PARALLEL COMBINED CYCLE uTILITY PLANT WITH APPLICATION OF CLOSE COUPLED GASIFIRE COMBUSTOR TECHNOLOGY

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BASIC CONCEPT

It can be shown that the appropriate integration of usual Combined Cycle (CC) architecture with Close Coupled Gasifire Combustors (CCGC) - Waterwide Technology (WT) - configured in a *Parallel Combined Cycle with WT* (PCC-WT) brings about both economy and environmental advantages. This can be demonstrated by utilities having the capacity in the range starting from, say 8 MWe – reasonable value - to those exceeding 500 MWe. The concept of plants with PCC-WT architecture exhibits unusual flexibility from the point of view of satisfying specific local requirements, repowering of existing utility facility and particularly then firing a wide spectrum of fuels, including waste.

Various combinations of fuels can be fired simultaneously. Several examples follow:

- WT CCGC:
  - Shredded tyres
  - Charcoal
  - Standard grade coal
  - Coal high ash
  - Coal fines
  - Peat
  - Petroleum coke
  - Wood air dry
  - Corncobs
  - Waste water treatment sludge

  - Refuse Derived Fuel
  - Straw- Rice hulls
  - Bark- Woodchip
  - Processed food waste
  - Municipal Sold Waste
  - Sawdust, waste wood
  - Wood fresh felled- Poultry litter
  - Abattoir waste

- Combust. Turb.:
  - Natural gas
  - Bunker oil
  - Distillates
  - Crude oil
  - Gas Oil
  - Medium and low Btu gas
  - Marine diesel
  - Coal bed gas

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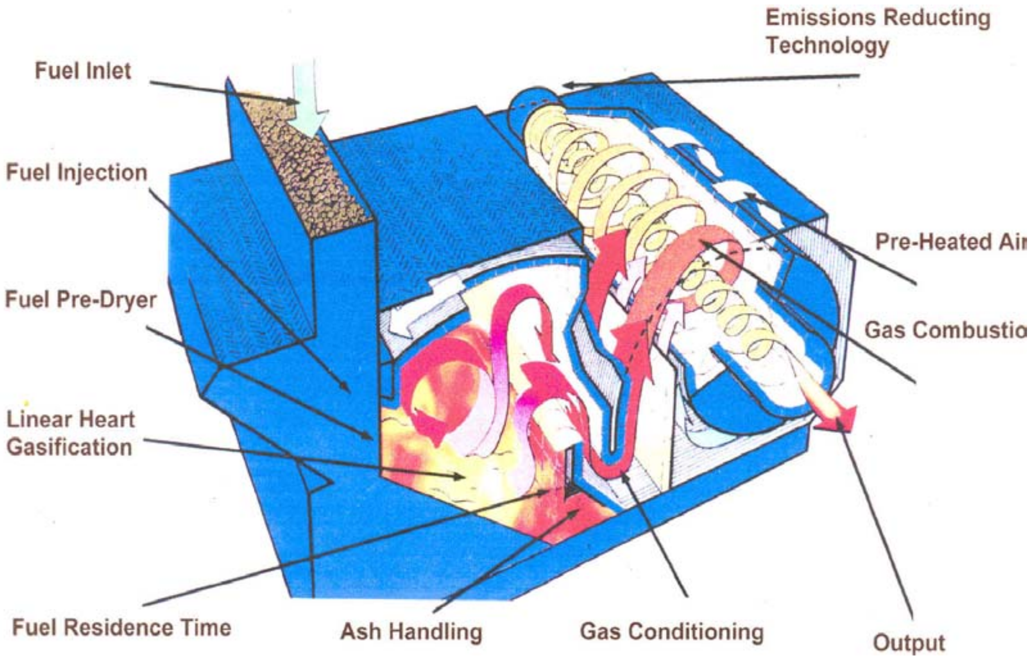
GASIFICATION - COMBUSTION TECHNOLOGY OF WATERWIDE

The heart of the technology is a Waterwide Close Coupled Gasifier Combustor (CCGC). Gasification is the Third Generation Combustion method, gradually replacing Fluidized Bed Combustion (the Second Generation), and very quickly replacing the old furnaces type systems.

The core principle of Waterwide CCGC concept is based on the outstanding arrangement of the facility consisting of separate gasification section, the hearth, and special combustion chamber of cyclone configuration. In the gasifier the processed fuel (a wide spectrum of fuel,e.g. listed above) is converted to syngas (hydrogen and carbon monoxide) at the temperature not exceeding 800°C. The not combustibles, such as ash, are extracted from the bottom of the gasifier hearth. The syngas is fed into the cycloburner where the temperature well exceeds the value of 1200°C with the retention time over 3 seconds. The whole combined process features high combustion efficiency, over 99,9% and exceptionally low emissions.



The Waterwide CCGC has been specifically developed with the need to protect the environment. The Waterwide process helps ensure that emissions are controlled to levels well below set by environmental protection agencies and other environmental watchdog groups.

Higher efficiency reduces CO and CO_2 emissions and fuel consumption. Gasification extracts many substances (such as sulphur an heavy metals) in elemental form. The Waterwide Gasification multiple oxygen application and Recycle Flows reduce NO_X. The cycloburner extracts fly ash. Regenerative Combustion increases temperature to destroy VOC's, hydrocarbons, dioxins and furans, PCB. Fuel versatility removes pure dependency on fossil fuel and reduces waste dumping, particularly deposition on landfills. Lower Excess Air increases efficiency. In short, the Waterwide emissions control takes place during, rather than after combustion.

Installations of Waterwide CCGC fuelled by „clean“ fuels such as wood or other biomass generally require no further emissions control, except where local conditions or regulations and erosion damage to heath exchangers and boilers.

“Cleaning“ the flue gas in the Waterwide equipment ahead of the downstream process not only permits direct firing, but also has advantage over indirect systems of vastly reducing tube cleaning and erosion damage to heat exchanges and boilers.

For more details see www.waterwide.co.nz

PLANT AND PROCESS ARCHITECTURE

The facility arrangement is illustrated on an attached layout – see page 10. The general concept is based on multiple CCGC of WT, coupled with steam boilers, in parallel with CC structure of steam turbine(s) (ST) and condenser(s), combustion turbine(s) (CT) and Heat Recovery Steam Generators (HRSG), installed downstream of a CT. Heat export is provided by the steam extracted from the steam turbine(s). Water-cooled condenser(s) with cooling towers or air- cooled condensers are considered. The power from the generators is transferred to the grid via. step up transformers.

Suitably selected pressures and temperatures of steam generated, first, in the HRSG, and, second, boilers attached to CCGC units, offers the possibility of applying "Carnotization" approach to the steam turbine thermodynamic cycle without necessity of installation of reheat loop.

The following description of the structure indicates the main units in the plants having the capacity of (i) 155 MWe and (ii) 515 MWe.

(i) **155 MWe Plant Main Units**

Unit	No. Units
Combustion Turbine - Rolls-Royce Trent www.rolls-royce.com	1*
CCGC of WT, size ER3000 – 30 MWth, heat capacity including recovery of heat from internal cooling system, www.waterwide.co.nz	8
Fire tube boiler coupled with CCGC, superheated steam of 25 bar -recommended, 600 - 630°C – achievable	8
Dry chemical sorption cleaning of the flue gas, sodium bicarbonate injection, e.g. Solvay www.solvay.com , Arm & Hammer www.armhammer.com	8
Bag house fabrics filters, one unit servicing 4 or 2 water tube boilers	2 or 4
Combustion air heater, one unit supplying combustion air to 4 or 2 CCGC through heating water loop	2 or 4
Condensing steam turbine with steam extraction (District Heating and/or Process steam) and coupled condenser, entered by axially flowing steam. Steam supplied from HRSG, attached to CT, through first admission nozzle and from joined streams of steam of fire tube boilers and of HP section exhaust through the second admission nozzle, e.g. Nuovo Pignone www.gepower.com/nuovopignone	2 or 1
Electric generator with driving shafts at both sides ends - one ST coupled to one end.	1
HRSG downstream of CT, superheated steam of 40 bar recommended, 420°C - achievable	1
Feed water treatment unit(s) + de-aerator(s) with the capacity sufficient for supplying feed water to all boilers	1
Heat exchangers station, e.g. heating water for District Heating service of 1000 TJ/year and/or Process steam	1
Station of wet cooling towers, e.g. Baltimore Aircoil www.baltaircoil.be or air cooled condensers, e.g. www.bdcooling.com, cooling water pumping station	
Step up transformer(s) - steam turbines generator and combustion turbine generator	1 for STs 1 for CT
Electric substation and Control modules	1
Fuel preparation facilities, e.g. for coal fines: sedimentation tank receiving coal fines-water slurry from the transporting pipeline, belt press filter to remove water from the slurry, pre-treatment of Municipal Solid Waste	1

(ii) **515 MWe Plant Main Units**

Unit	No. Units
Combustion Turbine General Electric - PG935(FA) www.ge.com	1*
CCGC of WT, size ER3000 – 30 MWth, heat capacity including recovery of heat from internal cooling system www.waterwide.co.nz	12
Fire tube boiler coupled with CCGC, superheated steam of 25 bar - recommended, 600 - 630°C - achievable	12
Dry chemical sorption cleaning of the flue gas, sodium bicarbonate injection, e.g. Solvay www.solvay.com , Arm & Hammer www.armhammer.com	12
Bag house fabrics filters, one unit servicing three (3) sets of CCGC – boiler	4
Combustion air heater, one unit supplying combustion air to three (3) CCGC through heating water loop	4
Condensing steam turbine with steam extraction (District Heating and/or Process steam) and coupled condenser, entered by axially flowing steam. Steam supplied from HRSG, attached to CT, through first admission nozzle and from joined streams of steam of fire tube boilers and of HP section exhaust through the second admission nozzle, e.g. Nuovo Pignone, www.gepower.com/nuovopignone	2 or 1
Electric generator driven from both ends of the shaft – one (1) ST coupled to one end through its front end drive	1
HRSG downstream of CT, superheated steam of 40 bar recommended, 570°C - achievable	1
Feed water treatment unit(s) + de-aerator(s) with the capacity sufficient for supplying feed water to all boilers	1
Heat exchangers station, e.g. heating water for District Heating service of 1000 TJ/year and/or Process steam	1
Station of wet cooling towers, e.g. Baltimore Aircoil www.baltaircoil.be, or air cooled condensers, e.g. www.bdcooling.com, cooling water pumping station	
Step up transformer(s) - steam turbines generator and combustion turbine generator	1 for STs 1 for CT
Electric substation and Control modules	1
Fuel preparation facilities, e.g. coal transport, pre-treatment of Municipal Solid Waste	1

** Combustion turbine(s) make it possible to install a plant having the required capacity and/or a fuel mix, as mentioned above, brings about significant advantages. Their typical peaking features can be also enhanced by CCGC outstanding fast response to the load demand and their high turndown ratio.*

PLANT CONSTRUCTION

Important feature of CCGC is the fact that the equipment is practically wholly completed at the shop floor and thus installation time period is measured in terms of days instead of several months that is usually the case, for example, for standard boilers.

The main purpose of indicated plant equipment configuration with two steam turbines and one electric generator - lower capital cost - reflects itself in a possibility to proceed in the process of plant construction in steps. In the initial period of construction “one row“ of CCGC with boilers (or less), a turbine hall, a one electric generator, a one steam turbine together with auxiliaries and a “one half“ of cooling towers station is built and the plant then can start operating at its “half capacity“. Then the scheduled construction can proceed in further steps.

PLANT PERFORMANCE

As already mentioned the plants of discussed configuration exhibit good flexibility from the viewpoint of the power export to the grid. This can definitely bring about a positive impact upon the revenue. To illustrate this feature it is assumed that the plant is being operated in a *mix mode*. Thus:

1. Power supply to the grid - *Base Load (BL)* + Heat export in full demand 6000 hr/year
2. Power supply to the grid - *Peak Load (PL)* + Heat export in full demand 2000 hr/year

155 MWe Plant

Item	*mix Operating mode*
Power output	114 MWe – BL 155 MWe – PL
Electricity to the grid – annually	9.98x10^5 MWh
Heat supplied to District Heating System - annually	1 000 TJ
Natural gas consumption – annually	8.8x10^7 Nm^3
Mix of coal and coal-fines consumption – annually	288 k tone
Municipal Solid Waste processed - annually	144 k tone

515 MWe Plant

Item	*mix Operating mode*
Power output	320 MWe – BL 515 MWe – PL
Electricity to the grid – annually	2.95x10^6 MWh
Heat supplied to District Heating System - annually	-
Natural gas consumption – annually	3.92x10^8 Nm^3
High ash coal consumption – annually	552 k tone
Municipal Solid Waste processed - annually	216 k tone

IMPACT UPON ENVIRONMENT

Natural gas, or any other hydrocarbon, being a component of the fuel together with the facilities for proper treatment of the flue gas, causes reduction of the polluting emissions of the plant in comparison with a standard coal firing utility. Further, thermal processing of waste results in preventing free release of landfill gas to the atmosphere and in significant shrinkage of waste volume.

Especially the PCC-WT plant of presented configuration contributes to reducing emissions of the greenhouse gases (GHG). This can be identified by the following phenomena, www.ucsusa.org

1. By firing natural gas instead of coal in a utility plant quantity of emitted CO_2 is reduced.
2. Generating the electricity and heat in a Waste to Energy (WTE) plant, that uses waste as a fuel, CO_2 emissions are reduced by the portion that is formed by thermal processing of the biomass, e.g. a part of Municipal Solid Waste (MSW) and additional substrates, such as waste wood, since this is „recycled“ in CO_2 consumption by surrounding plants in the relatively short time - CO_2 sequestration.
3. Processing MSW or any other waste by WTE plant results in reducing emission of landfill gas - methane (CH_4) and CO_2 - otherwise generated by waste deposited on the landfill. This can be illustrated by the observation that one (1) tone of waste on the landfill produces about three and halve (3.5) tone of GHG – equivalent of CO_2. The WTE plant generates only about halve (0.5) tone of CO_2 by processing one (1) tone of waste.
4. A special feature of CCGC can be seen in the fact that it is capable to process landfill gas, collected at the already existing landfill sites where the gas is not properly treated, and transported, possibly in pressure vessels, to the WTE plant site.

For assessment of the GHG emission reduction Global Environmental Facility (GEF) recommends to consider that the „Alternative Project“ will be operated for the period of fifteen (15) years. The following data show some estimation of the quantity of emitted polluting gases reduction in case of the presented plants.

155 MWe Plant

Item	***mix Operating mode***
Reduction of NO_x Emission - annually	1 860 tone
Reduction of SO_x Emission – annually, no FGD at coal firing plant	$8.77x10^6$ tone
Reduction of Greenhouse Gas Emission - annually	$8.6x10^5$ tone
Reduction of Greenhouse Gas Emission - plant operates for 15 years (recommendation of GEF)	$12.9x10^6$ tone

515 MWe Plant

Item	***mix Operating mode***
Reduction of NO_x Emission – annually	9 370 tone
Reduction of SO_x Emission – annually, no FGD at coal firing plant	$4.41x10^7$ tone
Reduction of Greenhouse Gas Emission - annually	$2.77x10^6$ tone
Reduction of Greenhouse Gas Emission - plant operates for 15 years (recommendation of GEF)	$41.5x10^6$ tone

INVESTMENT COST

The investment cost depends on the locality, conditions of the site, conditions of the market, expected performance, kind of fuels etc. For evaluating the investment cost of the plant, having the indicated architecture, the coupled regression with increments method approach can be used. As indicated above GHG emissions reduction, estimated by GEF methodology, opens an opportunity for GEF grant application. GEF regulations and standard procedures usually suggest that the financial contribution to the “Alternative Project” project ranges from the rate of $ 2 to $ 12 per one (1) tone of GHG emission reduction.

On these bases the assessment of the investment cost can be summarised as follows:

155 MWe Plant

Item	***Finance***
Investment Cost	***USD [95 – 110] x 10^6***
Specific Investment Cost	USD 630 per kW
Potential GEF Grant - rate USD 2.5 per t of Greenhouse Gas Emission Reduced (operating for 15 years)	USD 32 x 10^6

515 MWe Plant

Item	***Finance***
Investment Cost	***USD [210 – 230] x 10^6***
Specific Investment Cost	USD 410 per kW
Potential GEF Grant - rate USD 2.5 per t of Greenhouse Gas Emission Reduced (operating for 15 years)	USD 83 x 10^6

ECONOMY

The waste to energy *Parallel Combined Cycle with WT* plant exhibits positive economic figures in its operation. This is mainly influenced by the fact that expenses for fuel are low, in comparison with plants of "standard" configuration. This is because waste belongs to the category of cheap fuels or the cost may be even "negative" in case when it represents tipping fees.

Another important feature of the plant of discussed configuration is that it can be considered as belonging, at least partially, into the group of renewable energy facilities. General support to renewable-electric generation can be illustrated by an approach to this issue maintained by European Union (EU) countries. In the recent years renewable energy growth has been achieved through a mix of policy measures and actions. Although varying widely in implementation among the EU member countries, the most commonly used policy measures include:

- Direct government investment in renewable technology development through research, development, and demonstration programs.
- Government incentives to facilitate technology deployment.

The latter include such policy tools as commercialization incentives designed to lower the capital of renewables through loans, tax credits, grants, and subsidies; production incentives such as preferential feed-in rates for purchase of renewable electricity production; competitive market bidding; and consumer education and outreach *(see L. Goldstein, J. Mortensen, and* Heat supplied to District Heating System - annually *D. Trickett, Grid-Connected Renewable-Electric Policies in the European Union, USA-DOE, NREL/TP.620.26247 May 1999).*

The key tariffs, annual revenue, fuel cost, operating expenses, and cash income are presented by the following tables.

155 MWe Plant

Tariffs	***Finance***
Natural Gas	USD 0,11 / Nm^3
Coal + coal fines mix	USD 20 / tone
Municipal Solid Waste tipping fee	USD 13 / tone
Sell of electricity – *Base Load*	USD 0,03 / kWh
Sell of electricity – *Peak Load*	USD 0,05 / kWh
District Heating service sell rate	USD 6.3 / GJ

Annual Income and Expenses	***Finance***
Revenue from selling electricity and District Heating service	***USD 43.8 x 10^6***
Operating expenses	USD 4.85 x 10^6
Fuel cost	USD 13.5 x 10^6
Cash Income	***USD 25.5 x 10^6***

515 MWe Plant

Tariffs	*Finance*
Natural Gas	USD 0,11 / Nm^3
Coal high ash	USD 11 / tone
Municipal Solid Waste tipping fee	USD 13 / tone
Sell of electricity – *Base Load*	USD 0,03 / kWh
Sell of electricity – *Peak Load*	USD 0,05 / kWh
District Heating service sell rate	USD 6.3 / GJ

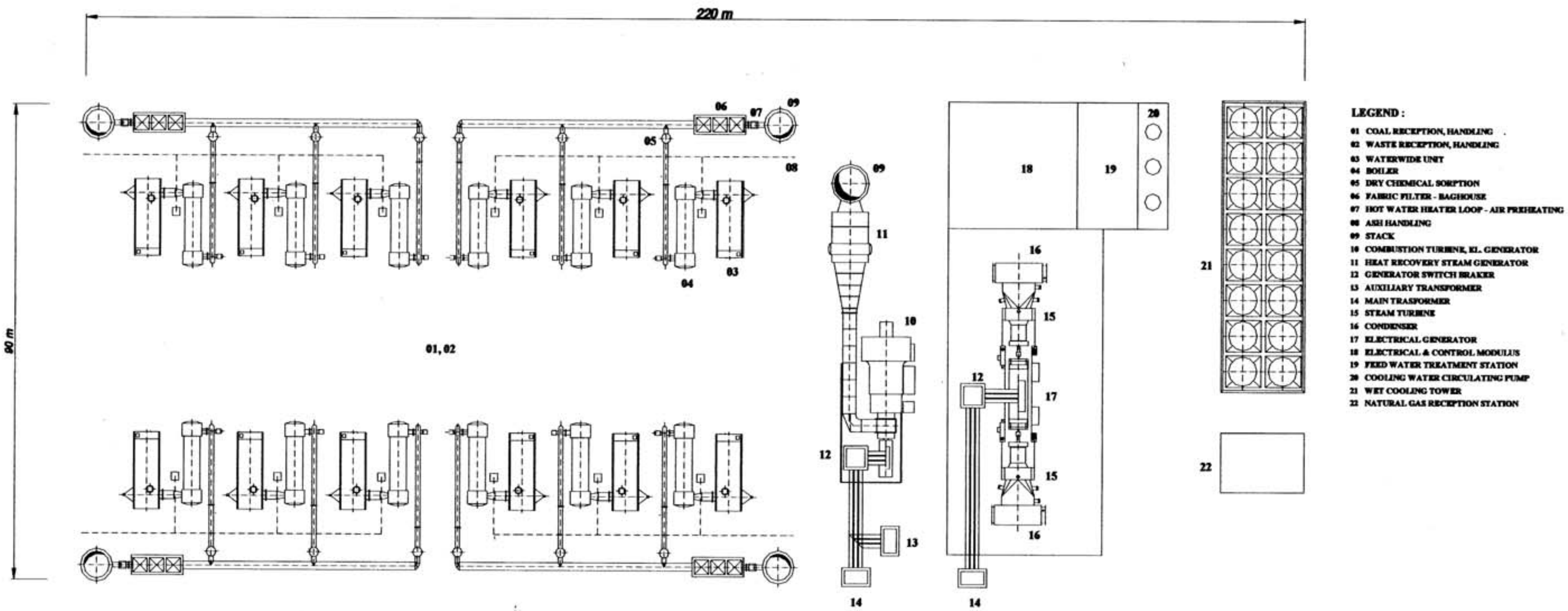
Annual Income and Expenses	*Finance*
Revenue from selling electricity	***USD 113.5 x 10^6***
Operating expenses	USD 14.4 x 10^6
Fuel cost	USD 46 x 10^6
Cash Income	***USD 53 x 10^6***

LAST REMARKS

The outstanding feature of the discussed utility configuration, even its simplified version without installing combustion turbines, appears to possess a high flexibility with respect to fuel brands and heat and power capacities. This makes it possible to build a new facility or retrofit/re-power the existing utility, which would closely and effectively match specific demands of a particular locality.

To extend the concept it is not difficult to show that a relatively simple expansion of the basic scheme by suitably installed dryers, that would recover some heat from the tail part of the flue gas system, can help to tackle presently amplified problems associated with handling organic sludge – biomass. To illustrate these issues the following examples can be quoted:

- Managing the waste, large quantities of litter generated by thousands of animals confined and crowded in feed sheds from birth until slaughter in the factory farms, by drying and thermal processing can recover reasonable amounts of energy and produce valuable fertilizers (see *A. G. Wright, A Foul Mess, Waste Management, 10/4/99*).
- Similarly, this approach of drying, and eventually thermal processing, can be effectively exploited in the process of sterilizing wastewater treatment sludge – biomass – and converting it into high quality fertilizers. It should be pointed out that this is a concern facing every city that has a wastewater utility (see *L. Tindal, Poconite – Solid Waste To Solid Gold, The South Carolina Market Bulletin, South Carolina Department of Agriculture, Vol. 72, No. 7, April 2, 1998*).
- It has been found that many waste matters in organic waste streams are an excellent source of nutrients. Thus e.g. Harmony Technology, *www.harmonyproducts.com*, process virtually recycles the organic waste by producing premium substrates for use in agriculture and horticulture. A dryer is an important component of the whole processing equipment chain. Integration this processing unit with the plant utility, that is based on PCC-WT architecture, where some waste can be used as a fuel, can be beneficial from the viewpoint of economy and environment protection.



COMBUSTION TURBINE GENERAL ELETRIC – PG935(FA)	
WATERWIDE GASIFIER–COMBUSTOR + BOILER	12 UNITS
POWER OUTPUT TO THE GRID	515 MWe
HEAT SUPPLY TO DISTRICT HEATING	–
MUNICIPAL SOLID WASTE PROCESSING CAPACITY	210 kt/year
CONSUMPTION OF COAL – HIGH ASH	550 kt/year
CONSUMPTION OF NATURAL GAS	390 MM Nm3/year

COMBUSTION TURBINE ROLLS–ROYCE TRENT	
WATERWIDE GASIFIER–COMBUSTOR + BOILER	8 UNITS
POWER OUTPUT TO THE GRID	155 MWe
HEAT SUPPLY TO DISTRICT HEATING	1000 TJ/year
MUNICIPAL SOLID WASTE PROCESSING CAPACITY	140 kt/year
CONSUMPTION OF COAL + COAL FINES – MIX.	288 kt/year
CONSUMPTION OF NATURAL GAS	88 MM Nm3/year

**PARALLEL COMBINED CYCLE UTILITY PLANT
APPLICATION OF CLOSE COUPLED
GASIFIER - CPMBUSTORS**