GAS CHP FACILITIES

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INTRODUCTION

CHP (“Combined Heat and Power”) is a specific form of distributed generation, which refers to the strategic placement of electric power genereting units at or near customer facilities to supply on – site energy needs. CHP enhances the advantages of distributed generation by simultaneous production of useful thermal and power output, thereby increasing the overall efficiency. CHP offers energy and environmental benefits over SHP (“Separated Heat and Power“) systems in both central and distributed power generation aplications. CHP systems have the potential for a wide range of applications and the higher efficiencies result the lower emissions than SHP systems. The advantages of CHP broadly include the following :

- The simultaneous production of useful thermal and electrical energy in CHP systems lead to increased fuel efficiency.
- CHP units can be strategically located at the point of energy use. Such on – site generation avoids the transmission and distribution losses associated with electricity purchased via the grid from central stations.
- CHP is versatile and can be coupled with existing and planned technologies for many different applications in the industrial, commercial and residential sectors.

A general working principles of CHP tehnologies are presented in this paper. Beside that, a general characteristics of biomass, which is used as a fuel in these tehnologies, is presented, with special review on wood residual technology which is using in most of the existing CHP systems. At the end, an example of the wood residual CHP is also given.

1. CHP SYSTEMS

CHP is sequential or simultaneous generation of multiple forms of useful energy, like mechanical and thermal energy, in a single, integrated system. CHP consist a number of individual components configured into one integrated system.That components are :

- prime mover (heat engine)
- generator
- heat recovery
- electrical interconnections

A type of equipment which drives overall system (i.e., prime mover) typically identifies the CHP system. Prime movers for CHP systems include reciprocating engines, combustion or gas turbines, steam turbines, microturbines and fuel cells. These prime movers are capable of burning a variety of fuels, including natural gas, coal, oil and alternative fuels to produce energy. Although mechanical energy from the prime mover is most often used to drive a generator, it can also be used to drive rotating equipment such as compressors, pumps and fans. Thermal energy from the system can be used in direct process applications or indirectly to produce steam, hot water, hot air for drying or chilled water for process cooling.Figure 1 shows the efficiency advantage of CHP compared with conventional central station power generation. When considering both thermal and electrical processes together, CHP typically requires only ¾ of primary energy of SHP systems. This reduced primary fuel consumption is key to the environmental benefits of CHP, since burning the same fuel more efficiently means fewer emissions for the same level of output.

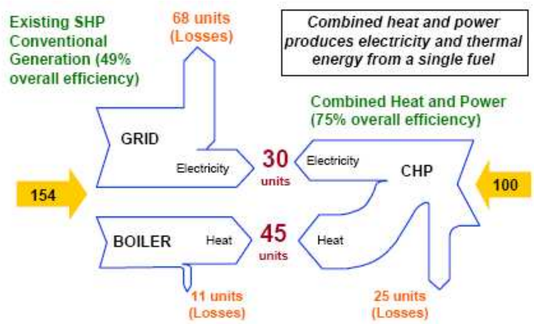

Figure 1 – CHP versus SHP production

1.1 Efficiency of CHP systems

Many of the benefits of CHP ensues from the relatively high efficiency of CHP systems compared to other systems. Because CHP systems simultaneously produce electricity and useful thermal energy, CHP efficiency is measured and expressed in a number of different ways. Table 1 summarizes the key elements of efficiency applied to CHP systems.

MEASURING THE EFFICIENCY OF CHP SYSTEMS			
System	**Component**	**Efficiency Measure**	**Description**
SHP	Thermal Efficiency (Boiler)	$EFF_Q = \frac{\text{Net Useful Thermal Output}}{\text{Energy Input}}$	Net useful thermal output for the fuel consumed
	Electric-only generation	$EFF_P = \frac{\text{Power Output}}{\text{Power Input}}$	Electricity purchased from central stations via transmission grid
	Overall Efficiency of SHP	$EFF_{SHP} = \frac{P+Q}{P/EFF_{Power} + Q/EFF_{Thermal}}$	Sum of net power and useful thermal output divided by the sum of fuel consumed to produce each
CHP	Total CHP System Efficiency	$EFF_{Total} = \frac{P+Q}{F}$	Sum of net power and useful thermal output divided by the total fuel consumed
	FERC Efficiency Standard	$EFF_{FERC} = \frac{(P+Q/2)}{F}$	Developed for the Public Utilities Regulatory Act of 1978, the FERC methodology attempts to recognize the quality of electrical output relative to thermal output
	Effective Electrical Efficiency (or Fuel Utilization Efficiency, FUE)	$FUE = \frac{P}{F - Q/EFF_{Thermal}}$	Ratio of net power output to net fuel consumption, where net fuel consumption excludes the portion of fuel used for producing useful heat output.Fuel used to produce useful heat is calculated assuming typical boiler efficiency, usually 80%
	Percent Fuel Savings	$S = 1 - \frac{F}{P/EFF_P + Q/EFF_Q}$	Fuel savings compares the fuel used by the CHP system to a separate heat and power system.Positive values represent fuel savings while negative values indicate that CHP system is using more fuel than SHP

P – Net power output from CHP systerm
Q – Net useful thermal energy from CHP system
F – Total fuel input to CHP system
EFF_P – Efficiency of displaced electric generation
EFF_Q – Efficiency of displaced tharmal generation

Table 1 – Measuring the efficiency of CHP systems

Another important concept related to CHP efficiency is the power-to-heat ratio. The power-to-heat ratio indicates the proportion of power (electrical or mechanical energy) to heat energy (steam or hot water) produced in CHP system. Figure 2 illustrates curves which display how the overall efficiency might change under assumption that CHP system use 5% less fuel then SHP system.

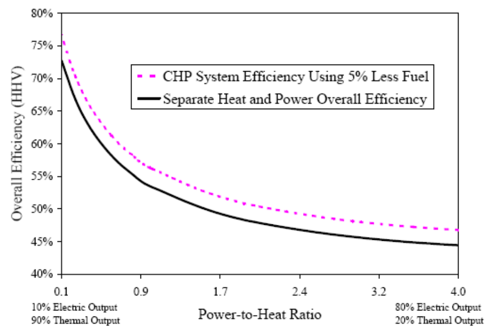

Figure 2 – Equivalent CHP and SHP efficiency

Displayed curves shows the efficiency of CHP and SHP systems on assumption that the efficiency of the electric generation is 40% and the efficiency of thermal generation is 80%.

1.2 Overview of CHP technologies

CHP TECHNOLOGIES			
CHP system	**Advantages**	**Disadvantages**	**Available sizes**
Gas turbine	High reliability. Low emissions. High grade heat available. No cooling required.	Require high pressure gas or inhouse gas compressor. Poor efficiency at low loading. Output falls as ambient temperature rises.	500kW to 40 MW
Microturbine	Small number of moving parts. Compact size. Loe emission. No cooling required.	High costs. relatively low mechanical efficiency. Limited to lower temperature cogeneration applications.	30 kW to 350 kW
Spark ignition reciprocating engine	High power efficiency. fast start-up. relatively low investment cost. Can be used in island mode. Operate on low-pressure gas.	High maintenance costs. Limited to lower temperature. Relatively high air emissions. Must be cooled. High levels of low frequency noise.	< 5 MW
Diesel/compression ignition reciprocating engine			High speed (1.200 RPM) ≤ 4MW Low speed (60-275 RPM)≤65MW
Steam turbine	High overall efficiency. Any type of fuel may be used. Long working life and high reliability. Power to heat ratio can be varied.	Slow start up. Low power to heat ratio.	50 kW to 250 MW
Fuel cells	Low emission and low noise. High efficiency. modular design.	High costs. low durability and power density. Fuels requiring processing unless pure hydrogen is used.	200 kW to 250 kW

Table 2 – Summary of CHP technologies

2. BIOMASS

As the world struggles to come to terms with the environmental, economic and social challenges of adopting more sustainable industrial systems and sources of energy, it is now widely accepted that dependence on non-renewable petrochemicals and fossil fuels must be dramatically curtailed. Using of alternative 'biobased' resources, as fuels, promise a new dynamic of economy characterized by:cleaner production using biomass (any organic matter that is available on a renewable or recurring basis – except old growth forests), advances in biotechnology and greater utilization of resources recovered from various waste streams.The potential benefits of this new economy are myriad – improved air quality and human health because biofuels burn far more cleanly, reductions in greenhouse gas emissions associated with climate changes, reduced risk of polluting oil spills, investment in rural communities, long-term energy sufficiency and security and a wide array of advanced specialty chemicals.Energy system of region can also be designed for power production as CHP system. Such facilities (Figure 3) can utilize biomass energy with more efficiency than the facilities which are producing only heat. Primary effects using biomass as fuel in local power system are :

- resources stays in local economy – using localy produced biomass can significatively improve a wealth of community by replacing resources used for fossil fuels, which are exporting from local economy, with resources which have been spent on fuel localy. By combining district heating system with biomass a new workplaces can be made. For example, according to study from 1994., made by NRBP (“Northeast Regional Biomass Program”), for each 120.000 gallons of oil replaced with biomass, 100.000$ stays in local economy and two new workplaces are made.
- energy security – using local resources for CHP system provide higher energy security because of using renewable energy sources. In many cases biomass is the cheapest accessible fuel.
- positive contribution in climatic changes prevention – biomass can be the key component in prevention of climatic changes, unlike oil or coal, because by burning of biomass CO_2 is been exhausted in atmosphere where it is going to be recycled through plants in photosynthesis.

A list of bio-materials which can be modified from renewable organic resources, instead petrochemical, is practicaly unlimited. In relation to primary role of biomass as renewable organic resource and momentary availability, the next resources are using for produce of biomass :

- wood residual
- agricultural waste
- urban/municipal solid waste (anaerobic matter/methane)
- specific waste from harvesting and threes

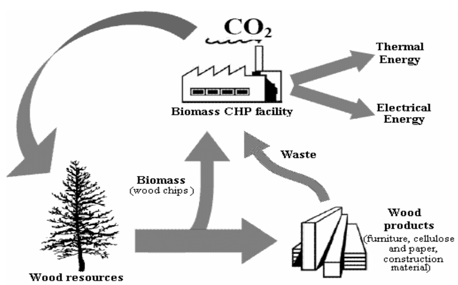

Figure 3 – Biomass CHP facility

2.1 Wood residual

Potential sources of biomass, which are producing from wood residual, are wood chips, cortex, waste from wood chipping, sawdust, short chumps, etc. Two of the most used biomass sources are sawmill waste and short chumps which are not of commercial quality.Small scale CHP plants using natural gas as a fuel for the generation of electrical power and utilize the engine waste heat for district heating.However, it is not that easy when the fuel is wood.Not even in the form of powder can wood be used directly as a fuel.First the wood must be converted to gas.This can be accomplished in a gasification process in a gas generator that is also termed a gasifier. The secret of gasification is the conversion of wood into gas at the least possible loss of energy and in a
way that the combustible gas is as purify as possible.The gas engine is damaged if the gas contains tar and other undesirable particles, so there is a lot of demands that have to be implemented in this process.In order to produce combustible gas, the wood should first be heated.It is most common to heat it by burning a small portion of the wood.The heating dries the fuel and not until then will the temperature be increased.At a temperature of approx. 200 °C, the so-called pyrolysis begins where the volatile constituents of the wood are given off.They consist of a mixture of gases and tars.When the pyrolysis is completed, the wood has been converted to volatile constituents and solid carbon residual (the char).The char can be converted into gas by adding a fluidizing agent which may typically be air, carbon dioxide or water vapour.If using CO_2 or H_2O this process requires heating at temperatures above approx. 800 °C.The combustible constituents in the product gas are primarily carbon monoxide, hydrogen and little methane.Together they constitute approx. 40% of the volume of the gas when using air for gasification, while the residual part consist of incombustible gases such as nitrogen and carbon dioxide.The major parts of the tars from the pyrolysis can be converted to gas if

heated to 900 – 1.200 °C .Many different types of gas generators have been developed over approx. 100 years the technology has been known.The most known gasifiers today are so-called updraft and downdraft gasifiers.

3. AN EXAMPLE OF CHP FACILITY

The gas quality produced by different gasification processes is affected by the gasification medium, which can be oxygen, air or steam.As gasification with pure oxygen is expensive, air is commonly used.Due to the high content of nitrogen this reduces the calorific value of the produced gas.For example, gasification with air produces a gas with Lower Calorific Value (LCV) of 4 – 6 MJ/kg, whereas gasification with oxygen produces a gas with a LCV of 10 – 15 MJ/kg.Typical volumetric fractions of the gases found in wood gasified in air are listed as in Table 3.

GAS	%v/v
CO	19 - 25
H_2	9,5 – 11,5
C_xH_y	1,5 - 2
CO_2	14,4 - 16
N_2	45 - 55
O_2	2,4 - 4

Table 3 – Typical gas composition of wood gasified in air

Wood gas contains other contaminants such as tar, char, ash particles and alkali salts, so they have to be filtered.To generate electricity and heat from the gasification wood gas, heat engines, internal combustion engines and micro gas turbines can be used as prime movers.Heat engines such as Stirling engine can be used by indirectly firing the gas through the engine.Their advantage is that all moving parts are not in contact with the tar or alkali salts commonly found in the wood gas.The engine with internal combustion (such as diesel engine) can provides up to 30% electricity and 60% of heat energy.However, these engines requires significant gas cleaning befor using.The micro gas turbine has advantage because the outlet gas has much higher temperatures leading better thermal efficiency of CHP system.However, they have lower electrical efficiency with only up to 20%.

Figure 4 – Prototype of gas CHP facility

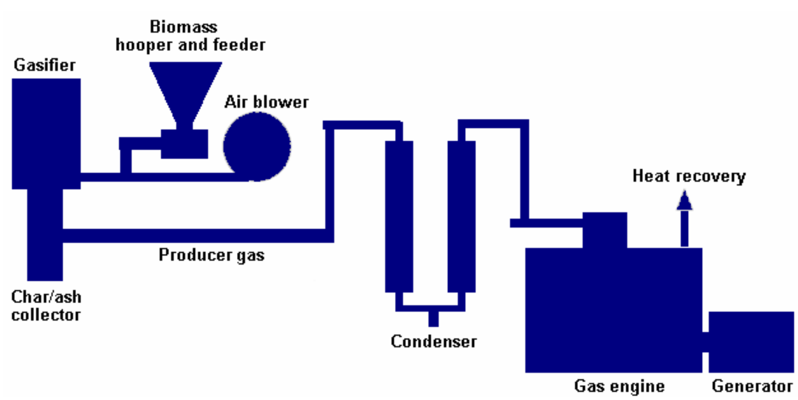

Figure 5 – Shematic of experimental set up

The system shown in this example by Figure 4 and 5 was sized to gasify 40 kg/hr of sawdust under atmospheric pressure, this given a total energy input to the gasifier of around 190 kW. A 6 – cylinder spark ignition 45 kW diesel engine was used as primary mover. Alternator is 3 phase, 400 V, 1500 rpm, rated power 12 kVA.The system gasifier and engine were designed and integrated with minimal control variables. Start up procedure contains next steps : extraction and air fan switched on, start up gas supply turned on for gasifier and engine, cooling water turned on, monitoring equipment turned on.The gasifier was first to be heated to initiate the reaction between the wood and transport gasification air. The warm up procedure was optimized to obtained minimum start up time.It was found that for faster combusting process the wall temperature greater than 600 °C was needed.Warm up time of less than 15 minutes was achieved using 0,255 m^3 of propane.Gasification initiates almost instantaneously, after which air is increased to ideal air/wood ratio. The engine was started on the start up gas and run to warm it up while gasification process initiated and stabilised.After a few minutes the wood gas was deverted through the cooler/condenser where his temperature was decreased at 30 – 40 °C. Once engine was operational at 1500 rpm electrical loading could be applied to the alternator.Start up procedures for gasifier and engine are given at Figures 6 and 7.

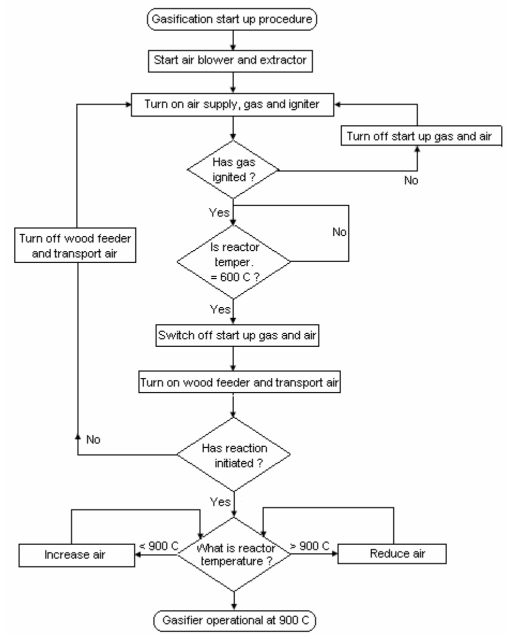

Figure 6 – Gasifier operation procedure

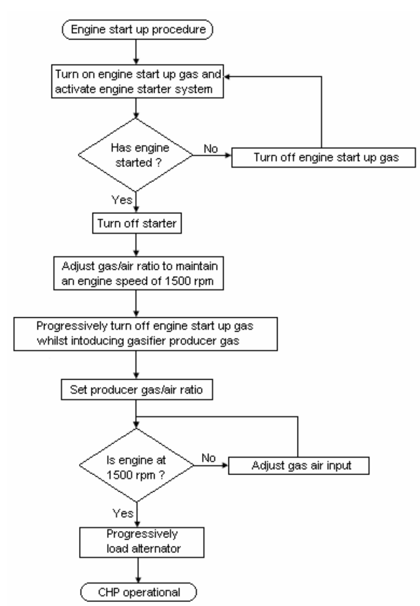

Figure 7 – Engine operation procedure

Sawdust was used as a fuel for gasifier which characteristics vary from 16,2 MJ/kg to 17,8 MJ/kg. These characteristics are shown in Table 4.

PROPERTIES	**VALUE**
LCV- Lower Calorific Value	17,6 MJ/kg
Density	165 kg/m^3
Moisture content	>10%
Particle size:	
< 0,1 mm	10%
0,1 mm – 0,25 mm	18%
0,25 mm – 0,5 mm	33%
0,5 mm – 1 mm	35%
1 mm – 2 mm	4%

Table 4 –Fuel properties

The average quantity of used fuel is 20 kg/hr, and air 400 liter/min. The wood gas composition is presented in Table 5.

GAS	**%v/v**
CO	15
H_2	9
C_xH_y	0,9
CO_2	13
N_2	57
O_2	1,2
CH_4	2

Table 5 – Wood gas composition

About 25% of energy is lost in the system.This losses are presented in Table 6.

ENERGY CONTENT	**%**
Wood gas	75
Residual energy value in char	8
Heat losses and energy for reaction	17

Table 6 – Energy loss in reaction

Such a system provides about 10 kW of electricity and about 20 kW of heat. Electrical efficiency for such a system is presented in Table 7.

Energy input	44 kW
Gasification efficiency	75%
Electrical loading applied	10 kW
Calorific value of wood gas	5,7 MJ/kg
Electrical efficiency (calculated)	22,7%
Wood gas to electrical efficiency	30,1%

Table 7 – Electrical efficiency data

3.1 Brief economic analysis

The predicted capital costs of the 50 kWe system are presented in Table 8.

EQUIPMENT	**COST (€)**
Dryer	7.500
Wood feed system	7.500
Gasifier	15.000
Gas cooling and cleaning	7.500
CHP engine/alternator	45.000
Control system and electrical	7.500
Total :	90,000

Table 8 – Capital cost for biomass system

The source of sawdust is manufacturing wood waste from local area.A preliminary study showes that about 150 tonnes/year is necessary for operating such a facility.The cost of that sawdust is about 30 €/ton.The system is designed to be fully automated and therefore only requires minimum operation and maintenance costs which can be calculated on a price of 2,25 €cent/kWh.Assuming 80% total operation per annum the system would generate 350.400 kWh of electricity. The value of the electricity generated is calculated up to 6 €cent/kWh. Assuming that the value of thermal energy is about 5 €cent/kWh, about 560.000 kWh of thermal energy is available during the annum.Considering all of investments and benefits the conclusion illustrated in Table 9 can be made.

EXPENSES	**COST (€)**
Facility installation expenses	90.000
Fuel costs (up to 30 €/ton)	4.500
Operation and maintenance costs	7.500
BENEFIT	**COST (€)**
Electricity value (9 €cent/kWh)	21.000
Heat value (1,5 €cent/kWh)	28.000
Payback time :	2-2,5 years

Table 9 – Economics of 50 kWe biomass CHP facility

So, the conclusion is that the payback time of such facility is about 2 to 2,5 years.However, a greater facility of about 250 kW would generate more electricity and thermal energy, so using the similar analysis the conclusion is that the payback time in this case is about 1,5 to 2 years.

4. CONCLUSION

Considering all of presented facts we can say that there is a lot of good reasons for exploring and analysing a biomass as a renewable energy source.These sources have a potential for decreasing a dependence of fossil fuels, which, as it is well known, have a limited life-time.Beside that, the fact is that a biomass fuel improves a quality of the environment by decreasing emission of harmful gases, what is vary important ecology factor.From the economic point of view, CHP facilities give the opportunity for utilization of local potentials, first of all in building such a facilities on local level, utilising a local resources, employing a local population as well as improving a life quality because an invested resources stay in the local community.Beside that, investment in such sources make a possibility for a new agricultural and wood markets refered to manufacturing of energy sources from this products. CHP is effective, clean and reliable way for electricity and heat producing from the same source.Such systems can achieve a 50 to 70% of efficiency which ia s considerable increasing in relation to existing SHP systems.Therefore, the attention in a number of countries is focused on developing and applying these systems. The most important place have Denmark, Norvege, USA, Austria, Germany etc.Even, from the economic point of view, it is look like such a facilities have a rather high cost, in long term they will take more important role because of environment protection and their practicaly unrestricted energy sources.Becouse of that, a larger significancy will be given in the future to improving a characteristics of such facilities.

5. REFERENCES

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