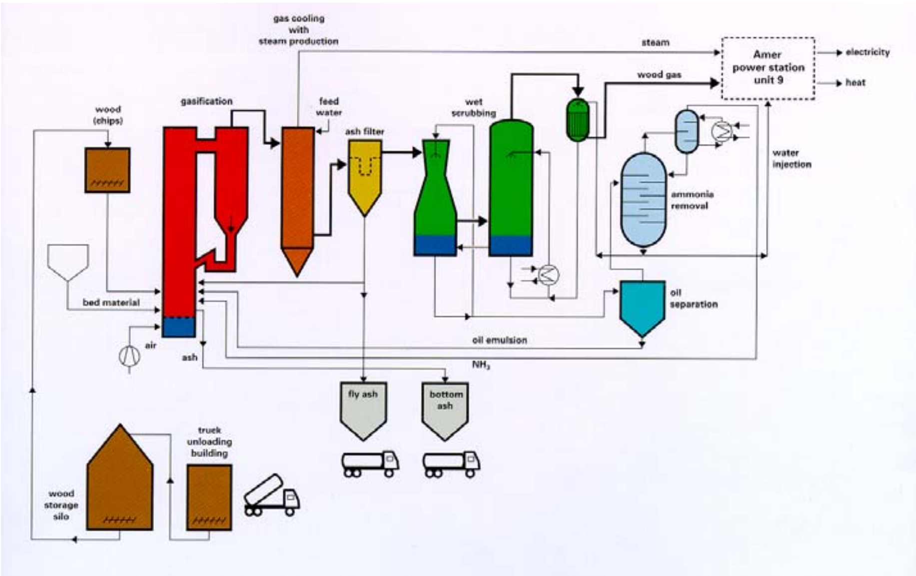
This short review on fuel gas co-firing in pulverised coal and natural gas-fired boilers shows that there is a lack of scientific knowledge on several aspects within this process. Most technical problems are related to the gas cooling and cleaning process, thus hindering the use of less clean fuels, which would make this application both technically and economically more attractive in comparison with, for example, direct co-firing.

Until these matters have been straightened out, it will not be possible to fully exploit all it's the potential benefits of fuel gas co-firing, which are more and more essential to the investors of this technology.

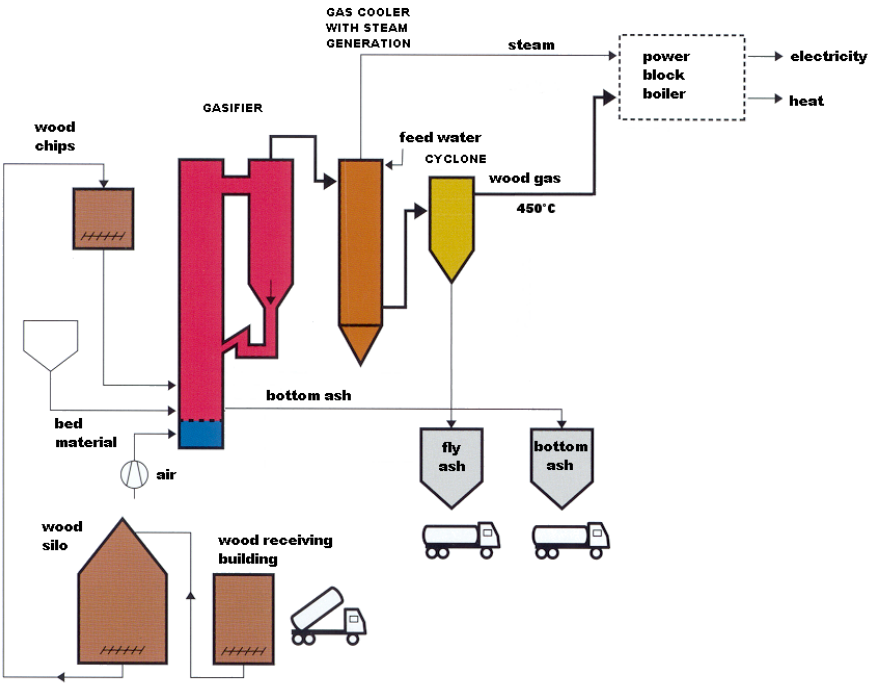
Name of plant	Amer–9
Location of plant	Geertruidenberg
Country	The Netherlands
Licensor/consortium	Essent
Building consortium	Lurgi, Siemens
Principal co-firing technology supplied by	Lurgi
Start of operation (date)	December 2002
Contact person(s)	Dr. W. Willeboer
Website	-
References	-
Capacity (MW_{th} input)	83
Thermal efficiency (%)	40 (E)
Net output generated (MW_e) by • **main unit** • **fuel gas combustion**	 600 MW_e 34 MW_e
Co-firing and main fuel(s)	B-wood (demolition wood)
Product(s)	Electricity / Heat
Price of generated electricity (EURct/kWh)	?
Short Process Description	

In the original set-up of the Amer gas project the fuel is gasified in a CFB gasifier (atmospheric pressure, 850°C). The fuel is pre-treated (size reduction) to meet the gasifier specifications (particle size distribution is up to 50 mm, moisture content < 20%). After gasification the raw fuel gas is cleaned in a low-temperature (LT) gas clean-up section (baghouse filter, scrubber), after which the clean fuel gas (5–6 $MJ.Nm^{-3}$) is combusted in the coal boiler via specially designed low calorific gas burners. About 150,000 t/a (5% of the total energetic plant input) of demolition wood is co-fired, substituting 70,000 t/a coal and resulting in a CO_2 emission reduction of 170,000 t/a. Features of this concept are: the relatively stringent fuel constraints that have to be met and the relatively high specific additional investment costs. An advantage of this concept is that the main part of the fuel-based contaminants is separated from the fuel gas before entering the coal-fired boiler. This means that a wide range of fuels can be co-fired in this concept, without causing applicable emission constraints and ash quality requirement problems.

Relevant Process Data and Process Scheme



Original scheme of the Amer 9 wood gasifier



New scheme of the Amer 9 wood gasifier

Investment Costs Co-firing Unit

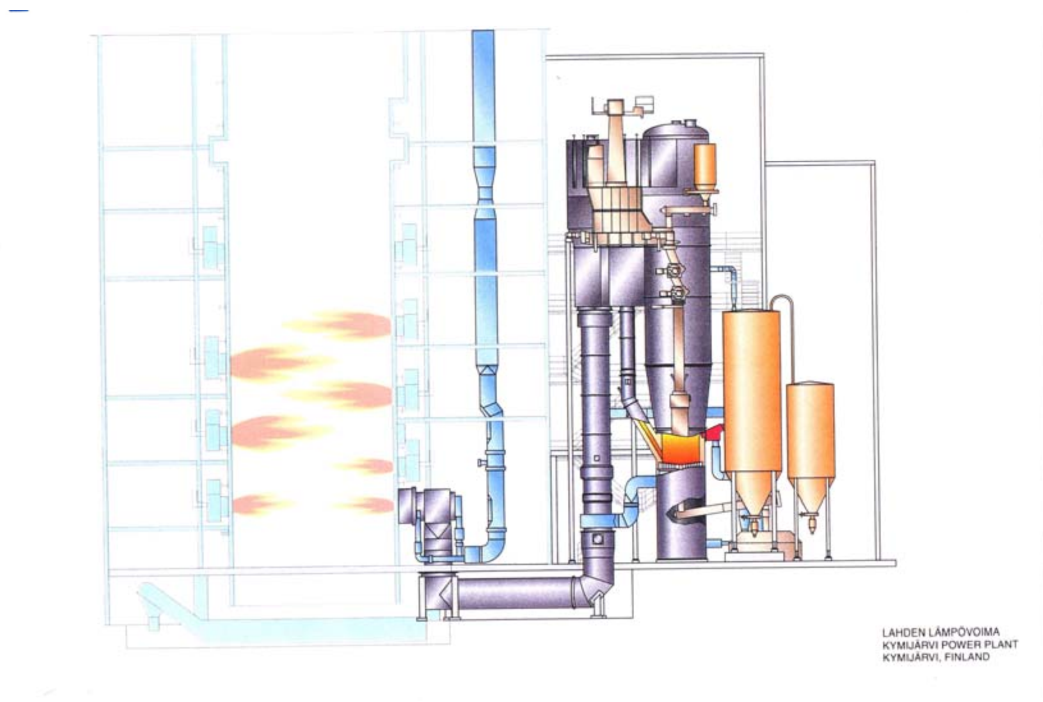
Approximately 1300 EUR/kWe

Status of the Installation
The modified installation has been in operation since December 2002. Results up to now are satisfactory. Operational experience is limited.
Technical and Non-technical Barriers
During commissioning of the Amer 9 wood gasifier it appeared that the syngas cooler suffered from severe fouling, which hampered normal operations. Finally, it was decided to change the process configuration drastically. In the original design the fuel gas was cooled to 200 °C, dedusted via a bag filter and wetly scrubbed to remove halogens and ammonia plus tars. In the new design the gas is cooled to 500 °C, it is partially dedusted by a hot cyclone and combusted as such in the boiler of the Amer 9 unit. This greatly simplifies the gas cooling and the cleaning system, but, on the other hand, reduces the fuel flexibility of the Amer project.

Name of plant	Kymijärvi power plant
Location of plant	Lahti
Country	Finland
Licensor/consortium	Lahden Lämpövoima Oy
Building consortium	Foster Wheeler Energia Oy
Principal co-firing technology supplied by	Foster Wheeler
Start of operation (date)	March 1998
Contact person(s)	
Website	
References	
Capacity (MW_{th} input)	40 – 70 MW_{th} (with moisture content of fuel of 50 – 20%)
Thermal efficiency (%)	depending on moisture content of fuel
Net output generated (MW_e) by • **main unit** • **fuel gas combustion**	max. 167 MW_e and 240 MW_{th} (district heating)
Co-firing and main fuel(s)	demolition wood, peat, REF, shredded tyres. Fuels' main bioler?? are coal and gas
Product(s)	Electricity and Heat
Price of generated electricity (EURct/kWh)	
Short Process Description	

At Lahti different (wet) biofuels are gasified at temperatures around 850 °C in an atmospheric air-blown CFB gasifier. Fuel specifications to be met are less stringent (maximum moisture content; 60%), by which fuel drying will, in most cases, not be necessary, resulting in lower investment costs. The raw fuel gas (typically 1.6 – 2.4 $MJ.Nm^{-3}$) is directly combusted (at 750°C) - without additional fuel gas clean-up and after pre-heating of the gasification air – in special (low calorific) gas burners in the coal-fired boiler. Fuels gasified are wood, demolition wood, peat, REF and shredded tyres. About 15% of the total fuel input (on energy base) consists of biomass and REF, replacing 45,000 t/a coal and reducing 110,000 t CO_2/a.

The gasifier shows some positive effects on the main boiler. The NO_x emission decreases by 10 mg/MJ (5 – 10 %), whereas SO_x decreases by 20–25 mg/MJ and particulates by 15 mg/Nm^3. HCl increases by 15 mg/Nm^3.

Process Scheme

Status of the Installation
The installation has been in commercial operation since March 1998. The operating data over the period 1998-2001 show 21,000 operating hours with an availability (whole plant) of 86.6 %, 1270 GWh (300 GWh/a) produced energy and 384,000 tonnes of gasified fuel
Technical and Non-technical Barriers
Up to now operation of the gasifier and gas burners has been stable and the stability of the steam cycle and coal burners is good. Probe tests or the heat transfer surface never showed any deposit formation or high-temperature corrosion.

Name of plant	Ruien
Location of plant	Ruien
Country	Belgium
Licensor/consortium	Electrabel
Building consortium	Foster Wheeler
Principal co-firing technology supplied by	Foster Wheeler
Start of operation (date)	Beginning 2003
Contact person(s)	Mr P. Houy
Website	www.electrabel.be
References	-
Capacity (MW_{th} input)	50 MW_{th} at 50% moisture content (nominal) 86 MW_{th} at 20% moisture content (maximal)
Thermal efficiency (%)	95 (gasifier only), overall 34%
Net output generated (MW_e) by • **main unit** • **fuel gas combustion**	coal-fired power plant Unit 5 540 MW_{th} on coal 17 MW_e (based upon 50% moisture in fuel)
Co-firing and main fuel(s)	Wood chips from recycled fresh wood, bark and hard and soft board residues and coal
Product(s)	Electricity
Price of generated electricity (EURct/kWh)	Classified

Short Process Description

Wood dust, atmospheric CFB gasification using air, hot and unpurified gas is co-fired.

Relevant Process Data and Process Scheme

In the Ruien gasification installation the raw fuel gas produced in the CFB gasifier is only cooled from roughly 850 to 750 °C, while pre-heating the gasification air (similar as in Lahti) and is, subsequently, directly combusted in the main boiler. Combustion of the fuel gas is performed in the lower part of the tangentially-fired 540 MW_{th} main coal (or optionally oil or gas)-fired boiler. Steam is produced in the main boiler at 540 °C and180 bar. With this installation Electrabel plans to gasify 100 kton/a of wood, leading to 120 ktons of CO_2 reduction and 50 ktons of coal substitution. The main fuel for the gasifier will be wet (up to 50% moisture content) clean wood. Pre-treatment consists of removing metal parts and optionally crushing in order to obtain the required particle size of L+W+H < 150 mm.

Investment Costs Co-firing Unit

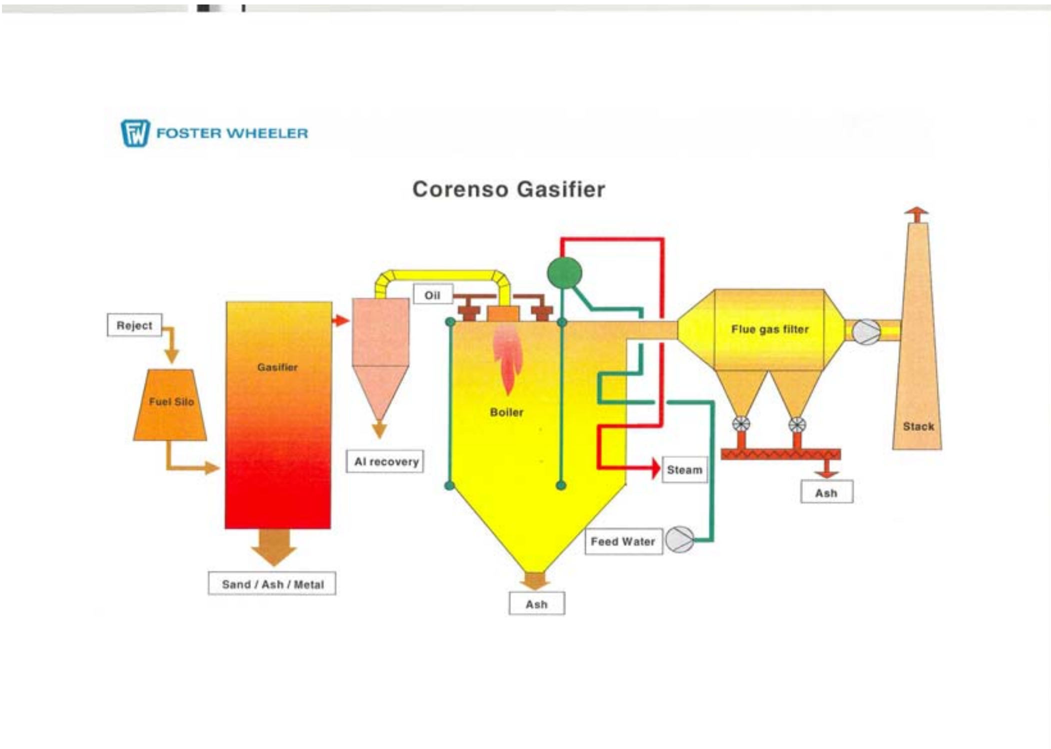
Comparable to those of Lahti

Status of the Installation

Hot start up-in December 2002, Gasification in January 2003. Up to now limited operational experience. Longest run of ten days (not limited by gasification installation).

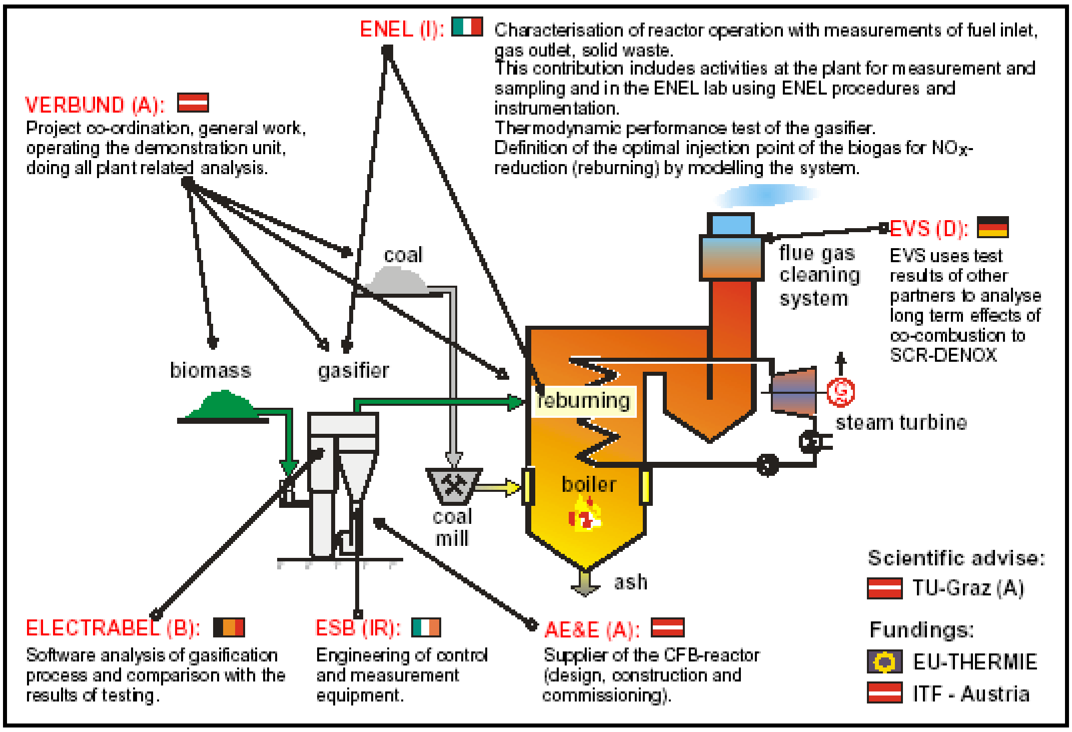
Technical and Non-technical Barriers
Tests planned, for example with lower moisture content in fuel.

Name of plant	Corenso coreboard mill in Varkaus
Location of plant	Varkaus
Country	Finland
Licensor/consortium	Corenso United Ltd
Building consortium	Foster Wheeler Oy
Principal co-firing technology supplied by	Foster Wheeler
Start of operation (date)	commercial operation from Autumn 2001
Contact person(s)	
Website	
References	
Capacity (MW_{th} input)	40
Thermal efficiency (%)	
Net output generated (MW_e) by • **main unit** • **fuel gas combustion**	Fuel oil is substituted by fuel gas
Co-firing and main fuel(s)	Aluminous plastic waste
Product(s)	Heat
Price of generated electricity (EURct/kWh)	n.a.
Short Process Description	
In Corenso aluminous plastic waste – originating from a recycling process for used liquid cartoons – is gasified in a 40 MW_{th} atmospheric air-blown BFB gasifier. Aluminium fibre is recovered (2100 ton/a) from the produced fuel gas, which is subsequently combusted in a steam boiler, thus replacing fuel oil consumption (16,500 ton/a) in the power plants of Stora Enso in Varkaus. The boiler will generate steam at 12.5 kg/s, 60 bar and 490 °C, thus producing 165 GWh of energy annually. The fibre component derived from the recycling process will be used by the manufacturer of coreboard for use by the paper, textile and plastic film industries.	

Process Scheme

Investment Costs Co-firing Unit
Total project costs 10 million US dollar
Status of the Installation
In operation since autumn 2001. In December 2001 approximately 3000 operating hours.
Technical and Non-technical Barriers

Name of plant	McNeil Generating Station
Location of plant	Burlington, VT
Country	United States
Licensor/consortium	Future Energy Resources (FERCO)
Building consortium	
Principal co-firing technology supplied by	FERCO
Start of operation (date)	1998
Contact person(s)	Mark Paisley
Website	www.future-energy.com
References	See web site
Capacity (MW_{th} input)	Gasifier – 40MW, power station -- 200
Thermal efficiency (%)	Gasifier – 75%, power station 23 to 24%
Net output generated (MW_e) by • **main unit** • **fuel gas combustion**	Power station boiler – 50 MW_e Gasifier – approximately 15% (7 to 8 MW)
Co-firing and main fuel(s)	Whole tree chips, waste wood
Product(s)	Electricity
Price of generated electricity (EURct/kWh)	Approximately $0.08/kWh
Subsidy provided for - **Investment costs (MEUR)** - **Electricity delivery (EURct/kWh)**	No subsidies
Short Process Description	
Gasifier uses an indirect process to produce a medium calorific value gas (17 MJ). Gas co-fired in a stoker grate boiler for steam generation. Steam used in a turbine for power generation.	
Relevant Process Data and Process Scheme	
Technical paper describing operation is available on web site	
Investment Costs Co-firing Unit	
Gasifier island approximately $11 to $12 million	
Status of the Installation	
Operational – unit is a demonstration plant and operated for testing campaigns only	
Technical and non-technical barriers	
Gas clean-up studies continue for turbine applications. System is commercial when co-firing is concerned. Primary non-technical barrier is general acceptance of biomass energy as an alternative.	

Name of plant	BioCoComb biomass gasification project
Location of plant	Zeltweg Power Station, Austria
Country	Austria
Licensor/consortium	EC-Project, Co-ordinator: *VERBUND Group (A)*
Building consortium	Austrian Energy (A), TU-Graz (A), ENEL (I), ELECTRABEL (B), ESB (IR), EVS (D)
Principal co-firing technology supplied by	Austrian Energy
Start of operation (date)	October 1997
Contact person(s)	Gerhard Moritz
Website	
References	
Capacity (MW_{th} input)	10 MW
Thermal efficiency (%)	
Net output generated (MW_e) by • **main unit** • **fuel gas combustion**	137 MW_e, about 3% replaced by biomass
Co-firing and main fuel(s)	Bark, sawdust, wood chips for gasifier Polish hard coal for coal power station
Product(s)	Electricity
Price of generated electricity (EURct/kWh)	
Subsidy obtained on - **Investment costs (MEUR)** - **Electricity delivery (EURct/kWh)**	The total costs for the BioCoComb project (engineering, biomass storage, conveying system, gasifier, connection to the coal boiler, commissioning and monitoring) were about 5.1 Mio. Euro.

Short Process Description
The process concept is based on the gasification of biomass (bark, wood chips, sawdust with a water content of 40-50%) in a fluidised bed. In this case, the air is fed to the system to exactly such an extent that part of the fuel burns and, while doing so, the heat is produced that is required for the gasification of the rest of the biomass, for the combustion of which not enough oxygen is available. Because it is neither a matter of total combustion nor a matter of total gasification it is called “partial gasification”. The gas is led uncooled from the gasifier to the boiler, where it serves as auxiliary fuel and replaces part of the coal. Apart from the CO_2-reduction, the NO_x-reduction through “reburning” is also of interest. For integration into the power plant the fluidised bed gasifier is installed near the coal-fired boiler. In the gasifier the biomass is converted to gas that is then directly conveyed to the boiler via a hot-gas-line as a second fuel. The partial gasification taking place in the reactor is sufficient respectively desired. Due to this process, pre-drying of the biomass and cleaning of the emerging gas is not necessary. Furthermore, this process can be used to reduce NO_x-emissions, due to the fact that, with the aid of the gas, a second combustion takes place in the coal-fired boiler.
Process Scheme


Investment Costs Co-firing Unit
The total costs for the BioCoComb project (engineering, biomass storage, conveying system, gasifier, connection to the coal boiler, commissioning and monitoring) were about 5.1 Mio. Euro. Assuming that the same project (10 MW_{th}) will be replicated the total (investment) costs will be in the order of 3.7 Mio Euro. These costs include the preparation of the technical specifications, the tenders, the erection of the whole installation and the commissioning. For a commercial version of the project (100 MW_{th}) the total (investment) costs will be in the range of 10 to 14.5 Mio Euro.
Status of the Installation
After the demonstration period the project can be referred to as very successful. The plant achieves stable operation with various fuels (bark, wood shavings, wood chips and also supplementary fuels) and shows an elastic behaviour regarding load changes, and with respect to the change of fuel quality, which is unavoidable in the case of biomass. Not only the ignition and gasification behaviour of the biomass in the gasifier fulfil all expectations, also the combustion behaviour of the gas in the boiler. The process-engineering critical change-over from combustion to gasification mode and vice versa takes place gently, with only a slight temperature increase, which is within tolerable limits though. The quality of the gas is well-suited for co-combustion in the boiler. In April 2001 the coal power station was conserved and it is, at the moment, not in operation, due to economic reasons. A restarting of the power station is possible, but depends on the future development of the electricity price.
Technical and Non-technical Barriers
Technical barriers: As with most biomass/waste-fired units, operation of the Zeltweg CFB gasifier has proved trouble-free. Inspection after the first demonstration period showed that the gasifier was in excellent condition, with no detectable damage. Also, as with most biomass/waste-fired units, problems arised in the preparation and feeding equipment. These were solved during the first demonstration period. Non-technical barriers: In Austria there was no subsidy for electricity produced by co-firing biomass in coal power stations until the end of 2002. This was the main reason that no co-firing installation was built in the last few years.