Programme Area: Distributed Energy

Project: Macro DE

Title: Technology Development Opportunities

Abstract:

This deliverable is number 3 of 3 in Work Package 3. Its objective is to model supply equipment improvements either already under development or which could theoretically impact the commercial viability of Macro DE. These models will be the input information for the Work Package 4 tool.

Context:

This project quantified the opportunity for Macro level Distributed Energy (DE) across the UK and accelerate the development of appropriate technology by 2020 for the purposes of significant implementation by 2030. The project studied energy demand such as residential accommodation, local services, hospitals, business parks and equipment, and is developing a software methodology to analyse local combinations of sites and technologies. This enabled the design of optimised distributed energy delivery solutions for these areas. The project identified a number of larger scale technology development and demonstration projects for the ETI to consider developing. The findings from this project is now being distilled into our Smart Systems and Heat programme. The ETI acknowledges that the project was undertaken and reports produced by Caterpillar, EDF, and the University of Manchester.

Technology Development Opportunities

Macro Distributed Energy Project

Work Package 3, Task 3.3

A report submitted to the ETI

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Work Package Team
Kane Lok (Caterpillar)
Dan Adler (Caterpillar)
Andrew Cripps (AECOM)
Paul Woods (AECOM – CTO)

Executive Summary

The aim of the Macro DE project is to assess the opportunity for optimising low carbon distributed energy solutions for the UK. This will be achieved by evaluating the aggregated UK energy demand, modelling the supply equipment and developing a software tool, which can use the provided supply and demand data to design characteristic energy centres.

The purpose of Work Package 3 (WP3) is to characterise the supply equipment to be used by the software tool being developed in WP4. The equipment to be modelled was agreed in Task 3.1. The commercially available supply equipment was modelled in Task 3.2. Task 3.3 was to model supply equipment improvements either already under development or which could theoretically impact the commercial viability of Macro DE. Any change in technical standards, which could help improve efficiency, was also covered as part of Task 3.3. In addition, it was decided to create models in Task 3.2 but at a larger scale due to a change made in the agreed upper boundary (from $10MW_e$ to $50MW_e$) of the equipment power rating as well as some additional technologies (with currently low penetration in the UK market) as requested by the ETI.

The range of equipment modelled had previously been specified as between 100 kW_e and 50 MW_e. It was hoped to include 3 sizes within these limits for each type of supply equipment. However, it was not possible for all technologies investigated due to their current available scale, for example large scale CHP using CCGT tended to be larger than 50 MW_e, so only two models could be included in the list.

AECOM were invited to conduct a portion of the work in Task 3.3 due to difficulty in obtaining data outside of Caterpillar's field of influence and requiring information from Caterpillar's competitors. Information to create the models was collected from manufacturers where possible but due to the commercially sensitive nature of the cost and availability or reliability data this could not always be achieved. In addition, some information was extracted from available literature for some systems, such as large scale solar heating, which have yet to be built in the UK.

The projected technical improvements (2020 – 2030) were obtained from consultation with manufacturers and experts in the industry. For the mature technologies like gas-engines, the projected technical advancement is the future technical standard set by the main players in the field. For less developed technologies like fuel cells, the projected technical advancement is the technical judgment from the manufacturer who has been contacted.

Despite the difficulties stated above, it was felt that the approach taken in Task 3.3 has provided the Macro Distributed Energy project with a view of the various types of technology at present and a reasonable estimate of the potential for technical improvements.

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1 Introduction

This project is to assess the opportunity for optimising low carbon distributed energy solutions for aggregated energy demand profiles in the UK. The project will evaluate the costs and benefits from such an approach focusing on potential cost savings, increased energy efficiency and security, and reduced CO_2 emissions. This evaluation will be achieved by characterising the UK energy consumption, modelling the technology available to meet energy demand and developing a software tool capable of designing Distributed Energy (DE) solutions to satisfy heat demand that has been aggregated over a characteristic geographical area. It is envisioned that selecting the most appropriate DE systems, and specifying efficient operating schedules, together with the use of thermal storage units, will provide the most cost effective solution to providing heat to a set of customers.

Overall Programme of Work and Work Packages:

1. **DE Design Practice Characterisation**
2. **Site and Zone Energy Demand Characterisation**
3. **Energy Supply Characterisation**
4. **Tool Development Methodology and Performance Evaluation by Zones**
5. **UK Benefits Case Opportunity Identification & Summary of the Individual Development Options**

1.1 Work Package 3

This Work Package is to characterise Macro Distributed Energy equipment, based on specifically defined criteria, within the DE technology value chain as illustrated in Figure 1, for inclusion into WP4's pre-prototype tool library. Additionally, potential technology development options and potential changes to technical standards are identified that could significantly improve the performance of DE solutions.

In order to make recommendations on areas of technology and DE system improvements, Task 3.3 looks at the technologies agreed with the ETI in Task 3.1 and identifies potential improvements to overcome significant performance and cost barriers. These recommendations, where appropriate, will be tested within the pre-prototype tool and assessed for their potential impact on a given DE system.

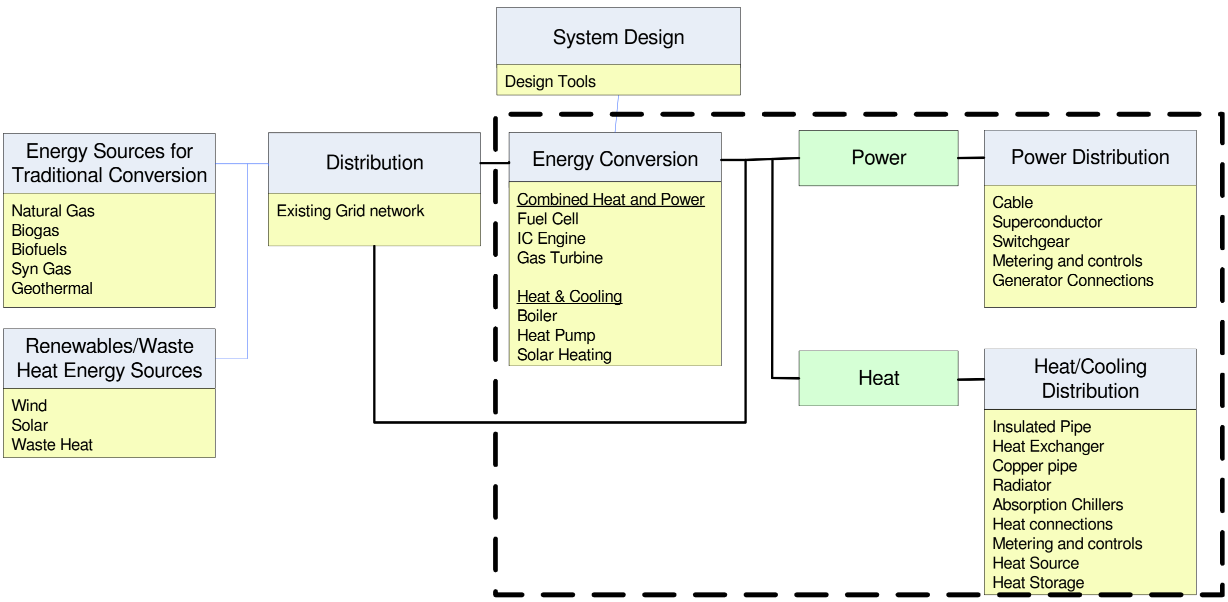

Figure 1: DE Technology Value Chain

1.2 Task 3.3

Using information gained from the evaluation of the stakeholder value chain in task 1.2 and the investigation into the operation and configuration of the DE equipment, as well as the equipment itself, this task is to identify the possible future cost and performance improvements. In addition, if any recommendations on equipment improvements can be made, they will be detailed under this task and modelled for inclusion in the new tool's library.

The deliverables from Task 3.3 are stated as:

- Report detailing:
  - Description of the technologies
  - Technical development opportunities
  - Technology models for simulation within the new tool to assess the benefits of the suggested improvement
  - Areas where improvements in technical standards could improve the viability of macro DE

- Spreadsheet (Excel format) containing:
  - The equipment models to be fed into the tool library in WP4

1.3 Scope of Task 3.3

A list of DE Equipment applicable to DE solutions (100kW$_e$ – 50MW$_e$) will be compiled and formatted as required by the new tool in WP4 into a spreadsheet or similar format (library tables are provided separately from this report). This list will include:

Type 1 – Technical standard improvement: This includes the technologies widely used in the DE application nowadays. The investigation is focused on their possible future technical improvement and the benefits if larger scale being utilised.

- Gas Boiler [1] – 20MW$_{th}$
- Fuel Cell [2] – 300kW$_e$, [3] – 1.4MW$_e$, [4] – 2.8MW$_e$
- Large Scale Solar Heating [5] – (2.1MW$_{th}$, 6MW$_{th}$, 10.6MW$_{th}$)
- Heat Pump [6] – 4MW$_{th}$, [7] – 4.7MW$_{th}$, [8] – 37MW$_{th}$
- Ground Source Heat Pump [9] – 2.5MW$_{th}$
- Gas Engine – Heat Recovery Enhancement
  - Condensing Exhaust Heat Exchanger [11] – Commentary only
  - Heat Recovery from Intercooler [10] – Commentary only
  - Heat Recovery from Air extracted from Enclosure [12] – Commentary only
- Gas Turbine [13] – 22MW$_e$
- Heat Storage – Phase Change Material Product [14] – Commentary only

Type 2 – Additional technologies recommended for inclusion in 3.3. The technologies included in this category are regarded as currently having insignificant impact on the DE solution due to their low penetration in the UK, but they may become important elements to the DE solution in of the future e.g. 2020 – 2030.

- Dual Fuel Type Compression Ignition Engine [15] – 2.6MW$_e$, [16] – 3.8MW$_e$, [17] – 8.7MW$_e$

- Large Scale Combined Heat and Power (CHP) Combined Cycle Gas Turbine (CCGT) [18] – 31MW_e, [19] – 50MW_e
- Energy from Waste
    - Incineration [20] – 3.2MW_e, [21] – 19MW_e
    - Anaerobic Digestion [22] – 250kW_e, [23] – 3.9MW_e
- Biomass Power System
    - Biomass Combustion CHP Plant [24] – (500kW_e, 5.6MW_e, 8.8MW_e)
    - Gasification [24] – (8.2MW_e, 14.3MW_e, 36.3MW_e)
- Biomass Boiler [25] – 840kW_{th}, [26] – 1MW_{th}, [27] – 3MW_{th}
- Condition monitoring system (commentary only) [28] – Commentary only

2 Criteria Format and Model Data

The equipment library created in Work Package 3 will be able to be read by the software tool developed in Work Package 4. Table 1 shows the format agreed upon in Task 3.1, which will be used to describe all of the supply equipment models. These completed models will be supplied to University of Manchester and form the basis of the equipment library.

General	Model			
	Total kWe			
	Fuel Type			
	Fuel heat value, MJ/Nm3			
	Cost of energy input, £/Nm3			
	Fuel CO2 generation, kg/Nm3			
Capital Costs	Capex (Installed Cost), £/kWe			
	Expected lifespan, h (average)			
	Footprint (Package), m x m			
	Availability of the Technology, %			
Operating Costs	Fixed Maintenance Cost, £/yr			
	Variable Maintenance Cost, £/kWhe			
Performance	CO2 manufacture, g/kWe			
	Load, %	Fuel consumption, Nm3/h	Electrical output, kWe	Thermal output at 99 deg C, kWth
	100			
	75			
	50			

Table 1 Agreed model format

The definition of the data fields in the library and assumptions used were agreed by the project consortium as shown in Table 2.

Model Data	Definitions and Assumptions Used
Capital expenditure (Capex)	The capital expenditure (Capex) represents the cost to supply and install the required equipment at a typical site. To ensure a fully operational system, the cost includes the supply of the balance of plant (BOP), such as heat exchangers and pipes, required to connect to the existing site infrastructure. The housing of the equipment, or the bricks and mortar, are considered in WP4.
CO_2 of manufacture	The CO_2 of manufacture defines the mass of CO_2 used to manufacture the equipment. The ISO 14040 and ISO 14044 have been followed.
CO_2 of generation	The CO_2 of generation defines the mass of CO_2 that is released when a fuel undergoes complete combustion.
Availability	The availability metric represents the ratio of time when the equipment is fully operational, versus the time when the equipment is non-operational as a result of planned/unplanned maintenance.
Fixed maintenance	The fixed maintenance cost defines the cost associated with maintaining the

cost	equipment independent of its usage. The cost has been defined over the period of a year, assuming that installation and operation of the equipment is in line with the manufacturer's recommendation and guidelines.
Variable maintenance cost	The variable maintenance cost defines the cost associated with maintaining the equipment dependant on its usage. The cost has been defined assuming that installation and operation of the equipment is in line with the manufacturer's recommendation and guidelines.

Table 2: Modal data definitions and assumptions used.

3 Technology Description and Specific Assumption

A list of DE technologies being investigated in this task has been agreed with the project consortium and the ETI.

3.1 DE Equipment Technical Standard Improvement

3.1.1 Gas Boiler

The gas-fired boiler is arguably the most widely used equipment in district heating for decades. Most of the boilers today are utilised for peak-load or back-up capacity as there is a need for a lower carbon source to supply the majority of the heat supply.

The fuel (natural gas) is burnt in the furnace section. Heat from the flames and the exhaust gas is used to heat water in the boiler section. This technology was examined in Task 3.2 already but it was felt that it should be re-investigated to establish the possible benefit from utilising a larger scale gas boiler (20 MW_{th}).

The large scale gas boiler (20 MW_{th}) model produced for the purpose of this project is based on a three-pass reverse flame, steel shell boiler designed to run on natural gas.

Capital expenditure includes the following;

- Boiler off-loading and positioning
- Internal water baffling
- 3 circuits with 4 pump circuits
- Insulation to all pipes required
- Automatic control and electrical works
- Flow and return valves
- Flue dilution fan
- Pressurisation unit (gas booster), expansion vessel and pumps

3.1.2 Fuel Cell

A fuel cell is an electrochemical device that converts the chemical energy contained in fuels into electrical energy and heat. A fuel cell is typically composed of a fuel electrode (anode) and an oxidant electrode (cathode) separated by an ion-conducting membrane. Oxygen passes over one electrode, and hydrogen over the other, generating electricity, water and heat. Due to no combustion in the conversion, the pollutants can be kept at a relatively low level compared with other devices such as a gas-engine and gas turbine. Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained. In principle, a fuel cell can run on a wide variety of fuels and oxidants. However, most fuel cells today use natural gas (or their derivatives) or hydrogen as reductant, and ambient air as the oxidant [29].

There are five main types of fuel cell classified by their electrolyte used in the cells - 1. Polymer Electrolyte Fuel Cell (PEFC), 2. Alkaline Fuel Cell (AFC), 3. Phosphoric Acid Fuel Cell (PAFC), 4. Molten Carbonate Fuel Cell (MCFC), and 5. Solid Oxide Fuel Cell (SOFC). Of these types, PAFC (150-200^{o}C), MCFC (600-700^{o}C), and SOFC (700-1000^{o}C) are suitable for district heating application due to their operating temperature range, which is also dictated by their electrolytes [30]. The fuel cell model studied in this project is a Molten Carbonate Fuel Cell.

3.1.3 Large Scale Solar Heating

Heat is collected by the solar collectors and transmitted to the load by a primary liquid handling unit usually via a storage system as shown in Figure 2. The system needs to be designed to cope with the full range of ambient temperatures experienced in the UK.

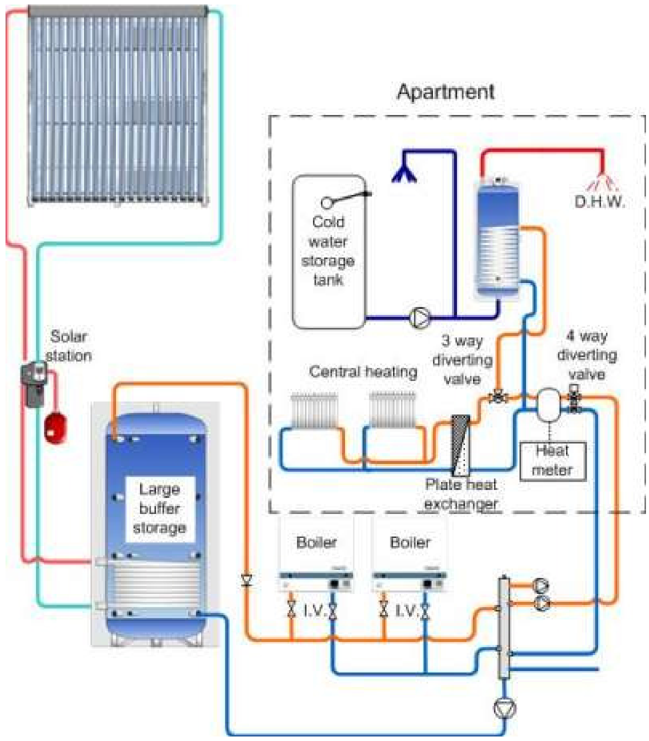

Figure 2: Schematic diagram of a typical solar heating system [31].

All solar heating used for district heating purposes will include heat-only boilers or CHP plants for ensuring that the heat demand is met if there is insufficient solar radiation input.

Assumptions required specifying the operating conditions of the solar thermal heating are:

- Flat panel based system
- Based upon a south facing installation inclined at 41° to the horizontal
- Solar heating levels averaged using London and Edinburgh as South/North references
- Solar heating levels averaged since 2000, using historical weather software Homer [32].

Capital expenditure includes the following for the systems being investigated in this task.

- Solar collectors

- Copper tanks
- Water storage
- Interconnecting pipework
- Automatic control and electrical works

3.1.4 Large Scale Heat Pump

Heat pumps draw heat from the ambient and convert the heat to a higher temperature through a closed process; either compressor heat pumps (using electricity) or absorption heat pumps (using heat; e.g. steam, hot water or flue gas). Heat pumps serve different purposes, e.g. industrial purposes, individual space heating, heat recovery and district heat production.

The performance of heat pumps is generally represented by a Coefficient of Performance (COP), which is the ratio of the heat generated to the electrical input. This COP depends on the efficiency of the system, but critically on the temperatures of the input and output. For this study the temperatures have been taken at:

- Energy source (30^{o}C) – taken as waste heat from industrial process or power generation
- Supply temperature (80^{o}C) – as the input to the District Heating (DH) network[1]

To achieve practical rates of heat exchange, the heat pump has to work at temperatures at least 5^{o}C difference between the hot and the cold side. Combining this with a good practice efficiency for a real heat pumps (around 65% of the Carnot maximum efficiency), this gives a best case realistic COP of 3.9.

Capital expenditure includes the following for the systems being investigated in this task.

- Heat pump
- Interconnecting pipework
- Automatic control and electrical works

3.1.5 Gas Engine

This technology has been utilised widely for many years. The most noticeable advancement over the years is higher shaft efficiency and lower emissions. The normal system configuration is that an electrical generator is connected to the engine mechanically and a heat exchanger is used to extract the heat from the exhaust gas. Apart from natural gas (i.e. most prevalent fuels), gas engines have been developed to run on fuels which have lower heating values and higher contents of impurities such as anaerobic digestion gas, landfill gas and syngas.

A CHP plant based on a gas engine can produce heat from three main sources - the engine jacket cooling system, the oil cooler, and the exhaust gases. Typically two-thirds of the heat is available in the engine jacket/oil cooler while the remaining one-third in the exhaust. A gas-engine CHP is normally used in low temperature hot water applications due to the maximum temperature in the engine jacket circuit (typically 95^{o}C). Generally enhanced heat recovery is achieved by having the following attachable devices.

[1] The DH temperatures nowadays have been lower than that in the past and also they do not need to be constant through the year. For example DH can be run at 70˚C in summer 80˚C in mid season and only 90C at times of peak demand. In addition, the peak demands could be met by boilers which operate in series with the heat pump to increase the flow temperature.

Condensing Exhaust Heat Exchanger

The heat recovered by such device can be used to generate additional heat by reducing the temperature in the exhaust gas to below 100°C. The choice of materials for exhaust gas channels, tubes and tube plates depends on the fuel used and the application. Particular to biogas plant where, if the exhaust gas is dropped below 160°C, sulphuric acid will be formed in the exhaust to severely shorten the life of the device. The efficiency of heat recovery can be from 59% to 72% depending on the exhaust gas pressure drop [11].

Heat Recovery form Intercooler

The heat contained in the jacket water and oil can be recovered by utilising this device. Usually such a device is located in series in the secondary circuit before the exhaust heat exchanger. A greater heat output can be achieved, provided the return temperature is low enough. If this device is run in parallel, low grade heat is available at its output for domestic hot water heating applications.

Heat Recovery from Air Extracted from Enclosure

Some CHP plants are modulated in enclosures. The heated air stream in enclosure can be used directly or upgraded in temperature by having an electric heat pump coupled with it. Suitable applications include distribution warehouses, process drying applications, space heating, and other applications where hot air is required on a continued basis [12].

3.1.6 Gas Turbine

Gas turbines are usually fuelled by natural gas or light oil. Nowadays some gas turbines can use other fuels like Liquefied Petroleum Gas (LPG) and biogas, and some turbines are available with dual-fuel capability. Typically a CHP plant would contain gas turbine, gearbox (if needed), generator, and heat recovery boiler (hot water or steam) as shown in Figure 3.

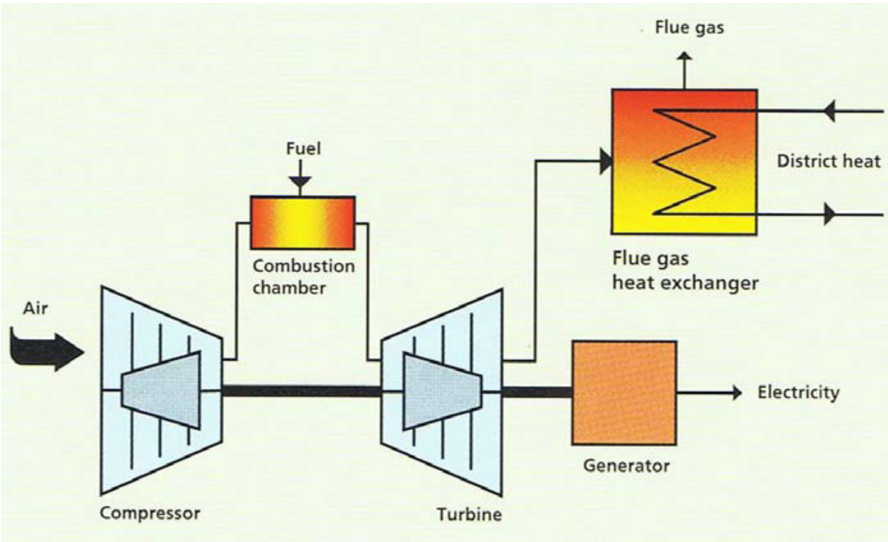

Figure 3: Schematic diagram of a CHP plant [34].

There are two types of gas turbines: Industrial and aero-derivative single-cycle gas turbine. The industrial gas turbines are usually for heavy duty, so the frames, bearing, and blading in such system are of heavier construction. Aero-derivative turbines are normally more efficient than industrial ones. Industrial gas turbines have longer service intervals than the aero-derivatives.

3.1.7 Heat Storage

The main library (Task 3.2) already contains data for conventional water based thermal stores, and so this section reviews the potential for the use of phase change materials (PCM) within thermal stores in place of water only stores.

The principle behind the use of a PCM is that it can, in some circumstances, require a much smaller volume of material to store an equivalent amount of energy, because it uses the latent heat associated with the phase change. This energy (usually the melting / freezing of a solid) can be significant, and has the benefit of taking place within a small temperature range.

However for the normal application needed for district heating, namely storing heat at a relatively high temperature, the use of PCM is not favourable, as the following simple calculations indicate.

Specific heat capacity of water:	4.2 kJ/kg.K
Heat capacity for 40K change:	~160 kJ/kg
Latent heat of typical PCM:	145 kJ/kg

Therefore where we have a temperature difference across the store of 40K (typically 90^{o}C flow, 50^{o}C return), a similar volume of PCM or water is needed to store the same amount of energy. Since the PCM has a cost, and the water is very low cost, there will not be a benefit from using the PCM for district heating applications.

It is worth noting that in a cooling system, the position can be different, since there may only be 10K difference across the store, and then the PCM store would need to be just one quarter of the volume of the water based store, with associated savings in tank costs and space requirements.

Because there do not appear to be any commercial or technical benefits of PCM for district heating it is not recommended that PCM systems are included in the further analysis.

3.2 Additional Technologies

3.2.1 Ground Source Heat Pumps

Ground source heat pumps (GSHP) use the relatively stable temperature in the ground as a source for the ‘cold’ side of the heat pump cycle. Because the ground temperature will typically be no more than 10^{o}C, the efficiency of a GSHP for district heating at 80^{o}C will not be as high as for the electric heat pump (waste heat) option discussed in Section 3.1.4. The typical COP level is around 2.9 in practice.

GSHP have most potential where they are used for roughly equal amounts of both heating in winter and cooling in summer, so that the ground temperature can be partly replenished by heat rejection into the ground during the summer ready for the start of the heating season. Systems can become inefficient if the temperature of the ground drops too low.

Unless there is ground water readily available, a closed loop borehole field will be required to capture heat and the scale of such system will be limited by the amount of land available. Such systems use water/glycol mix to exchange heat with the ground and the heat pump refrigerant. This suggests that systems will only make sense at the smaller end of the scale of heat demands, up to 1 or 2 MW_{th}. Above this level an aquifer thermal energy system will make more sense which can store greater quantities of heat; but these are clearly only possible where the ground conditions are appropriate and so cannot be generally applied within this study.

The borehole field can make a significant additional cost to the heat pump system, meaning that the total cost can be double or more that of an air source heat pump system. Further the pumping energy for the heat exchange fluid can be a significant part of the total energy use.

GSHP systems use the same heat pumps as any other systems, so essentially all of the other data (other than cost and performance) are the same as for air source or waste heat pumps.

3.2.2 Dual-Fuel Type Compression Ignition Engine

Compression Ignition engines (diesels) are very widely used for small scale power generation, particularly for emergency power systems, running on diesel oil or other similar fuels. Similarly spark ignition engines running on gas are also widely used for small scale CHP systems.

It is possible to use a compression ignition engine fuelled mainly with natural gas if a small amount of oil is used to remove the need for a spark within the cycle. This enables higher efficiency of the engine (compared to the spark ignition) and lower carbon emissions (compared to a diesel engine) because of the use of gas fuel. Operating cost savings may be achieved but depend on the relative prices of gas and oil. This type of engines generally has a higher capital cost.

3.2.3 Large Scale CHP using Combined Cycle Gas Turbine

A system diagram for a typical CHP Combined Cycle Gas Turbine (CCGT) is shown in Figure 4. The gas turbine and the steam turbine drive a shared generator, but in some plants the two turbines might drive separate generators. The single shaft configuration enables a higher reliability, but the multi shaft design has a slightly better overall performance. The return water from the district heating network is used to cool the steam condenser. The condensation temperature can be fairly low (depending on designs) since the DH water is then sequentially heated by the flue gas from the gas turbine.

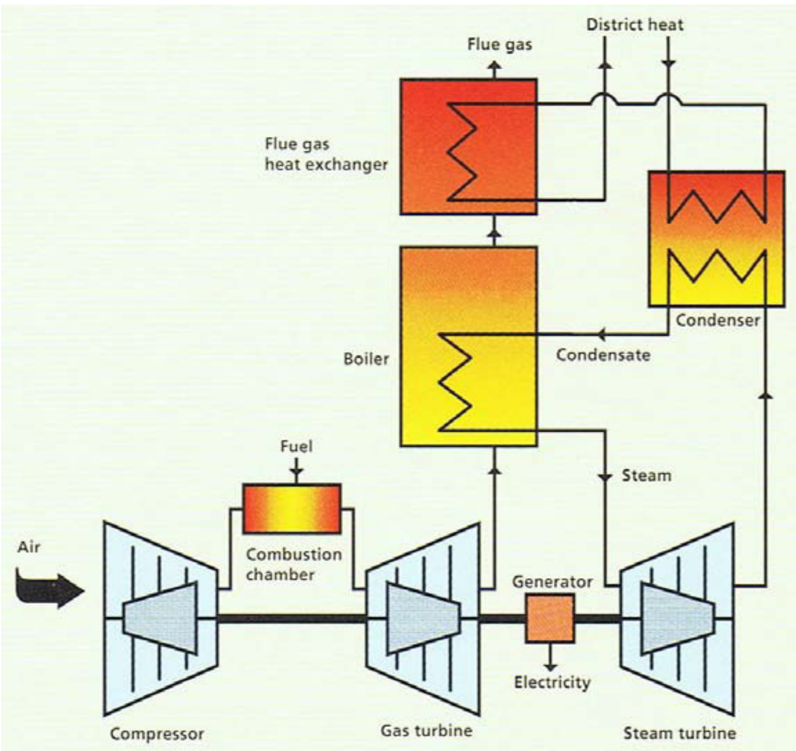

Figure 4: Typical plant designed for combined heat and power production [34].

The overall energy efficiency is dependent upon the flue gas exhaust temperature while the power efficiency depends on the district heating flow temperature. Typically the gas turbine generates twice the power of the steam turbine.

CCGT is widespread in power generation and for industrial CHP, but rarely used for smaller scale CHP for district heating. The objective for this part of the study is to study packaged systems around $50MW_e$ which could be attractive in the future for larger scale heating networks as the electrical efficiency should be higher than gas-engines and closer to the large-scale CCGT on the power grid.

3.2.4 Energy from Waste

Waste is mainly divided into two types (dry and wet waste). Two technologies (incineration and anaerobic digestion (AD)) were included in this study.

Incineration

Figure 5 shows the schematic diagram of an incineration plant. The system can be divided into several major components: A waste reception area, a feeding system, a grate fired furnace interconnected with a steam boiler, a back pressure or condensing steam turbine, a generator, an extensive flue gas cleaning system and systems for handling of combustion and flue gas treatment residues.

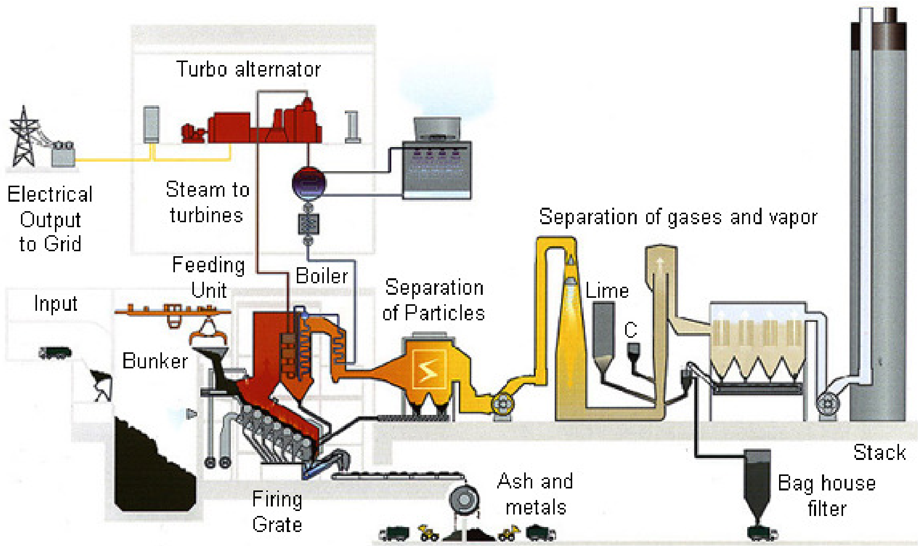

Figure 5: Schematic diagram of an incineration plant [35].

Waste is transported to the bunker, which functions as a waste buffer and allows dangerous or incompatible materials to be detected and removed from the bunker, where the waste is subsequently fed to the firing grate by the feeding unit. In the grate, the waste is burnt at a temperature of more than 1000°C. The boiler above the grate is used to generate the superheated steam which is used to drive the turbine and electrical generator. The ash at the bottom of the grate is transmitted to a specialist processor to separate metals for re-use. The ash is usually contaminated and has to be disposed of in a hazardous waste landfill site. The flue gas from the grate passes through a gas cleaning system where the flue gas firstly has dust extracted, secondly neutralised and pollutants removed by injecting the lime and activated carbon, before emitting to the atmosphere [20].

Anaerobic Digestion (AD)

Anaerobic Digestion (AD) is the process used to compost wet waste (animal material, garden waste, paper, and food), in the absence of oxygen, producing a biogas which is used to generate electricity and heat. Figure 6 shows a schematic diagram of an anaerobic digestion plant.

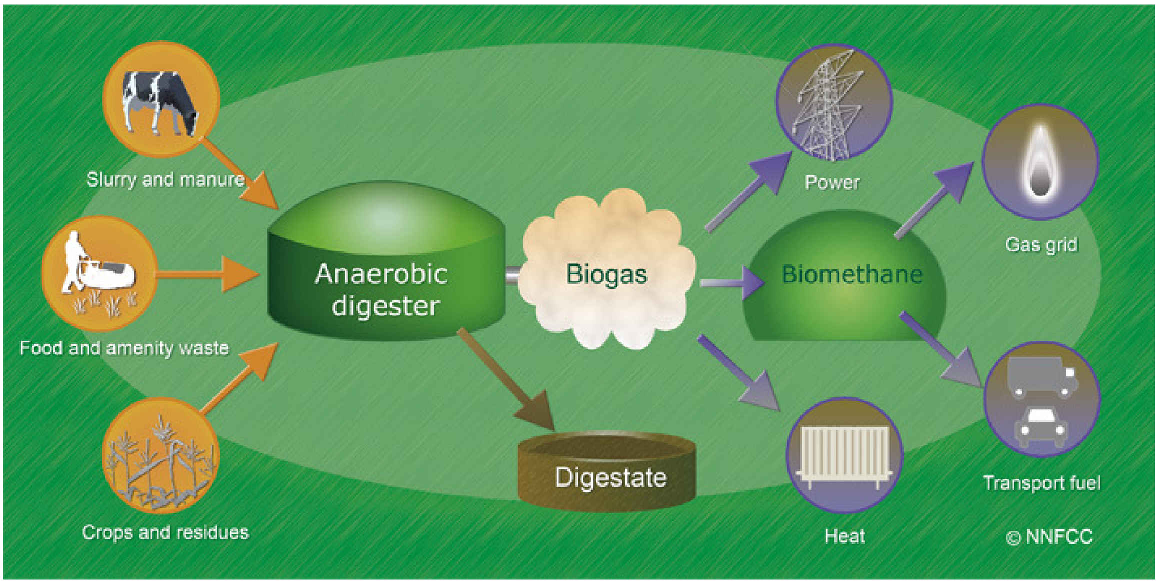

Figure 6: Schematic diagram of an anaerobic digestion (AD) plant [36].

Waste is poured inside sealed tanks and naturally occurring micro-organisms digest it, releasing methane. The direct products of AD are biogas and digestate. Biogas is a mixture of 60% methane, 40% carbon dioxide and traces of other contaminant gases. Biogas can be used as a fuel to a CHP plant to provide heat and electricity. Alternatively, the biogas can be cleaned up and the bio-methane injected into the mains gas grid or used as a road transport fuel. Digestate is the indigestible material and dead micro-organisms. It contains valuable plant nutrients and can be used as a fertiliser and soil conditioner. Some of the heat from the CHP plant may be used to raise the temperature in the digesters.

3.2.5 Biomass Power System

In this category there are two main approaches; gasification and biomass combustion CHP plant.

Gasification

Gasification is a process to break down the biomass waste (carbon based materials) into gaseous fuels by heating but without having combustion. The process creates a chemical reaction which combines waste with oxygen and steam under high pressure at a temperature generally in excess of 800^{o}C. The continuous pyrolysis process produces a syngas which contains carbon monoxide, hydrogen and methane. The gas has a net calorific value of 4-10 MJ/Nm^3 and can thus be used to generate electricity. Figure 7 shows the schematic diagram of a gasification plant.

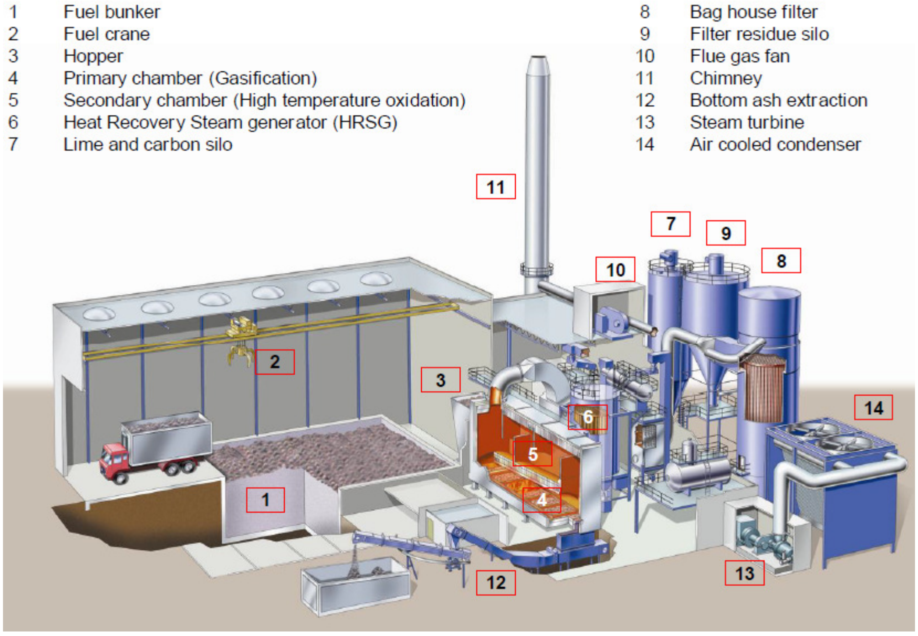

Figure 7: Schematic diagram of a gasification plant [37].

A gasification plant is generally composed of four main modules: a waste pre-processing unit, the gasification/oxidation chambers, the energy recovery section and finally the flue gas cleaning module. The biomass waste is sorted, grinded, shredded, stored and dried in the pre-processing module in order to obtain a gasification-friendly feed material which is free of metals, glass and plastic bottles. Gasification of the solid waste takes place in the primary chamber. The carbon reacts with oxygen and steam to form syngas at below the stoichiometric air requirement and at temperatures between 400 and 1000°C. In the high temperature oxidation unit (the secondary chamber), a staged oxidation of the syngas is facilitated by multiple injections of air and recycled flue-gas. At the end of the gasification grate, the bottom ash is discharged. The generated heat in the secondary chamber is used to heat up the water pipes in a boiler and convert water into steam to drive a turbine and generate electricity. The remaining flue gases are cleaned using the dry sorption system. Acid components are absorbed by lime injected on the flue gas stream while the activated carbon adsorbs the dioxins, heavy metals and total organic carbon [24].

Biomass Combustion CHP plant

Biomass CHP plant is usually fuelled by straw or forest residues (e.g. wood-chips). The system normally includes the major components as fuel storage and feed-in system, combustion chamber, high-pressure steam boiler, steam turbine, generator and flue-gas heat recovery boiler (hot water or steam) as indicated in Figure 8.

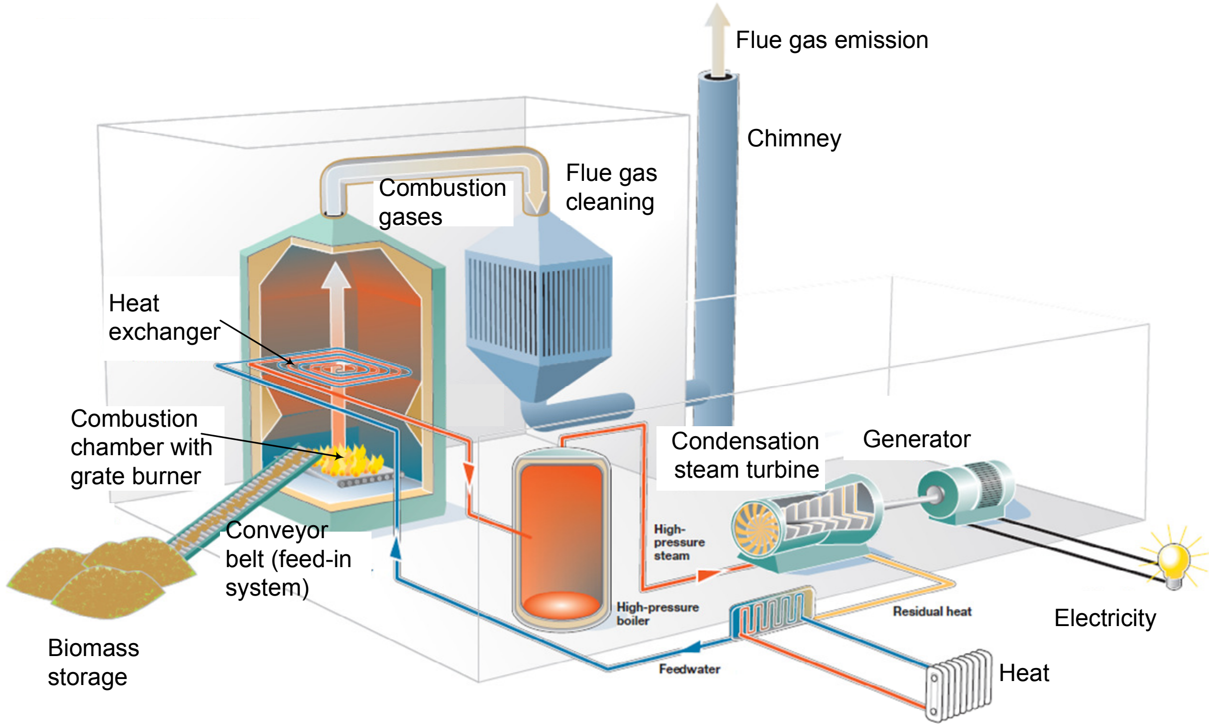

Figure 8: Schematic diagram of a typical biomass CHP plant [38].

Such biomass plants tend to be large in physical space terms, because it requires space for fuel handling, storage and potentially processing, in addition to the need for relatively large boilers. Because these issues apply to any system, this means that smaller scale plant is relatively expensive [24].

3.2.6 Biomass Boiler

A biomass boiler is typically fuelled by wood-chips from forestry waste or from the wood industry. Wood-chips are normally referred to the wood pieces of 5 – 50 mm in the fibre direction, longer twigs (silvers), and a fine fraction (fines). The biomass boiler used in district heating can possibly burn the fuel (wood-chips) with up to 50% moisture content according to the design or technology. Flue gas condensation is normally employed if the moisture content of the fuel is above 30-35%. It may lead to the thermal efficiency exceeding 100% (Net Calorific Value (NCV) basis) depending on the system design.

3.2.7 Condition Monitoring System

A condition monitoring system in district heating is a system that searches real-time data on the status of the district heat network from various sensors/databases, which enables proactive and efficient condition management. The system possibly includes street information, technical information and data on the ownership of buildings, other connections built into the street network, 3D aerial photos with the desired angle of view, and structural, condition, identification, sluicing, outage and damage data of the district heating network.

With such system implemented, it is possible to reduce the amount of heat produced, from approximately 4 to 7% surplus production, while the quality of service is maintained. The heat losses can be reduced to about 6% per year and the average annual outage time can be lowered to 2.8 hours per customer [28].

4 Projected Future Technical Improvement

4.1 Gas Boiler

It is a very mature technology. Therefore, no future technical improvements are expected [39].

4.2 Fuel Cell

A gas cleanup system is required particularly if there is a desire to use anaerobic digestion gas or landfill gas. Such gas cleanup systems can cost up to approximately 70% of the whole plant cost depending on the fuel quality. There will be some scope for cost reduction in this area. The cell stack life may be extended from 5 years to 10 years which represents ~40% opex reduction compared with today cost (2010). The power density of the fuel cell stack may have an increase of 20% in 2020 which leads to ~10% decrease in material required [40] [41].

4.3 Large Scale Solar Heating

There is no significant technology improvement on the solar collector efficiency expected. The advancement is mainly on the cost reduction of the solar collector and the associated heat storage (~10-15% compared with that in 2010). In addition, there is potential for the variable opex cost coming down slightly (~5% compared with that in 2010) [42] [43].

4.4 Large Scale Heat Pump

There are likely to be only small improvements in performance as this is a well-established technology. Similarly there may be some scope for cost reductions if the market for large heat pumps were to grow, but again only to a limited extent. There are ongoing changes to refrigerants driven by Greenhouse Gas issues, and this may result in a loss of performance in some circumstances, as FlouroCarbon based refrigerants are removed from use [44].

4.5 Gas Engine

Around 2020, electrical efficiency is expected to improve from ~40% to ~45% (NCV basis) while 10% reduction in capex cost is anticipated. Power density is thought to have 10% increase. However, there is no change expected in opex cost and emission level – other than total GHG emission decreases 20% by virtue of reduced unburned methane and reduced fuel consumption.

For 2030, the electrical efficiency is considered to reach 50% before accounting for heat recovery while the capex cost is reduced by 20%. 20% higher in power density is anticipated. The opex cost is expected to decrease by having reduced oil consumption, 50% longer maintenance intervals, and reduced required maintenance. Lower emissions are expected by reducing 0.1g/Bhp-hr NOx and 20 % reduction in GHG emission by virtue of reduced unburned methane and reduced fuel consumption. In addition, the engines are expected to have the ability to run on fuels from 30-100 methane number without compromising power or efficiency [45].

4.6 Gas Turbine

The electrical efficiency is likely to be improved by about three percentage points by 2020 resulted from the higher inlet temp at the first turbine blades and the higher pressure ratio achieved by increasing the air pressure from the compressor. The capex and opex costs are not foreseen to have any reduction due to the high maturity of this technology. Typical capacity will remain at where it is today (2010). However, Coke Oven Gas (COG) and biogas will become significantly more popular as fuels for gas turbines by 2020 particularly with a view to replacing some coal fired power station plants by COG [46].

4.7 Dual-Fuel Type Compression Ignition Engine

Performance is unlikely to change substantially, as engines have been improved over decades already. The application to district heating may need to be optimised, and part load performance may be possible to improve to some extent [47].

4.8 Large Scale CHP Combined Cycle Gas Turbine (CCGT)

This is not a tested market, so there may be scope for reductions in cost particularly if the use of such systems were to expand and more standardised designs emerged [48].

4.9 Energy from Waste

Incineration
There is no scope of technical improvement in terms of capex, lifespan, opex, in the future. However, the electrical efficiency may benefit from small technical advancements in steam turbine design [49].

Anaerobic Digestion
The capex of plant may reduce by 10% reduction by 2020 and another 10% around 2030. The other aspects (such as lifespan, conversion efficiency, and opex) are thought to be stable [49].

4.10 Biomass Power Station

Biomass combustion and steam turbine systems are a long established technology and will therefore not change substantially. However there are ongoing efforts to improve gasification systems such that the electrical efficiency of biomass CHP can rise, and both footprint and costs reduce. Hence there is potential for improvement both in terms of cost, efficiency, and reliability for these systems in the future; at present they do not appear competitive [50].

4.11 Biomass Boiler

A biomass boiler is likely to take on new types of fuels such as energy crops and garden waste. Because the biomass boiler is a well-established technology, there is no evidence for future development that shows any significant technical advancement, or in terms of cost, efficiency, and reliability [51] [52].

4.12 Heat Storage

It is unlikely that PCM system will be widely utilised in district heating systems unless radical new materials emerge. Therefore no projected future technical improvement can be predicted [53].

5 Summary

The objectives of this task are to characterise the required 100kW$_e$ – 50MW$_e$ distributed energy equipment to form a library of DE supply equipment models and to project, by consultation, the technical improvement of these technologies in 2020 and 2030. These models will be the input information for the Work Package 4 tool. The models described in this document have been supplied separately, in the agreed format in the Excel (.xls) and are ready to be incorporated into the Work Package 4 software package.

Manufacturers, equipment installers, and industry experts were approached for data and information gathering. However, some data, such as capex and opex, have been difficult to obtain, particularly by asking for data from Caterpillar's competitors, due to their commercially sensitive nature. As a result, AECOM were subcontracted to conduct a portion of the work in Task 3.3. Information to create the models was collected from manufacturers where possible but due to the commercially sensitive nature of the cost and availability or reliability data this could not always be achieved. In addition, some information was extracted from available literature for some systems, such as large scale solar heating, which have yet to be built in the UK.

The projected technical improvements (2020 – 2030) were obtained from consultations with manufacturers and experts in the industry. For the mature technology like gas engine, the projected technical advancement is the future technical standard which is set by the main players in the field. For less developed technologies like fuel cells, the projected technical advancement is the technical judgment from the manufacturer who has been contacted.

Despite of the difficulties stated above, it should be noted that the approach taken in Task 3.3 has provided the Macro Distributed Energy project with a view of the various types of technology at present and a reasonable estimate of the potential for technical and cost improvements.

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