Integration of District Heating with existing Combined Cycle Gas Turbines in North Dublin

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DECLARATION

I declare that this thesis is entirely my own work, except where otherwise stated and has not been previously submitted to any Institute or University.

Signed: ....

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ABSTRACT

There is potential in Ireland for the development of existing large scale CCGT by conversion to CHP. A district heating network developed for North Dublin would provide this opportunity for CCGT generating stations. Connecting two CCGT plants currently optimized for electricity production to a district heating network would require the plants to be converted to allow a Combined Heat and Power mode. It would make use of the thermal energy produced during electricity production and increase the plant efficiency, while significantly reducing the energy required to run condenser cooling fans. It would also reduce the carbon intensity of the energy generated, as the use of the waste heat would increase the total energy with no increase in the greenhouse gas emissions from the combustion process. Use of waste heat increases efficiency, avoids emissions and helps enhance the quality of the environment.

The pipe network for North Dublin would circulate hot water in an underground, pre-insulated pipe system with supply and return lines. Flow temperatures would be in the range of 80 - 95˚C with return temperatures of 60 - 65˚C. The biggest cost of district heating is the investment required to establish a pipe network. However such a scheme would service the local area for many decades and would allow flexibility by using alternative heat sources if required.

TABLE OF CONTENTS

1. INTRODUCTION 1

1.1 Background 1

1.2 Objectives 3

1.3 Rationale for study 4

2. LITERATURE REVIEW 5

2.1 Combined Cycle Gas Turbine (CCGT) 5

2.1.1 Gas Turbine Operating Principles 6
2.1.2 Steam Turbine Operating Principles 8
2.1.3 Combined Cycle Gas Turbine Operating Principles 9

2.2 District Heating 13

2.2.1 Barriers to District Heating Uptake 15
2.2.2 District Heating Pipe Design 15
2.2.3 District Heating Network Design 17
2.2.4 District Heating Density 17
2.2.5 Advantages of large scale CHP for DH 18
2.2.6 Barriers to CHP uptake in Ireland 19

2.3 Integration of district heating & CCGT 22

2.3.1 Extraction Condensing Steam Turbine 23
2.3.2 Condenser Source Heat Pump 25
2.3.3 Other Waste Heat Sources Considered 26

2.4 Legislation 28

2.4.1 Irish Legislation 28
2.4.2 EU Legislation 29
2.4.3 Planning 29
2.4.4 Regulation 30

3. METHODOLOGY 31

3.1 Interested Parties 31

3.1.1 Fingal County Council 31
3.1.2 Energy and Network Management Company 32
3.1.3 Customers 32

3.2 Huntstown Power Plant 33

3.2.1 Phase 1 33
3.2.2 Phase 2 34

3.3 Excess Energy available from CCGT 35

3.4 Future Running Profile of CCGT Plants 37

3.5 Security of Supply 38

3.6 Equipment Requirement for Integration 41

3.6.1 Condenser Heat Pump 41
3.6.2 LP Bleed Steam 44

3.7 Area, Buildings & Services to be Considered for Supply 47

3.8 Heat Mapping 48

3.8.1 Residential 49
3.8.2 Office/Commercial 50
3.8.3 Hotels 51
3.8.4 Recreational 52
3.8.5 Institutional 52

3.9 Estimated Demand 53

3.10 Estimated Cost of System 54

3.10.1 Cost of Network 55
3.10.2 Cost of Equipment Energy Supply Side 57
3.10.3 Cost of Equipment Energy Consumer Side 57

4. DISCUSSION 58

4.1 Comparison of Integration Options 58

4.2 Comparison of Results 59

4.3 Study Costing 60

4.3.1 Cost of Heat Produced 60
4.3.2 Payback Period on Capital Investment 61
4.3.3 Consumer Installations 61
4.3.4 Operation and Maintenance 62
4.3.5 Business Model 63

5. CONCLUSIONS & RECOMMENDATIONS 66

5.1 Conclusions 66

5.2 Further Studies/Recommendations 69

6. APPENDICES 70

6.1 Potential Heat Customers 70

6.1.1 Hotels 70

6.1.2 Recreational 71
6.1.3 Office & Business Parks 72

6.2 Unit Heating Costs 73

LIST OF ILLUSTRATIONS

Figure 1 District Heating Barometer (Orita, 2011). 3

Figure 2 Gas turbine basic components (Courtesy of Wiley) 6

Figure 3 The Brayton Cycle (Courtesy of E.On) 7

Figure 4 Simple or open cycle gas turbine (Courtesy of Energy Efficiency and Renewable Energy). 8

Figure 5 The Brayton Cycle (Courtsey of E.On) 9

Figure 6 Combined Cycle (Courtesy of E.0N) 10

Figure 7 Illustration of a combined cycle power plant energy flows (Rezaie and Rosen, 2010) 11

Figure 8 Serrated Finned Tubes as fitted in HRSG modules (Courtesy of Babcock-Hitachi Inc) 12

Figure 9 Temperature–entropy diagrams of combined cycle, simple Brayton cycle and Rankine cycle (Polyzakis et al., 2008). 12

Figure 10 Diagram of district heating network (Courtesy of Grundfos) 14

Figure 11 Pre-insulated pipe work to EN253 standard (courtesy of GermanPipe) 15

Figure 12 Natural Gas Network (Courtesy of Bord Gais Networks) 21

Figure 13 Rankine Cycle, showing steam reheat between HP & LP Turbine 24

Figure 14 Rankine Cycle, showing bleed steam used for feed water heating 24

Figure 16 Huntstown Multi-shaft CCGT 33

Figure 17 Huntstown Single-shaft CCGT 34

Figure 18 Huntstown Power Plant showing Phase 1 (red) and Phase 2 (blue) (courtesy of Viridian plc) 35

Figure 19 A 65m high accumulator tank at Ostersund, Sweden with a restaurant on the top floor. 39

Figure 20 Electrical system demand showing typical January evening peak and night time valley (Courtesy of Eirgrid) 40

Figure 21 Absorption inlet air cooling system (Ibrahim et al., 2010) 42

Figure 22 Katri Vala heating and cooling by sewage and seawater heat source (Courtesy of Friotherm) 43

Figure 23 Absorption heat pump with integrated gas burner (Žīgurs et al., 2011) 44

Figure 24 LP steam bleed schematic (Courtesy of RETScreen) 45

Figure 25 Bleed steam heat exchanger for district heating 46

Figure 26 Construction of shell and tube heat exchanger (Courtesy of TNT) 47

Figure 27 RETScreen climate data Dublin Airport (Courtesy of RETScreen International) 48

Figure 28 North Dublin should Industrial Business Parks highlighted (LaSalle, 2012), Huntstown Power station location noted by red star 50

Figure 29 Savillis Estimated average sizes of developments 2000-2010 (Savills, 2010) 51

Figure 31 Outline of main pipes (purple) DN 600mm - DN 100mm 56

Figure 32 Breakdown of Capital Investment) 62

Figure 33 Breakdown of €38/MWh Heat Cost 63

ABBREVIATIONS/GLOSSARY OF TERMS

ACC	Air Cooled Condenser
AD	Anaerobic Digestion
BAT	Best Available Technology
BMW	Biodegradable Municipal Waste
CCGT	Combined Cycle Gas Turbine
CCCW	Closed Circuit Cooling Water
CER	Commission For Energy Regulation
CH4	Methane
CHP	Combined Heat & Power
CO2	Carbon Dioxide
ELV	Emissions Limit Value
EPC	Engineer Procure and Construct
GT	Gas Turbine
HRSG	Heat Recovery Steam Generator
Hz	Hertz (frequency cycles per second)
IGV	Inlet Guide Vane
IPPC	Integrated Pollution Prevention Control
kW	Kilowatt
kWh	Kilowatt-hour
kWe	Kilowatt electric
MW	Megawatt
MWe	Megawatt of electricity
MWth	Megawatt of Thermal Energy

NOx	Oxides of Nitrogen
NCC	National Control Centre (Eirgrid)
O&M	Operation and Maintenance
ST	Steam Turbine
WtE	Waste to Energy

1. INTRODUCTION

Heating of households, businesses and industrial properties in Ireland is primarily provided by their own heating systems. The aim of the project is to investigate the feasibility of retrofitting existing large Combined Cycle Gas Turbine (CCGT) plant to provide district heating and improve the efficiency of heat consumption. Two large natural gas CCGT power plants with a combined output of approximately 740MWe are located at North Finglas in Dublin. As part of the process, approximately 45% of the energy used in generating this power is lost to the atmosphere. These plants will be the basis of the study to investigate the possibility that they may provide a heat source for the surrounding community through the capture of heat energy normally lost to the atmosphere.

1.1 Background

Thermal uses for energy accounted for 34% of all primary energy requirements in Ireland in 2009 with oil and gas being predominantly used for space heating, water heating and cooking (SEAI, 2010). Significant progress is being made towards renewable energy sources under the 2008 EU integrated approach to climate and energy policy known as the 20-20-20 targets. Some of the targets set in place to address climate change and the issues of energy supply are:

- 20% (later increased to 30%) improvement in energy efficiency across the whole economy by 2020.
- 20% reduction of GHG emissions compared with 2005 by 2020.
- 16% of all energy to come from renewable energy sources by 2020.

- 10% of all transport energy to come from renewable energy sources.

Additional renewable generation is coming on-stream regularly, mostly in the form of wind energy. But if these targets set out by the Governments are to be achieved, then significant changes will be required in the efficiency of the primary fuel sources we use and the associated production mix. Renewable sources still supply energy intermittently and fossil fuel power generation will still be required for the foreseeable future.

District heating (DH) and combined heat and power (CHP) are well developed and understood; despite this these technologies currently have a limited development in Ireland. This is compared to some other European countries where we see district heating as the dominant heat source. District heating accounts for 60% of the heat source in Denmark and 49% in Finland. When we look at countries lower levels of district heating, such as Austria with around 18%, here district heating is concentrated in the cities. Vienna is provided with 36% of its heat supply from district heating, covering 270,000 households (Macadam et al., 2009).

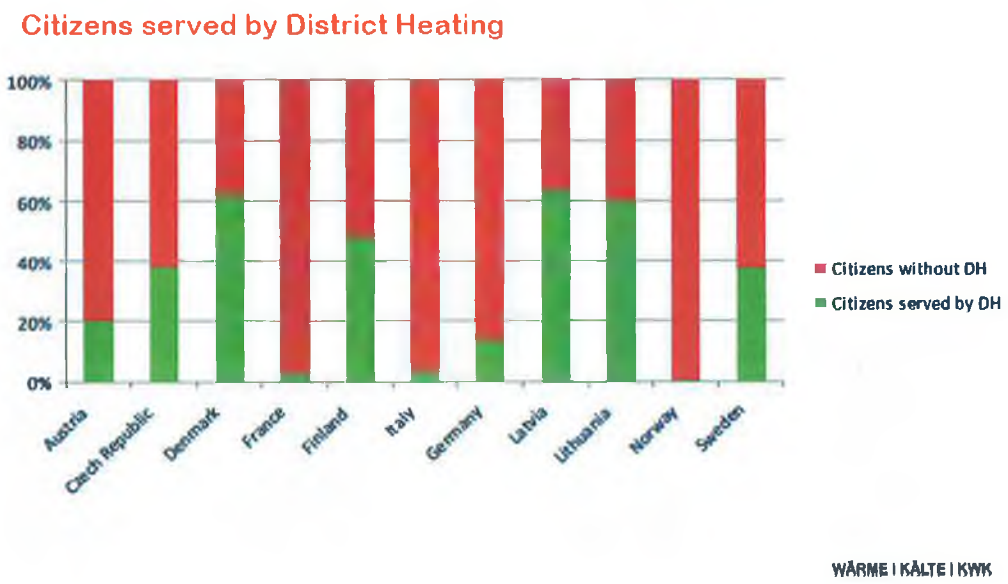


Figure 1 District Heating Barometer (Orita, 2011).

To improve energy efficiency and reduce Ireland's dependency on imported fossil fuels improvements could be made in areas where energy is wasted. Heat energy from power stations is often rejected to the atmosphere in large quantities. This energy can be recovered, an example of this is where Scandinavian countries have established large district heating networks with heat supplied from large power stations (Woods et al., 2005). This study will examine the prospects for recovery of heat from large scale CCGT plant in Ireland.

1.2 Objectives

The purpose of this work is to examine:

i. The amount of heat energy available from the CCGT process.

ii. Optimisation of waste heat recovery for district heating.

iii. Cost of district heating scheme for Finglas and the surrounding area in North Dublin.

iv. Benefits of district heating for the area.

v. Barriers and enablers to such a project.

1.3 Rationale for study

District Heating schemes have been developed in Northern and Eastern Europe since the 1900's. Countries such as Finland and Denmark have developed large district heating networks due to the lack of indigenous fuels and to limit the need for imported oil. District heating is a very efficient way of heating. The oil price rises in the 1970's were also a big driving force. Ireland relies heavily on imported fuels, approximately 89% import dependency in 2008. The installed capacity of CHP in Ireland in 2009 was 299MWe, with natural gas being the fuel of choice. The targets set out in the Governments Energy White Paper of 2007 states that growth in combined heat and power is an important objective to 2020. The targets set out were for 400MW of installed combined heat and power by 2010 and 800MWe by 2020. The vast majority of the installed units are <1MWe and are mostly systems which use the heat locally and not through a district heating network.

The Governments Energy White Paper of 2007 contains a commitment to removing the regulatory barriers to CHP and district heating systems. Using low temperature heat from industrial waste heat in district heating has proven to be attractive. The heat loss in thermal power stations is very large and could potentially be used in district heating. There are often geographical difficulties when planning district heating projects as the consumer needs to be relatively close to the heat source.

2. LITERATURE REVIEW

Demand for electricity is increasing, while we are still challenged with limited sources of fossil fuels and the need to reduce environmental pollution. The resources that we consume must be used in systems that achieve high efficiency, while at the same time making best use of these resources. Approximately 21% of the world's electricity is produced by natural gas. SEAI figures show that in 2008 it accounted for 55% of total primary input to electricity generation in Ireland. In the same year the final useful electricity consumption showed a 55% loss on the total energy inputs. Any system that will capture lost energy in electricity generation and use it to displace fossil heating fuels could lead to significant reductions in emissions and energy inputs.

2.1 Combined Cycle Gas Turbine (CCGT)

Gas turbines and steam turbines operate on different thermodynamic cycles. When they are brought together in a combined cycle gas turbine the efficiency of the system of the two cycles together is far higher than either could achieve individually. State of the art CCGT plant designs have achieved an efficiency of 60% and this is expected to increase to 64% by 2020 (Seebregts, 2010). An equivalent sized coal plant would take five years to plan and construct. CCGT plants are typically planned and constructed in two years (Westner and Madlener, 2011) produce 50% less CO_2 and nine times less NOx per unit of electricity generated. Cost of fuel for CCGT is higher though, and independent power producers can be exposed to current uncertainty in prices paid for natural gas (Seebregts, 2010).

CCGTs generally operate between 40% and 100% of nominal capacity. Some efficiency drop will be apparent when running at lower loads as they are most efficient when running at full load. A drop in efficiency of approximately 5% may be expected when running at 50% of full load. Despite these drawbacks the overall flexibility of CCGT plants has allowed them to benefit from different selection environments, to a point where it has been the electricity industry's current technology of choice when considering new thermal plant (Watson, 2004).

2.1.1 Gas Turbine Operating Principles

The Brayton Cycle is the thermodynamic cycle that describes the operation of gas turbines. In their simplest form they consist of three basic components: a compressor, combustion chamber and an expansion turbine.

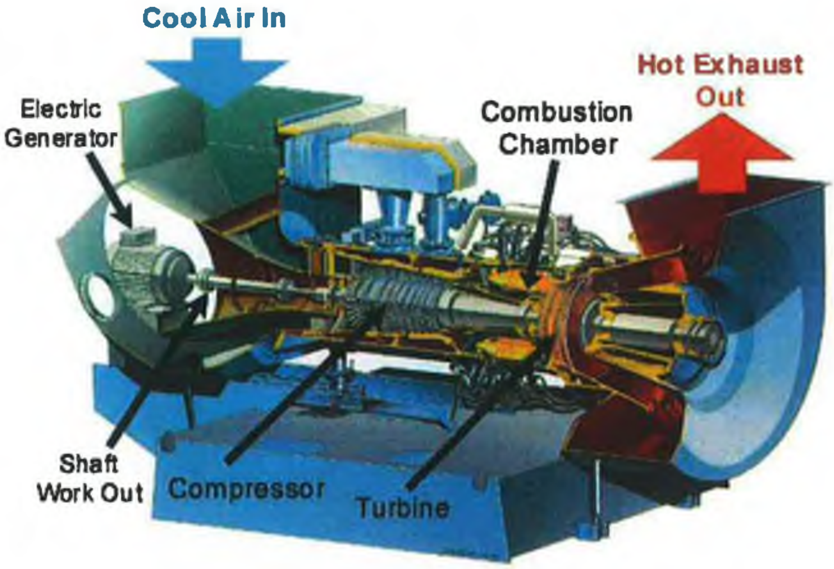


Figure 2 Gas turbine basic components (Courtesy of Wiley)

Atmospheric air enters the compressor, where it is compressed to the required pressure (typically 17bar for large CCGT plants). Because of this adiabatic compression the temperature of the compressed air is also raised. The amount of air entering the compressor is controlled by the inlet guide vane (IGV). As the amount of fuel entering the combustion chamber changes the IGVs will adjust the airflow. The IGV will be in the fully open position when the unit is at base load. After compression it is then passed through a combustion chamber where it is mixed with fuel (Lalor, 2005).

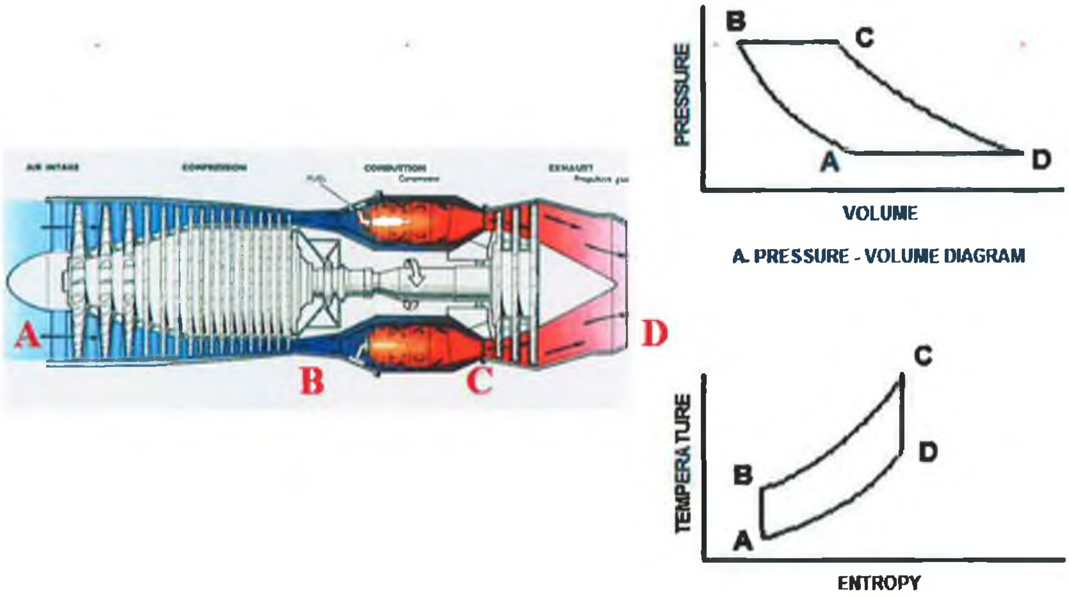


Figure 3 The Brayton Cycle (Courtesy of E.On)

Combustion of the air fuel mixture causes further increase in the temperature and these hot gases expand across the turbine blades causing them to rotate. The power produced by the turbine, less the power required to drive the compressor is that power which is available for the production of electricity. A gas turbine produces a large amount of power for its size and weight; when operated in this way it is known as an open cycle gas turbine (OCGT). The exhaust gases exiting the gas turbine still contain a lot of enthalpy due to the high temperatures of 500 to 600°C (Polyzakis et al., 2008).

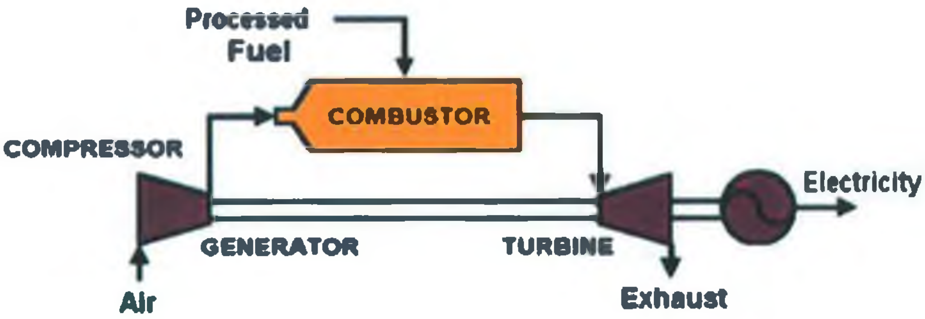


Figure 4 Simple or open cycle gas turbine (Courtesy of Energy Efficiency and Renewable Energy).

2.1.2 Steam Turbine Operating Principles

Steam Turbine working fluid is water. It operates on the Rankine Cycle by extracting the thermal energy from pressurised steam and converting it into rotary motion. This is done by expanding the steam across a number of stages. As the steam is expanded through the stages of turbine blades, the pressure and temperature will drop as the energy is imparted to the rotating turbine blades. The flow rate of the steam will depend on the pressure differential between the steam drum and the turbine. Like the gas turbine, the rotary motion of the steam turbine is ideally suited to driving an electrical generator (Lalor, 2005).

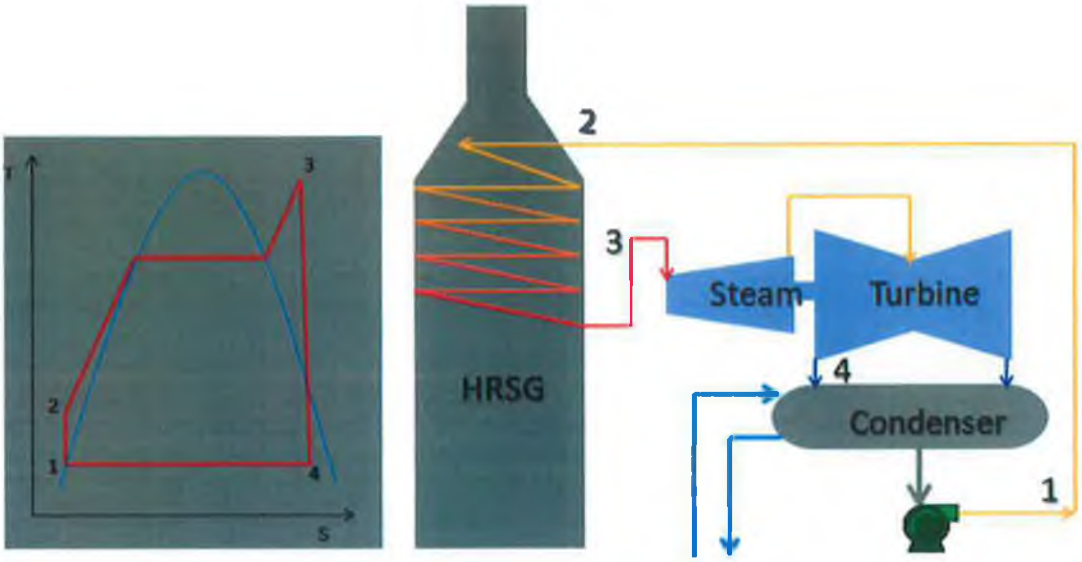


Figure 5 The Brayton Cycle (Courtsey of E.On)

When the plant is starting it may take a number of hours before the steam portion of the plant has heated up to operating temperature - this will depend on how long the plant has been off line. In comparison, the gas turbine can be at load in a few minutes.

2.1.3 Combined Cycle Gas Turbine Operating Principles

The fuel (normally gas, but diesel oil is often used as a standby fuel) is burned in a gas turbine. This generates electricity and waste heat. The waste heat exhausts the turbine and is passed through a heat recovery boiler, where it generates steam; the Heat Recovery Steam Generator (HRSG) is where the two different power cycles are coupled together. The HRSG conveys the heat energy in the exhaust gases to the water and steam inside the HRSG tubes. The heat transfer depends on the difference between the exhaust gas temperature and the water/steam in the HRSG. For large CCGT plants it would be usual for a single, horizontal type HRSG, triple pressure reheat unit that operates in natural circulation mode with low pressue (LP), intermediate pressure (IP) and high pressure (HP) systems.

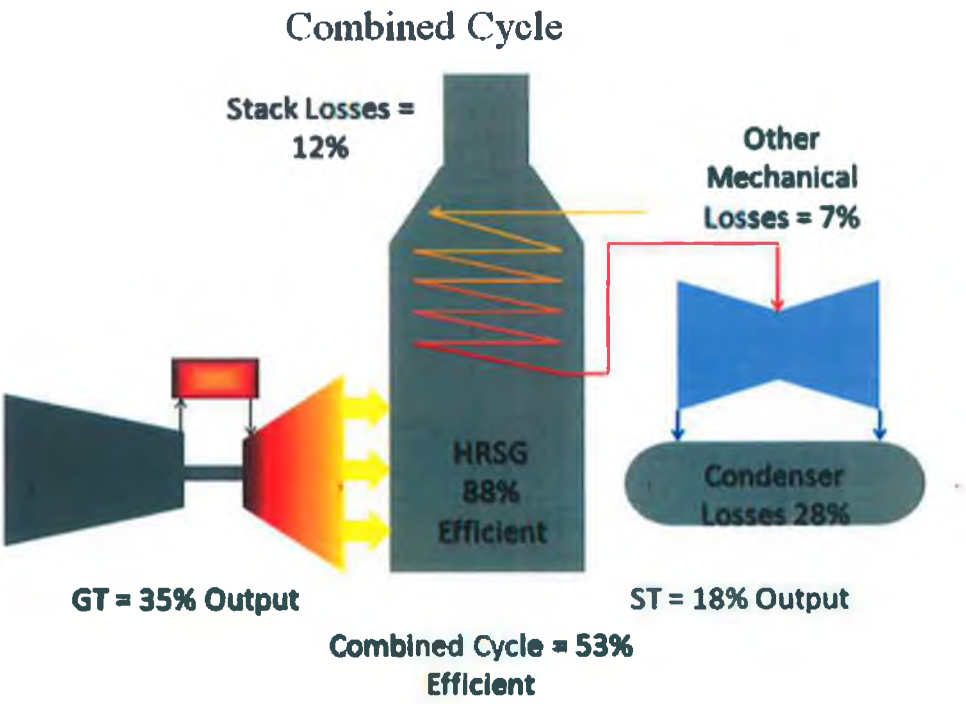


Figure 6 Combined Cycle (Courtesy of E.0N)

The steam is used to drive the steam turbine and produce more electricity. In CCGTs, the steam turbine is designed to produce approximately one third of the total power output, the remaining two thirds being met from the gas turbine (Watson, 2004). This combined cycle configuration results in significant increase in efficiencies over what could be achieved by either system running on its own. Typical output for a modern CCGT set would be approximately 400MW, where 280MW is generated by the gas turbine and 120MW is generated by the steam turbine.

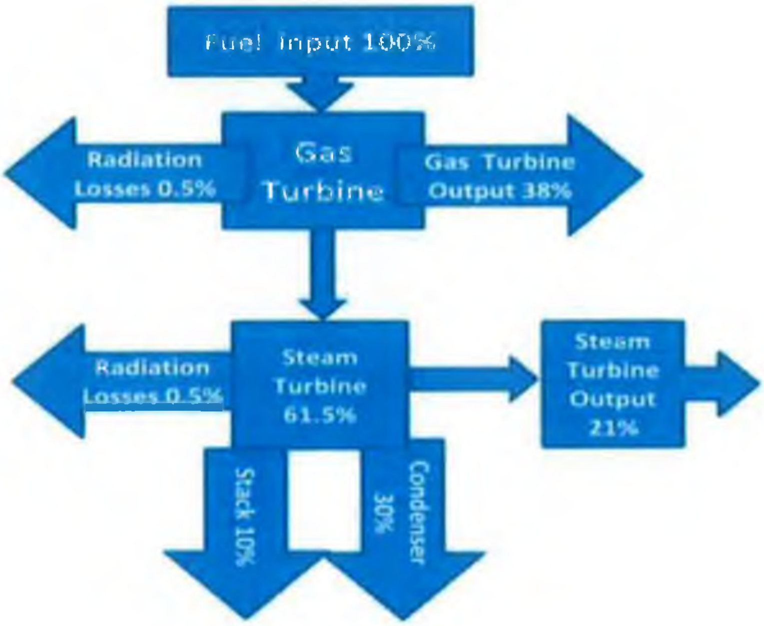


Figure 7 Illustration of a combined cycle power plant energy flows (Rezaie and Rosen, 2010)

In CCGT applications the gas and steam turbines are selected from commercially available models. The design performance of the combined process under varying running conditions and practical limits leads to a HRSG which is tailored to each power plant(Godoy et al., 2010). If the exhaust gas temperature from the gas turbine deviates from optimum temperature there will be a loss of efficiency. The GT exhaust gas and steam temperature at the HRSG are restricted by the minimum temperature difference at the pinch point and, the approach point, these are determined at the design stage. Typically they are unfired and of modular design, and heat transfer surfaces are finned to increase the surface area of the heat exchanger. Circulation may be natural or forced.

Figure 8 Serrated Finned Tubes as fitted in HRSG modules (Courtesy of Babcock-Hitachi Inc)

The combined cycle system will incur a higher capital cost than an open cycle system due to its complexity compared to a simple cycle system. However, the higher efficiency in converting the fuel (such as natural gas) into electricity makes the CCGT process competitive at intermediate and base loads.

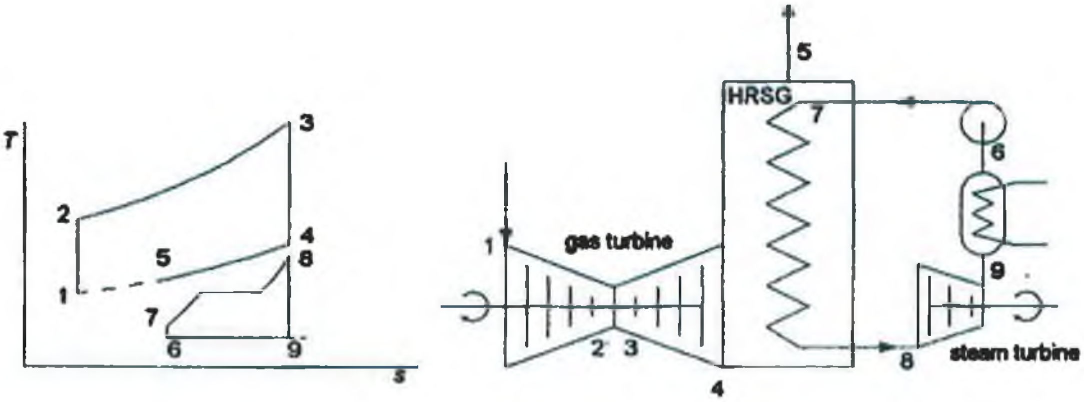


Figure 9 Temperature–entropy diagrams of combined cycle, simple Brayton cycle and Rankine cycle (Polyzakis et al., 2008).

2.2 District Heating

District heating is the distribution of hot water through a system of insulated pipes to buildings. The hot water is passed through heat exchangers in buildings to provide space heating and hot water requirements. It is an efficient use of thermal energy, which can be from a number of sources such as combined heat and power plants (CHP), incineration, waste heat from industry, geothermal heat source, biomass and fossil fuel boilers. Larger systems may incorporate a number of these sources. Through the integration of these technologies with district heating, significant reductions in CO_2 emissions and greenhouse gases can be achieved while at the same time leading to an increase in energy security.

The heat provided by district heating networks is fully controllable and provides a very reliable service that offers savings in space and operation and maintenance of individual boiler systems that they would replace. The scale of installed systems can range from CHP plants in individual buildings using spark ignition gas engines to citywide systems supplied by large CCGT plants. These CHP plants have the possibility to decrease fuel consumption between 20 and 30% when compared to thermal power plants coupled with boilers (Fragaki and Andersen, 2011).

Advantages of district heating:

- Heat is delivered to the building through a heat exchanger. It is a static device, longer lasting and is not as subject to controls and maintenance of traditional boilers.

- The energy is carried by water, which will be directly brought from the district heating network. There is no risk of leakage of gas, oil or other substances.
- The equipment for heat exchange takes up less space than traditional boilers.
- Heat exchangers have no combustion chamber, no flame and exhaust gas flues are no longer necessary.
- The distribution system is remotely controlled with real-time management of heat production and distribution.

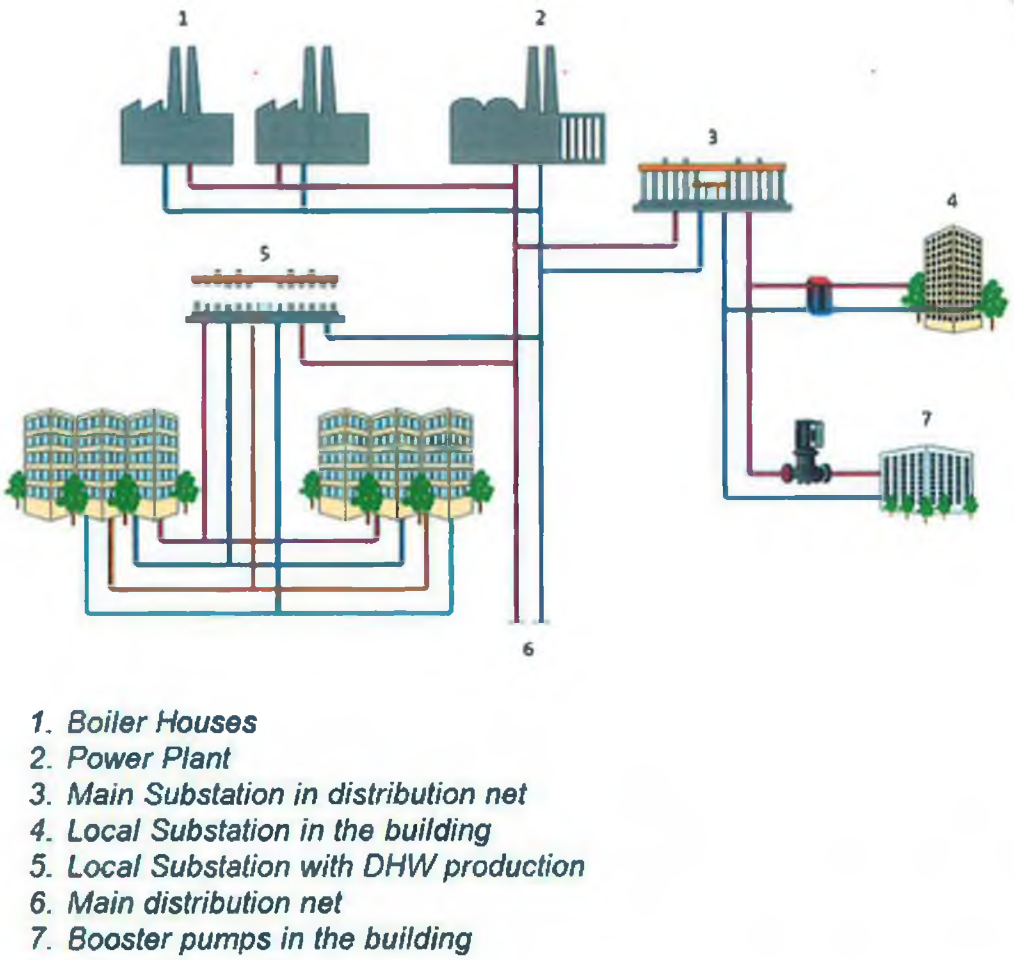


Figure 10 Diagram of district heating network (Courtesy of Grundfos)

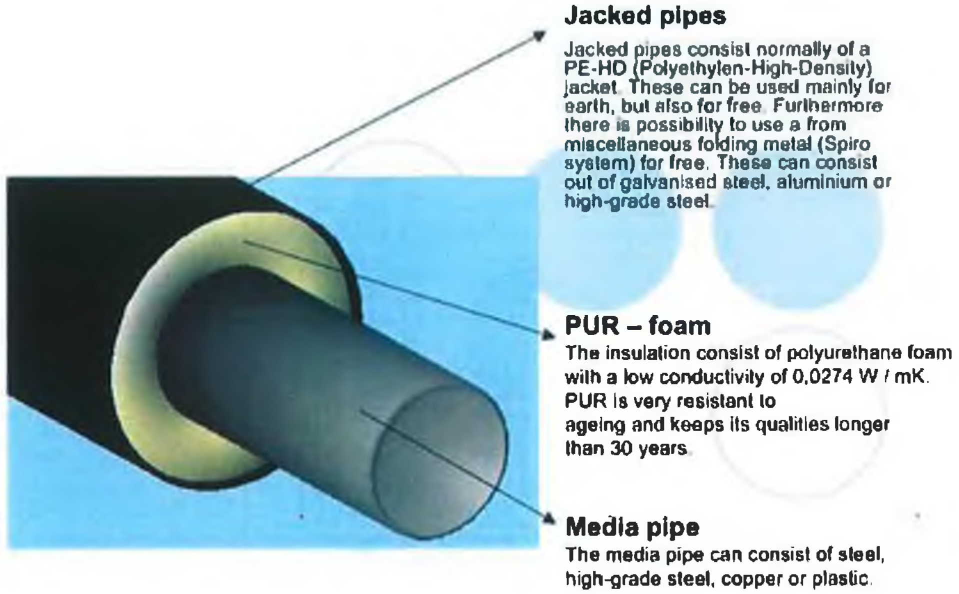
2.2.1 Barriers to District Heating Uptake

District heating in Ireland is still in its infancy, with the exception of some small scale systems. Generally they only service a single development and bear little resemblance to the large scale citywide systems that are common in some European cities. Part of the problem of future district heating is the low urban population density and high investment cost in the pipe network. In other European countries apartment living is much more common. Another barrier to DH uptake in Ireland is the large number of efficient gas fired central heating systems in homes (Ecoheat4eu, 2011)

Previous attempts at district heating in Ireland have had limited success and proved unpopular. Ballymun district heating system was built between 1966 and 1969 and supplied seven tower blocks and a total of 2814 flats. At the time it was the largest district heating system of its size in the British Isles. Heat was supplied by 45MW oil and gas boilers to flats with little or no thermal insulation, and poor control of supplied heat. The project was hailed as one of the state's biggest planning disasters and lead to a bad public attitude towards district heating in Ireland ever since (Power, 2000).

2.2.2 District Heating Pipe Design

A district heating network, whether it is a local or citywide system, represents a significant investment in both capital and operational costs. District heating networks would be assumed to be constructed to standard EN253 (Woods et al., 2005). This standard covers pre-insulated bonded pipe systems for directly buried hot water networks, as shown. The insulation minimises heat loss in the system. Pipe assembly is of a steel service pipe covered by polyurethane insulation with a polyethylene outer casing.



Jacked pipes

Jacked pipes consist normally of a PE-HD (Polyethylen-High-Density) jacket. These can be used mainly for earth, but also for free. Furthermore there is possibility to use a from miscellaneous folding metal (Spiro system) for free. These can consist out of galvanised steel, aluminium or high-grade steel.

PUR – foam

The insulation consist of polyurethane foam with a low conductivity of 0,0274 W / mK. PUR is very resistant to ageing and keeps its qualities longer than 30 years.

Media pipe

The media pipe can consist of steel, high-grade steel, copper or plastic.

Figure 11 Pre-insulated pipe work to EN253 standard (courtesy of GermanPipe)

Insulated pipes usually incorporate an electrical device for detecting and locating leaks. To detect leaks in the carrier pipe and casing, an exposed wire is installed in the pipe insulation. The electrical resistance between this electrical conductor and the metal carrier pipe can then be measured. Leaks can be detected by comparing this measured resistance with a reference value.

European standards also cover other aspects of the district heating pipe work:

- Installation of these pre-insulated pipes EN13941
- Fittings EN448
- Joint Assembly EN449
- Valves EN488

2.2.3 District Heating Network Design

The pipe network is the link between the heat source or sources and the heat consumers. The size of the pipe required will be matched to the peak heat flow, with the largest bore required closest to the heat source. Pipe diameter will decrease as the system branches out further away from the heat source (Colin et al., 2011).

2.2.4 District Heating Density

District Heating systems may be categorized by the application and what market they serve by considering the usage density (Rezaie and Rosen, 2010):

- **Dense population in urban areas**. In this case a district heating system can serve a large number of customers but require a complicated system and a significant financial investment.
- **High density buildings**. High rise residential buildings, institutional buildings, shopping malls and high density suburban developments.
- **Industrial complexes**. Similar to the high density building, but may require steam and hot water.
- **Low density residential.** This type of area would typically consist of single or double residential units and tend to have a heat network of less than 10MW.

District heating that is developed in areas of low density results in a higher distribution cost. Reidhav and Werner, 2008 have shown that low density areas may still be viable. They analysed one-family houses connected to district heating between 2000 and 2004 in Göteborg, Sweden. The density must be more than 2GJ/m and use of the district heating should be greater than 50GJ/house per annum. Low density areas where these systems have been successful would include Sweden due to the presence of carbon tax on fossil fuels and electricity. Smarter ways of constructing the network in sparse, areas such as reduction in the pipe depth and low marginal costs for the heat generated are required (Reidhav and Werner, 2008).

2.2.5 Advantages of large scale CHP for DH

There are many options when considering CHP, such as small scale units which serve hotel and leisure centres, usually spark ignition gas engines. Larger complexes, such as hospitals, may use gas turbines. Above these sizes we tend to see actual district heating networks with gas engines which can deliver up to 8MWe. Often a number of these units are coupled together to supply a network. Recently smaller scale CCGT in the range of 30 to 70MWe range have become available. As a result of these changes, it is not so clear a choice when planning district heating networks which system offers the best returns in emissions and cost benefit.

Comparison of these different options has shown that large power stations operating as CHP for district heating offer a number of important advantages over a large number of small generators offering the same service. Maintenance cost is relatively low and the life cycle is longer when the gas turbine is compared to the piston engine. Large scale power generation, such as the 400MW range of CCGT plants, benefit from economies of scale, giving a lower cost per megawatt of electricity generated and also tends to have a higher efficiency when considering electrical generation alone. This provides an opportunity for the electricity power producer to take advantage of the additional revenue provided by heat energy sales (Westner and Madlener, 2011).

2.2.6 Barriers to CHP uptake in Ireland

There are numerous barriers that have been identified as having limited the uptake of CHP in Ireland over the last number of decades. Some of these barriers have been identified in the past, some have been removed, but also there are new or potential barriers which will have to be dealt with to see an increase in both large and small scale CHP uptake in Ireland (SEAI, 2009a).

2.2.6.1 Social Economic Structure

Ireland does not have large heavy industry, energy intensive plants which would generally be a prerequisite to large scale CHP. The large services and commercial sector is a significant consumer of both electricity and fossil fuels, but they tend to have an occupancy pattern of mainly daytime and a 5-day week. In this scenario, the heat demand for a year is reduced from a potential 8,760 hours to a figure of around 3,000 hours. Exceptions to this would be hotels, hospitals and other buildings requiring a constant demand.

Population density in Ireland is low; even our urban centres have a low density when compared to continental Europe. Waste to energy is now being considered, with plants such as the planned Poolbeg incinerator expected to start exporting to district heating networks after 2012.

2.2.6.2 Economic

The economic viability of any CHP plant has to consider fuel cost, investment cost, operating cost, correct sizing of unit to load, and where necessary, a grid connection and price for exported electricity. The low amount of CHP in Ireland shows that the economics still do not show enough of a return to make CHP a dominant feature.

Payback periods may be longer than the three to four years that corporate investors would wish to see prior to investing in such projects. Viable projects may also find funding difficult to secure given the recent economic downturn.

2.2.6.3 Fuel Price

Generally, CHP plants are dependent on the price of fuels, the efficiency of the process and savings made on electricity purchases. For small CHP plants this leads to a number of scenarios where it must be determined if the project is to export to the grid (permitting and licensing requirements) or only produce electricity for its own use. Large scale users have greater power to negotiate the price they pay per unit of gas and electricity. It may also be possible that through investing in a CHP plant a large scale user may show such a decrease in the energy they require to purchase as top up, that they no longer maintain the same negotiating advantage with energy suppliers that they once had.

Also, a majority of CHP plants are not run during night-time, so that advantage can be taken of night rate electricity supplied by the national grid. Night rate electricity is often cheaper to purchase than the cost of generating power through the use of an onsite CHP unit.

2.2.6.4 Large Heat Loads

As mentioned previously, large industrial opportunities for CHP are limited nationally. Any industries that are large enough to consider it, such as cement manufacture and mining, can be too far outside the urban environment being considered here and may also be unsuited to CHP applications due to the thermal to electricity power ratio (SEAI, 2009a).

2.2.6.5 Availability of Fuel

Availability of fuel that is appropriate to a CHP application can present a barrier. Natural gas is currently the most widely used fuel for CHP (95% of installed CHP capacity is fuelled by natural gas). The natural gas network in Ireland is significant, but large areas remain unconnected to the grid system. The chances of low density areas currently not connected being connected in the short to medium term are remote. It may be feasible for the cost of connection to be borne by the end user to connect to the grid if it is relatively close by.

Figure 12 Natural Gas Network (Courtesy of Bord Gais Networks)

For oil-fuelled CHP availability is generally not an issue, oil supply is widely available throughout the country due to its extensive use for central heating systems (46% households use oil heating). Small and even micro CHP units fuelled by kerosene or gas oil are feasible from a technical aspect. Maintenance tends to be higher than gas systems, limiting their attractiveness. As the size of the CHP plant increases, the storage required onsite to maintain an appropriate supply of fuel may become an issue.

2.3 Integration of district heating & CCGT

The efficiency of thermal electricity generation was 39% in 1995 and improved to 46% in 2007. This excludes wind and hydro etc (SEAI, 2009b). When considering a CHP plant and comparing it to a gas boiler for supplying the heat for a district heating system, it is found that the reduction in electrical output from a CCGT plant due to the use of bleed steam for example, would be significantly less than the energy required to heat the gas boiler. The recovery of low grade heat and putting it to use effectively in large CHP could see energy efficiencies of 80% (Kelly and Pollitt, 2010).

Large generation units are cost effective at producing electricity alone; more opportunities should be investigated where these units are located so they may be incorporated into future developments. Large power-stations (>200MW) such as CCGT plants have been used for CHP (EcoHeatCool, 2006) for example the Vuosaari B in Helsinki, Finland has a total power of 463MWe and 416MW of district heat. Such schemes can be economically viable at generating electricity and leaving income generated from heat to be used as the finance for the district heating infrastructure (Kelly and Pollitt, 2009).

2.3.1 Extraction Condensing Steam Turbine

This type of system is ideally suited to large CCGT plants. Heat is extracted from the steam turbine before it reaches the final stages and used to heat the district heating network. This is not true waste heat as steam still has work to do in the steam turbine, but does avoid losing the majority of the steam's latent heat to the air cooled condenser. Nevertheless, some fall in electrical output will be observed.

For a typical hot water network, conventional boilers would supply water at 80°C, with a return temperature of 70°C. Steam needed to supply the network heat exchangers would be bled from the boiler at the lowest useful temperature and pressure, approximately 2.4bar and 126°C.

In large power plants the steam exiting the High Pressure section of the turbine is often returned to the HRSG to be reheated. This steam is referred to as cold reheat on exiting the HP turbine. After being reheated in the HRSG, it is known as hot reheat and it is then sent to the IP turbine. By raising the temperature again the enthalpy is increased even though the pressure is dropping. The reheat gives the steam turbine a significant boost in output while avoiding moisture forming on the turbine blades due to lower temperature. Cold reheat is a usable location for steam extraction, as is the Low Pressure turbine inlet. Although use of higher pressure cold reheat has a larger impact on electrical output (Brinckerhoff, 2010). The amount of electricity generation not available due to the steam bled off is referred to as the Z factor. For steam at this bled pressure, the Z factor is 6.3 (CHPQA, 2007). This means that for every 6.3MW of steam extracted there will be a 1MW reduction in the steam turbine electrical output.

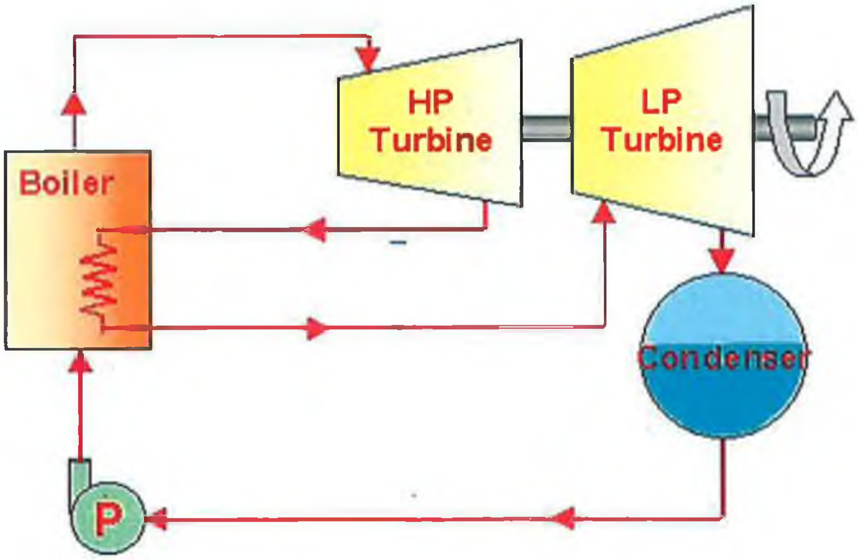


Figure 13 Rankine Cycle, showing steam reheat between HP & LP Turbine

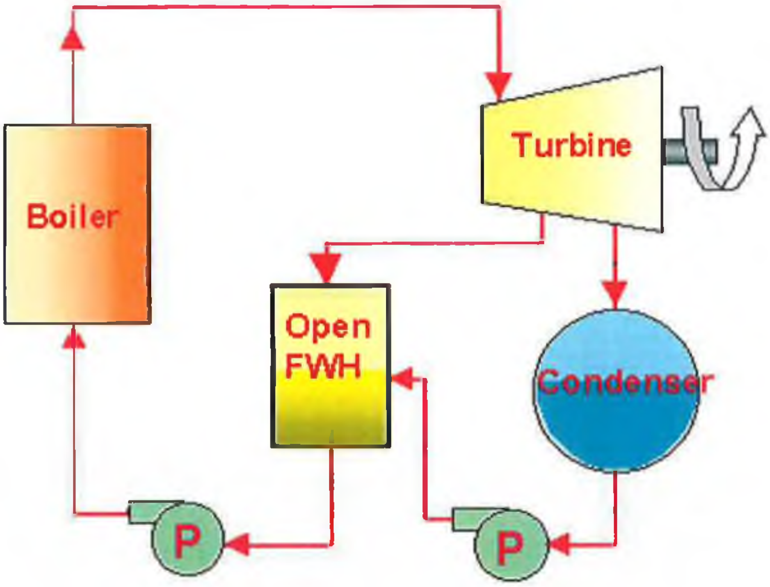
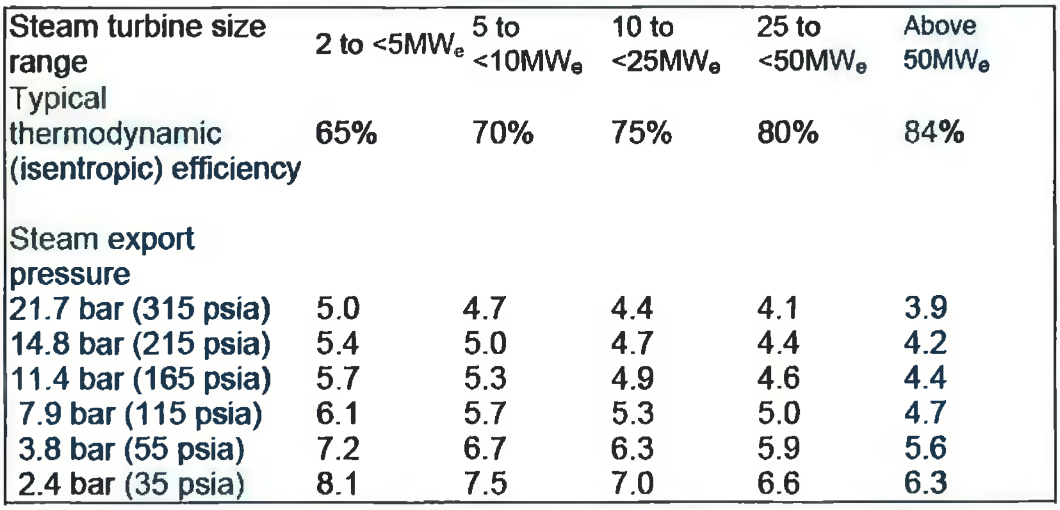


Figure 14 Rankine Cycle, showing bleed steam used for feed water heating



Steam turbine size range	2 to <5MW$_e$	5 to <10MW$_e$	10 to <25MW$_e$	25 to <50MW$_e$	Above 50MW$_e$
Typical thermodynamic (isentropic) efficiency	65%	70%	75%	80%	84%
Steam export pressure					
21.7 bar (315 psia)	5.0	4.7	4.4	4.1	3.9
14.8 bar (215 psia)	5.4	5.0	4.7	4.4	4.2
11.4 bar (165 psia)	5.7	5.3	4.9	4.6	4.4
7.9 bar (115 psia)	6.1	5.7	5.3	5.0	4.7
3.8 bar (55 psia)	7.2	6.7	6.3	5.9	5.6
2.4 bar (35 psia)	8.1	7.5	7.0	6.6	6.3

Figure 15 Typical z ratios for given steam turbines and steam pressures (CHPQA, 2007)

For district heating, the heat source directly from the HRSG that would show the most ease of retrofit would be low pressure superheated steam. This would be in the region of 3.8bar and would have a lower Z factor of 5.6. Lower Z factor would mean higher losses of electricity generation. Extraction points on the HRSG steam system would have to be retrofitted in such a way that they will have minimal impact.

2.3.2 Condenser Source Heat Pump

The air cooled condenser of the CCGT rejects large quantities of low grade heat with temperatures of approximately 40°C. This temperature in itself is too low to be used in a district heating network, but it has huge potential when upgraded using a heat pump. Heat pumps have previously been used in district heating systems: examples can be found in Sweden where seawater and sewage sludge water are used as a heat source. These heat pumps are often found on large systems with a 500GWh annual heat delivery (Eriksson and Vamling, 2007).

The project would involve utilization of the low-grade heat from the combined cycle process which is released to the atmosphere through the air cooled condenser. Two heat pump technologies are available for such a project: compression and absorption. A compressor-driven heat pump would require a motor driven compressor and would have a direct impact on the efficiency of the CCGT plant.

The absorption heat pump is an established and proven technology. Water/lithium bromide absorption chillers of single-stage and double-stage heat pump cycles can be designed and adapted to specific applications. Absorption heat pumps can either be fossil-fuelled or driven by heat from other sources. Water/lithium bromide technology is commonly used for chilled water air-conditioning. The same working fluid and main components of the heat pumps can be used for any useful heat temperature from about 10 °C to 180 °C and for heating capacities from about 50kW to 5MW. They have the advantage of being a simple design when compared to what is required when considering a customised vapour compression system, which would require a suitable compressor and refrigerant supply (Keil et al., 2008).

2.3.3 Other Waste Heat Sources Considered

2.3.3.1 Steam Turbine Exhaust

Heat that is rejected to the condenser from the steam turbine exhaust is at approximately 40°C, This is lower than the temperature required by the consumers and is unsuitable for direct heat recovery to the district heating system. As discussed in Section 2.3.2 it would be necessary to upgrade this heat to a more useable temperature. Alternatively this low grade heat could be used directly at 40°C in horticulture or agriculture for the heating of greenhouses. It may be possible to attract a suitable user to locate adjacent to the site; they may then access the large volumes of low grade heat.

2.3.3.2 Flue Gas Heat Recovery

Flue gas temperatures exiting the CCGT are in the region of 100°C on natural gas and 120°C when running on fuel oil (normally fuel oil will only be considered as a backup to a loss of natural gas supply). The amount of energy that could be recovered from the flue gas is potentially significant as it contains both sensible heat in the given temperature and latent heat in the water vapour present in the flue gas (Jennings, 2011). The limiting factor for the heat that can be extracted from the flue gas is to avoid corrosion issues due to any sulphur that is contained in the fuel. Fuel oil has higher sulphur content than natural gas and therefore a CCGT unit running on fuel oil maintains a higher flue gas temperature. The HRSG is designed to extract as much heat as possible while still avoiding corrosion issues due to the sulphur dew point being reached. Furthermore the addition of an extra module would require an extended period of the plant being off and prove disruptive to plant operations (Brinckerhoff, 2010).

2.3.3.3 Cooling Water Heat recovery

Closed circuit cooling water systems (CCCW) are used to cool lubrication oil, generators and various other auxiliary systems. The heat exchangers for this system are cooled by fans which are controlled by the temperature of the cooling water. The temperature of this system can vary; typical temperature of this system would be 12°C supply and 18°C return. This would be considered too low to be of any significant value in a district heating network and these systems are critical to plant operation and would need extensive redundancy to ensure that plant availability was not affected.

2.4 Legislation

A number of statutory bodies must give approval to allow the development and operation of a CHP facility and district heating network, but there are no laws or schemes that support district heating specifically.

2.4.1 Irish Legislation

Nationally there are no measures or laws to support district heating, although the following will support them indirectly:

- Building Regulations Part L: connection of dwellings to district heating systems is credited as meeting renewable requirement if fuelled by CHP.
- Building Energy Rating (BER): rating is improved if connected to a district heating network. Encourages investment in building energy performance.
- CHP and reheat deployment programs encourage the development of heat sources for district heating by means of grant aid.
- REFIT: increased tariffs for electricity supplied by high efficiency CHP and all potential DH heat sources.
- Renewable Heat deployment program (ReHeat): To increase the use of renewable energy systems for heating from heat pumps, biomass and solar

thermal. Ensure design and installation is efficient and achieves the desired carbon savings.

2.4.2 EU Legislation

There are a number of EU directives that support the development of district heating:

- Energy Performance of Buildings Directive - 2002/91/EC.
- Co-generation (CHP) Directive - 2004/8/EC.
- Energy Services Directive - 2006/32/EC.
- Renewable Energy Sources (RES) Directive - 2009/28/EC.

2.4.3 Planning

Planning authorities and systems will need to look at ensuring that demand and heat supply are located near each other, similar to the Danish heat law that was implemented in 1979. National heat targets involved increased use of waste heat from cogeneration, municipalities conducting heat planning and identifying areas suitable for district heating. Potential sources of surplus heat were identified, and municipalities were responsible for providing an appropriate heat load, either through expansion of existing district heating systems or through establishment of new ones. Compulsory connection provided security for the large investment necessary for a district heating network. There was little opposition to the implementation of the heat law in Denmark as district heating was and still is the cheapest heating option for a building (Lauersen, 2008).

2.4.4 Regulation

There is no regulation for district heating in Ireland which is a major barrier. This should be controlled by the Commission for Energy Regulation. Regulation will ensure that companies operating in the market have the required knowledge and experience. They may also set pricing and monitor the market to protect the consumer (Ecoheat4eu, 2011).

Price regulation on district heating was also introduced with the heat supply act of 1979 in Denmark. District heating in Denmark supplies a large number of houses and compulsory connection, gives it a dominating position in the heat market and a natural monopoly. District heating is therefore operated as non-profit activity, with cost-based pricing. The average price for district heating has remained below the price of the most alternatives such as gas or oil (Lauersen, 2008).

3. METHODOLOGY

To consider a District Heating network supplied with energy from a CCGT plant for west Dublin, the methodology applied has been:

1. Identify the potential interested parties of the system, from management, council and costumers.
2. To present the amount of energy that will be available and how best to harness this energy.
3. To identify the cost of such a network and heating requirements of the buildings connected to that network.

3.1 Interested Parties

There would be many stakeholders that would have an interest in the development of a DH network. These would include developers, Semi-State bodies, financial institutions and consultants, public bodies, engineering companies and so on. This study will focus on the three main parties that would be involved in a North Dublin District Heating Network.

3.1.1 Fingal County Council

As the local authority Fingal County Council would be a key stakeholder in the development. To date they have not indicated any plans where they intend to develop such a system. It will be necessary for Fingal county Council to use their unique position to promote and co-ordinate the development of the planned district heating network.

3.1.2 Energy and Network Management Company

It would be expected that an Energy Services Company (ESCO) would be formed. The services it would provide would begin with the design and development phase and continue through construction to operation and management. The structure of such a company would include both public and private participation and be operated on a not for profit basis. The advantages of using the ESCO model is that it allows the company to operate outside the restrictions that may be faced by a local authority, where it may have flexibility to respond quickly to opportunities. This model would still allow Fingal County Council an influence on its operation and also allow the ESCO consider marginal and long term decisions that a private company may not. Similar schemes have been successful for Southampton's Milbrook CHPDH and the Aberdeen CHP projects (Pöyry, 2007).

3.1.3 Customers

The heat provided to the customers must be at a price that is competitive with natural gas heating. Heating by a DH network should be an advantage to the consumer by reducing their energy bills, increasing reliability and decreasing green house gas emissions. It would be expected to see a 5 to 15% reduction in space and hot water heating per annum (Linger, 2009). Regulation must be put in place to protect the customers. If the ESCO is set up with the correct contractual safe guards as is the case in mainland Europe there is little risk to the customer. This can be ensured through transparency of pricing and contracts.

3.2 Huntstown Power Plant

Huntstown Powers Plant comprises of two combined cycle gas turbine (CCGT) units located in the Huntstown Quarry adjacent to the M50 motorway on the north of Dublin City. One is a Siemens multi shaft unit capable of generating 343MW and the other a Mitsubishi single shaft unit capable of generating 401MW, giving a total plant output of 744MW. Both plants operate on natural gas with distillate oil as a backup fuel source.

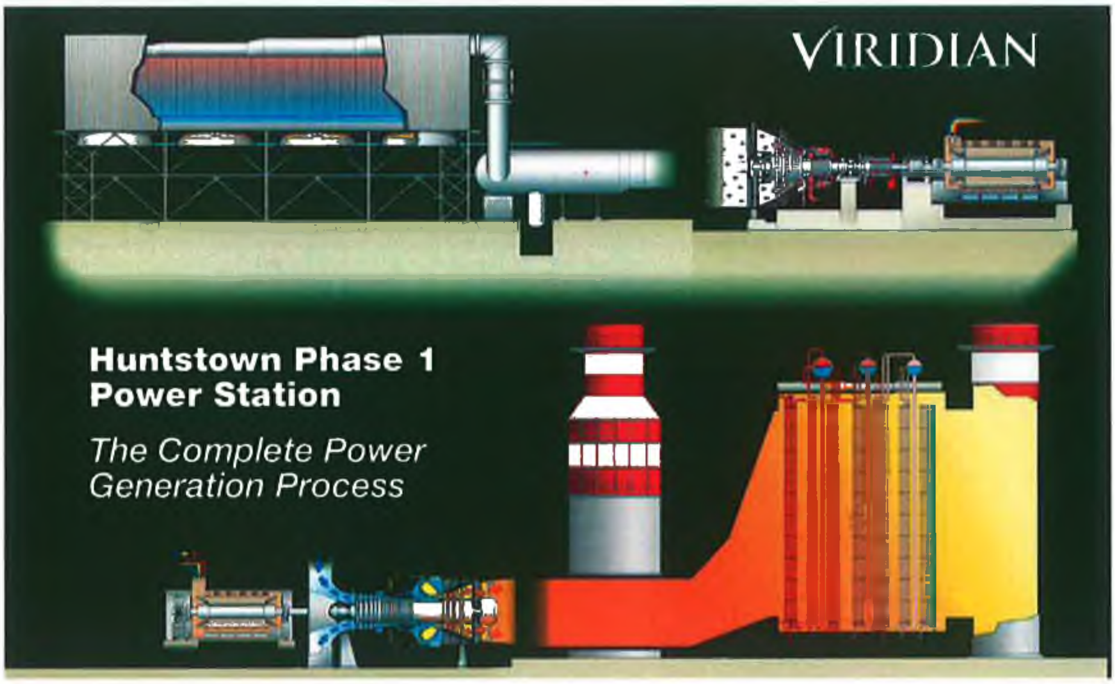


Figure 16 Huntstown Multi-shaft CCGT

3.2.1 Phase 1

Phase 1 was commissioned on November 2002 and consists of a Siemens V94.3A1 gas turbine, two Siemens generators, a Hitachi heat recovery steam generator, a Siemens H30-25-35/E30-25-2-1x6.3 steam turbine and a 16 bay GEA air cooled condenser. A spilt shaft arrangement allows the plant to run in open cycle mode where only the gas turbine runs, this gives the plant added flexibility. The plant generates 343MW at 54.8% efficiency where the gas turbine generates 228MW and the steam turbine 115MW. Power is exported from the plant at 220kV via an Eirgrid site switchyard and then underground to the local ESB Finglas substation.

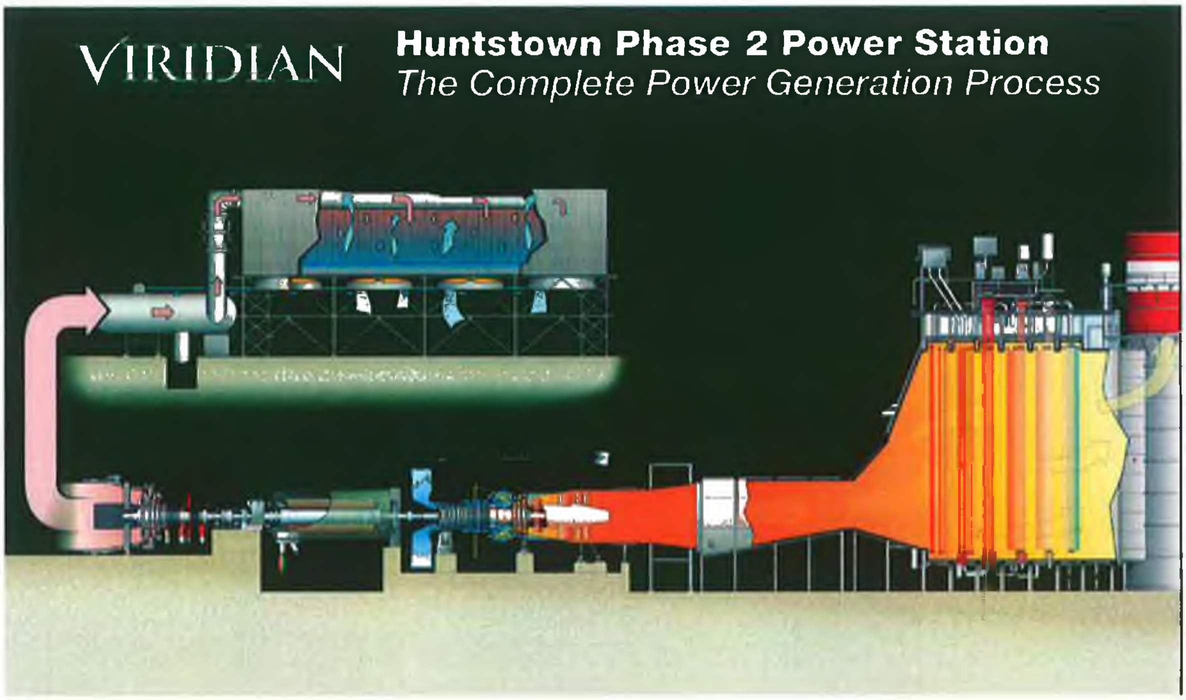


Figure 17 Huntstown Single-shaft CCGT

3.2.2 Phase 2

Phase 2 was commissioned in October 2007 and consists of a Mitsubishi M701F3 gas turbine, a Mitsubishi generator, a Nooter Eriksen heat recovery steam generator, a Mitsubishi SRT-48AX steam turbine and a 20 bay SPX air cooled condenser. It operates at an efficiency of 56% where the gas turbine generates 260MW and the steam turbine 140MW.

Figure 18 Huntstown Power Plant showing Phase 1 (red) and Phase 2 (blue) (courtesy of Viridian plc)

3.3 Excess Energy available from CCGT

CCGT plants need to operate as efficiently as possible. The areas of losses must be identified and minimised where possible. Compromises in efficiency are sometimes unavoidable to maintain output and availability. The vast majority of power stations do not capture low grade heat. When located near the coast, seawater is used as the cooling medium. If this is not possible and there is no suitable cooling water supply available, an air cooled condenser (ACC) can be utilised. At Huntstown CCGT plants, ACCs are used. Regardless of the condenser being air or water cooled, when combined with other losses approximately 40% of the energy is lost. In this case 600MW of the energy in the fuel is being discharged to the environment when both units are running at base load.

When the energy for a DH network is taken from the CCGT process by controlled extraction steam turbine operation, the steam extraction depends on the steam demand required to maintain the temperature in the DH network, while the remaining steam is condensed in the ACC. This option has been the usual choice for large industrial or district heating plants. It is possible that CCGT CHP plant design may be operated with a minimum electrical efficiency of about 40% based on the gas turbine simple cycle efficiency, with full utilisation of the steam being used for another process rather than electricity generation (Lako, 2010).

An important observation is that more generation capacity is lost at higher steam extraction pressures. Also, turbine extraction results in a reconfiguration of the power station - the turbine design must be optimised to operate at a particular steam flow-rate. In addition to a drop in overall electrical efficiency of the turbine, significant fluctuations away from this design point may also affect the efficiency. This must be remembered when considering the short and long-term demand profiles of any potential heat off-take. Therefore, extractions should be taken at the lowest pressure possible. This would be considered more appropriate for the Huntstown project as the main source of business is electricity generation.

It would be expected that district heat extraction for any district heating system would be available between 50 and 100% of relative load. Both Huntstown plants ran without restriction during the harsh winters of 2009/2010 and 2010/2011 when minimum air temperatures fell below -15°C. During this time they had a high utilisation factor in demanding conditions and demonstrated high reliability.

Other advantages to recovering heat from existing power station include:

- No increase in NOx as the emissions from the power station remain unchanged.
- No requirement for planning permission which would be required if a new plant was considered
- No impact on the local electricity infrastructure

3.4 Future Running Profile of CCGT Plants

Wind generation is having a large impact on the running cycle of thermal generation plants in Ireland and CCGT plants are no exception. High wind forecast means that plants modulate output to match those dispatch instructions received from NCC (Eirgrid) and these plants can also be instructed to shutdown when not required. A plant running outside optimum conditions will run less efficiently and therefore observe an increase in fuel used per MWh produced. This is even more pronounced when a plant is instructed to stop generating due to over capacity on the electrical grid. A knock on effect of increased fuel use and emissions can be observed when the plant is required to restart (Bass et al., 2011).

Power systems will have to evolve to incorporate greater penetration of renewable generation and increased flexibility is a demand that will have to be met. CCGT plants are not considered to be very flexible units. This limitation is due to the steam cycle where many thick walled components that need to be brought up to operating temperature slowly. An exception to this is where unit are fitted with a bypass stack which allows the gas turbine to run in open cycle mode (Troy et al., 2012). CCGT plants supplying large quantities of thermal energy may also be capable of having greater flexibility with regard to electrical output as discussed in section 3.5.

3.5 Security of Supply

It would be usual for district heating systems to have a number of heat sources rather than one stand alone boiler that would be typical of individual buildings not connected to a heating network. Because of the multiple heat sources there is security in supply. A failure of one heat source will not have an adverse effect on the heating system. The operator of the district heating will also be more inclined to maintain equipment at a higher level than homes and businesses.

When considering heat recovered from a power station there are extra considerations that need to be taken into account. Security of supply focus is now on electricity production as this is the main business. But this focus would need to expand to include the security of supply of heat. The plant will need to accommodate daily load variations on the grid and run between 50 and 100% of relative load. It would also be expected that at least one of the plants could go through a period of daily start-up and shutdown, which will also need to be considered. For heat to be available to the district heating network the power station must be generating. In this case security of supply will be from back- up boilers that will be required to run to provide the heat if the power station is not running (Colin et al., 2011).

An alternative way of overcoming the possibility of a CCGT plant cycling on and off would be the use of heat sink or accumulators. This would allow the generated heat to be stored for later use. Backup boilers may still be required for times when demand exceeds capacity or extended periods of a plant being off.

Figure 19 A 65m high accumulator tank at Ostersund, Sweden with a restaurant on the top floor.

Thermal storage may also allow the power station to run at reduced electrical output during times when electricity prices are low. This would keep the unit on line and avoid unnecessary cycling. In this case the amount of extracted heat energy from the CCGT would be increased to the maximum allowable for extended periods while the power station was at minimum generation. Where this heat is above the demand required for the district heating network, at night for example, the excess energy could be used to charge the thermal storage vessel. Also during peak times when electricity prices are at a premium, the power plant could stop any heat extraction and maximise electrical output. The thermal storage could supply the required heat to the district heating system during this time. This benefit will become more important in the future as there is a move towards greater use of intermittent wind energy, thermal storage will be beneficial in giving flexibility to district heating networks (Woods et al., 2005), while capturing electrical revenue during periods where they would otherwise have been offline.

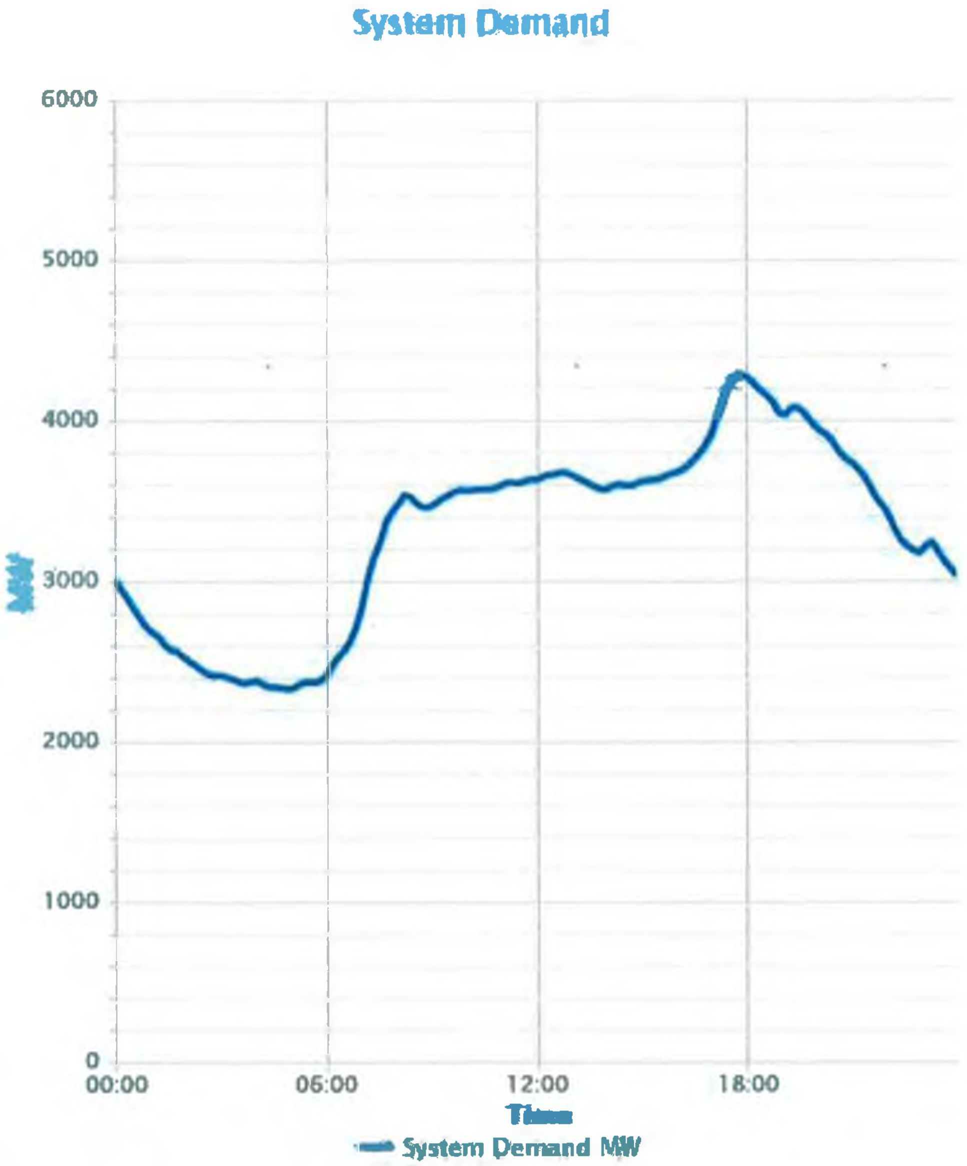


Figure 20 Electrical system demand showing typical January evening peak and night time valley (Courtesy of Eirgrid)

3.6 Equipment Requirement for Integration

Regardless of the manner in which the energy is recovered from either of the Huntstown plants, close co-operation with OEM companies Siemens and Mitsubishi will be required to adapt the main plant components and control systems to offer a customized steam turbine and district heating design in order to supply the optimum district heating plant solution. An Instrumentation and Control system will permit the safe running and supervision of the plant in CHP operation. Staff at Huntstown will control the operation and monitoring of gas turbines, water/steam cycles, HRSG, steam turbine, all the auxiliaries, and electrical equipment.

3.6.1 Condenser Heat Pump

Condensing steam is a convenient heat source that a heat pump can easily use. The operating principle of the absorption heat pump uses two working fluids; boiling point elevation and heat of absorption give an increase in temperature and allow heat to be delivered at a higher temperature.

Absorption chillers have been widely used in hot/humid climates, where the performance of a gas turbine mainly depends on the inlet air temperature. The power output of a gas turbine depends on the flow of mass through it. On hot days, when air is less dense, power output falls off. An increase of 1°C of inlet air temperature decreases the power output by 1%. Absorption chillers have been utilised to cool the inlet air from temperatures of 35°C to 10°C (Ibrahim et al., 2010).

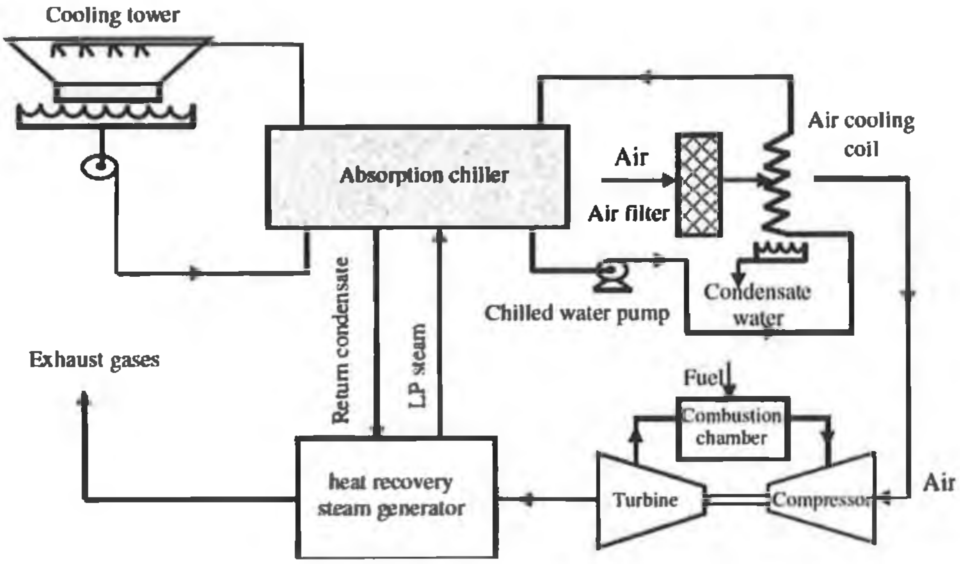


Figure 21 Absorption inlet air cooling system (Ibrahim et al., 2010)

In cold climate areas this type of cooling is not necessary as the number of hours per year that the ambient temperature is above 15°C is not enough to need such as system. The lower air inlet temperature is also limited as below 5°C may cause icing in the compressor section of the gas turbine.

Compression type heat pumps could also be considered in this type of application; this would require an electrically driven compressor and would have a direct reduction of the CCGT electrical output. An example of a compression heat pump system can be seen in Helsinki where five units have been installed giving a total output of 90MW of heat and 60MW of cooling. In this case the heat source is from seawater and treated sewage.

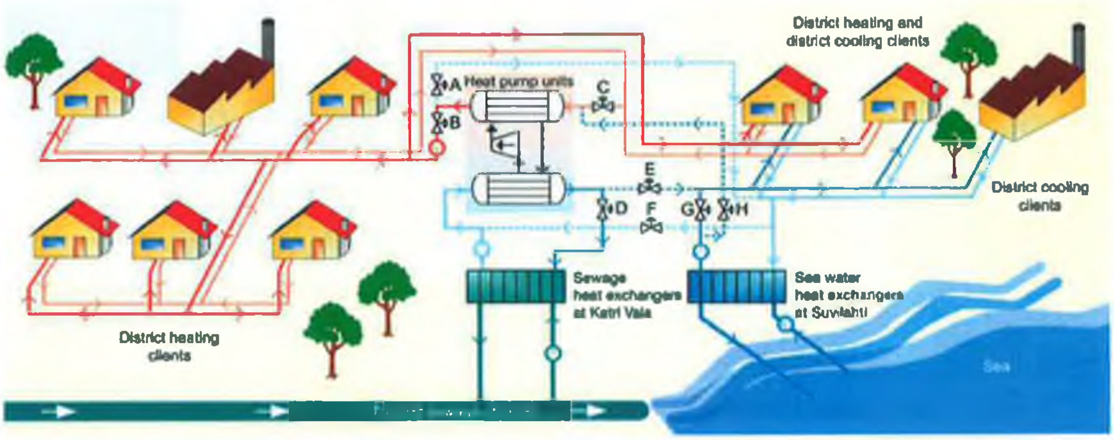


Figure 22 Katri Vala heating and cooling by sewage and seawater heat source (Courtesy of Friotherm)

One major possible limitation of a heat pump combined with waste heat from a power station for district heating would be the load condition. The unit optimum operating efficiency would be designed to work at higher loads during winter. The ability to operate a heat pump at full load outside the heating season would be minimal. Operational experience in the city of Riga, Latvia where CHP plants have been combined with absorption heat pumps, has found it to be more efficient to use steam extraction to supply the required heat load during the summer months when the heat pump may only run at part load. In this case the installed heat pump is primarily used during the heating season (Žīgurs et al., 2011).

Installation of an absorption heat pump with an integrated gas burner was seen as a possible way to solve the issue of poor part load operation of the system during times of low demand.

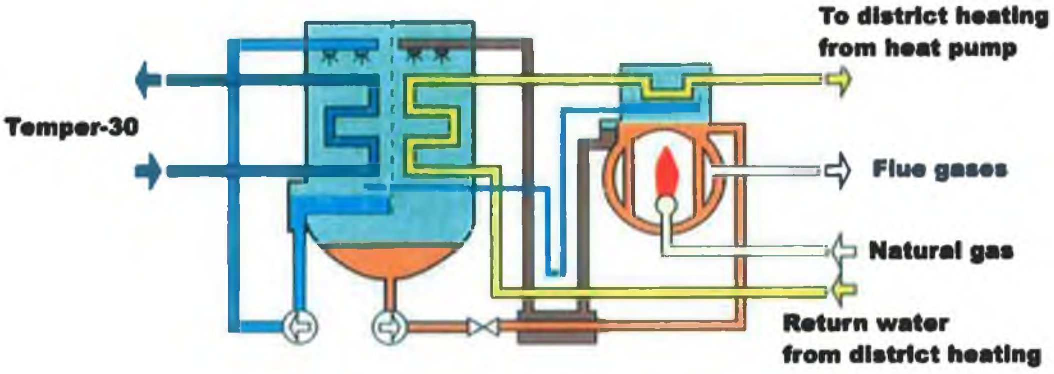


Figure 23 Absorption heat pump with integrated gas burner (Žīgurs et al., 2011)

The size of the heat pump required for Riga was estimated to be 11MW, the flexibility of this type of system allowed a heat pump to operate between 1 and 11MW. The latent heat from the CHP cooling system of the CHP plant produces useful heat for the district heating system (Žīgurs et al., 2011).

3.6.2 LP Bleed Steam

The most common option of supplying steam from a CCGT plant is through steam extraction. Studies in this field have shown that 1,000MWe CCGT plants have been found to be capable of delivering 200MW through steam extraction from low pressure turbines (PBpower, 2005). This would suggest that a plant such as Huntstown with two CCGT plants could deliver up to 150MW of thermal energy for district heating with a corresponding electrical loss of 24MW at a Z factor of 6.3.

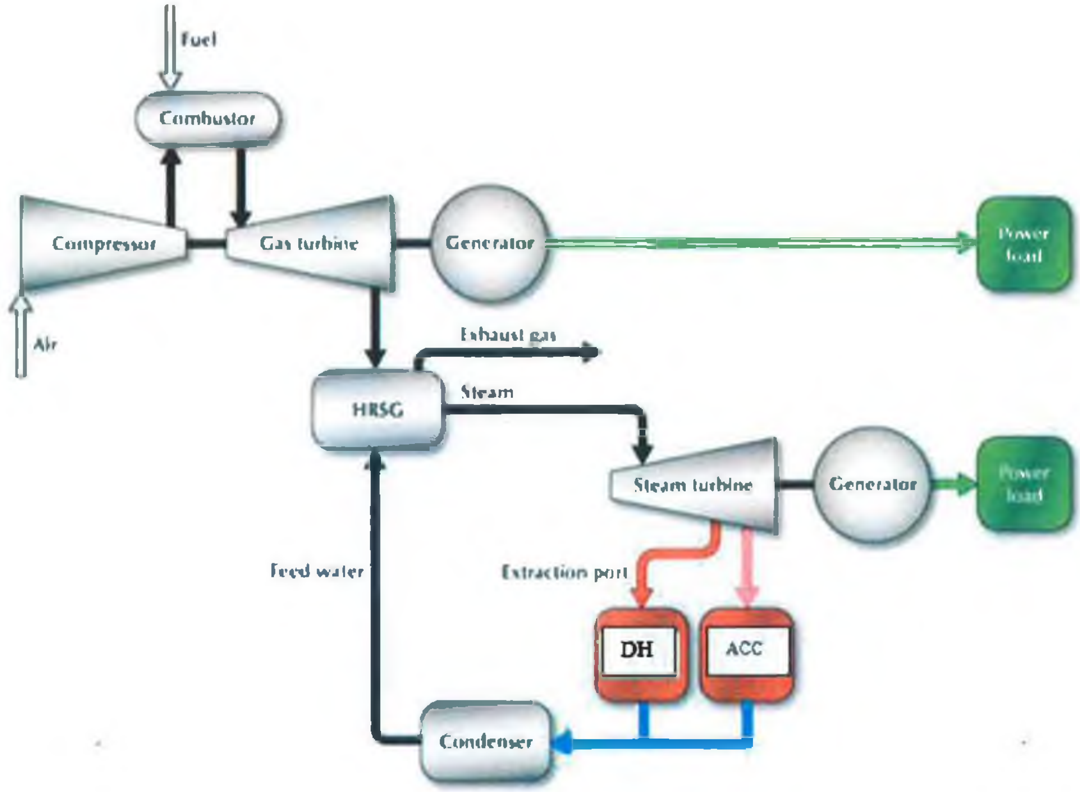


Figure 24 LP steam bleed schematic (Courtesy of RETScreen)

The LP steam turbine on each plant will be equipped with an extraction point for district heating operation. Steam for the district heater is drawn off from the LP turbine prior to exhaust at 2.4bar and 126°C. Cooled condensate from the district heater will be pumped to the condensate collecting tank. Should it become necessary at a later date to expand the system, it would be possible to add a second district heater that would receive steam from the LP steam turbine at an upstream stage. This would be of a higher pressure and temperature. It would be necessary for a minimum amount of steam to be flowing through the last stages of the LP turbine in order to prevent ventilation, which would then be discharged into the condenser. Ventilation occurs at very low steam flows, the low velocity of steam through the turbine blade passages is completely incorrect for extraction of energy from the steam flow. In fact, the rotating turbine blades churn the steam, and actually add energy to the steam, increasing its enthalpy and temperature. It is possible to exceed the allowable temperatures for the turbine blades and equipment if this should occur.

The amount of district heating will be controlled by the amount of steam that is extracted. This will be considered in the plant automation and will also be controllable by the plant operators through a human machine interface module. It is important to note that more generation is lost at higher steam extraction pressures. At a 5bar steam extraction point the power loss would be 0.2MWe/MWth Steam, while at 20bar it would be in the region of 0.3MWe/MWth Steam (Jennings, 2011). For this reason all low pressure extraction opportunities should be explored prior to commencing steam extraction from higher pressures.

The district heater will consist of surface heat exchangers: the district heating water enters the inlet water box of the first heater, flows through the tubes and leaves the heater via the outlet water box.

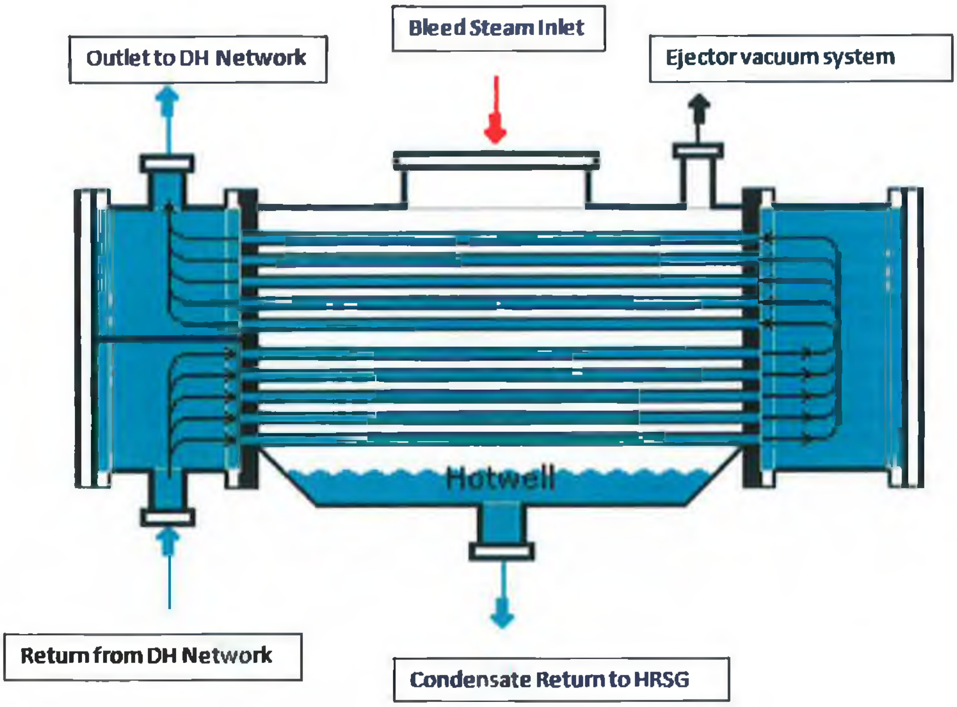


Figure 25 Bleed steam heat exchanger for district heating

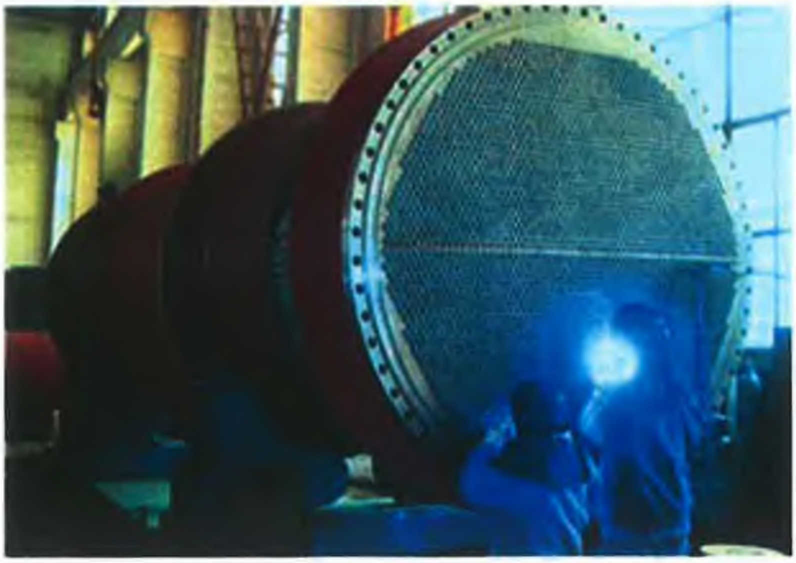
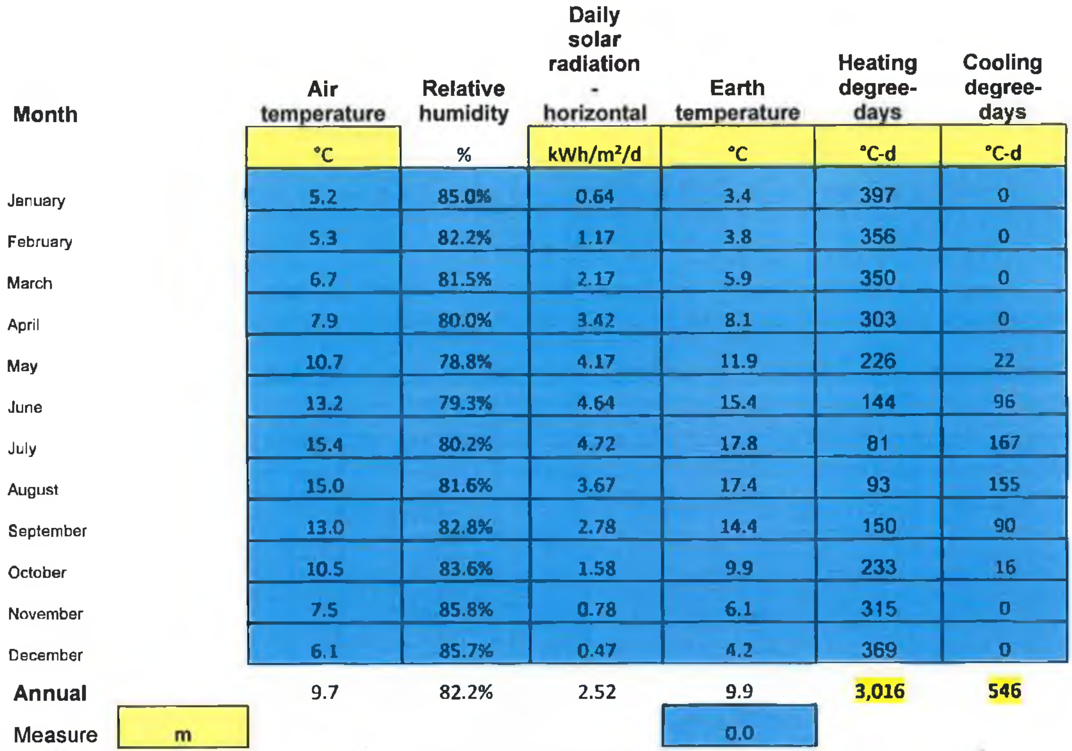


Figure 26 Construction of shell and tube heat exchanger (Courtesy of TNT)

3.7 Area, Buildings & Services to be Considered for Supply

The study will look at potential customers within the target area of 10km around the heat source. Studies have shown that heat loads up to 30km from the potential heat source through a properly designed network are feasible (Colin et al., 2011). This would allow for future expansion of the system in phases and possible connection to other planned district heating networks in Dublin city.

Heating degree days for Dublin are above 3,000 for the year. At this point a combined heating and cooling network has not been considered due to the ambient temperatures in Ireland. Climate data for the areas show that for 6 months of the year there would be no cooling requirement, with a total of only 546 cooling degree days per annum.



Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	°C	°C-d	°C-d
January		5.2	85.0%	0.64	3.4	397	0
February		5.3	82.2%	1.17	3.8	356	0
March		6.7	81.5%	2.17	5.9	350	0
April		7.9	80.0%	3.42	8.1	303	0
May		10.7	78.8%	4.17	11.9	226	22
June		13.2	79.3%	4.64	15.4	144	96
July		15.4	80.2%	4.72	17.8	81	167
August		15.0	81.6%	3.67	17.4	93	155
September		13.0	82.8%	2.78	14.4	150	90
October		10.5	83.6%	1.58	9.9	233	16
November		7.5	85.8%	0.78	6.1	315	0
December		6.1	85.7%	0.47	4.2	369	0
Annual		9.7	82.2%	2.52	9.9	3,016	546
Measure	m				0.0		

Figure 27 RETScreen climate data Dublin Airport (Courtesy of RETScreen International)

Types of load that are considered include:

- Residential
- Office
- Hotels
- Recreational
- Institutional
- Industrial

3.8 Heat Mapping

Heat mapping has been undertaken in order to establish the existing heat demand and identify potential customers for the heat from the proposed heating network. This exercise was hindered by the heat load information being confidential or not available and lack of information available on the details of the extensive business and industrial parks in north Dublin.

When calculating the estimated demand the following information was utilised:

- Size of the building/development in m^2 or
- Estimated heat demand in MW or
- The building development use.

3.8.1 Residential

Charlestown Centre Finglas

Distance <2km

Charlestown is a mixed use development in Dublin 11 comprising of 285 apartments with a total area of 24, 225m^2 based on average 85m^2 per apartment. There is also an 18,800 m^2 shopping centre, underground car parking and roof top gardens. The anchor tenant in the shopping centre includes a Dunnes Stores with a footprint of 7,600 sq meters. Electricity and heat are generated using a 225kW CHP plant, with the produced heat and electrical energy fed directly into the complex. When more heat is required, standby gas boilers are used to provide additional back-up. There is also a 1 MW wood pellet boiler but this may possibly not be used. The onsite CHP plant runs approximately 12 hours per day with gas boilers providing the heating requirements the remaining time. A connection to a district heating network would allow the use of supplied hot water to an already existing system and avoid top up through the use of the gas boilers when the complex CHP is not in operation.

3.8.2 Office/Commercial

This area of North Dublin is occupied by a large number of industrial and business enterprise parks; this is due to a number of factors such as its close proximity to Dublin Airport and the Port Tunnel as well as an excellent road network. The M50 motorway which runs around the south, west and north of the city, connects important national and primary routes to the rest of the country. Figure 19 shows this large volume of business and enterprise parks in the area surrounding Huntstown Power Station.

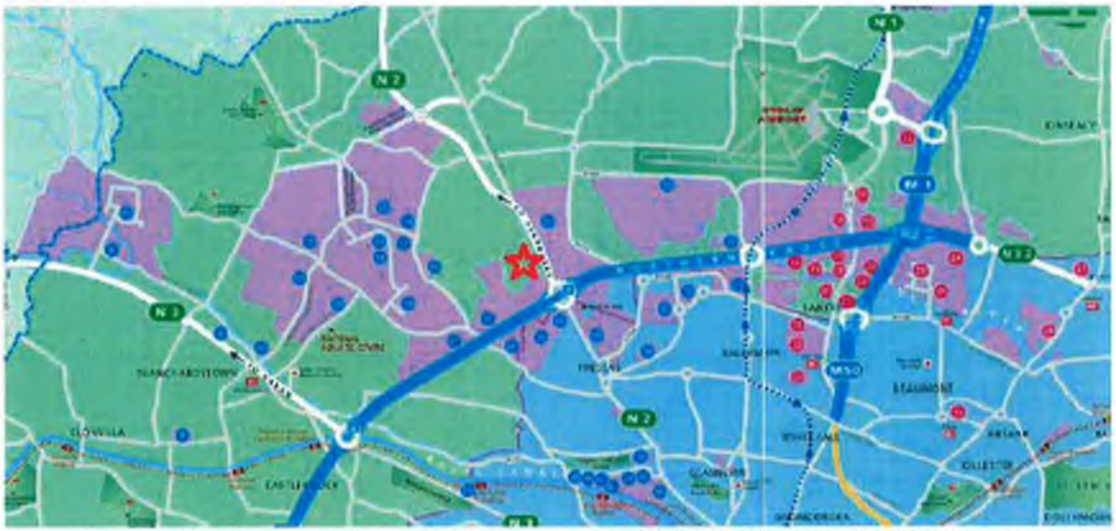


Figure 28 North Dublin should Industrial Business Parks highlighted (LaSalle, 2012), Huntstown Power station location noted by red star.

In total 30 of these enterprise parks could be serviced by district heating due to their close proximity to the power station. No figures have been gathered for the total amount of industrial space. Previous research (Fitzpatrick report) has indicated that the bulk of industrial space in Dublin is concentrated around Fingal and Dublin airport with major developments having been constructed in recent years. This area has proven popular with multi-national companies. Among the list of companies that have offices in the area are Amazon, eBay, IBM, Nike, Puma, Wyeth and others.

Research conducted by Savills and Trinity College Dublin has found the average size of commercial developments built in Ireland from 2000 to 2010 varied between 2,500 and 11,000m², giving an average of 5500m² over the 10 years. Central Statics Office of Ireland figures give a figure of 179 local industrial units for the area in 2009 (CSO, 2009)

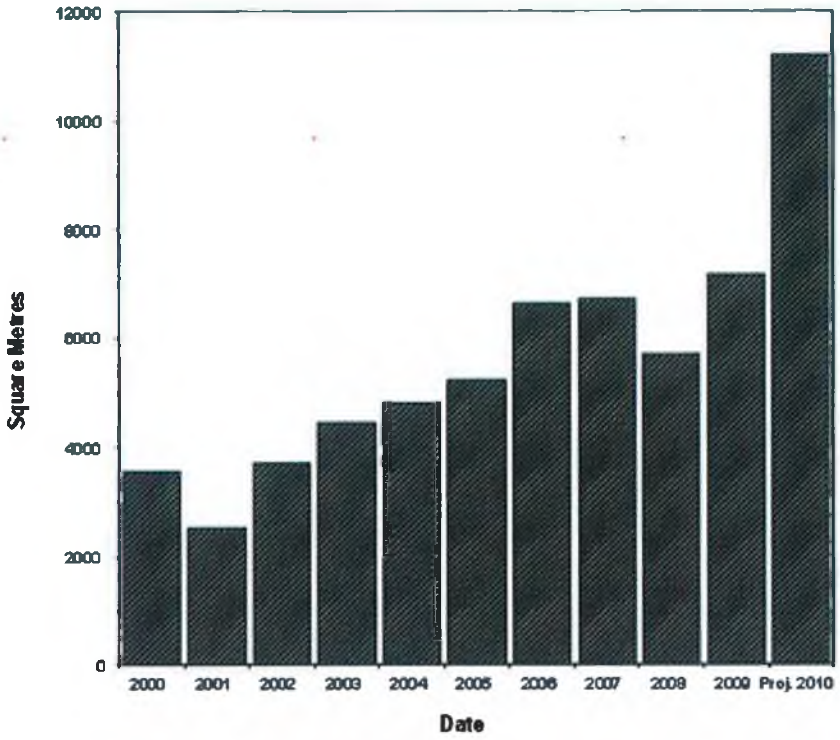


Figure 29 Savillis Estimated average sizes of developments 2000-2010 (Savills, 2010)

3.8.3 Hotels

Over 1400 hotel bedrooms are located in the area around the heat source serving both the airport and local business parks. A typical hotel room in Dublin is estimated at approximately 65m². This gives a total approximation of the area to be in the region of 91,000m².

3.8.4 Recreational

Blanchardstown Shopping Centre

One of Irelands leading shopping destinations with 83,000m^2 of retail space, when combined with the Charlestown shopping centre this figures gives a total area of 102,000m^2.

3.8.5 Institutional

Connolly Hospital Blanchardstown

Distance - 4km

Large public sector buildings such as hospitals are a very attractive heat load as they tend to be large. Connolly Hospital Blanchardstown is a major hospital with 425 in patient and 44 day. The Hospital provides a range of services such as acute medical & surgical service, acute psychiatric services, long stay care, day-care, outpatient, diagnostic and support services to a population of 290,000. The Hospital's catchment area extends into West Dublin, Meath & Kildare. Emergency services are provided 365 days a year 24 hours a day. Approximate area of Blanchardstown hospital is 100,000m^2.

Blanchardstown Institute of Technology

Blanchardstown Insitute of Technology was opened in 1999 and is located within the Business & Technology Park in Blanchardstown Road North. The college caters for 2,500 students with a total building area of 22,000m^2.

3.9 Estimated Demand

The heat demand for different building types has been taken from the table below

Development Type	Average Heat Demand (kWh/m2/yr)	Area to be heated (m^2)	Annual Heating Requirement
Residential	70	24,225	1,695,750
Office/Commercial	95	984,500	93,527,500
Hotel	200	91,000	18,200,000
Educational	150	22,000	3,300,000
Recreational	350	102,000	35,700,000
Institutional	200	100,000	20,000,000
Total Area		1,323,725m²	
Total Heat		172,423,250kWh	

Table 1 Heat Demand Calculations (Gaillot et al., 2007) combined with available heat loads

The total area connected to the network would be over 1,300,000m². The amount of heat energy that would be required for a district heating system would be in the region of 172,000GWh annually. The emissions abatement that will be achieved by switching to energy from district heating would be 0.205kgCO_2/kWh. This would mean over 35,000tCO_2/year would be saved by avoiding the use of gas boilers normally used for space and hot water in these homes and businesses. This figure is much higher than that which could be achieved in most district heating networks where gas fired peak boilers would be used. It would be expected that the excess energy from the power station would be able to supply the areas maximum heat load with a minimal limited impact on the overall electrical output of the plant. Supply would be expected to be equal to heat demand, plus 5% for transmission and approximately 18% for network losses.

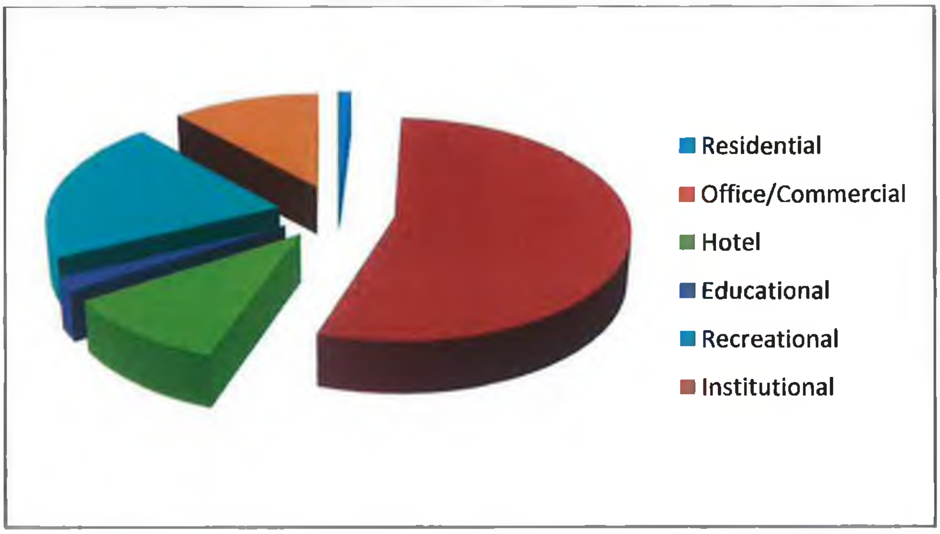


Figure 30 Breakdown of Heat loads

3.10 Estimated Cost of System

Several scenarios were considered. The purpose of the financial modelling is to demonstrate the viability of the project. Some scenarios would require more investment, but will provide more positive results and greater flexibility than others. If the development of such a network was to proceed, more rigorous analysis for business case funding would be required. Financial institutions typically lend based on a 15 year loan term with a 20 year plant operating life for this type of project. In order for the system to be viable, it needs to break even before 15 years (Linger, 2009).

The main reason for the high cost of district heating is pipe network. It has been estimated that a district heating network to serve a population of 270,000 households similar to a scheme in Vienna could cost in the region of €1.8billion. Some of the ways of reducing the relative cost include such measures as using waste heat from conveniently sited power stations. (Macadam et al., 2009).

3.10.1 Cost of Network

There are four key points to consider for the cost of a district heating network.

- Operating temperature and pressure.
- Complexity of area to be serviced, city centre is more expensive than suburbs.
- The length of the heat main.
- Peak demand.

The construction of a network will assist in the achievement of a sound and cost-effective heating system, especially in areas that are under development, new areas of urban centres such as Chalestown in Finglas. Additionally, areas of dense commercial developments optimize the efficiency of a network and minimize the initial capital investment, for economy-of-scale reasons.

Any constructed network will have to consider future building expansion, so that the pipelines will be installed from the outset with appropriate diameters. The district heating networks should be designed according to the pressure drops, so that the supply pumps will be capable of conveying water to all branches (Vallios et al., 2009). The routing around urban block areas must be carried out considering the number and size of energy consumers and also the possible expansion or connection to the proposed Dublin Docklands district heating network.

At local level the district heating networks will be designed as a low temperature system with flow and return temperatures of 95°C flow 65°C return. A larger temperature difference would be preferable if designing a system for new buildings with district heating incorporated into the design. The limiting factor will be the existing heating systems, which typically will be 80°C flow 60°C return for standalone boiler and radiator heating systems. This will allow future expansion of the system to private residential dwellings such as some apartment blocks and houses. Connections would be through direct connection so long as there is pressure compatibility between the heating systems. The low temperatures would allow plastic carrier pipes to be used if there was a cost advantage, particularly for final connections to buildings. For these reasons peak pressures in parts of the network would to be limited to 6bar (Woods et al., 2005).

Figure 31 Outline of main pipes (purple) DN 600mm - DN 100mm

Figure 31 shows area covered by the district heating network with the main pipes DN 600mm to DN 100mm in purple. The routing of the largest pipes would be closest to the station and follow the contour of the M50 east and west at junction 3 to junction 6. This route should minimise disruption to traffic as the M50 phase of work may be carried out off the road. Some traffic disruption may be experienced when the pipe routing has to be carried along the M1, M2 and M3. This disruption should be limited to lane rather than complete road closures. The total length of main pipe would be in the region of 16km. Cost per km district heating €1.3million (Linger, 2009) giving an estimated total network cost of approximately €20 million.

3.10.2 Cost of Equipment Energy Supply Side

The assumed capital costs of a gas fired CCGT are estimated to be €850/kWe. Making a CCGT plant capable of heat recovery for district heating is estimated at 1.5% of the basic capital cost (Colin et al., 2011). For a total output of 750MW, cost of converting both CCGT at Huntstown to CHP mode would be in the region €9.5million.

3.10.3 Cost of Equipment Energy Consumer Side

Customer connection cost is lower if the district heating system is designed and developed at the same time as a community is built. The cost increases significantly for a project where the heating system is retrofitted in existing buildings. A 2009 feasibility study into district heating for the Cork Docklands area gave the following costs for district heating equipment required by the consumer (Linger, 2009).

Residential Costs

- Average size 70m2
- Cost of residential heat exchanger €2,750
- Annual Standing Charge €100

Commercial Building Costs

- Average size 500m2
- Cost of commercial heat exchanger €5,000
- Standing Charge €500

4. DISCUSSION

4.1 Comparison of Integration Options

Two methods of heat recovery from the CCGT process were considered, steam extraction and heat pump. This study would suggest that an exhaust steam supplied heat pump would have limitations during summer months. Therefore this would only be feasible as an addition to the thermal energy supplied by the steam extraction. Low pressure steam extraction would be best suited to such a system. Heat pump integration may well be considered at a later stage depending on the success and expansion of the district heating system

Addition of a thermal storage vessel to any district heating network would be a major advantage. This technology acts as a buffer between the mismatch in supply and demand of energy, while allowing more flexibility to the CCGT when supplying thermal energy to the district heating network. Capital investment cost of such a thermal storage system would be considerable but be deemed necessary to see the full potential of CHP-CCGT.

For an independent power producer to invest in such a program depends on whether the trade-off between the high investment costs and the increase in revenue as a consequence of the sale of heat energy is cost effective or not. Integrating a DH system will also lead to a reduction in power generation. Although this reduction would be low, the real impact of this loss in electrical power generation can only be fully assessed following discussions with potential heat customers to access take up of such a scheme.

4.2 Comparison of Results

For independent electricity generators to embrace a CHP option it will be necessary for the value of heat and electricity to exceed the production cost, production must be profitable. Conversion to CHP mode of operation must be an economically attractive choice. The amount of steam extracted at a low steam pressure and the corresponding Z factor of 6.3 help to minimise the loss of electrical generation while still providing adequate heat energy from a single CCGT plant supply the needs of the network and allow for significant expansion of the system at a later stage.

Phase 1	**Electric Mode**	**Combined Mode**
Electric Power	343MW	330MW
Heat	0MW	75MW
Efficiency	55%	64%
Fuel	Natural Gas	

Table 2 Efficiency comparison of CCGT and CHP-CCGT Phase 1 Huntstown

Phase 2	**Electric Mode**	**Combined Mode**
Electric Power	401MW	388MW
Heat	0MW	75MW
Efficiency	56%	65%
Fuel	Natural Gas	

Table 3 Efficiency comparison of CCGT and CHP-CCGT Phase 2 Huntstown

The efficiency figures given in Table 1 and 2 for the Huntstown CCGT plants would indicate the approximate power available at lower steam extraction pressures of 2.4bar for a total of 150MWth. These improved efficiency figures for CHP mode of operation are higher than any efficiency that an electricity only CCGT plant can achieve. Higher amounts of thermal energy taken from the system would increase the overall efficiency but would have a higher impact on the reduction in electrical output due to a lower Z factor at higher steam pressures.

4.3 Study Costing

Capital costs for such a project will be considerable. While some of the major systems are already in place such as gas and electricity network connections, also each CCGT plant requires conversion rather than construction of a CHP plant from new. The equipment required to allow CHP-CCGT, the district heating distribution network and operation and maintenance costs must all be considered to ascertain the total cost of the project and a payback period.

4.3.1 Cost of Heat Produced

1MWth will cost 0.16MWe to the CCGT plant, electricity prices fluctuate in the single electricity market that CCGT plants operate in. A snapshot of the single electricity market for the 30th of April 2012 shows the market price ranging from a valley price of €30.28 to peak of €84.70/MWh (SEMO, 2012). With the flexibility offered by the addition of thermal storage it would be expected that the loss of generation at peak prices could be avoided. An estimated electricity price of 40€/MWh has been taken to represent the revenue lost by the reduction in electrical output. Based on these assumptions the heat balance heat production price has been calculated at:

Cost of Primary heat from CHP-CCGT: 40 x 0.16 = €6.40/MWh

4.3.2 Payback Period on Capital Investment

The capital investment required at the energy supply side has a number of major components, the CCGT steam extraction, heat exchanger, thermal storage, pumps and instrumentation the cost of which has been estimated at €9.5 million. The district heating network system piping has been estimated at €20 million. Loan term interest rate as be taken as 6% (Gaillot et al., 2008).

On a simple payback:

Loan amount:	€29.5million
Loan term:	10 years
Interest rate:	6.0%
Annual repayment:	€3.28million
Cost of finance:	€18.93/MWh

4.3.3 Consumer Installations

The vast majority of the consumer installations would be for commercial use at 1,300,000m^2, the residential figures is 25,000m^2. Heat exchanger and associated equipment for such installations has been estimated at €5,000 per 5000m^2 (Linger, 2009). It is envisaged that this cost would be borne by the ESCO to increase the take-up of district heating within the catchment area and would represent a major attraction to potential energy consumers. Total cost for this service to commercial consumers is estimated at €1.3million. Residential consumers could also benefit from this service but at a much higher cost, estimated at €2,700 per 70m^2. Residential connections currently considered are serviced by the Charlestown heating network and therefore will not be subject to this connection cost. Retrofit of individual homes are considered to be small scale heat loads and incur a high connection costs, for this reason they are not considered in the study.

On a simple payback:

Loan amount:	€1.3million
Loan term:	10 years
Interest rate:	6.0%
Annual repayment:	€0.15million
Cost of finance:	€0.90/MWh

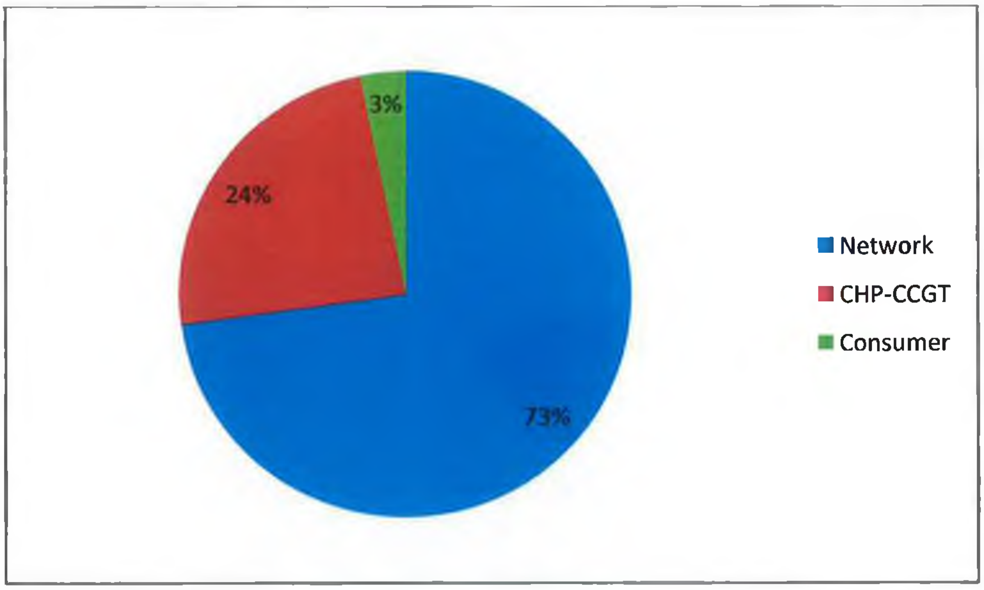


Figure 32 Breakdown of Capital Investment.

4.3.4 Operation and Maintenance

Operational costs have been estimated from the experience of similar district heating networks as being 4% of total investment (Linger, 2009). Maintanence costs have considered all capital investment, this includes CCGT, network and consumer equipement. Total operation and maintenance cost is €1.27million/annum.

Cost of Operation & Maintenance:	€7.34/MWh

4.3.5 Business Model

The heat consumption Table 1, Section 3.9 shows an annual heat load of approximately 173,000 MWh/annum. Commercial natural gas costs for January 2012 were €42.20/MWh for consumers <28,000MWh annum (SEAI, 2012a), while domestic customers paid €61.00/MWh (SEAI, 2012b). A small number of domestic customers have been considered within the scope of the study, these residential units are currently supplied by a heating network at Charletown, Finglas. As such the ESCO would supply the required heat energy to the Charletown heating system rather than individual units.

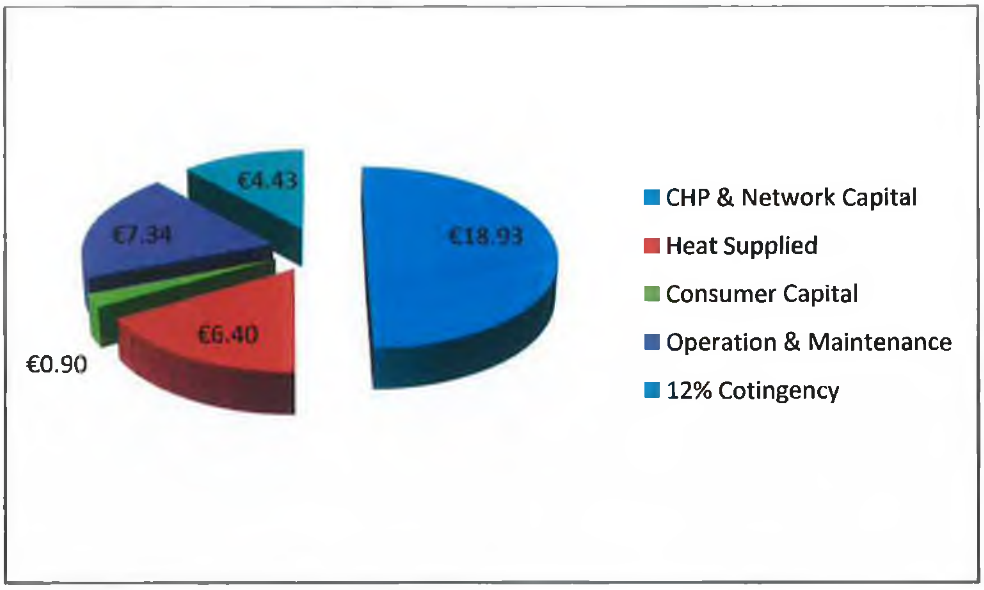


Figure 33 Breakdown of €38/MWh Heat Cost.

District heating for west Dublin based on the use of recycled heat could be competitive with natural gas supplied heating. It would require significant take-up of the system by consumers at an early stage to ensure a timely payback period. This would be incentivised by offering significant advantages such as removing the cost of conventional boiler replacement and also avoiding the €10/MWh operation and maintenance cost associated with boiler installations (Gaillot et al., 2008). Total cost of the system could be financed by a price of €38/MWh which would include the consumer's equipment and associated running costs. While the price paid for the heat energy shows a saving of 10% over the current natural gas price paid by commercial gas customers, the actual saving realised by the consumer could be as high as 35% when gas connection, metering, maintenance and standing charges are considered.

Accumulated Income:	€66million
Operating Costs:	€12.7million
Total Repayments:	€41million
Heat Cost:	€11million
Projected Earnings:	**€12.3million**

Table 4 Projected 10 year investment and return

Figures show that it is possible to finance the project through ten year loans that would cover all necessary equipment on both heat supply and consumer side. Critically this is less than the 15 year payback deemed necessary to make district heating schemes viable. This financial model includes a 12% return per annum during the payback period. This return would be required to cover cost overruns and delayed take-up of the system by consumers prior to returning a profit to the ESCO and energy supplier.

Government or European grant aid should be provided to help cover the large capital cost associated with the construction of a district heating network. This would be considered more effective in attracting investors than supports such as feed in tariffs. Investors will consider the risk to be far lower with upfront investment grants as annual support can be changed or removed and therefore pose a long-term risk. Current financial incentives to support environmental measure tend to focus on renewable energy. As the heat recovered is ultimately sourced from fossil fuel it does not receive approval for financial aid. EU and Irish legislation will have an influence on heat recovery from CCGT. However, this legislation was not developed specifically to support the type of scheme that is the focus of this study.

5. CONCLUSIONS & RECOMMENDATIONS

The objective of this study was to determine the feasibility of supplying district heating with energy from the heat normally lost to the atmosphere by thermal power stations.

5.1 Conclusions

Investment in a district heating network supplied by waste heat from power generation could significantly contribute to Ireland's energy policy objectives. This would be achieved by improving security of supply, improving energy efficiency and reducing GHG emissions through a number of means:

- Higher efficiency than separate heat supply and electricity generation
- A reduction in primary energy supply
- A reduction on the energy imported into Ireland
- Lower CO_2 emissions

It would lead to the efficient use of energy and contribute to a major reduction in CO_2 emissions while offering significant savings over natural gas heating. To make these possible benefits a reality requires more legislation to promote the use of district heating networks in high-density areas that are located near a suitable heat source. The concept of large scale CHP based on CCGTs envisages the development of CHP-CCGTs as a direct alternative to electricity-only CCGTs. Under the EU Emissions Trading Scheme increased carbon allocations are given to CHP plants compared with electricity-only generation. More carbon allowances compared with a power only plant will reduce the number of allowances that will need to be purchased by the generator.

The recent economic downturn and ongoing difficulties in securing finance for projects is a huge barrier to would-be viable schemes. Current REFIT measures aimed at increasing electricity from CHP, anaerobic digestion, ocean energy and wind has seen almost all of the support, 98% in 2006, go to wind farms.

In the medium term it would be hoped that with the right commitment from policy makers and joined up thinking between stakeholders, major progress could be made in this area. Government budget for 2012 provides that the supply of district heating is liable to VAT at the reduced rate of 13.5 per cent, this is a step in the right direction but more needs to be done. District heating targets must be set, similar to the current 800MWe by 2020 of installed CHP, to enable progress become a reality. It will also take a major shift in market energy pricing and by policy makers to see large scale take-up of district heating in the existing domestic building stock. The highest uptake of district heating will take place if government support the development of such a program by taking any perceived risk of switching to district heating away from the customer.

The lifetime of a district heating schemes is assumed to be 40 years. Over this long timeframe there will be many new developments with housing, business and community buildings within the catchment area. Fingal County Council document ‘Up to 2017’ states that in this area of north Dublin there will be an estimated requirement for 16,074 new housing units between January 2011 and the end of 2016 inclusive (Fingal, 2011). Consideration should be given to fitting these units with the ability to accept connection to and located close to any proposed heating network.

Once a district heating network is established in North Dublin, it is likely that district heating can be expanded further. Other developments at greater distances may propose to join the network.

This would be a long-term project with a long-term payback. Future energy efficiency and carbon minimisation trends will encourage the power plants to sell heat and an established pipe network would service the local area for many decades.

5.2 Further Studies/Recommendations

Heat Supply

- A detailed cost and plan of all aspects of the project by a reputable consultant to allow application for outline planning and make a decision on how to proceed.

- Other opportunities exist in the area around Huntstown Power Station that may present and opportunity for the station to sell energy in the form of heat. Roadstone Quarry currently supplies steam through boiler for its onsite processes. The CCGT plant is situated very close to this area and could supply the required steam and avoid running these heat only boilers.

- Fingal County Council intends building an anaerobic digestion plant at Kilshane Cross. Again steam could be provided for this process and the power station could possibly utilise the gas produced by the anaerobic process.

Consumers

- It is likely that more housing developments could also be connected to the district heating network, as opposed to just new buildings and commercial/institutional developments availing of the scheme. It may be a case that these types of connections would be feasible when their current heating system requires replacement.

6. APPENDICES

6.1 Potential Heat Customers

6.1.1 Hotels

Clarion Hotel, Dublin Airport

Distance - 6km

Hotel offers 245 bedrooms, bar & restaurant

Radisson Blu, Dublin Airport

Distance - 6km

Hotel offers 229 bedrooms, bar & restaurant

Premier Apartments, Dublin Airport

Distance - 6km

It comprises of 30 contemporary two-bedroom apartments. Each apartment consists of two double bedrooms, two bathrooms, sitting room with dining area and fully equipped kitchen.

Carlton Hotel, Dublin

Distance - 5.5km

Hotel offers 100 bedrooms, bar & restaurant

Crowne Plaza, Northwood, Dublin

Distance - 5km

Hotel offers 204 bedrooms, bar & restaurant

Dublin Airport Hotel, Ballymun Travelodge

Distance - 4km

Hotel offers 125 bedrooms.

Travel Lodge, Castleknock Dublin

Distance - 4km

Hotel offers 97 bedrooms & restaurant.

Crowne Plaza, Blanchardstown

Distance - 3.5km

Hotel offers 188 bedrooms, bar & restaurant.

Carlton Hotel, Blanchardstown

Distance - 4.5km

Hotel offers 155 bedrooms, bar & restaurant

6.1.2 Recreational

National Aquatic Centre

Distance - 4.5km

One of the world's largest indoor water centres. It comprises of 10-lane 50 metre x 25 metre international standard swimming pool. There is also a 25 metre international standard diving pool/warm up pool, fitness area, café and reception area.

ALSAA Sport Fitness Association

Distance - 7km

25 metre pool & gym

Westpoint Health & Fitness

Distance - 5.5km

25 metre pool & gym

6.1.3 Office & Business Parks

Damastown Industrial Park and Plato Business Park

Hills Industrial Estate

Coolmine Business Park

Westpoint Business Park

Base Park, Mulhuddart

College Business and Technology Park

Blanchardstown Corporate Park

Blanchardstown Business and Technology Park

Ballycoolin Business and Technology Park

Orion Campus, Ballycoolin

Northwest Business Park (Phase2)

Northwest Business Park

Old Quarry Industrial Park

Rosemount Business Park

Millennium Business Park

Stadium Business Park

Abbotstown Business Park

Phoenix Industrial Estate

North City Business Park

Northern Cross Business Park

North Park

Dublin Airport Logistics Park

Horizon Logistics Park

Century Business Park

Mygan Business Park

Poppintree Industrial Estate

North Point Business Park

Ballymun Industrial Estate

Unidare / Jamestown Industrial area

Damastown Industrial Estate

6.2 Unit Heating Costs

Dimensions			Price								
Nominal (DN)	Pipe (mm)	Jacket (mm)	€/m	Muffs €/10m	Fittings 10% (€)	Transport 30% (€)	Total Materials (€/m)	Assembly (€)	Excavation (€)	Tota
20	26	90	12.0	26.9	1.5	4.9	42.1	27.7	109.2	1
25	33	90	12.9	26.9	1.6	5.1	44.5	27.7	109.2	1
32	42	110	16.0	30.7	1.9	6.3	54.4	27.7	111.3	1
40	48	110	16.7	30.6	2.0	6.5	56.6	27.7	111.3	1
50	60	125	20.4	34.8	2.4	7.9	68.3	30.9	116.5	2
65	76	140	24.4	36.0	2.8	9.2	80.2	35.0	119.5	2
80	88	160	29.4	41.3	3.4	11.1	96.0	42.1	121.6	2
100	114	200	39.4	53.0	4.5	14.7	127.7	47.5	131.7	3
125	139	225	48.4	56.3	5.4	17.8	154.6	49.4	139.0	3
150	168	250	60.3	66.2	6.7	22.1	191.3	71.3	163.4	4
200	219	350	87.0	84.6	9.5	31.5	272.9	74.7	198.9	5
250	273	400	131.1	138.6	14.5	47.8	414.5	86.6	312.7	8
300	323	450	165.3	161.0	18.1	59.9	518.7	98.3	365.7	9
350	355	500	191.5	176.0	20.9	69.0	598.1	111.5	438.1	1,
400	406	560	239.1	192.5	25.8	85.3	738.9	133.2	486.8	1,
450	457	630	279.6	213.9	30.1	99.3	860.9	159.1	562.5	1,
500	508	710	334.7	247.9	35.9	118.6	1,028.1	190.9	675.0	1,
600	610	800	407.8	318.8	44.0	145.1	1,257.5	229.1	810.0	2,

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