LARGE SCALE CFB GASIFICATION OF WASTE AND BIOMASS

Joonas Kaasalainen[1], Melina Kallio-Könnö[2], Juhani Isaksson[3]

[1]Lahti Energia Oy, 15140 Lahti, Finland

[2]Vaskiluodon Voima Oy, 65170 Vaasa, Finland

[3] Valmet Technologies Oy, 33101 Tampere, Finland

Abstract - This paper focuses on real-life experiences from operating large-scale CFB-gasification plants. The first example is a CFB gasification plant in Vaasa, where in a 560 MWth coal-fired super critical PC boiler 140 MWth of coal power is replaced by product gas coming from a CFB gasifier. The fuel fed to the gasifier is a mixture of various biomass types such as saw dust, forest residues, bark, shredded stumps, uncontaminated waste wood, etc. This concept enables the operability of the existing power plant to remain intact, and high steam parameters can be maintained without problems caused by corrosion and fouling. The gasifier has been operating successfully for over 16,000 hours at over 97% availability, replacing up to 40% of fossil fuel annually. Emission levels have clearly improved after gasifier installation: CO content has dropped, SO_x emissions have reduced and the NO_x emissions have dropped by 30% in spite of the fact that the original PC boiler was already designed as a Low-NO_x boiler.

The second successful CFB gasification plant presented in this paper is the Kymijärvi II plant in Lahti, were SRF (solid recovered fuel) is gasified to produce gas that is cleaned and combusted in a dedicated gas-fired boiler at high steam parameters (540°C and 120 bar). By using this concept high efficiency from waste-based fuel can be achieved, yielding out of 160 MW fuel input 50 MWel and 90 MW district heat. This gasifier has been operating successfully for over 26,000 hours. In the future the Lahti concept could also be applied at low investment costs in the same manner to existing boilers to utilize existing infrastructure and to gain advantages of high steam parameters in combination with use of waste.

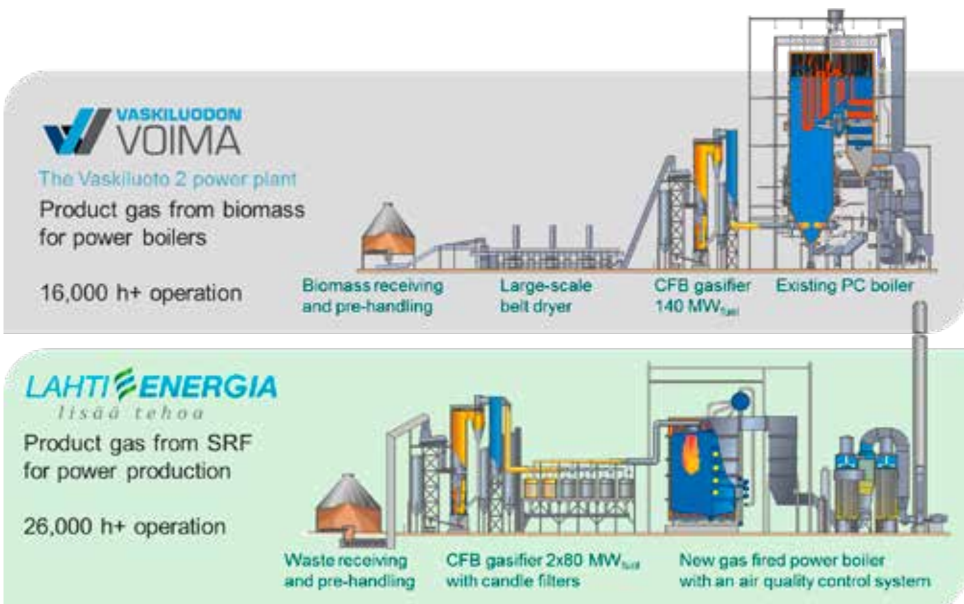

Fig. 1. Schematic of the presented CFB Gasification plants

INTRODUCTION

Gasification in different forms has been used for decades to process solid fuels into gas for use in applications which do not allow for solid fuel firing. Due to its special features the CFB process enables good mixing, uniform and stable temperature and high thermal and chemical inertia, which buffer fluctuations in fuel quality. The temperature window of 750-900°C is highly suitable for reactive fuels such as different kinds of biomass types, wastes and other non-fossil fuels. CFB gasifiers have been used for different kind of process industry needs since late 1970's; for example bark and wood have been gasified in order to generate product gas into limekilns in the pulp and paper industry.

Valmet has now applied the proven process in diverse power production applications. This step has been relatively easy as Valmet has gained lots of experience from CFB boilers, which can partly be transferred to gasification reactors.

One of the two novel applications is a 140 MW-sized biomass gasification process which is used for production of gas from different kinds of wood-based fuels and peat to be used as a partial fuel in a large-scale coal firing plant at the Vaskiluodon Voima plant in Vaasa. The main motivation for this application is to reduce CO2 emissions and to utilize fuels that are cheaper than pellets on a large scale.

The other CFB gasifier application is used for the gasification of waste, RDF/SRF, in order to produce gas that can be cleaned by removing corrosive compounds. This makes it possible to use waste in a high-efficiency boiler with steam parameters comparable to a conventional power boiler. This solution is being demonstrated at the Kymijärvi II plant in Lahti, with live steam values of 540°C and 120 bar. This plant has two 80 MW-sized CFB reactors coupled with gas cooling and cleaning, and a dedicated gas-fired steam boiler.

At the moment both plants have been in commercial operation for several years.

VALMET CFB GASIFIER

The CFB process serves well for gasification. The good mixing evens up the fuel quality fluctuations, and the process tolerates many kinds of fuels in regard to ash content, moisture and heating value. The reactor size can easily be scaled down to a few megawatts and up to several hundreds of megawatts. The economically justified size seems to range from 30-50 MW and upwards.

Adding a product gas cooling and filtering process enables to efficiently remove corrosive contaminants such as alkali chlorides and sulphates. Due to this waste-based product gas can be regarded as free from corrosive components. This opens an opportunity to utilize high-efficiency steam cycles with high parameters even in reheat in case of waste-to-energy production. This option has now been demonstrated by the Lahti Energia company in its Kymijärvi II plant.

Gas cleaning is not required if the fuel is clean biomass, wood, forest residues or other types of wood. In these cases product gas can be fired directly in a steam boiler. This has been implemented at the Vaskiluodon Voima plant, where 140 MW woody biomass is gasified and product gas is directly fired in an existing once-through steam boiler. The benefit of this solution is that a large share of coal can be replaced with relatively cheap biofuel. Pellets or other high grade biofuel is not needed and broad variation in the fuel can be accepted, which makes fuel sourcing much easier and more economical.

The main parameters to be controlled in the gasification process are load and reactor temperatures. Load control is typically done by adding or decreasing air flow to the reactor, and the temperature control is done by increasing or decreasing the fuel feed rate in proportion to the air flow which helps to keep the autothermal process temperature unchanged. Final trimming is needed in the fuel flow as the ratio between air and fuel changes according to the fuel heating value and especially if the moisture content in the fuel changes. In Fig. 2.

There are no exact limits for the fuel moisture, but in a given reactor the fuel moisture affects the generated gas heating value and the production capacity of the reactor considerably. As a rule of thumb it can be said that fuels with moisture content higher than 40-45% start to generate gas that may be difficult to be burnt in a stable way without any support fuel. Also, if the gas is used to replace high-heating-value fuels such as hard coal the fuel may have to be dried first.

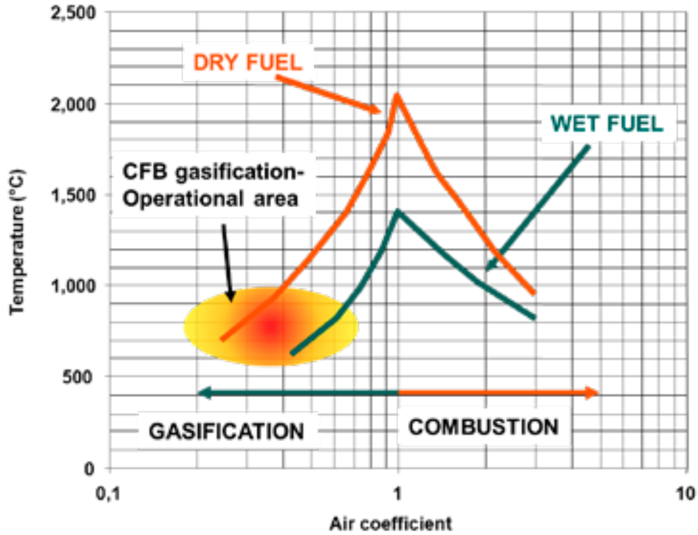

Fig. 2. Principal illustration of the effect of the fuel moisture content and air ratio to the gasification reaction temperature

The design of the CFB reactor used in the Valmet gasifier is for the most parts in line with the CFB boiler, but the evaporative walls are replaced by a refractory lined structure. The fuel, bed material and bottom ash handling systems as well as the air distributor -grid are quite similar to the ones used in CFB boilers. A schematic description of the Valmet CFB gasifier is shown in Fig. 3.

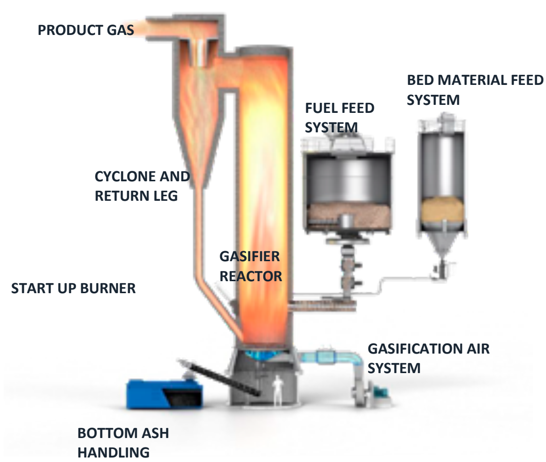

Fig. 3. Principal structure of the Valmet CFB gasifier

The physical size of a gasifier is much smaller than that of a combustion application. This is due to the fact that a FB gasifier does utilize only 25-30% of the amount of air that is needed for the same fuel power. For example, the Vaskiluoto gasifier with gas production capacity of 140 MW is only 6 meters in diameter. The cylindrical shape is chosen for easy manufacturing as there is no need for heat transfer surfaces. The round shape also makes it easier to reach a complete gas tightness, which is required in the case of gasification reactors. Shortage in air availability also makes the use of a fluidized loop seal also problematic. Due to this a direct inclined return leg design has chosen.

Complete gas tightness is required as there is a slight overpressure inside the process due to the need to deliver hot gas after the gasifier to the burners or for other use without any intermediate fans. This normally sets the process pressure inside the reactor between 10 and 20 kPa, g.

Slight overpressure in the process sets requirements for the fuel and ash handling in order to eliminate gas leakages. A practical solution adopted for this is a set of two rotary feeders with an intermediate air purge. The air purge is designed to let only clean air leak out from the system.

The solution selected for the mechanical structure is a self-supported design, in which the foot of the gasifier takes all mechanical loads from the reactor and cyclone. Only auxiliary equipment such as fuel feeding, gas pipes, platforms etc. are supported by a steel structure. The reactor walls are internally isolated and protected by a refractory. That is why the temperature of steel casing typically is only 60-70°C, and normal carbon steel plates can be used. Special attention must also be paid in the design and construction of product gas ducts: the gas is hot and volumetric flows are high. Fig. 4. shows the main gas duct at the Vaskiluoto plant, which delivers 750°C gas from the gasifier to the boiler burners. Also here heavy refractory and good internal insulation are needed.

Fig. 4. Main gas duct during construction at the Vaskiluoto gasification plant

VASKILUODON VOIMA GASIFICATION PLANT

The Vaskiluoto power plant is located in the city of Vaasa, on the west coast of Finland. The power plant is operated by Vaskiluodon Voima Oy, a utility company operating two power plants in western Finland.

The boiler of the VL2 unit is a once-through type (Benson) pulverized coal-fired boiler with reheat. The live steam pressure is 185 bar (g) and temperature 535°C. The reheat steam parameters are 46 bar (g) and 570°C. The maximum fuel capacity is 560 MW. The boiler was delivered by Tampella and has been in operation since 1982. The unit produces 240 MW of electricity and 170 MW of district heat. The annual coal consumption on the plant ranges between 400,000 and 500,000 tons.

The main drivers for the Vaskiluoto gasification investment were commercial: the European emissions trading system provides a feed-in tariff for forest biomass, and there is a heavy taxation of fossil fuels used for district heating. Also, in Finland there is a national target to decrease the use of coal.

Before making the investment decision regarding the gasification plant, Vaskiluodon Voima also investigated other options. The alternatives were to replace the existing coal-fired boiler with a completely new CFB boiler, or to grind and pulverize biomass and fire it in the existing boiler. CFB gasification technology was selected for its merits as listed below:

-With a CFB gasifier the plant can utilize a wide range of fuels, especially when compared to pellet firing
-The investment cost was low, roughly one third of a new similar size fluid bed boiler
-The existing boiler was fully utilized
-The existing coal firing capacity was maintained as a fallback option
-Short delivery time and short downtime of the existing plant

The size of the gasification plant was set at 140 MW, which is roughly 25% of the full power of the plant. However, as the gasifier is operated at full power, independent of plant turndowns the annual coal replacement is close to 40%.

Fig. 5. shows the new gasification plant including the biomass fuel reception, fuel dryer, gasifier and new burner installation to the existing boiler. It is worth noting that the existing PC firing capacity was left intact.

Fig. 5. The Vaskiluoto gasification plant

In the gasification plant the fuel is first dried down to approximately 30% moisture content in order to guarantee adequate product gas quality and stable flames in the burners with a wide variety of incoming fuels. Table 1. lists utilized fuels during the history of the plant. It can be seen that the moisture content of the "as received" fuel has been up to 66% which would be impossible to utilize without a dryer.

Table 1. Design fuel and analyses of used fuels in the Vaskiluoto gasification plant

	LHV dry	Moisture before dryer	Ash
	MJ/kg	%	% ds
Design fuel	20.1	47.0	2.8
Experienced mean	19.0	37.5	3.1
Round wood	18.7 – 19.9	23.4 – 50.9	0.4 – 1.9
Forest residue	16.8 – 19.7	30.4 – 51.6	1.2 – 15.4
Stumps	16.6 – 19,3	24.4 – 40	1.1 – 14.3
Sawdust	19.0 – 19.3	53.7 – 59.8	0.2 – 2
Bark	18.8 – 19.2	63.1 – 66.5	0.4 – 3.1
Peat	19.6 – 21.1	41.1 – 46.2	3.7 – 11.6
Recycled wood	18.2 – 18.7	26.8 – 39.3	1.5 – 4.1

Table 2. shows typical gas composition generated in Vaskiluoto. Despite a relatively low heating value of 4-5 MJ/Nm^3 combustion has been stable, and a very good burnout rate as well as low emission levels have been reached. One reason for this is that the produced gas is hot, approximately 750°C, when it reaches the burner.

Table 2. Typical gas composition in the Vaskiluoto gasification plant

LHV (wet gas)	MJ/Nm^3	4 – 5
H2	Vol-%, dry	7 – 11
N2	Vol-%, dry	50 – 56
CO	Vol-%, dry	12 – 14
CO_2	Vol-%, dry	16 – 17
CH_4	Vol-%, dry	4 – 5
H_2O	Vol-%	26 – 38

The impact on emissions has also been positive. The SO_2 emissions have decreased in proportion to the use of biofuel instead of coal and the CO emissions have remained at a very low level. It is worth noting that the NO_x emissions have also reduced by 25-30% compared to same load conditions with coal only.

The CFB gasifier has operated very reliably and the annual availability during the first three years for the entire new system has ranged between 97% and 99%.

KYMIJÄRVI II GASIFICATION PLANT

Even if the basic gasification process in the Lahti Kymijärvi II plant is similar to Vaskiluoto, the application is very different. The Kymijärvi II plant is a high-efficiency power plant that utilizes waste as the only fuel. The entire plant is schematically described in Fig. 6. The waste received at the plant is pre-treated SRF/RDF and demolition wood. These are first gasified in a CFB gasifier, after which the gas is cleaned of corrosive compounds to allow the gas be burnt in a gas-fired boiler that generates superheated steam at 120 bar /540°C.

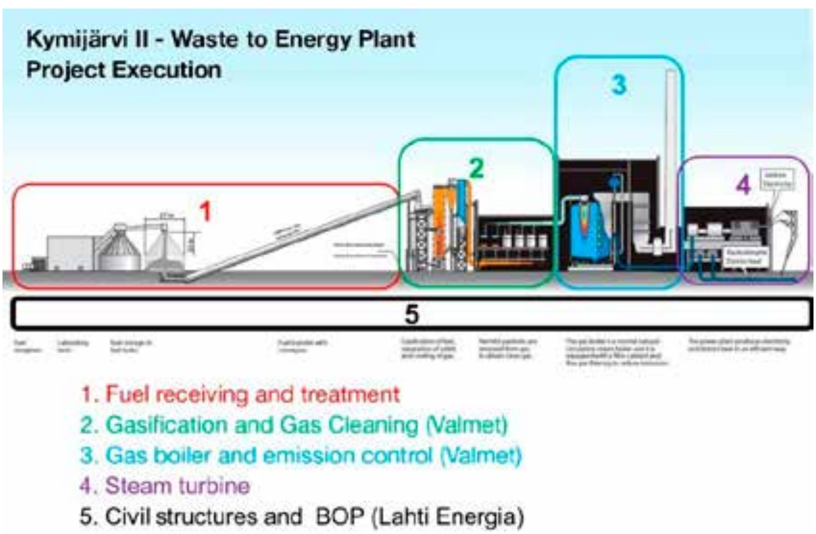

Fig. 6. Schematic structure of the Kymijärvi II plant

These steam parameters allow the electrical efficiency of the CFB-gasification-based waste-to-energy plant to be increased from the typical 20-25% up to a 30% range, and potentially even higher than that as using reheat steam cycle is also possible.

The Kymijärvi II plant is a combined heat and power plant and with heat 90 MW thermal and 50 MWe electricity (gross) production capacity. The fuel power of the plant is 160 MW.

At Kymijärvi II, there are two 80 MW Valmet CFB gasifiers operating parallel to each other. The gasifiers are each equipped with two fuel feed lines and two bottom ash handling systems to give redundancy for the operation.

The reactor as well as the recirculation cyclone is 100% refractory lined and insulated in order to minimize any heat losses and to ensure that the reactors will tolerate the demanding conditions set by waste fuel gasification. The fuel feeding system is based on a volumetric feeder, "a Feeding master", which features technology proven in waste-fired CFB boilers. The bed material, which is a mixture of silica sand and limestone, reacts with the chlorine and sulphur in the fuel, hence reducing the - HCl and H2S content in the product gas.

The gas cleaning process in the Kymijärvi II plant utilizes condensation method. Chlorine and sulphur compounds (alkalis and heavy metals) that are in the gas phase at gasification temperature are cooled down to approximately 400-450 degrees, when practically all of them are condensed on the dust particles that still exist in the gas. This dust is then filtered in the ceramic filters. As a result, the product gas becomes free of any species capable of inducing corrosion. The relatively small amounts of HCl and H2S/SO2 are not causing any superheater corrosion as all alkalis and heavy metals that could react and form salts do not exist in the gas.

The gas filtration temperature of approximately 400–450 degrees is selected in order to filter practically all chlorides and sulphur compounds, but no tar condensation can take place while this is done. For this reason, ceramic-based felt is selected. All vessels and other components need to be designed to withstand these temperatures.

The filtration system is presented in Fig. 7.

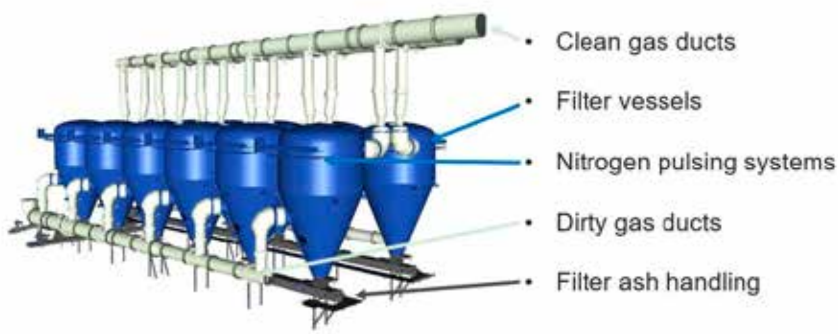

Fig. 7. Ceramic filter unit in the Kymijärvi II plant. Two parallel lines, each containing six modules. Each line serves one gasifier.

OPERATIONAL EXPERIENCES

The first gasification in the Kymijärvi II plant took place on December 15th in 2011 and the plant was taken in commercial use in June 2012. Since then the plant has accumulated more than 30,000 hours of operation serving the district heat net in the city of Lahti and producing electricity for the national grid. During this time, the plant has treated more than one million tons of different kinds of waste-derived fuels, generating valuable information on the novel technology.

As the plant is the first of its kind, the plant operator has gone through lots of hands-on practice in operating the plant. Some mechanical improvements have also been needed.

The plant proved capable of reaching the production capacity already during the first weeks of operation, and it also turned out to be easy to control. In addition, the plant's response was prompt and reliable. However, the start-up and shutdown procedures generated overheating in the hot gas filtration. It also turned out that even though the nitrogen pulsing in the filter did remove the filter cake, some residue accumulated in the filter media due to which periodic (6-8 week interval) offline cleaning was needed. This new offline cleaning system was installed in late 2013, which simplified the operational practices considerably.

Besides the improvements in the filtration system, some changes in the fuel feeding and pre-handling have been done to cope with the metal content in the fuel, which turned out to be higher than anticipated. In addition, the moisture content of the fuel has been higher than predicted but in spite of this, the process has been stable, even with fuels with up to 40% moisture content.

The plant that is in full commercial use is presently the main production unit in the Lahti Energia network.

Since taken into use, the Kymijärvi II plant has processed over one million tons of different waste-driven fuels and produced approximately 900 GWh of electricity and over 2,000 GWh of heat.

Due to frequent fuel sampling, the major characteristics of the fuel used can be summarized as monthly averages as shown in Table 3. It should be noted that the data shows monthly averages; some daily data shows, for example, that the fuel moisture content is occasionally higher than 40%, which still has not created any operational problems. Similarly, the extreme Cl and S content has not created any emission or corrosion problems.

Table 3. Fuel statistics 2012 -2016 at the Kymijärvi II plant

	LHV, ar	Moisture	Ash	C	S	Cl	Na+K	Hg
	MJ/kg	%	% in dm	% in dm	% in dm	% in dm	% in dm	mg/kg in dm
Predicted design data	16.1	21.0	7.6	55.5	0.15	0.60	0.20	<0.1
Experienced average	14.1	26.6	8.5	50.1	0.3	0.33	0.15	0.1
Experienced min	10.8	19.0	5.2	44.4	0.2	0.11	0.09	0.05
Experienced max	17.5	37.5	14.8	57.0	0.6	1.8	0.35	0.3

The emissions of the Kymijärvi II plant have to comply with the IED directive for waste-firing units including the need for at least 2 seconds of residence time above 850 degrees Celsius. All emission limits, as shown in Table 4. are met.

Table 4. Emission limits and annual AST/QAL2 proof measurement results for the Kymijärvi II plant

From annual AST/QAL2 measurements

Emission	Limit 0,5 h average and unit	2016	2015	2014	2013
NOx	400 mg/Nm³	211	217	184	152
SO_2	200 mg/Nm³	40	55	43	32
CO	100 mg/Nm³	4	1	1	1
Dust	30 mg/Nm³	< 1*	< 1*	< 1*	1
HCl	60 mg/Nm³	3	7	2	8
HF	4 mg/Nm³	< 0,2*	< 0,9*	< 0,2*	< 1
TOC	20 mg/Nm³	< 1*	< 1*	1	1
PCDD/F Compounds	0,1 mg/Nm³	0,0004	0,001	0,0004	0,001
Hg	50 µg/Nm³	< 0,7*	< 1,2*	0,1	< 0,02*
Cd+Tl	50 µg/Nm³	< 0,2*	0,01	< 0,01*	< 0,7*
Sb+As+Co+Cr+Cu+Mn+Ni+Pb+V	500 µg/Nm³	7,6	2,0	1,5	0,3*

* Means the measured value is below analysis detection limit

It is worth noting that the environmental performance of the Kymijärvi II plant complies well with the existing regulations, and the selected control methods can absorb changes in fuel quality without violating the emission limits. The low CO and TOC emissions act as a proof of good combustion efficiency, which allows the use of low excess oxygen, typically between 3-4%.

CONCLUSIONS

The Vaskiluoto and Kymijärvi Gasification plants have demonstrated the flexibility of the CFB gasification process and proven that it can be reliably utilized in power generation in several ways.

The Vaskiluoto plant opens new cost effective and flexible ways to implement large-scale fuel changes from fossil fuels to a broad variety of biofuels, and at the same time makes it possible to reuse the already existing infrastructure and simultaneously reduce CO2 and other emissions.

The Kymijärvi II plant is a first-of-a-kind high-efficiency gasification-based waste-to-energy plant, which paves the way for using high-efficiency steam cycles without a fear of hot corrosion.

Both plants are in commercial operation and have a proven track record for several years of operation.

REFERENCES

Bolhar-Nordenkampf, M, Isaksson J.: Operating experiences of large scale CFB-gasification plants for the substitution of fossil fuels, 24th European Biomass Conference, Amsterdam – The Netherlands, 2016

Hankalin, V., Helanti, V., Isaksson, J.: High efficiency power production by gasification, Thirteenth International Waste Management and Landfill Symposium, Sardinia, 2011.

Kallio-Könnö Melina, Keitaanniemi Piia, Savolainen Kati: Operating Experiences from an Industrial Biomass Gasifier, 2016

Savelainen, J., Isaksson, J.: Kymijärvi 2 Plant – High Efficiency use of SRF in power production through gasification, Power-Gen Europe, 2013.