“An Investigation into the Utilisation of Energy in Landfill Gas to Supply a Community Electricity and District Heating Scheme.”

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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: Ian Ryan Dated: 18th May 2011

Ian Ryan

Acknowledgements

The undertaking of this study has been a long and challenging journey. There are numerous people whom I wish to acknowledge and thank, for without their help and support I could not have completed this work.

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Nomenclature

BAT	Best Available Technologies
BER	Building Energy Rating
Biogenic	Part of the natural carbon cycle.
BMW	Biodegradable Municipal Waste
CER	Commissioner for Energy Regulation
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DH	District Heating
DSO	Distribution System Operator
Economically Justifiable Demand	The demand that does not exceed the needs for heat or cooling and which would otherwise be satisfied at market conditions by energy generation process other than cogeneration.
EfW	Energy-from-Waste
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ESCo	Energy Supply Company
ETS	Emissions Trading System
ETSU	Energy Technology Support Unit
EU	European Union
GHG	Greenhouse Gases
GTR-H	GeoThermal Regulation – Heat
GWP	Global Warming Potential
H_2	Hydrogen
IPC	Integrated Pollution Control
IPPC	Intergovernmental Panel on Climate Change
IPPC (License)	Integrated Pollution Prevention Control (Licence)
°K	Degree Kelvin
LFG	Landfill Gas
LTSA	Long Term Service Agreement
MSW	Municipal Solid Waste
MW(s)	Megawatt(s)
N_2	Nitrogen
NO_x	Nitrogen Oxide
O_2	Oxygen
PE-X	Polyethylene
PRF	Primary Resource Factor
SEAI	Sustainable Energy Authority of Ireland
SI	Statutory Instrument
SO_2	Sulphur Dioxide
SO_x	Sulphur Oxide
USA	United States of America
VAT	Value Added Tax
WtE	Waste-to-Energy

CHAPTER 1 - Introduction

1.0 Introduction

The aim of this study is to determine the feasibility of producing and distributing energy in the form electricity and district heating, derived from LFG (Landfill Gas) produced by an existing municipal waste stream.

The body of this document investigates the legislative, technical applications, feasibility and community attitudes to the installation of an EfW (Energy-from-Waste) plant in the community of Inagh, Co. Clare.

1.1 Study Objectives

The objectives of this study are;

- To determine if community based energy schemes can be implemented in Ireland and if they are a practical, efficient and cost effective method for delivering energy to a community.
- To review current policies documents and provide recommendations to improve these in line with the overall aims of this research.
- To assess the barriers / enablers within the Irish landscape to community based energy developments.
- To estimate the available energy in the LFG at the waste management site.
- To review the technical aspects of heat engines, including CHP (Combined Heat and Power) plants with a view to determining their suitability for LFG combustion and the overall plant efficiency.

1.2 Background

In January 2008 the Commission of European Communities published the 20% by 20-20 Renewable Energy Technology Roadmap Document (European Renewable Energy Council - Renewable Energy Technology Roadmap 2008). This document outlines three basic requirements in relation to energy for member states:

1. To have a 20% share of EU (European Union) energy from renewable sources by the year 2020.
2. To improve energy efficiency by 20% by the year 2020.
3. To have 10% of renewable energy in transport from sustainably produced biofuels by 2020.

The fundamental goal of the 20% by 20-20 document is to limit the rise in average global temperature to less than 2°C. The commitments contained in this 20% by 20-20 document have been transposed into Irish national policy through the Energy White Paper 2007 (Department of Communications, Marine and Natural Resources - Energy White Paper 2007) and The National Energy Efficiency Action Plan (Department of Communications, Energy and Natural Resources - The Nation Energy Efficiency Action Plan 2009).

With these policies in mind, this study will consider the feasibility of developing a community based energy scheme to empower people at a local level to become involved in the generation and management of their energy needs. The local community considered in this study have to date shown keen interest in how and where their energy needs are provided for. The wider community in County Clare has the state's largest coal fired power plant in Moneypoint producing approximately 990 MW (Mega Watts) of electrical energy. In more recent times 30 landowners from the community have come together to form West Clare Renewable Energy Ltd. co-operative, to develop a 90 MW wind farm on the slopes of Mount Callan, for which planning permission has now been granted (Clare County Council - Mount Callan Planning Application 2010).

In September 2002, Clare County Council's central waste management facility was opened in Inagh to much local scepticism. Engagement from the local community will be required if the proposed LGF powered CHP and district heating system are to be a viable project for providing the communities energy needs. This engagement may aid the community in adjusting its current disapproving attitude to the waste management facility, should the community see direct benefits in the form of economic heating and energy provision.

The people of Inagh and its surrounding region, through the Inagh development committee may wish to enter into an ESCo (Energy Supply Company) agreement. This agreement may be contracted with the project developer, county council or the community may establish its own ESCo for the purpose of providing their energy requirements. A map of the community can be seen below in Figure 1 - map of local community.

Figure 1 - map of local community

(Map Copyright of Ordnance Survey Ireland 2005, Scale: 1: 25,000)

Ireland's national CHP targets were set down in the National Climate Change Strategy 2007. This paper set a target of 400 MW_e of installed electrical capacity from CHP by 2010 and 800 MW_e by 2020 (Department of the Enviroment, Heritage and Local Government - Ireland National Climate Change Strategy 2007). The 2009 SEAI (Sustainable Energy Authority of Ireland) report confirms that at the end of 2008 CHP installed capacity was running at 298.7 MW_e well below the 400 MW_e target for 2010, as set out in the National Climate Change Strategy. It is worth noting that CHP units that do not utilise an "*economically justifiable demand*" do not meet the criteria to be considered as additional CHP capacity within the SEAI report. This is often the case with landfill fired CHP as there is little or no heat demand on site (Sustainable Authority of Ireland - CHP Potential in Ireland 2009).

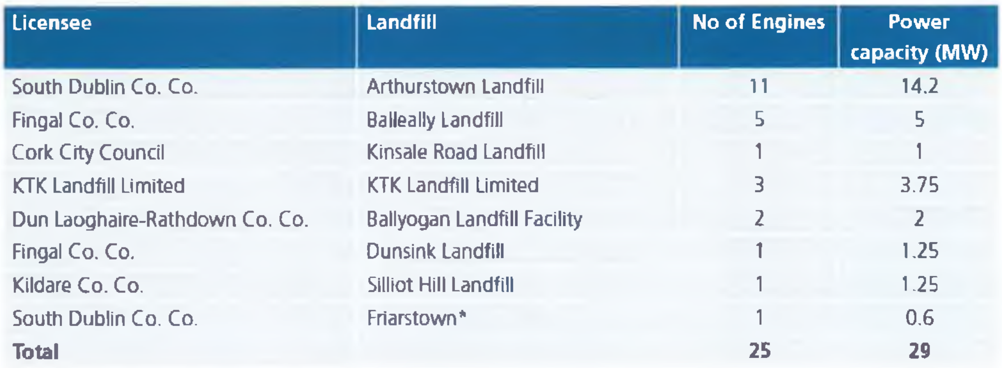
In 2009 Ireland produced 2,952,977 tonnes of municipal waste. Of this 1,723,705 tonnes ended up in landfill sites throughout the country (Environmental Protection Agency - National Waste Report 2009). The corner stone of the national waste management strategy is the "The Waste Management Act 1996". This document outlines a framework for the management of waste streams based on environmental impact. The key consideration within this framework is "The Waste Pyramid" shown below in Figure 2 - the waste pyramid. This places emphasis on Prevention, Reduction, Reuse and Recycle. The final two stages in the waste pyramid are Energy Recovery and Disposal (Irish Statute Book - Waste Management Act 1996). It is this energy recovery that this study will focus on, that is the energy that can be recovered from waste disposal in the form of LandFill Gas.

Figure 2 - the waste pyramid

(Image Copyright of Lancashire County Council 2008)

The first commercial landfill gas energy recovery project was in California, USA (United State of America) in 1975. This plant converted landfill gas to pipeline quality gas for distribution. The first plant to produce electricity from landfill gas went into commercial operation in 1982, in the USA. There are over 500 landfill gas powered projects worldwide, with 60 in operation in the UK (Sustainable Energy Authority of Ireland - LFG Resource 2010/2020 Potential and Scenario Development 2004).

As shown in Figure 3 - MSW landfill sites using landfill gas to generate electricity, there are 25 CHP generation units fired on LFG in Ireland. With a total installed capacity of 29 MW_e (Enviromental Propection Agency - Focus on Landfilling in Ireland 2010).



Licensee	Landfill	No of Engines	Power capacity (MW)
South Dublin Co. Co.	Arthurstown Landfill	11	14.2
Fingal Co. Co.	Balleally Landfill	5	5
Cork City Council	Kinsale Road Landfill	1	1
KTK Landfill Limited	KTK Landfill Limited	3	3.75
Dun Laoghaire-Rathdown Co. Co.	Ballyogan Landfill Facility	2	2
Fingal Co. Co.	Dunsink Landfill	1	1.25
Kildare Co. Co.	Silliot Hill Landfill	1	1.25
South Dublin Co. Co.	Friarstown*	1	0.6
Total		**25**	**29**

Figure 3 - MSW landfill sites using landfill gas to generate electricity

(Enviromental Propection Agency - Focus on Landfilling in Ireland 2010)

There is an estimated potential for 304.7 MW_e in LFG resources in Ireland (Sustainable Energy Authority of Ireland - Landfill Gas in Ireland 2004). Studies from the UK (United Kingdom) ETSU (Energy Technology Support Unit) in 1997 and Irish Power Systems in 2003 predict that with the correct incentives making smaller capacity sites feasible that between 30-50MW_e of installed capacity is possible in the Irish landscape leading up to 2020. An SEAI study predicted that feasible landfill gas resources could be a much as 80MW_e by 2010. This figure only considers landfills sites with less than 1 million tonnes of total waste deposited (Sustainable Energy Authority of Ireland - LFG Resource 2010/2020 Potential and Scenario Development 2004).

The UK Environment Agency considers 200,000 tonnes of total waste disposed a benchmark for feasible landfill gas extraction. If this rational was applied to Ireland's landfill stock there are 32 landfill sites with greater than 200,000 of total waste disposed that have no landfill gas recovery systems in place. As all landfill sites in the future will be required under the European Union Landfill Directive to recover landfill gas, it is expected that the potential energy in this landfill gas will be recovered (European Union - Landfill of Waste 1999).

Post 2020 there will be a fall off in the development of landfill gas plants. This is due to the Landfill Directive and the Waste Management act 1996, which calls for the reduction in the quantity of biodegradable waste matter going to disposal by 2016. In tandem with these policies the government paper "Changing our Ways 1998 – 2013" aims to (Enviromental Protection Agency - Changing Our Ways 1998):

- Divert 50% of household waste from landfill through Reduce, Reuse and Recycle strategies.
- Reduce 65% of biodegradable municipal waste in landfill through initiatives, e.g. the www.foodwaste.ie website.
- Reduce the amount of operational landfill sites from approximately 93 to 20 by 2013.

As can be seen in Figure 4 - Waste-to-Energy plants operating in Europe 2008, Europe currently has 432 WtE (Waste-to-Energy) plants in operation, where energy is recovered from waste prior to going to landfill. Ireland currently has no WtE plants in operation. This is mainly a legacy issue arising from state waste collection in the past and planning objections. WtE plants are specifically designed to extract energy from waste material and are considered to be a method of disposal. EfW (Energy-from-Waste) i.e. the recovery of landfill gas for the generation of heat and power, is considered to be a method of recovery and therefore preferable to WtE. There are eight EfW sites in operation in Ireland. These sites recovery landfill gas from waste disposal sites and the landfill gas is used to generate electricity. To date none of these landfill gas powered plants utilise the heat produced by their engines. It is proposed within this study to ascertain the feasibility of using this heat to supply a district heating system for a community.

Figure 4 - Waste-to-Energy plants operating in Europe 2008

(Map Copyright of Confederation of European Waste-to-Energy Plants 2008)

1.3 Study Layout

This study contains the following chapter headings:

- Chapter 1 - Introduction
- Chapter 2 - Literature Review
- Chapter 3 - Methodology
- Chapter 4 - Results
- Chapter 5 - Conclusions & Recommendations

1.4 Project Limitations

The following are limitations within this study, these include:

- Difficulties in obtaining accurate costing Figures from equipment manufacturers.
- Unable to acquire detailed costing from the electricity DSO (distribution system operator) for the construction of overhead power line to central waste management site, due to confidentially.
- Tri-generation and cooling are not considered within this study.
- Not in the scope of this study is a detailed survey of public attitudes to development of sustainable energy projects.
- Future potential savings/revenue stream from trading of carbon credits.
- Fuel cell technologies are not considered.

1.5 Executive Summary

This study proposes to determine the feasibility of producing and distributing energy in the form of electricity and district heating derived from LFG and was carried out for the community of Inagh, Co. Clare.

It is proposed that the current waste management site which is owned and operated by Clare County Council will supply the LFG to the community. The LFG gas flare on the central waste management site is recording an average of $8m^3$/min of LFG gas, with a methane content of ~34%. The total energy potential from LFG on the central waste management site is 19.3 million kWh per annum.

The community of Inagh currently consumes ~4,336,686 kWh of heat energy, ~912,672 kWh of electrical energy and ~571,091kWh of transportation energy per annum. These estimates are based on calculations within this study in section 4.2 Energy Requirements of the Community.

The communities' electricity and heating energy requirements are more than capable of being supplied by the LFG fired CHP units which will produce 4,999,040 kWh_h and 4,231,628 kWh_e per annum. The surplus LFG from the central waste management site is more than capable of supplying the transportation fuel requirements of the community.

Post implementation of the LFG project, the community can expect a net saving in energy costs of €251,947/yr or €981/yr for each household. The current payback period for the project is 20 years under a capital finance agreement @ 6% interest per annum. However, should the community decide not to take the annual savings of €981 per household, the simple project payback would be 6.53 years, including its yearly operation and maintenance fees. A further breakdown of costs is contained within this study in section 4.6 Study Costing.

The use of carbon neutral LFG avoids greenhouse gas emissions that would arise if conventional fossil fuelled systems were utilised. The community of Inagh will avoid this unnecessary fossil fuel derived energy usage and prevent 1,601 tCO_2/yr of entering the environment.

It is proposed that the community will utilise the ESCo energy delivery model to supply the communities' residents with the energy they require in a sustainable manner.

Chapter 2 – Literature Review

2.0 Literature Review

When waste is disposed of in landfill the organic matter in this waste under anaerobic conditions (without oxygen) breaks down producing a gas which is composed principally of up to 65% CH_4 (methane) and 35% CO_2 (carbon dioxide) by volume. This gas is referred to as landfill gas and can be utilised within a combustion process to produce energy. While the concentrations of CH_4 in LFG will decrease once the landfill site has been capped, it is reasonable to expect combustion acceptable levels of CH_4 for up to 20 years post capping, (EPA - National Waste Report 2008).

Both CH_4 and CO_2 are greenhouse gases. The CO_2 produced by LFG is considered by the (IPPC) Intergovernmental Panel on Climate Change to be "biogenic" or part of the natural carbon cycle and therefore not considered as a GHG from an emissions perspective. CH_4 has a (GWP) Global Warming Potential of 21; therefore each CH_4 molecule is 21 times more detrimental to the environment than a molecule of CO_2 (although it doesn't stay active as long as CO_2). The combustion of this CH_4 producing energy and CO_2 marks a clear reduction in GHG emissions (The World Bank - Santa Tecla Study 2005).

Currently Ireland generates three million tonnes of municipal waste per annum. Two million tonnes of this waste is BMW (Biodegradable Municipal Waste), 57% of this is consigned to landfill. It is anticipated that the municipal waste stream will increase by 3-4% per annum over the next 10 years, which is equivalent to a one million tonne increase per annum (EPA - National Waste Report 2008).

The EU Landfill Directive (1999/31/EC) sets obligations to reduce the volume of BMW to landfill, from a maximum of 75% of the BMW generated in 1995 by 2010, further reducing this Figure to a maximum of 35% of the BMW generated in 1995 by 2016. This will reduce the maximum quantity of BMW to landfill by 2016 to approximately 427,000 tonnes per annum. This target is on track to be achieved mainly through the introduction of the green and brown refuge waste bins to segregate waste more effectively at source allowing this waste stream to be diverted away from landfill to other waste processing technologies (EPA - National Waste Report 2008).

Each tonne of biodegradable municipal waste can produce approximately 6m^3 of LFG per annum. It is expected that this landfill waste stream will continue to produce feasible quantities of LFG for 10 – 15 years from its time of emplacement.

Currently many landfill sites in Ireland use flaring technologies to dispose of landfill gas in a controlled manner. Flaring is a controlled combustion process where the landfill gas is combusted at 1000°C in an enclosed chamber with a combustion residence time of at least 0.3 seconds. The EPA allows as an interim measure the use of open flares on a temporary basis with prior agreement. These are usually to control odours coming from the landfill site.

From 1990 – 2008 the quantity of landfill gas from waste management sites has increased steadily, as can be seen in Figure 5 - methane generation and emissions from landfill 1990 – 2008. Despite this the quantity of methane emissions from landfill sites has decreased. This is due to the increased flaring and utilisation of landfill gas on waste disposal sites, brought about by the EU Landfill Directive. This has resulted in a 20% reduction in greenhouse gas emissions from landfill sites in Ireland from 1,173ktCO_2eq in 1990 to 936 ktCO_2eq in 2008, equating to 1.4% of total greenhouse gas emissions in Ireland. In the Irish context this has meant that the waste sector has seen the largest relative reduction in greenhouse gas emission in this period. In 2008 landfills accounted for 85.5% of greenhouse gas emissions from the waste sector (Enviromental Protection Agency - Focus on Landfilling in Ireland 2010).

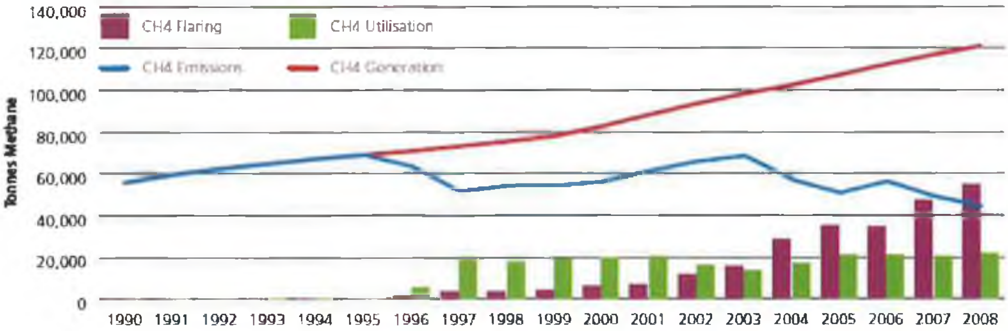


Figure 5 - methane generation and emissions from landfill 1990 – 2008

(Table Copyright of Environmental Protection Agency 2010)

2.1 Legislation

The following legislation requires consideration when determining the opportunities for energy recovery from landfill gas. This study will consider EU and Irish waste legislation, its impact now and for the future of landfill gas. The study will investigate the regulation for CHP plants and their planning requirements. Finally, the study will consider regulation for DH (District Heating) and the shortfall in this regulation in the Irish context, with a focus on its impact on community based "not for profit" schemes and the incentives (grants / tax reliefs) that may be available to these communities.

2.1.1 Waste Legislation

2.1.1.1 EU Waste Legislation

Outlined below is the EU legislation that is of direct interest in relation to energy-from-waste and landfill diversion:

- 1999/31/EC - Landfill Directive
- 2000/76/EC - Incineration
- 2008/01/EC – Integrated Pollution Prevention Control
- 2009/28/EC - Renewable Energies
- 2008/98/EC - Revised Waste Framework

Of these the most significant piece of legislation from the EU in relation to waste is the 1999/31/EC Landfill Directive, supplemented by the EU Council Decision 2003/33/EC9 which specifies detailed criteria for acceptance of waste at landfill (European Union - Landfill of Waste 1999). Both of these directives are implemented in Ireland through the Waste Management Licensing Regulations 2004 (Irish Statute Book - Waste Management (Licensing) Regulations 2004). Briefly, the EU directives require that:

- Landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and used.
- If the gas collected cannot be used to produce energy, it must be flared.
- The collection, treatment and use of landfill gas shall be carried on in a manner which minimises damage to or deterioration of the environment and risk to human health.

2.1.1.2 Ireland's Waste Legislation

There are 121 SI (Statutory Instruments) in the Irish Statute Book in relation to waste, ranging from The General Waste Materials Reclamation Trade Board act in 1933 (Irish Statute Book - The General Waste Materials Reclamation Trade Board 1933) to the Waste Management (Landfill Levy) Order in 2010 (Irish Statute Book - Waste Management (Lanfill Levy) Order 2010). Of these the following salutatory instruments are of direct interest in relation to energy from waste and landfill diversion:

- SI: 10/1996 Waste Management Act
- SI: 27/2003 Protection of the Environment
- SI: 347/1993 Air Pollution Act, 1987 (Municipal Waste Incineration) Regulations, 1993
- SI: 395/2004 Waste Management (Licensing) Regulations 2004

The following papers are also of note in the context of waste legislation in Ireland:

- Energy White Paper 2007
- National Renewable Energy Action Plan
- National Strategy on Biodegradable Waste
- National Bio-Energy Action Plan
- Irish Climate Change Strategy

Of these the most significant piece of legislation on the Irish statue book in relation to waste is SI: 10/1996 Waste Management Act. This act is derived from the Environmental Protection Agency Act 1992 which established the EPA (Environmental Protection Agency) and the commencement of IPC (Integrated Pollution Control) licensing. This act takes directives from the previous legislation and builds on them as follows:

- Measures shall be taken to minimise nuisances and hazards arising from emissions of odours.
- Landfill operators must ensure that landfill gas is collected and used to produce energy or flared and avoid causing harm or nuisance off-site.
- In addition, the first Landfill Directive target for diversion of biodegradable municipal waste applies from 16/07/2010 for Ireland.

2.1.2 CHP Regulatory Instruments

The following regulatory instruments need to be considered in relation to the planning, installation and operation of combined heat and power plants:

- EIA (Environmental Impact Assessment) - EPA
- Authorisation to construct a generating station - (CER).
- Licence to generate electricity – (CER).
- Fire safety certification – (Local Authority).
- IPPC licence – (EPA).
- Emissions trading licence - (EPA).
- Waste licence – (EPA).
- Water extraction licence – (Local Authority).
- Air pollution license - (Local Authority).

2.1.2.1 Planning Permission

Planning permission will be required for installation of the proposed energy system and CHP unit, as there is a requirement for civil works to provide:

- CHP Unit Foundations
- LFG Gas Connections
- District Heating Piping
- DCW Supply
- Electrical Supply Cabling

2.1.2.2 Air Pollution Act

Under the "Air Pollution Act, 1987" the CHP operator must apply for or modify their existing license for the use of this CHP unit, as it is an non-domestic residence and is sited in an "Special Control Area" (Irish Statute Book - Air Pollution Act 1987).

2.1.3 District Heating Legislation

Currently there is no legislation or regulation pertaining directly to District Heating existing in European law or the Irish Statute Book.

2.1.3.1 EU District Heating Support Legislation

The EU has however established a number of directives which can be construed as supporting district heating development, these directives are outlined below:

- EU Action Plan for Energy Efficiency - COM (2006) 545
- 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
- Waste Framework Directive - 2008/98/EC
- Technical guidance note "Heating and Domestic Hot Water Systems for Dwellings".
- Directive of Promotion of Use of Renewable Energy - 2009/28/EC

The EU Action Plan for Energy Efficiency set forth the objective of developing minimum performance requirements and regulations for district heat. This combined with the CHP Directive, should provide a future framework of regulation for district heating systems. Also, studies being conducted by GTR-H (GeoThermal Regulation – Heat) will assist in the formation of regulatory framework: not only geothermal, but CHP and district heating also. The regulatory barriers and deficiencies identified by the GeoThermal Regulation – Heat study will draw on experience from 3 EU countries which have adopted national district heating regulation These countries (France, Germany and the Netherlands) are seen as a benchmark for the 4 target countries (Poland, Hungry, Northern Ireland and the Republic of Ireland). It is expected that this study will provide EU wide framework documents for national governments to transcribe in to legislation (GeoThermal Regulation - Heat 2011).

2.1.3.2 Ireland's District Heating Support Legislation

As with the EU, Ireland also has no clear legislation existing in relation to district heating. There is one reference in relation to district heating within the national Energy White Paper 2007, section 2.4.9 which states that "*The need to develop combined heat and power and district heating was also identified as an area where energy efficiency could be improved at a structural level*" (Department of Communications, Marine and Natural Resources - Energy White Paper 2007). However, there are a number of measures which support district heating indirectly, these include:

- Building Regulations Part L - Connection of dwellings to DH systems is credited as meeting renewable requirement if fuelled by CHP.
- BER (Building Energy Rating) - Improved if connected to a DH network.
- Renewable Energy Feed In Tariff - Increased tariffs for electricity supplied by anaerobic digestion, biomass CHP and high efficiency CHP – all potential DH heat sources.
- Training and standards for installers.

2.1.4 Community Legislation

Currently there is no legislation or regulation pertaining directly to Community Energy Schemes existing in European Law or the Irish Statute Book. However, these schemes can be operated under the following frameworks:

- Co - Operative Scheme
- ESCo

2.1.4.1 Co-Operative

A co-operative is a business that is owned and democratically controlled by its members, whom use and share its services. There is no definition of co-operative in Irish law, however co-operatives in Ireland have registered as co-operative societies under the Industrial and Provident Societies Acts of 1893 - 2005 by the office of the Registrant of Friendly Societies. Co-ops in Ireland may also incorporate as conventional companies limited by share or guarantee with or without share capital or as partnerships through the Companies Registration Office and thus fall under Company Law (Department of Enterprise, Trade and Interprise - Co-operative Societies 2011).

2.1.4.2 ESCo – Energy Supply Company

ESCo's are organisations that;

- Provide the same level of energy service at a lower cost through the implementation of an energy efficiency or renewable energy project.
- Typically finance or assist in financing a project through guaranteed cost savings.
- Retain an operational role, over the financing period of a project, to measure and verify the savings against contractual arrangements.
- Are rewarded based directly on the energy cost savings achieved.
- Guarantee energy savings to the end user.

The services that an ESCO may provide include:

- Energy management.
- Energy analysis and auditing.
- Project design and implementation.
- Maintenance and operation.
- Energy and equipment supply.

Guaranteed energy savings are utilised to initially provide payback for the capital investment required in implementing the energy efficiency project. Once this payback period concludes the energy efficiency project will continue to deliver cost saving to the end user.

2.2 Landfill Gas

2.2.1 Landfill Gas Formation

There are 8 distinct phases in the formation of LFG as identified by (Christiansen & Kjedsen 1989), these are;

1. An aerobic phase. Following waste deposition in which the residual oxygen is used up. This phase typically lasts for a few days to months, depending on local factors such as temperature and moisture availability.
2. Acid phase. Populations of facultative and fermentative anaerobic bacteria develop, producing volatile fatty (aliphatic) acids, CO_2 and H_2 (Hydrogen), displacing the remaining N_2 (Nitrogen) entrained with the waste. Phase II may last for weeks to years, depending on conditions.
3. Initial methanogenic phase. Microbial respiration reduces oxygen concentrations to extremely low values, allowing populations of methanogenic bacteria to develop, producing CH_4. Concentrations of H_2 and CO_2 start to fall.
4. The stable methanogenic phase. Here the remaining H_2 is used up in the reduction of CO_2 to CH_4 and H_2O. Phase V may begin within months to years after waste deposition and last for decades. Landfill sites which collect gas for energy recovery are commonly designed around an assumed useful life of 10 – 15 years of phase IV. Typical landfill gas collected in this phase consists of 40 – 65 % CH_4 by volume, with most of the balance made up by CO_2. A vast range of trace components are also present (such as volatile fatty acids, reduced sulphur compounds, etc.) plus water vapour at saturation point.

These substances usually make up only 1 or 2 % of the landfill gas, but account for its characteristic sweetish smell.

5. Air intrusion. The rate of methanogenic activity begins to fall as substrate is used up, resulting in air beginning to enter the waste. Lower rates of gas formation lead to relatively faster washout of CO_2, so that its concentration falls relative to that of CH_4.
6. Methane oxidation. Rates of methanogenesis have now fallen to low levels, allowing the rate of air ingress to increase, so that the surface layers of the waste and the capping material now become aerobic. Methane migrating through these layers is increasingly oxidised to CO_2 by methanotrophic bacteria. Methane concentration in the gas decreases, whilst that of CO_2 steadily increases.
7. CO_2 phase. Return of aerobic conditions. By now the rate of landfill gas formation has virtually ceased because of substrate limitation and anaerobic decomposition becomes inhibited by the ingress of O_2 (Oxygen) in the air. This allows the aerobic decomposition of solid organic matter resistant to anaerobic decomposition.
8. Soil air phase. The final phase occurs when degradable organic matter has been oxidised and the landfill gas resembles that of typical soil air. The duration of each of these phases is highly variable. Apart from the initial aerobic decomposition, which may be complete in days to months, the remaining phases have durations measured in years, decades, or even centuries for the final phases.

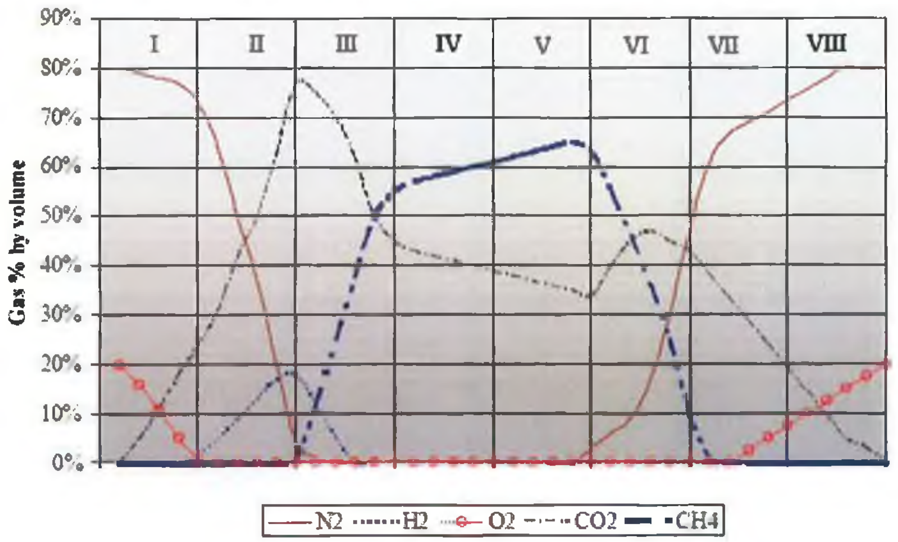


Figure 6 - phases in landfill gas composition

(Image Copyright Christiansen & Kjedsen 1989)

When evaluating the gas potential in a LFG recovery project it is important to consider the moisture content in the deposited waste and "degradability" of the various waste stream feeding the landfill (The World Bank - Muribeca 2005).

2.2.2 Landfill Gas Collection

Waste in landfills is deposited in waste stacks or cells, with the intention of closing each cell within one year of opening in order to minimise odour, for the local residents. The landfill gas is extracted from these cells through a series of wells that are placed into the waste stack. These wells are connected throughout the site by a network of piping referred to as the ring main. A vacuum pump is then utilised to apply a negative pressure (~150mbar) to the cells stack via the piping network and the landfill gas is extracted. Many landfill sites today use a flaring system to dispose of the landfill gas extracted. That is they combust the landfill gas at over 1000°C with a combustion resonance time of at least 0.3 seconds. A diagram illustrating a typical LFG recovery system is shown in Figure 7 - recovery of LFG for conversion to energy.

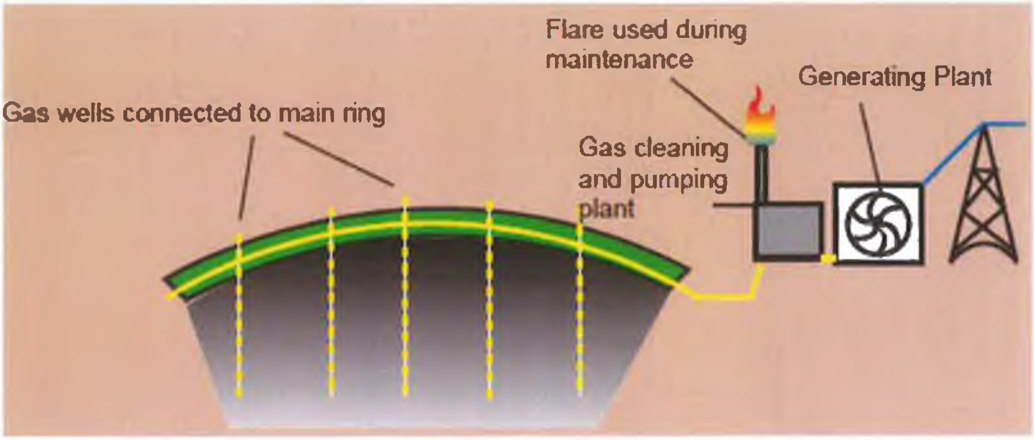


Figure 7 - recovery of LFG for conversion to energy

(Image Copyright of SEAI)

It is proposed to substitute this flare with a heat engine. The Ballyduffbeg landfill site in Inagh currently produces approximately 480m^3 of landfill gas per hour. With an expected energy value of 4.59kWh/Nm^3, this equates to ~2.2 MWh of energy in the landfill gas.

2.2.3 Landfill Gas Energy

Once the LFG is collected it can be either flared to atmosphere, compressed and scrubbed removing the CO_2, to produce vehicle grade fuel or utilised within a heat engine to produce energy both electrical and heat. Landfill gas is classified as being "biogenic" or part of the natural carbon cycle under the International Intergovernmental Panel on Climate Change.

Key parameters for estimating the potential energy from the LFG include:

- The proportion of the collected LFG utilised for energy recovery.
- The overall system efficiency of conversion of LFG to energy, both electricity and heat.

As illustrated in Figure 8 - biogas production curve from deposited waste, the production of CH_4 in landfill waste steadily increases after initial deposition to a peak after ~5-10 years and then begins to taper off.

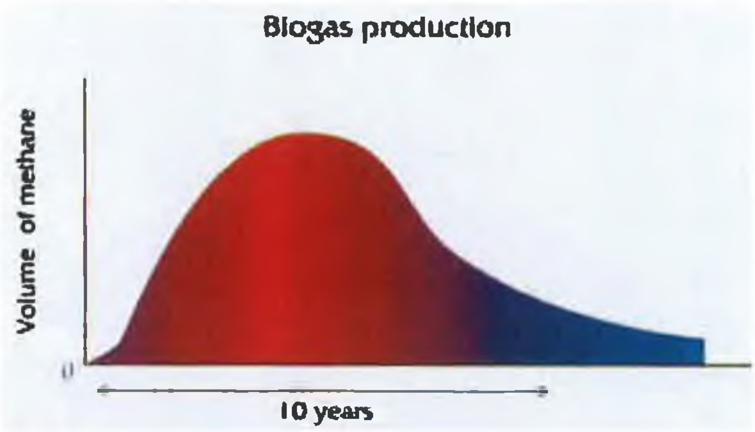


Figure 8 - biogas production curve from deposited waste

(Image Copyright of SEAI)

2.2.4 Landfill Gas Recovery

Once the landfill gas has been collected from the waste cells the potential energy within the gas can be recovered through a variety of methods, including:

- Direct Combustion – Utilised within heat engine / generation plant.
- Storage – Compressed and storage in gas storage vessels.
- Scrubbing – Filtered to remove CO_2, trace elements and pumped as required.

LFG gas recovery provides excellent greenhouse gas abatement as illustrated, in Figure 9 - greenhouse gas emissions saving from LFG. It is interesting to note that this chart compiled by SEAI in 2004, does not consider the emissions saving potential from utilising LFG within a CHP plant as the technology to operate CHP on biogas was unavailable.

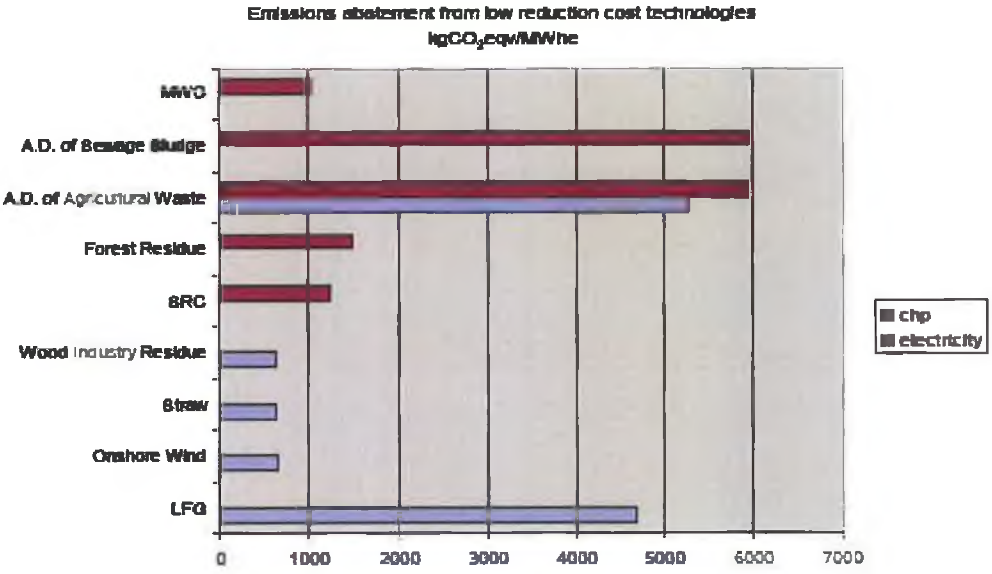


Figure 9 - greenhouse gas emissions saving from LFG

(Image Copyright of Sustainable Energy Authority of Ireland - LFG Resource 2010/2020 Potential and Scenario Development 2004)

2.2.5 Landfill Gas Utilisation

Landfill gas when combined with post recovery processing, can be utilised for:

- Heat engines.
- As a supplement to natural gas.
- As a vehicle fuel.
- District Heating.

LFG is a low cost option, its relative cost compared with that of other renewable energy options can be seen in Figure 10 - cost of LFG energy production vs. other renewable technologies. This chart shows that LFG energy production costs are amongst the lowest in the renewable industry. As with Figure 9 - greenhouse gas emissions saving from LFG this chart compiled by SEAI in 2004, does not consider the further production cost saving that can be realised from utilising LFG within a CHP plant.

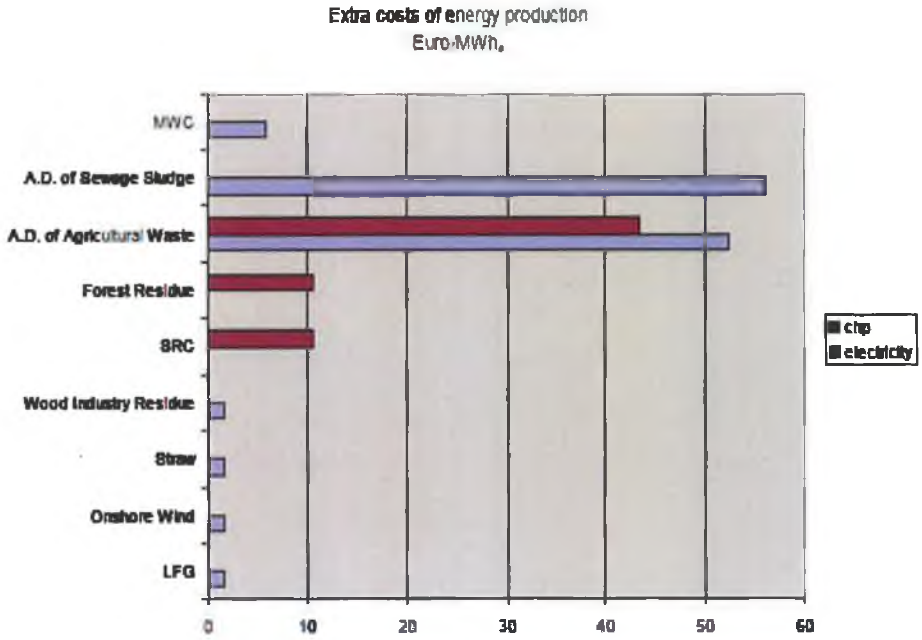


Figure 10 - cost of LFG energy production vs. other renewable technologies

(Image Copyright of Sustainable Energy Authority of Ireland - LFG Resource 2010/2020 Potential and Scenario Development 2004)

2.2.6 Landfill Gas Future Potential

As part of the suite of measures to improve the sustainability of waste management, the Landfill Directive (1999/31/EC) introduces requirements on member states to reduce the amount of biodegradable wastes disposed untreated to landfills. To achieve this objective, the Landfill Directive has introduced targets for reducing biodegradable waste disposed in landfills to 35% of 1995 levels by 2016. The directive also requires improvements in environmental standards of landfills, in particular by requiring greater use of landfill gas collection and energy recovery from the methane in order to reduce the greenhouse gas impact of this waste management option (EPA - National Waste Report 2008).

2.3 CHP

This study proposes that a CHP (Combined Heat and Power) plant be utilised as the prime mover/heat engine, Figure 11 - energy generating systems relative fuel efficiencies illustrates CHP as a highly efficient combustion method. The heat energy from the CHP unit will supply the heat energy for the district heating system. In Ireland to date landfill gas has been used to produce only electricity, with no use been made of its available heat output (Sustainable Energy Authority of Ireland - LFG Resource 2010/2020 Potential and Scenario Development 2004).

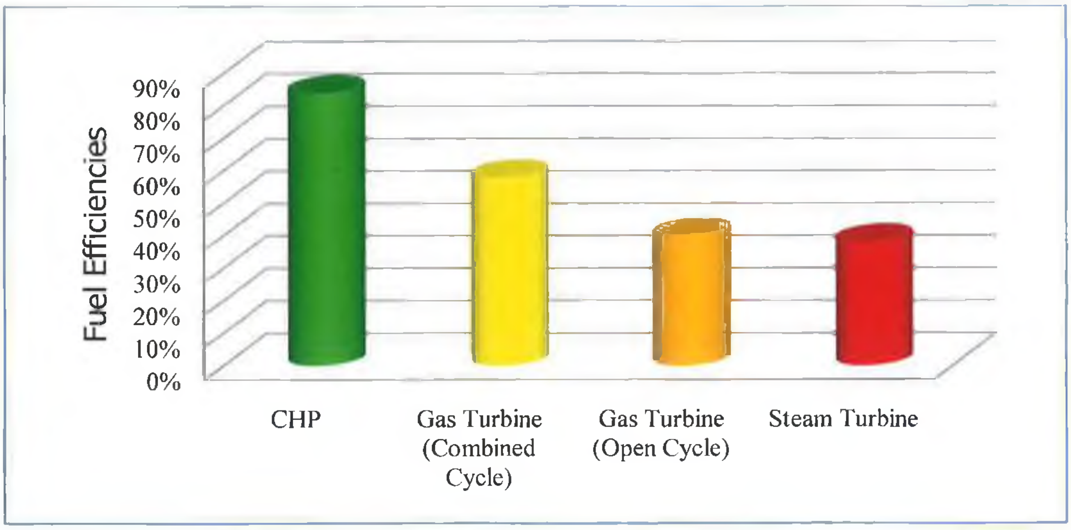


Figure 11 - energy generating systems relative fuel efficiencies

To combust landfill gas in any engine some basic pre-treatment is required this includes:

- Removal of condensed liquids.
- Particulate filtering.

The most common prime movers for CHP plant are:

- Spark Ignition Engine
- Compression Ignition Engine
- Gas Turbines

These prime movers are used to drive a generator to provide electricity. Heat energy is also recovered from:

- Exhaust Gases (~ 23%)
- Air Cooler (~14%)
- Jacket Water Cooler (~5%)
- Lubricating Oil (~3%)

The exact amount of heat energy recovery for a given CHP plant will depend on its load-looping ratio. Load-looping is the ability of the CHP unit to modulate its output in order to give varying amount of heat or electricity depending on system demands; this ratio is typically 2:1 for a gas spark ignition engine. These ratios are determined by calculating the base load for electricity and heat for a given project and selection of a suitable CHP plant for the application requirements. Usually, a compromise has to be reached between the required heat-to-electrical power ratio and the manufacture's best fit plant.

Typical CHP plants range in output from $250kW_e$ to $2.5MW_e$ for spark ignition engines, $2\ MW_e$ to $10\ MW_e$ for compression ignition engines, greater than $5MW_e$ for gas turbines and modern micro gas turbines can be sized down to $35kW_e$.

The process of combustion of landfill gas to generate energy has a number of environmental impacts. Air emissions of potential air pollutants to atmosphere are of the most concern. These pollutants include:

- Carbon Monoxide (CO)
- Carbon Dioxide (CO_2)
- Sulphur Oxides (SOx)
- Nitrogen Oxides (NOx)
- Hydrocarbons
- Particulates
- Hydrogen Chloride
- Hydrogen Fluoride
- Heavy Metals

From a regulatory view point these pollutants are controlled / monitored through the “Air Emissions License” granted by the local authority. There is also a number of technical control measures employed to reduce these emissions. These are divided into two distinct groups:

- Primary Control Measures
- Secondary Control Measures

Primary control measure aim to reduce the production of contaminates within the combustion process, these include:

- Utilising BAT (Best Available Technologies).
- Employing Stoichiometric combustion principles.
- Ensuring the plant is operating at design combustion efficiency.
- Fuel pre-treatment.
- Utilising additives.

Secondary control measures aim to reduce/remove the pollutants after they have formed during the combustion process. These include:

- Flue Gas Treatment
- Carbon Capture

Primary control measures are often simpler to implement and are much more cost effective than expensive secondary control measures.

It is an EPA requirement that landfill gas is combusted at over 1000°C with a combustion resonance time of at least 0.3 seconds. This temperature in the combustion chamber is deemed adequate to ignite and sustain the combustion of the landfill gas. The 0.3 seconds combustion resonance time is to ensure complete combustion, or that the combustion chemical reaction has been completed fully.

There is also a requirement for turbulence within the combustion chamber to ensure adequate mixing of the landfill gas with the oxygen in the combustion air. These three elements, Temperature, Time and Turbulence are referred to as the "3T's" of combustion (Enviromental Protection Agency - Landfill Site Design 2002).

2.3.1 CHP Systems Considered

As illustrated in Figure 12 - lower CH4 working limits for LFG utilisation shows the operational limits of CH_4 concentrations that are viable for differing CHP technologies. The curve represents the concentration of CH_4 expected from a typical landfill over a 50 year period. As can be seen from the diagram gas turbines and internal combustion engine technologies are most suitable to the combustion of the available LFG given the concentration of CH_4 in the landfill gas from the central waste management site.

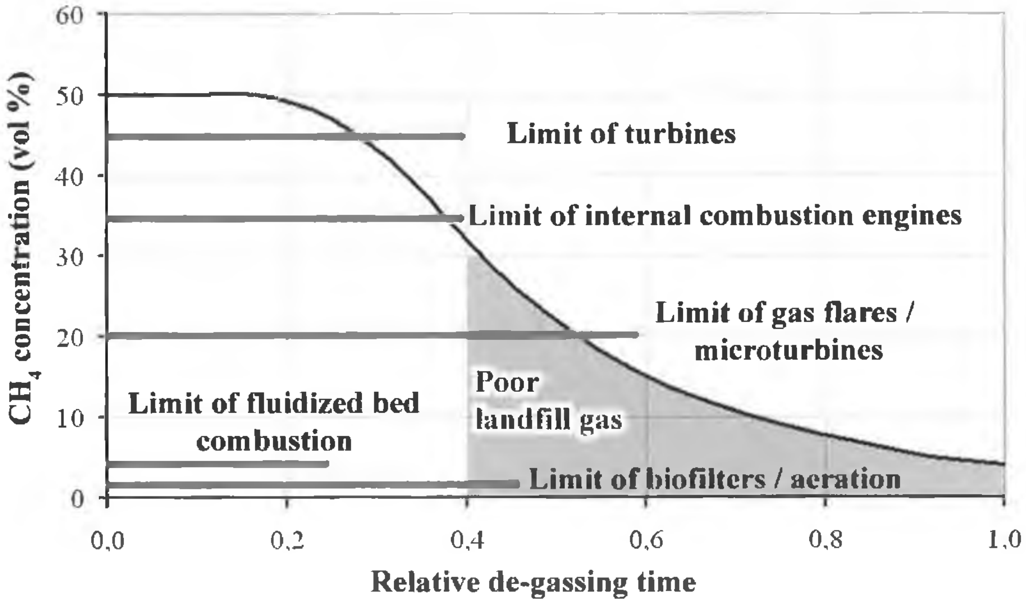


Figure 12 - lower CH4 working limits for LFG utilisation

(Image Copyright of T. Tsatsarelis & A.Karagiannidis 2008)

The different CHP systems which were considered for utilisation on site were:

- Micro Gas Turbine
- Internal Combustion Engine

2.3.2 Micro Gas Turbine

Gas turbines have now reached a stage of refinement where micro turbines which can be sized down to 35 kW_e are commercially available. Gas turbines are new to the CHP market but have been used in aviation and large commercial gas turbine plants for several decades. This technology is well understood and proven. One of the major advantages from micro turbines is their relatively simple design, consisting of one main moving component. This reduces the likelihood of mechanical failure and simplifies maintenance routines. One manufacture of particular interest is Capstone Turbine Corporation. Their patented air bearing system resolves the issue of lubrication, a major cause of failure in high speed mechanisms such as turbines. This turbine provides an overall efficiency of 82% (Capstone Turbine Corporation 2011). A diagram of the turbine can be seen in Figure 13 - micro gas turbine diagram.

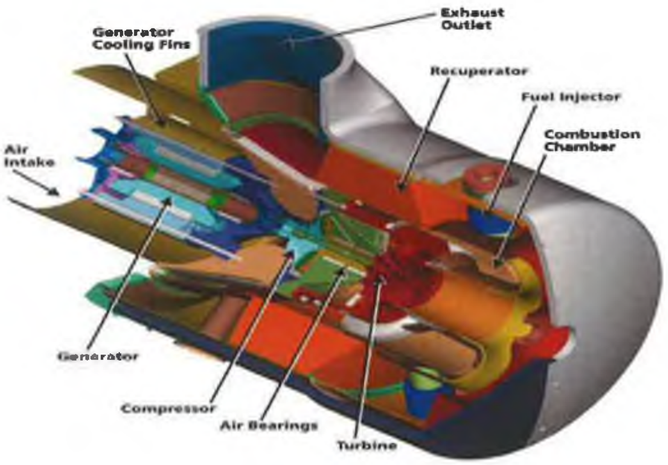


Figure 13 - micro gas turbine diagram

(Image Copyright of Capstone Turbine Corporation 2011))

The diagram below in Figure 14 - micro gas turbine layout shows typical CHP arrangement for a micro turbine. It principal of operation is as follows, air is drawn in by the compressor through a series of high performance filters. This air is then forced through the compressor where its pressure and temperature is increased. This "combustion" air is feed into combustion chamber via burners where it is mixed with the fuel (in our case biogas in the form of LFG) and ignited by electrodes. The rapidly expanding mixture is forced to pass through a turbine where it offers up its energy to the turbine blades as a turning force. This turning force is utilised to turn the shaft and in turn the generator which produces electrical energy. The expanding gases are passed through a waste heat recovery boiler to extract any remaining energy. This energy is then utilised to provide heat to the load.

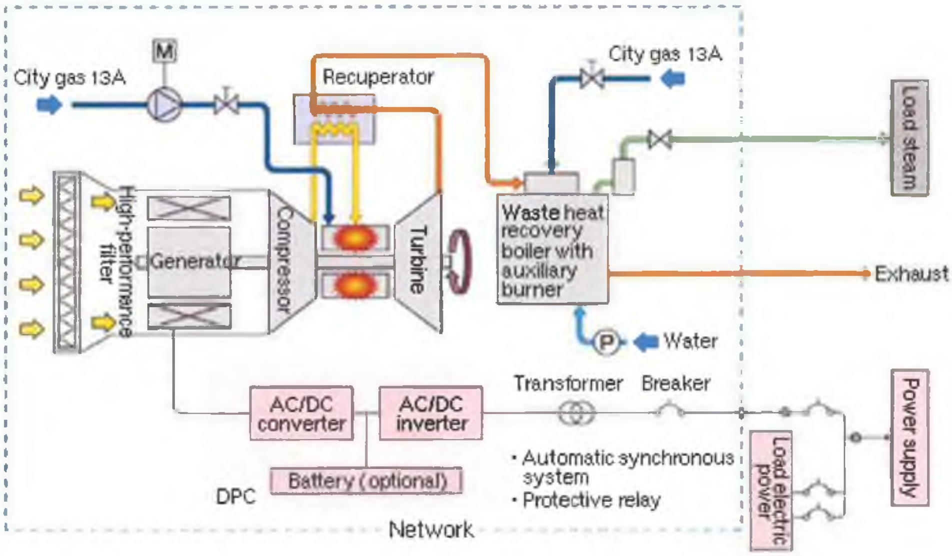


Figure 14 - micro gas turbine layout

(Picture courtesy of Kerr Enterprises 2006)

2.3.3 Internal Combustion Engine

CHP plants based on the internal combustion engine are the most common system in use today. There are several manufacturers of these plants which lends to competitive pricing. The technology is well understood and proven. Maintenance is necessary, but not a concern as it can be carried out by service companies specialising in engine maintenance and repair. Motive power is provided from the engines crankshaft and heat energy is collected from the engines cooling system and exhaust as well as its lubrication oil on larger systems. The systems are divided into two main groups: spark ignition and compression ignition. This allows use of a wide range of fuels, including blended fuels. One of the major drawbacks with these systems is the cost associated with service interval requirement on the internal combustion engine. This can increase the payback period due to the direct cost of maintenance as well as the requirement for backup energy provision during scheduled downtime of the engine. A diagram outlining a typically spark ignition CHP plant is shown in Figure 15 - schematic of typical spark-ignition gas CHP engine.

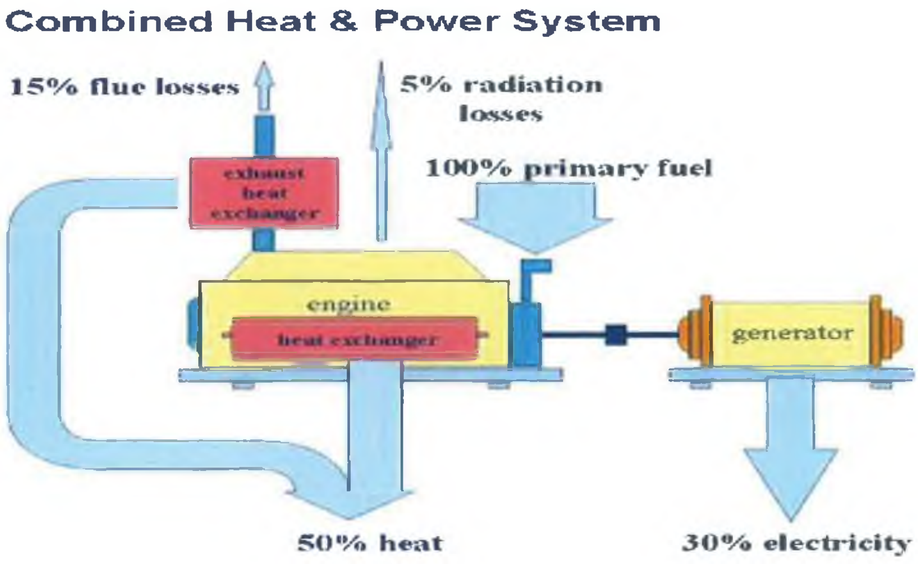


Figure 15 - schematic of typical spark-ignition gas CHP engine

(Image Copyright of City and County of Swansea 2011)

This is an overview of suitable CHP technologies that are available in the market place today. While each technology would meet with the system requirements for this project, individual assessment of the most beneficial system is required. This appraisal should include consideration of; efficiency, fuel availability, duty cycle, maintenance schedule and cost.

2.3.4 Barriers Constraining CHP Development in Ireland

The Irish CHP Associated has identified the following barriers in relation to the on-going development of CHP in Ireland (Irish CHP Associatation - Barriers Constraining CHP Development in Ireland 2009):

- Cost of fuel – minimising bulk gas price to CHP.
- Definition of CHP (in current Irish electricity legislation) too restrictive.
- Payment for electrical spill too low.
- Cost of electrical top-up too high.
- Restrictions on trading of surplus electricity.
- Interconnectors – regulation, access, capacity.
- Electricity network connection charges and procedures.
- Use-of-System charges and procedures (maximum demand tariff in particular).
- System reward for embedded generation capacity. (Currently no recognition for potential CHP contribution to network).
- Reward for contribution to reduced national emissions.
- Reward for contribution to lower fuel import costs.

- Disproportionate regulatory overhead – 2MW CHP plant treated much the same as 400MW power station.
- Extent of development of network – availability of natural gas.
- Treatment of CHP under gas regulations.
- Gas network connection charges/conditions.
- Treatment of CHP under national energy taxation regime (CHP enjoys more favourable regime in UK).
- General tax treatment of CHP – capital allowances, etc.
- Lack of unified lobby for CHP.
- Limited customer awareness of:
    - Technological Developments
    - Finance Options

2.4 District Heating Technologies

The concept of district heating is not a new one. This technology was first utilised by the Roman Empire back in the first century. The Romans utilised the energy in natural hot springs to build bathing rooms with hot baths and provided heat to greenhouses to produce food. The oldest district heating system still in operation today is providing heat to the French village of Chaudes-Aigues Cantal from geothermal hot springs since the early fourteenth century. The U.S. Naval Academy in Annapolis constructed a steam supply district heating system in 1853. The first commercially successful district heating system was installed in Lockport, New York in 1887, designed by Birdsill Holly, a hydraulic engineer and a pioneer in the field of modern day district heat systems (Pierce 1994). More recently in the 1980's, the city of Southampton in the United Kingdom began utilisation of a combination of geo-thermal, CHP, fuel oil and natural gas to provide heat into its 11 kilometres of mains district heating network. In Denmark 60% of homes are supplied with district heating provided by 450 privately owned supply companies (Greenpeace - Case Study Southampton 2007).

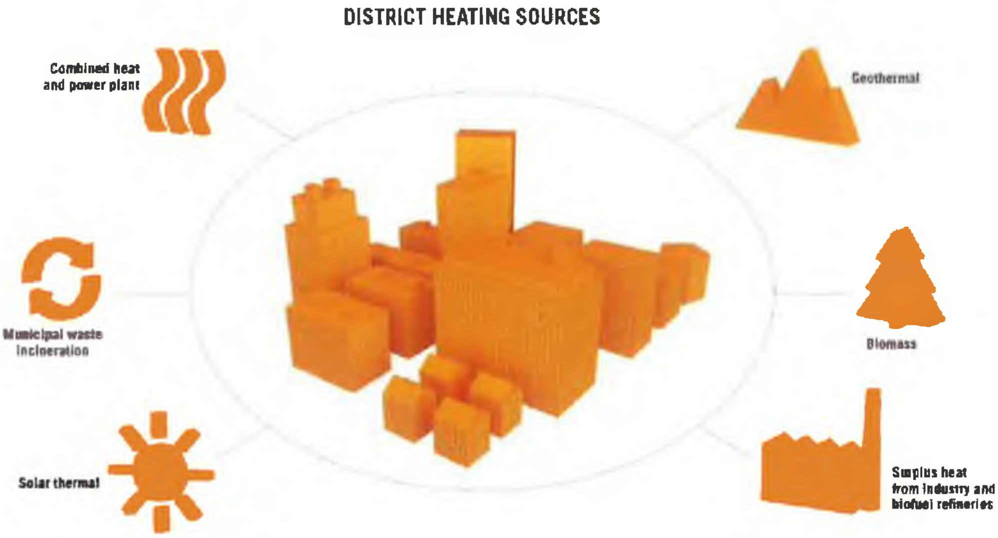


Figure 16 - district heating energy sources

(Image Copyright of Euroheat & Power 2010)

As shown in Figure 16 - district heating energy sources, district heating can be supplied from numerous sources of energy, both fossil and renewable these include; geothermal, biomass, heat recovery, solar thermal, municipal waste and CHP.

PRF (Primary Resource Factor) can be used to compare a heating system's contribution to reducing the use of fossil fuels. PFR takes into account the complete cycle of a heat source from its conversion to its delivery, including transportation losses, efficiency and heat recovery technologies. The lower the PRF number the greater its contribution in reducing the need to use fossil fuels Figure 17 - primary resource factor for heating systems illustrates the PFR for common heating systems.

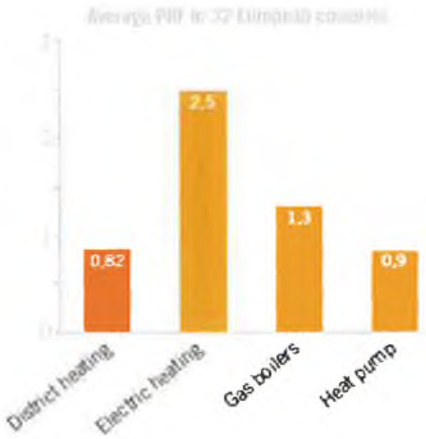


Figure 17 - primary resource factor for heating systems

(Image Copyright of Euroheat & Power 2010)

As shown in Figure 18 - district heating market share in Europe, penetration of district heating is low. This poor penetration is due in the main to market structures. These liberalised markets tend to invest capital in schemes which have a short term payback period and do not wish to be involved in capital projects which have longer term payback periods. Renewable technologies also experience these barriers. Utility companies will require support from legislation, government and market incentives if they are to increase the penetration of district heating in the marketplace. These changes must be accompanied by an agenda of climate change. Countries with relatively high market penetration, for example; Denmark, Sweden and Finland, have succeeded in removing these barriers to the installation of district heating systems; however they also have substantial geo-thermal resources.

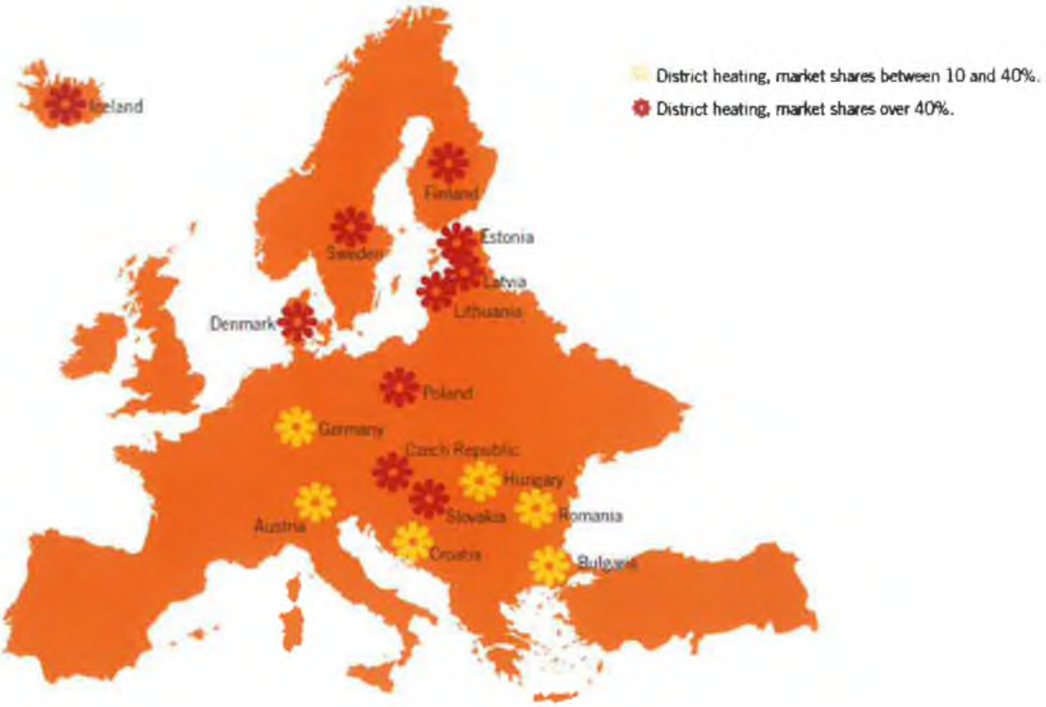


Figure 18 - district heating market share in Europe

(Image Copyright of Euroheat & Power 2010)

2.4.1 Public Perceptions of District Heating

The following is an outline of public perceptions in relation to district heating technologies:

- Performance misconceptions of district heating systems at a national level in the Dublin Ballymun tower complexes constructed in the 1960's, which were infamous for their poor performing district heating systems.
- Perceived as the "poor man's heat".
- Lack of tradition, engineering and installation expertise in Ireland.
- Competing fuels were relatively cheap to merit looking at district heating.
- Perception of being too dependent on one source of heat.
- Lack of control of the heat energy supply.

2.4.2 District Heating Networks Advantages

- Security of supply.
- Environmental benefits.
- Controllable costs.
- More efficient and economical than individual units.

2.4.2.1 Security of Supply

As per the National Energy Efficiency Action Plan 2009 - 2020 one of the key pillars of national energy policy is security of energy supply (Department of

Communications, Energy and Natural Resources - The Nation Energy Efficiency Action Plan 2009). District heating systems can play a pivotal role in improving security of supply through:

- Generating and distributing energy within the load centre, reducing transmission and distribution losses, through reduced transmission distances.
- Facilitating operation of large, more efficient combustion technologies improving fuel efficiencies.
- Thermal energy storage, that can store both hot and chilled water, can shift loads from times of peak usage to off-peak periods.
- District heating systems provide fuel flexibility; since district heating systems can be supplied from almost any fuel source. As fuel and combustion technologies change the district heating network remains a constant unchanged reliable energy distribution system.

2.4.2.2 Environmental Benefits

Environmental benefits for the community from the installation of CHP powered district heating scheme include:

- Improved air quality.
- Reduction in the use of fossil fuels.
- Greatly improved energy efficiency.

The combustion process of CHP plants can be controlled more precisely when compared with that of hundreds of smaller household boilers which are often not well maintained. District heating makes use of waste heat from the combustion process - therefore the emissions per unit of delivered heat are reduced. In the past 10 years the SO_2 (Sulphur Dioxide) emissions from Danish CHP plants have reduced by 50%. In 1990, Helsinki in Finland was awarded the United Nations Environmental Prize for its CHP powered district heating scheme. In 1994 it was estimated that worldwide 45 million litres of fuel oil per annum was being saved through the use of district heating technologies, that is the equivalent of removing 160,000 tons of CO_2 from the atmosphere (Pierce 1995).

A report commissioned by the World Commission on Environment and Development entitled "Our Common Future" in 1987 states that:

> *"An important method of heating buildings is by hot water produced during electricity production and piped around whole districts, providing both heat and hot water...the cogeneration of heat and electricity could revolutionize energy efficiency of buildings worldwide."*
>
> (United Nations - Our Common Future 1987)

2.4.2.3 Controllable Cost

There is a twofold cost saving to the community from the proposed district heating scheme. One is the reduced cost of energy and the other is the cost savings from maintaining current heating systems on site. The Dublin District Heating Project carried out a detailed feasibility study, its aim was to provide Dublin city with a district heating network, the study was completed in 2008 and it concluded:

> *"That the development of a DH network for Dublin was feasible, and can provide a cost-effective and environmentally sustainable source of available heating (and potentially cooling) for Dublin."*
>
> (Engineers Journal - District Heating in Ireland 2010)

2.4.3 Development in Standards for DH Technologies

The following standards have been adopted by the European Union in relation to technologies for district heating infrastructure:

- EN 253 for pipe work.
- EN 448 for fittings.
- EN 488 for valves.
- EN 489 for joint assemblies.
- EN 13941 for design and installation.

2.4.4 District Heating Distribution Systems

District heating distribution systems are categorised by the type of heat delivery system, these include:

- Steam Systems
- Hot Water Systems

2.4.5 District Heating Underground Pipework

Pre-insulated pipes are extensively utilised within district heating networks for the transmission of both heating and cooling systems, pre-insulated pipes were first introduced in Denmark in the 1960. Steel bonded systems are controlled by European standard EN 253 for pipe work and these have now reached levels of insulation that make transmission distances of up to 20 kilometres feasible. There are European standards for; fittings EN 448. Valves EN 488, jointing assemblies EN449 and for design and installation EN 13941. The illustration below in Figure 19 - pre-insulated district heating pipe shows the construction of pre-insulated pipe to EN 253.

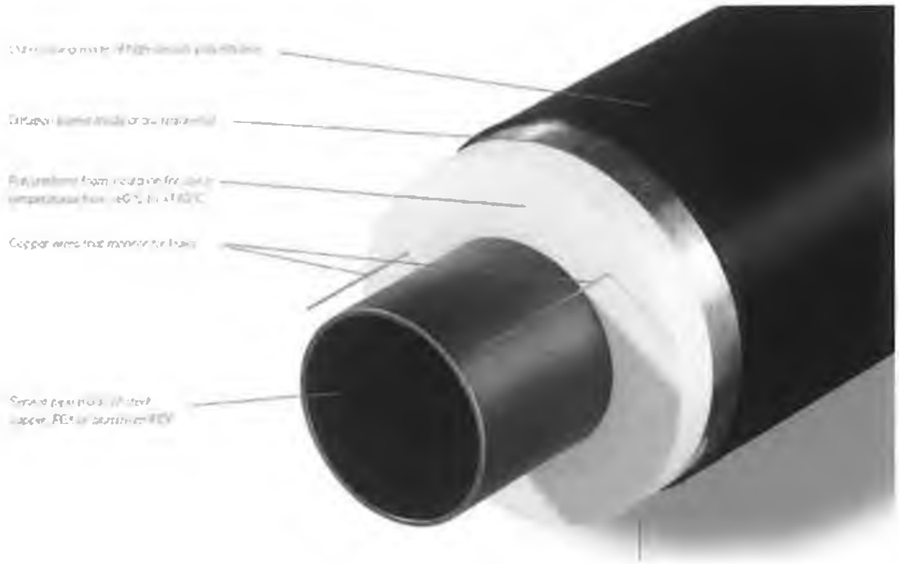


Figure 19 - pre-insulated district heating pipework

(Image Copyright of Logstor 2010)

The most common piping system in use today is the bonded pipe system. In this system the insulation is bonded to both the carrier pipe and the outer jackets, in turn each pipe section is welded together to give one continuous pipe as are flanges for control and instrumentation equipment. However this can cause sheer stress due to thermal expansion between the piping system and the surrounding soil. To relief this stress several techniques are employed these include; expansion joints, Z bends and expansions loops.

The pipe laying methods are carefully selected depending on length of run of pipe network, these include; compensated, heat pre-stressed in open trench, cold laid and heat pre-stressed with start-up compensators which are only locked into position when sufficient displacement of the piping network with the surrounding soil has taken place during commissioning. Most bonded piping systems now incorporate a pair of electrodes placed into the insulation as a leak detection system. If the pipe network develops a leak it will cause a short in the electrodes. Their resistance can then be measured to determine the position of the leak within the network (Logstor 2010).

2.4.6 District Heating Heat Stations

On the transmission network of large district heating systems heat stations are fitted at points of substantial load. This installation consists of; heat exchangers, pumps, safety devices, and control and instrumentation equipment. The function of these heat stations is to extract heat from the transmission network, reduce its operational temperature and pressure and pump this throughout the distribution system for use by individual units, such as households.

2.4.7 Heat Interface Unit

The heat substation consists of; a plate heat exchanger to heat domestic hot water with a bypass valve to ensure that hot water is always instantly available, electronic heat meter for control and billing purposes and the necessary safety and control valves to ensure heating and hot water temperature control. A variation on this heat substation also has a secondary plate heat exchanger with circulation pump, safety valve, expansion vessel and controls build in, this unit is installed where it is desirable to connect the load indirectly to the district heating distribution system, it is commonly referred to as an indirect unit and is now the most common type of heat interface unit fitted in new systems.

Figure 20 - indirect plate heat exchanger unit

(Image Copyright of Construct Ireland - Gemina Termix 2010)

2.4.8 District Heating Operation Parameters

A typical district heating transmission network will have operating pressures of up to 25 bar, with flow temperature of 125°C and a return temperature of 45°C. Distribution systems typically operate at pressures between 6-16 bar with a flow temperature of 75°C and a return temperature of 40°C.

2.4.9 District Heating Network Maintenance

With the inclusion of a leak detection system, improvement in insulation materials and techniques allowing systems to operate at lower temperature thus reducing stress and the addition of the correct additives to prevent corrosion within the system, district heating network systems require almost no maintenance once they have been installed.

Chapter 3 - Methodology

3.0 Methodology

In this chapter the study will consider:

1. The community in which the LFG powered CHP and district heating system will be located.
2. The mathematical models available of determining the energy available from LFG on the waste management site.
3. The methods that will be employed to estimate the energy requirements for the community in terms of electricity, heating, domestic hot water and transport.
4. Community involvement and participation.

3.1 Study Area

The village of Inagh consists of mixed dwellings including; 2 residential estates (one developed in the 1970's with approximately 40 dwellings, the second estate was developed in 2004 with 56 dwellings), primary school, church, community centre, post office, 2 shops and 2 public houses. As well as these structures there are approximately 21 one off developments. A street map of the Inagh village is shown in Figure 21 - street map of Inagh. This map clearly indicates the community is a "focus on routes" and as such has a clustered settlement pattern. The central waste management site that produces the LFG fuel considered within this study is shown in Figure 22 - central waste management site. The site was constructed in 2002 on 65 hectares of forestry.

Figure 21 - street map of Inagh

(Image Copyright of Ordnance Survey of Ireland - Street Map 2005, Scale 1:25,000)

Figure 22 - central waste management site

(Image Copyright of Ordnance Survey of Ireland - Ortho Map 2005, Scale 1:25,000)

3.2 Energy Available from LFG

The quantity and quality of LFG produced by any landfill site varies depending on site conditions these include; waste deposition start date, waste deposition expected end date, moisture content, biodegradable organic matter content of deposited waste, quantity of waste deposited, pH of the soil, temperature, biochemical feedback, gas recovery efficiency and the density of the waste. Accurate calculation of LFG yield requires these data sources to be available.

There are a number of mathematical models used to calculate methane generation from a waste management site, these include:

- Zero Order Model
- Simple First Order Model
- Modified First Order Model
- First Order Multi-Phase Model

3.2.1 The First Order Model

The more utilised of these models is the First Order Multi-Phase Model, shown below;

$$G = WL_0\left[F_{(r)})(k_{(r)}e^{-k_{(r)}(t-t_1)})+F_{(s)}(k_{(s)}e^{-k_{(s)}(t-t_1)})\right]$$

Where:

G = Methane Generation (Million Cubic Feet per Year)

W = Waste in Place (Tons)

L_0 = Methane Yield Potential (Cubic Feet Methane per Ton of Waste)

t = Time After Waste Placement (Years)

t_1 = Lag Rime, Between Placement and Start of Generation

$K_{(r)}$ = First Order Decay Rate Constant for Rapidly Decomposable Waste

$K_{(s)}$ = First Order Decay Rate Constant for Slowly Decomposable Waste

$F_{(r)}$ = Fraction of rapidly Decomposable Waste

$F_{(s)}$ = Fraction of slowly decomposable Waste

3.3 Energy Requirements of the Community

The energy requirements of the community fall into four distinct categories:

1. Electricity Energy
2. Space Heating
3. Domestic Hot Water
4. Transportation

3.3.1 Electrical Energy Requirements

The average domestic household consumes 5,591 kWh of electricity per annum (Sustainable Energy Authority of Ireland - Energy in the Residential Sector 2008). Utilising the information provided in this SEAI report, Table 1 – community electrical demand requirements will be compiled, which outlines the requirement in the community for electricity generation.

3.3.2 Space Heating Requirements

The space heating requirement of the community will be supplied via the district heating systems as there is a mixture of buildings. This report will estimate the heating requirement based on a heat rate in w/m^2. This value will vary depending on the type of buildings. The results of these estimates for space heating requirements are available in Table 2 – community space heating requirements.

3.3.3 Domestic Hot Water Requirements

It is estimated that the average household consumes 122 litres/day of domestic hot water ±18 litres per occupant based on an average occupancy rate of 3.2 persons per dwelling (The New York State Energy Research and Development Authority - Energy Use and Domestic Hot Water Consumption 1994). As illustrated in Table 3 - domestic hot water consumption per occupant, are the design figures that should be utilised when estimating the requirement for domestic hot water for various building types (The Engineer Toolbox - Hot Water Consumption per Occupant 2010).

Domestic hot water should be stored at a minimum temperature of 60°C to militate against the effects of bacterial growth, particularly legionella. Domestic cold water on average enters a dwelling at ~10°C; therefore we need to increase the temperature of the domestic cold water by 50°K (Kelvin) to bring it to a safe 60°C.

The energy required heat a liquid is expressed as:

$$Q = Cp.m.dT$$

Where:

Q = Amount Of Heat (kJ)
Cp = Specific Heat Capacity (kJ/kg K)
m = Mass (kg)
dT = Temperature Difference Between Hot and Cold Side (K)

3.4 CHP Equipment Selection

The following criterion will be considered when assessing the suitability of a CHP plant for the study site:

- Thermal output, which can be recovered for use on-site, including data on the temperature and flow rate of the fluid in which the heat is contained.
- Electrical output, which should include data relating to the power consumption of the CHP plant's own, motors etc., so that the net output can be defined.
- Fuel consumption of the equipment, taking care to ensure that this can be expressed in gross calorific value terms.
- The approximate cost per kilowatt hour (kWh) generated which should be allowed for servicing and maintaining the equipment.
- Any essential auxiliary plant items that are not contained within the scope of the supplied equipment.
- After-sales service, including on-site maintenance provision and availability of spare parts.
- The cost of supplying and installing the equipment.
- The dimensions and weight of the equipment.
- Emissions from the CHP unit.
- Site Constraints

3.5 Community

A key consideration within this study is community involvement. For this project to be a success it requires not only the involvement but the support of the local community. This study is centred on making the community responsible for its energy needs within a sustainable framework.

> The dictionary defines community as "*a social group of any size whose members reside in a specific locality, share government, and often have a common cultural and historical heritage*"
>
> (Dictionary - Community 2011).

This study will consider the methods of community participation, the benefits to the community, the opportunities forthcoming to the community and the potential barriers from within the community, to a project of this nature.

Chapter 4 - Results

4.0 Results

In this chapter the study will:

- Estimate the potential energy from landfill gas on site.
- Estimate of the community's energy requirements.
- Report on the most suitable technologies for project implementation.
- Provide a detailed costing for project funding and implementation.
- Outline the community considerations for the implementation of the project.

4.1 Metered LFG Energy Potential on Site

While the models referred to in section 3.2 Energy Available from LFG can be utilised to estimate the quantity of landfill gas on site. The central waste management sites flaring system carries out continuous monitoring of the quantity and quality of landfill gas being produced by the site. These measurements include: gas flow rate, methane concentration and oxygen concentration among others.

Commercial grade natural gas with a methane content of ~80% produces ~10.8kWh/m^3 of energy. The waste management site currently produces 8m^3/min of LFG, with a methane content of ~34%. Therefore the metered potential energy available from LFG on site is 4.59kWh/m^3, or with a flow rate of 8m^3/min 2,203kW/h.

4.2 Energy Requirements of the Community

The energy requirements of the community fall into four distinct categories:

1. Electricity Energy
2. Space Heating
3. Domestic Hot Water
4. Transportation

4.2.1 Electrical Energy Requirements

The average Irish domestic household consumes 5,591 kWh of electricity per annum (Sustainable Energy Authority of Ireland - Energy in the Residential Sector 2008). Utilising the information provided in this SEAI report Table 1 – community electrical demand requirements was compiled, which outlines the requirement in the community for electricity generation.

Building Type	***Description***	***No. of Buildings***	***kWh/building/yr***	***Total kWh/yr***
House A	1970's 3 Bedroom Semi-Detached	32	5,040	161,280
House B	1970's 3 Bedroom Terraced	10	4,896	48,960
House C	2000's 4 Bedroom Semi-Detached	32	6,336	202,752
House D	2000's 3 Bedroom Detached	12	5,568	66,816
House E	2000's 3 Bedroom Terraced	12	4,992	59,904
School	Primary School	1	100,800	100,800
Church	Community Church	1	33,600	33,600
Community Centre	Community Centre	1	24,000	24,000
Post Office	Post Office	1	960	960
Supermarket	Local supermarket/shops	2	9,600	19,200
Public Houses	Local Pub	2	14,400	28,800
Crèche	Modern Crèche/Play School	1	14,400	14,400
One Off Developments	Single Dwelling Homes	21	7,200	151,200
Total		128		912,672

Table 1 – community electrical demand requirements

4.2.2 Space Heating Requirements

The space heating requirement of the community will be supplied via the district heating systems as there is a mixture of buildings we will estimate the heating requirement based on a heat rate in w/m^2, this value will vary depending on the type of building.

Annual heating load per household is as follows:

Degree days (<15.5°C) = 2,352

Building Type	***Description***	***No. of buildings***	***Floor Area (m²)***	***kWh/dwelling/Yr***	***Total kWh/Yr***
House A	1970's 3 Bedroom Semi-Detached	32	105	17,535	561,120
House B	1970's 3 Bedroom Terraced	10	102	17,034	170,340
House C	2000's 4 Bedroom Semi-Detached	32	132	22,044	705,408
House D	2000's 3 Bedroom Detached	12	116	19,372	232,464
House E	2000's 3 Bedroom Terraced	12	104	17,368	208,416
School	Primary School	1	2100	350,700	350,700
Church	Community Church	1	700	116,900	116,900
Community Centre	Community Centre	1	500	83,500	83,500
Post Office	Post Office	1	20	3,340	3,340
Supermarket	Local supermarket/shops	2	200	33,400	66,800
Public Houses	Local Pub	2	300	50,100	100,200
Crèche	Modern Crèche/Play School	1	300	50,100	50,100
One Off Developments	Single Dwelling Homes	21	150	25,050	526,050
Total		128			3,175,338

Table 2 – community space heating requirements

As can be seen in Table 2 – community space heating requirements, the community will require ~3,175,338 kWh of energy for space heating.

4.2.3 Domestic Hot Water Requirements

It is estimated that the average household consumes 122 litres/day of domestic hot water ±18 litres per occupant (The New York State Energy Research and Development Authority - Energy Use and Domestic Hot Water Consumption 1994). As illustrated in Table 3 - domestic hot water consumption per occupant, are the design Figures that should be utilised when estimating the requirement for domestic hot water for various building types (The Engineer Toolbox - Hot Water Consumption per Occupant 2010).

Type of Building	***Consumption Per Occupant***	***Peak Demand Per Occupant***	***Storage Per Occupant***
	Litre(s)/day	***Litre(s)/hr***	***Litre(s)***
Factories	22 - 45	9	5
Hospitals (General)	160	30	27
Hospitals (Mental)	110	22	27
Hostels	90	45	30
Hotels	90 - 160	45	30
Houses and Flats	90 - 160	45	30
Offices	22	9	5
Schools	15	9	5

Table 3 - domestic hot water consumption per occupant

Utilising the domestic hot water Figures from Table 3 - domestic hot water consumption per occupant, the following Table 4 – community domestic hot water requirements were developed.

Building Type	***Description***	***No. of Buildings***	***Occupancy Per Dwelling***	***Total DHW usage/Yr/building type***
House A	1970's 3 Bedroom Semi-Detached	32	3.1	5,069,120
House B	1970's 3 Bedroom Terraced	10	3.1	1,584,100
House C	2000's 4 Bedroom Semi-Detached	32	3.1	5,069,120
House D	2000's 3 Bedroom Detached	12	3.1	1,900,920
House E	2000's 3 Bedroom Terraced	12	3.1	1,900,920
School	Primary School	1	200	780,000
Church	Community Church	1	0	0
Community Centre	Community Centre	1	0	0
Post Office	Post Office	1	2	11,440
Supermarket	Local supermarket/shops	2	4	131,400
Public Houses	Local Pub	2	2	65,700
Crèche	Modern Crèche/Play School	1	30	117,000
One Off Developments	Single Dwelling Homes	21	3.1	3,326,610
Totals		128		19,956,330

Table 4 – community domestic hot water requirements

Domestic hot water should be stored at a minimum temperature of 60°C to militate against the effects of bacterial growth, particularly legionella. Domestic cold water on average enters a dwelling at ~10°C; therefore we need to increase the temperature of the domestic cold water by 50°K (Kelvin) to bring it to a safe 60°C.

The energy required heat a liquid is expressed as:

$$Q = Cp.m.dT$$

Where:

Q = Amount Of Heat (kJ)
Cp = Specific Heat Capacity (kJ/kg K)
m = Mass (kg)
dT = Temperature Difference Between Hot and Cold Side (K)

Therefore to heat the water in our system we would need:

Cp (water) = 4.19 kJ/kg K
m = 19,956,330 kg (1L of Water = 1kg)
dT = 50K

$$Q = 4.19 \times 19{,}956{,}339 \times 50$$

$$Q = 4{,}180{,}853{,}021 \text{ kJ}$$

$$\Rightarrow Q = 1{,}161{,}348 \text{ kWh}$$

We need to supply ~1,161,348 kWh of energy to supply the community with a sufficient supply of domestic hot water.

4.2.4 Transportation

The census carried out in 2006 shows the area to have a population of 187 (Central Statistics Office - Census 2006). In Ireland the vehicle ownership per 1000 people is 359 (United Nations - World Statisics Pocketbook 2009). Therefore, the vehicular ownership in the community of Inagh is ~68 vehicles. The combined average mileage in Ireland is ~16,892 km per vehicle per annum with an average combined fuel consumption of 6.7 litres/100km. Therefore the community would require 76,960 litres of fuel per annum (Sustainable Energy Authority of Ireland - Energy Map 2010). In terms of supplying this fuel requirement via LFG that would equate to 200,201m^3 of LFG per annum of scrubbed and compressed gas to fuel petrol vehicle converted to run on LFG gas.

4.2.5 Community Energy Requirements Summary

The community of Inagh currently consumes ~4,336,686 kWh of heat energy, ~912,672 kWh of electrical energy and ~571,091kWh of transportation energy per annum. This energy requirement is more than capable of being supplied by the LFG fired CHP unit which produces 4,999,040 kWh of heat and 4,231,628 kWh of electricity per annum. The surplus LFG from the central waste management site is more that capable of supplying the transportation fuel requirements of the community. This energy supply system can cope with transmission, distribution and energy conversion losses of up to 14%, well above the anticipated overall efficiency of the system. Detailed calculations can be found in the appendixes A.1 – A.4.

4.3 District Heating System Equipment

The proposed district heating system equipment will comprise of; biogas scrubbing system, scrubbed LFG fired biogas CHP plant with associated isolated boiler house, pumping and control station, heat exchangers separating the CHP from the district heating transmission network, super insulated pipe work ran underground to each dwelling through a distribution network via a pressure reduction station centrally located in the village and finally at each user point a heat pod with metering, integrated heat exchanger and controls.

4.3.1 Biogas Scrubbing Plant

The first element in this system is a filtration skid for the LFG or scrubber as it is commonly known. This system utilises plain water to remove the carbon dioxide and hydrogen sulphide from the LFG, without the use of chemicals. The carbon dioxide and hydrogen sulphide are separated from the LFG under pressure by absorption into the water. The system also contains a compressor to force the gas through the scrubbers. Post scrubbing the methane content of the gas will be >98%. The gas quality produced by this plant can be bottled, utilised as a vehicle fuel or in our case feeds directly into our LGF gas network. The waste water from the skid can be feed to the existing leachate treatment system on the central waste management site.

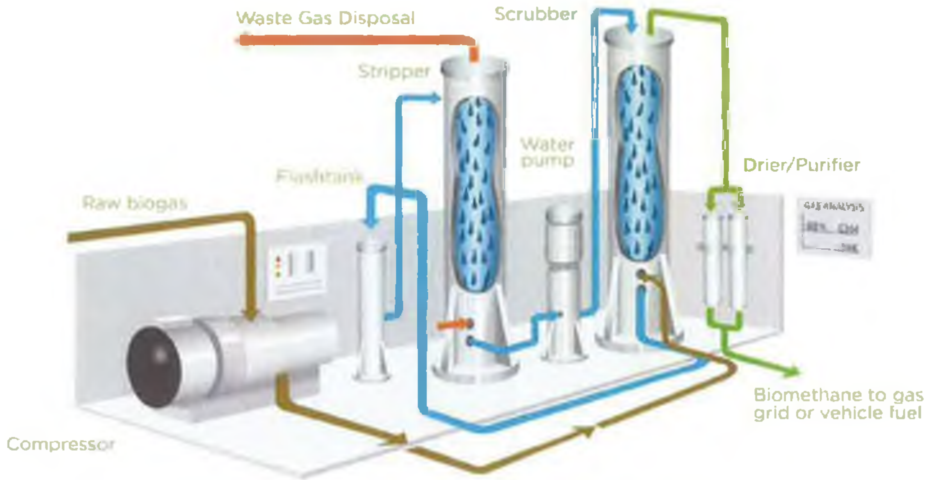


Figure 23 - biogas scrubber

(Image Copyright of Flowtech Greenlane 2010)

4.3.2 LFG Network

This project proposes to run a polypropylene LFG piping network from the gas scrubber plant at the waste disposal site to the CHP site in the heart of the village as shown in Figure 24 - LFG network. This pipe work system will follow the natural contour of the existing road network along the N85 and turning left along the R460 into the village of Inagh. The LFG network will be ~2.3 km in length.

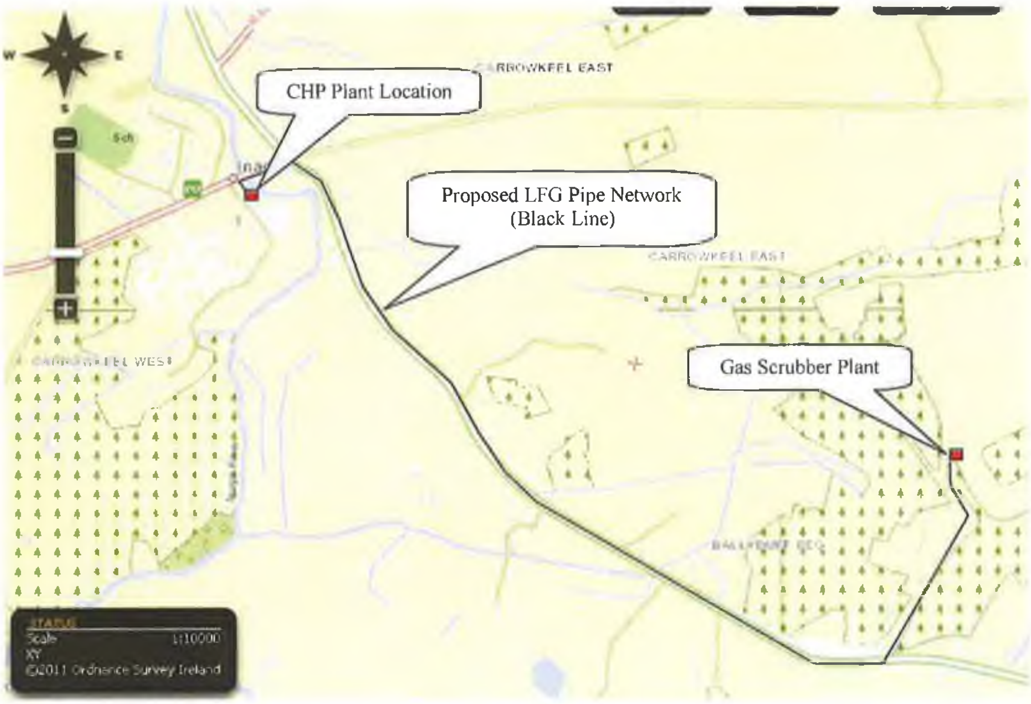


Figure 24 - LFG network layout

(Image Copyright of Ordnance Survey of Ireland - Ortho Map 2005, Scale:1:25,000)

4.3.3 CHP Plant

The CHP system to be utilised as a heat engine to provide heat energy to the district heating network will be discussed in detail in section 4.4 Combined Heat and Power Plant Equipment.

4.3.4 District Heating Network

The district heating system can be constructed from steel or plastic pipe work, as the distances involved are relatively short within this project this study has elected to use plastic pipe work. It is also more cost effective over short distances, more flexible in installation and requires less specialist skill to connect and terminate.

There are three basic types of super insulated plastic pipe work, these relate mainly to the type of insulation surrounding the pipe itself. These are:

- Foam
- Dynamic
- Vacuum Jacketed

Of these the dynamic and vacuum jacketed offer by far the greatest efficiency in terms of thermal performance, however their material and installation costs are prohibitive as can be seen in Figure 25 - super insulated pipe work comparisons.

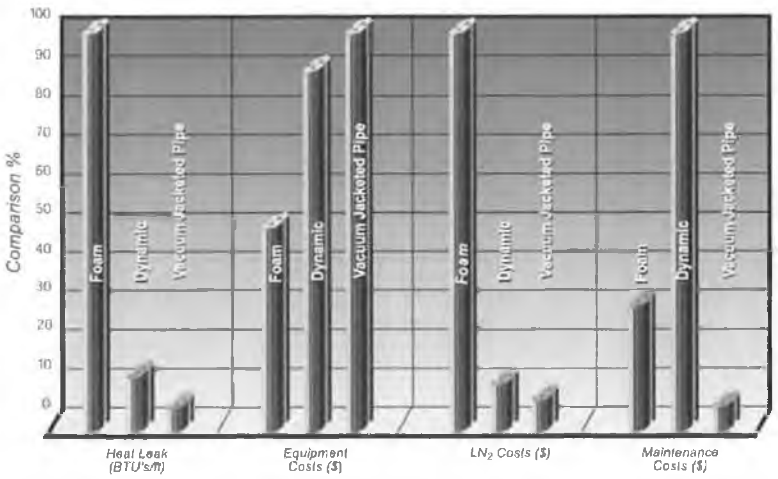


Figure 25 - super insulated pipe work comparisons

(Image Copyright of ACME Cryogenics 2007)

With this in mind the community will install foam insulated pipe work as the network distribution distances will be relatively short and the thermal losses therefore will be relatively small. Within the foam insulated pipe work category there are still many different types of insulation available. As longevity is an important factor within this project, pipe work with PE-X (Polyethylene) insulation will be utilised (Plastic Pipe Institute - A Serive Lifetime Study 2005).

The entire district heating network will be fitted with a Durotann pre-insulated piping system. This system is PE-X insulated and shrouded and it was designed specifically for district heating networks, it has been in commercial use for over 40 years, can be fusion welded reducing cost and is available in a wide range of diameters from 16–110mm. Also, there are a wide range of fitting and fixtures available for this pipe work system. An example of this pipe work can be seen in Figure 26 - super insulated PE-X pipe.

Figure 26 - super insulated PE-X pipework

(Image Copyright of Durotan - Pre-Insulated Piping Systems Installation & Technical Guide 2007)

The preliminary layout of the district heating system is shown in Figure 27 - district heating network layout.

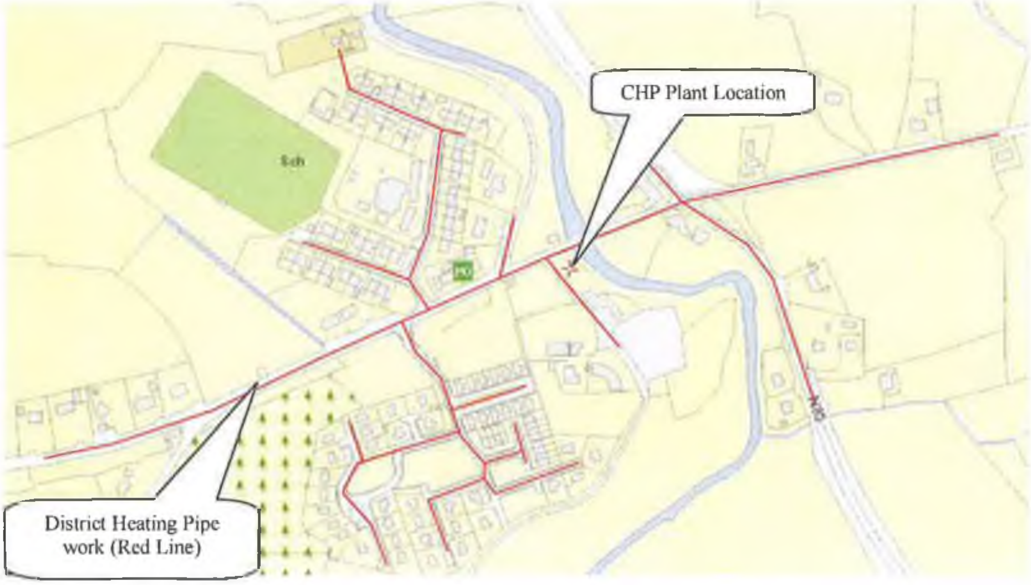


Figure 27 - district heating network layout

(Image Copyright of Ordnance Survey Ireland - Street Map 2005)

4.3.5 Heat Interface Unit

The heat interface unit chosen for the study is a Giacomini GE556Y137 and is capable of transferring 44kW$_h$ of heat energy. It has two heat exchangers; one for the central heating system and one for the domestic hot water. This heat stations footprint is 450 x 630 x 200mm. It is important to note that this is an indirect system therefore the water in the main district heating distribution piping network is not utilised within the dwelling.

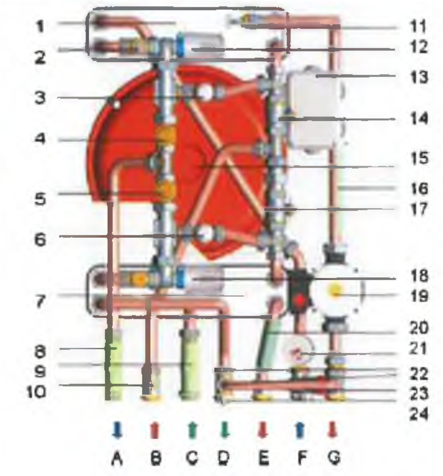
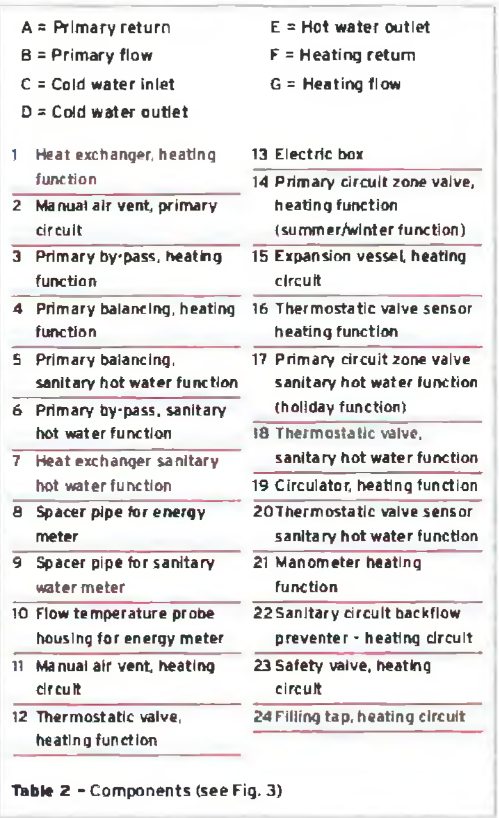


Figure 3 - Components



A = Primary return
B = Primary flow
C = Cold water inlet
D = Cold water outlet
E = Hot water outlet
F = Heating return
G = Heating flow

1 Heat exchanger, heating function
2 Manual air vent, primary circuit
3 Primary by-pass, heating function
4 Primary balancing, heating function
5 Primary balancing, sanitary hot water function
6 Primary by-pass, sanitary hot water function
7 Heat exchanger sanitary hot water function
8 Spacer pipe for energy meter
9 Spacer pipe for sanitary water meter
10 Flow temperature probe housing for energy meter
11 Manual air vent, heating circuit
12 Thermostatic valve, heating function
13 Electric box
14 Primary circuit zone valve, heating function (summer/winter function)
15 Expansion vessel, heating circuit
16 Thermostatic valve sensor heating function
17 Primary circuit zone valve sanitary hot water function (holiday function)
18 Thermostatic valve, sanitary hot water function
19 Circulator, heating function
20 Thermostatic valve sensor sanitary hot water function
21 Manometer heating function
22 Sanitary circuit backflow preventer - heating circuit
23 Safety valve, heating circuit
24 Filling tap, heating circuit

Table 2 - Components (see Fig. 3)

Figure 28 - Giacomini heat interface unit

4.3.5.1 Heat meter

The heat meter is an optional accessory for the Giacomini GE556Y137 and can be supplied in two variants, one with a local reading display and one with M-Bus technology the European standard for remote meter reading. With this M-Bus system, individual energy usage can be communicated back to a central computerised system for monitoring and billing purposes.

4.3.6 Thermal Storage

There are many options for thermal storage both hot and cold. In the Irish climate the need for cooling is minimal and therefore will not be considered. In relation to the thermal storage for hot water there are two options:

- Domestic Hot Water Tank Upgrade
- Bulk Central Thermal Storage

4.3.6.1 Domestic Hot Water Tank Upgrade

The dwellings in Inagh in the main have oil fired boilers with traditional central heating systems. These systems already have thermal storage as an inherent part of their system in the form of the hot water storage vessel. On site thermal storage can be improved by upgrading this vessel to a factory insulated tank with large capacity where practical.

Also, in the case of large peak demand the district heating system has been designed with heat pods which have bypass valves. During extreme peak demands on the system these valves open bypassing the local heat exchanger, thus supplying the district heating system heat directly to the dwelling load.

4.3.6.2 Bulk Central Thermal Storage

An alternative to this is to provide thermal storage at central locations throughout the community or in location of particular peak demand, for example at the school when the heating is initially warming the building each morning or during periods of large demand for domestic hot water, e.g. during break times.

As the LFG fired CHP has a defined service life of 15–20 years when the LFG gas methane content will no longer support combustion in the CHP plant, it is prudent to select a site within the community for buffer tanks that can facilitate a central boiler system in the future, thus future proofing this system for the community.

4.4 Combined Heat and Power Plant Equipment

4.4.1 CHP Equipment Selection

The following criterion was considered when assessing the suitability of a CHP plant for the study site:

- Thermal Output
- Electrical Output
- Capacity
- Emissions
- Site Constraints
- Simple Payback

Once the energy and cost data have been collected and tabulated, the next step is to select a potentially suitable CHP system. As a minimum, information obtained for each potential CHP plant should include:

- Electrical output, which should include data relating to the power consumption of the CHP plant's own, motors etc., so that the net output can be defined.
- Heat output that can be recovered for use on-site, including data on the temperature and flow rate of the fluid in which the heat is contained.
- Fuel consumption of the equipment, taking care to ensure that this can be expressed in gross calorific value terms.
- The cost of supplying and installing the equipment.

- The dimensions and weight of the equipment.
- The approximate cost per kilowatt hour (kWh) generated which should be allowed for servicing and maintaining the equipment.
- Any essential auxiliary plant items that are not contained within the scope of the supplied equipment.
- After-sales service, including on-site maintenance provision, availability of parts etc.

The CHP systems as outlined in section 2.3.1 CHP Systems Considered, were evaluated through a quantitative and qualitative comparison of thermal and electrical output, comparison of prime movers, capacity, emissions, environmental impact, maintenance requirements, availability/reliability, capital cost and simple payback.

It emerged that the "Micro Gas Turbine" solutions were not feasible due to their cost and lack of development in operation on biogas. Therefore the reciprocating engine design model was the only feasible CHP solution for this project. This study has identified 7 developers whom are involved in the delivery of CHP plants in Ireland, these included:

- BG Cogen
- Clarke Energy Ireland
- Combined Energy Solutions Limited
- Edina

- F4 Energy
- Fingleton & Co. Ltd.
- Temp Technology

From these suppliers Clarke Energy Ireland, Edina and Temp Technology offered an off the shelf solution suitable for biogas operation. The units available from Clarke Energy Ireland and Edina had an electrical and thermal output far in excess of the requirements for this project.

Temp Tech's ENER-G 375PTB CHP solution fitted all the energy requirements & selection criteria for the project. The proposed CHP plant will consist of two ENER-G 375PTB biogas CHP plant producing 377 kW_e and 428kW_h with a fuel flow rate of 157M^3/hr at a methane content of 60%. The study landfill site can produce 480m^3 of LFG at 34% methane per hour. This quantity and quality of gas is capable of continuously running two ENER-G 375PTB units at full load, therefore producing 754kW_e and 856kW_h of energy each hour. That equates to 4,231,628 kW_e and 4,999,040 kW_h of energy per annum based on 5,840 operating hours. The prime mover in this unit is a Mercedes 6 cylinder inline turbocharged spark ignition engine rotating at 1500 rpm. It has a 630 KVA continuously rated electrical generator. The total efficiency from the ENER-G 375PTB system is expected to be in the region of 82%, with the generator having an efficiency of 96.1%. Total energy from the CHP unit is expected to be 805 kW/h at full load and an anticipated turn down ratio of 2:1, i.e. the unit can run at 50% output (Temp Tech Ener-G - 375 2010).

CHP Manufacturer Data:	
- Fuel Type	Biogas
- Electrical Output	377kWe
- Heat Output @81°C	428kWe
- Fuel Input LHV	978 kWg
- Min Gas Pressure (mbar)	20
- Max Gas Pressure (mbar)	60
- Max Return Water Temp	80°C
Prime Mover:	
- Type	Reciprocating Engine
- Cylinders	6 Inline
- Combustion Cycle	4 Stroke Spark Ignition
- Speed	1500 rpm
- Aspiration	Turbocharged
- Acoustic Enclosure	75 dBA @ 1m std. (internal)
Generator:	
- Type	Synchronous
- Generator Capacity	630 KVA
- Frequency	50 Hz
- Voltage	400 Volts
- Full Load Current	607 Amps
- Efficiency	96.1 %
Heat Recovery System:	
- Fully closed primary water circuit - Exhaust gas heat exchanger in primary circuit - PHE between primary & secondary circuits - Primary water pump integral - Secondary water pump loose for external fitting - Auto heat output modulation	
Control & Protection:	
- On board computer control, protection and monitoring - Engine stop/start, synchronising, modulation - Mechanical, electrical and thermal protection - 70+ parameters monitored, historical data recorded - 2 way communication between unit and Head Office	

Table 5 - CHP manufacturer data

4.4.2 Operation and Maintenance

The proposed system will be supplied with an LTSA (Long Term Service Agreement) from Temp Technology whom carry out all the CHP units maintenance based on a per unit charge per kW_e produced by the plant. With this arrangement the CHP unit supplier will carry all the risk of unit failure, maintenance and associated costs.

4.4.3 CHP Plant Control & Monitoring

The control equipment required to operate the CHP unit comes supplied in the unit's electrical panel. This includes:

- On board computer control, protection and monitoring.
- Engine stop/start, G10 synchronising and modulation.
- Mechanical, electrical and thermal protection.

The on board control system is connected via modem to the Temp Tech remote monitoring centre in the company's head office in Limerick. Operation of the CHP unit is therefore continuously monitored from this location and any possible faults are dealt with from this central monitoring centre.

The monitoring centre also provides production data on the performance of the CHP unit and produce monthly reports to the customer.

4.4.4 CHP System Integration

There are utility systems connections required on site to interconnect the CHP plant to the required infrastructure, these include:

- Gas Supply
- Electrical Grid Connection
- Thermal Connections
- DCW (Domestic Cold Water)

4.4.4.1 Gas Supply

Connection of the LFG gas supply to the CHP unit will be from the gas scrubbing skid at the waste management site via the LFG gas network, in the event of a failure in the CHP units the current LFG flaring system on the waste management site will re-start automatically. This gas connection will require the laying of approximately 2.3 km meters of polyethylene gas piping for connection to the gas scrubber skid.

4.4.4.2 Electrical Grid Connection

Electrical grid connection is available locally in the village at 10 KV and 400V from the distribution network operator, for connection of the CHP electrical output to the grid. The central waste management site operators have obtained a quotation for a 10KV electrical grid connection from site to the local 10KV electrical network from the distribution system operator. The capital costs involved where prohibitive in the extreme (this information is confidential). However, if the required 10KV network was installed at the central waste management site payback from the landfill gas installation would not be feasible. The illustration in Figure 29 - electrical distribution network shows the 10KV electrical grid network within the locality.

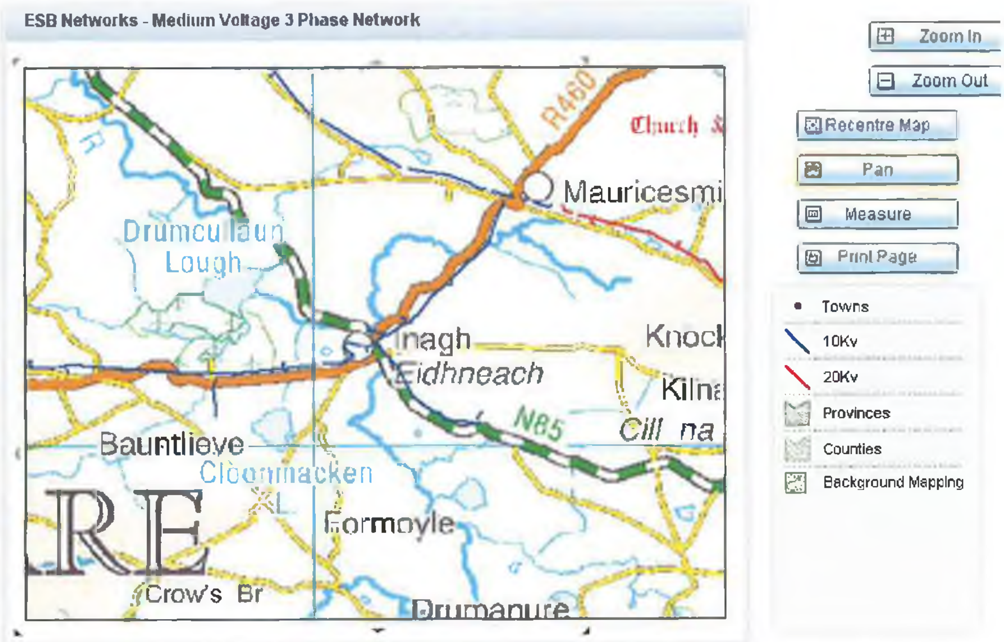


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Figure 29 - electrical distribution network

(Image Copyright of Electricity Supply Board - 10/20 KV Medium Voltage Network 2010)

4.4.4.2.1 Grid Connection Options

1. 10kV overhead line.
2. 400V, 3 phase connection into local transformer.

Planning Permission With Respect To Grid Connection Options:

- 10kV overhead line.
    - Planning Permission exemption for overhead line not exceeding 20kV.
    - Application to Local Planning Authority.
- Underground cable.
    - Generally exempted.
    - Road opening permit required from Local Authority.

4.4.4.2.2 Grid Connection Agreement Process

The specification as outlined in the ESB Networks document "Conditions Governing Connection to the Distribution System" outline the requirements as per grid code governing connection for generators with a capacity less than 20 MW to the distribution system. These requirements include but are not limited to; incomer circuit breaker, earthing switch, protection, synchronising, boundaries, warning notices and labels, operation, cable terminating, metering, terminal station, earthing and commissioning and certification (ESB Networks - Conditions Governing Connection to the Distribution System 2006).

4.4.4.3 Thermal Connections

The 428kW_h of thermal energy produced by the CHP unit will be tied into the district heating primary heat exchanger for distribution to the community.

4.4.4.4 DCW (Domestic Cold Water)

The CHP unit requires connection to a 2 bar domestic cold water supply, mains water supply is available at the proposed CHP location along the site roadside.

4.4.5 CHP Environmental Considerations

There are environmental effects from the construction of any CHP development. These will be carefully controlled via the EIS (Environmental Impact Statement) which will be assessed by the EPA (Environmental Protection Agency). Also, the detailed planning guidelines set down within the planning regulations and the planning process will reduce to a minimum any environmental impact.

Any negative impact from the construction and operation of the proposed CHP unit will be greatly out weighted by the more efficient energy the CHP plant will produce in its lifetime. Under the “Air Pollution Act, 1987” the CHP operator must apply for an Air Pollution License for the use of this CHP unit, as it is not a domestic residence and is sited within a “Special Control Area” (Irish Statute Book - Air Pollution Act 1987).

4.4.6 Planning Requirements

Planning permission will be required from the local authority for installation of the proposed CHP unit as there is a requirement for civil works to provide:

- Access to CHP unit.
- CHP unit foundations.
- Gas connections (including pipe connection to the existing flaring system).
- DCW supply.

4.5 Project Implementation

With regards to community energy projects they can be implemented by means of three methods. These are:

- National / Local Authority
- Developer
- Community

For community led projects to be success the inhabitants must display the following attributes; strong historical links with the local authorities, community organisation, project management expertise and a viable energy resource to be exploited. These attributes are illustrated in Figure 30 - criteria for a viable community based energy project (Center for Sustainable Energy - Scoping Study Into Community Based Renewable Energy Projects 1997).

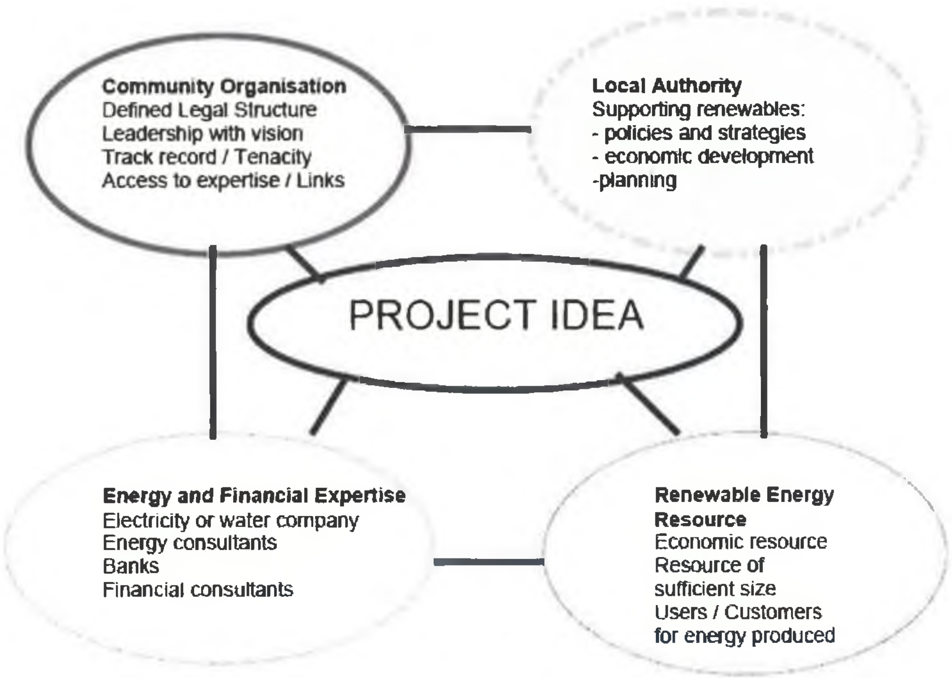

Figure 30 - criteria for a viable community based energy project

(Image Copyright of the Centre for Sustainable Energy - Scoping Study Into Community Based Renewable Energy Projects 1997)

4.5.1 Community Participation

In relation to project implementation does the community of Inagh have the necessary skills to meet the criteria as outlined in section 4.5 Project Implementation? In relation to links with local authorities, the community is involved through the community liaison committee for the central waste management facility. Community organisation is a key attribute and Inagh has shown leadership in this area with the formation of Inagh Development Ltd., whom have lead infrastructural projects within the community including the development of a child care facility and a public amenity area at Clonmackon Lake. The community have shown excellent project management skill and delivery in the past. The community may lack some of the skills required to develop an energy based scheme.

However, these skills can be acquired from a consultant for the duration of the project. With respect to natural resource the LFG gas and future biomass availability within the community (the current landfill site is developed on 65 hectares of forestry) provide excellent resource which can be exploited for the benefit of its inhabitants.

4.5.2 Community Benefits

The availability of an efficient economical energy system brings many advantages to the community, these include:

- Environmental (Air Quality).
- Security of energy supply.
- Efficient use of energy.
- Energy costs that is independent of fossil fuel prices.
- Income from the sale of excess energy.
- The utilisation of local resources.

4.5.3 Community Opportunities

The project will provide opportunities for the community in:

- Employment (Construction and Maintenance).
- Education.
- Steering group for other community based initiatives.
- Deployment of infrastructure alongside the district heating network.

  E.g. Gas Network, Fibre Powered Broadband.

4.5.4 Project Barriers

Below is an extract from Clare County Councils annual report 2010. This report outlines the waste management strategy to divert biodegradable organic waste from landfill. This organic waste is the key to the formation of LFG in landfill site. The removal of this waste stream is a significant barrier to the implementation of this project (Clare County Council - Annual Report 2010).

"*The roll out of the National Biodegradable Waste Strategy has commenced and organic waste is being diverted from landfill in accordance with specific targets set out in the EU Directive. Roll-out of a third household bin has commenced in Shannon and Ennis. A 50% diversion of commercial organic waste from landfill has been achieved already with 100% diversion of commercial waste to be achieved from January 2010. A regional awareness campaign has been undertaken to ensure that household organic waste is diverted from landfill and our revised waste license will assist in this regard.*"

(Clare County Council - Annual Report 2010)

Further potential barriers to the development of this project must also be addressed. This study has identified the following as potential barriers to project implementation:

- County Council not granting access to the LFG.
- Objections from residents.
- Objections to planning permission.
- Finance for the project.
- Lack of appetite for the project within the community.
- Lack of anchor loads for the CHP within the community, especially during the night.

4.6 Study Costing

Within the costing for this study we need to consider the capital costs of the complete system including, gas scrubber, LFG gas network, CHP plant and the district heating distribution network. The operation and maintenance costs of the system will also be considered.

The current cost of energy to the community will be ascertained and the cost of energy from the proposed LFG powered system will be calculated. A comparison will then be made between the systems relative cost to the community. Ideally the energy costs saving from the LFG powered system will payback in a reasonable period, the capital investment required for the LFG energy system. The typical payback period for a CHP unit both grant aided and non-grand aided are shown in Figure 31 - CHP payback period. SEAI have indicated that currently grand aids are suspended for CHP units.

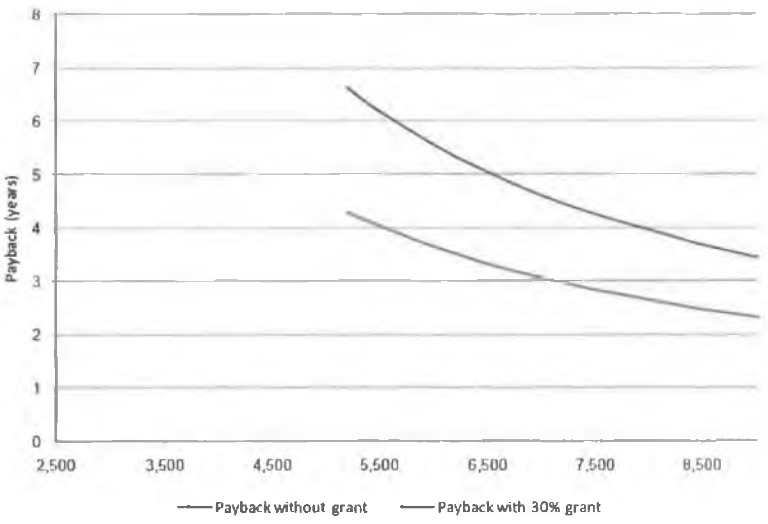

Figure 31 - CHP payback period

(Image Copyright of Sustainable Energy Authority of Ireland - CHP Potential in Ireland 2009)

4.6.1 Capital Costs

A breakdowns of the capital cost associated with this project are provided below in Table 6 - project capital costing.

Equipment Description:	***Estimated Capital Cost €***
Biogas Scrubber	34,125
Civil Works For Biogas Scrubber	10,000
Gas Pipe Network 2.3km	195,500
CHP Plant x 2	760,000
Connection To Water Supply	700
Electrical Grid Connection Charge DSO	17,350
Cabling From DSO Switch To CHP Unit	4,800
District Heating Network System Piping 3.5km	67,200
Pipe work & Connection Into Each Dwelling	42,260
Laying Of District Heating Pipe Network 3.5km	297,500
Heat Interface Unit With GSM Heat Meter	250,000
Sub Total	1,679,435
Contingency 10%	167,944
Project Total	1,847,379

Table 6 - project capital costing

4.6.2 Operation & Maintenance Costs

The yearly operation and maintenance cost associated with the system are shown in Table 7 - system operating and maintenance costs. The CHP unit will require service every 800 hours, with an anticipated running of 5,840 hours per annum the CHP plant will require 8 service visits per year. The cost of maintaining this Temptech CHP unit will be ~€5,600 per annum.

Equipment Description:	***Operational Cost €/Yr***	***Maintenance Cost €/Yr***
Biogas Scrubber	4,991	1,200
CHP Plant	0	5,600
Connection to Water Supply	200	0
District Heating Network System 3.5Km	0	3,600
Heat Interface Unit with GMS Heat Meter	7,200	6,250
Total	12,391	16,650

Table 7 - system operating and maintenance costs

Chart 1 - annual operation and maintenance costs

4.6.3 Current Community Energy Costs

In Table 8 - current energy systems costs, detail is provided on the cost of energy to the community to provide both electrical and heating energy. This costing is based on the kWh usage calculated in section and the fuel costs are provided by SEAI (Sustainable Enegy Authority of Ireland - Domestic Fuel Comparison of Energy Costs 2011).

Energy Type:	***kWh/yr***	***Fuel Cost €cent/kWh***	***Cost €/yr***
Electricity	912,672	16.39	€149,587
Heat (Kerosene)	3175338	8.17	€259,425
Domestic Hot Water (Kerosene)	1161348	8.17	€94,882
Total			€503,894

Table 8 - current energy systems costs per annum

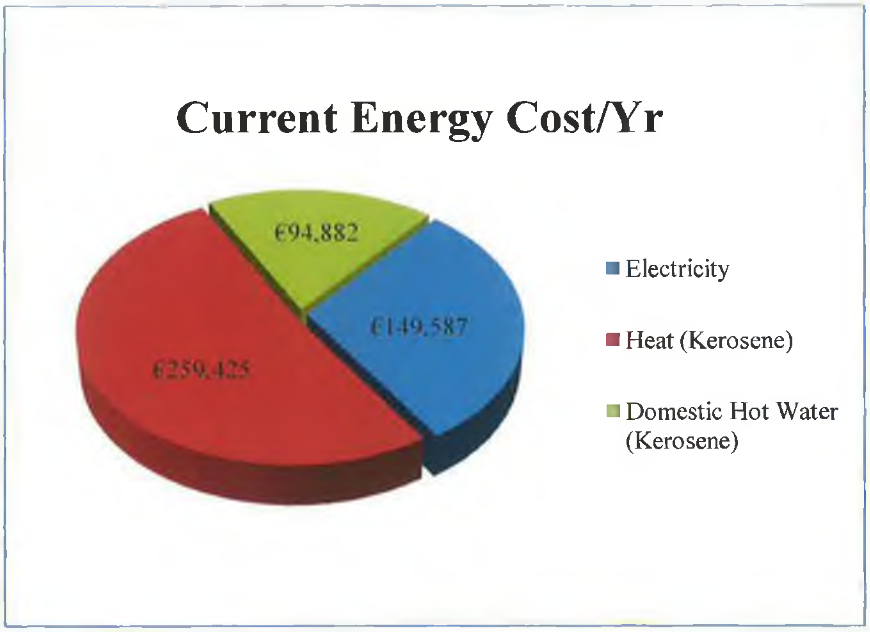

Chart 2 - current energy cost per annum

4.6.4 Proposed Community Energy Charges

In Table 9 - proposed LFG powered energy systems charges, the cost to the community are outlined once the LFG powered energy system is fully in place.

Energy Type:	***kWh/yr***	***Proposed Cost cent/kWh***	***Cost €/yr***
Electricity	912,672	8.195	€74,793
Heat (Kerosene)	3,175,338	4.085	€129,713
Domestic Hot Water (Kerosene)	1,161,348	4.085	€47,441
Total			€251,947

Table 9 - proposed LFG powered energy systems charges

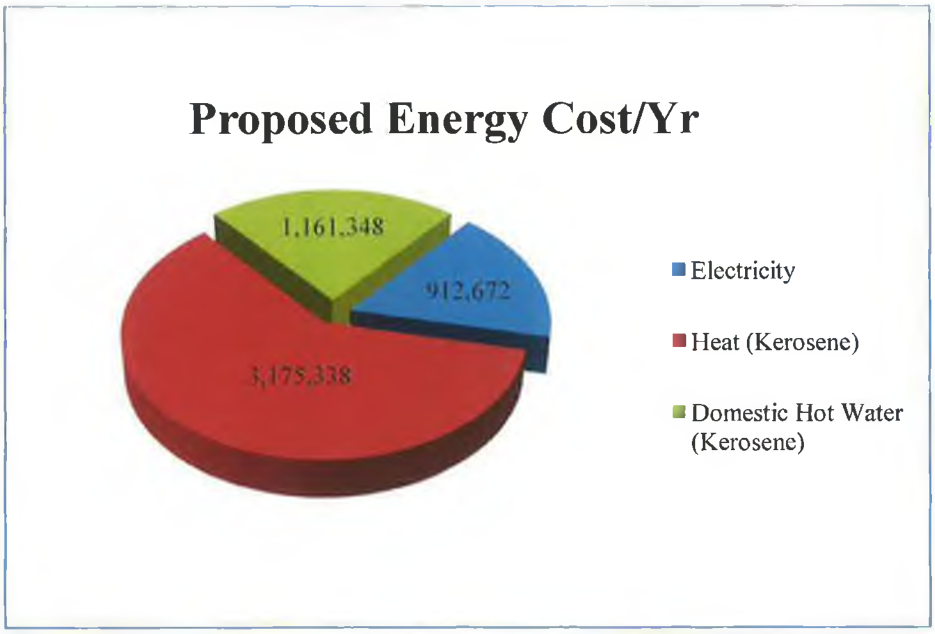

Chart 3 - proposed energy system charges

4.6.5 Projected Savings from the LFG Powered Energy System

As the Figures indicate, the community can expect a gross saving in energy cost of €251.947 per annum. From this saving the community would have to finance the capital cost of the system, fuel cost to Clare County Council for provision of the LFG and the systems continuing operation and maintenance fees. In Table 10 - projected cost/saving of LFG powered energy system to the community, considers all of the above costs involved in building, operating and maintaining the LFG powered energy system.

Description:	**€**
Energy Cost Saving	251,947
Monies from Clare County Council to Community for Operation Of Landfill	44,450
Sale of Excess Electricity To Grid	132,758
Capital Loan Repayment Cost of The Project + Interest @ 6%	-161,063
Operation and Maintenance of System	-29,041
Cost of LFG From Clare County Council	-104,987
Cost for Maintaining Backup Systems	-12,400
Projected Annual Savings	121,664
Saving Per Dwelling/Annum	981

Table 10 - projected cost/saving of LFG powered energy system to the community

This proposed energy project for the community will save €981 per annum for each household. The rationale for charging for energy from the LGF powered system is to finance the project capital costs, provide for on-going maintenance of the system and ensure residents are not wasteful with the energy provided. As the LFG gas is being provided by the landfill site which is in the ownership of Clare County Council, a fee for the supply of the LFG gas will also be payable. The current payback period for the project is 20 years under a capital finance agreement @ 6% interest per annum.

However, should the community decide not to take the annual savings of €981 per household the project would provide a simple payback for its capital installation cost in 6.53 years, including its yearly operation and maintenance fees.

It is proposed that the community will set up an ESCO to supply its residents with the energy they require and also the energy required by Clare County Council for the landfill sites continued operation.

4.6.6 Emission Abatement

The community of Inagh are currently dependant mainly on imported oil to provide their heating requirement. Their electricity is supplied by utility companies whom depend mainly on imported fossil fuels for generation.

The emissions abatement that will be achieved through switching from imported fossil fuel to LFG as can be seen in Table 11 - LFG system emissions . This table does not take into consideration any of the future GHG emissions avoided from the release of methane gas into the atmosphere, which as outlined earlier is 21 times more damaging to the environment than carbon dioxide. Emission factor figures utilised within this table were obtained from CER for electrical emission factors (Commission for Energy Regulation - Fuel Mix and CO2 Emission Factors 2009) and Kerosene fuel emission figures were obtained from (Enviromental Protection Agency - Country Specific Net Calorific Values and CO2 Emission Factors 2010).

Energy Type:	***kWh/yr***	***Emission Factors kgCO2/ kWh***	***Total Emissions tCO2/Yr***
Electricity	912,672	0.533	486
Heat (Kerosene)	3,175,338	0.257	816
Domestic Hot Water (Kerosene)	1,161,348	0.257	298
Total tCO_2/Yr			1,601

Table 11 - LFG system emissions abatement

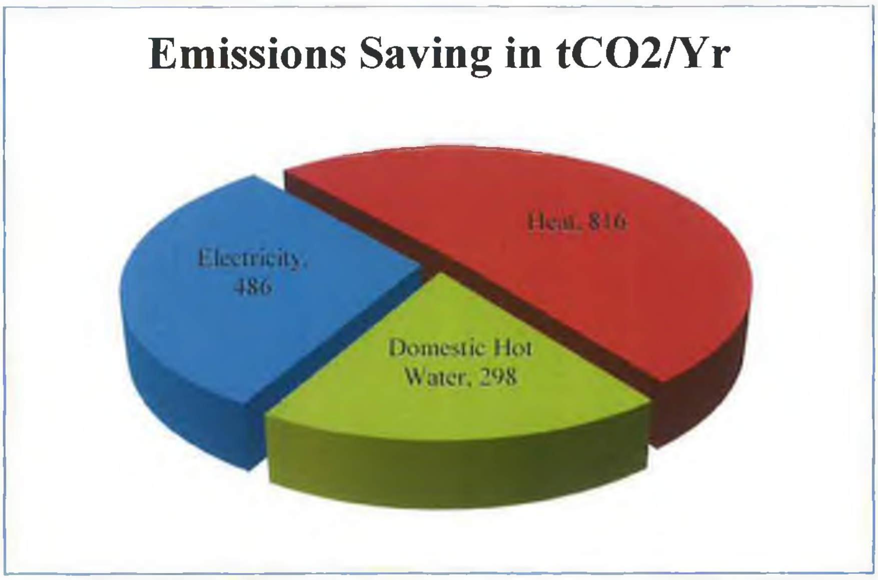

Chart 4 - emission savings from LFG

To put these emissions saving into context Table 12 - equivalent emissions savings was compiled to illustrate the emission savings of 1,601 tCO_2/yr in terms of environmental impact.

Equivalent Emission Saving:	
Cars & light trucks not used	320
Litres of gasoline not consumed	650,967
Barrels of crude oil not consumed	3,362
People reducing energy use by 20%	1,601
Acres of forest absorbing carbon	480
Tonnes of waste recycled	480

Table 12 - equivalent emissions savings

As the European ETS (Emission Trading System) that currently applies mainly to power generation is expanded, the community may have an opportunity to trade the carbon credits generated from the conversion to LFG fuel on the open market. Presently these carbon credits trade for €30-€40 per tonne of CO_2. This would provide an additional revenue stream of over €48,000 per annum to the community.

4.6.7 Backup Systems

With this being a retro fit project, the dwellings within the community currently have an operational heat and electricity supply, this study proposes to utilise these systems as a back up to proposed district heat system and ESCo electricity supply. The annual cost of maintaining these backup systems has been accounted for in the costing within this project, section 4.6 Study Costing. This includes an annual service of the existing boilers in each dwelling at a cost of €100 per annum per dwelling. There are no additional costs associated with the electrical grid supply as this will be handled through the ESCo agreement with the current utility suppliers.

CHAPTER 5 - Conclusions & Recommendations

5.0 Introduction

The objective of this study was to determine the feasibility of producing and distributing energy in the form electricity and district heating derived from landfill gas produced by an existing municipal waste stream.

This study has shown that LFG powered CHP and district heating networks can be implemented in Ireland through community initiatives, they are a practical, efficient and cost effective method of delivering energy to the community.

As outlined in section 1.2 Background, the wider community has shown an interest in the methods used to generate the energy they require. The community of Inagh has set up a charitable company "Inagh Development Ltd." to develop the natural resources of the community in a positive way (Inagh Development 2008). These developments show that the community already has a willingness to enhance their community and a structure in place to deliver these projects. The implementation of the energy supply system outlined in this study should be a natural extension of these activities.

5.1 Conclusions

The benefits to the implementation of LFG powered CHP with district heating to the community include; lower emissions, reduced energy consumption, lower energy costs for households and businesses, certainty regarding future energy costs, security of supply and an opportunity to reinvest the savings from the project back into future developments for the community not only in the area of energy efficiency but also in employment, education, and as a stepping stone to community sustainability.

The first aim of this study was to "*review current policy documents and provide recommendations to improve these in line with the overall aims of this research*"; in this respect this study has outlined the relevant European and Irish legislation in relation to waste, CHP, district heating and the community. The study has pointed out the lack of regulation in relation to district heating in Ireland. The study illustrates the volume of regulation covering waste and especially the installation of CHP. Our government could take a lead from the Lithuanian government whom incentivise the construction of district heating projects through reduced VAT (Value Added Tax) rates which are applied to the materials and labour employed on district heating projects (European Union - 2006/637/EC (Rebuplic of Lituania to apply a reduced rate of VAT to the supply of distrcit heating) 2006).

It is the view of the study that we need to draw up a framework of national legislation in relation to district heating. The legislators also need to streamline national legislation in relation to CHP and the planning process. With national legislation streamlined this would greatly simplify the process to community based projects, which often need to draft in specialist consultants to aid in the planning process. The benefit of this is that communities may examine more closely their opportunities for sustainable energy. Often the overwhelming legislative constraints are a barrier to these community led projects getting off the ground.

The second aim of this study was "*to assess the barriers/enablers within the Irish landscape to this manner of development*". Throughout this study barriers and enablers have been identified. The most significant enabler is the community itself: the community's spirit to set-up a development committee for the betterment of their locality; and their vision to take concepts and transform them into delivered project often against a tide of difficulties.

Of these difficulties the most significant barrier to any community led development at present is finance. Even with careful project costing finance is at best difficult to secure. This is especially true of a project of this nature where the payback (like so many sustainable energy projects) is spread over a long time period. The financial markets today are investing mainly in high growth/highly profitable markets in an attempt to recover from the current world economic crises.

There is however hope that some, financial institution which specialises in the sustainable energy field and which understands the technologies and operations of these systems are providing seed capital for these projects. This combined with community led fund raising the capital required to launch a project of this nature can be delivered.

An option for the community in relation to the financing the project is to construct the project on a phased basis. The community could install the LFG gas network and CHP plant initially to benefit the community from lower cost electricity. In the future the second phase could be rolled out to install the gas scrubber to improve the quality of the LFG to the CHP and the district heating network to recover the waste heat from the CHP. In this respect the project could become self-financing once the initial capital cost of the LFG gas network was raised and the CHP unit was obtained through a lease agreement through the manufacturer.

Another objective of the study was "*to estimate the available energy in LFG at site*". There are many different models to determining the expected gas quantity and the concentration of methane in the gas from a waste management site. These models were identified in section 3.2 Energy Available from LFG. Fortunately, the waste management site contains a LFG control flare to burn off the excess LFG at present. This system monitors the flow and concentration of methane in the LFG. With this data it was possible to calculate the energy potential from the LFG gas on site.

The final objective of the study was to "*to review the technical aspects of energy generators, including CHP plants with a view to determining their suitability for LFG and their efficiency*"; this study through its literature review and results examined many differing technologies in relation to CHP and district heating networks. Chapter 4.0 Results examined the specific technologies that would be most suited to the projects needs in terms of cost, maintenance and operation. Where feasible, suppliers from the wider community were sought. This was not always practical as many of the technologies being utilised within this project are highly specialised and have not gained a market share in Ireland as yet.

With the current fiscal situation the world economy finds itself in presently and the constraints placed on project capital finance, community lead projects may be the only viable and affordable method to project implementation.

The increasing cost of fuel, poor housing construction together with an inability to produce traditional fuels such as timber from the land due to the increase density of resent housing stock development has meant that many citizens today suffer from fuel poverty. The implementation of this project would alleviate much of this suffering and allow the community to provide "social energy" to its most venerable groups, through its ESCo operations.

It is the opinion of this author that this local LFG resource should be harnessed for the betterment of its community. Not only will the LFG provide fuel security and cost control for the community but it will lay the foundations for the community to have a voice in relation to their sustainability and future energy supply.

"There is enough for everyone's need but not for everyone's greed"

(Gandhi n.d.)

5.2 Recommendations

This study proposes that a sub-committee of Inagh Development Ltd. is set up to implement the recommendations of this study. In parallel the set-up of an ESCo for the delivery of the energy provided by the LFG powered CHP should be considered at this planning stage.

The sub-committee should familiar themselves with the technologies as outlined in this study. Once they have completed this task they should visit other community based energy schemes in the area, with special interest in schemes that are developed on the ESCo model.

Ideally the sub-committee members should carry out field excursions to:

1. An operating LFG powered CHP plant to observer its operation. The LFG powered CHP plants in Dunsink landfill county Dublin would be ideal.
2. A community district heating scheme, the one megawatt wood chip powered district heating scheme in Tobar Naofa, Moyderwell, Tralee, Co. Kerry would be an ideal scheme to examine.

The next step for the community is to acquire the services of a reputable consultant to cost and plan all aspects of the project in detail and submit an outline planning document to Clare County Council to ascertain if the project will attract any opposition with respect to planning. Finally, once the community as satisfied that the project is viable they can make approaches to financial institution to obtain the required capital to finance the project in conjunction with local fund raising efforts.

5.3 Further Research

This study has necessitated research of legislation, community attitudes to sustainable energy schemes and an examination of technologies including; combined heat & power plants and district heating systems. The study recommends the following areas for further research.

5.3.1 Drafting of Specific District Heating Legislation for Ireland

As outlined in section 2.1.3 District Heating Legislation, there is need for specific national district heating legislation in Ireland. If these district heating systems are to be installed to best international practices the industry requires a set of guidelines to insure system quality and delivery.

5.3.2 Survey of Public Attitudes to Sustainable Energy Schemes

A detailed survey is required to assess the public's attitude to sustainable energy schemes in the Irish context. In Ireland we often find ourselves legislating in order to persuade the Irish public to make the correct choices for a sustainable future. An example of this is the plastic bag levy, when a prohibitive cost was introduced on the use of plastic bags public attitude quickly adjusted to reusable alternatives. Education is a key enabler to public understanding and attitudes.

5.3.3 Study into Future Energy Requirements for the Community

As the community of Inagh develops, a study into the future energy requirements for the community would facilitate the correct investment in technologies that will provide for their energy requirements. This study would also feed valuable data into the research of sustainable viable alternative fuels to supply the communities' future energy requirements.

5.3.4 Study of Fuels to Supply the Communities Future Energy Needs

A comprehensive study into sustainable viable alternative fuels to operate the district heating network at the heart of this study is required. The current LFG gas has an expected viable lifespan of 10-15 years supposing waste continues to be deposited at the waste management site. The community needs to consider the alternative fuel sources that can sustain their community into the future, these energy sources may include; biomass fired boilers, solar collectors and geothermal heat sources.

5.3.5 Study of Long-Term, Low Thermal Loss Energy Storage

As with many energy applications, storage is a barrier. A study into long-term low thermal loss energy storage would be beneficial, especially for systems that may be solar or geothermal sourced. As Ireland has large seasonal demand variation in heating requirements. A thermal energy storage system that would storage energy during the relatively warm summer period for use during the cooler winter period would be beneficial.

5.3.6 Feasibility of Manufacturing “Dry Ice” From CO_2 in LFG

The carbon dioxide removed by the gas purification skid is an economically valuable commodity, once compressed it can be stored as a liquid carbon dioxide or “Dry Ice” as it is commonly known. This liquidised carbon dioxide is often used for cooling systems due to its inert nature. It is also used in fire fighting system and in special effects equipment. The study would ascertain the feasibility of installation of the required plant on the central waste management site alongside the proposed LFG gas purification station.

Appendix A - Calculations

A.1 Energy Available in LFG

The Inagh landfill site currently produces 8-9m^3/minute of LFG, with a methane content of ~ 34% CH_4.
Assuming that 1m^3 of commercial quality natural gas produces ~10.8kWh @ 80% CH_4.
Therefore it is safe to calculate that 1m^3 of landfill gas produces ~4.59kWh @ 34% CH_4.

	m^3/min	*m^3/hr*	*kWh*
Gas potential on site:	8.00	480	2203.2
	kWh	kWh/d	kWh/yr
Heat energy available:	2,203	52,877	19,300,032

A.2 Cost of LFG from Clare County Council

Total Energy Required kWh	*Energy in LFG kWh/m3*	*Total LFG Gas Required m^3*
5,249,358	4.59	1,143,651
Total cost of LFG from Clare County Council @ €0.0918/m^3.		€104,987

A.3 Community Energy Calculations

A.3.1 Community Energy Calculations (Electricity)

Building Type	*Description*	*No. of Buildings*	*kWh /buildings/yr*	*Total kWh/yr*
House A	1970's 3 Bedroom Semi-Detached	32	5,040	161,280
House B	1970's 3 Bedroom Terraced	10	4,896	48,960
House C	2000's 4 Bedroom Semi-Detached	32	6,336	202,752
House D	2000's 3 Bedroom Detached	12	5,568	66,816
House E	2000's 3 Bedroom Terraced	12	4,992	59,904
School	Primary School	1	100,800	100,800
Church	Community Church	1	33,600	33,600
Community Centre	Community Centre	1	24,000	24,000
Post Office	Post Office	1	960	960
Supermarket	Local supermarket/shops	2	9,600	19,200
Public Houses	Local Pub	2	14,400	28,800
Crèche	Crèche/Play School	1	14,400	14,400
One Off Developments	Single Dwelling Homes	21	7,200	151,200
Totals		128		912,672

A.3.2 Community Energy Calculations (Space Heating)

Building Type	***Description***	***No. of Buildings***	***Stories***	***Floor Area (m^2)***	***Energy /Building /yr kWh***	***Energy/ Building Type/yr kWh***
House A	1970's 3 Bedroom Semi-Detached	32	2	105	17,535	561,120
House B	1970's 3 Bedroom Terraced	10	2	102	17,034	170,340
House C	2000's 4 Bedroom Semi-Detached	32	2	132	22,044	705,408
House D	2000's 3 Bedroom Detached	12	1	116	19,372	232,464
House E	2000's 3 Bedroom Terraced	12	2	104	17,368	208,416
School	Primary School	1	2	2100	350,700	350,700
Church	Community Church	1	2	700	116,900	116,900
Community Centre	Community Centre	1	2	500	83,500	83,500
Post Office	Post Office	1	1	20	3,340	3,340
Supermarket	Supermarket	2	1	200	33,400	66,800
Public Houses	Local Pub	2	2	300	50,100	100,200
Crèche	Crèche/Play School	1	1	300	50,100	50,100
One Off Developments	Single Dwelling Homes	21	2	150	25,050	526,050
Totals		128				3,175,338

A.3.3 Community Energy Calculations (Domestic Hot Water)

Building Type	*Description*	*DWH Required /Person /day Litres*	*Average Persons/ Building*	*DHW usage/yr /building Litres*	*DHW Usage/yr/ building type Litres*	*DHW kWh/yr*
House A	1970's 3 Bedroom Semi-Detached	140	3.1	158,410	5,069,120	294,995
House B	1970's 3 Bedroom Terraced	140	3.1	158,410	1,584,100	92,186
House C	2000's 4 Bedroom Semi-Detached	140	3.1	158,410	5,069,120	294,995
House D	2000's 3 Bedroom Detached	140	3.1	158,410	1,900,920	110,623
House E	2000's 3 Bedroom Terraced	140	3.1	158,410	1,900,920	110,623
School	Primary School	15	200	780,000	780,000	45,392
Church	Community Church	0	0	0	0	0
Community Centre	Community Centre	0	0	0	0	0
Post Office	Post Office	22	2	11,440	11,440	666
Supermarket	Supermarket	45	4	65,700	131,400	7,647
Public Houses	Local Pub	45	2	32,850	65,700	3,823
Crèche	Crèche/Play School	15	30	117,000	117,000	6,809
One Off Developments	Single Dwelling Homes	140	3.1	158,410	3,326,610	193,590
Totals					19,956,330	1,161,348

A.3.4 Community Energy Calculations (Transportation Fuel)

The average vehicle required ~80 kWh per 100 km driven.
Source:
http://withouthotair.blogspot.com/2008/11/petrol-diesel-miles-per-gallon-litres.html

Average km	*No. of Vehicles*	*Total km*	*Energy Required kWh*	*LGF Required m^3*
16892	68	1148656	918,925	200,201

A.4 Electricity Available for Export to Grid

	kWh	*Source*
Total Electricity Generated	4,231,628	377kWhe x 5,680 full load operating hours
Total Electricity Required by Community	-912,672	Calculated in Appendix A.3
Available to Export	3,318,956	
Value of Exported Electricity	€132,758	Export @ €0.04/kWh

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