Renewable Energy Generation

Development of a software tool to analyse the possible synergies of an integrated Bioenergy Park

by

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Abstract

The concept of a Bioenergy Park is that renewable energy processes are integrated to maximise the total energy production potential while ensuring environmental sustainability. The three processes selected are a) Biodiesel production, b) Straw Pelleting and c) Anaerobic Digestion. The aim of the study is to develop a software tool to analyse the possible synergies of the integrated processes within the Bioenergy Park

The study has shown that the Bioenergy Park system can operate at a profit margin of 29% and is thus considered viable both in terms of economics and environmental sustainability. Glycerine, the main by-product of the biodiesel process, is identified as a significant feedstock, having a high energy generation potential when added in small quantities (<6%) to the anaerobic digester. There is a significant over-supply of thermal energy (172% to 393%) generated within the integrated system. This potential remains unexploited in the context of the Bioenergy Park as described.

When bundled together, the output of ten local Bioenergy Parks can supply from 7 to 14% of the National Biofuel target. Ten Bioenergy Parks could generate sufficient straw pellets to replace 2.1% of home heating oil, based on 2006 National oil consumption figures. The carbon emission reduction potential of ten bundled Bioenergy Parks is marginal (0.48%) when measured against the national targets carbon emission reduction targets of circa 64 million tCO_2.

Dedication

To the class of 2008.

"Twenty years from now you will be more disappointed by the things that you didn't do than by the ones you did do. So throw off the bowlines. Sail away from the safe harbour. Catch the trade winds in your sails. Explore. Dream. Discover." **Mark Twain**

Acknowledgements

I would like to express my sincere gratitude to Walter Ryan-Purcell, Michael Holland and the Biopower team for sharing the Bioenergy Park concept and providing me with the challenging questions which formed the basis of this thesis. Thank you for your unwavering support and assistance in facilitating the research work carried out in this study.

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Overall, to my parents, family and friends, thank you for your love, support and patience. Thank you for the challenges and debates. Of special note are the walkers, readers, listeners and even the sleeper! You all played a key role in assisting this work to the end line, thank you.

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1.0 Introduction

Climate change is among the greatest challenges of our time. Reducing greenhouse gas emissions is a global priority and commitment for action is required on a national and international level (NCCS, 2007). In contradiction, energy security and its complex supply and demand dynamics, weighs heavily on the scales of environmental provision for global energy needs. Energy production and carbon emissions are inextricably linked. Sustainability holds the key. In a global context, Europe is the largest importer of energy in the world. European Union (EU) member states have varying degrees of import and export requirements. Ireland's dependency on energy imports, for example, reached 91% in 2006 (SEI-6, 2008).

There are a myriad of renewable energy technologies that have potential in the Irish context, these include wind, wave, wood and so forth. In 2006 the Irish sugar beet industry ceased, making 31,000 hectares of land available for alternative use. This opportunity together with Ireland's failure to achieve targets of biofuel and renewable energy focused this study on indigenous renewable production resourced by the land. The concept of a Bioenergy Park is that locally supplied raw material is processed, producing renewable energy on a small scale in an environmentally sustainable way. By bundling the outputs of a number of Bioenergy Parks, the expectation is that renewable energy generated is sufficient in capacity to positively impact the national targets of biofuel production, renewable energy generation and carbon emissions reduction in a meaningful way.

1.1 Scope of this study

Within the scope of this study are the renewable energy processes of biodiesel production, straw pellet manufacture and anaerobic digestion. The local raw materials are defined as Oil Seed Rape (OSR), waste straws of OSR and other crops, agricultural slurries and biodegradable waste. This study broadly considers the impact of integrating a Bioenergy Park into a local agricultural community and recognizes that there are issues such as landbank availability and limitations, environmental impact assessment and resultant planning and development implications. However a detailed analysis of these impacts is considered beyond the study scope. In addition the wider debate of 'Food Versus Fuel' is not within the scope of this study.

1.2 Aim of this study

The goal of the Bioenergy Park system is to balance the processes to maximize renewable energy production while minimizing environmental impact. This study finds a way to balance the three processes within the system. The aim of this study is to develop a software tool to analyze the possible synergies of integrated renewable energy processes in a Bioenergy Park. The software tool, 'Integration Matrix' facilitates scenario analysis of Bioenergy Parks with respect to the following:

Box 1.1

Power Supply and Margin	Renewable Energy Outcome	Impact on Land Bank
% Electrical Energy Supplied	Reduced Carbon Emissions	Biofertilizer - Land bank
% Thermal Energy Supplied	Renewable energy generated	Oilseed Rape - Land bank
% Project Profit Margin	Tonnes of Oil Equivalent	Bioenergy Park - Radius (Absolute).
	Homes Heated - Straw Pellets	
	Number of Cars – Biodiesel	

The Integration matrix is developed using Microsoft Office Excel® software.

1.3 The study objectives

In order to develop a tool to analyze the possible synergies of integrated renewable energy processes in a Bioenergy Park three main objectives were identified as presented in figure 1.2 below.

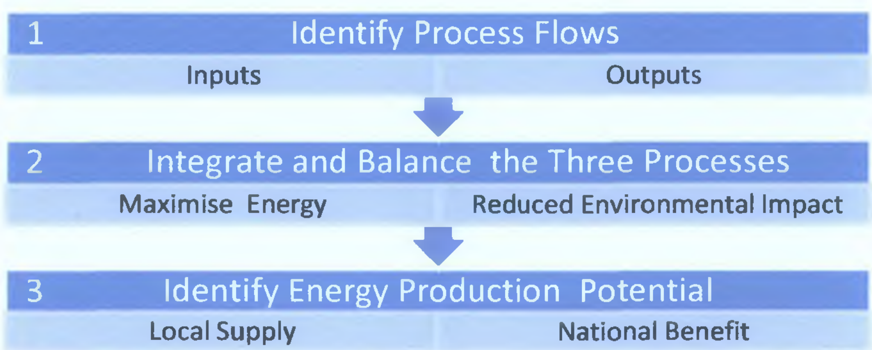


Figure 1.1 Bioenergy Integration Park study objectives

The first objective is to identify the process flows for each of the three processes with regard to input and output requirements. This includes, plant capacity, plant energy balance and plant energy output potential and resultant value.

The second objective is to integrate the process, balancing the size of the anaerobic digester so that sufficient energy is generated to fuel the integrated processes of biodiesel and straw pelleting. The objective is to maximise energy potential while focusing on reducing adverse environmental impacts.

The third objective is to investigate the total energy production potential of the Bioenergy Park as a whole and get an understanding of how locally produced renewable energy could impact on national targets and objectives.

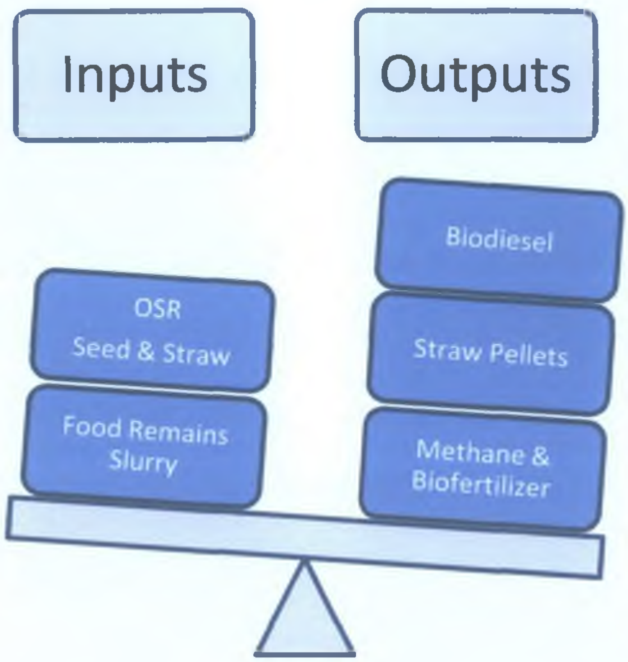


Figure 1.2 Bioenergy Park - getting the balance right.

1.4 The drivers for change

"*Sustainable Development is that which meets the needs of the present without compromising the ability of the future generations to meet their own needs*" (UN, 1987). Boyle, 2003, expands this definition to consider a sustainable energy source as one that is not depleted, non hazardous to humans or the environment and gives consideration to socio-economic stability (Boyle, 2003).

1.4.1 Global warming

Man's exploitation of fossil fuel stocks (coal, oil and gas) for the production of energy has been fundamental in the socio-economic development landscaping the globe. The consequence of this exploitation however is realized in the unprecedented rate of climate change.

The '4th Assessment Report' by the Intergovernmental Panel on Climate Change was the collaborative work of 2500 expert scientists from 100 countries (IPPC, 2007). The reports stated that there is now 90% certainty that greenhouse gas emissions resulting from human activities are the cause of climate change.

The possible consequences if carbon gas emissions are not radically and systematically reduced as reported include:

- Snow will disappear from all but the highest mountains.
- Sea levels could rise several meters by 2100.
- Oceans will become acidic, leading to destruction of coral reefs and marine life.
- Agriculture will collapse widely and deserts will expand.
- Hundreds of millions of people will suffer water shortage and famine

Mans impact on the environment
Colorado River levels reflecting 7 years of drought

Figure 1.3 Source: www.ecobuddhism.org

Global Choices, Global Consequences
Polar bears stranded on an ice-floe By DAVID JONES

Figure 1.4 Source:www.dailymail.co.uk/worldnews

1.4.2 Combating Climate Change

The United Nations Framework Convention on Climate Change (UFCCC) negotiated a treaty in Kyoto, Japan in December 1997. The treaty, known as the 'Kyoto Protocol', came into force on February 16, 2005. Under the Kyoto Protocol, industrialized countries are required to reduce emissions of six greenhouse gases. Some argue that the Kyoto Protocol was fundamentally flawed in that it exempted China and India from mandatory reductions. China has subsequently surpassed the United States as the world's greatest carbon gas polluter.

1.4.3 The Irish Commitment

Ireland's immediate target under the Kyoto Protocol is to limit emissions for 2008-2012 to 13% above the 1990 level. Preliminary figures show that this equates to an annual reduction of 64,000,000 tCO_2 equivalents annually. The scale of the challenge facing Ireland means that a systematic and coherent approach is required with input from all sectors of the community (NCCS, 2007). The National Climate Change Strategy (NCCS) involves a cross-functional approach and includes targets in the transport, residential, industrial, waste and agricultural sectors. Some of the targets and supports under the remit of the National Climate Change Strategy that fit neatly within the remit of the Bioenergy Park concept are outlined in box 1.2 below.

Bioenergy Park and the National Climate Change Strategy Linked **Box 1.2**

The principal measures in the National Climate Change Strategy draw together the Irish Government's collective effort across all sectors to tackle climate change.

Energy Supply Sector

- 15% of electricity to be generated from renewable sources by 2010 and 33% by 2020
- Biomass to contribute up to 30% of energy input at peat stations by 2015
- Support for Combined Heat and Power projects

Waste

- Use of waste biomass in energy production
- Support for waste-to-energy projects under REFIT scheme

Transport Sector

- Introduction of biofuels obligation scheme in 2009
- All public sector fleets to be required to move to biofuel blend

Thermal Energy Residential/ Public Sector

- Grants for renewable energy heating under Greener Homes Scheme
- Biomass heating in schools

Agriculture, Land-use and Forestry

- REPS 4 scheme will support carbon sequestration and reduction of emissions from fertilizers
- Feasibility of anaerobic digestion to be explored
- Top-up to EU premium for energy crops
- Biomass Harvesting Scheme (NCCS, 2007)

These measures support environmental sustainability, enabling Ireland to meet its global responsibilities while maintaining Ireland's competitive position according to An Taoiseach (of the day), Bertie Ahern, T.D. (NCCS, 2007).

1.5 Bioenergy Park embracing the National Climate Change Strategy

The Bioenergy Park concept, in its capacity as a biofuel producer, renewable energy generator and biodegradable waste consumer, certainly embraces the Irish National Climate Change Strategy. However, one could question to what extent local production of renewable energy in an integrated Bioenergy Park can impact on national environmental and energy targets. And is this option commercially viable.

2.0 Methodology

The Bioenergy Park, as described, is a concept not a reality and as such poses a number of obstacles in delivering the defined objectives of this study. This thesis is then a desk-study rather than the documented findings of an existing Bioenergy Park process. The scope of the study is broad in that there are three systems and the requirement is to operate as one. Research must include the diversity of the three aspects, namely biodiesel, straw pelleting and anaerobic digestion and funnel the detail into a tangible result.

2.1 Introduction

Four methodologies were used in compiling the information required to develop the software tool called the 'Integration Matrix'. These were literature review, attendance to relevant conferences, interviews with experts and site tours to review technology developments were appropriate. The methods used are outlined in figure 2.1 below.

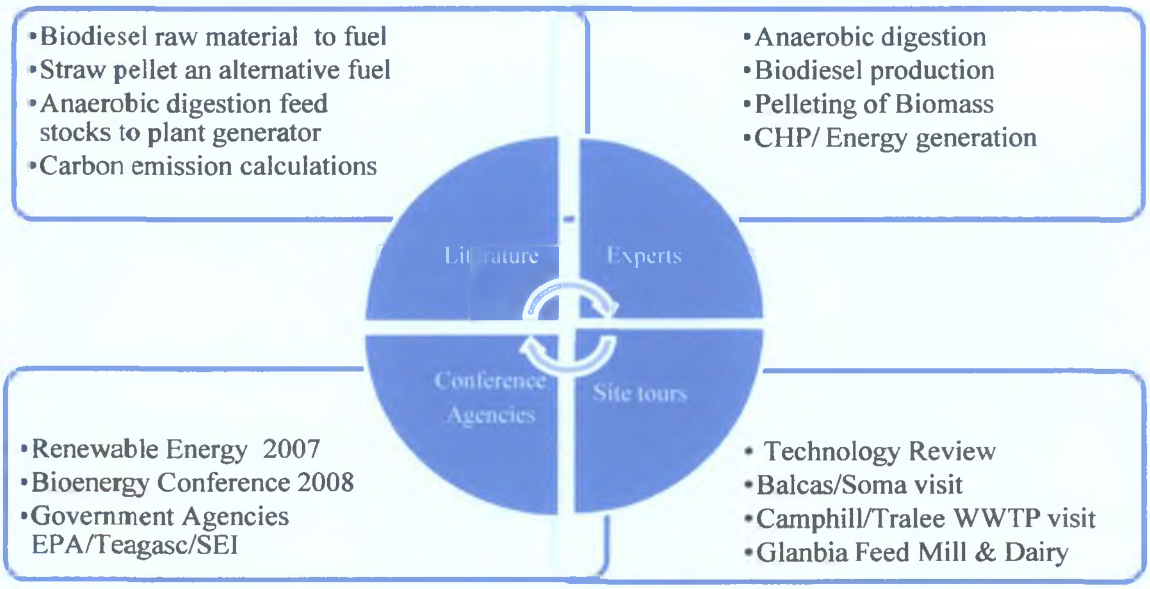


Figure 2.1 Methodology cycle

2.2 Main literature shaping this study

A significant quantity of literature was reviewed through out the course of this study and the key pieces are outlined below.

Optimal Biomass and technology for production of biofuel as a transport fuel by T Thamsiriroj (2007) under the supervision of Dr.J Murphy University College Cork. Thamsiriroj's thesis included a case study on GRO Oil Biodiesel process in County Cork. His case study is used extensively in the exploration of biodiesel production within the Bioenergy Park matrix.

Reduction of energy consumption in biodiesel fuel life cycle by P Janulis, (2003). Janulis conductes a life cycle analysis (LCA) on biodiesel in Lithuania. In the context of the propagation of oil seed rape for biodiesel production, Janulus explores the options of replacing artificial fertilizer with biofertilizer and the envionmental impact of same on the LCA was considered.

Cost benefit of biomass supply and pellet processing by S Sokhansanj, (2006). Sokhansanj's study investigated the typical process flow and subsequent energy consumtion and cost per unit of biomass pellets. This piece of litrature, together with his other work and that of S.Mani, were used to give an insight into the pelleting process of biomas.

Feedstocks for Anaerobic Digestion - (AD-NETT). University of Agricultural Sciences Vienna: by R Steffen (1998). This piece of litrature contained a table demonstrating the biogas and metane potential of various feed stock when processed in an anaerobic digester. As such, this table forms the foundation for the integration matrix from an energy production point of view.

Anaerobic Digestion: Decision Software by M Poliafico (2007) under the supervision of Dr. J Murphy University College Cork. Poliafico, as part of his study, derived an equation to estimate the capital and operational cost of and anaerobic digester system. Poliafico based his study on the central anaerobic digester capital costs and operational costs experienced in Denmark. This equation is embedded into the integration matrix and is used to derive costs based on the anaerobic digester feed stock volumns.

Feasibility study for centralized anaerobic digestion for treatment of various wastes and wastewaters in sensitive catchment areas by T Mahony, (2002). This report, published by the Environemtnal Protection Agency (EPA), was conducted by team which included Professer Emer Colleren and Dr Vincent O'Flaherty of National University Institute of Galway. The report provides an insite to the benefits of anaerobic digestion in the Irish context and researches feed stock availability, plant design and site selection. The report uses R Steffen (1998) table as a guide to feed stock viability as a methane producer.

Rural Bio-Energy Production as a Bundled CDM Project. Presented at the 3rd International BioFuels conference by Singh, M. G. (2006). Finally, under the topic of carbon emission trading and Clean Development Mechanisims (CDM), Singh recommends that to improve uptake and output of CDM, bundling together of projects is a requirement. Bundling will facilitate a more inclusive development and improve economic benefit to rural communities of CDM projects. Singh's bundling suggestions are presented in box 2.1 below.

Box 2.1

- Bundle the capture of methane from de-oiled cake and subsequent power generation projects.
- A bundle of integrated solid waste management (waste to energy) projects.
- Credits for fuel substitution, bundled small scale projects in some cases and stand alone in other cases, depending on the scale of operation.

In the context of small scale carbon emission reduction, which will be synonymous to the operation of Bioenergy Parks, Singh's theory of bundling was of interest.

2.3 Conferences attended and agencies consulted

2.3.1 'Bioenergy'07 - Fuelling Ireland's Future '

COFORD, Teagasc and Sustainable Energy Ireland presented a one day event on 30th of August 2007 at Oak Park, Carlow. The purpose of the event was to promote the use of solid biomass and raise awareness across all sectors on the many uses and advantages in growing, harvesting and using wood fuels and energy crops for energy generation.

Some examples of exhibitor categories:

- Boiler suppliers and manufacturers for the domestic and commercial sectors.
- Stove suppliers including alternative fuel stoves, facilitating a survey of the potential availability of alternative fuel boilers on the Irish market.
- Refined wood fuel suppliers and producers – chips, pellets, briquettes and logs. Companies represented included Balcas and D- pellets among others. Opportunity was made to speak with representatives from these companies, and an invitation was extended to visit both sites. Balcas site was visited in October 2007.

Presentations attended included:

- Teagasc research in the area of alternative fuels pelleting and burning – Dr John Carroll
- Fuel pelleting and the development of the market in Ireland – David Kidney, Balcas

Introduction was made to Dr B Rice of Teagasc and a conversation regarding the burn potential and surrounding issues of straw ensued. Dr B Rice proved an invaluable contact, having expertise in a many key aspects relevant to this study including biofuel production, oil seed rape propagation in Ireland, and straw availability and use in Ireland.

2.3.2 'Bioenergy – Making it a sustainable reality'

Teagasc and the Irish Bioenergy Association (IrBEA) jointly held a one-day conference on the 12 February 2008 in Tullamore, County Offaly. The conference focused on policy, vehicle fuel, solid biomass, investigating the bioenergy supply chain from beginning to end.

Presentations of interest to this study included the following;

Vehicle biofuel production in Ireland – pure plant oil and biodiesel by *Liam Foley, Plant Technical Services Lead, ConocoPhillips, Whitegate Refinery*

The Cork city biofuel vehicle roll-out experience by *Brian Cassidy, Senior Executive Engineer, Cork City Council*

Marketing biomass for heat by *Joe O'Carroll, Managing Director, Imperative Energy*

Biomass supply chain by *Damian Dolan, Engineering Director, GreenTech*

Animal by-products as a feedstock for anaerobic digestion by *Tom Loftus, Principal Officer, Meat Hygiene and Animal By-Products, Department of Agriculture, Fisheries and Food*

Bioenergy scheme and land required to achieve our policy targets by *Barry Caslin, Bioenergy Specialist, Teagasc.*

The conference provided excellent up-to-date information on key research topics.

2.3.3 Government agencies consulted

Communication with and research of relevant reports published by government agencies proved to be of significant value. Agencies that were referenced within the study included the following:

- Environmental Protection Agency EPA
- Sustainable Energy Ireland SEI
- Teagasc
- Department of Agriculture, Fisheries and Food
- Department of Environment, Heritage and Local Government
- Department of Communications, Energy and Natural Resources

All communications and reports are suitably referenced within the text of this study with full details incorporated into the reference chapter.

2.4 Experts consulted

The list of contacts made over the period of this study was many and there is some over lap with section 2.2, 2.3 and 2.5 above. In addition to those all ready mentioned, the following are some of the key experts contact. All experts were interviewed between September 2007 and March 2008.

Michael O'Rian, Technical sales for EcoOla, a biodiesel processing plant in Galway. Mr. O'Rian described in detail the EcoOla biodiesel process and provided valuable information in the area of energy efficiency and generation from a processing point of view.

AJ Navratil, Ballinacurra House, Cork. Mr Navratil provided information on straw pelleting technology, the sugar beet industry and its demise in Ireland, and was an excellent tour guide in his native Czech Republic on the trip to Soma Engineering. Mr Navratil also provided a business case template which has been used for each aspect within this study.

Ronan Beasley, Acorn Recycling provided a working knowledge of anaerobic digestion with particular reference to Camphill Community anaerobic digester.

Tom Egan, Plant Manager of Edenderry Power Station. Mr Egan provide a valuable insight into combined heat and power (CHP) and its uses. The use of straw and straw pellets as a replacement renewable fuel for power generation was discussed as was the potential market price.

2.5 Site tours conducted

Camphill Community Center (anaerobic digestion plant), visited in 2005, in conjunction with Acorn Recycling and A Quick Sharp. The visit focused on the following;

- Investigation of Anaerobic digestion as a solution to processing food waste
- Investigation scale of application, visual impact and odour containment
- Processing from reception to final effluent – gas production and digestate
- Land spreading - the impact of handling animal by-products.

Glanbia Mill Portlaois, Co Laois, visited in August 2007. The visit focused on the following;

- Investigation of a large scale pelleting process
- Energy consumption per tonne of pellets
- Pellet integrity and binding materials

Tralee County Council waste water treatment plant, anaerobic digester and combined heat and power plant, visited in October 2007. The visit focused on the following;

- Handling sewage sludge in an anaerobic digester
- Combined heat and power (CHP) running off biogas
- Comparing processes, reception to final effluent, sludge separation issues.

Balcas Pelleting Plant Co Fermanagh, visited in October 2007. The visit focused on the following;

- Investigate process operation of a wood pelleting process
- Comparing feed (pelleting) mills with wood pelleting operations
- Process technology and energy flows

Soma Engineering, Czech Republic together with two pelleting plants using soma technology, visited in December 2007. The visit focused on the following;

- Pelleting technology for small scale process – using straw as a raw material

- Tour included two operating plants using Soma Technology
- Comparison information to measure against wood pelleting processes

2.6 Unfolding the study in logical steps.

Figure 2.2 below presents the flow of chapters to follow. Research findings on biodiesel, straw pelleting and anaerobic digestion are presented in chapter 3.0, 4.0 and 5.0 respectively. Each aspect is considered in terms of raw material supply, process technology, integration potential and possible constraints in an Irish context. The focus of these chapters is primarily to build an understanding of the three processes in respect to a) integration in a Bioenergy Park and b) integration of the Bioenergy Park with the local agricultural environment.

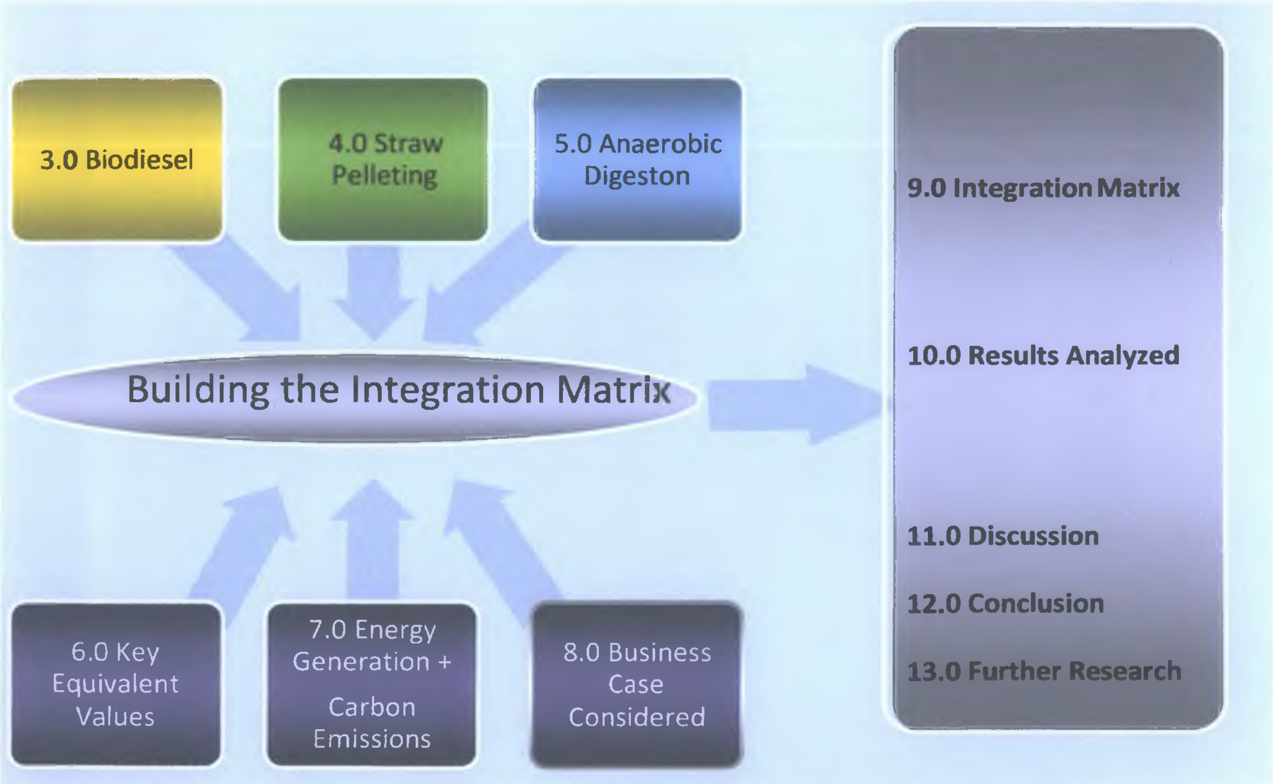


Figure 2.2 Methodology - Unfolding the study in logical steps

Chapter 6.0, 7.0 and 8.0 extrapolate facts and figures to build the frame work of the Integration Matrix. These chapters are detailed, deriving the necessary calculations to build the interactive Integration Matrix. The limitations of the plant output capacity are defined within these chapters. Extracts from the Integration Matrix will be presented through these chapters to link the research findings with the matrix build.

Chapter 6.0 investigates key energy equivalents for each of the energy flows. This chapter considers the potential energy output of the Bioenergy Park and then measures this value against the national energy consumption requirements.

Renewable energy generated also results in carbon emission reductions. Chapter 7.0 explores the supply and demand energy dynamics of the Bioenergy Park and investigates the total carbon emission reduction potential on site as defined. Key integration values are calculated for use in the integration matrix.

Production of a renewable fuel has many positive local and national benefits. However, the commercial viability assessment is fundamental with respect to project realisation. Chapter 8.0 considers capital and operational costs within the Bioenergy Park as defined. The individual business cases are combined within the integration matrix, acting as a guide to the potential viability of the Bioenergy Park.

The integrated model and matrix are introduced in chapter 9.0. The matrix combines the findings and values as defined in chapter 6.0, 7.0 and 8.0 into one. Chapter 9.0 demonstrates the mechanics of the integration matrix as established and provide the reader with an understanding of how the matrix delivers on the following;

- Balancing the energy flows of the integrated processes
- Facilitate comparison by using key equivalent values to measure local energy generation against national consumption targets
- Providing a means of assessing business case scenarios
- Establishing land bank requirements of a Bioenergy Park

The matrix is built to facilitate plant design considerations based on the users own circumstance. For example, if the location is County Monaghan, the main feed stock available to the anaerobic digester may be poultry manure, while OSR may be decidedly lacking in this region, however, if based in County Cork, cattle slurry and food remains may have greater availability and together with access to an arable land bank a very different scenario arises. The matrix thus allows the user to design a Bioenergy Park site and investigate its outputs and viability in a few easy steps. The potential to explore multiple scenarios, within the constraints of the matrix is infinite. In chapter 10.0, ten scenarios are examined. Discussion of scenario findings and conclusion of report then follow.

2.7 Inspiration from abroad

Sunflower Electric Power Corporation, formed in 1957 by six rural electric cooperatives, is a regional wholesale power supplier that operates a 1257 MW system of wind, gas, and coal-based generating plants with a 2300-mile transmission system for the their 400,000 customers in central and western Kansas. The Holcomb station sits on a 10,000 acre site. Low sulphur coal is the primary fuel source for the power plant. Annually, 1.5 million tons of coal is shipped 640 miles from the Power River Basin in Wycoming to the Holcomb station by train for processing and generation of 360 MW of electricity.

Sunflower Electric Power Corporation aims to reduce its dependence of the finite coal reserve. As such, they have formed an alliance with the National Institute for Strategic Technology Acquisition and Commercialization (NISTAC) and the Kansas Bioscience Authority (KBA) to develop an Integrated Bioenergy Center, integrating several commercial or near commercial renewable energy technologies with the existing power plant.

Figure 2.3 Sunflower Integrated Bioenergy Centre
Source: *www.sunflower.net/BioEnergyNewsletter*

Figure 2.4 Sunflower System Integration

Earl Watkins, President and Chief Executive Officer of Sunflower is quoted as saying that the *"Integrated Bioenergy Center could dramatically improve our ability to help serve our cooperative ag-producers and add another level of value to the products they raise in central and western Kansas."*

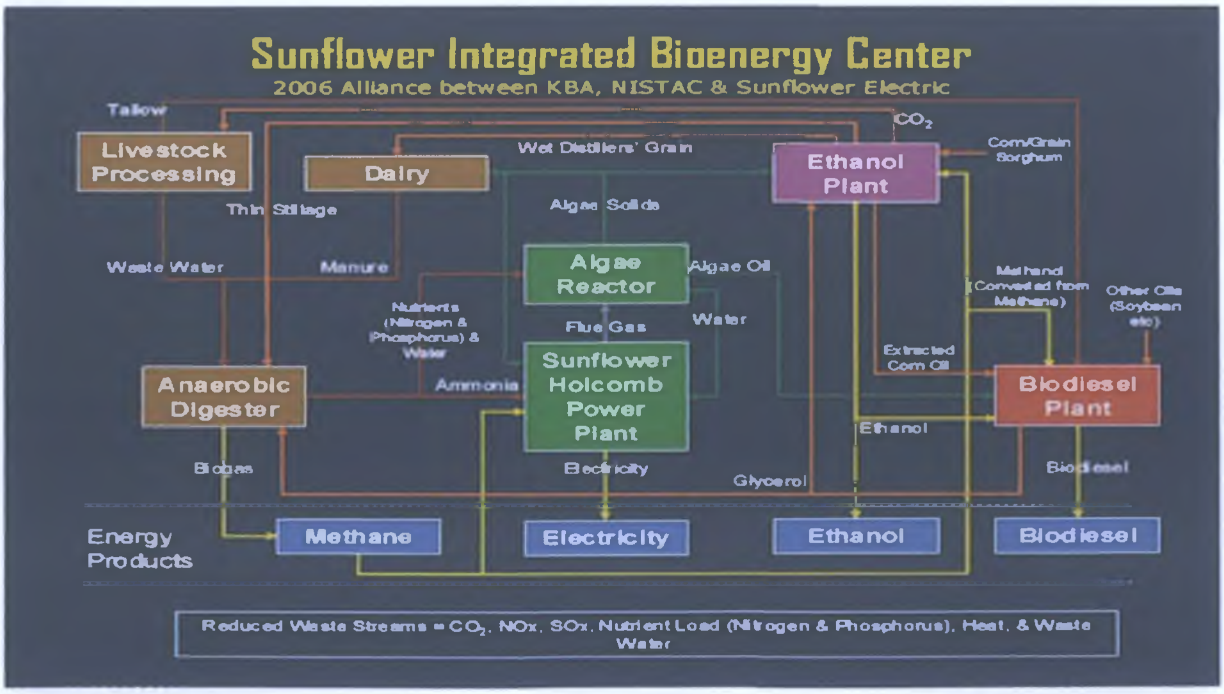


Figure 2.5 Sunflower Integrated Bioenergy Centre Source: (Sunflower, 2007).

The Holcomb site offers several resources for an integrated bioenergy facility. These include access to land, water, rail, natural gas and carbon dioxide from power plant emissions.

Box 2.2

Coal-Based Power Plant
The emissions produced by the power plant, when passed through the algae reactor, optimize algae growth by utilizing the heat and carbon dioxide from the flu gas.

Algae Reactor
Algae are very efficient in converting sunlight, carbon dioxide, and nutrients into oil (for biodiesel) and starch (for ethanol). Algae will use micro-nutrients from the digesters and the carbon and nitrogen from the coal plant, thus reducing emissions and generating biomass.

Anaerobic Digestion
An anaerobic digester is used to process wastewater and manure from the dairy, thin stillage from the ethanol plant, and possibly glycerol from the biodiesel plant. Bacteria in the digester will produce methane that can be used by the ethanol and/or the power plant. Other co-products from the digester could include and treated sludge that can be used as fertilizer.

Biodiesel Plant
The biodiesel plant will be a multi-feedstock facility and will receive animal fat, possibly extracted corn oil from the ethanol plant, and algae oil from the algae reactor. Many of the crops that produce oil require large acreages to produce a significant volume of oil. In contrast, one acre of algae could produce 8,000 gallons of biodiesel per year.

Dairy
The dairy will provide manure and wastewater to an anaerobic digester where it will be converted to methane. The starch and wet distillers grain from the ethanol plant and possibly solids from the algae reactor will be used by the dairy for cattle feed.

Ethanol Plant
The ethanol plant will consume local corn and among other resources will receive starch from the algae reactor, and methane from the anaerobic digester. Co-products generated include extracted corn oil to the biodiesel plant, thin stillage to the anaerobic digester, and distillers grain to the dairy and surrounding livestock industry. Source :**(Sunflower, 2007).**

The process is currently being patented and detail on the integration is limited to the schematic in figure 2.4 and box 2.2 above. The integration efficiencies are quoted as the primary benefit of the process. However, one can conclude that at an investment of 3.6 billion US dollars, the integration potential must be significant and is therefore something to consider as part of a local renewable energy system albeit operating at a smaller scale. In July 2007, engineering surveys were well underway and the biodiesel and ethanol plants were scheduled for construction in autumn 2007. In a 2008 update, reports indicate that there have been project delays due to planning and environmental issues and as a result the completion date of 2013 may not now be realized (Sunflower 2007).

3.0 Biodiesel

Rudolf Diesel said, 'the use of vegetable oil for engine fuel may seem insignificant today but such oil may become, in the course of time, as important as petroleum oil and the coal-tar products of the present time'. The year was 1912. Nearly one hundred years on and José Manuel Barroso, in his capacity as President of the European Commission, discusses the reasons why there is such 'new interest in old technologies', citing simply, energy security and climate change (Barroso, 2007). The European Union (EU) is the largest importer of energy in the world, relying on 50% of supply from external sources. This could reach 70% by 2030. Indigenous biofuel production can offer benefits, by diversifying the energy supply base and providing a tangible means of reducing greenhouse gas (GHG) emissions (Barroso, 2007).

3.1 Introduction

The Directive 2003/30/EC 'on the promotion of the use of biofuels or renewable fuels for transport' , referred to as the Biofuels Directive, is the driver to facilitate and support EU member states for the production of self sustaining energy supply and the reduction of greenhouse gas emissions. The Biofuels Directive allows for biodiesel production from animal or vegetable fats for use in its pure state or as a blended fuel. The Biofuels Directive also promotes local sustainable biofuel production and encourages the change to and inclusion of 'farming for energy' as a means of diversification in country life activities.

This chapter investigates the aspect of biodiesel in relation to the following;

- European production capacity
- The environmental benefits of biodiesel.
- The cultivation and value of Oil Seed Rape as a crop is explored from an Irish agricultural perspective.
- Research is conducted on the processing of biodiesel with respect to inputs and outputs and also technology developments which would be considered applicable in a local Bioenergy Park.

3.2 European Union (EU) Position

The EU renewable energy target for the transport sector is set at 10% biofuels by 2020. It is expected that the EU will achieve this target in the next two years, if production continues at its current rate (Caslin, 2008). Germany at 4.1 million tonnes has the largest biodiesel capacity in Europe. The industry was supported in the earlier years by tax exemptions. In August 2006 however, the German Finance Minister implemented a tax of nine euro cent per liter on biodiesel. This new tax, together with the increase in raw material costs means that the competitive margin for biodiesel production is being eroded in Germany. It is hoped that the new incentive established on the 1st January 2008, placing a requirement on fuel 'majors' to blend to 5% biodiesel content and expected targets of 15% blend obligation by 2015 will keep the supply demand dynamic positive in the German market (Caslin, 2008).

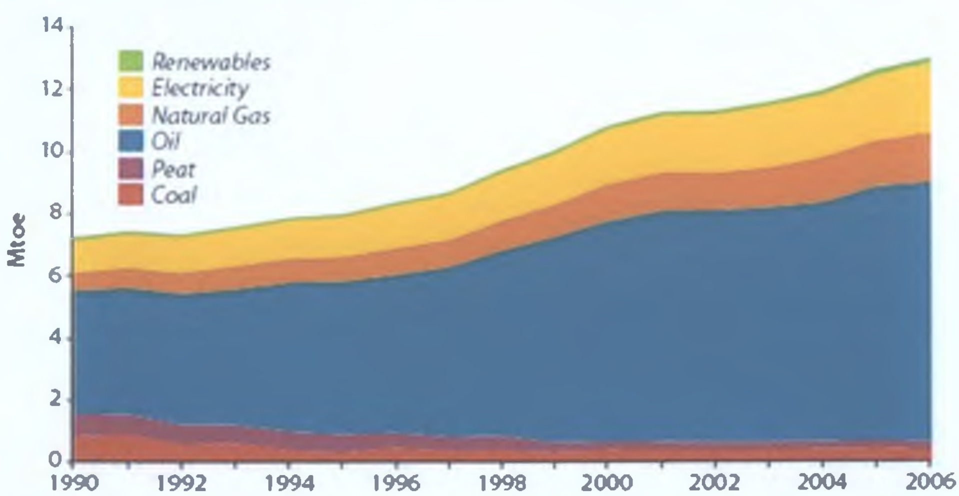
Italy has a production capacity of 1.65 Mt (million tonnes). Spain has a production capacity of 0.925 Mt with 2.18 Mt capacity under construction. Britain has almost 0.7 Mt production capacity with 0.6 Mt under construction. And France has a production capacity of 0.62 Mt with 0.85 Mt under construction (Caslin, 2008). By comparison, Ireland produced 4000 tonnes of biodiesel in 2006 (EBB, 2007).

Incentives vary, but the 'Biofuel Obligation' implemented in nine of the member states seems to be favored over tax incentive schemes for the achievement of sustainable biofuel targets (Caslin, 2008). The 'Biofuel Obligation', is where high energy users are obliged to utilize a certain percentage of renewable energy as part of their energy consumption mix. In addition, the producer is rewarded by being allowed to trade carbon credits for emissions reduced. The actual percentage of obligation is set by the member state.

3.3 Biodiesel in Ireland

Ireland's transport sector energy consumption in 2006 totaled 5,405 ktoe, (kilo tonnes of oil equivalent) 34% of total primary energy fuel consumption (SEI-6, 2008). Renewable energy accounted for only 2.6 ktoe of the total fuel supply. Diesel at 2509 ktoe (47%) had the largest share of the total fuel consumed in 2006. Transport energy use increased by 167% over the period 1990 to 2006, and is averaging an annual growth rate of 6.3% (SEI-6, 2008). Figure 3.1 depicts the total final consumption by fuel type from 1990 to 2006. Irelands 2006 production of 4000 t of biodiesel is a mere 0.0016% of the total diesel consumed.

Total Final Consumption by Fuel 1990 to 2006



- Oil increased its share of the total from 55% in 1990 to 64% in 2006 which was an increase of 111% (4.8% per annum on average).

Figure 3.1 Total final consumption by fuel 1990-2006, Ireland **Source: (SEI-6, 2008)**

In order to achieve targets set out in the Biofuel Directive, the Irish government set up a Motor Oil Tax Relief scheme (MOT Relief). Applications were made by interested fuel producers for motor oil tax relief on planned biofuel production volumes. An independent panel, comprising of officials from the Department of Communications, Marine and Natural Resources (DCMNR), Sustainable Energy Ireland (SEI) and Enterprise Ireland, assessed the applications and made selection recommendations based on the following selection criteria; technical excellence and viability, sourcing of feedstock, quality, access to market, and ability to deliver. The pilot scheme was implemented in 2005. The second scheme is currently in place for the period 2006 – 2010. Of the 102 applications, 36 applied in the EN590 Diesel Production category, 18 applied in the Pure Plant Oil (PPO) category and 37 applied in the Captive Fleets category. The remaining 11 were applicants for the Bioethanol category.

On 23rd November 2006, Minister of the day, Noel Dempsey T.D. announced the names of sixteen biofuels projects granted excise relief under the second MOT Relief scheme. The successful biodiesel and pure plant oil projects are as listed in table 3.1.

Table 3.1 MOT Relief in Scheme II for the period 2006 – 2010

Category	Company Awarded MOT Relief	Million Litres
EN590	Conoco Phillips Whitegate Refinery Ltd Whitegate, Co Cork	93 ML
EN590	Biodiesel Production Ireland/Topaz Energy Limited, Dublin 4	68 ML
EN590	Green Biofuels Ireland Ltd Blackstoops, Co Wexford	32 ML
EN590	Irish Food Processors Ltd 14 Castle Street, Ardee, Co Louth	97 ML
Pure Plant Oil	Biogreen Energy Products Ltd The Leap, Co Wexford	7 ML
Pure Plant Oil	Eilish Oils Ltd Kilmurry, Newtownmountkennedy, Co Wicklow	7 ML
Pure Plant Oil	Goldstar Oils Ltd Oldcourt, Inistioge, Co Kilkenny	7 ML

Source DCMNR http://www.dcmnr.gov.ie/Energy/Sustainable

There has been much debate in the biofuel industry about the success of the MOT relief scheme, the selection criteria, its implementation, and indeed the development of the industry in Ireland as a whole. Some of these issues are outlined below in box 3.1.

Success of the MOT relief scheme considered by others **Box 3.1**

On large scale production facilities such as ConocoPhilips Whitegate Refinery, where 1 million tonnes of EN590 diesel is sold to the Irish market per annum, the 1 million liters awarded in the first MOT relief scheme was just a 30 day production run (Foley, 2008). Of the allocated 93 million in the second scheme, 17 million liters were processed by the end of 2007. Imported soya bean oil is used as base feedstock. '*The company will support indigenous raw material supply, but it must be delivered to port, in bulk, at the right specification and the right price*', says Foley 2008. Even with the tax relief, ConocoPhilips warn that given the feedstock costs, which have doubled over the last year, the economics are marginal. ConocoPhilips will have to reconsider their position as a biofuel processer if raw material prices continue to rise (Foley, 2008)

Conor Toolan of Clear Fuels Ltd. debated that while 44 M Liters were allocated to support biodiesel production in the 2006-2010 MOT Relief scheme, only one of the companies awarded the tax relief could actually process the production allocation and questioned why those that had invested in plant were not awarded the excise relief. (C Toolan, 2006).

Finally, there are three Pure Plant Oil [PPO] production facilities in Ireland with a combined capacity of 32 million liters of PPO (Caslin, 2008). Only 21 million liters of this PPO has MOT relief. In order to maximize profits on a marginal process, producers are exporting the remainder to other member states where carbon credits are awarded under the renewable obligation scheme. Ireland's carbon reduction targets fail to reap the benefit of this Irish produced biodiesel and resultant carbon emission reduction. (J O Meara, 2008).

Arguably there is some bias in the opinions of the three producers quoted above, however the points are still valid and warrant further discussion. In chapter 7.0 carbon emission reduction is explored and in chapter 8.0 the operating cost of biodiesel production is investigated.

In March 2007, Minister Noel Dempsey T.D. (DCMNR) published the "Bioenergy Action Plan for Ireland". One of the commitments included as part of the Action Plan is : *"By 2009 a new biofuel obligation will mean that all petrol and diesel will have on average a 5.75% biofuel mix (this will lead to CO_2 savings of 770,000 tonnes per year)."* (Bioenergy, 2007). A 'biofuel obligation' will be a welcome improvement to sustainable development of the industry in Ireland going forward (Caslin, 2008).

3.4 Benefits of Biodiesel

Biodiesel from vegetable oil has many environmental benefits over petrochemical oil.

- ✓ Biodiesel is biodegradable (95% degraded in soil in 21 days (Kőrbitz, 1998)), and has low exotoxity and toxicity towards humans.
- ✓ Biodiesel is renewable and has no net carbon emissions (IENICA, 2000).
- ✓ Biodiesel from pure rape methyl ester (RME) has a higher flash point than fossil diesel, which makes it safer to transport (Kőrbitz, 1998).
- ✓ Biodiesel is also an effective lubricant which can be added to ultra-low sulphur diesel to compensate for losses in lubricity characteristic with ultra low sulphur diesel (N Dunn, 2002).

✓ Biodiesel yields 3.2 units of fuel product energy for every unit of fossil energy consumed in its life cycle (IENICA, 2000).

✓ Biodiesel reduces net emissions of CO_2 by 78.45% compared to petroleum diesel (IENICA, 2000)(J Sheehan, 1998).

3.5 Raw Material and Resource Requirements

In producing biodiesel from rapeseed, a key consideration is raw material supply. Oilseed rape is a relatively minor crop in Ireland, with only 5100 hectares cultivated in 2006 (figure 3.2 below). However, there has been an increased interest in growing oilseed rape in Ireland, for a number of reasons.

1. Renewable energy targets and the energy crop (O'Mahony, 2005).
2. The ending of the sugar beet industry in Ireland, resulted in 31,000 ha of land which was once planted with sugar beet (CSO-1, 2005), now available for alternative crops.
3. In addition beet was used as a break crop, and now another break crop was required to fill the gap. OSR is reported to be an excellent break crop in a cereal rotation (O'Mahony, 2005).

Figure 3.2 Area of OSR under cultivation in Ireland Source : www.gmoinfo.ie/index

3.5.1 Growing of OSR in Ireland

Free draining, medium to heavy soils are best suited to oilseed rape propagation (O'Mahony, 2005). While OSR will also grow on very light or water logged soils, the crop yield potential is reduced. Oilseed rape is susceptible to several fungal diseases including light leaf spot and stem rot, all of which impacts crop yields (www.gmoinfo.ie, 2008). Competition from weeds, especially grasses, which are significant nutrient competitors, can also affect the crop yield. A major problem for oilseed rape is in premature pod shattering prior to and during harvesting, and seed loss could be in the order of 25% (Hennessy, 2007).

Crop management issues that arise in Ireland include:

- ✓ High fungicide and fertilizer requirements
- ✓ Premature and late ripening of crop
- ✓ Too high a ratio of straw: seed yield
- ✓ Lack of varieties suitable for growing in Ireland
- ✓ Profit margins is low, if a main crop
- ✓ Control of volunteers (plants that emerge from remaining seed from the previous crop in the rotation) (www.gmoinfo.ie, 2008)

Figure 3.3 Oilseed rape crop – Kildalton College
Source: www.teagasc.org

Teagasc, Oak Park, has produced a booklet entitled 'Growing oilseed rape in Ireland'. This booklet advises of the most up-to-date farm management practices required to achieve high yields of oilseed rape under Irish conditions. In Oak Park trials, yields harvested reached over 5.5 t/ha. In order to be economically viable, Teagasc recommend that a grower requires high yields in the order of 4.5 t/ha and to achieve this, the very highest levels of crop management is essential (IFJ-1, 2006).

SEI indicates that an average yield of 3 tonnes per hectare is expected (SEI-5, 2005). Actual yield as reported by the Central Statistics Office (CSO), were 3.1, 3.1, 3.0, 3.8, 3.5 tonnes per hectare in 2002, 2003, 2004, 2005, 2006 respectively (CSO-2, 2004), (CSO-3, 2006). However, the statistics hide the yield variations encountered because of variables such as varieties planted, soils condition and farm management. The winter oilseed rape crop, for example, has a higher yield and generally, higher oil content than the spring crop (IFJ-1, 2006).

3.5.2 Farming income considered

From a farming point of view, the land used to grow energy crops is eligible for the single farm payment (€383 / ha (Teagasc, 2007)) plus the EU energy crop payment (Kavanagh, 2006). The energy payment is €80 per hectare with a cap for an individual grower of 37.5 hectares per grower over a three year period (Hennessy, 2007).

In 2007, Glanbia plc planned to contract up to 10,000 acres of oilseed rape for harvest (IFJ-1, 2006). The Glanbia contract was for a minimum price of €240/t at 9% moisture delivered to the point of processing and for a minimum of 20 acres per contract. Taking an average of 3 tonnes of seed per hectare and with considerations to the grants the income calculation could gross € 1183 / ha for the farmer.

Given the increased price of rapeseed (€500/t (IFJ-2, 2008) this cold reach a gross of € 1963 / ha in 2008. The 2008 value is comparable to the expected gross income from sugar beet (for cattle fodder) (Teagasc, 2007) and therefore, oil seed rape could be reasonably considered as a valuable break crop alternative.

In summary, while oilseed rape is a marginal crop in Ireland, it could be a valuable replacement break crop for sugar beet. Rape seed yield will vary from region to region depending on soil quality, variety set and farm management practices. For a farmer to consider oil seed rape as main crop, yields in the order if 4.5 t/ha is required, however, generally the average yield is 3 tonnes per hectare. For the purpose of the Bioenergy Park integration matrix the values 3 tonnes of seed per hectare is considered.

3.6 The land bank

The land bank size required to produce sufficient OSR to supply the biodiesel plant must be a key consideration to a Bioenergy Park. To produce one tonne of biodiesel 3 tonnes of rape seed is required. OSR is a 1 in 4 rotation. This means that the crop can only be set in a location once every four years. The impact of this rotation is that the land bank is increased by a factor of four. Table 3.2 calculates the land bank required for 2592 tonnes.

Table 3.2	**Land Bank Requirement**	
Area of land of set crops 1)	864 ha	2135 acres
Landbank required 2)	3456 ha	8540 acres
1) Yield per hectare 3/t 2) Crop set 1: 4 year rotation		

To put this land bank in perspective, consider that 1 hectare is equivalent to a unit area of 10000 m^2 or 2.471 acres. Given that the area of a circle is equal to πr^2, and access to 3500 ha is required. Then the absolute radius from the Bioenergy Park must be a minimum of 3.3 km, where 100% of the surrounding land is available and arable and farmers are agreeable to grow and sell the oil seed crop to the Bioenergy Park. In reality the radius will be much greater, but the calculation indicates the potential land constraint.

3.7 Converting Oil Seed Rape to Biodiesel

While vegetable oil can be derived from many crops, soya bean, palm, sunflower etc., from and Irish agricultural view point, the best option is high oleic rapeseed (high fat) for the production of vegetable oil. Biodiesel production from oil seed rape can be divided into two distinct processes. Oil seed rape is firstly pressed to produce PPO then this feedstock is converted into biodiesel through the chemical process of transesterification.

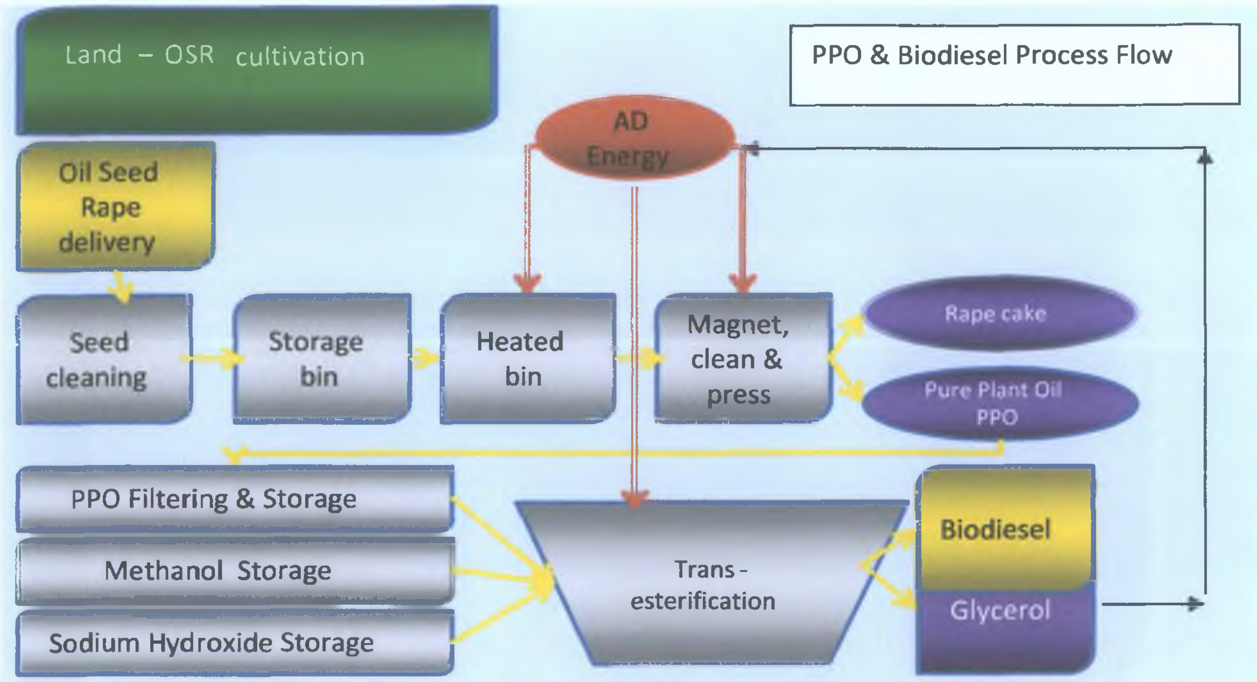


Figure 3.4 Process Flow- Land to Fuel in a Bioenergy Park

3.7.1 Pure Plant Oil Production

The typical process flow of oil extraction begins with intake and inspection, followed by sieving, heating of the grain, pressing and filtration of the resultant oils.

The OSR is inspected upon delivery and tested for water/ moisture content, the level of split grain and inspected for foreign material contamination such as straw, stones and metal (Kiernan, 2003). The ideal moisture content 9% or less. While inferior grain can be accepted, to maintain plant efficiencies, it is better to keep the moisture level less than 9% (O'Rian, 2008).

Once acceptance criteria are achieved, the OSR is passed through a magnet and then sieved to remove undesirable foreign matter before feeding into a press-feed hopper. The grain is generally heated. This heating can be achieved by using the waste heat from the electric generator, on route to press (O'Rian, 2008) (Thamsiriroj, 2007). The next stage is pressing. Figure 3.5 demonstrates two German design press with gravity feed inlet hoppers.

The press is the process line bottle neck, and as such there is oftentimes more than one seed press working in parallel with one infeed system and one filter and storage system following the pressing stage. One third of the seed is converted to oil and approximately two thirds or the seed is converted into rape cake (Kiernan, 2003).

KEK-P0020 KEK-P0101

Figure 3.5 Small scale KEK German Design Presses. Source : (Rhodes, 2008)

Once pressed, the oil needs filtering to remove the particulates. Figure 3.6 below demonstrates the process flow with and in line 'amafilter'. Normally there are three filter steps required to achieve the correct grade vegetable oil. The first filter is the main filter followed by a safety filter and then finally a polishing filter. The 'Amafilter', depicted in figure 3.7, is one such filtering system used in PPO filtration. The leaf filters are fitted on an oil circulation loop. As the solids build up on the filter, the particulate size allowed through the filter is reduced. This causes a pressure differential across the filter system. Once the correct pressure is achieved the system switches from recirculation to forward feed, passing the filtered vegetable oil to the second and third filter until the oil is ready for storage or onwards to biodiesel production (Rhodes, 2008). To clean the filter cake, the filter is first dried with compressed air, inert gas or steam, and then discharged by a pneumatic vibrator connected directly to the reinforced upper side of the filter leaves. Cake removal is via a butterfly or slide valve, or a cake door.

Figure 3.6 Rape Seed to Oil Process
Source: (Rhodes, 2008)

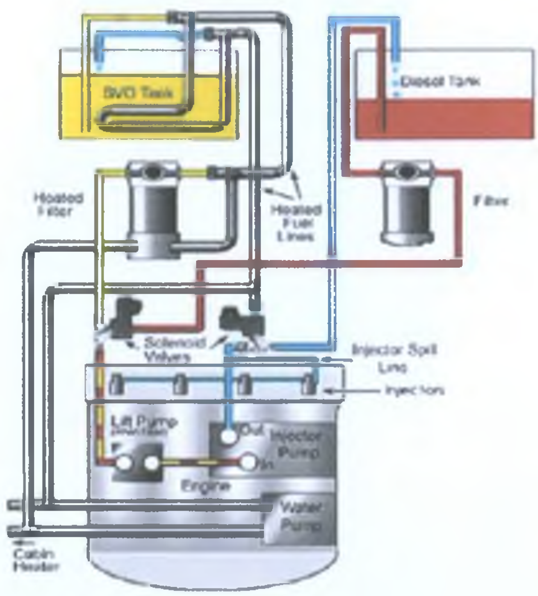
Figure 3.7 Amafilter
Source: www.Amafilter.com

The benefits of using an amafilter process are that there is very little maintenance and there is no bag filters required, thus reducing the ongoing cost of PPO processing (Rhodes, 2008).

3.7.2 Vegetable oil as a fuel

Vegetable oils can be used directly as diesel engine fuel, but the diesel engine requires modification. This is related to the characteristic of the oil over diesel. The major issues are their very high viscosity, poor thermal and hydrolytic stability and PPO is slightly more difficult to ignite (Cassidy, 2008). The cost of converting a diesel engine to use PPO is in the region of 1,600 euro per engine (SEI-5, 2005). Figure 3.8 demonstrate a two tank conversion systems (Meara, 2007).

Cassidy, 2008, recommended that while it is possible to purchase change over kits, the reality is that PPO is a duel tank solution for either stationary engines or long haul transport and not suitable for short journey transport systems in his experience.



from http://www.vegburner.co.uk/heat.htm

Figure 3.8 Two tank conversion system

By contrast, biodiesel can be used either as a blend or as a fuel at 100% addition in diesel engines with very little performance issues (Cassidy, 2008).

3.7.3 Transesterificaiton explained

Biodiesel can be defined as the mono alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, for use in compression-ignition (diesel) engines (USA, 2007).

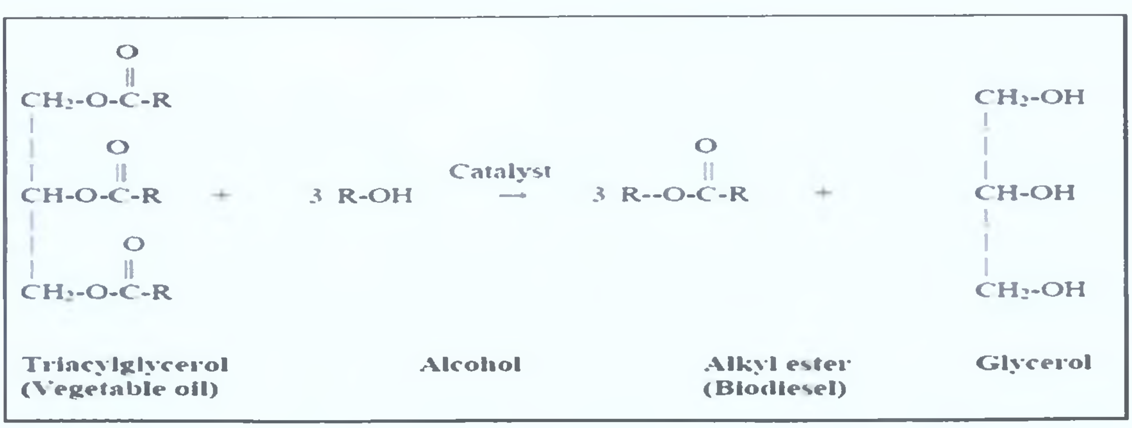


Figure 3.9 The transesterification reaction. Source : (J. Van Gerpen, 2004)

The chemical process is referred to as transesterificaion. What this means is simply that the esters are changed from one type to another. Usually glycerol is interchanged with methanol but ethanol or indeed bioethanol can be used equally (Janulis, 2004). Figure 3.9 depicts the chemical reaction of transesterification using a catalyst to produce alkyl ester and glycerol as a by-product. 'R' represents the alcohol used in the reaction

3.7.4 Production process of biodiesel

Generally, one tonne of PPO yields 0.980 tonnes of biodiesel with an energy value of 32.8 MJ/L and a density of 0.88 (Thamsiriroj, 2007). To ensure trouble free operation in diesel engines, the most important aspects of biodiesel production are; a complete reaction, removal of glycerine, removal of catalyst, removal of alcohol and the absence of free fatty acids. Most of the biodiesel produced today is processed using the base catalyst reaction (USA, 2007) for a number of reasons, namely:

- It is a low temperature and pressure process,
- It has a high yield (98%) with minimal side reactions and reaction time,
- It is a direct conversion to biodiesel with no intermediate compounds.

The basic recipe for biodiesel is :

Vegetable oil	100.0 kg	
Methanol	11.0 kg	(slightly in excess)
Sodium hydroxide	0.1 kg	

The first step in conversion process (Figure 3.10) is the mixing of methanol with the selected catalyst. The catalyst is either sodium hydroxide or potassium hydroxide and is added at 0.1%. Methanol is added at slightly greater than 10%. The excess is to ensure the total conversion of the triglycerides into esters (O'Rian, 2008). If ethanol or bioethanol is used, excess is not required and the overall biodiesel yield is increased by 10% (Janulis, 2004).

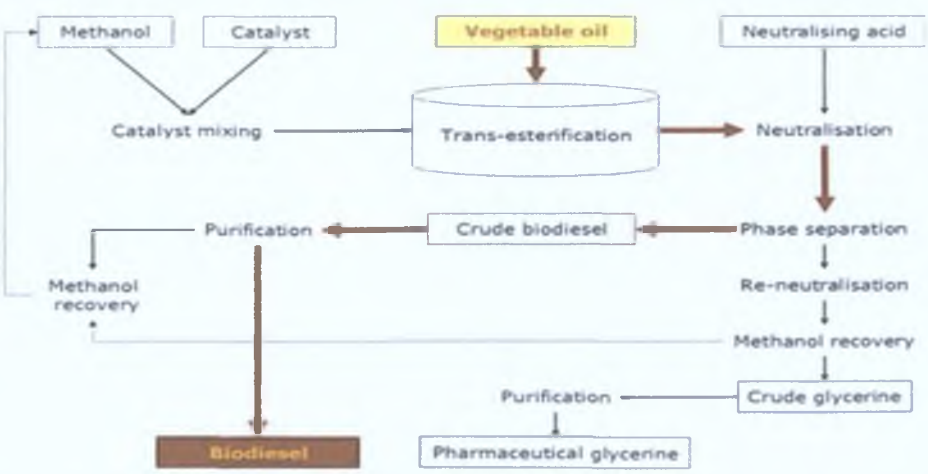


Figure 3.10 Biodiesel transesterification process flow **Source (USA, 2007)**

The catalyst/methanol mixture is fed into a closed reactor vessel, which prevents the loss of the alcohol, the vegetable oil is then added to the reactor (O'Rian, 2008).

The reaction is heated to approximately 60°C. While heating is not essential, where used the reaction time is reduced and the yield increased. Temperature control is important as at temperatures greater than 60°C the methanol will boil off leading to hazardous processing and line loss resulting in an overall yield reduction (O'Rian, 2008).

The reaction mixture is left to settle in the vessel for 1 to 8 hours allowing the phases to separate (USA, 2007). Generally the transesterification is conducted in two passes to maximize the biodiesel yield (O'Rian, 2008). The first pass is to ensure the bulk of the reaction has occurred, the second phase is to maximize yield. Reactions can occur in single tank batch systems or on a continuous flow system, the process however is the same, but in a continuous flow system the process has more tanks and equipment and therefore reduced residence time per tank.

Once the reaction is complete, the crude biodiesel (methyl-ester) is separated from the glycerol (USA, 2007). Again there are many different approaches to the separation process. EcoOla use a centrifuge, which is difficult to manage and increases cost and energy consumption (O'Rian, 2008) where as GroOil (Thamsiriroj, 2007) use a settlement tank.

Following separation, the crude glycerol and the methyl ester require a purification step.

Purification is generally by means of a washing process where residual catalyst and soaps are removed. The esters produced in this way will return a yield of approximately 98% (O'Rian, 2008). This can be improved further by distillation The end product is an amber-yellow liquid with a reduced viscosity (USA, 2007).

Figure 3.11 Biodiesel before and after filtering.
Source: www.biofluidtech.com/images/purolite.jpg

The methods of washing include light misting of warm water over the separated biodiesel or gentle bubbling of water through the biodiesel. The washing process could consume between 10% to 30% volume / volume of biodiesel produced, dependent on the quality of the feed stock (O'Rian, 2008) (J. Van Gerpen, 2004) (Biodiesel, 2008).

3.7.5 Glycerine or Glycerol and its potential

Glycerine or glycerol is the main co-product resulting from biodiesel production. It is a colorless, odorless, viscous and nontoxic liquid. It has a sweet taste and has literally thousands of uses particularly in its pure state. Glycerol can be sold directly as crude glycerol or purified even further to pharmaceutical standard (Thamsiriroj, 2007). However, for small scale operation, generally, it is not cost effective to purify the crude glycerol (O'Rian, 2008). Every tonne of biodiesel produced generates 0.10 tonnes of glycerine. So as the increased biodiesel production capacities in Europe is realized, the quantity of glycerine increases retrospectively, generating a glut on glycerine on the European market. Biodiesel production is now the most important determinate in the supply of glycerine and the European glycerine is already in over supply.

Researchers at eTEC Business Development Ltd., a biofuels research company based in Vienna, Austria, have designed specially adapted engines that successfully convert the biodiesel by-product glycerine, in its crude state, into electricity (Crooks, 2007). The system consists of a glycerine processing module, a combustion engine with a generator and a control unit that is compatible with any biodiesel. The facility, according to researchers, will provide substantial economic growth for biodiesel plants while turning glycerine into productive renewable energy (Biodiesel, 2007).

Glycerine is reported to increase biogas yields considerably, provided the right microbial populations are used (Crooks, 2007). A limit of 5-7 g L^{-1} concentration inside the anaerobic digester is defined as further increase can cause strong imbalance in the anaerobic digestion process (JB Holm-Nielsen, 2007). Studies demonstrated that the co-digestion of pig manure and glycerol, at maximum glycerol levels of 3 to 6%, resulted in improved methane yields which amounts between 18 and 22 % compared to the each separate digested substrate (Kryvoruchko V, 2006). Organic Waste Systems (OWS), a Belgian biogas firm, is investigating the use of crude glycerine as a base feedstock for a methane digester system. The digester plant is integrated into a commercial-scale biodiesel facility and the anticipation is that the co-product glycerol will be able to power the biodiesel plant itself (Crooks, 2007). And Weltec Biopower GmbH estimate that the value of one tonne of glycerine as a mixed feed stock in an anaerobic digester is 838 m^3 of Biogas. This identifies further integration potential between biodiesel production and anaerobic digestion.

3.8 New technologies

The waste water of the biodiesel wash step can be treated in an anaerobic digester however, given the potential volume of waste water production, a water-free process was researched with a view of reducing the environmental impact of the process on the Bioenergy Park. The technologies researched were;

1. Ultrasonic processing
2. Bernoulli Principle in transesterification processing
3. Ion exchange resin bed to replace the wash step

The Ion exchange resin bed system was found as the best solution based on ease of use, and commercial available technology that does not entail excessive cost.

3.8.1 Ultrasonic processing

A new technology yielding excess of 99% biodiesel is reported by researchers at Mississippi State University. Hielscher, a small German company provides this new ultrasonic processing equipment for biodiesel production. The use of ultrasonic process, in itself, generates energy for the reaction, and achieves better mixing and more rapid separation than the conventional methods. This efficiency is due to the increased chemical activity. The amount of catalyst required is reduced and the purity of the glycerol is increased. Hielscher, claims that costs for ultrasonic technology in biodiesel processing will vary between €0.002 and €0.015 per liter when used in commercial scale (dependent on the flow rate and capacity).

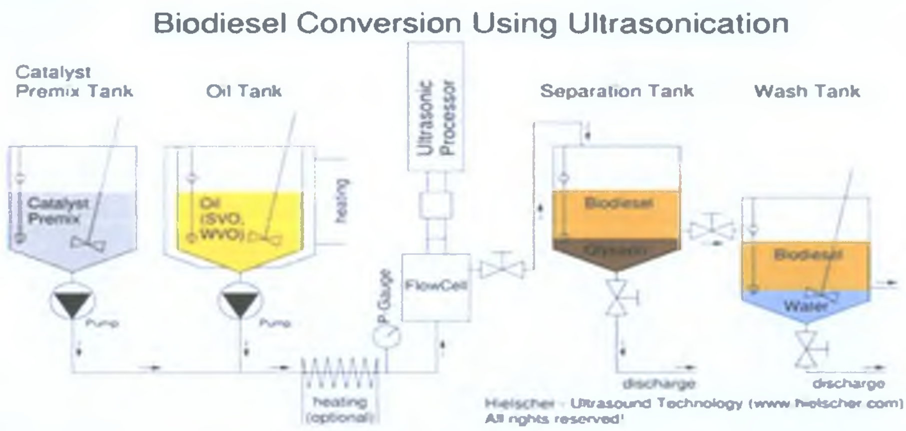


Figure 3.12 – Ultrasound technology **Source: (www.hielscher.com, 2007)**

This technology is still in laboratory development and will be of significant interest to processers of small to medium scale when it reaches commercial realization.

3.8.2 Using the Bernoulli principle in transesterification.

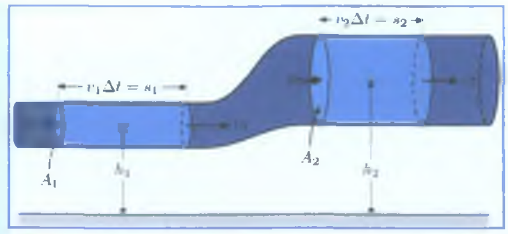
A Ukrainian company Biodiesel-Mach offers a technology that provides a unique way of mixing the reaction components (vegetable oil and methyl alcohol) in a hydrodynamic process. Using the Bernoulli principle (Figure 3.13), the transesterification reaction is intensified thus speeding up the reaction process (biodieselmach, 2007). The net result is a more complete reaction with a significant reduction in the reaction time when compared to the conventional process.

The process allows for use of a minimal amount of alcohol and a reduced quantity of catalyst for the reaction. There is no wash or dry step required in this process thereby reducing process time, energy consumption and resource requirements. In addition a conventional biodiesel process requires a two pass system while in the BioDieselMach system the reaction is complete in one pass. According to the website, only 11 kW of electric energy is required for processing of one ton of oil, (this is several times less than that required by conventional technology). The system is designed for operations of scale suitable for small to medium scale.

The Bernoulli principle

$$\rho gh + P_o = \frac{\rho v^2}{2} + P_o$$

where



P_0 – atmospheric pressure;
H – the height of the liquid in the vessel;
v – outflowing fluid velocity;
and
Toricelli formula $v = \sqrt{2gh}$

The liquid flows from an opening in a wide vessel at the same velocity as a free falling object.

Figure 3.13 The Bernoulli principle **Source (biodieselmach, 2007)**

Unfortunately, despite a number of attempts to contact the company regarding testimonials, case studies and prices for plant at scale of 1 tonne/hour to 4 tonne /hour as advertized, there has been no response to date.

3.8.3 Ion exchange resin bed

And finally, a water free processing plant using ion exchange resin bed technology was sourced in the United Kingdom (UK). This technology combines old with new, getting the best performance from both. The technology is commercially available and used in Germany and the UK. The front end of the process is similar to the conventional batch processing of biodiesel as described in section 3.7 above. When the biodiesel reaction is complete an ion exchange resin bed is used instead of the usual methods of phase separation and washing. The resin bed system described is the 'AmberliteTM BD10 DRYTM'. Advantages of the Green Fuels Biodiesel Purification system are that there is no water required, the biodiesel is maximized and there are no expensive filters required. The resin bed can be cleanout easily with a methanol backwash facility. This back wash and waste can be treated in an anaerobic digester. It is estimated that 1 kg of 'the resin beads is capable of treating between 900 – 1600 kg of biodiesel. www.greenfuel.co.uk

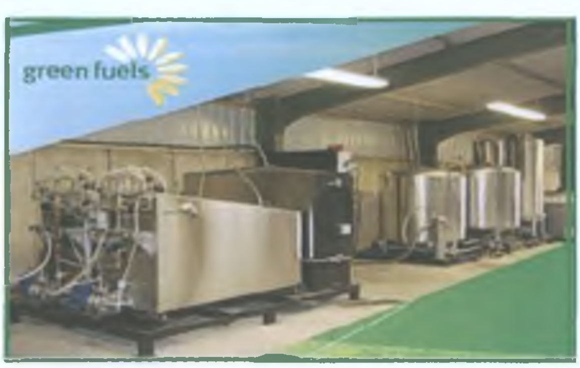


Figure 3.14 Ion exchange resin colums
. Source: www.greenfuel.co.uk

The ion exchanger only requires recharging every three weeks. The total operation costs are reduced by approximately 1 pence per liter of biodiesel. The 'AmberliteTM BD10 DRYTM' is developed by ROHM and HAAS and is reputed to eliminate unwanted impurities from biodiesel made from any feedstock. Soap and catalyst traces in the process are also removed together with the residual glycerol. Greenfuels has trialed the product with selected partners in the UK and at a 35,000,000 liter per annum plant using this technology in Germany. Currently a plant is being commissioned in Devon in the UK for to process biodiesel from recovered vegetable oil (Abbott D, 2008).

The system is easy to integrate into all new or existing batch and continuous biodiesel plants and meets all Biodiesel standards including ASTM and EN standards (Appendix 3.1).

Further research on ion exchangers as a solution to 'water free' biodiesel purification identified another system (Box 3.2).

Box 3.2

PUROLITE® PD 206 *a dry combined desiccant and ion exchange media specially formulated to enable maximum removal of residual glycerine and trace methanol and water, as well as salts, catalyst, and soaps from crude Bio-Diesel.* ***PUROLITE® PD 206*** *is designed for use in "purification" vessels installed after phase separation and demethylation.* ***PUROLITE® PD 206*** *improves productivity and lowers operation costs while enabling ASTM or EN specifications for B100 to be achieved* (http://www.purolite.com/).

From a Bioenergy Park perspective, an ion exchange system would be the best solution on a number of fronts.

1. No waste water generated means reducing the hydraulic load on the anaerobic digester.
2. Operational costs would be reduced.
3. Resin waste residues can be treated in an anaerobic digester.
4. The ion exchange resin can treat recovered vegetable oil and pure plant oil allowing system and raw material flexibility.

For the purpose of the Bioenergy Park business case the ion exchange system will be considered.

3.9 Integration opportunity and constraints of biodiesel production.

Oil seed rape can be grown with success in Ireland given the right soil conditions. The crop yields on average 3 tonne of seed per hectare and gives a comparable income to the farmer as a rotational crop solution. However, marginal land will prove more difficult in terms of return.

PPO and biodiesel can be produced from locally grown oil seed rape. Three tonnes of seed is required to produce one tonne of biodiesel. Given that one hectare yields on average three tonnes of seed, the land bank required becomes apparent.
PPO can be used as a fuel, however for market penetration biodiesel is perceived as the better option. Biodiesel can be used as a blend with little or no impact on diesel engine performance or reliability.

Glycerol, a by-product of the biodiesel process, can be sold as a commodity in its crude or purified form or digested in the anaerobic digester to improve methane yields in the order of 20%. Equally, all wastes from the biodiesel or pressing process can be diverted to the anaerobic digester to produce energy.

The processes of OSR pressing and biodiesel transesterification are simple technologies and research and development is underway to improve energy consumption, waste generation and yield potential. Some new technologies are at commercial realization stage with others in the pipeline.

The fertilizer required for the propagation of oil seed rape can be supplied by the digestate of the anaerobic digester closing the loop.

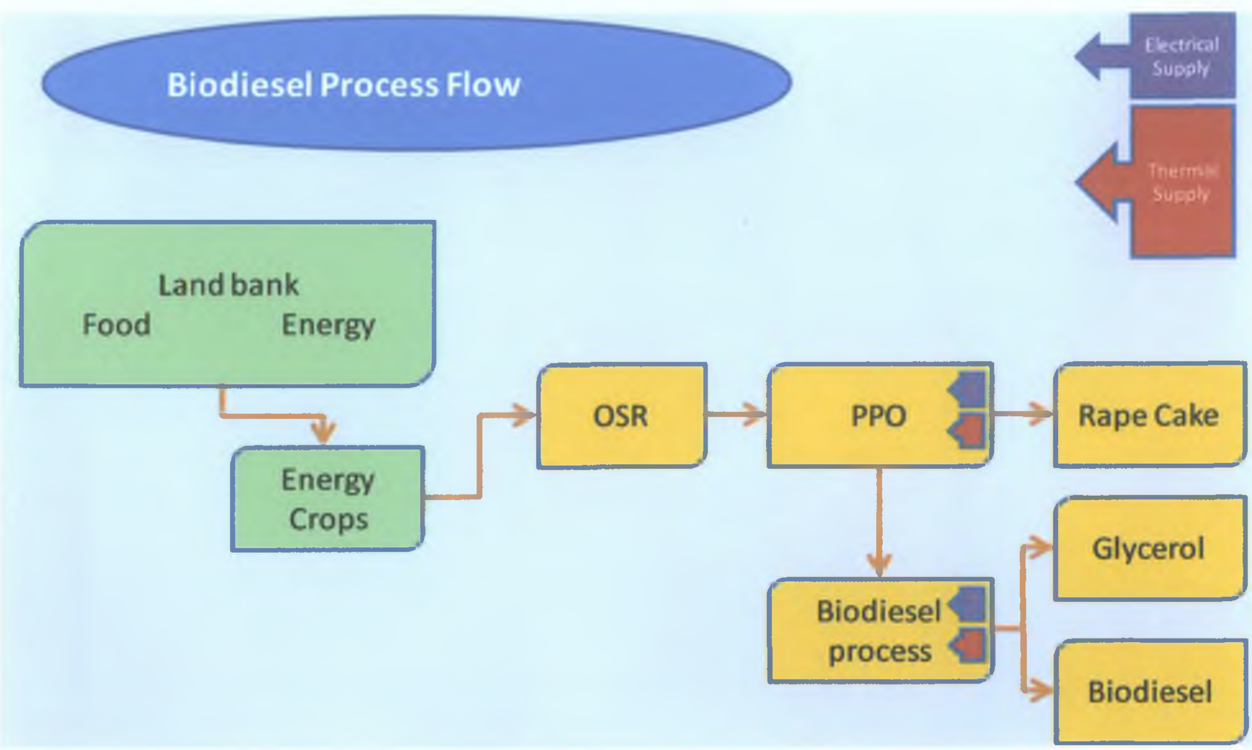


Figure 3.15 Process Flow simplified - Integrated into a Bioenergy Park

4.0 Biomass Pellet

Mankind has used biomass for heat generation since the discovery of fire all those millennia ago. As a biomass, wood was probably one of the first fuels used. Since the advent of coal, oil and gas, the status of biomass on the hierarchy of fuels has slipped in order of importance. However, changes are emerging in the global energy policies causing a shift in focus from the high carbon fossil fuels in favour of renewable indigenous fuel sources such as biomass.

4.1 Introduction

Fuel pellets manufactured from waste straw will positively impact carbon emissions, contribute to renewable energy targets and reduce the overall heating bill of those converting from oil to a biomass (solid) fuel. The Bioenergy Park, proposes to utilize existing straw wastes to generate renewable solid fuel.

The objectives of this chapter are as follows:

- Investigate market development of fuel pellet
- Investigate the availability of waste straws in Ireland
- Research issues relating to the combustion of straw
- Review pelleting technology suitable for application in a local Bioenergy Park

4.2 European situation

Since 2004 biomass pellets have become an economical alternative fuel. The market forces at play include a sharp increase in the price of oil and resultant impact on the home heating bill (Herold, 2007). The market volume for pellets is predicted to reach 142 million tonnes by 2020. Sweden is the largest producer and consumer of wood pellets in Europe. The Danish market experienced rapid growth in the late nineties, but a change in the subsidies has resulted in a decline of the market. In Sweden, Belgium and the Netherlands pellets are mainly used for power generation whereas in central European countries pellets are used in household central heating systems that have a power rating of below 25 kW (figure 4.1).

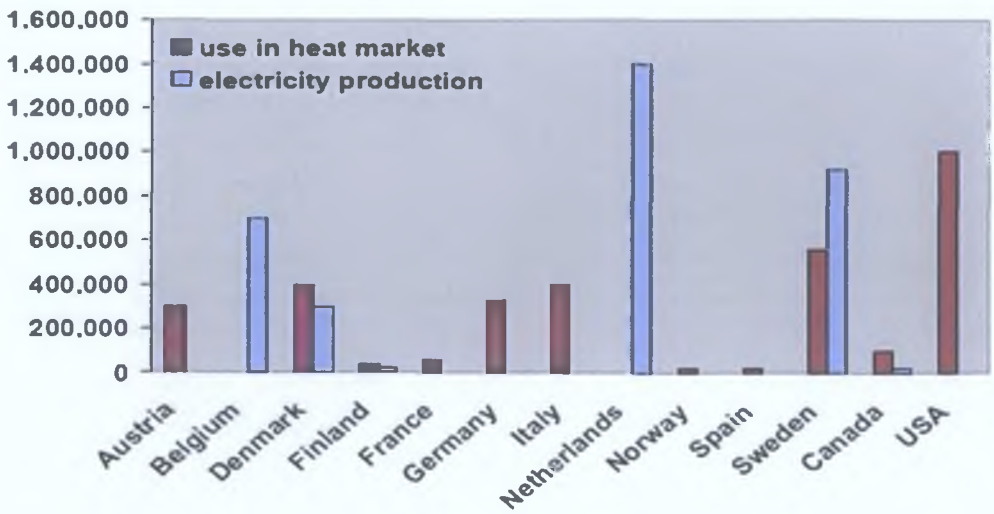


Figure 4.1 Pellets consumption, 2006: tonnes per year Source : http://pelleta.com.ua (Herold, 2007)

Canadian pellet production increased from 400,000 tonnes in 2001 to over 1 million tonnes in 2006. The majority of Canadian pellets are exported to European power stations via the port of Rotterdam. It is estimated that to transport pellets by ship from America to Europe costs approximately $40 per tonne, this is an equivalent cost to 500 road kilometers (Herold, 2007).

4.3 Pellet manufacturers based in the United Kingdom (UK) and Ireland

In 2007 the total UK pellet production capacity was in the region of 134,000 tonnes per year (Pellet@tlas, 2008). There are 10 pellet producers in the UK, the two largest, being Welsh Biofuels and Balcas in Northern Ireland (Pellet@tlas, 2008). Pellet production capacity development is set to increase significantly during 2008 and 2009. Balcas, for example, is building a new 100,000 tonne plant in Scotland (Keelagher, 2007). The capital of this plant will be in the region of £ 25 million sterling, of which 25% is grant aided. The plant is expected to be commissioned in 2009 (Keelagher, 2007).

Table 4.0 Pellet production capacity in UK	**2007 Capacity (tonnes)**	**2009 Capacity Expectations (tonnes)**
Welsh Biofuels	55,000	55,000
Balcas in Northern Ireland	55,000	155,000
Clifford Jones Timber in North Wales		30,000
Puffin Pellets in Scotland		25,000
Arbuthnott Wood Pellets in Scotland	15,000	35,000
Express Fuels in Wales		50,000

By contrast, in 2007, 100% of the wood pellets sold in Ireland were imported (Cammish, 2008). All 'Irish' pellets are imported from various locations, including Northern Ireland, Canada, Austria, Baltics and Norway (SEI-9, 2007). In March 2008, D-Pellets wood pelleting plant was commissioned. This production facility, located in Knocktopher, Co. Kilkenny, has a production capacity of 50,000 tonnes per annum. Capital spend was in the region of € 6 million, with no grant aid (Tracey, 2007).

4.4 Pellet demand in Ireland.

In the 2006 budget, the Minister of Finance allocated €65 million over the period 2006 to 2010 to "*launch several innovative grant schemes relating to biofuels, combined heat and power, biomass commercial heaters and domestic renewable heat grants*". € 22 million was made available for a 'Bioheat Boiler Deployment Programme', running in the period, 2006 to 2010 (SEI-stats, 2008).

In the 2007 budget an additional € 4 million was allocated to expand the 'Bioheat Boiler Deployment Programme' to include 'Solar Thermal Systems' and 'Heat Pumps' (SEI-stats, 2008). The initial grant scheme had 18,300 applications, and the technology split between the three categories of Heat pump, Biomass and Solar was 27%, 29% and 44% respectively (SEI-stats, 2008). Figure 4.2 depicts the uptake of the biomass technology county by county. The many counties with biomass systems installed were Cork, Galway and Wexford.

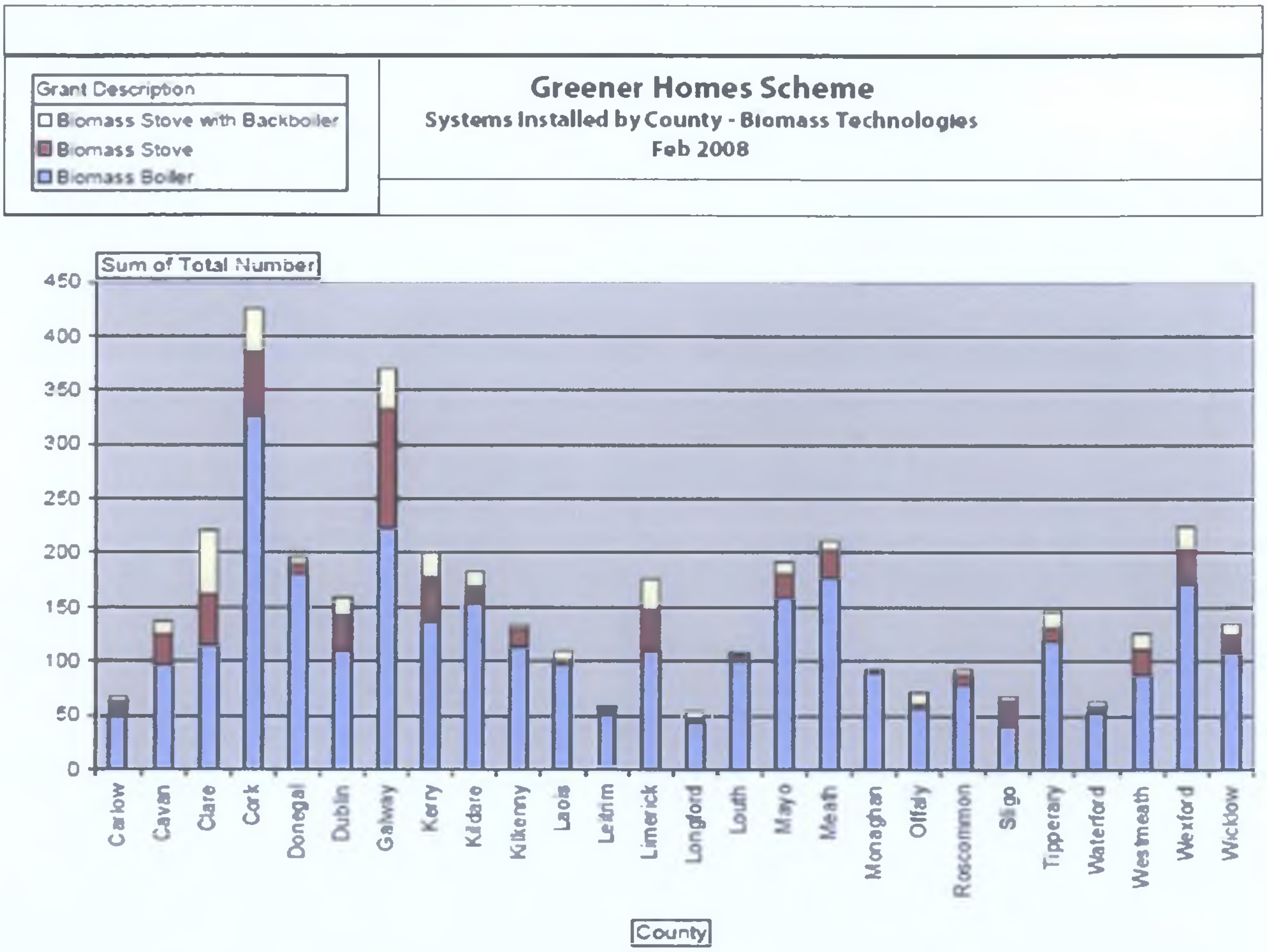


Figure 4.2 Number of boiler systems installed by county – Greener Homes (SEI-stats, 2008)

The new grant scheme called the 'Renewable Heat (ReHeat) Deployment Programme' and provides grant aid for renewable heating systems in industrial, commercial, public and community premises in Ireland. Notably, in addition to wood chip and wood pellets, the grant scheme now includes, '*uniform agricultural and industrial residues, free of any sign of smoke and with emissions comparable to modern oil fired systems*' (SEI-stats, 2008). This effectively opens the door for agri-pellets as a market opportunity in Ireland.

4.4.1 Pellet comparable costs to other fuels per kWh

The oil price reached the US $ 126 per barrel in May 2008 (RTE, 2008) and continues to rise steadily, while pellet costs have remained stable. This can only indicate a greater demand on the supply base of wood pellets and potentially a stress on the global wood supply in future years. Alternative biomass pellets are a real consideration to offset this new and ever increasing demand for fossil fuel replacement world wide. The cost comparison test is a measure of the demand trend expectation. Table 4.1, demonstrates that even with a lower efficiency rate that pellets supplied in bulk are within the target range of natural gas and significantly cheaper than oil.

Table 4.1 Domestic Fuels Comparison of Energy Costs for Space Heating		(SEI-10, 2008)
Fuel Type	c/kWh Delivered	Efficiency Rated
Pellets Bulk	4.40	50%
Oil (Jan 2008)	6.95	55%
Natural Gas	5.47	55%

4.5 Straw - a raw material for biomass fuel pellets

The main raw material used in fuel pellet manufacture is wood waste material. This includes chippings of wood from forestry, forestry thinning, milling waste and saw dust. In Southern Europe where wood reserves are low (Italy, Spain, Greece) other alternatives are being investigated (ALTENER, 2002). The term 'agri-pellets' depicts the development of a new biomass fuel which include, waste straws from various food crops, (barley, wheat, oats), pruning cuttings, garden wastes and food by-products including vegetable peelings, rice husks and hulls from olive oil pressings for example (ALTENER, 2002). In the Southern Europe contexts, straws have been identified as a primary resource for agri-pellet production (ALTENER, 2002). Equally, Eastern Europeans are investigating the possibility of straw from crops including oilseed rape and on a recent visit to Czech Republic, even anaerobic digestate fibers were presented in a pellet form for use as fuel rather than a pelleted fertilizer.

4.5.1 Straw availability in Ireland

Sustainable Energy Ireland (SEI-2, 2003) reported that the there was a significant renewable energy potential that could be derived from agricultural residues. The report indicated that two thirds of the harvested crop of wheat, barley or oats is straw and when other uses were considered that approximately one tenth of the total straw is available for biofuel production. Using the SEI methodology an estimate table (4.2) was drawn up to establish available straw resource in Ireland. The table also calculates the total energy available based on a straw energy value of 13.5/MJ/kg @ 20% moisture (SEI-2, 2003).

Table 4.2 The potential energy available in straw biomass as from 2005 to 2007						
Year	Wheat Straw (Mt)	Oaten Straw (Mt)	Barley Straw (Mt)	Total Straw Million Tonnes (Mt)	10% of Straw = Fuel Pellet Opportunity (Peta Joules)	GWh 'Green' Electricity Generated
2005	1.3	0.2	2.0	3.5	4.7 PJ	394 GWh
2006	1.5	0.3	2.0	3.8	5.2 PJ	414 GWh
2007	1.1	0.3	2.0	3.4	4.6 PJ	385 GWh

Source: (SEI-2, 2003) (Thorne, 2007) (CSO-2, 2004). (CSO-1, 2005) (CSO-3, 2006)

Table 4.2, thus calculates the potential energy available in straw biomass as from 2005 to 2007 ranged from 4.6 to 5.2 PJ. To put this value in prospective, if this straw was combusted in as a primary fuel source in a power station then 385 GWh of carbon neutral electricity could have been generated in 2007 (efficiency of 30% is assumed). Similarly, 2006 and 2005 straw could have delivered 414 GWh, and 394 GWh of carbon neutral electricity respectively.

4.5.2 Agri-pellets, Emissions the burning issue

In a discussion with Bernard Rice, 2007, on the topic of fuel pellets and wood alternatives, Dr. Rice advised that a number of factors need to be considered:

- *The definition of a wood pellet is set down by specification CEN/TS 14961 – therefore mixing of materials or indeed alternative materials cannot be sold as wood chip/pellet.*
- *The emissions of alterative material need to be considered.*
- *Energy value of alternative materials differs from wood and equally combustion properties may not be suitable for conventional wood chip/pellet burners and may have adverse effect on burner approved for wood*
- *Use of other materials in wood chip/pellet burners possibly negates the warrantee of the burner*

At the Bioenergy Conference in Carlow Carroll, 2007, presented preliminary research findings on the topic of pelleting alternative materials. The materials under reviewed were; miscanthus, and straws of oats, triticale, wheat and barley. A number of issues including moisture content, binding properties, chlorine levels and ash content of these materials were discussed during the presentation and are recounted in box 4.1 below.

Preliminary Findings – Straw Pellets as an alternative to wood **Box 4.1**

Moisture content

Moisture content can vary from crop to crop of a single crop variety. But more importantly, moisture content can vary from bale to bale within one crop. Inconsistent moisture levels causes problems in the grinding and pelleting stages of the process. To this end Teagasc have set up an additional study to investigate the 'on-the-farm' drying process, examining how bales dry in the natural environment.

Binding properties

Binding properties are different in raw materials variants. Poor binding properties results in pellet inconsistency and poor pellet definition. Poor pellet definition may not manifest itself until after a rest period of 24 hours, where pellets appear properly formed coming off the press but then levels of fines increase significantly following a rest period. The quantity of lignin in the raw material and rate of cooling following pressing are contributory factors to pellet definition. Where a pellet specification defines a maximum level of fines, poor definition could result in a day's production being down graded or reworked.

Chlorine level

Chlorine is naturally present at various levels, and is dependent on crop variety and method of harvesting. Generally, chlorine is associated with the leafy green area of a plant. Where plants are allow ripen and are harvested without greenery then chlorine levels are significantly reduced. Miscanthus for example has very high chlorine levels in its leaves while chlorine levels are significantly less in the stalks.

The impact of high levels of chlorine is that it causes pitting and rusting in metals and is corrosive to boilers. A higher grade more resistant material is required for the boiler build and this would increase the overall cost of the boiler. High chlorine level and low combustion temperatures have been linked to the production dioxins in gas emissions. Both issues need further research.

Ash levels

Ash levels vary from crop type to crop type. Typical values for miscanthus, rape straw and wheaten straw are 2.0%, 7.2%, 6.6% respectively. In contrast, wood ash level is as low as 0.5%.

The impact of high ash levels include;

1) Design alterations to the combustion chamber
2) Design alterations to the ash box to cater for additional ash load
3) Increased dust emissions
4) Increased risk of clinker formation in the grate, combustion chamber and flue
5) Increased frequency of cleaning out the ash pit

(Clinker is formed when ash melts. Ash becomes molten and acts like flowing lava, however, when cooled, the clinker solidifies and can cause blockages in flues, chimneys and fire grates disrupting air flow and thus combustion efficiency). ***Approved by (Carroll, 2007)***

Obernberger I, 2004, recommended straw pellets should be used in medium and large scale plants rather than in small scale residential heating units. Large-scale burners such as power plants are better able to withstand the negative impact of emissions and have generally more sophisticated combustion and emission control technology than domestic burner systems (Obernberger I, 2004). Despite this, residential straw pellet combustion appliances are already on sale in Sweden, Germany, Denmark and Austria (Olsson, 2006).

In a study of wheaten straw and peat/wood pellets as fuels Olsson, 2006, showed that the emissions were relatively low during combustion. However, wood pellets did burn more efficiently and with even lower emissions than straw and peat/wood pellets during flame burning. Also, Olsson, 2006, identified that emissions of the polycyclic aromatic hydrocarbons naphthalene and henanthrene were higher from straw than from peat/wood pellets. Combustion of wheaten straw differs in many ways from the combustion of wood pellets and may therefore lead to problems with the organic compounds measurements (Olsson, 2006).

In more recent studies from Sweden, (C. Tullin, 2008) investigates emission levels from straws including barley and rape straw versus wood (table 4.3). Ash levels are highest for barley at 6.5%, rape straw has 28% less ash than barley, while wood ash levels can be as low as <0.5%. The interesting point, however, is the melting point of the rape straw ash is similar to that of wood, which means the probability of clinker is significantly less if rape straw is used. Unfortunately the majority of straw available to pellet in Ireland is barley straw (table 4.2), so the problem of clinker will need to be addressed in some fashion.

Chlorine levels are high in rape straw relative to wood pellets (0.18% to 0.01% respectively) and barley straw pellets at 0.71% have the highest chlorine level (table 4.3). C. Tullin, 2008, recognized that conventional secondary emissions methods were not easily adapted to small scale burners, being cumbersome to apply and cost prohibitive. As such alternative abatement methods were considered. These included the use of additives at point of combustion and mechanical intervention by means of under ground flue extraction.

Table 4.3	**Characteristics of Pellet Variants**		
	Barley Straw pellets	**Rape Straw pellets**	**Wood pellets**
Dry Matter % (DM)	90.7	90.7	93.5
Ash %	6.6	4.7	<0.5
Melting point of Ash	<980 °C	1590 °C	1550 °C
Chlorine %	0.71	0.18	0.01
MJ/kg of DM	17.4	17.6	19.1
kWh/kg of DM	4.8	4.9	5.3
		Source: extract from (C. Tullin, 2008)	

Limestone was added at 2% to the fuel and reductions of 30% dust and 20-40% sulphur and chlorine was achieved.

Flue gas emissions are diverted into an underground pipe, where the drop in temperature causes the moisture to condense. This condensate is channelled into a condensate well, where it can be neutralized. Additionally, ash and dust particles are trapped in the under ground flue pipe. A 40% reduction in dust and sulphur was achieved and a 70% reduction in chlorine levels was recorded.

The underground flue system can easily be adapted for use in small scale domestic burner systems where the fuel used is acid rich with acidic flue gasses. The underground flue installation costs were documented as € 900.

Incidentally, S. Mani S. X., 2006, cites the use of limestone (at < 2.6%) for use as a binder. It is possible that both emissions and binding issues could be resolved with the one additive.

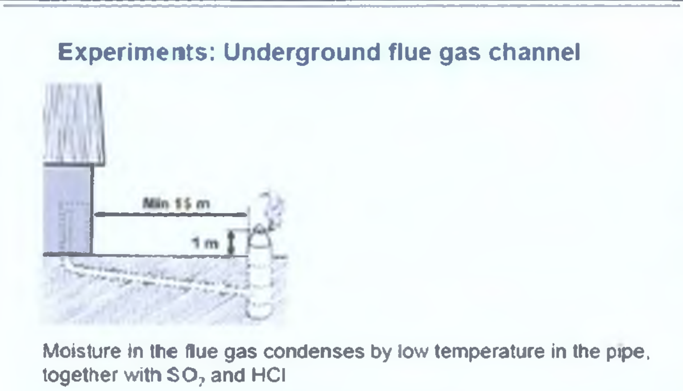


Figure 4.3 Under ground flue gas channel source (C. Tullin, 2008)

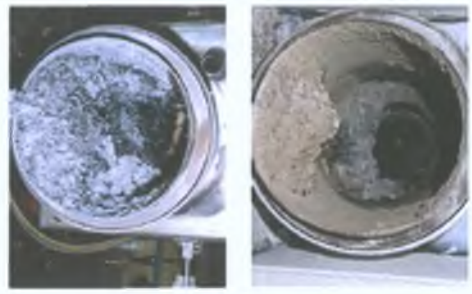


Figure 4.4 Example of clinker build up in flues.

Source: (C. Tullin, 2008)

4.5.3 Emission Legislation

Boiler emissions must comply with regulations set out in the Air Pollution Act 1987.

"Air pollution" in the Air Pollution Act 1987 is defined as 'a condition of the atmosphere in which a pollutant is present in such a quantity as to be liable to—

(i) be injurious to public health, or

(ii) have a deleterious effect on flora or fauna or damage property, or

(iii) impair or interfere with amenities or with the environment'.

Where national limits for emissions are not available then, for boilers up to 300kW, boiler emissions should conform to Euro Norm EN303-5 1999 (eca.gov.uk, 2008).

4.5.4 Burners designed for the combustion of straw

A review was conducted on the boilers presented at the Bioenergy Conference in Carlow 2007, to investigate number and percentage of alternative fuel burners available on the Irish market. Of the 33 brochures collected and examined, 4 burners were approved for burning straw pellets. This was an encouraging result on two points. Over 12% of the boilers were approved for burning straw and four companies recognized the Irish market as a business opportunity by presenting their products at the Bioenergy conference. One of the interesting aspects of alternative fuel pellet burners is that their design is usually approved to burn a variety of materials, including wood pellets, whereas a wood pellet burner is under warrantee for the combustion of wood pellets only. The web address for the companies presenting approved biomass burning were, www.verner.cz, www.primeenergysolutions.ie, www.ecotec.net, and www.justsen.dk.

4.6 Pelleting supply and demand summary

In summary, straw pellets can be used as an alternative fuel to wood pellets There is sufficient waste straw in Ireland to produce 350,000 tonnes of straw pellets. Specially adapted burners are required when using agri-pellet fuel in respect to combustion and emissions. There are approved burners on the market for the combustion of straw pellets. Emissions can be abated using additives and smart design for domestic boilers. Emissions abatement equipment may be required for larger scale boilers in line with the Air Pollution Act 1987.

Mixing of straw variants looks unfavourable given the learning's of 4.2. The approval of fuel, for a specific burner type, is the responsibility of the burner manufacturer and not the role of the fuel supplier. Burners cannot be placed on the market with out certification from a regulatory body. And grant approval from SEI will not be given for unapproved / non certified burners.

The market demand is set to increase, driven on by oil costs and continued support under grant schemes.

The potential customer base can be identified as follows:

1 Large scale combustion - power generation plants – Domestic/ Export
2 Large scale industrial plants using solid fuel burners to generate heat/electricity
3 Medium scale facilities with approved straw burners
4 Domestic/residential with approved straw burners

4.7 Fuel pellets, the pellet and the process

Fuel pellets are a source of a renewable energy. The calorific value and energy output potential are similar for rape straw and barley straw varieties, 17.4, 17.6 MJ/kg (Table 4.3), and when compared to wood there is a 8% calorific value difference in favour of wood pellets (C. Tullin, 2008).

4.7.1 Fuel pellet defined

The fuel pellet has a cylindrical form, 6mm to 8mm in diameter and must not be longer than 38mm. Pellets are an easily managed, free flowing, virtually dust free fuel. The Pellet Fuel Institute, an association of stove producers, fuel producers and their suppliers, has established two residential fuel standards, a Premium Grade and a Standard Grade (R H. Leaver, 2008).

Figure 4.5 Field to fuel a) straw bales, b) straw pellets, c) pellet burner
Source: Vasen (ETA) 2005

The Premium Grade Pellet Standard - specifies the inorganic ash content shall be less than 1%, the pellet bulk density shall not be less than a specific gravity of 0.64 and the fines (<3mm) in the pellets shall not be more than 0.5% by weight (R H. Leaver, 2008).

The Standard Grade Pellet Standard – has the same criteria for % fines, bulk density and dimensions but specifies less than 3% for inorganic ash. (R H. Leaver, 2008). Figure 4.5 b) depicts the straw pellet form.

4.7.2 Description of a Typical Biomass Pelleting Operation

A typical process (Figure 4.6) includes infeed conveyors, chopping, grinding, pelleting press, cooling, storage and perhaps bagging dependant on market demands.

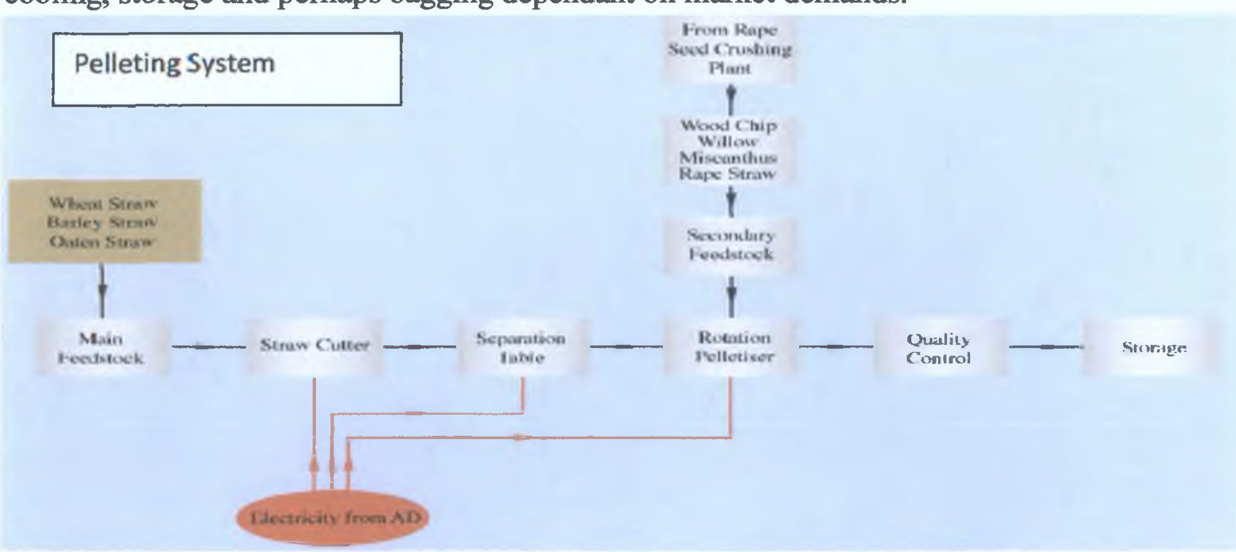


Figure 4.6 Biomass Pelleting Process Source: (Ryan-Purcell, 2008)

Intake conveyors feed the material, through a foreign body screen to a chopper, where the material is cut into 2-4 mm in length. Once chopped, the material is feed through to a hammer mill. The material is then conditioned by heating the fibres and lignin in the wood material (S. Mani S. X., 2006). In the cooling stage, the conditioned fibres constrict to the original size, improving integrity and reducing fines (Keelagher, 2007). Where lignin levels are low in straws for example, additional binders can be added. The most widely used binders in the animal feed industry are molasses, lactose waste water (Green, 2007), calcium lignosulfonates, bentonite, starches, proteins and calcium hydroxide have also been quoted by S. Mani S. X., 2006. Lignin can also be added at 0.2% and acts as a natural binder with excellent result (Feed, 2006).

The pelleting press is the main piece of equipment on the pelleting line, both in terms operating costs and energy consumption (Fig 4.7). While the engineering process is simple, the engineering design is intricate. Raw material is fed into the product inlet at a predetermined rate. Roller bearings rotate pressing the fine dust material through the die, a flat plate with holes. The diameter of the holes in the die and the thickness of the die dictate, a) the diameter of the pellet and b) the length of the pellet.

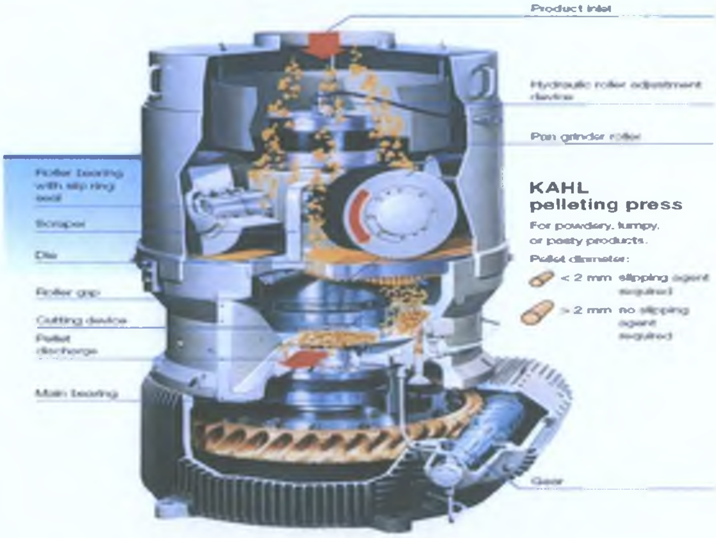


Figure 4.7 Kahl a typical press system

Figure 4.8 depicts the size and nature of die change over on a large scale pelleting processing line. The temperature of the pellets coming off the press can range from 70°C to 90°C. Elevated temperatures need to be reduced to within 5°C of ambient as quickly as possible to maintain pellet integrity and definition (Keelagher, 2007). To this end, once the pellets are pressed they are passed through a cooling system. This system can be as simple as cooling fan passing ambient air over the pellets as they pass on their way to storage silos or a complex counter current air system with a cooling system with condensation extraction systems (S. Mani S. X., 2006). Cooled pellets can then be transferred into bulk storage for bulk dispatch or bagged off into various customer specific bag sizes. 1000 kg, 18 kg, 12.5 kg bags are currently available on the Irish market.

Fig 4.8 Large Scale Press die – being fitted.
Source: Coford Connects

4.7.3 Taking a closer look at pelleting systems in operation

As part of the study two pelleting processes were reviewed. Balcas, located in Fermanagh was selected as it was a new planted specifically designed for the pelleting of wood from waste saw dust. And Soma Engineering in Czech Republic was selected as a representative pelleting operation specifically designed for the pelleting of straw. Details of the site tours are contained in Appendix 4.3 (Balcas) and Appendix 4.4 (Soma Technology)

The comparisons between processes can be summarised as follows;

- Balcas was a high capacity and highly automated line carrying a price tag of £15 million. While Soma offered an agricultural solution, low capacity and low automation line and a matching price tag of € 250,000.

- The Balcas operation required a drying step and resulted in consumption of large quantities of thermal energy to dry the saw dust from 50 - 60% moisture to a target of 12%. While in the Soma process, the straw was delivered at the correct moisture value and as such did not require a drying step. The Soma line did need a facility or access to add a fine mist of water or other additives to improve pellet durability.

- The quality of the pellets from the Balcas line was far superior to that produced on the Soma line. But this must be qualified in two respects, firstly the Soma lines were only in operation for 1 and 3 weeks respectively and secondly the specification of the customer (a local peat power station) requested a low grade pellet and was satisfied with the pellet as presented (Figure 4.21- Appendix 4.4).

- The Soma Engineering process is more suitable to a small scale Bioenergy Park, however assurance on issues such as health and safety, product quality versus customer/boiler expectation, output per hour and finally energy demand per tonne of product would need to be addressed before entering a purchase agreement. Line output, energy demands and the cost of pelleting on a small scale operation such as Soma will be examined further in chapter 8.0

4.8 Pelleting straw -a question of bulk density

The bulk density of loose straw biomass is generally 30 kg/m^3, pelleting can increase this bulk density to more than 500 kg/m^3 (S. Mani, 2006). Pellets contain nearly half of the energy of oil in terms of weight, and one third in terms of volume. Wood chips, by contrast have approximately 18 times less energy than oil per unit volume (ALTENER, 2002). When considered together this implies that from a market access point of view, that transportation of pellet fuel would be significantly more efficient, cost effective and a better environmentally option than the transportation of wood chip.

The distance over which pellets can be transported before the cost of this service becomes equal to its production is not too large. For example, to transport via the trucking route, over a 1000 km distance, costs arise between 50 and 100% of the production costs of pellets itself, while trains consume 3 times less primary energy per 1000 km travelled (ALTENER, 2002). Ironically, fuel movement from continent to continent can be cost and energy efficient where the shipping route is used. The transporting of pellets great distances thus can be a competitive alternative and explains the economics of the shipping of the Canadian supply of pellets into Rotterdam, Europe.

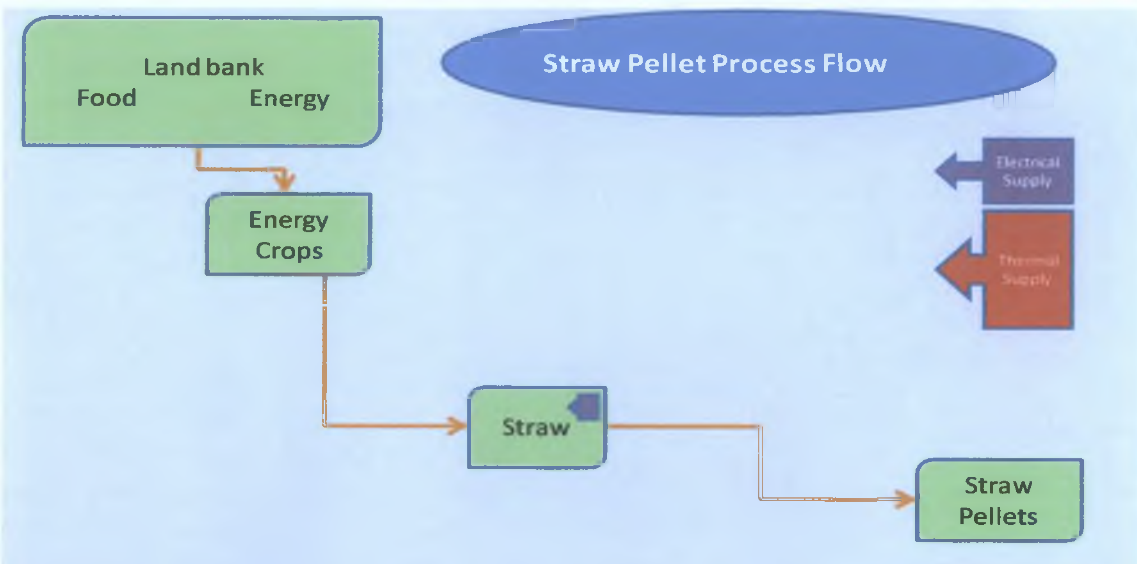
4.9 Integration opportunity of Straw Pellets

SEI estimate that 10% of straw produced annually is wasted and could be utilized as a renewable energy resource. From an environmental view point, where the bale of straw can be burned to generate heat in local units, clearly, this should be the first consideration. However, once this market is saturated, the next best solution for straw, as a fuel, is possibly in a pellet format where the fuel pellet market opportunities can then be realized.

Densification of straw into a pellet increase transport efficiencies. The net result ensures that greater market opportunities are opened up.

Pelleting straw, while consuming energy, is also adding value by generating a biomass fuel that relative to the straw bale is clean, efficient and easy to use. Systems are being designed to handle pellets that minimize the work load of the domestic user.

The calorific value of straw pellets is comparable to wood pellets. Wood pellets having the higher calorific value of 8% greater than straw pellets. However, the value is such that straw pellets can be sold and used in an identical fashion as wood pellets. Incidentally there is a similar disparity between the calorific value of biodiesel and diesel.



4.22 Straw pellet process flow simplified for Integration

4.10 Constraints identified

As straw is associated with arable farming activity, then obviously the primary constraint is its location in an arable region. Furthermore, locating in close proximity to markets or market access is important from a cost perspective.

The issues of combustion and emission to air is discussed and while there are straw burners available on the Irish market, further study is required in this area to ensure that straw combustion remains a safe alternative to fossil fuel.

While wood pellet burners have been installed across Ireland, the use of straw pellets are not approved in wood pellet burners. The Bioenergy Park needs to develop the straw pellet market in conjunction with alternative pellet burners.

5.0 Anaerobic Digestion

Anaerobic digestion is far from being a modern day application. As early as the 1000BC Assyrians had employed anaerobic digestion technology to heat bath water (L. Bandieramonte). The industrialization of AD began in 1859, with the first digestion plant in having been established Bombay (Ostrem, 2004). The first full scale application in Europe took place in Exeter (UK) where in 1895 the biogas recovered from a sewage treatment facility was used to fuel street lamps (Callander IJ, 1983).

5.1 Introduction

Anaerobic Digestion (AD) is included in the Bioenergy Park as the 'energy generator', creating renewable energy from waste to drive the other process within the site. This chapter investigates anaerobic digestion and examines the inputs and outputs of an anaerobic digester in the context of a Bioenergy Park. The chapter gives an overview of the anaerobic digestion process. Key aspects in relation to anaerobic digestion are considered in the Irish context as follows;

- The advantages and disadvantages of AD in the local agricultural community
- Basic design criteria for an anaerobic digester
- Feedstock characteristics and energy generation potential
- The impact of the Animal by-products directive in the Irish context
- Digestate production and land spreading in line with the Nitrate Directive

5.1.1 European experience

The table below provides comparative information on biogas production relevant to a cross section of Western European countries including Ireland since 2001. In Germany for example, there are over 2000 farm based AD plants and over 4000 sewage works plants (SEI-3, 2004).

Table 5.1	**EU25 Biogas Production (in ktoe)**					
Country	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Germany	600	659	685	1291	1594	1923
United Kingdom	904	1076	1151	1473	1600	1696
The Netherlands	161	149	154	110	119	119
Austria	56	59	64	42	31	118
Denmark	73	62	62	93	92	94
Ireland	28	28	28	19	34	35
TOTAL	**2572**	**3062**	**3291**	**4216**	**4707.7**	**5347**

Source: EurObserver, Biogas Barometer 2004-2007

ktoe = Kilo Tonnes of Oil Equivalent

The German government provide for favourable electricity feed in tariffs for electricity produced from biogas. Similarly the Danish government provide for incentives that include support grants, CO_2 tax rebates, and access to special loans while also providing support legislation with regard to 'nutrients to ground water' and 'slurry storage' to facilitate development of AD (SEI, 2004). In 2004, there were 129 plants, ranging from farm based plants, co-operative, to industrial plants and sewage treatment works in Denmark (SEI-3, 2004).

5.1.2 The Irish Experience

As can be seen from the 'Biogas Barometer', (Table 5.1 above) Ireland's biogas production performance, while on the increase, is significantly less than the UK and Germany. Denmark, perhaps a geographically more comparable nation, produces 3 times more biogas than Ireland based on 2006 figures. The first full-scale digester was installed in the 1980s on a farm in Bandon, Co. Cork (Mahony, 2002). Kerry Ingredients, Listowel, Co. Kerry, ADM Ringaskiddy, Co. Cork and Carbery Milk Products, Ballineen, Co. Cork are examples of industrial processes which utilize anaerobic digestion as a waste treatment tool (Mahony, 2002). These statistics indicate how far Ireland is behind its European cousins, in terms of experience and of working knowledge of anaerobic digestion and similarly its use of organic wastes as a natural resource for energy production.

5.2 Anaerobic Digestion

Anaerobic digestion (AD) is a natural biological process of decomposition that takes place in the absence of oxygen. Within the process organic matter is broken down to its simpler chemical components. The AD process can be used to turn organic residues from livestock farming, food processing industries, waste water treatment sludge among others into biogas and digestate. The biogas can be used to generate heat and/or electricity. The digestate can be separated into its two primary components, fibre and liquor. The fibre fraction can be used as a soil conditioner while the liquor fraction can be used as a liquid fertilizer. The biogas content generally comprises of methane at (60-80%) and carbon dioxide at (20-40%) plus a small quantity of hydrogen sulphide (H2S) and ammonia (NH3), as well as traces of other gases. The wide range in the percentage of the methane values gives a sense of the impact of various parameters such as variable feed stocks, plant design and digester performances. In section chapter 7.0 feedstocks and energy values are examined more closely as energy yield is critical to the performance of a Bioenergy Park

5.2.1 AD for the microbiologists

AD is a complex bacteriological and biochemical process, where distinct groups of anaerobic bacteria work together in a symbiotic relationship. Each bacteriological group is dependant on the activities and the output of the previous group of bacteria. Methane production is thus divided into four phases. The first phase is where the large compounds of carbohydrates, fats and proteins are broken by hydrolyzing bacteria into smaller molecular groups of amino acids, fatty acids and sugars (Figure 5.1). Acid forming bacteria feed on the newly available smaller molecules. This is a fermentation process step and the outputs include propionic and butyric acids, hydrogen and carbon dioxide as well as lower alcohols. However this group of bacteria is inhibited by its own output of hydrogen and as such relies on the methane producers to detoxify their environment. The acetic acid forming and finally the methane forming bacteria can now become established within the system. The energy yield of methane-forming bacteria is very low and causes them to grow and multiply very slowly. This slow growth is responsible for the gradual release of methane over an extensive time frame (in bacteriological terms). In addition to the methane-producers, another group of bacteria called the sulphate reducing bacteria, form hydrogen sulphide from organic and inorganic sulphur compounds and hydrogen. (Bilitewski B, 1997)

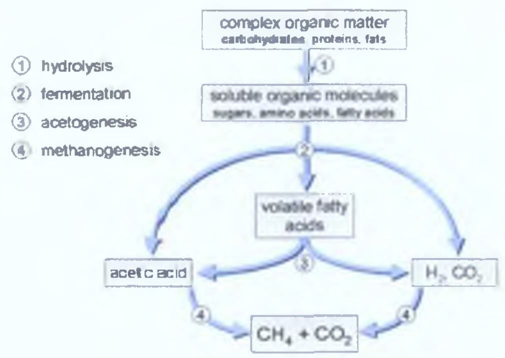


Figure 5.1 AD Biological Process Flow
Source http://water.me.vccs.edu/courses/ENV149

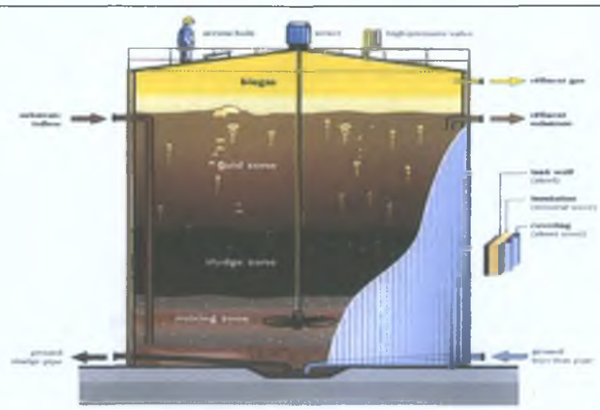


Figure 5.2 Anaerobic digester from Haase
Source www.daviddarling.info/anaerobicdigestion

In summary the out puts of the anaerobic digester are as follows:

- Biogas which can be used to generate heat and/or electricity;
- Fibre, which can be used as a soil conditioner;
- Liquor, which can be used as a liquid fertilizer.

5.3 The advantages and disadvantages of Anaerobic Digestion

Anaerobic Digestion has a number of benefits which include reduction of greenhouse gas emissions, reducing land and water pollution potential, nutrient recycling, production of renewable energy, odour emission abatement and pathogen reduction in slurries. However the perception of anaerobic digestion as a waste process mechanism is an unfortunate but real label associated with anaerobic digestion in the Irish context. The National impact of converting local biodegradable waste to energy is considered in Appendix 5.3.

5.3.1 Reducing emission of greenhouse gases

Methane, as previously mentioned, is the main constituent of the biogas and is a major contributor to greenhouse gas emissions in Ireland (EPA-1, 2005). In 2006, of the 69.77 million tonnes (Mt) of CO_2 equivalent emitted by Ireland, agricultural practices contributed 27.7%. Methane has 21 times greater global warming potential (GWP) than carbon dioxide (EPA-3, 2006). By trapping methane and generating energy through gas combustion, the quantity of methane lost to the atmosphere is reduced by a factor of 18. Equally, energy generated from waste derived methane is a renewable source of energy, displaces its value in fossil fuels such as coal and oil.

5.3.2 Reducing land and water pollution potential

Land and water pollution potential can be reduced through efficient waste management. AD can reduce the risk of pollution by stabilizing and allowing more control of residues (EPA-1, 2005) (Kottner, 2004). AD is not a complete waste treatment system but rather an effective first step for the removal of organic carbon and its conversion to methane and carbon dioxide. All other minerals and elements that existed in the feed stock still remain in the digestate either as solids or in liquid form. From an environmental view point, the impact of this is that the Chemical Oxygen Demand (COD) or pollution potential has been significantly reduced due to the removal of organic carbon but the eutrophication potential remains unchanged (EPA-1, 2005).

5.3.3 Nutrient recycling

The nutrients available in the digestate (liquor and fibre) can be used as part of an overall fertilizer nutrient management plan. The use of this 'biofertilizer' reduces the need for the production and use of synthetic fertilizers. The nature of the nitrogen and phosphorus contained in the liquor are more readily available for plant uptake making the biofertilizer more efficient in terms of nutrient transfer than untreated slurry (EPA-1, 2005). While it is possible to further treat the digestate and process it back to the basic elements such as nitrogen, phosphorus, water and others, this would be a very expensive option and not conducive to a small scale plant. Equally the EPA-1,2005, have investigated current technologies for removal of nitrogen and phosphorus from animal slurries and have indicated that further technical development is required (EPA-1, 2005).

5.3.4 Renewable Energy Potential

Renewable energy from organic waste is in the form of biogas with a high methane content. This methane can be used as a fuel in its own right or further processed to produce electrical or thermal energy through burning in generators, boilers or combined heat and power units (CHP). The renewable energy potential of slurries will be examined in detail in chapter 7.0. Box 5.2 below gives comparisons of one cubic meter of biogas with other fuels.

Renewable energy potential of biogas per cubic meter	Box: 5.1
One m³ of biogas with a methane content of 70% (20MJ/m³) is equivalent to:	
0.61 litres of petrol	
0.58 litres of alcohol	
0.90kg of charcoal	
1.70kWh of electricity (assuming a conversion efficiency of 30%)	
2.50kWh of heat only (assuming a conversion efficiency of 70%)	
1.70kWh of electricity and 2.5kWh of heat in CHP system (Combined heat & power)	
Source: (Mahony, 2002)	

Warburton, 1997, cites that one m^3 of biogas with a methane content of 70% (20 MJ/m^3) is equivalent to 1.70 kWh of electricity and 2.0 kWh of heat in CHP system (Combined heat & power). While Murphy, 2005, estimates that one m^3 of biogas with a methane content of 55% will yield 2.04 kWh of electricity (35% electrical efficiency) and 2.33 kWh of heat (40% thermal efficiency) in CHP system (Murphy, 2005). Calculating this to 70% methane content in biogas, this equates to 2.6 kWh of electricity and 3 kWh thermal supplied per 1 m^3 of biogas.

5.3.5 Reducing odour

Land-spreading of untreated slurries, a standard activity on Irish farms, is associated with significant odour nuisance. AD can reduce the odour from farm slurries and food residues by up to 80%. (EPA-1, 2005) (Kottner, 2004). Figure 5.2 demonstrates the comparison environmental impact of odour from raw and digested manures.

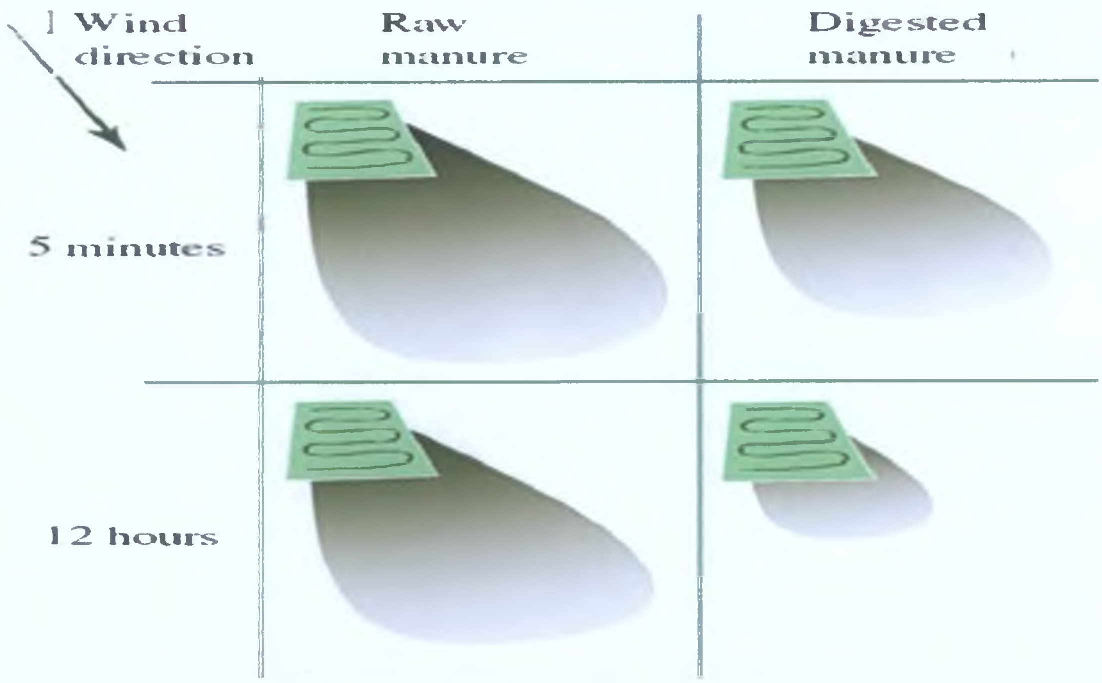


Figure: 5.2 Odour reduction as a result of anaerobic digestion **Source: (Høegh, 2007)**

5.3.6 Pathogen reduction

Anaerobic digestion results in the reduction of pathogens in the final digestate. Thermophilic and mesophilic processes results in significant load reduction of bacterial, viral and protozoan pathogen. Where a hygienization step is introduced (70°C for 1 hour), the pathogen load is further reduced. This provides for a public health and animal welfare benefit (EPA-1, 2005).

5.3.7 The perceived disadvantages of anaerobic digestion.

The big issue is financial costs. Capital costs and operational costs are significant and pay-back on investment is generally 20 years when considered as a stand alone process. There is currently no means of payment for improved environmental conditions, such as the reduction in greenhouse gas emissions (GHG) or the reduction in pollution potential. In addition, where combined heat and power (CHP) is used, sourcing an outlet for thermal capacity and thereby realising the full financial potential, is a problem in the Irish context.

Another issue for consideration is site location. Anaerobic digestion is seen a waste operation and in this context 'NIMBY' (not in my back yard) is applied. While other European countries reap the energy benefits of converting organic waste to energy and fertilizer, Ireland imports 90% of their energy requirements and 100% of its synthetic fertilizer.

Note for perspective, Organic Kompost Limited was refused planning (PLno 20.211827) in Roscommon for a central anaerobic digester in 2004, and Bioverda Sustainable Energy was refused planning permission for a large central anaerobic digester in Cork in 2007. Bioverda were planning to build a 250 kilo tonne anaerobic digester plant, which would have provided 30 local jobs, generating 32 MW of renewable electricity with a capital investment of 75 million euros (Hogan, 2006).

Figure 5.4 AD at Camphill Community
Source: (Healion, 2005)

Figure 5.5 New Age – Egg Shaped AD
Source: Water-technology.net/Island-Road

5.4 Key criteria for the design of an Anaerobic digestion system

There are a number of key criteria to be considered when designing an anaerobic digester, and these include the percentage solid content of the feed stock material, operating temperature range and finally the retention time required to maximize biogas yield.

5.4.1 % Total Solids

A covered lagoon digester is an earthen lagoon fitted with a cover that collects biogas as it is produced from the manure. These digesters are best suited for flush manure collection systems with total solids content of 0.5 to 3 percent (EPA.USA, 2002).

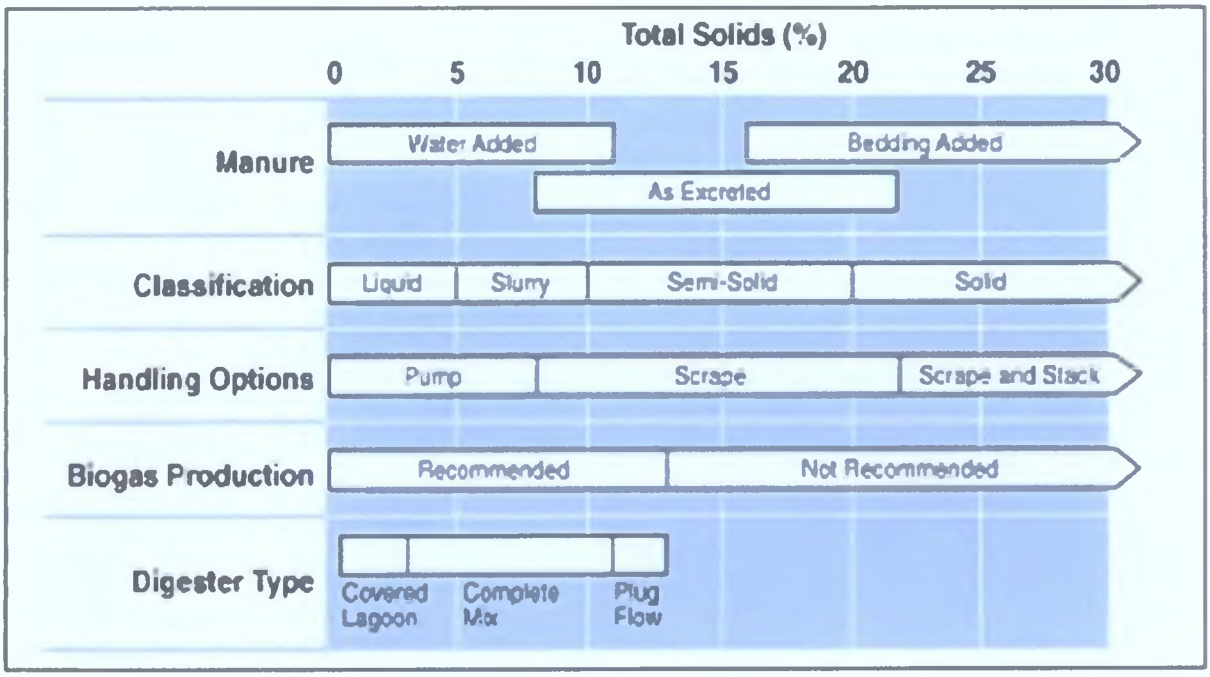


Figure 5.6 Choosing the Digester type based on Total Solid % **Source: (EPA.USA, 2002)**

A complete mix digester is a heated tank, constructed of either reinforced concrete or steel, with a gas-tight cover. The digester contents are mixed periodically, either by a motor-driven impeller or a pump. This digester type works best with slurry manure and with a total solids content of 3 to 10 percent (EPA.USA, 2002).

A plug flow digester is a long, relatively narrow, heated tank, often built below ground level, with an air tight cover. Plug flow digesters are used only for dairy manure. This type of digester requires thick manure ranging between 11 and 13 percent total solids. Plug flow digesters can tolerate some bedding, but the amount should be minimized, and sand bedding must be avoided (EPA.USA, 2002).

5.4.2 Operating Temperature

Operation temperature of an anaerobic digestor can be one of three ranges:

1. Psychrophilic with an operating temperature around 10^0C
2. Mesophilic with and operating range between 32 and 50 ^0C
3. Thermophilic with an operating range between 50 and 70^0C (Bilitewski B, 1997)

In general, profile 2 and 3 are more frequently utilized for anaerobic digestion. Mesophilic is a more robust biological process, has less heat energy requirements and the process control technology is cheaper and easier to operate. However, gas yield is greater, retention time is reduced and pathogen kill is improved in the thermophilic process (Bilitewski B, 1997). The relationship between temperature and biogas yield is displayed in figure 5.7 below.

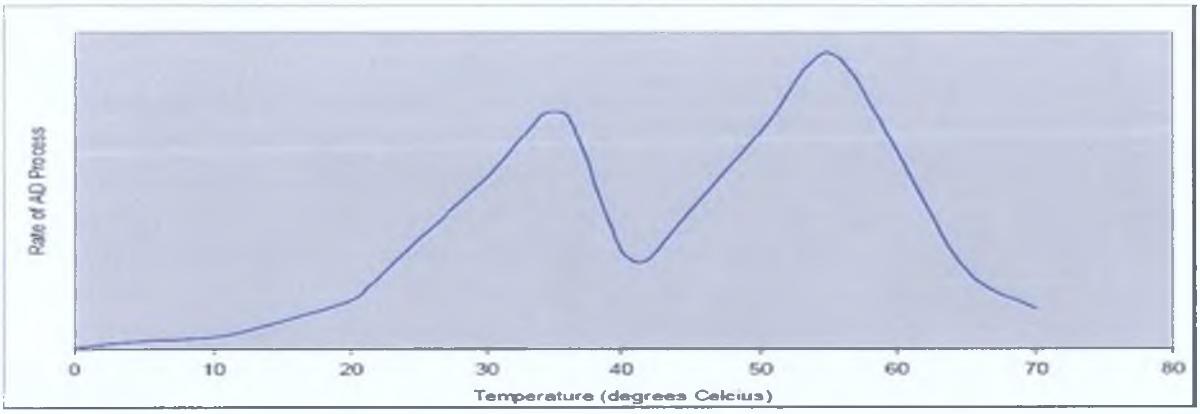


Figure 5.7 – Influence of temperature on biogas production Source (Poliafico, 2007)

There are a number of important observations that can be made from this graph. Thermophilic operation conditions give a higher rate of processing over mesophilic operating conditions. While bacteria can grow successfully at a wide range of temperatures, there is a sharp decline in production once there is a drift from optimum temperature. The stability of temperature is even more important than the value itself (Thy, 2008). Balanced temperature control will be necessary in an anaerobic digester to maximize gas yield. This can be achieved by good heat transfer facilities and appropriate insulation on tanks and valves. For the purpose of this study the mesophilic operating temperature range will be considered as the range more appropriate for a local small scale anaerobic digester.

5.4.3 Retention Time (RT)

Retention time means the length of time the feed stock will be retained in the digester. The retention time depends on the temperature range being used, the digester load, bacteria population size/concentration and the desired degree of degradation. Figure 5.8 over leaf presents a typical bacterial growth curve. When bacteria are grown in a closed system the population of cells initially adjust to the new medium (lag phase) until they can start growing regularly by the process of binary fission (log phase). When their growth becomes limited, the cells stop reproducing (stationary phase), until eventually they show loss of viability (death phase). Note the parameters of the x and y axes and growth curve vary dependant upon the bacteria population being observed (Kenneth, 2007). For example methanogens reach the stationary phase between day 14 to day 19 and gas production is in decline there after, (dependent on feed stocks).

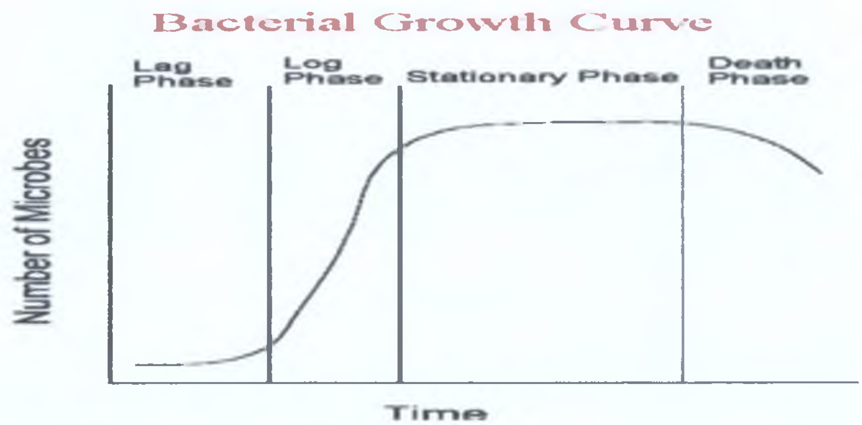


Figure 5.8 Bacterial Growth Curve. **Source : http://bioc.rice.edu/**

When considering the retention time, the feedstock content and bacterial growth curve needs to be considered. For effective operation, consideration should be made in the design stage to minimize time of bacteria establishment, or lag phase. This can be done by back feeding bacterial load to incoming substrate. Various methods are used to prevent loss of viable population such as counter current feeding and recirculation of substrate liquor back into the incoming feed. Also, the design should ensure that feed stock is kept in suspension, optimizing food availability and growth opportunity for the bacteria in each phase. Method of mixing by scrape surface stirrers, slow agitation paddles or gentle gas bubbling will keep the solids suspended within the liquor to maximize the feeding opportunity of the bacteria (Clark, 2007).

Retention time can also be reduced by optimizing the process. This can be done by splitting the fermentation and methanogen phases using a two tank system. Alternatively, install a biogas collection dome on the final storage tank to capture methane produced in the final bacteriological stage (Clark, 2007). Up to 10 – 15% additional gas could be captured in the final storage phase (Mahony, 2002).

5.4.4 Contributory factors that encourage microbial population growth

5.4.4.1 Nutrient balance

The feed stock must contain sufficient balance of nutritional substance to allow a stable decomposition process. Inhibitors such as antibiotics or disinfectants can reduce or stop the bacterial growth and subsequently, impede gas production. Bacteria also need trace elements and nutritive salts to grow. Heavy metals and salts are toxic to the anaerobic digestive system and need to be avoided (Bilitewski B, 1997). The nutrients of carbon, nitrogen and phosphorus are required in an anaerobic process in the ratio of (C:N:P) 100:5:1 (Steffen & Szolar, 1998)

5.4.4.2 pH balance

pH control is critical in both the operation of an anaerobic digestion system and the production of gas. In general, the pH range should be between 5.5 and 8.5, however the pH requirements change from bacteriological phase to phase. For example the fermenting bacteria prefer slightly acidic pH, whereas the methane forming bacteria work best nearer neutral pH (optimum performance in the range 7.0 –7.2) (Bilitewski B, 1997).

5.5 Feed Stocks

Biogas yield and methane yields will be dependant upon consistency of feedstock, volatile organic solid content, material size and consistency of material size and mixing of material.

5.5.1 Feed stock suitable for anaerobic digestion

Feedstocks can include any organic substrate that can be converted to methane by anaerobic bacteria. Feedstocks range from readily degradable wastewater to complex high-solid waste.

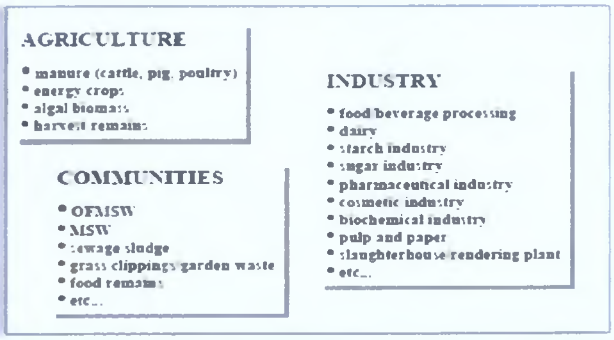


Figure 5.9 Range of substrates for anaerobic digesters. **Source: (Steffen & Szolar, 1998)**

Even toxic compounds may be degraded anaerobic conditions depending on the technology applied. (Steffen & Szolar, 1998).

Figure 5.9 depicts the range of organic materials that can be anaerobically digested. The list is not limited.

5.5.2 Feed Stock Characterization

An extensive European study on anaerobic digester feedstock characteristics and resultant biogas and methane yield was carried out by AD-NETT (Steffen & Szolar, 1998). A comprehensive table of biogas and methane yields was derived. In this table feedstocks are tabulated with probable ranges of total solids(%), volatile solids(%), carbon : nitrogen ratio, biogas yield and methane % in biogas and other general characteristics and operational parameters of agricultural waste digesters.

Table 5.2 Biogas production and composition from different feedstocks

Feedstock	Total solids (TS), %	Volatile solid (VS), % of TS	Biogas yield, m^3/kg VS	Methane content, vol. %	Retention time, days
Pig slurry	3-8	70-80	0.25-0.50	70-80	20-40
Cattle slurry	5-12	75-85	0.20-0.30	55-75	20-30
Chicken slurry	10-30	70-80	0.35-0.60	60-80	>30
Garden waste	60-70	90	0.20-0.50	-	8-30
Fruit waste	15-20	75	0.25-0.50	-	3-20
Food remains	10	80	0.50-0.60	70-80	10-20
	Source	(Steffen & Szolar, 1998) –full table in Appendix 5.0			

(Mahony, 2002), (Poliafico, 2007) and (B Smyth, 2007) used this table of results to predict outcomes of biogas and methane yield. As part of the integrated design model in this study (Steffen & Szolar, 1998) data will be extrapolated and as such will provide the building blocks for the anaerobic digestion phase of the integrated matrix.

From table 5.2 it is clear that there is a significant variation in total solids, volatile solids and resultant biogas and methane yield per feed stock type. Where the net biogas output is calculated from the least value in a range verses the maximum value in the range there will be large variation in methane yields. Key to maintaining high biogas output, will be the reduction of water in feed stock and maintaining cattle, pig and poultry slurry at the higher end of the total solids specification.

While total solids can be high, it is important that the volatile solid content of the total solids is maintained at high level also. Solids can be a combination of indigestible fibres and lignin and fatty acids, proteins sugars and alcohols.

Retention time is also tabulated with an overall range of between 3 to 40 days for feed stock shown. Therefore knowledge of the expected feedstock available prior to design is essential to biogas productivity through the lifecycle of the anaerobic digester plant. For example if the feed stock in the main was fruit waste mixed with cattle slurry then retention time to maximize yield would be in the region of 20 days, whereas if the feedstock was predominantly chicken slurry then retention time of more than 30 days would be required.

Indeed, total solid % will direct the designers to choose the digester design (Figure 5.6) where dilute substrates with low solids can be treated in a covered lagoon, greater than 3% solids can be treated in a complete mix type digester system and plug flow systems are required at higher solid levels. It table 5.2, chicken slurry, garden waste and fruit waste, for example, would require dilution prior to processing.

5.6 Feedstock variants dictating the anaerobic digester design (DAFF-3, 2008)

In general, the operating temperatures of an anaerobic digestion are as described in 5.4.2 however, where animal by-products are utilized as a feedstock then the anaerobic digester comes under the European Commission Animal By-Products Regulation (1774/2002) which lays down rules concerning animal by-products in Europe. The regulation sets out minimum guide lines for the control of animal by-products in terms of a feedstock processing and the resultant disposal of digestate, while allowing member states to add to the constraints where deemed necessary. From an Irish perspective the relevant legislation controlling the use and disposal of animal by-products are as follow:

- S.I. 612 of 2006 (European Communities (Transmissible Spongiform Encephalopathies and Animal By-Products) Regulations 2006, transposes EU Reg. 1774/2002 into Irish law.

- S.I. 615 of 2006 (Diseases of Animals Act 1966 (Transmissible Spongiform Encephalopathies) (Fertilisers and Soil improvers) Order 2006 lays down national rules for organic fertilisers and soil improvers.

The impact of this legislation is translated into the follow restrictions for the design and operation of an anaerobic digester.

a) The anaerobic digester must be licensed and approved by DAFF and also must have a waste permit
b) There are restrictions in the use of animal by-product categories as a feedstock
c) Strict time and temperature control are required and these parameters vary with respect to feedstock types.
d) The principle of HACCP (hazard analysis critical control points) must be applied.
e) Strict controls are placed on the transport and spreading of resultant digestate and again these vary with respect to feedstock types, and will be discussed in 5.9.2.

The purpose of the legislation is to provide control on treatment and disposal of animal by-products to minimise the risk to the safety of human or animal health (DAFF-3, 2008). A full understanding of what comes under the umbrella of an animal by-product and its impact is thus important before designing an anaerobic digester.

5.6.1 Animal by-products defined

Under the legislation an animal by-product is defined as *'animal by-products: entire bodies or parts of animals or products of animal origin referred not intended for human consumption, including ova ,embryos and semen'*

Under Regulation (EC) No. 1774/2002, animal by-products are categorised in 3 distinct categories:

Category 1

- BSE carcass or suspects
- Specified Risk Material
- Catering waste from international transport

This material must be destroyed in accordance with Regulation (EC) No. 1774/2002 and is completely banned from use as feedstock in anaerobic digestion plants.

Category 2

- Manure
- Digestive tract content separated from the digestive tract
- Milk and colostrums

Category 3

- Catering waste – defined as ' *all waste food including used cooking oil originating in restaurants, catering facilities and kitchens, including central kitchens and household kitchens.'*
- Former foodstuffs containing products of animal origin, which are no longer intended for human consumption and do not present any risk to humans or animals.
- Parts of slaughtered animals, which are fit for human consumption
- Parts of animals, which are rejected as unfit for human but were derive from carcasses that are fit for human consumption.
- Fish caught in the open sea for the purposes of fishmeal production.
- Fresh by-products from fish from plants manufacturing fish products for human consumption.
- Raw milk of animal origin that is free from disease that is communicable to humans or animals through the milk.
- Egg by-products originating from animals that is free from disease that is communicable through that product to humans or animals.

5.6.2 Animal by-products list that can be used as a feed stock

Animal by-products list that can be used as a feed stock are as follows:

Category 2

- Manure
- Digestive tract content separated from the digestive tract

Category 3

- Catering waste (as defined above).
- Former foodstuffs containing products of animal origin as defined above.
- Fresh by-products from fish from plants manufacturing fish products as above.

5.6.3 Processing conditions required

Manure may be processed in on-farm biogas plants without the requirement of a pasteurization /hygienisation step but only when the manure originates from animals on the same farm and the digestate is subsequently spread within the farm boundaries. These facilities must be approved by DAFF. Where mixed farm slurries are processed then a pasteurisation/hygienisation step is required in addition.

Animal by-products used as raw material in an anaerobic digester plant must be submitted to the following minimum processing requirements under the EU legislation:

- Maximum particle size before entering the unit: 12 mm;
- Minimum temperature in all material in the unit: 70 °C; and
- Minimum time in the unit without interruption: 60 minutes.

Where catering waste (category 3) is used as a feedstock, further controls are required under Irish legislation. The following are the minimum standard requirements that must be met:

- Maximum particle size before entering the unit: 400 mm;
- Minimum temperature in all material in the unit: 60 °C; and
- Minimum time in the unit: 48 continuous hours.

The digestate must be processing twice to the above time, temperature and particulate size as set out.

5.6.4 The HACCP plan

Hygiene, cleaning, disinfection, material segregation from raw to processed are base line requirements for an anaerobic digester plant using mixed feed stocks containing animal by-products as described in 5.6.3 above. The next restriction is the introduction of the onerous food safety system that must be implemented in a anaerobic digester plant. HACCP is a food safety management tool that has been widely used in the food industry for years to assure the safety of food produce. The principle is based on an evaluated and systematic risk assessment of a process to consider the hazards (physical, chemical and microbiological) and put in place systems and procedures to ensure that the hazard is either eliminated or reduced to an acceptable low risk level. The HACCP plan then sets out the critical control points, such as pasteurization time and temperature and defines the who, why, what, where of controlling the process steps. The plan also details the action to be taken in the event of a process failure.

Given the restriction outlined in this section, it can be appreciated how the plant designer must have a full evaluation of the proposed feedstocks for used in the anaerobic digester in order that the system can be designed appropriately and in compliance with the legislation. The second pass hygiene step is unique to Ireland and may prove a design challenge as it is not an off-the-shelf design in the European context.

5.7 Volumes of Digestate

In addition to biogas the secondary output from the anaerobic digester is the digestate. Figure 5.10, indicates that the final digestate can range from 96-98% of the feedstock initial volume. The digesate can be separated by various means to yield fibrous fraction and nutritious liquor.

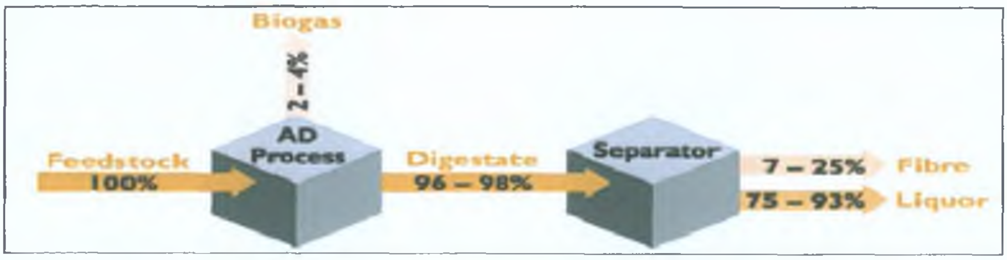


Figure 5.10 Digestate percentage of feedstock (Poliafico, 2007)

The quantity of fibre will directly relate to the total solids (TS) and type of solids in the feed stock. Some materials such as lignin and cellulose fibres are difficult to digest and will pass through the system, whereas volatile solids are broken down to yield biogas (section 5.2.1). Pain, 1978, documents that for a 10% dry solids feed, following digestion and then separation the dry solids content of 4 to 5% would be expected (Pain 1978). This implies that of the totals solids in the feed stock approximately 50% will be available in the form of fibre in the final digestate (i.e. if % TS of the feed stock is 10% then the % TS in the digestate will be 5%). It can also be extrapolated that the feedstock less the total solids percentage approximates to the liquor quantity of the digestate.

5.7.1 Quantity of digestate produced

Using the values derived from table 5.2, the following calculations were made to extrapolate, in general terms, the quantity the % fibre and % liquor that will be available per tonne of feedstock variant for further use following digestion.

Calculations

% Fibre available = Total solids% x 50%

% Liquor available = Feedstock quantity% – (Total solids% x 50%)

Table 5.3 Median Value Feed Stock - (Fibre and liquor quantities calculated)

Median Value Feed Stock	Total Solids TS%	% Fibre / 1T of biomass	%Liquor /1T of biomass	Fibre in 10000 t	Fibre in 50000 t	Liquor in 10000 t	Liquor in 50000 t
Pig Slurry	5.5	2.75	97.25	275	1375	9725	48625
Cow Slurry	8.5	4.25	95.75	425	2125	9575	47875
Food Remains	10	5.00	95.00	500	2500	9500	47500
Chicken Slurry	20	10.00	90.00	1000	5000	9000	45000
Straw	70	35.00	65.00	3500	17500	6500	32500

When considering the fibre content of the digestate for sale as a soil conditioner, table 5.3 above gives an indication of expected volumes. In a plant of annual capacity of 10000 tonnes of biomass, where the feed stock 100% pig slurry for example then the quantity of fibre arising will be around 275 tonnes. Similarly for cow or chicken slurry at 100% of feedstock the resultant fibre approximates to 425 and 1000 tonnes respectively.

The liquor quantities in a 10000 tonne and a 50000 tonne plant are also outlined in table 5.3. The impact of these quantities of liquor and fibre is that a sizeable landbank is required to utilize this biofertilizer as a resource.

5.8 End use and land requirements

To estimate the landbank requirement from a digestate spread point of view, a multitude of variables including soil quality and geology, land use and fertilizer requirement and finally feed stock content must be considered. Land spreading is considered an environmentally and economically sustainable option for the use of organic fertilizer. Crops utilize nutrients from the soil, including nitrogen (N), phosphorus (P) and potassium (K), to grow and produce grass or grains thus completing the nutrient cycle.

According to Magette,1999, Irish agricultural land has the capacity to utilize the total nutrient loads of animal manure without negatively impacting the environment (Magette, 1999). In 2006/2007 the Irish fertilizer consumption was circa 1.3 million tonnes annually. This volumes of N, P K are presented in table 5.4 below.

Table 5.4 Fertilizer use in Ireland 2000 to 2005 (,000 tonnes)

Year	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Total Fertilizers
2000/01	369	43	107	1546
2001/02	364	42	106	1523
2002/03	388	44	111	1628
2003/04	363	43	111	1538
2004/05	352	39	101	1479
2005/06	345	37	93	1427
2006/07	322	32	85	1310 (Est)

Source: (Teagasc, 2008)

Teagasc, 2008, has reviewed the use of artificial fertilizer and compares the quantities of artificial fertilizer used versus the total quantity of pig manure available. The contribution of pig manure against the total fertilizer nutrients being applied to land amounts to about 3.3% of the chemical N and 7% of the chemical P used on farms in Ireland annually (Teagasc, 2008). Animal manures can be used as a substitute for chemical fertilizer. It is a rich source of N, P, K and trace minerals (Teagasc, 2008) (Magette, 1999) (Mahony, 2002), although the concentration of each nutrient in the manure varies with the total solids % and with the diet feed (Teagasc, 2008).

5.8.1 Digestate liquor compared with untreated slurry

In the EPA report entitled 'Benefits for Waste Management, Agriculture, Energy, and the Environment' (EPA-1, 2005), the benefits of digestate as a fertilizer are discussed. Anaerobic digestion is reputed to increase the proportion of nutrients available for plant uptake. During the digestion process nutrients are mineralized therefore an increased percentage of nutrients absorbed by the plant. It is estimated that digestate has 25% more accessible inorganic nitrogen (NH_4-N) and a higher pH value than untreated liquid manure, (Gannon, 1994).

Table 5.5	**Analysis of N,P and K in manure and treated digestate**					
Slurry Type	Dry Matter	Total N Kg/tonne	NH4-N Kg/tonne	Total P Kg/tonne	Total K Kg/tonne	pH factor
Cattle Slurry	6.0	5.0	2.8	0.8	3.5	6.5
Pig Slurry	4.0	5.0	3.8	1.0	2.0	7.0
Digested Slurry*	2.8	5.0	4.0	0.9	2.8	7.5

*Digested Slurry in this instance is mixed feed stock of manures. (Birkmose, 2000)

In table 5.5 typical analytical values are depicted for untreated cattle and pig slurry, and a digested slurry which is of equal parts cattle and pig slurry. The total N, P, and K content in the digested slurry remain, but the dry matter is reduced by 2% making the digestate slurry considerably thinner. In addition there is slight increase in ammonium (NH_4-N) content and the overall pH value rises too and becomes lightly alkaline.

5.8.2 Ground water pollution potential

The Water Framework Directive and the Groundwater Directive impact directly on the management of animal slurry and its use as a land fertilizer (Teagasc, 2008). *SI 378 EC Good Agricultural Practice for Protection of Water Regulations of 2006* has resulted in Ireland being carved into three distinct zones based on geology and water pollution potential risk zones.

Table 5.6 Storage capacity and times of year for spreading of manure per Zone				
Zones	Storage Capacity Required	Prohibited Application Period		
		Chemical	Organic	Farmyard
A	16 Weeks	15 Sept-12Jan	15 Oct – 12 Jan	1 Nov- 12 Jan
B	18 Weeks	15 Sept-15Jan	15 Oct – 15 Jan	1 Nov – 15 Jan
C (Donegal and Leitrim)	20 Weeks	15 Sept-31Jan	15 Oct – 31 Jan	1 Nov – 31 Jan
C* (Cavan & Monaghan)	22 Weeks	15 Sept-31Jan	15 Oct – 31 Jan	1 Nov – 31 Jan

Zones A,B,C and C* are depicted in the map below (Figure 5.11). Each zone has different rules regarding storage capacity and times of year that spreading of manure (organic or chemical) is prohibited (Table 5.6).

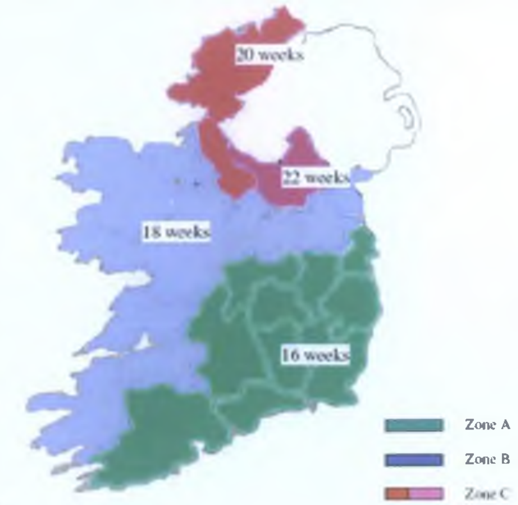


Figure 5.11 Ireland Land Spreading Zones
Source : National Action Programme under the Nitrate Directive. DAFF 2005

Rules Simplified (DAFF-2, 2006)

1. 170 kgs is the maximum quantity of nitrogen per hectare in a year that can be spread.
2. There are times of the year when fertilizer (organic or chemical) must not be spread on land, either organic or chemical. Adequate storage for the livestock manure is required for the prohibition period.
3. The overriding rule is that no more fertilizer is spread on the land than is required by the crops.

Teagasc: Recommendations for the use of animal manure **Box 5.2**

Cattle slurry should be recycled to land conserved for hay or silage at not more than 55m^3 per ha per year, and not more than 33m^3 /ha in one application.

Pig slurry should be applied at lower rates because of its higher phosphorus content. 27.5m^3 /ha may be applied for first cut silage and to root crops. 11m^3 per ha per year will normally be adequate for grazing and cereals

When applying slurry avoid direct contamination of watercourses by leaving adequate buffer strips. Streams and drains, Lakes and rivers, Domestic wells, Public water sources leave a buffer zone of 10, 20, 50 and 50-300metres respectively.

To minimize slurry odour and nutrient losses to air by adopting a common sense approach by availing of suitable weather conditions and using best practices

5.9 Land-spreading complying with the legislation

In respect to landspreading of digestate there is a number of consideration to be made in relation to feedstock used.

5.9.1 Sewage sludge as a feed stock

Where sewage sludge is used as a feed stock in an anaerobic digester then the S.I No 148/1998 — Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998, must be complied with in relation to land-spreading. Under this legislation sewage sludge that has undergone biological treatment such as fermentation is considered a 'treated sludge'. In terms of landbank requirements the relevant piece of this legislation is inserted below:

Treated sludge shall not be used or supplied for use on grassland or forage crops where the grassland is to be grazed or the forage crops to be harvested within three weeks of such use

The maximum amount of sludge which may be applied to land shall be two tonnes of dry matter per hectare per year.

A later amendment, S.I. No 267 of 2001 Waste management (Use of Sewage Sludge in Agriculture) (Amendment) Regulation, 2001, takes into account heavy metal limits (kg/hectare/year). And the limits set are as follows; Cadmium 0.05, Copper 7.5, Nickel 3.0, Lead 4.0, Zinc 7.5, Mercury 0.1, Chromium 3.5

5.9.2 The impact of animal by-product as a feedstock on land bank requirements (DAFF-3, 2008)

Category 1 material is banned from use as a feed stock then the situation of landspreading will not arise.

Category 2 material containing only animal manure and / or digestative tract content may be used on land as an biofertiliser subject to landspread regulations. S.I. 615 of 2006 regulates the use of organic fertilisers and soil improvers.

Category 2 material, other than manure and the contents of the digestive tract as mentioned above, cannot be used on any land in accordance with S.I. 615 of 2006

Category 3 material, containing catering waste only or where catering waste is mixed with manure, the digestate may be spread on land with the condition that following application to the land, farmed animals must not be allowed access to the land for at least 21 days and in the case of pigs, this restriction is extended to 60 days.

Catering 3 material as defined* as former foodstuffs containing products of animal origin once intended for human consumption and/ or fresh by-products from fish from plants manufacturing fish products for human consumption' may be spread on land subject to the following conditions:

- A farmed animal does not have access to any part of the land where the digestate is spread for three years after spreading.
- A farmed animal does not have access to the digestate and it does not come into contact with feeding material.
- Ensiled crops or hay should not be made from a crop grown on land on which an digestate has been spread during the previous 12 months.

Category 3 material other than mentioned above where used as a feedstock may not be spread on land . * ***Article 6 (1) (f) or (i) of EU Regulation (1774/2002)***

5.9.3 Review of land spreading rules and impact

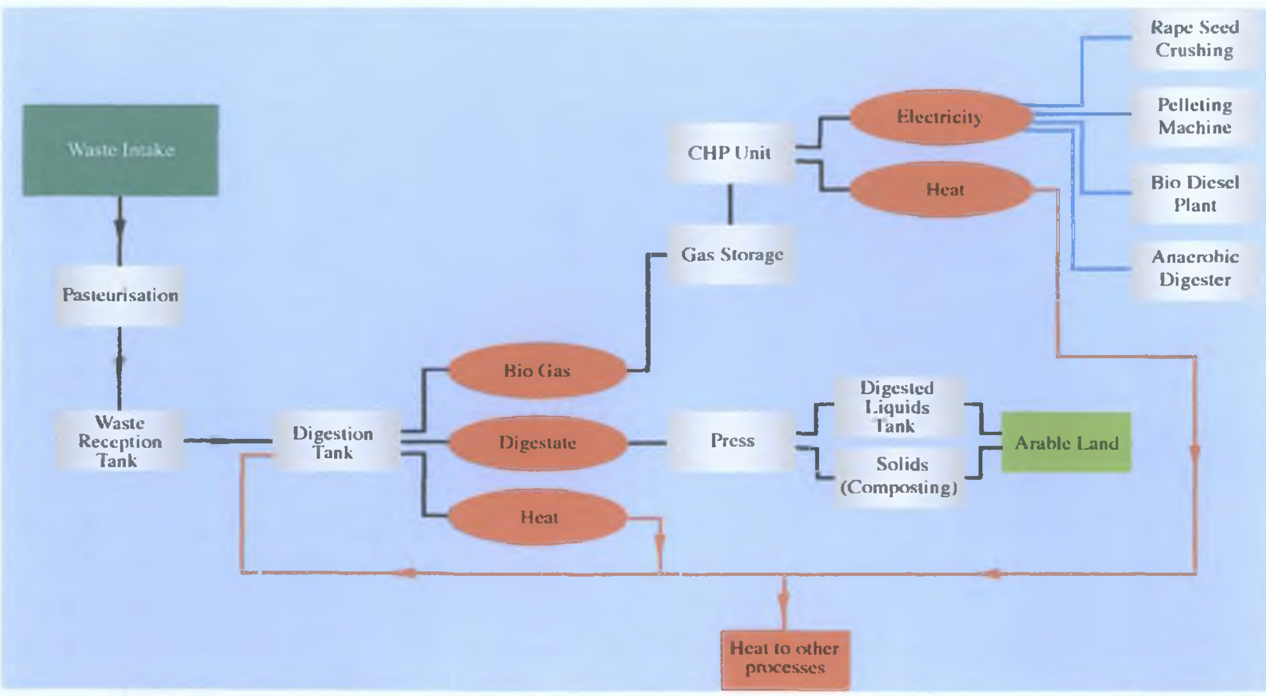
In determining the land bank requirements to spread the volume of digestate then the following rules must be applied :

- ✓ A rule of thumb of 11m^3 for pig slurry per hectare for grass land and 27.3m^3 for crops can be land spread. Cattle slurry can be spread at a rate of 33m^3 per hectare of land.
- ✓ Where sewage sludge is part of the feed stock, consideration of heavy metals and maximum load of 2 tonnes dry matter per hectare can be applied to land.
- ✓ Where catering waste is part of the feedstock, a restriction of grazing of 21 days is applied and this is extended to 60 days for pig related by-products.
- ✓ Where category 3 material is part of the feedstock a 12 month ban on the production of feed crops (animal or otherwise) and in addition a 3 year ban on grazing is applied.

For the purpose of the integration matrix, where it is anticipated that the Bioenergy Park will be located in an arable region and in consideration of the raw material requirements of straw and rapeseed, the value of 27.3 m^3 per hectare for all feedstocks will be applied to calculate the land bank required. However, this does not negate the need to consider the implications of the various feedstocks and resultant landbank requirements based on the legislation requirements.

5.10 Integration potential and constraints of anaerobic digestion in a Bioenergy Park

The anaerobic digester sits at the core of the Bioenergy Park (Figure 5.12), generating renewable energy to fuel renewable energy processes. As referred to in this study there is a list of environmental benefits associated with anaerobic digestion. However, the development of anaerobic digestion as a waste processing system, in Ireland, has been hindered by the excessive capital and operational costs.



5. 12 Anaerobic Digester Process Flow in the Bioenergy Park **Source: Ryan-Purcell 2008**

Feedstock in terms of supply, quality and consistency is important both from design and operational perspective, and is also key to energy generation potential of the anaerobic digester. Further on in chapter 7.0 are the details of investigation into the energy potential of various feedstocks and the resultant reduction in carbon emissions.

The landbank requirement is dependant on feedstock type which can demonstrate significant constraints. Yet, it is worth noting that the land bank requirement for the cultivation of Oil Seed Rape to supply the Biodiesel process is of a similar scale and significantly greater when the 4 year rotation requirement is considered as part of the equation (Chapter 3, Section 6).

6.0 Determination of Bioenergy Park key equivalent energy values

Renewable energy in its diverse forms must fit into the existing patterns of energy use (Boyle, 2004). The Bioenergy produces solid, liquid and gas energy forms. To assess the overall output of renewable energy as against national consumption rate a single unit of energy measure is required. The purpose of this chapter is three fold;

- The national energy consumption rates per fuel type and per sector is considered.
- The energy value of each fuel generated is converted to comparable units of measure. These key equivalent values are inserted into the 'Integration Matrix' to facilitate scenario analysis (Chapter 10.0).
- The key equivalent values are used in this chapter to examine how the Bioenergy Park can satisfy National Renewable energy and Biofuel targets in defined sectors.

6.1 National energy consumption

The total primary energy consumption in Ireland in 2006, was in the order of 16 million tonnes of oil equivalent (SEI-6, 2008). Consumption can be subdivided by sector or by fuel type, both have been presented in table 6.1 below. Transport is the single biggest energy user as a sector (34%) and not surprising then, oil as a primary energy source is the significant fuel type, at 8978 ktoe (kilo tonnes of oil equivalent).

Table 6.1 Total Primary Energy Requirements (TPER) in 2006

TPER measured in (ktoe) **source:** (SEI-6, 2008)

Sector	(ktoe)	% of TPER	Fuel	(ktoe)	% of TPER
Industry	3748	23.2	Coal	1631	10.3
Transport	5487	33.9	Peat	707	4.4
Residential	3965	24.5	Oil	8978	56.4
Service	2575	15.9	Natural gas	4019	25.3
Agriculture	396	2.4	Renewable	422	2.7
Total	16171	100	Total	15910	100

Table 6.2 depicts the diesel consumption for the transport sector at 2509 ktoe and also approximates the associated tCO_2 at 8 M tonnes. Interestingly, the total biofuel consumption is recorded at 2.6 ktoe.

Table 6.2 Transport Consumption 2006 **Source:** (SEI-6, 2008)

Fuel	Toe	%	tCO_2/toe (NCV)	tCO_2 (NCV)
Diesel	2509000	46.52	3.17	7964761
Petrol	1884000	34.93	3.00	5659229
Kerosene	970000	17.99	3.16	3060927
Biofuels	2600	0.05		

NCV= Net Calorific value

This value shows the distance Ireland has to travel before achieving its biofuel target of 5.75% before 2010. In excess of 144 ktoe are required to achieve this biofuel target based on 2006 consumption figures. The thermal energy flow (Figure 6.1) for 2006, highlights the residential sector as the primary consumer accounting for 42% of the thermal energy use. The industrial sector follows as the number two thermal consumer in the 2006 analysis.

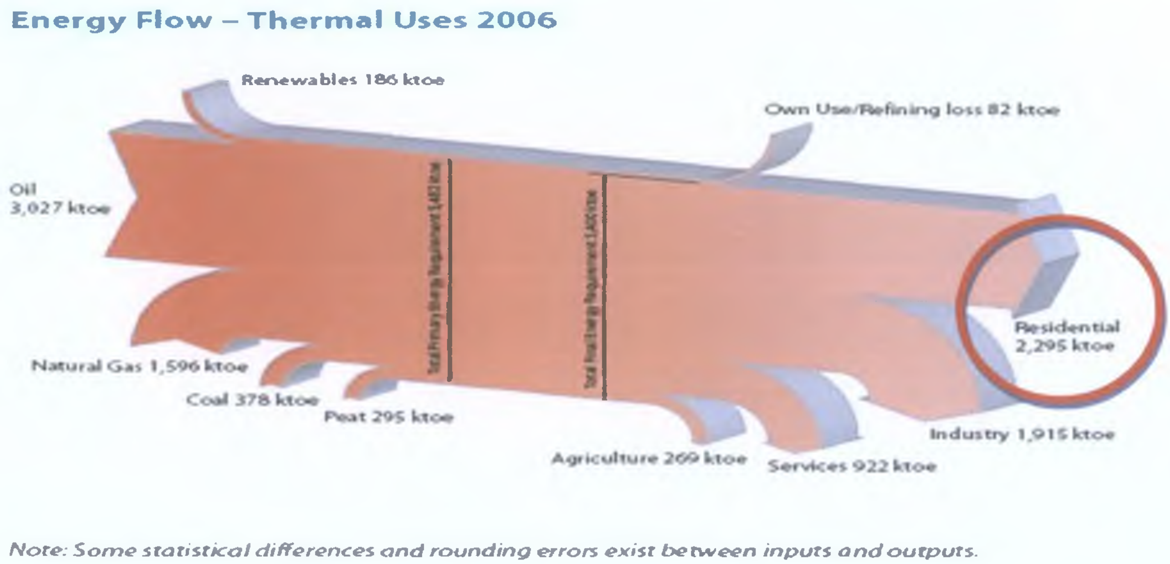


Figure 6.1 Energy Flow Thermal Uses 2006 Source: (SEI-6, 2008)

In terms of primary energy consumed to provide the thermal demand, oil is again the significant player. Oil consumed was reported as 3027 ktoe where as renewable energy supplied only 186 ktoe or 3.4%. Table 6.3 provides the full break down of thermal consumption again with the carbon tonne emissions extrapolated to demonstrate the national impact of Ireland energy consumption.

Table 6.3 Thermal Consumption 2006 source: (SEI-6, 2008)

Fuel	toe	%	tCO_2/toe (NCV)	tCO_2 (NCV)
Oil	3027000	55.22	3.17	9609140
Natural gas	1596000	29.11	3.16	5036329
Coal	378000	6.90	2.63	995597
Peat	295000	5.38	0.91	268079
Renewables	186500	3.40		
Residential	2295000	41.9	*NCV= Net Calorific value*	

The Bioenergy Park outputs need to be challenged against national consumption and renewable energy targets. The first step is finding representative values. Clearly, tonnes of oil equivalent is key common measurement unit, in addition cars fuelled and homes heated are also fundamental in assessing the national impact of locally supplied renewable energy from one or many Bioenergy Parks.

6.2 Biodiesel integration - key equivalent values

The energy value of biodiesel is comparable to fossil fuel diesel. When measured on a volumetric basis, diesel has the higher calorific value, by 8%, over biodiesel (Thamsiriroj, 2007). The biodiesel produced can be equated to mega joules (MJ) of energy, tonnes of oil equivalent (toe), homes heated, cars fuelled and even electricity generation potential if the biodiesel was used in a power station. The key values determined are presented in table 6.4 below.

Table 6.4 Biodiesel Key Equivalents

Biodiesel	**1 tonne**
GJ of energy	28.86
Tonnes of oil equivalent (toe)	0.69
Homes Heated (3.05 t/home/year)	0.33
Avg. cars fuelled (1.91 t/car/year)	1.72
Electrical generation potential MWh	2.40

6.2.1 One tonne of biodiesel in MJ

The energy value of biodiesel is 34.8 GJ/ 100 L (Thamsiriroj, 2007). One tonne of biodiesel's energy value is calculated at 28.86 GJ/tonne, where the density of biodiesel is equal to 0.88

6.2.2 Tonnes of oil equivalent (toe) per tonne of biodiesel.

1 toe = 41870 MJ (SEI-3, 2004). Where one tonne of biodiesel is equal to 28.86 GJ, this implies that one tonne of biodiesel is equal to 0.69 toe

6.2.3 Tonnes of oil to heat an average domestic home (Ireland)

The annual domestic heating requirement for a typical family home is calculated as 18 MWh or 66 GJ (Murphy-2, 2006). If a domestic boiler is assumed to have a thermal efficiency of 75%, then the primary demand is 24 MWh or 88 GJ or 88000 MJ. Where one tonne of biodiesel is equal to 28.86 GJ then 3.05 tonnes of biodiesel is required per annum to heat a typical family home. In the integration matrix, this calculation is not included. Home heating values will be calculated based on straw pellets only as the thermal fuel.

6.2.4 Fueling a car for a year in Ireland

In 2006, the average mileage of a diesel car was 15,071 miles or 24,255 km (EPSSU, 2007). The specific energy consumption for all new cars on the road in Ireland in 2006 was 2.3

MJ/km. This implies that the average diesel car consumes 55.79 GJ/annum. Where one tonne of biodiesel is equal to 28.86 GJ then 1.93 tonnes of biodiesel is required per annum to fuel the average car.

6.2.5 Electrical energy generation potential.

Electrical energy generation potential if biodiesel was combusted in a power generation plant at a conversion rate of 30% (Murphy-2, 2006). One tonne of biodiesel is equal to 28.86 GJ. At 30% conversion, this equates to 8.658 GJ. As 1 MWh equals to 3.6 GJ this implies that one tonne of biodiesel has an electrical generation potential of 2.4 MWh.

In summary, one tonne of biodiesel has an energy value of 28.86 GJ/tonne with a net energy value of 15.24 GJ/t, and is equal 0.69 toe.

To heat a typical family home approximately 3.05 tonnes of biodiesel is required per annum.

If used in a power station to generate electricity one tonne of biodiesel has an electrical generation potential of 2.4 MWh, again unlikely to occur.

And finally 1.93 tonnes of biodiesel is required per annum to fuel the average car. In the integration matrix, these key values will be used to calculate the total inputs and outputs of the Bioenergy Park.

A Bioenergy Park that has a biodiesel output, of 2952 tonnes for example, would replace 1788 tonnes of fossil fuel oil, and fuel 1343 cars or heat 850 homes per year.

At a national level, where 2509 ktoe diesel was consumed in the transport sector in 2006, and where the biofuels target (5.75%) demands 144 ktoe of renewable fuel, ten Bioenergy Parks could produce 14% of the national requirement.

6.3 Straw Pellets integration - key equivalent values

The energy output potential for rape straw and barley straw varieties is similar in value at 17.4, 17.6 MJ/kg respectively (C. Tullin, 2008). When compared to wood there is a 8% energy difference in favor of wood pellets (SEI-2, 2003). The energy available in the form of fuel straw pellets is equated to mega joules (MJ) of energy, tonnes of oil equivalent (toe), homes heated and electricity generation potential if the pellets were used in a power station.

The key values determined are presented in table 6.5 below.

Table 6.5 Straw Pellets Key Equivalents

Straw Pellets	1 tonne
GJ of energy	17.0
Tonne of Oil Equivalent (toe)	0.4
Homes Heated (5.2 t/home/year)	0.195
Electrical generation potential MWh	1.42

6.3.1 One tonne of straw pellets MJ value

In consideration of baling and collection of straw and the inherent energy consumed in the process, the final energy value for straw pellets is calculated at 17028.2 MJ/tonne (Chapter 7 table 7.5).

6.3.2 One tonne of straw pellets in tonnes of oil equivalent (toe)

One toe is equal to 41870 MJ (SEI-3, 2004). Thus one tonne of straw pellets is equal to 0.40 toe.

6.3.3 Tonnes of straw pellets required to heat an average domestic home (Ireland)

As per 6.2.3 above the annual domestic heating requirement for a typical family home is assumed to be 88 GJ. Where one tonne of straw pellets is equal to 17.028 GJ then 5.2 tonnes of straw pellets are required per annum to heat a typical family home.

6.3.4 Electrical energy generation potential

As per 6.2.4 above the conversion rate of 30% is considered to calculate the electrical energy generation potential if straw pellets were combusted in a power generation plant. One tonne of straw pellets is equal to 17.0 GJ. At 30% conversion, this equates to 5.1 GJ. As 1 MWh equals to 3.6 GJ, this implies that one tonne of straw pellets has an electrical generation potential of 1.42 MWh.

In summary, one tonne of straw pellets has an energy value of 17.0 GJ/tonne and is equal 0.40 toe. To heat a typical family home approximately 5.2 tonnes of straw pellets are required per annum. And finally, if used in a power station to generate electricity one tonne of straw pellets has an electrical generation potential of 1.29 MWh. In the integration matrix, these key equivalent values will be used to calculate the total inputs and outputs of the Bioenergy Park.

A Bioenergy Park that has a straw pellet output of 12000 tonnes, for example, would replace 4800 tonnes of fossil fuel oil, and heat 2300 homes with a carbon neutral fuel. At a national level, where the residential heating bill was in the order of 2295 ktoe in 2006, ten Bioenergy Parks could replace 2% of this fossil fuel oil (48 ktoe) with renewable energy from waste straw.

6.4 Anaerobic Digestion integration - key equivalent values

The renewable energy potential of slurries will be examined more closely in chapter 7, however, box 6.1 below gives comparisons of one cubic meter of biogas with a methane content of 70% from where key equivalent factors can be derived.

Key equivalent values per cubic meter of biogas **Box: 6.1**

One m³ of biogas with a methane content of 70% (20MJ/m³) is equivalent to:
1.70 kWh of electricity (assuming a conversion efficiency of 30%)
Source: (Mahony, 2002)

3.0 kWh of heat only (assuming a conversion efficiency of 70%)
2.60 kWh of electricity and 2.5kWh of heat in CHP system (Combined heat & power)
(Murphy-1, 2005).

Chapter 7.0 will focus on biogas production from individual feed stocks. However, once biogas and methane yield potential is calculated, key equivalent factors will be required so relevant values can be calculated within the integration matrix. The initial step will be to convert the all biogas values to a standard 1m³ of biogas at 70% methane and all subsequent calculation can then be based on m³ of biogas @70% methane.

Back to the Index

Characteristics and operational parameters of agricultural waste digesters Steffen et al 1998									
Extrapolated to give:									
Feed Stock	CH4 Yield m³ in 1t of Biomass	Tonnes Of Methane	GWP= tCO2	Biogas m³@70% methane	MJ equivalent /1t of Biomass	toe Tonne of Oil Equivalent / 1t of Biomass	Electrical Energy Generated @30% Conversion Methane KWh	CHP Elect KWh	CHP Thermal KWh
Pig Slurry	11.60	0.011	0.200	14	289	0.0069	25	38	43
Cow Slurry	11.05	0.012	0.219	18	366	0.0087	31	48	55
Food Remains	33.00	0.032	0.568	41	821	0.0196	70	107	123
Sewage Sludge	11.38	0.013	0.226	19	377	0.0090	32	49	57
Glycerin	586.60	0.601	10.815	838	16760	0.4003	1425	2179	2514
Chicken Slurry	49.88	0.051	0.920	71	1425	0.0340	121	185	214
Whey	16.08	0.016	0.296	23	459	0.0110	39	60	69
Leaves	79.20	0.103	1.858	183	3665	0.0875	312	477	550
Wood Shavings	83.60	0.109	1.962	193	3869	0.0924	329	503	580
Straw	138.60	0.181	3.252	321	6415	0.1532	545	834	962
Garden Waste	112.61	0.147	2.643	261	5212	0.1245	443	678	782
Table1 Median values									

Figure 6.2 ADFSCal Sheet from Integration Matrix – (Appendix 1.4)

6.4.1 Biogas equated to MJ

1000 m^3 of Biogas @ 70% methane per feedstock variant is equal to 20,000 MJ of energy equivalent (Mahony, 2002).

6.4.2 Biogas equated to tonnes of oil equivalent (toe)

One toe is equal to 41870 MJ (SEI-3, 2004). Thus 1000 m3 of Biogas @ 70% methane per feedstock variant is equivalent to 0.48 toe.

6.4.3 Electrical energy generation potential

Electrical energy generation potential (if methane was used to generate electricity at a conversion rate of 30%) is equivalent to 1.75 MWh per 1000 m^3 of Biogas @ 70% methane per feedstock variant using Mahony, 2002, figures.

6.4.4 Electrical and thermal energy generation potential when using CHP.

Electrical energy generation potential (if methane was used in CHP system) is equivalent to 2.6 MWh per 1000 m^3 of Biogas @ 70% methane per feedstock variant using Murphy-1, 2005 figures.

Thermal energy generation potential if methane was used in CHP system is equivalent to 3.0 MWh per 1000 m^3 of Biogas @ 70% methane per feedstock variant using Murphy-1, 2005 figures.

In regard to electrical energy generation using CHP , Mahony, 2002, reported lesser values, however, following consultation with Dr V O'Flaherty (party to the Mahony, 2002 report), Murphy-1, 2005 figures were used for CHP as they were deemed to be more up-to-date with current technological performances and energy conversions, and also given Dr. J D Murphy's position as Director of the Environmental Research Institute, University College Cork and is an expert in the field of waste to energy.

As the anaerobic digester results above are factors relating to biogas output and methane content of various feed stocks, a true value cannot be documented at this point in the study. Chapter 7.0 will examine feed stock with respect to methane production potential and both the values derived in chapter 7.0 together with the key equivalent factors documented above will be merged in the integration matrix in chapter 9.0.

6.5 Integration- key equivalent value summary

Table 6.4 summarises the key equivalent values which form an integral part of the integration matrix (chapter 9.0 'BP Live'). Biodiesel and Straw Pellet values are integrated directly against tonnes of fuel produced. Anaerobic digestion is slightly more complex and the values need to be integrated as an interactive spread sheet within the matrix. The energy yield will depend on the quantity and volume of each feedstock used and one arbitrary figure will not be sufficient in the case of anaerobic digestion energy generation potential.

Table 6.6	Summary of Key Equivalent energy values		
Biodiesel	**1 tonne**	**Straw Pellets**	**1 tonne**
GJ of energy	28.86	GJ of energy	17.0
Tonne of Oil Equivalent (toe)	0.69	Tonne of Oil Equivalent (toe)	0.4
Homes Heated (3.05 t/home/year)	0.33	Homes Heated (5.2 t/home/year)	0.195
Avg. cars fuelled (1.91 t/car/year)	1.72	Electrical generation potential MWh	1.42
Electrical generation potential MWh	2.40		
Anaerobic Digestion Biogas @ 70% Methane content	**1000 m^3**		
GJ of energy	20.0		
Tonne of Oil Equivalent (toe)	0.48		
Electrical generation potential MWh	1.42		
Electrical generation CHP MWh	2.6		
Thermal generation CHP MWh	3.0		

Key values embedded in to the matrix in

'BP live'

'ADFSCal'

7.0 Energy Balance and Carbon Emissions

The Bioenergy Park concept is that both biodiesel production and straw pelleting are fuelled by the energy generated in the anaerobic digester. Effectively renewable energy producing renewable energy.

7.1 Introduction

This chapter explores in detail the supply and demand dynamics of each of the individual processes within the Bioenergy Park to investigate the following:

1. Thermal and Electrical Energy requirements of each process and the anaerobic digesters ability to supply this demand
2. Net energy generation potential for each process
3. The carbon emission reduction potential for each process within the site

The chapter considers each individual process and aims to calculate key integration values for use in the 'Integration Matrix'.

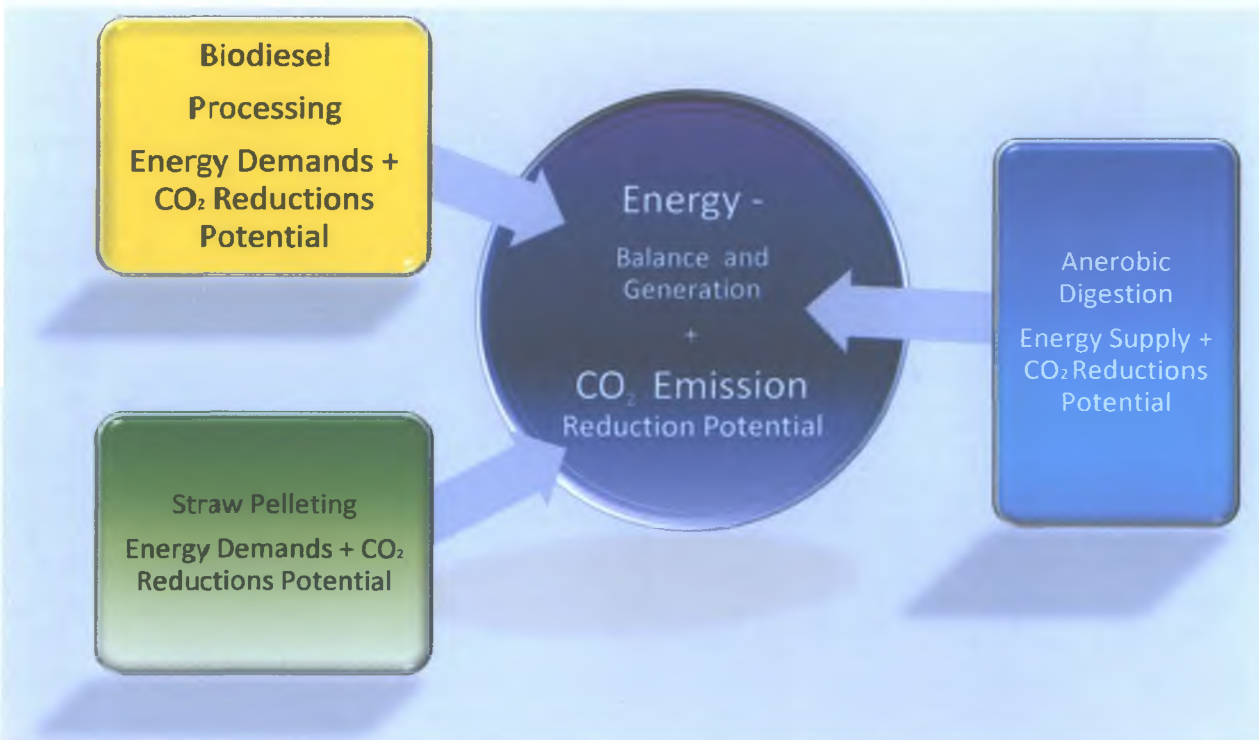


Figure 7.1 The push and pull of the three processes within the Bioenergy Park

The summary findings are presented in table 7.4 for biodiesel and table 7.7 for straw pellets while anaerobic digesting findings based on 11 feedstocks is presented in Appendix 1.4 of this study.

7.2 Biodiesel energy generation and carbon reduction potential

In this section of the chapter a detailed investigation of the energy demands of the biodiesel production process flow in respect to energy consumption, energy generation and carbon emission reduction. The biodiesel process can be summarized in two significant energy consuming steps, the first being the pressing of pure plant oil from the rape seed and the second step can be defined as transesterfication. Both steps require thermal and electrical energy. The Bioenergy Plant needs to understand the quantity of these energies required in order to ensure that the anaerobic digester is designed to supply this energy demand. Figure 7.2 indicates the flow of calculation to be considered in order to determine the energy values per tonne of biodiesel produced. Table 7.1 below identifies the chapter findings following detailed analysis of the process flows.

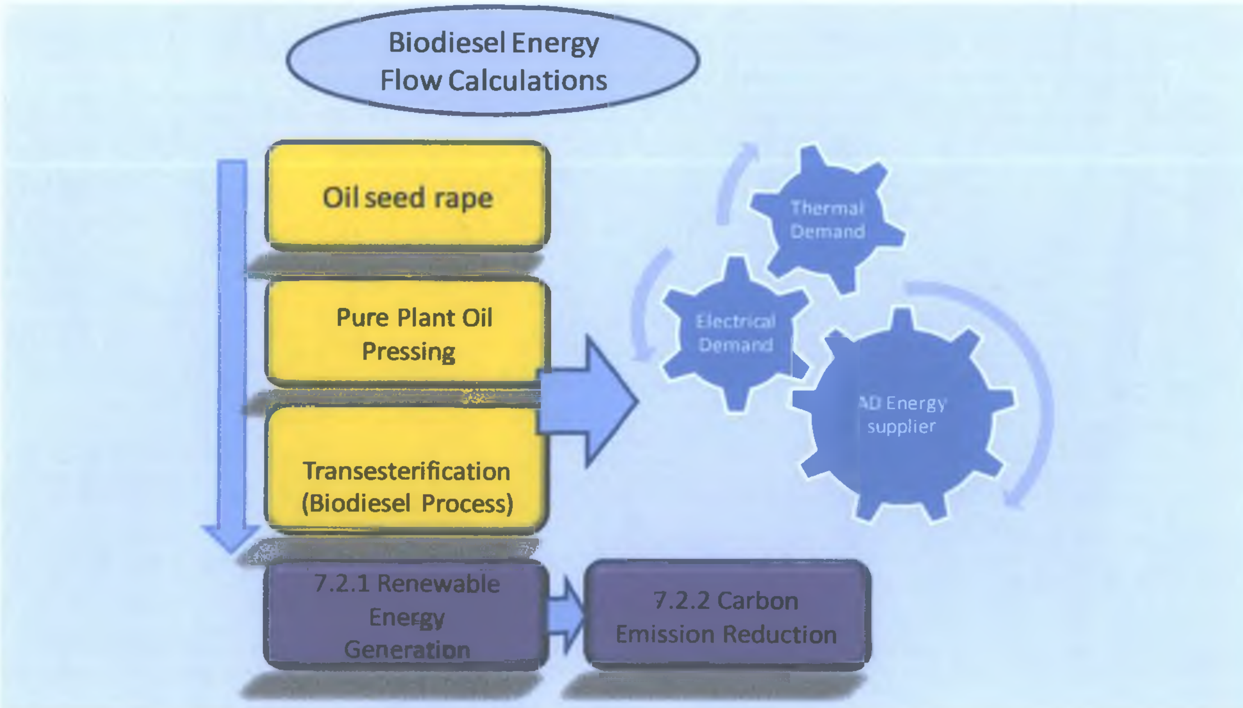


Figure 7.2 Biodiesel energy flow calculation

To assess the values depicted in table 7.4 below a recently conducted Life Cycle Analysis (LCA) of biodiesel from oil seed rape in GroOil Limited in Cork, Ireland was examined.

Table 7.1 Biodiesel Integration Key Values	1 tonne
Reduced tCO_2 emissions	2.23
GJ of energy	28.86
Tonne of oil equivalent (toe)	0.69
Oil Press Parasitic Thermal Demand kWh	79.10
Oil Press Parasitic Electrical Demand kWh	50.36
Biodiesel Parasitic Thermal Demand kWh	44.70
Biodiesel Parasitic Electrical Demand kWh	28.42

7.2.1 Irish LCA to determine thermal and electrical demand and net energy production

GroOil is a West Cork based company established in 2004. The Life Cycle Analysis (LCA) on the production of biodiesel from oilseed rape was documented. GroOil have a PPO crushing facility with the capacity of 1 million litres per year and process 910 tonnes of locally produced oilseed rape annually.

Table 7.2 The total, parasitic and net energy (GroOil) (Thamsiriroj, 2007)

Description	**GJ/ha/a**	**MJ/L biodiesel**
Gross energy of biodiesel	40.37	32.80
Primary energy demands		
Agricultural practices of oil-seed rape	12.18	9.90
Transport of rapeseed (farm to plant)	0.11	0.09
Oil pressing	2.28	1.85
Biodiesel trans-esterification	4.46	3.62
Distribution of biodiesel (plant to customer)	0.03	0.02
Total in-process demand energy	19.06	15.48
Net energy of biodiesel	21.31	17.32

The total net energy from the processing of biodiesel is calculated at 17.32 MJ/ L biodiesel produced. Table 7.2 depicts the gross, parasitic and net energy produced based on the LCA. The primary energy demands are presented in table 7.2 above but this information is insufficient with respect to the Bioenergy Park as the anaerobic digester needs a breakdown in thermal and electrical demand. Thamsiriroj, 2007 figures are used to extrapolated the required values for the anaerobic digester.

The two areas to be examined in detail are ;

1 Pure Plant Oil (PPO) Pressing Process
2 Transesterification

The carbon reduction potential is then calculated in 7.2.2 based on the findings of 1and 2

7.2.1.1 PPO process

In the PPO pressing process, energy is supplied by a stand alone generator. The electrical energy is used to operate the press, while the waste thermal energy is diverted to the infeed seed hopper. The heat raises the temperature of the seeds and improves the PPO yield.

In the production of energy, the PPO press generator consumes between 2-3 gallons of diesel per hour and this equates to a primary energy demand of 0.518 GJ/ tonne as documented. To estimate the thermal and electrical energy requirements the following calculations were considered.

The primary energy consumed in pressing is 0.518 GJ/tonne or (518 MJ/t). To estimate the actual electrical energy consumed a conservative conversion efficiency factor of 35% is used.

Oil Pressing Energy Demand Calculations **Box 7.1**

This implies that	518 MJ	= Primary energy demand
	518 x 35%	= electrical energy required
	181.3 MJ/tonne	= electrical energy required

Thermal generation is estimated conservatively at 55% conversion efficiency

This implies that	518x 55%	= thermal energy required
	284.9 MJ/tonne	= thermal energy required

7.2.1.2 Transesterification Process in GroOil

As per the PPO process, the transesterification process has a stand alone generator to fuel the energy demands of the plant. A separate 135 kW generator is used with a 35% energy conversion rate as documented in the study. Thermal (waste) energy is used to heat the PPO to 60°C via a heat exchanger. The parasitic electrical energy demand is documented as 102.3 MJ/ tonne, representing 35% of the primary energy consumption.

Transesterification energy demand calculation **Box 7.2**

This implies that	102.3 MJ/tonne	= Electrical energy requirement
	102.3/35%	= Primary energy required
	292.3 MJ/tonne	= Primary energy required

Thermal generation is estimated conservatively at 55% conversion efficiency

This implies that	292.3 x 55%	= thermal energy required
	160.8 MJ/tonne	= thermal energy required

Arguably the thermal energy could be less as only a 10% loss is considered in the calculation above. GroOil has no further heating elements of electrical / heat generation activities on site. Thus in the absence of true measure, one can assume that the thermal energy is not greater than the values calculated. The expectation is that the quantity of thermal energy supplied by the anaerobic digester, (Section 7.4), will far exceed the thermal energy demand and it is in this context that thermal energy demand, as calculated here, is sufficient in detail and accuracy for the Bioenergy 'Integration Matrix'.

A sense check of the thermal demand of transesterification– **Box 7.3**
The Specific Heat Capacity of Vegetable Oil at 25°C is 2 J/g/°C or 2 MJ/tonne/°C
To raise 1 tonne of vegetable oil from ambient (12^0C) to 60^0C ie (48°C), thermal energy of 98 MJ/tonne of is required. [48 x 2 = 98]
This value equates to 60% of the thermal energy consumption as calculated from Thamsiriroj, 2007, figures presented in Box 7.2.

To complete the parasitic thermal and electrical demand calculations, both values are converted from MJ to kWh and the results are displayed in table 7.3 and 7.4 below.

Table 7.3 Parasitic Energy Demand for the Biodiesel Process MJ/t

Process Step	Thermal MJ/t	Electrical MJ/t
PPO pressing	284.9	181.3
Transesterification	160.8	102.3
Total	445.7	283.6

Table 7.4 Parasitic Energy Demand for the Biodiesel Process kWh/t

Process Step	Thermal kWh/t	Electrical kWh/t
PPO pressing	79.1	50.36
Transesterification	44.7	28.42
Total	123.8	78.78

Note: *1 kWh = 3.6 MJ*

In summary, the anaerobic digester is required to supply 123.8 kWh thermal and 78.78 kWh electrical energy per tonne of biodiesel produced in the Bioenergy Park. A total parasitic energy demand of 202.58 kWh/ tonne of biodiesel produced. The key values of thermal and electrical energy are embedded into the 'Integration Matrix' of the Bioenergy Park.

7.2.2 Biodiesel Carbon Emissions Reduction Potential

As energy production and carbon emissions are inextricable linked the calculation of the carbon emission reduction potential should be straight forward however there are a number of factors that must be considered. Carbon emissions reduction potential as a result of the biodiesel process being integrated in Bioenergy Park can be summarised under the following headings:

1 Biofertilizer from anaerobic digestion is used in oilseed rape crop propagation rather than imported synthetic fertilizer.
2 Anaerobic digester provides thermal and electrical energy which would otherwise have been generated from fossil fuels
3 Biodiesel generated and can replace fossil fuel as a transport biofuel.
4 Biomass (straw) generated is also used to generate solid fuel pellets.

This section of the chapter explores the four possibilities in relation carbon emission reduction potential in the calculations to follow.

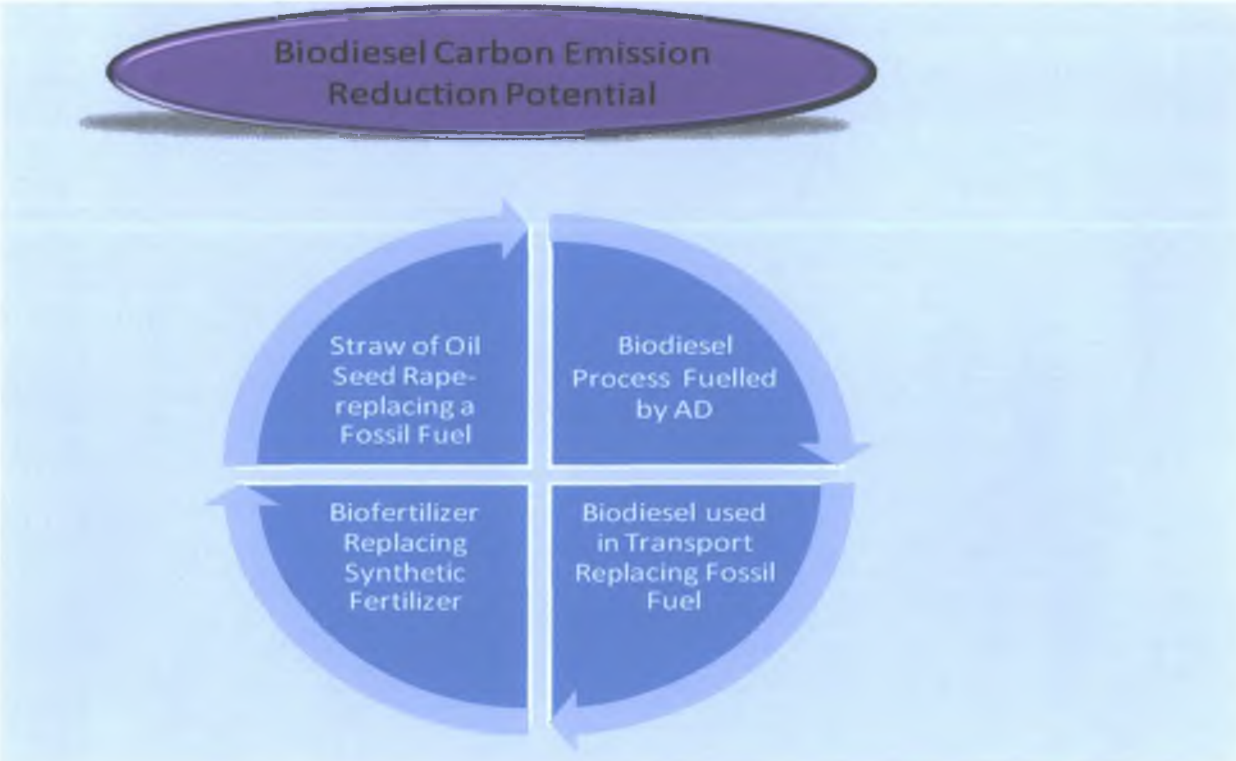


Figure 7.3 Biodiesel Carbon Emission Reduction Potential

7.2.2.1 Replacing fertilizer with biofertilizer

To improve energy balance in the life cycle of biodiesel, Janulis, 2004, investigated new methods in agricultural practices, agrochemical and process technologies.

By using biofertilizer from an anaerobic digester, in compliance with EU guidelines, and adjusting up the potassium levels (12% in the Lithuanian situation) to balance the feed, energy reductions per tonne of seed produced equated to 3193 MJ/tonne. A reduction of 51% of the overall energy requirement for the agricultural phase was achieved.

Using (SEI-8, 2008) carbon factor for electrical generation, 0.636 kg CO_2 /kWh, for every tonne of seed produced, where biofertilizer replaces artificial fertilizer, 0.56 tCO_2 emissions are avoided. As 3 tonnes of seed is required to produce 1 tonne of biodiesel then where biofertilizer replaces artificial fertilizer, 1.68 tCO_2 emissions are avoided per tonne of biodiesel produced.

7.2.2.2 Anaerobic Digestion providing thermal and electrical energy

Based on UNFCCC guidelines, Singh, 2006, calculated carbon emission reduction by considering the methane captured coupled with the carbon reduction where the methane is subsequently used to generate electricity there-by replacing fossil fuels. Carbon credit is allowed for both in the one project. The carbon emission factor (CEF) for replaced electricity, termed a mixed cycle is equal to 0.4 tCO_2/MWh (Singh, 2006). The same logic can thus be applied to the Bioenergy Park activities. The captured methane calculation is considered in section 7.7 and will not be included in this section.

In table 7.3 the parasitic electrical energy demand for PPO production and biodiesel production is documented as 50.36 kWh/t and 28.42 kWh/ tonne respectively. This implies that when the anaerobic digester fuels the processes the Bioenergy park, then for every tonne of biodiesel produced there is a net carbon emissions reduction by 0.03 tCO_2

7.2.2.3 Biodiesel replacing fossil fuel

Singh, 2006, documents that 1 $kgCO_2$ reduced by 0.4 1L of biodiesel when used to replace fossil fuel in transport (Singh, 2006). Given the density of biodiesel is 0.88 kg/L, this implies that one tCO_2 is reduced by 0.45 tonnes of biodiesel or 1 tonne of biodiesel used to replace fossil fuel diesel will give a net reduction of 2.2 tCO_2 of carbon emissions.

7.2.2.4 Straw from Rape seed utilized as solid fuel

The carbon reduction in respect to straw pellets will be considered in the section 7.5 of this chapter.

To calculate the Carbon Emission Reduction Potential of Straw : Box 7.4

1.68 +0.03 +2.2 = 3.91 tCO_2 reduced per tonne of biodiesel produced.

However, the emissions relating to biofertilizer use will not be included in the matrix calculations as the value derived is specifically related to OSR propagation in Lithuania, where soil and farming practices and therefore fertilizer consumption are not directly comparable to the Irish situation.

Recalculated less the value for the biofertilizer:

$$0.03 + 2.2 = 2.23\ tCO_2 \text{ reduced per tonne of biodiesel produced.}$$

Thus the emission reduction value per tonne of biodiesel produce used in the integration matrix will be 2.23 tCO_2.

7.2.3 Biodiesel summary of key integration values

It is generally agreed that the ratio of energy output / energy input for biodiesel from oil seed rape is 3:1 when the energy value of the by-products such as the rape cake, straw and the glycerol are included in the calculations (Bruton, 2002) (N. D. Mortimer, 2003) (Janulis, 2004) (BABFO, 2008). Equally, Life Cycle Analysis studies have shown that biodiesel reduces net emissions of CO_2 by 78% where used to replace petroleum diesel (IENCA, 2000) (J.Sheehan, 1998).

The Department for the Environment, Food and Rural Affairs (UK), commissioned an in-depth review on a number of life cycle analysis (LCA) studies of biodiesel from rapeseed. There is a significant range (0.89- 0.39 MJ/MJ) documented for energy requirements (N. D. Mortimer, 2003). The reported identified that *"the studies display varying degrees of transparency in regard of basic data, assumptions and methods of calculation, especially allocation procedures."*

The summary the key values identified for inclusion in the Integration Matrix are outlined in table 7.5 below.

Table 7.5 Integration Key Values Biodiesel	1 tonne
Reduced tCO_2 emissions	2.23
GJ of energy	28.86
Tonnes of Oil Equivalent (toe)	0.69
Oil Press Parasitic Thermal Demand kWh	79.10
Oil Press Parasitic Electrical Demand kWh	50.36
Biodiesel Parasitic Thermal Demand kWh	44.70
Biodiesel Parasitic Electrical Demand kWh	28.42

Extract Appendix 1.2 Ref: Integration Matrix ' BP Live'

7.3 Straw Pellet energy generation and carbon reduction potential

As for the biodiesel process a number of key integration values are identified to calculate the energy generation and carbon reduction potential of straw pellets. In determining the energy generation potential from straw pellets, the energy flow of cultivation, agricultural practice and processing must be considered. Once the net energy generation potential the known then the carbon emission reduction potential can be determined. Figure 7.4 depicts the energy flows within the straw pelleting process and table 7.6 presents the key findings of this section in relation to integration key values.

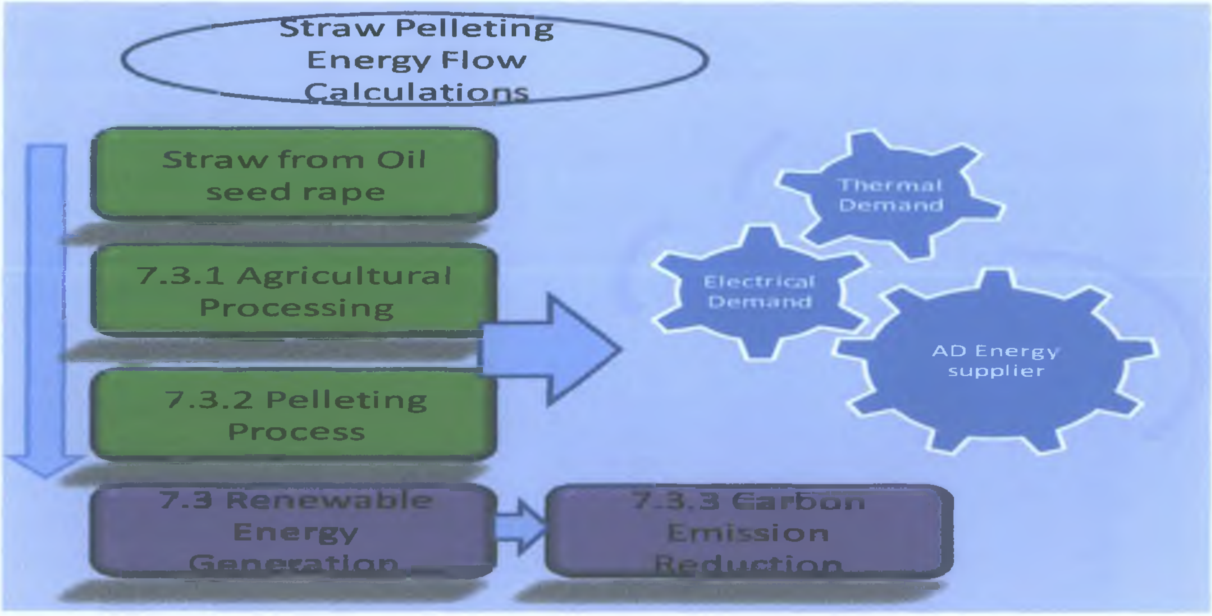


Figure 7.4 Straw Pelleting Energy Process Flow

Table 7.6 Integration Key Values Straw Pellets	1 tonne
Reduced tCO_2 emissions	1.5
GJ of energy	17.0
Tonnes of Oil Equivalent (toe)	0.4
Homes Heated (5.2 t/home/year)	0.195
Electrical generation potential MWh	1.42
Parasitic Electrical Demand kWh	73.42
Parasitic Electrical Demand MJ	264.30
Extract from Appendix 1.2 Ref: Integration Matrix ' BP Live'	

7.3.1 Agricultural practices

From a life cycle analysis point of view, the energy required to propagate and harvest the straw is considered as part of the biodiesel calculation, however the baling and delivery of the straw needs to be considered to get a true net energy value. The British Association of

Biofuels and Oils considers the energy consumed in baling, stubble mowing and tractor as 72.7 MJ/t and 107.5 MJ/t for wheat straw and rapes straw respectively (Table 7.7) (BABFO, 2008). This implies that a tonne of rape straw and wheaten straw delivered in bale format to local Bioenergy Park has a net energy value of 17292.5 MJ/t, 17527.3 MJ/t respectively.

Table 7.7 Energy consume in the baling and collection of straw

Source: Derived from (BABFO, 2008)	**Wheat straw**	**Rape Straw**	**Unit**
Straw baling	258	129	MJ/ha
Carting 2 tractors	215	172	
Stubble Mow	Not required	129	
Total MJ used per hectare	473	430	MJ/ha
Straw Yield	6.5	4.0	t/ha
Energy consumed per tonne	72.7	107.5	MJ/t

7.3.2 Processing

The parasitic demand in the pelleting process will vary from raw material type and quality, design and operation of plant equipment and production capacity and finish product specification. In the Soma + Eko-Press plant combined as described in chapter 4 the parasitic electrical demand is calculated as 73.42 kWh/t (Table 7.8).

Table 7.8 Soma + EKOPress Combined Quote	**Value**	**Unit**
Electrical Demand	183.55	kWh
Expected Out Put	2.5	t/h
Electrical Demand	73.42	kWh/t
Electrical Demand	264.3	MJ/t

As straw can be harvested at the correct moisture content, there is no thermal energy requirement for the straw pelleting process. Thus, where rape straw from the OSR used in the biodiesel production is subsequently processed into straw pellets, the net energy can be calculated as 17028.2 MJ/tonne. Similarly the net energy for wheaten straw pellets can be calculated as 17263 MJ/tonne. For the purpose of the integration matrix calculation, the lesser value of 17028.2 MJ/tonne is used.

7.3.3 Straw Pellet Carbon Emissions Reduction Potential

Straw is considered a carbon neutral fuel. In a paper on life cycle analysis of biodiesel, Sheehan J, 1998 discusses carbon balances of energy crops, and concluded that CO_2 uptake by the crop is released back to the environment through decomposition of plant residue, left in field after harvesting period, or through the combustion of fuel made from the crop (Sheehan J, 1998). Then equally, the net biomass derived CO_2 balance for growing and burning straw pellets is zero.

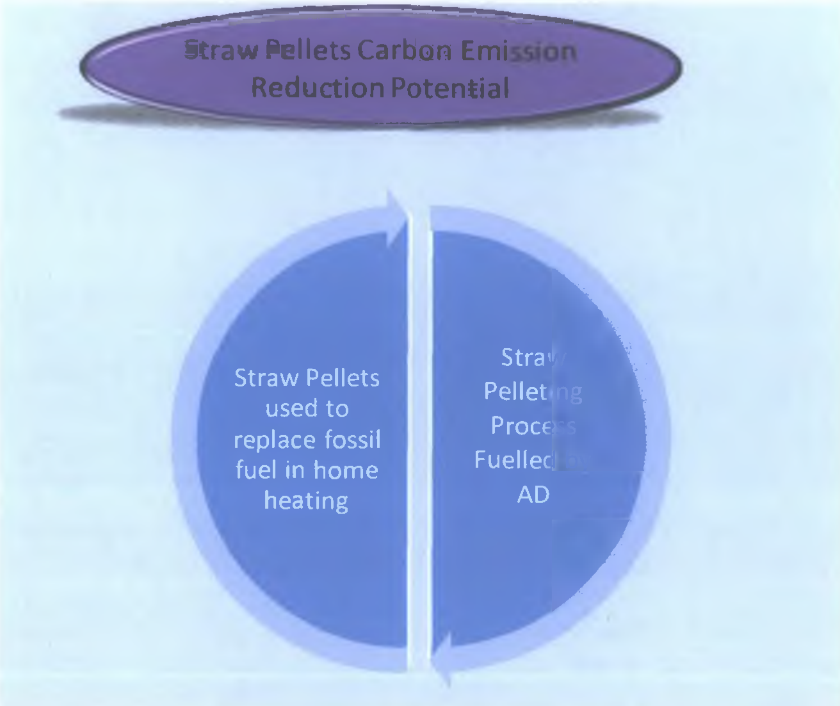


Figure 7.5 Straw Pelleting Carbon Emission Reduction Potential Process Flow

Carbon emissions reduction potential as a result of straw pelleting process being integrated in Bioenergy Park can be summarised under the following headings:

1. Anaerobic digester providing electrical energy which would otherwise have been generated from fossil fuels
2. Straw Pellets generated and can replace fossil fuel as a home heating fuel

7.3.3.1 Anaerobic Digestion is the electrical energy provider and thus the carbon emission factor (CEF) for replaced electricity needs to be considered. The CEF for a mixed cycle is equal to 0.4 tCO_2/MWh. In table 7.8 above the total parasitic energy demand is documented as 73.42 kWh/tonne of straw pellets. This implies that for every tonne of straw pellets produced, the Bioenergy park reduces 0.03 tCO_2 when the anaerobic digester fuels the process.

To Calculate the Carbon Emission Reduction Potential of Straw Pellets **Box 7.5**
CEF for a mixed cycle = 0.4 tCO_2/MWh or 0.0004 tCO_2/kWh
Reduced Carbon Emissions = 0.0004 tCO_2/kWh x 73.42 kWh/tonne
Reduced Carbon Emissions = 0.03 tCO_2/t of straw pellets

7.3.3.2 Reduced carbon emissions by replacing home heating oil with straw pellets

- Straw Pellets have a net energy value of 17028.2 MJ/tonne. One toe is equal to 41870 MJ Thus one tonne of straw pellets is equal to 0.40 toe.

- The energy value of diesel oil is 36800 MJ/1000L (Thamsiriroj, 2007) Then 0.40 toe is calculated as 455 litres.
- The emission factor for diesel oil is 3.2 kg CO^2/ L (International Panel for Climate Change).
- To calculate the tonnes of carbon dioxide avoided, the number of liters is multiplied by the CO_2 emission factor of 3.2 kg CO_2/ L.
- The tonnes of CO_2 avoided by replacing fossil fuel oil (in home-heating) by straw pellets is 1.456 tonnes per tonne of straw pellets.

7.3.3.3 The total tCO_2 reduced can be summarized as 1.486 tCO_2 per tonne of straw produced where the Bioenergy Park anaerobic digester has generating the parasitic energy demand for processing the pellets and the straw pellets replace oil for home heating.

7.3.4 Straw Pelleting summary

In summary the key values identified for inclusion in the integration matrix are outlined in table 7.9 below.

Table 7.9 Integration Key Values Straw Pellets	1 tonne
Reduced tCO_2 emissions	1.5
GJ of energy	17.0
Tonnes of Oil Equivalent (toe)	0.4
Homes Heated (5.2 t/home/year)	0.195
Electrical generation potential MWh	1.42
Parasitic Electrical Demand kWh	73.42
Parasitic Electrical Demand MJ	264.30

Extract from Appendix 1.2 Ref: Integration Matrix ' BP Live'

7.4 Anaerobic Digestion Feed Stock Energy Generation Potential

To determine the energy generation potential, carbon emission reduction potential and the parasitic thermal and electrical demand in anaerobic digestion, the calculation is slightly more cumbersome. In chapter 5, section 5.5.2, the issue of feed stock variables was discussed. Steffen & Szolar, 1998, comprehensive table of biogas and methane yields gives an indication of the expected variability in feedstocks and also indicated probable values of biogas yield and methane % in biogas.

Table 7.10 Biogas production and composition from different feedstocks

Feedstock	Total solids (TS), %	Volatile solid (VS), % of TS	Biogas yield, m^3/kg VS	Methane content, vol. %	Retention time, days
Pig slurry	3-8	70-80	0.25-0.50	70-80	20-40
Cattle slurry	5-12	75-85	0.20-0.30	55-75	20-30
Chicken slurry	10-30	70-80	0.35-0.60	60-80	>30
Garden waste	60-70	90	0.20-0.50	-	8-30
Fruit waste	15-20	75	0.25-0.50	-	3-20
Food remains	10	80	0.50-0.60	70-80	10-20

Source (Steffen & Szolar, 1998) – Subsection for demonstration full table in Appendix 5.0

Generally, the average value of each feedstock type would be sufficient to give an idea of the expected methane yield, however, given the anaerobic digester is the energy generator and is critical to the function of the plant, then from a plant design and energy balance view point, an in depth analysis of the feedstocks potential methane yield range is essential. The concern from a Bioenergy Park is that there is a fixed energy demand from the three processes and where the feedstock energy potential varies as a result of characteristic differences then the energy output could change dramatically different depending on the feedstock mix and quality.

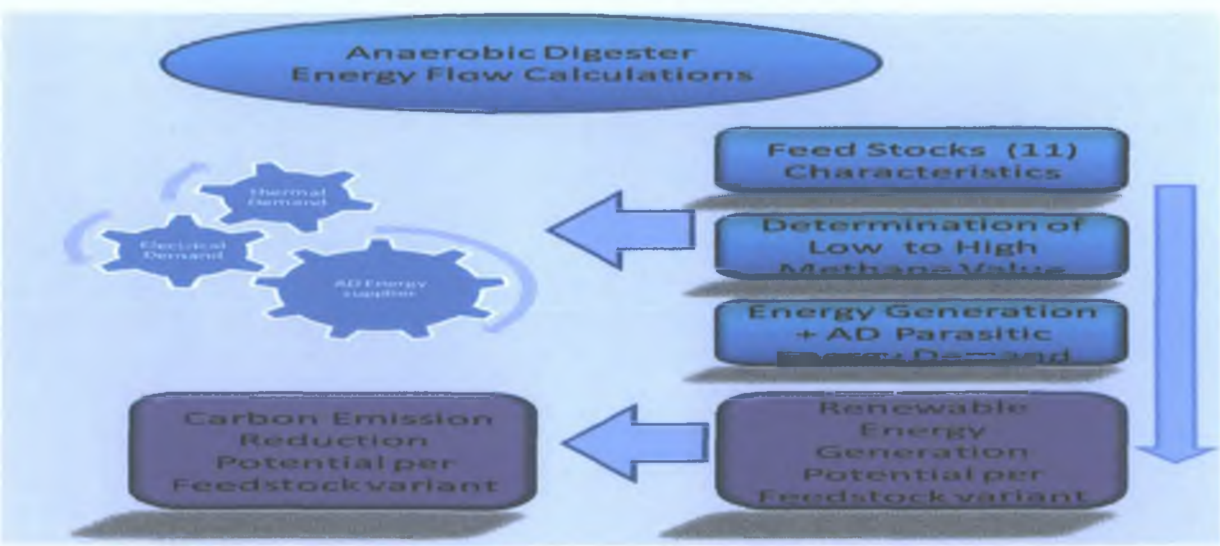


Figure 7.5 Anaerobic Digester Energy Flow Calculations

Given the characteristic differences between feedstocks and the further complications that arise when the range value of each feed stock characteristic is considered the extrapolation of the energy generation potential becomes difficult calculate albeit necessary. In order to investigate the impact of the high value, median value and lowest value from each feedstock variant, the table was extrapolated and the results calculated are displayed in Appendix1.4 Table 7.11 represents the format and results of the median values while table 7.12, over leaf, presents a comparison of the low, median and high values as calculated for each feedstock.

How to calculation of the low, median and high values of a Feedstock Box 7.6
Calculation example TS% of Pig slurry = 3 to 8% Low value = 3, High value = 8, Therefore the Median value = 5 .5 All values with a range were divided into low, median and high values and to determine the approximate value of each feedstock based on the characteristics in table 7.10 as discussed.

Table 7.11 Median value Feed Stock table							**1 tonne of Biomass**
Feed Stock	**Total Solids TS%**	**Volatile solids (% of TS)**	**Volatile Solids kg [Cal- per x kg of Biomass]**	**C:N Ratio**	**Biogas Yield m^3/kg VS**	**Retention time (days)**	**CH_4 %**
Pig Slurry	5.5	75	41.25	3 to 10	0.375	30	75
Cow Slurry	8.5	80	68	6 to 20	0.25	25	65
Food Remains	10	80	80	not Avail	0.55	15	75
Sewage Sludge*	*1*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*22.5*	65
Glycerine **	*1*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*70*
Chicken Slurry	20	75	150	3 to 10	0.475	30	70
Whey	3	87.5	26.25	not Avail	0.875	6.5	70
Leaves	80	90	720	30 to 80	0.2	14	55
Wood Shavings	80	95	760	511	0.2	30	55
Straw	70	90	630	90	0.4	30	55
Garden Waste	65	90	585	100 to 150	0.35	19	55

Least values taken from Steffen et al table
Sewage Sludge Value taken from (Mahony, 2002)*
*Glycerine** Value take from Weltec Anaerobic Digestion Specification*

Extract from Appendix 1.4 Ref: Integration Matrix 'ADFSCal'

To determine the methane yield per feedstock variety a number of calculations are required.

Taking one tonne of pig slurry for example and using the median values for each characteristic as presented in table 7.11 the following is the sequence of calculations required.

The total solids percentage value is 5.5 % of the tonne of pig slurry. Of this quantity of total solids only 75% are volatile solids. Multiplying these values gives 41.25 kg of volatile solids in one tonne of pig slurry. However, the biogas generated from the volatile solids is rated at 0.375 m^3/ kg of volatile solids. Of the biogas generated, 75% is methane. When calculated out equates to 12 m^3 of methane per tonne of pig slurry. For each of the feedstocks listed, a matrix was established to calculate the low, median and high values based on table 7.10. The fully extrapolated list is available for review in the Integrated Matrix 'ADFSCal' and Appendix 1.4 within this document.

Table 7.12
A comparison of High Median and Low Feed Stock - Biogas and CH_4 Yield

1 tonne of a Feed Stock	Highest Value Biogas m^3	Median Value Biogas m^3	Lowest Value Biogas m^3	Highest value CH_4 m^3	Median Value CH_4 m^3	Lowest Value CH_4 m^3
Pig Slurry	32	15	5	26	12	4
Cow Slurry	31	17	8	23	11	4
Food Remains	48	44	40	38	33	28
Glycerine	Na	Na	Na	70	70	70
Sewage Sludge	18	18	18	11	11	11
Chicken Slurry	144	71	25	115	50	15
Whey	45	23	6	36	16	4
Straw	284	252	221	156	139	121

7.4.1 Feedstock values discussed

The comparison table 7.12 demonstrates that there is a significant difference in methane production potential when the results from the high to low value range are considered. For example, pig slurry ranged in biogas value from 5 m^3 to 32 m^3 at the higher value while the methane yield ranged from 4 to 26 m^3. This equates to 7 times more biogas production and 6.5 times more methane production from low to high range values. The median value for pig slurry resulted in 15 m^3 of biogas and 12 m^3 of methane.

Results are similar for cow slurry, having biogas yield ranging from 8 to 31 m^3 and methane yield ranging from 4 to 23 m^3. Chicken slurry, results show a biogas yield range from 25 to 144 m^3 and methane yield range from 15 to 115 m^3. Just on a point of clarity, no range was documented for 'food remains' or 'sewage sludge', however, it is expected that there is will be a similar methane yield variation and not a flat value as is depicted through the matrix calculations.

The results presented indicate how feed stocks, variants, quality and consistency of supply are important and could have a significant impact on energy generation for an anaerobic digester. Therefore it is extremely prudent to investigate both the quantity and quality of feedstock available to the anaerobic digester. Consistent high quality feedstock will result in high energy yields on an ongoing basis. On the other hand, low quality feed stocks, while requiring the same parasitic energy demand, will yield low returns of biogas and methane, and provide very little methane for energy generation for the other process within the Bioenergy Park.

Inconsistent feed stock is also recognized as a significant issue and where possible should be avoided. The anaerobic digester in Camphill Community Center in Kilkenny has four main farming units supplying the digester. Three of the farms have excellent slurry management system while the fourth farm produces variable quality slurry. The methane yield is noticeably reduced when the fourth farm's slurry is added to the digester (Beasley, 2007).

7.4.2 Summary of feedstock values

In summary, knowing the feedstock value and consistency of supply in advance will allow location decisions to be made on a sound scientific basis. The information generated will be used as base building blocks in the Bioenergy Park integration matrix and are presented in appendix 1.4 of this study.

7.5 Anaerobic Digestion carbon emission reduction potential

In addition to the energy benefit of methane production, the global warming potential of methane captured is a key benefit of anaerobic digester in the Bioenergy Park.

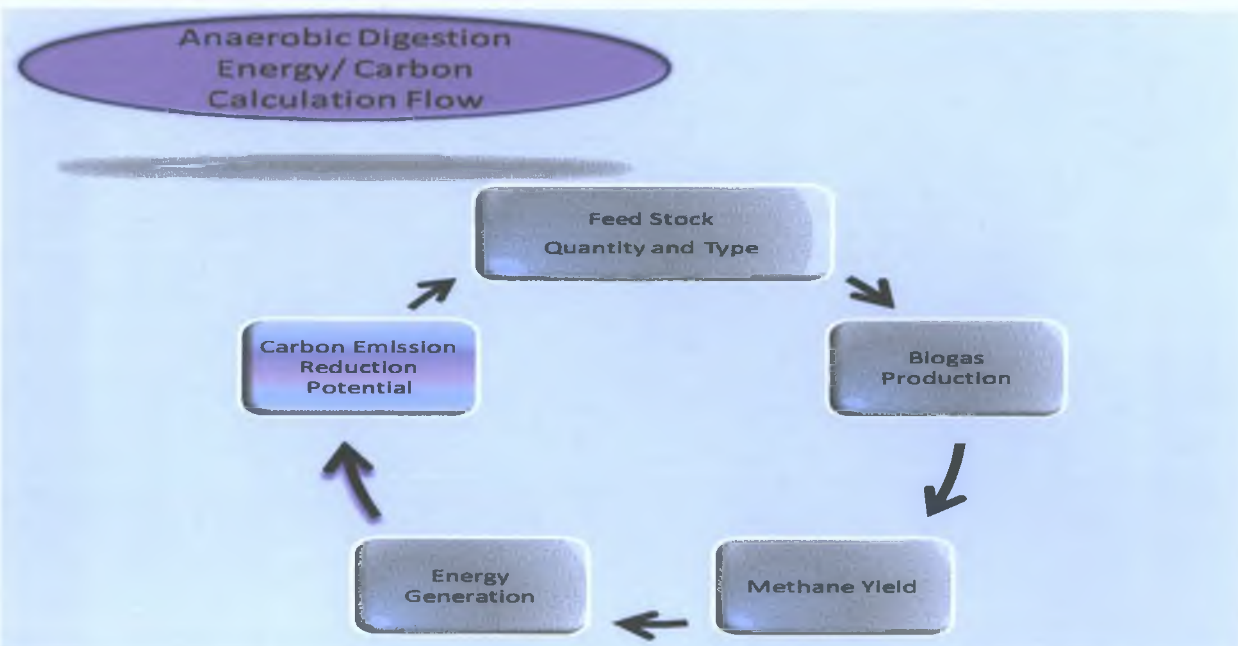


Figure 7.6 Calculating the Carbon Emission Reduction Potential in AD

In order to assess the environmental impact, the variable methane outputs per feedstock must be examined and the resultant carbon emission reduction calculated. Figure 7.6 depicts the calculation flow to determine the carbon emission reduction potential.

7.5.1 Calculating reduced carbon emissions

The following calculations as presented in box 7.7 are embedded into the Bioenergy Park integration matrix.

Calculations used to determine reduced carbon emissions in AD **Box 7.7**

1 Biogas yield per 1 tonne of biomass (feed stock)
2 = (1000kg x TS% X VS%)
= kg of VS in 1 tonne of biomass
= Kg of VS x Biogas yield m^3 value (a)

3 Methane (CH_4) Yield m^3 per 1 tonne of Biogas

= value (a) x CH_4 content % (volume V) Nm^3 value (b)

4 Tonnes of Methane (CH_4) captured per tonne of biomass

Convert Methane V to kg

Density of a homogeneous substance, is expressed as:

$$\rho = \frac{m}{V}$$ where, in SI Units:

ρ (rho) is the density of the substance, measured in $kg \cdot m^{-3}$
m is the mass of the substance, measured in kg
V is the volume of the substance, measured in m^3

Density of Methane is 0.717 kg/m^3, gas (http://www.engineeringtoolbox.com-Methane)
⇨ mass = ρ x V or value(b) x 0.717)
⇨ And divide by 1000 to bring kg to tonnes value (c)

5 Global warming potential (tCO_2) of methane captured per tonne of biomass
GWP of methane is 21 times 1 tonne of Carbon dioxide tCO_2 (IPCC, 1996)
GWP of Combustion of methane is 3
Net GWP = 18 tonnes of CO_2 captured

= value (c) x 18 tCO_2 value (d)

By using the values outlined in box 7.6 together with the tables 7.9, 7.10, 7.11 the quantity of methane and subsequent tCO_2 avoided emissions per tonne of feedstock variant can be extrapolated.

7.5.2 Calculating the Carbon Emission Reduction Potential of Each Feedstock

Table 7.13 presents the feedstocks calculations with regard to the median values and resultant methane yield and tCO_2 reduced emissions per tonne of feedstock. In appendix 1.4 the low, median and high values are presented. Interestingly, glycerine is by far the most significant feedstock from a methane production view point. Glycerine yields three times more methane than straw, and unlike straw that requires dilution to reduce its solid content, glycerine can be added neat.

Table 7.13 Calculating the reduction of Global warming potential of Median FS

Feed Stock	Biogas Yield m^3 / 1t of Biomass	CH_4 Yield m^3 in 1t Biomass	Tonnes of Methane	GWP= tCO2	Biogas m^3@70% methane
Pig Slurry	15	11.60	0.011	0.200	14
Cow Slurry	17	11.05	0.012	0.219	18
Food Remains	44	33.00	0.032	0.568	41
Sewage Sludge	*17.5*	11.38	0.013	0.226	19
Glycerine	*838*	586.60	0.601	10.815	838
Chicken Slurry	71	49.88	0.051	0.920	71
Whey	23	16.08	0.016	0.296	23
Leaves	144	79.20	0.103	1.858	183
Wood Shavings	152	[illegible]	0.109	1.962	193
Straw	252	138.60	0.181	3.252	321
Garden Waste	205	112.61	0.147	2.643	261

Extract from Appendix 1.4 Ref: Integration Matrix 'ADFSCal'

For ease of discussion table 7.14 and figure 7.7 below presents a comparison of the high, median and low values of methane produced and resultant global warming potential reduced in tCO_2.

Table 7.14 High Median & Low Feed Stock Reduced GWP calculated

1 tonne of a Feed Stock	High Tonnes of Methane	Median Tonnes of Methane	Low Tonnes of Methane	High GWP= tCO_2	Median GWP= tCO_2	Low GWP= tCO_2
Pig Slurry	0.023	0.011	0.004	0.413	0.200	0.068
Cow Slurry	0.022	0.012	0.005	0.395	0.219	0.097
Food Remains	0.034	0.032	0.029	0.619	0.568	0.516
Sewage Sludge	0.013	0.013	0.013	0.226	0.226	0.226
Glycerine	0.601	0.601	0.601	10.815	10.815	10.815
Chicken Slurry	0.103	0.051	0.018	1.858	0.920	0.316
Whey	0.032	0.016	0.005	0.582	0.296	0.083
Leaves	0.155	0.103	0.052	2.788	1.858	0.929
Wood Shavings	0.163	0.109	0.054	2.943	1.962	0.981
Straw	0.203	0.181	0.158	3.659	3.252	2.846
Garden Waste	0.226	0.147	0.077	4.065	2.643	1.394

The impact of using different and mixes of feed stocks can clearly be seen. Low quality feed stock provides for a low methane yield and the resultant global warming potential is reduced significantly.

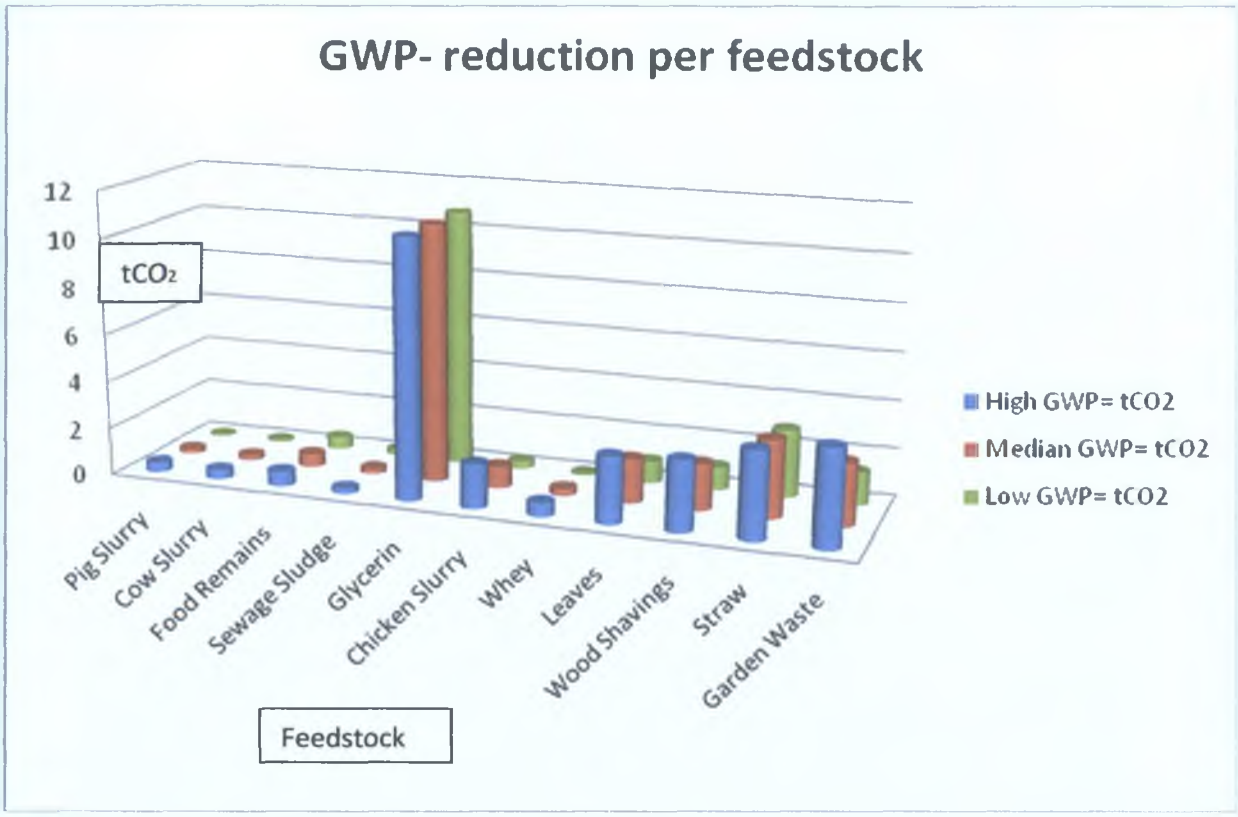


Figure 7.7 Graph of values in table 7.14

The impact of a low methane yielding feedstocks is demonstrated in Tralee Waste Water Treatment Plant, Co. Kerry. The plant has an anaerobic digester which processes the towns sewage sludge. The plant is fitted with a state-of-the-art combined heat and power (CHP) system. Unfortunately the biogas yield from the sewage sludge feedstock provides insufficient gas to run the CHP plant. The electricity bill for the waste water treatment plant is in the region of € 150,000 euro per year while the collected methane is flared off and the expensive CHP plant sits idly by (Clark, 2007).

In line with methane production variation, reduced carbon emissions vary from one feedstock to the next. For example in pig slurry, the carbon emission reduction potential ranges from 0.068 t CO_2 / t of feed stock to 0.4 t CO_2 / t from lowest value to the highest value. Similarly straw values ranging from 2.846 t CO_2 / t of feed stock to 3.659 t CO_2 / t from lowest value to the highest value and so on.

In the integration matrix, the extrapolated median values are used to determine the approximate energy generation potential of feedstock mixes at various percentage inclusions. This will give a more accurate estimate of the energy and reduced carbon emission potential in the anaerobic digester within the Bioenergy Park. The low and high values will be considered in the results chapter where scenarios are challenged.

7.6 Anaerobic Digestion parasitic energy demand

To understand the degree of parasitic thermal energy requirement required for an anaerobic digester a back to basics approach was taken.

Calculating the parasitic energy demands in AD **Box 7.8**

Specific heat capacity of water = 4.184 kJ/kg/ °C
Or Specific heat capacity of water = 4.184 MJ/Tonne/ °C

Assuming that feed stock is at ambient temperature and taking ambient to be 15°C mesophilic conditions require feed stock at 35 °C

= 35-15 = 20 °C rise in temperature step 1

Hygienezation step requires all the liquor to be raised from 35 °C to 70 °C
= 70 – 35 = 35 °C rise in temperature step 2

Assuming that 100% of the feed stock will require the same heat capacity as water and both the fibre and liquor digestate will be treated in the hygienezation step
Then all calculation are based on 100% feed stock raised through step 1 and step 2 above.

100% feed stock (20 +35) = 55 °C rise in temperature

Estimated thermal demand = 4.184 x feed stock tonnes x 55
= 230.12 MJ/tonne of feed stock
= 63.9 kWh/tonne of feed stock (1 kWh = 3.6 MJ)

This would appear excessive given that 1 tonne of pig slurry yields 289 MJ (median value).

The calculation above does not consider efficiencies such as the heat exchangers used to re-circulate the thermal mass from infeed to outfeed within a plant. The actual specific heat capacity of the solids part is not considered and the reduction in volume from step 1 to step 2 following the removal of the biogas load is also not incorporated into the calculation.

B Smyth, 2007, estimates a parasitic thermal demand of 18.59 % per tonne of feedstock, but has assumed 100% boiler efficiency and considered heating through 45 °C and not 55 °C as above. In her calculations she assumes that there is no heat requirement for the feedstock dry matter and calculates the demand based on the water content only. Finally, in-plant efficiencies were not included in her calculations (B Smyth, 2007).

On review of papers, (Warburton, 1997) estimated that the thermal parasitic demand will be in the region of one third of the biogas energy generated and the average value of electrical energy consumed parasitically is generally 10%.

For the purpose of the integration matrix a figure of 30% thermal consumption will be utilized and electrical consumption will be calculated at 10%. Table 7.15 extrapolates the median range of values only, however in the integration matrix all ranges are fully extrapolated.

Table 7.15 Determination of the parasitic thermal and electrical demand per tonne of feedstock

Feed Stock (1 tonne)	Biogas m^3@70% methane	CHP Elect kWh	CHP Thermal kWh	Electrical kWh Parasitic Demand	Available Electrical kWh	Thermal kWh Parasitic Demand	Available Thermal kWh
Pig Slurry	14	38	43	4	34	13	30
Cow Slurry	18	48	55	5	43	16	38
Food Remains	41	107	123	11	96	37	86
Sewage Sludge	19	49	57	5	44	17	40
Glycerine	838	2179	2514	218	1961	754	1760
Chicken Slurry	71	185	214	19	167	64	150
Whey	23	60	69	6	54	21	48
Leaves	183	477	550	48	429	165	385
Wood Shavings	193	503	580	50	453	174	406
Straw	321	834	962	83	751	289	674
Garden Waste	261	678	782	68	610	235	547
Median values per tonne of feedstock							

At this point the true value of the feed stocks is apparent. The ability of an anaerobic digester to provide meaningful thermal and electrical energy is demonstrated in the table above.

Chicken slurry is significantly more valuable a resource than pig slurry, but chicken slurry requires dilution in order to process in an anaerobic digester. Food remains are also valuable at three times the value of pig slurry and just over twice the value of cattle slurry for final energy production. Leaves, wood shavings, straw and garden waste provide very high yields, however at between 65 – 80% solids these too will have be diluted to an operating solids % and will depend on selected design as discussed in chapter 5.0 regarding mixed batch reactors or plug flow reactors.

In chapter 3.0, studies documented that the co-digestion of pig manure and glycerine up to a maximum glycerine levels of 3 to 6%, resulted in improved methane yields which amounts between 18 and 22 % compare to the each separate digested substrate (Kryvoruchko V., 2006). Glycerine stands out in table 7.15 as a key feedstock in the anaerobic digester, however it must be remembered that beyond the maximum limit of 5-7 g L^{-1} concentration can cause strong imbalance in the anaerobic digestion process (JB Holm-Nielsen, 2007).

The impact of variations in methane from an anaerobic digester is two fold. Firstly, from an operations point of view an inconsistent supply of methane may mean inconsistent supply of energy and thus impact the dependant processes and their output capacity. Secondly, the capital input is based on feed stock capacity requirements, and where the yield is low, the return on investment can be significantly reduced.

7.7 Summary of energy generation and carbon emission reduction potential

In summary, the parasitic thermal and electrical demand of the biodiesel and straw pelleting processes is established. Key equivalent values for the carbon emission reduction potential are established for both biodiesel and straw pellets per tonne.

Feedstocks have been evaluated in terms of their energy production potential and factors per feedstock have been calculated in relation to methane production potential, carbon emission reduction potential and also the parasitic thermal and electrical demand per feedstock.

By incorporate these values into an integrated matrix with an interactive facility, the opportunity to balance the processes is now possible. The ability of the anaerobic digester to supply the plant's thermal and electrical demand will be challenged based on feedstock mix and the results will be documented in chapter 10.0.

Note : references made to Integration Matrix within this chapter summarized below:

Section	Integration Matrix Code	To View Detail refer to Appendix
7.2	'BP Live'	1.2
7.3	'BP Live'	1.2
7.6	'ADFSCal'	1.4

8.0 The Bioenergy Park business case – establishing the building blocks

Clearly, production of a renewable fuel has many positive local and national benefits but greenhouse gas emissions alone will not convince investors to part with their hard earned cash. In this chapter the costs associated with each of the three activities in the Bioenergy Park is considered. Biodiesel and straw pelleting system are based on quotations, valid in January 2008 for fixed capacity production lines, deemed suitable for small scale operation. For anaerobic digestion a recent cost model is extrapolated to predict capital and operational cost based on feed stock volume and plant capacity requirements.

The aim of this chapter is to review the individual business cases for each element of the Bioenergy Park and also provide the building blocks for the Bioenergy Park business case which will be used in the 'Integration Matrix'.

8.1 Biodiesel business case

The Biodiesel business case is built around a number of key factors such as raw material costs, capital costs and operational costs.

8.1.1 Resource costs

To produce one tonne of biodiesel, 3 tonnes of oil seed rape is required.

- ✓ Oilseed rape was sold at € 240/ t in 2006 (Teagasc, 2007), at the start of 2007 the price reached € 365/t, and by the end of 2007 oilseed rape commanded a price of €480/ t (IFJ, 2008). OSR is expected to cost in the region of € 500 to € 550 a tonne in 2008. For the purpose of the Bioenergy integration matrix, €500 /t will be considered, however, the matrix user will have a facility to change this value in real time, as market prices change, as will be the case for all consumables. (Reference Appendix 1.7 and Integration Live discussion chapter 9.0)
- ✓ Methanol is consumed at a rate of 11% at a cost of € 0.60 / litre (Thamsiriroj, 2007)
- ✓ Sodium hydroxide is consumed at a rate of 0.01% and at such a rate is not considered in subsequent calculations.
- ✓ Glycerine market price is € 90 / t (Thamsiriroj, 2007). This means that for every tonne of biodiesel produced, € 9 worth of glycerine is produced for sale. However, given its potential as a feed stock for the anaerobic digester where up to 5% of the feedstock quantity can be added as glycerine, 100% will be diverted to the anaerobic digestor for methane production.
- ✓ Rapeseed cake sold for € 170 / t (Thamsiriroj, 2007) . This means that for every tonne of biodiesel produced, approximately, 2 t or € 340 of rapeseed cake is produced for sale.
- ✓ Biodiesel is sold for € 1.00/ L (Caslin, 2008), or € 880 /t
- ✓ MOT Relief where awarded is equal to €0.368/ L or € 323.84/t

8.1.2 Biodiesel capital costs

The capital costs for the GroOil process is documented as €1.2 million (Thamsiriroj, 2007). Given the scale of the plants and the mismatch between the capacity of the oil pressing plant (1 million litres) and the biodiesel plant capacity (7 million litres), further research was carried out on current small scale plant costs. In addition, the desired process for the Bioenergy Park is that of low or no water usage. In this context a turnkey plant and capital and operational costs were sought from Feed Service and Greenfuel (as discussed in Chapter 3 section 3.4.3).

The total capital cost in sterling for the oil press system was £ 229,000 and at an exchange rate of 1.227 quoted on the 09/04/08, this equates to € 280,983 (table 8.1 below- extract from Appendix 1.7 Integration Matrix' BD Cap')

A KEK PO 500 oil press will process 500 kg seed per hour producing approximately 180 kg oil per hour. Feed Services recommend an AMA VERSIS1000 pressure leaf filter. This machine has a filtration area of 24 m^2 and has capacity to filter 700 kg of oil per hour. A fully automated system is advised. This system is sized to have sufficient capacity to filter the product of four KEK500 oil presses (Rhodes, 2008).

Table 8.1 Capital Costs for Oil press	£ *Sterling*	€ euro	Exchange rate
Oil Press System	Cost	Cost	1.227
Screen	2000	2454	
Seed cleaner	40000	49080	
KEK PO 500 Press x 2	94000	115338	
AMA VERSIS1000 pressure leaf filter	40000	49080	
Siemens controls	19000	23313	
Compressor	10000	12270	
System Fully Automated	24000	29448	
Total Cost for 0.36 t/h oil press system	229000	280983	
Feedservices quotation Feb 2008, Greenfuels quotation Dec 2007			
Biodiesel: Twin Auto FuelMa 8400 L/Day (24hrs)			
FuelMatic Project site survey and installation definition	750	920.25	
Pre Heat Module - Input Oil 1300 liters	9500	11656.5	
FuelMatic Twin Reactor Tanks	23800	29202.6	
FuelMatic Glycerin Separator	7700	9447.9	
FuelMatic Biodiesel Purification Module Twin Column 900l/h	18500	22699.5	
FuelMatic PLC Control Panel Twin System	38000	46626	
Baseplate for Twin Reactor FuelMatic	5750	7055.25	
Twin FuelMatic Installation and Site work pre commissioning	6500	7975.5	
Twin FuelMatic Commissioning and First Year Maintenance	5500	6748.5	
Total Cost for 0.38 t/h biodiesel system	116000	142332	
Biodiesel for oil seed rape - total capital cost	345000	423315	
Extract from Appendix 1.7 Ref: Integration Matrix – ' BDCap'			

Table 8.1, also documents the cost of the biodiesel plant for a capacity of 8400 L/day. A full specification and quotation is available in appendix 3.2. The system size matches the output from the oil pressing plant. The plant is capable of processing both PPO and recovered vegetable oil. This is an added bonus, as feed stocks can be alternated dependant on location of the Bioenergy Park. The total capital cost in sterling for the biodiesel system was £ 116,000 and at an exchange rate of 1.227 quoted on the 09/04/08, this equates to € 142,332. The overall capital cost for equipment installed is then calculated at £ 345,000 or € 423,215.

The maximum capacity of this plant is 2592 tonnes of biodiesel if the plant was to run 24 hours a day, 6 days for 50 weeks of the year. This approximates to 3 million liters of biodiesel per year. Where a liter is sold at € 1 then this equates to a turnover of € 3 million per year on an investment of € 500,000. This is an encouraging result. Together with the sale of the rape cake and glycerol the outlook is good. The next step is to investigate the operational costs.

Figure 8.1 Field of OSR flowers for the honey bee
Source: www.tempesthillhoneyfarm.co.uk

Figure 8.2 Sampling Biodiesel
Source: http://www.sflorg.com

8.1.3 Biodiesel operational costs

The operational costs are a combination of payback capital costs, resource costs together with labour and energy consumption costs. Note, the cost of collection or distribution of any raw materials or finished product is not considered in the model. Table 8.2 itemises the operational costs and considers three options.

Option 1, 2,3 are in consideration of OSR priced at € 300, € 450, € 500 / tonne respectively. There are two scenarios investigated per option. The first scenario is where the energy is purchased from the Electricity Supply Board (ESB). The second scenario is where the energy is supplied by the anaerobic digester, and effectively free.

Using a business case template provided by (Navratil, 2008) a business case was thus derived to illustrate the impact of various tonnage issues and also the impact of in-house green electricity being supplied by the anaerobic digester. In option 1, the capital costs amount to € 723,315 euro and considering raw material costs of OSR @ € 300/tonne and methanol, together with cost of labour, electricity and other overheads as listed in table 8.2, the total operational costs is tabulated as € 2,737,103 per annum. The majority of this cost can be attributed to the OSR (85%). By comparison, option 3 considers OSR @ € 500/ tonne and the operational costs become € 4,292,303 per annum or 90% of the total operational cost.

Costings on Biodiesel Feedservice and Greenfuel (combination) 0.36t/hr						2592 t/year
Table 8.2	**Option 1** (OSR € 300/t)		**Option 2** (OSR € 450/t)		**Option 3** (OSR € 500/t)	
Capital	ESB	BioEnergy Park Supply	ESB	BioEnergy Park Supply	ESB	BioEnergy Park Supply
Equipment	423315	423315	423315	423315	423315	423315
Land and Buildings (estimate)	200000	200000	200000	200000	200000	200000
Running Capital	100000	100000	100000	100000	100000	100000
Total	723315	723315	723315	723315	723315	723315
Annual capacity - Biodiesel Tonnes	2592	2592	2592	2592	2592	2592
Oilseed Rape 2592 t x3 (3 tonnes OSR = 1 t biodiesel)	2332800	2332800	3499200	3499200	3888000	3888000
Electricity:202.58 kWh/t @ 0.15 € x 2592	78763	0	78763	0	78763	0
Wages (Industrial average) 6x€400*50	120000	120000	120000	120000	120000	120000
Methanol @ € 0.60/ l Added at 28 l/t of biodiesel (Thamiriroj's 2007)	43546	43546	43546	43546	43546	43546
5 Year depreciation	84663	84663	84663	84663	84663	84663
Interest on Capital @5% for 5 years	36166	36166	36166	36166	36166	36166
Maintenance and office (est)	20000	20000	20000	20000	20000	20000
20 year depreciation	21166	21166	21166	21166	21166	21166
Operating Cost	2737103	2658340	3903503	3824740	4292303	4213540
Break even price / tonne	1055.98	1025.59	1505.98	1475.59	1655.98	1625.59
Biodiesel Income (€880/t)	2280960	2280960	2280960	2280960	2280960	2280960
Glycerol Income (€90/ t)	23328	23328	23328	23328	23328	23328
Rape Cake Income (€ 170 /t)	881280	881280	881280	881280	881280	881280
Total Income	3185568	3185568	3185568	3185568	3185568	3185568
Net Income	448465	527228	-717935	-639172	-1106735	-1027972
Margin %	14	17	-23	-20	-35	-32
Extract from Appendix 1.8 - Integration Matrix Sheet 'BD Bus'						

The margin of 14 % is reasonable in the case of option 1. And when the energy is supplied by the anaerobic digester the margin improves to 17%. However, in the case of OSR increase to

€ 450/ tonne in option 2 and € 500/ tonne in option 3 the margin becomes negative. Option 3 shows a minus 32% margin and that includes energy being supplied by the Bioenergy Park.

While there is a positive impact in having 'free' energy, it really only equates to approximately 3% of the overall margin. If the 2008 expected price of € 500 plus per tonne for OSR is realised, then biodiesel production would require some subsidy in order to achieve even break-even margins. Clearly the cost of the raw material is rendering biodiesel production a loss making operation in the current climate.

While there is no guarantee that a Bioenergy Park would be awarded MOT Relief or indeed that there will be an additional scheme following scheme II (2006 to 2010), however, it is worth considering the financial impact of same to the operational cost. Table 8.3, considers the impact of 100% MOT Relief of € 0.368 per litre.

The percentage margins indicate that for an OSR price of € 300 /t the business is viable, however at a price of OSR of € 450 /t margins are as low as 3% and 5%, where energy is purchased from the ESB, or supplied 'free' by the Bioenergy Park respectively.

Table 8.3 MOT Relief Realized	**Option 1** (OSR € 300/t)		**Option 2** (OSR € 450/t)		**Option 3** (OSR € 500/t)	
Add MOTRelief €0.368/ L or € 323.84/t	839393	839393	839393	839393	839393	839393
Biodiesel Income (€880/t)	2280960	2280960	2280960	2280960	2280960	2280960
Glycerol Income (€90/ t)	23328	23328	23328	23328	23328	23328
Rape Cake Income (€ 170 /t)	881280	881280	881280	881280	881280	881280
Total Income	4024961	4024961	4024961	4024961	4024961	4024961
Net Income	1287858	1366621	121458	200221	-267342	-188579
Margin %	32	34	3	5	-7	-5

Extract from Appendix 1.8 Ref: Integration Matrix Sheet 'BD Bus'

Unfortunately, where OSR is priced at € 500 /t the production of biodiesel is not viable even with consideration of 100% MOT Relief being awarded. In summary the overall business case result is unfavourable at the current and expected OSR prices.

But a number of factors could tip the balance in the future.

1. As Ireland continue to under achieve on the agreed biofuel minimum targets, additional schemes could come into play to support processing and sale of biodiesel. This could be in the form of increased or renewed MOT Relief incentives, further investment tax rebates, or indeed the provision of a carbon credit trade schemes for small scale carbon emission reduction favouring the local renewable energy producer.
2. Government incentives could change, as they have in Germany, where fuel majors are forced to blend a specific volume of biodiesel thus increasing market demand.

3 Implementation of the 'Biofuels Obligation' system should also incentivise the purchase of higher cost carbon neutral fuels for high energy consumers. Incidentally, this is scheduled for Ireland in 2009, but the scheme as of yet is not defined and thus the impact of same cannot be assessed.

4 Finally, the continued increase in fossil fuel oil bodes well for the economics of biodiesel production.

8.2 Straw Pellets Business Case

The total cost of pelleting includes, raw material costs, transport costs and processing costs. All these costs must be balanced against the possible income in order to investigate viability of straw pelleting in the context of the bioenergy park.

8.2.1 Costs of straw as a raw material for pellets

The reality of any agricultural commodity is that the price is, quite literally, as changeable as the weather. Optimal conditions result in good crop yield and lower prices based on supply and demand dynamics. Equally suboptimal conditions result in low yields, giving resulting in increased demand on low stock thereby increasing prices. To use straw in a pelleting operation, the straw must be delivered in a bale format, with a moisture content of between 10 to 12% moisture. Teagasc, 2007, reported 'on the farm' barley, wheat and oaten straw at € 57.7, € 55.2 and € 63.6 per tonne respectively (table 8.4).

Table 8.4 Comparison pricing for Straw at 2006 prices

Straw variant	Value € Per tonne	Value € Per Square bale (12 Sq bale = round bale 4x4)	Value € Per round bale 4 x 4	Value € Per round bale 5 x 4
Barley Straw	57.7	0.72	8.7	13.0
Wheaten Straw	55.2	0.69	8.3	12.4
Oaten Straw	63.3	0.79	9.5	14.2

12 Square bales(12.5kg) = 1Round bale 4x4, & 5x4 bale is 50% bigger than 1Round bale 4x4

Source: (Teagasc., 2007)

8.2.1.1 Straw baling and delivery costs

The large 'square' bale, format is by far the most efficient in terms of transport costs. A standard 40 foot trailer, when full, will carry 18 tonnes or 30 large square bales (B Smyth, 2007). Delivery costs will depend on the distance travelled, however, there will be a surcharge for shorter distances. Table 8.5 presents delivery costs for large square bales for various transport distances at 2003 prices.

Table 8.5 Delivery costs of straw for various delivery distances			
Distance from collection points to processing location		Delivery cost (€/t)	Delivery cost (€/t/km)
Short distance	48km	8.52	0.18
Medium distance	96km	14.17	0.15
Long distance	144km	19.93	0.14

Delivery costs for large square bales for various distances (SEI-2, 2003)

Considering a 10 km radius, the raw material and transport costs (Table 8.8) accounted for 49% of the total operational cost for pelleting (S. Mani, 2004), (S Sokhansanj, 2006). While the study was carried out in America, the large percentage attributed to raw material and transport combined can not be ignored and will be a constraint on location of the Bioenergy Park site.

A brief check on current market place (April 2008) prices indicate that Nolan Transport, based in New Ross, charge 150 euro per load (18 tonnes) for 0 – 50 km and 300 euro for 100 km round trip. Nolan Transport pointed out that generally, a farmer will shunt bales within a local area, so where a local radius is applied then the delivery costs will be insignificant.

In summary, the cost delivered for 30 large square bales of straw at € 15 per bale, in a 10 to 50 km radius is €600 (€ 33 /t) and in a 100 km radius is € 750 (€ 42/t). Both baling and transportation costs will continue to rise, mapping the increasing costs in diesel. Obviously, minimizing transport to a pelleting plant will keep raw material costs down while at the same time reduce the environmental impact in a positive way.

8.2.2 Straw Pelleting operational costs

A multitude of variables such as raw material characteristics, temperature, moisture content, feed rate, particle size, and pressure use to form pellets can impact the energy consumed and therefore the eventual cost of pelleting (S.Sokhansanj, 2003).

In addition to raw material and transport cost, the next significant cost contributor is personnel (table 8.6). This cost is variable based on country of application, level of line automation and the level of technology used in a plant.

For example Balcas employ 8 personnel in the pelleting plant, and these personnel are mainly highly trained process engineers with a particular skill set. The plant is a 24 hr operation and is so in order to redress capital expenditure (Keelagher, 2007). This 24 hr work pattern adds a premium to salaries. Soma Plants on the other hand operate with 2 general operatives and work hours can be organised based on market requirement rather than capital pay back constraints.

Table 8.6 Cost of biomass pellet production for the base case (2004 US dollars)

	Capital Costs $/t	Operation Costs $/t	Total Cost $/t	% Cost Distribution
Raw Material- biomass and transport 10km)	0.34	19.39	19.73	49.0
Hammer mill	0.25	0.7	0.95	2.4
Pellet mill	1.43	1.88	3.31	8.2
Pellet cooler	0.13	0.21	0.34	0.8
Screening	0.11	0.05	0.16	0.4
Packing	0.56	1.37	1.93	4.8
Pellet Storage	0.07	0.01	0.08	0.2
Miscellaneous equipment	0.42	0.33	0.76	1.9
Personnel cost	0	12.74	12.74	31.6
Land use & building	0.21	0.05	0.26	0.6

Source: (S. Mani L. T., 2004) (S Sokhansanj, 2006)

The final grouped expense can be attributed, in the main, to energy consumption. S. Mani, 2004, reported that the energy consumption per tonne was 130 kWh. The Bioenergy Park is to generate its own electricity, fuelled by the process of anaerobic digestion. In theory, this means that despite high and variable raw material costs, by having 'free' electricity, the Bioenergy Park could produce straw fuel pellets competitively. Section 8.7 examines the business case to investigate this theory.

8.2.3 Capital and operational costs using chosen technology

In chapter 4 section 4.3, Soma Technology was identified as the best fit for small scale production in a Bioenergy Park application. However, there were some issues raised on the site tour, in particular the level of dust in the work area was significant and warranted remediation. In addition, following a detailed review of the quotation, a number of items were not included in the price. In order to rectify both these issues an additional quotation was secured from a company called EKO-diesel. EKO Diesel is distributor for a range of small scale, affordable and sturdy pellet presses and milling systems (Guntrip, 2008). Guntrip, 2008, provided a 1 tonne an hour turnkey wood-pelleting plant that was fully fitted with dust extraction, storage silos and dispatch feed conveyors. A merger of the two specifications was required to build and price a Bioenergy Park solution. Table 8.7 compiles the two specifications. The shaded area is additional plant required. Both prices and additional energy demands are added to the soma quotation.

While unusual, the combination of quote provides a true reflection of costs of plant for a turnkey solution. The final price was € 374,250 for a design output 2.5 tonne an hour, with an electrical demand of 73.43 kWh. The design specification does not include a bagging plant.

For the purpose of the integration matrix, straw pellets will be manufactured for supply in bulk.

Table 8.7 Soma + EKOPress Combined Quote	kWh/t	Additional Plant Requirement
Crusher		
Hammer Mill		
Belt conveyor		
Impulse dust filter	1.1	18000
Cyclone	0.75	4200
Rotory drum screen		
Magnet separator		
Bucket conveyor		
Buffer		
pellet press		
Bucket conveyor		
Cooler	1.1	21250
Grade screening	1.5	10650
Fan	11	3750
Screw conveyor	1.1	3750
Dust filter net		21250
Bucket conveyor	1.5	3750
Buffer	0.5	2650
Bulk Storage		35000
Electrical cabinet		
Quoted Elect demand	165	
Fit and commission		
Quoted cost	250000	**374250**
Electrical Demand kWh	**183.55**	
Expected Out Put t/h	**2.5**	
Electrical Demand kWh/t	**73.42**	
Extract from Appendix 1.10 Ref Integration matrix – 'SP Cap'		

Table 8.7 – the highlighted rows depict additional plant required Prices were valid in January 2008.

8.2.4 Straw Pelleting plant capacity per year considered

The Soma pelleting press is the bottle neck on the production line. Generally, the pre-press section of the system can feed at least two if not three presses. According to Soma, it is possible to add another press onto the production line as quoted. Additional requirements include a feed conveyor from the hammer mill to the second pellet press, an additional press and dust extraction equipment. Obviously, additional equipment will increase the electrical demand, but overall the energy consumption per tonne will decrease as will the cost per tonne. For the purpose of the integration model only one pelleting press will be considered.

Capacity, for a one pellet system can then be calculated based on man-hours worked.

Hours	Days	Weeks	Total Hours Available	Tonnes Produced 2.5t/hr	Electrical Demand MW/h	Tonnes Produced 1.5t/hr
16	6	50	4800	12000	881.04	7200
24	5	50	6000	15000	1101.3	9000
24	7	50	8400	21000	1541.82	12600
a)	Electrical demand per hour = 183.55 kWh					
b)	Expected output = 2.5 t/hr					
c)	Electrical energy demand per tonne = 73.42 t/hr					

Table 8.8 Capacity based on available work hours of Soma line -one press

Extracted from Appendix 1.10 ref: Integration Matrix 'SP Cap'

Table 8.8 demonstrates the possible production output capacity for the Soma- one pellet press system in consideration of various work patterns. As indicated, work patterns do not translate linearly in price. Local agreement will dictate shift patterns and shift rate costs. In addition, during the Soma site tours, early indications were that the line performance was rated at 2.5 t/h but expectations were closer to 1.5 t/h.

A final calculation using 1.5 t/h demonstrates the significance of this expected output verses the specification output on an annual basis. For example a 16 hour, 6 day, 50 week year could produce a range between 7200 tonnes to 12000 tonnes of fuel pellets per annum. When purchasing a plant, design specifications and performance criteria need to be included as part of the purchase agreement.

8.2.5 Straw pellet income potential

To identify the potential income, firstly the potential customers need to be identified. In chapter 4 section 4.2.4, the availability of appropriate burner types were discussed and resultant potential customers were identified.
The potential customer base can be thus identified based on an income point of view

1) High grade pellet market
2) Low grade pellet market

8.2.5.1 The high grade pellet market is that of the domestic consumer. Currently, the market price of wood pellets is € 210 per tonne. Balcas stipulate a minimum deliver order of 3 tonne. The energy value of straw pellets is approximately 8% less than wood. However, currently pellets are sold in weight and not in energy value so it is expected that the market price for Irish straw pellets would mirror wood pellet prices. Table 8.9 calculates the annual income based on the Balcas price per tonne and considers the output of the line as rated at 2.5 t/h. Gross income could range from € 2.5 to €4.4 million per annum. However, a realistic income of €1.5 to € 2.6 million per annum is expected if the 1.5 t/h was realized.

Table 8.9	**Potential income based on current market prices**	
Tonne Per Annum	**Income Balcas Price €**	**Income ESB Price €**
12000	2,520,000	1,170,000
15000	3,150,000	1,462,500
21000	4,410,000	2,047,500

8.2.5.2 Low grade pellet market is that of solid fuel power plants. In the main there are two power stations in Ireland that are currently fueled by solid fuel. Edenderry/West Offaly Power has a capacity of 150 Megawatts (Table 8.10). This plant consumes over 1,245,000 tonnes of peat per annum. The plant's electricity generation from renewable feedstocks target is set at 30%, as such the means of converting from peat to biomass is currently being investigated by the newly appointed biomass manager.

To put this quantity into prospective, to supply 30% of the day's fuel a total of 120 articulated loads (40 ft trailers) of straw is required. Even if it was possible to collect, transport and handle, the plant would not be able to process the straw as presented in the bale format, however, Egan, 2008, agreed that straw pellets could be utilized without any line modifications (Egan, 2008).

Table 8. 10 ESB Generation Stations Listed with Capacity (MWS) and Fuel Type		
Station	**Capacity MW**	**Fuel Type**
Edenderry/West Offaly Power	150	Peat
Lough Ree Power	100	Peat
Moneypoint	915	Coal
Source :http://www.esb.ie/main/about_esb/power_stations_intro.jsp		

On the issue of price, the ESB will pay the cost of the peat less the carbon emissions certificate value of the renewable energy fuel. The value of a tonne of carbon is approximately €20. The price would be set at approximately € 97.5 euros per tonne. Table 8.9 above calculates the potential income per annum at 1 – 2 million euros, but this could be as low as 0.7 to 1.1 million if the line production output dropped to 1.5 t/h.

In summary, the potential tonnes of straw pellets for sale could range between 7900 to 21000 tonnes with one pellet press on line. Cost of labour is dependant on shift pattern and local wage agreements. The parasitic energy demand is rated at 73.4 kWh/tonne. And the potential gross income could yield between 700,000 to 4.4 million euros per annum. This is a significant disparity in the income range potential.

8.2.6 Investigating the business case

In order to examine the impact of this income a business case estimate was required. Using again the template provided by (Navratil, 2008) a business case was derived to illustrate the impact of various tonnage issues and also the impact of in house green electricity being made available to the pelleting system. The total capital costs for the straw pelleting operation is estimated at € 674,250 with an operational cost of between € 798,253 to € 1,542,274 depending on electricity supply source and output potential.

Table 8.11 Costings on Soma (combination) 1 Pellet Press system

	Option 1 (7900 tonnes)		Option 2 (12000 tonnes)		Option 3 (21000 tonnes)	
Capital	ESB	BioEnergy Park Supply	ESB	BioEnergy Park Supply	ESB	BioEnergy Park Supply
Equipment	374250	374250	374250	374250	374250	374250
Land and Buildings (estimate)	200000	200000	200000	200000	200000	200000
Running Capital (estimate)	100000	100000	100000	100000	100000	100000
Total	674250	674250	674250	674250	674250	674250
Feed Stock @ 50 euro/tonne	474000	474000	720000	720000	1260000	1260000
Electricity:73.4 kWh/t (15c €/kWh)	86979	0	132120	0	231210	0
Wages (Industrial average)	90000	90000	90000	90000	135000	135000
5 Year depreciation	74850	74850	74850	74850	74850	74850
Interest on Capital @5% for 5 yrs	33712	33712	33712	33712	33712	33712
Maintenance and office	20000	20000	20000	20000	20000	20000
20 year depreciation	18712	18712	18712	18712	18712	18712
Operating Cost	798253	711274	1089394	957274	1773484	1542274
Tonnage	7900	7900	12000	12000	21000	21000
Break even price	101.04	90.03	90.78	79.77	84.45	73.44
Balcas current price / tonne	210	210	210	210	210	210
ESB @ 6.5euro /GJ (15GJ (9%aw)	97.5	97.5	97.5	97.5	97.5	97.5
% Margin - at Balcas Price	108	133	131	163	149	186
% Margin at ESB price -	-4	8	7	22	15	33
Net Profit at Balcas price	860747	947726	1430606	1562726	2636516	2867726
Net Profit at ESB price	-28003	58976	80606	212726	274016	505226

Extract from Appendix 1.11 Ref: Integration Matrix 'SP Bus'

Three options were considered. Option 1 equates to the worst case scenario, having an output of only 7900 tonnes per annum. Option 2 equates to specification output of 12000 tonnes.

Option 3 equates to maximum output of 21000 tonnes based on 24 hour production and specification rating. Each option is considered with respect to provision of electricity from the ESB and provision of electricity from the Bioenergy Park anaerobic digester. The profit margin is measured against the Balcas wood pellet market price and the ESB pellet price.

If the plant achieves the design output of 2.5 t/h, then the profit at Balcas prices is in the region of € 1.4 million per year, but only € 0.08 million at ESB prices. And the return on investment is increased by 8% on Balcas prices and 60% on ESB prices when energy is supplied by the Bioenergy Park. In the extreme, where the plant is running at 24 hour production and the design output capacity is achieved, a significant return on investment is evident.

8.3 Anaerobic Digestion Business Case

The Anaerobic Digestion business case is considered in relation to capital and operational costs and income potential in relation feedstock gate fees and biofertilizer sales

8.3.1 Anaerobic digestion capital costs

In general, the capital costs on an anaerobic digester can be subdivided into a number of categories. The pie chart in figure 8.3 is representative of plant equipment costs (Scotland, 2004). The documented plant is sized for an input tonnage of 64200 tonnes/year. The largest individual material costs can be grouped and is for the two digesters units, the digestate storage vessel and the feed-in-stock storage system. Material costs were estimated to be in the order of £1.4 million while the overall cost is estimated between £3.9 - £6.3 million. The technology cited was Kompogas.

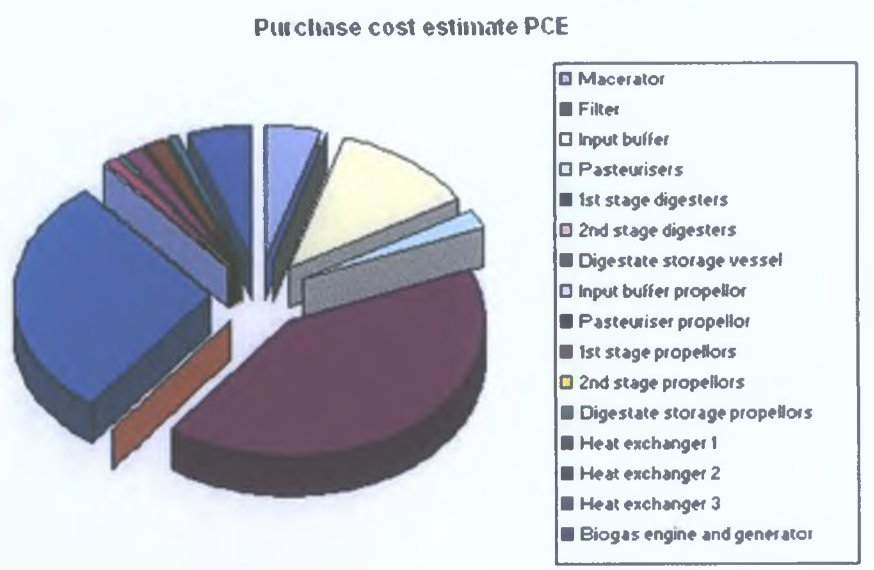


Figure 8.3 **Capital Cost for a Central AD system** **Source ((ESRU, 2004)**

In comparison, a design specification and associated cost for a small scale plant to digest 30000 tonnes of slurry per year was provided a company called Weltec-biopower.de. The anaerobic digester plant costs of € 2,150,450 (Appendix 5.1) (Ryan-Purcell, 2008).

8.3.2 Decision Support System to calculate capital and operational costs

In a recent study, Poliafico, 2007, produced a decision support system that includes a geographical specific database of animal wastes and a methodology for assessment of biogas production from these wastes. As part of his study, Poliafico, 2007, derived a formula that can calculate a best estimate capital and operational costs for anaerobic digestion (Poliafico, 2007). The study took into consideration capital and operational costs of 20 central anaerobic plants in Denmark. Adjusting for costs, currency and rates of inflation the following formula as presented in table 8.12 was derived.

Table 8.12	**Equation to calculate capital and running costs**
Capital cost:	$y = 6.6892 \times \chi^{0.5863}$
Running cost:	$y = 1.8*0.124 \times \chi^{0.7467}$

Where χ is the cubic meters of feedstock,
y is the cost in '000 euros

Using the formula in table 8.12 the estimated costs for various plants sizes are tabulate in table 8.13

Table 8.13 Poliafico, 2007, equation calculating AD Capital and Operational costs

	2008	2008
Feed Stock m^3/year	Capital Cost euro	Operation Costs euro
30000	€ 3,843,913	€ 670,230
64200	€ 6,004,753	€ 1,182,888
100000	€ 7,786,411	€ 1,646,862

Extract from Appendix 1.5 Integration Matrix ' ADCap'

In summary, a reasonable estimate of a small scale digester is between 2.5 to 4 million euro with operating costs of 750,000 euro per annum. This formula is embedded into the integration matrix of the Bioenergy Park.

8.3.3 Income potential from feed stocks and biofertilizer

In consideration that the digester is sized to provide sufficient electricity to the Bioenergy Park with no surplus, then the two remaining potential incomes are biofertilizer and gate fees. A gate fee is only considered for feed stocks from industrial sources, and not from farm supplied manure. A € 100 /t is sited by Poliafico, 2007. This value is thought to be reasonable, considering the current cost of land fill in Ireland is over double the price, region dependant. The EPA in the *National Waste Report 2006*, averages the cost of landfill between € 140 and € 160 in the period of 2003 to 2006. In addition the biofertilizer value is considered to be in the order of € 15 /t. But unfortunately following on from chapter 6.0 discussions regarding feedstocks and land spreading constraints, income will be very much dependant on content and nutritional mix of the digestate.

8.4 Bioenergy Park business case integration values

In summary, key values and equations have been defined for inclusion in the integration matrix. The anaerobic digester costs will adjust based on the equation and as feed stock values change so too will the capital and operational costs. The biodiesel and straw pelleting capital costs are fixed while the variable cost of feedstocks and consumables adjust the price per tonne. The following table 8.14 outlines the key integration values. All key values can be adjusted in the integration matrix as and when market value changes.

Table 8.14 Key Integration value	Adjustable	
Finished Products	**Income Potential**	
Biodiesel	880	€/t
Straw Pellets	210	€/t
Rape Cake	170	€/t
Bio –Fertilizer	15	€/t
Glycerine (up to 5% addition to AD)	0	€/t
Income from Feed stocks	**Income Potential**	
Pig Slurry	0	€/t
Cow Slurry	0	€/t
Food Remains	100	€/t
Sewage Sludge	100	€/t
Chicken Slurry	0	€/t
Whey	100	€/t
Leaves	0	€/t
Wood Shavings	0	€/t
Straw	0	€/t
Garden Waste	0	€/t
Extract from Appendix 1.1 Ref: Integration Matrix 'BP Live'		

Note : references made to Integration Matrix within this chapter summarized below:

Section	Integration Matrix Code	To View Detail refer to Appendix
8.12	'BDCap'	1.7
8.1.3	'BD Bus'	1.8
8.2.3 & 8.2.4	'SP Cap'	1.10
8.3.6	'SP Bus'	1.11
8.4.2	' ADCap'	1.5
8.5	'BP Live'	1.1

9.0 Bioenergy Park Integration Model and Matrix Explained

Integration of processes is not a new phenomenon. There is evidence of the integration of biodiesel with anaerobic digestion. Biodiesel processes are integrated with heat provision from biomass. Indeed the integration of anaerobic digestion with electrical and thermal production is well documented and has been effective for many years. However, the integration of the three processes as defined, in a locally supplied Bioenergy Park is new to Ireland and there is no evidence to suggest that the concept is currently in operation in Europe or beyond, to the best of the authors knowledge. The exception, as discussed in chapter 2.0, is the Sunflower Integrated Bioenergy Centre, currently under development in Kansas, America at a cost of $ 3.6 billion US dollars.

The overriding principle of the Bioenergy Park is that the provision of raw material must be local. Secondly, the three processes identified are biodiesel production, straw pellet processing and anaerobic digestion. Thirdly the three systems must be fully integrated with minimum waste generation and maximum renewable energy production. The study objectives (Figure 9.1) aim to facilitate an analysis of the possible synergies of integrated renewable energy processes in a Bioenergy Parks.

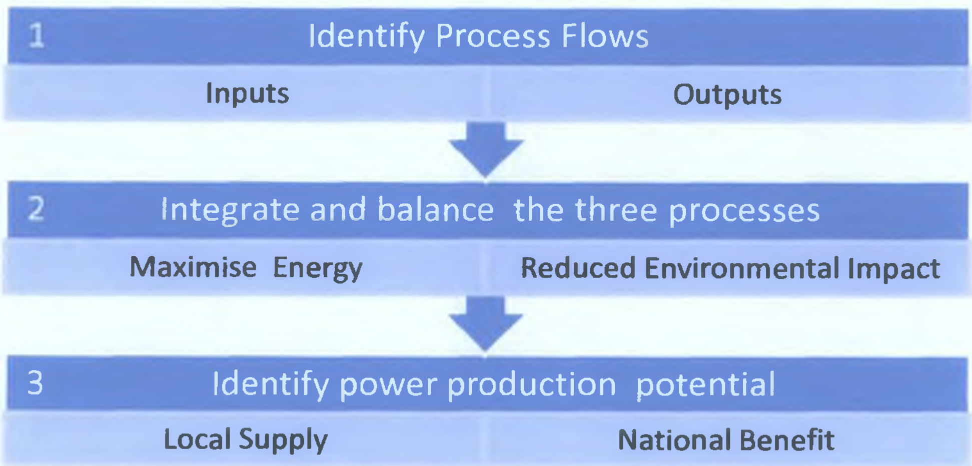


Figure 9.1 Bioenergy Integration - study objectives

9.1 Bioenergy Park Model

Chapter 3.0, 4.0 and 5.0, investigated the integration potential of biodiesel, straw pelleting and anaerobic digestion respectively and each chapter concluded with a list of integration potentials and development constraints. Chapter 6.0 considered the renewable energy output potential of the three process and determined key equivalent values per tonne of finished product or feedstock used. Chapter 7.0 investigated the thermal and electrical demand and related carbon emission reduction potential of each of the three processes and determined values per tonne of output also. Chapter 8.0 then considered the business case of the individual processes to determine viability based on current market prices of commodities and finished products. The findings of these six chapters need to be merged to investigate the possible synergies of the processes in a Bioenergy Park.

A complex integrated model presented in figure 9.2 below demonstrates how the processes fit together. The land bank is the foundation on which the Bioenergy Park relies. The Bioenergy Park is dependent on the local provision of materials to supply all three processes and requires access to the land bank to dispose of the digestate/biofertilizer from the anaerobic digester. The process engine is the anaerobic digester which generates renewable energy from waste slurries and other organic matter which can include sewage sludge and food remains. Both the straw pelleting and biodiesel processes are subsequently fuelled by the anaerobic digestion engine. The model however, cannot determine the integration value of the Bioenergy Park. The means of analysis of these synergies is outstanding. The need for an interactive Integration Matrix thus evolved.

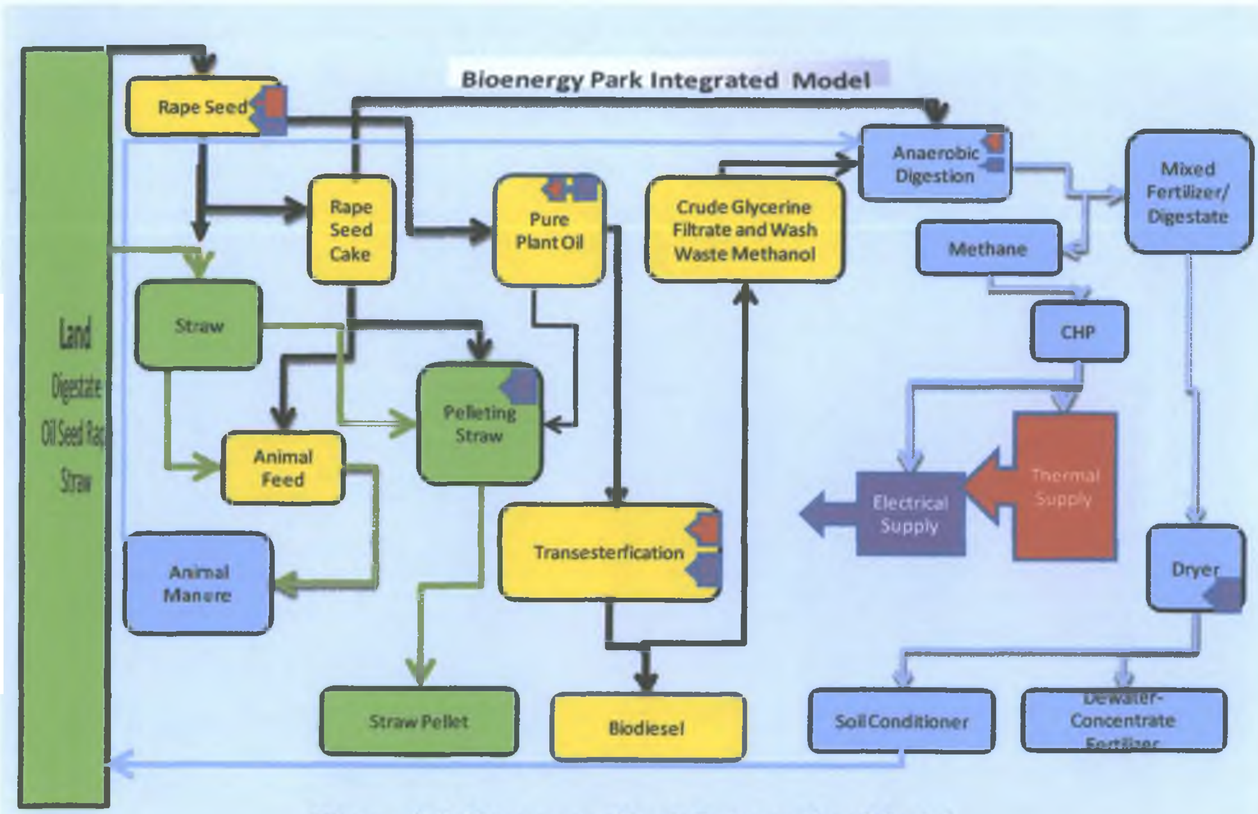


Figure 9.2 Bioenergy Park Integration Model

9.2 The concept of the Integration Matrix

The Integration Matrix was developed using Excel® a Microsoft Office package. The software version used was 2007. The matrix can be broken into three elements namely static sheets, interactive sheets and feedback sheets. Abbreviations used within the matrix are as follows;

BD - Biodiesel,	BP - Bioenergy Park	Scen - Scenario
SP - Straw Pellets	Cap - Capital	FSCal - Feed Stock Calculations
AD - Anaerobic Digestion	Bus - Business Case	

9.2.1 The Integration Matrix overview

The lead spread sheet in the matrix is called BP-Live . In this sheet the user can select various production output scenarios and can adjust commodity and finished product prices. BP-Live interacts with the six feeder sheets where the scenario is investigated. These sheets, highlighted in yellow, green and blue in figure 9.3 below, feedback detailed analysis to 'BP 1-10'. The detail in 'BP 1-10' is then summarized and headline analysis of energy balance, renewable energy generated, carbon emission reduction potential and profit margin of the selected scenario is returned to BP-Live.

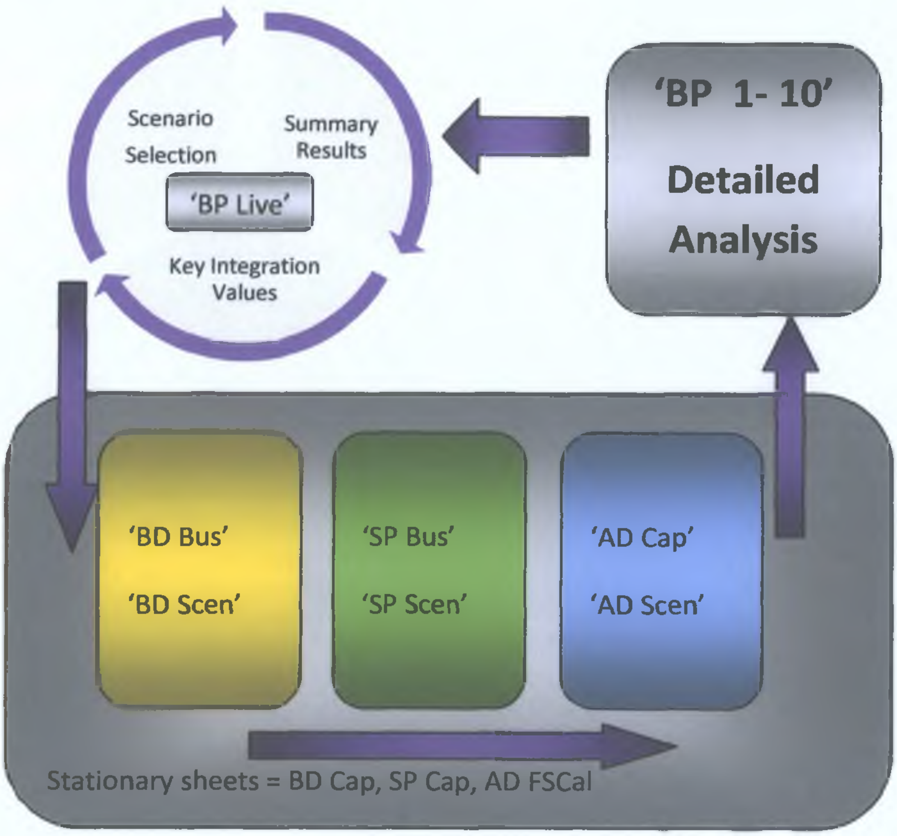
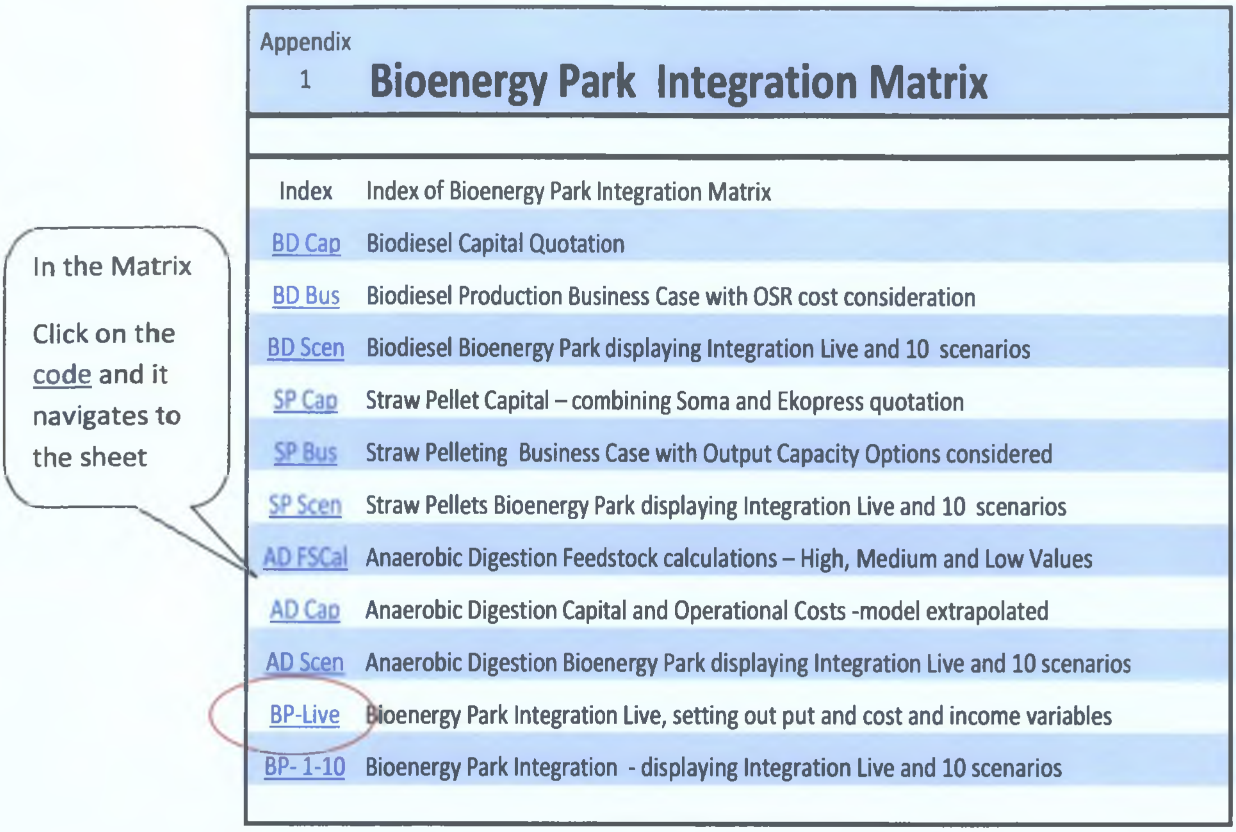


Figure 9.3 Integration Matrix Overview

9.2.2 Integration matrix orientation

On opening the excel sheet entitled 'Integration Matrix', the user should select the spread sheet labelled 'Index'. From this spread sheet the user can navigate to all spread sheets within the matrix by 'clicking' on the underlined code, circled in the pictorial below (Figure 9.4).



Appendix 1 Bioenergy Park Integration Matrix

Index	Index of Bioenergy Park Integration Matrix
BD Cap	Biodiesel Capital Quotation
BD Bus	Biodiesel Production Business Case with OSR cost consideration
BD Scen	Biodiesel Bioenergy Park displaying Integration Live and 10 scenarios
SP Cap	Straw Pellet Capital – combining Soma and Ekopress quotation
SP Bus	Straw Pelleting Business Case with Output Capacity Options considered
SP Scen	Straw Pellets Bioenergy Park displaying Integration Live and 10 scenarios
AD FSCal	Anaerobic Digestion Feedstock calculations – High, Medium and Low Values
AD Cap	Anaerobic Digestion Capital and Operational Costs -model extrapolated
AD Scen	Anaerobic Digestion Bioenergy Park displaying Integration Live and 10 scenarios
BP-Live	Bioenergy Park Integration Live, setting out put and cost and income variables
BP- 1-10	Bioenergy Park Integration - displaying Integration Live and 10 scenarios

Figure 9.4 Pictorial of the Integrated Matrix

On flicking between sheets, the user will observe tables presented in chapter 5.0, 6.0, 7.0 and 8.0. All spread sheets are attached in appendices 1.1 to 1.11 of this document.

9.2.3 Integration Live - <u>BP-Live</u> setting up scenarios and receiving results

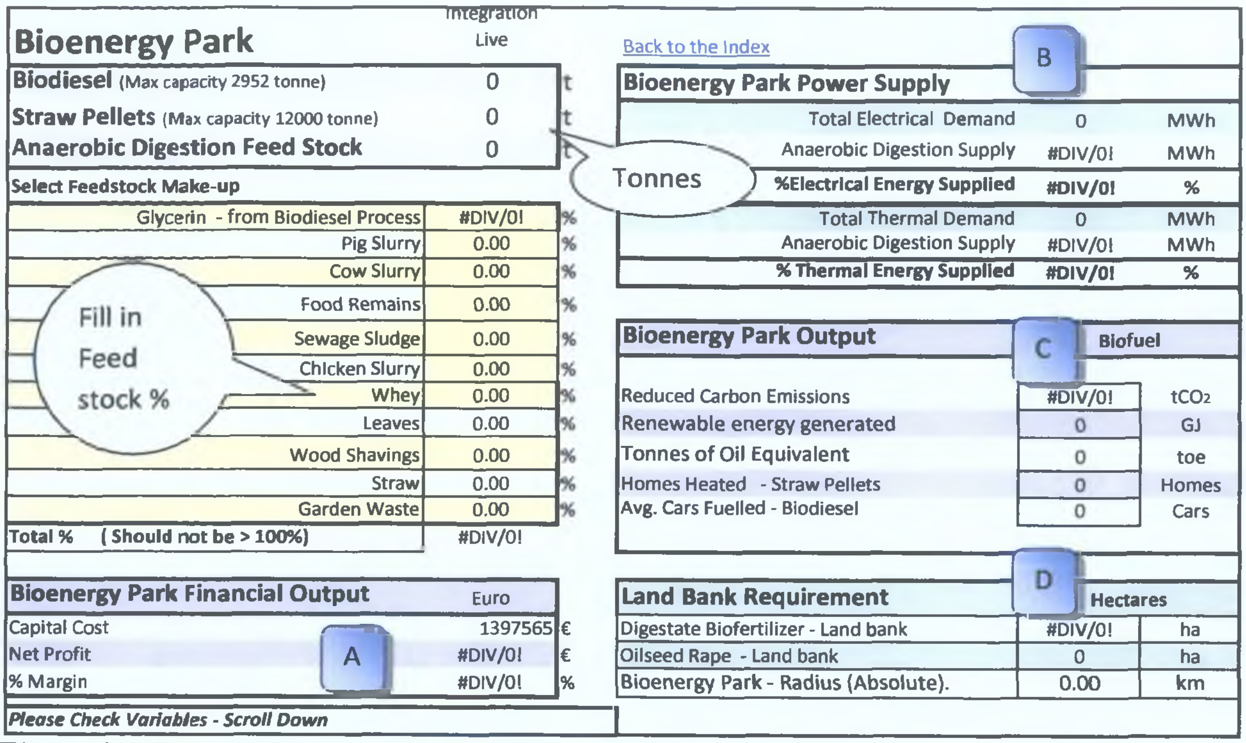
On clicking on <u>BP-Live</u> the user is presented with a spread sheet that requires some key information (Figure 9.5).

- Production output of Biodiesel in tonnes
- Production output of Straw Pellets in tonnes
- Feedstock volume and percentage mix in tonnes for the anaerobic digester

The user can adjust the feedstock tonnes and feedstock percentage mix, to balance the energy supply and demand within the Bioenergy Park. It is important to ensure that the feed stocks add up to 100%. The calculation works off the percentage value of the total feed stock and has no logic to consider an erroneous calculation of total feed stocks of greater than 100%.

As previously discussed in this study, the maximum capacity of the biodiesel plant is 2952 tonnes per annum. This is limited only by the fixed capital cost embedded into this matrix. Equally, the maximum capacity of the straw pellet operation is 12000 tonnes per annum. Should additional capacity be required then the core matrix calculation would have to be adjusted to reflect additional capital expenditure. This is not the case for anaerobic digestion.

The capital and operational costs are automatically adjusted using the embedded formula, and as such is not limited to capacity.



Bioenergy Park	Integration Live	
Biodiesel (Max capacity 2952 tonne)	0	t
Straw Pellets (Max capacity 12000 tonne)	0	t
Anaerobic Digestion Feed Stock	0	t

Tonnes

Select Feedstock Make-up		
Glycerin - from Biodiesel Process	#DIV/0!	%
Pig Slurry	0.00	%
Cow Slurry	0.00	%
Food Remains	0.00	%
Sewage Sludge	0.00	%
Chicken Slurry	0.00	%
Whey	0.00	%
Leaves	0.00	%
Wood Shavings	0.00	%
Straw	0.00	%
Garden Waste	0.00	%
Total % (Should not be > 100%)	#DIV/0!	

Fill in Feed stock %

Bioenergy Park Financial Output	Euro	
Capital Cost	1397565	€
Net Profit	#DIV/0!	€
% Margin	#DIV/0!	%

A

Please Check Variables - Scroll Down

Back to the Index

Bioenergy Park Power Supply		
Total Electrical Demand	0	MWh
Anaerobic Digestion Supply	#DIV/0!	MWh
%Electrical Energy Supplied	#DIV/0!	%
Total Thermal Demand	0	MWh
Anaerobic Digestion Supply	#DIV/0!	MWh
% Thermal Energy Supplied	#DIV/0!	%

B

Bioenergy Park Output	Biofuel	
Reduced Carbon Emissions	#DIV/0!	tCO_2
Renewable energy generated	0	GJ
Tonnes of Oil Equivalent	0	toe
Homes Heated - Straw Pellets	0	Homes
Avg. Cars Fuelled - Biodiesel	0	Cars

C

Land Bank Requirement	Hectares	
Digestate Biofertilizer - Land bank	#DIV/0!	ha
Oilseed Rape - Land bank	0	ha
Bioenergy Park - Radius (Absolute).	0.00	km

D

Figure 9.5 Integration Live 'BP Live' Key in required tonnage and % feed stock

Once the user keys in the tonnage of biodiesel, straw pellets and anaerobic digestion feed stock, then the live matrix populates the remaining cells giving the user feed back on the Bioenergy Park output and energy balance (Figure 9.5).

A

The Bioenergy Park Financial Output (Figure 9.5) returns a probable capital cost to the user on the same screen. Equally the net profit is presented and the percentage margin also calculated. This information is summarized from 'BP-1-10' which has been feed from the individual business case sheets for AD, Biodiesel and straw pellets respectively. When commodity prices and income potential are changed the resultant profit margin will change also. The methods used to calculate these values were presented in chapter 8.0

B

The Bioenergy Park Power Supply (Figure 9.5) investigates the thermal and electrical demand of the three processes and then weighs up the total energy generation potential of the anaerobic digester given the volume and feedstock mix as selected by the user. Generally, as the electrical demand is greater than the thermal demand, the user focuses on balancing the electrical supply/demand equation. This can be done by adjusting the volumes or feedstock mix. The median value of the feedstock is used in the 'integration live' however the user will remember the impact of the low and high feedstock values when considering energy generation potential as was demonstrated in chapter 7.0

C

Once the energy balance is achieved then the user can observe the Bioenergy Park output (Figure 9.5) in terms of the following parameters as determined in chapter 6.0.

Reduced Carbon Emissions	tCO_2
Renewable energy generated	GJ
Tonnes of Oil Equivalent	Toe
Homes Heated - Straw Pellets	Homes
Avg. Cars Fuelled – Biodiesel	Cars

In chapter 7.0 the carbon emission reduction potential for biodiesel, straw pelleting and anaerobic digestion was calculated per tonne. These individual key values are embedded into the spread sheets and as the user challenges the matrix with various scenarios the total carbon emission reduction potential of the three processes is returned in an instant.

The renewable energy generated is a calculation of both straw pellet plus biodiesel energy value in Giga Joules.

Equally this value is presented in tonnes of oil equivalent to facilitate measurement against the national biofuel and renewable energy targets.

The number of homes heated is based on the tonnes of straw pellets produced only and similarly the number of cars fuelled is based on the tonnes of biodiesel produced. The methods used to determine these value per tonne were discussed in chapter 6.0

D

Land bank requirements are considered (Figure 9.5) with respect to the hectares required to spread the digestate / biofertilizer from the anaerobic digester This is set at a spread rate of 27.5m^3 / ha and without consideration to feedstock type or nutrient management plan. The impact of same was discussed in chapter 5.0.

The landbank in hectares to support the cultivation of the oil seed rape (OSR) crop as required by the selected biodiesel feedstock demand is presented. The value considers the 4 year rotation aspect of the OSR crop management system.

A calculation regarding the absolute radius in kilometres of land required to support a Bioenergy park is calculated based on the 4 year rotational OSR crop requirements is presented.

9.2.4 Integration Live - BP-Live Setting the commodities and finished product prices

The second feature contained in BP-Live , is the market price of commodities and finished product. The user has an opportunity to check and adjust these prices to ensure that value used in the business case is up to date with current market prices.

The user can also adjust prices to investigate the impact of market changes on the business case, or indeed to reflect market price change.

Back to the Index

Back to the top

Investigate Scenarios

Adjust to market value

Commodities		
Oil Seed Rape (local delivered)	500	€/t
Straw (local delivered)	65	€/t
Methanol	475	€/t
ESB Electricity Supply kWh	0.15	€/t
Thermal Electricity Supply kWh	0.12	€/t

E

Straw Pellets	1 tonne
Reduced tCO_2 emissions	1.5
GJ of energy	17.0
toe	0.4
Homes Heated (5.2 t/home/year)	0.195
Electrical generation potential MWh	1.42

Finished Products	Income Potential	
Biodiesel	880	€/t
Straw Pellets	210	€/t
Glycerin	90	€/t
Rape Cake	170	€/t
Bio -Fertilizer	15	€/t

F

Biodiesel	1 tonne
Reduced tCO_2 emissions	2.41
GJ of energy	28.86
toe	0.69
Avg. cars fueled (1.91 t/car/year)	0.518
Electrical generation potential MWh	2.40
Oil Press Parasitic Thermal Demand kWh	79.10
Oil Press Parasitic Electrical Demand kWh	50.36
Biodiesel Parasitic Thermal Demand kWh	44.70
Biodiesel Parasitic Electrical Demand kWh	28.42

Income from Feed stocks	Income Potential	
Pig Slurry	0	€/t
Cow Slurry	0	€/t
Food Remains	100	€/t
Sewage Sludge	100	€/t
Chicken Slurry	0	€/t
Whey	100	€/t
Leaves	0	€/t
Wood Shavings	0	€/t
Straw	0	€/t
Garden Waste	0	€/t

G

Figure 9.6 Integration Live ' BP Live' Key in area for market prices

E

The user can adjust the value of the commodities in euros per tonne of product (Figure 9.6). If there is a market price change in oil seed rape for example, by changing the value from € 500 / tonne as presented above to the new value € xxx / tonne, the impact of this market change can be investigated.

F

Finished product values can also be adjusted by keying in alternative values. For example if straw pellets did not achieve the 'Balcas ' price as presented above then the impact can be examined (Figure 9.6). Equally biofertilizer may command a greater value and the price per tonne can be altered in this section of the matrix.

G

Finally the income from various feedstocks can be adjusted (Figure 9.6). As presented in the matrix there is zero value considered for pig, cow, and chicken slurry while sewage sludge and food remains command a gate fee of € 100 / tonne. These values can be changed in this section of the matrix as the market dynamics change.

Once the prices are checked then the user can scroll back to the top or simply click on the link Back to the top and the results sheet, as depicted in figure 9.5, is returned.

9.3 Examining the detail contained in the summary sheet BP-Live

BP-Live , is the engine driving the integration matrix. To examine the detail behind BP-Live , the user can 'click on' integrated sheet called BP- 1-10. Data is received from the individual feeder sheets as depicted in figure 9.2 above and presents the detailed analysis on the following aspects;

1. Energy supply and demand
2. Individual process outputs with respect to energy generation and carbon emission reduction
3. Individual business case calculations
4. Land bank requirements

The top line summary information is then fed back to the BP-Live . Appendix 1.3 presents the detailed analysis of BP- 1-10.

9.4 Integration made easy

When using the Integration Matrix the user needs only to focus on Integration live (BP-Live) where outputs and variables are keyed in and where the summary results are reviewed. Where detail is required the user can browse (BP- 1-10). Box 9.1 describes the steps to operating the Integration matrix.

Integration in six easy steps	**Box 9.1**
Step 1 Open the Excel Spread Sheet 'Integration Matrix'	
Step 2 Open up the Index page 'Index'	
Step 3 Click on BP-Live	
Step 4 Key in values in tonnes for Biodiesel, Straw Pellets and Anaerobic Digester Feed Stock and check Commodity prices by scrolling down	
Step 5 Choose Feed stock types ensuring the total quantity of feed stock is 100%	
Step 6 Let the Matrix do the rest	

10.0 Results

The matrix has been designed as a tool to analyse the integration potential of numerous Bioenergy Park scenarios. The opportunity to explore scenarios is endless, within the matrix constraints. This chapter investigates the results generated in ten scenarios. These scenarios are designed to explore integration potentials and possible constraints that were identify in the research chapters 3 to 8 inclusive.

10.1 Introduction

The following identify the ten selected scenarios and their grouping for the purpose of scenario comparison and discussion.

1) The importance of feedstocks and the mixing of feedstocks, in relation to energy yield, has been identified as key to the performance of the anaerobic digester as the energy generator of the Bioenergy Park. Scenarios 1 – 5 investigate various feed stock mixes. In order to focus on the impact of the feedstocks the straw pellet plant and biodiesel plant are selected to produce to capacity. In all five scenarios the quantity of feedstock is increased to ensure that the electrical energy demand is balanced in all cases and the feedstock values are based on the median range.

2) Scenarios 6 and 7 are designed to investigate the potential of ten Bioenergy Parks operating at capacity. The feedstock values are based on the median range and the systems are in balance from an electrical energy perspective. The difference between 6 and 7 is that the capital and capacity of the biodiesel plant in scenario 7 has been reduced by 50%. Scenario 7 benchmarked against scenario 6 investigates both the financial impact of the cost of OSR and the value of the by-product glycerine in the anaerobic digester plant.

3) Scenarios 8-9-10 investigate the impact high, median and low values of feed stock. The plants are operating at a single output capacity. The plants are balanced from an electrical energy point of view. The feed stocks percentage mix is as close as is reasonably possible. This group of scenarios also investigate the reduced output potential if the biodiesel plant and straw pellets plant do not deliver on designed output capacity.

Full details of all values and results are available in Appendix 1.3 (ref. Integration 'BP 1-10') of the study and on the attached disk.

10.2 Scenarios 1 – 5 investigate various feed stock mixes.

The biodiesel plant and straw pellet plant are selected to produce to the design capacities of 2952 t and 12000 t respectively in all scenarios. This means that in all cases the thermal and electrical demand on the anaerobic digester is equal. Table 10.1 indicates the selected feedstock mixes per scenario. Scenario 1, for example, is a mix of 64% pig slurry, 20% cow slurry and 14.03% sewage sludge with the balance of 1.97 % as glycerine from the biodiesel plant. The feedstock values are based on the median range (as discussed in chapter 7.0).

Bioenergy Park	Capacity (tonnes)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Production Output	Max capacity	**med FS value**	**med FS value**	**med FS value**	**med FS value**	**med FS value**
Biodiesel Fixed (t)	2952	2952	2952	2950	2950	2950
Straw Pellets (t)	12000	12000	12000	12000	12000	12000
Anaerobic Digestion Feed Stock (t)		15000	7600	6000	7700	11000
Glycerine	%	1.97	3.88	4.92	3.83	2.68
Pig Slurry	%	64.00	57.00	59.00		
Cow Slurry	%	20.00	20.00	20.00	73.16	68.20
Food Remains						15.00
Straw	%		5.00	8.00		
Sewage Sludge	%	14.03	14.30	8.50		14.00
Chicken Slurry	%				23.06	0.00
Total % (Should not be > 100%)		100	100	100	100	100

Feedstock %

Table 10.1 Feedstock mixes examined for Scenario 1- 5

Having selected a feedstock mix percentage ratio, the feedstock quantity is then adjusted in order to satisfy the Bioenergy parks energy demand. Notably the quantity of glycerine supplied by the biodiesel plant is a constant for all 5 scenarios and is fixed at 10% of the biodiesel output or 295.3 tonnes.

Glycerine is expressed as a percentage of the total feedstock. When the feedstock quantities are adjusted so too is the % value of glycerine. This explains the range of glycerine percentages from 1.97% to 4.92% as depicted in table 10.1.

The total quantity of feedstock required based on the mix ratios is 15000, 7600, 6000, 7700 and 11000 tonnes, for scenarios 1-5 respectively. Figure 10.1 depicts a representative graph to facilitate comparison demonstrating the significant capacity variance from scenario to scenario.

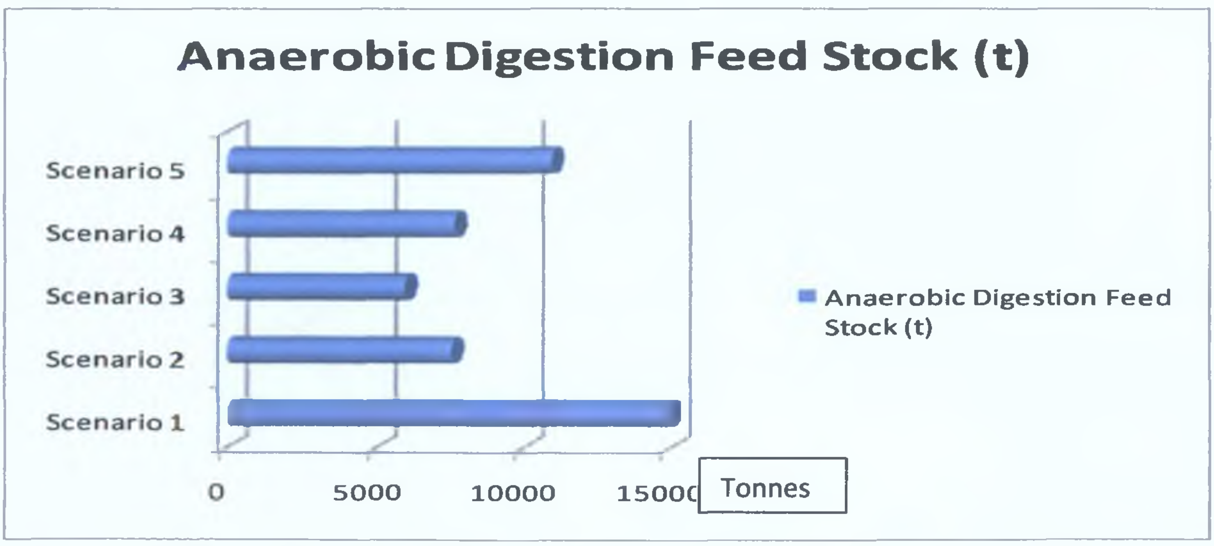


Figure 10.1 FeedStock variable and its impact on the size of the anaerobic digester.

Of the 5 scenarios selected, scenario 3 is far more productive from an energy point of view while scenario 1 provides a relatively low energy yield. Clearly, given the results provided in figure 10.1 the impact of feed stock mix, availability and supply is critical to the design size and energy production of the anaerobic digester.

Note: These results are based on median feedstock values. Scenarios 8, 9 & 10 will investigate the consequence of using low through to high value.

10.2.1 Electrical and Thermal Energy Balance

The primary focus of the anaerobic digester is to supply 100% of the electrical energy demand of the plant, as the electrical demand is the greater than that of the thermal. Once the electrical energy balance is achieved, the oversupply of thermal energy becomes apparent. In the five scenarios selected the quantity of thermal heat oversupply is in the order of 174% to 177% (Table 10.2). The generation of excess thermal energy is an unfortunate result of the disparity in the demands versus the supply.

% Electrical Energy Supplied		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Electrical Demand MWh						
Straw Pellet Production	MWh	881	881	881	881	881
Oil Press Production	MWh	149	149	149	149	149
Biodiesel Production	MWh	84	84	84	84	84
Total Electrical Parasitic Demand	MWh	1114	1114	1113	1113	1113
AD Net Electrical Supply	MWh	1115	1119	1129	1115	1126
% Electrical Energy Supplied	%	100	100	101	100	101
Thermal Demand MWh						
Straw Pellet Production	MWh	0	0	0	0	0
Oil Press Production	MWh	234	234	233	233	233
Biodiesel Production	MWh	132	132	132	132	132
Total Thermal Parasitic Demand	MWh	365	365	365	365	365
AD Net Thermal Supply	MWh	1000	1004	1013	1000	1011
% Thermal Energy Supplied	%	274	275	277	274	277

Table 10.2 Energy demands satisfied – Scenario 1- 5

The anaerobic digester generally produces similar quantities of thermal and electrical energy (55% and 45% respectively in the examples above). Biodiesel and oil pressing together demand a ratio of 3:2, thermal and electrical energy, but the straw process, a relatively high energy user, requires 100% electrical energy. This shifts the overall ratio to 1:3 thermal and electrical energy demands and hence the over supply of thermal energy.

Unfortunately, irrespective of the selected scenario the quantity and percentage oversupply of thermal energy will be significant and thus new opportunities of utilizing this energy flow arises. In chapter 11.0 the thermal energy generation and potential use is considered.

10.2.2 Bioenergy Park Outputs

The outputs delivered by the Bioenergy Park are presented in table 10.3, these are based on the selected inputs together with the key equivalent values derived in chapters 6.0, 7.0 and 8.0. Since all 5 scenarios are set at an operating at capacity to produce 2958 tonnes of biodiesel and 12000 tonnes of straw pellets, then the output values in all scenarios are equal bar the element of reduced carbon emissions where some variability is noted.

Bioenergy Park Output		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Reduced Carbon Emissions tCO_2	tCO_2	31131	30792	30757	30995	31063
Renewable energy generated GJ Straw pellets and Biodiesel	GJ	289533	289533	289475	289475	289475
Tonnes of Oil Equivalent Straw pellets and Biodiesel	toe	6837	6837	6836	6836	6836
Homes Heated - Straw Pellets (5.2 t/home/year)	Homes	2340	2340	2340	2340	2340
Avg. cars fueled - Biodiesel (1.91 t/car/year)	Cars	1529	1529	1528	1528	1528
Electrical generation potential MWh Straw pellets and Biodiesel	MWh	24125	24125	24120	24120	24120

Table 10.3 Bioenergy Park outputs Scenario 1-5

The carbon emission reduction potential of the Bioenery Park per scenario is depicted in the graph below (Figure 10.2). The emission reduction potential is a bundling together of the three processes.

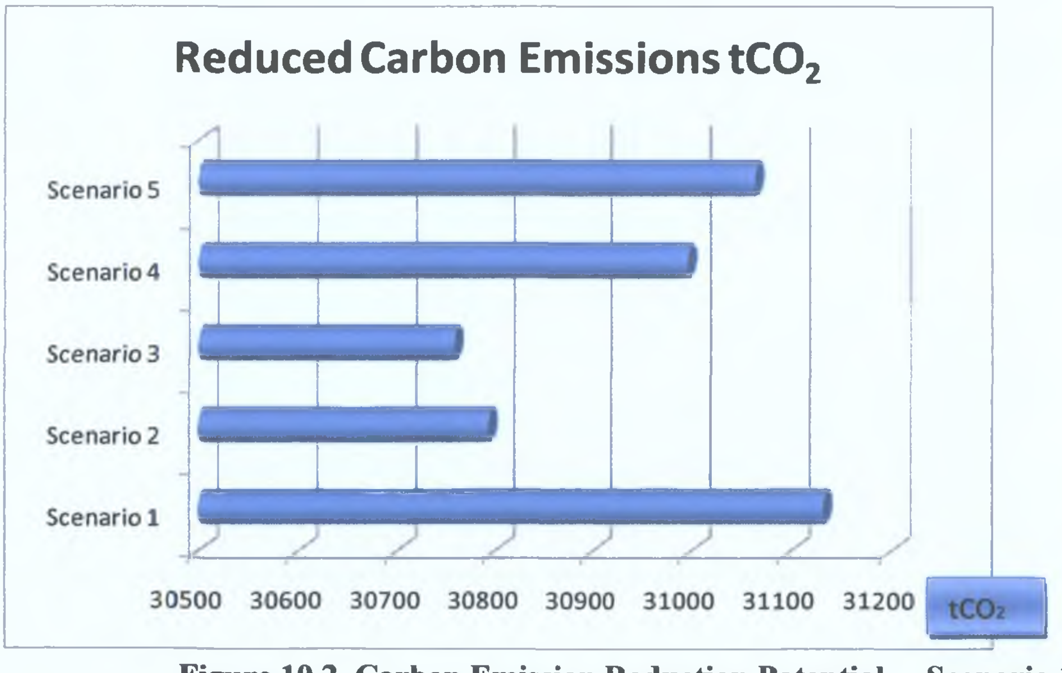


Figure 10.2 Carbon Emission Reduction Potential – Scenario 1 – 5

As the straw pelleting and biodiesel outputs are constants therefore the variability lies in the feedstock quantities required in the anaerobic digester to fuel the processes. In fact the graph in figure 10.2 is almost a mirror image of the feedstock graph in figure 10.1. However, the increase in carbon reduction potential as per the feedstock volume increases is not as significant, comparatively. The actual range is from 30400 to 31200 tCO_2 and depicts a minor difference from highest to lowest carbon emission reduction potential and therefore not as significant a variance as was discussed in relation to feedstock capacity requirements (Reference: Section 10.2.1).

10.2.3 National Targets Achieved

To compare the output values against the national targets the Bioenergy parks need to first operate in a bundle. The values from table 10.3 have been multiplied by a factor of ten and the resultant bundled values of the five scenarios are compared against national targets (Table 10.4). The results are similar for all five scenarios selected. Ten Bioenergy Parks can potentially reduce 0.48 % of the national carbon emission reduction requirement. However, it should be remembered that the impact of replacing synthetic fertilizer with biofertilizer is not considered in the calculations. According to Janulis, 2004, by replacing synthetic fertilizer with biofertilizer in the cultivation of OSR and additional carbon emission reduction potential of 1.68 tCO_2 per tonne of biodiesel produced could be added. When this is considered the net result could move from 0.48% to 0.56% and as such is not significantly different to that documented in table 10.3. In any case, while synthetic fertilizer production is a high energy consumer, there is no production facility in Ireland therefore the carbon emission reduction could not be banked nationally.

National Impact of a Bundle of Ten Bioenergy Parks						
Bioenergy Park Output	***X 10***	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Reduced Carbon Emissions tCO_2	tCO_2	311310	307924	307569	309950	310627
Tonnes of Oil Equivalent Straw pellets	toe	48000	48000	48000	48000	48000
Tonnes of Oil Equivalent Biodiesel	toe	20369	20369	20355	20355	20355
National Impact						
Reduced Carbon Emissions tCO_2	tCO_2	64000000	64000000	64000000	64000000	64000000
% Reduction of tCO_2	%	0.486	0.481	0.481	0.484	0.485
2006 DieselConsumption in Transport	toe	2509000	2509000	2509000	2509000	2509000
Biofuel 5.57% target	toe	144268	144268	144268	144268	144268
% achievement against target	%	14	14	14	14	14
2006 Home Heating oil consumed	toe	2295000	2295000	2295000	2295000	2295000
% Renewable energy supplied	%	2.1	2.1	2.1	2.1	2.1

Table 10.4 National Impact of Ten Bioenergy Parks - Scenario 1-5

The biofuel target of 5.75% is calculated based on 2006 figures of diesel consumption in transport. Ten Bioenergy Parks could potentially supply up to 14% of Irelands biofuel obligation in relation to diesel oil requirements in transport (Table 10.4).

The 2006 consumption of oil for home heating was 2295 ktoe in Ireland. Based on straw pellet output of 12000 tonnes per Bioenergy Park, 10 parks could replace 2.1% of this oil with renewable energy from waste straw (Table 10.4).

10.2.4 Landbank Considerations

There are three key considerations to be taken into account regarding the land bank requirements for a Bioenergy Park, namely; the landbank for spreading digestate, the landbank for cultivating the annual supply of Oil Seed Rape (OSR) and the landbank required in consideration of the 4 year rotation of the OSR crop. The landbank requirements by each consideration per scenario are presented in figure 10.3. As discussed in chapter 5.0, the arbitrary value of 27.5 m^3 per hectare is selected for land spreading of digestate. This is irrespective of the feedstock mix variable. Nonetheless, even if the worst case scenario of 11 m^3 per hectare, (based on Teagasc recommendations for spreading pig slurry), was realized then the land bank required to spread would match the landbank required to cultivate the OSR crop.

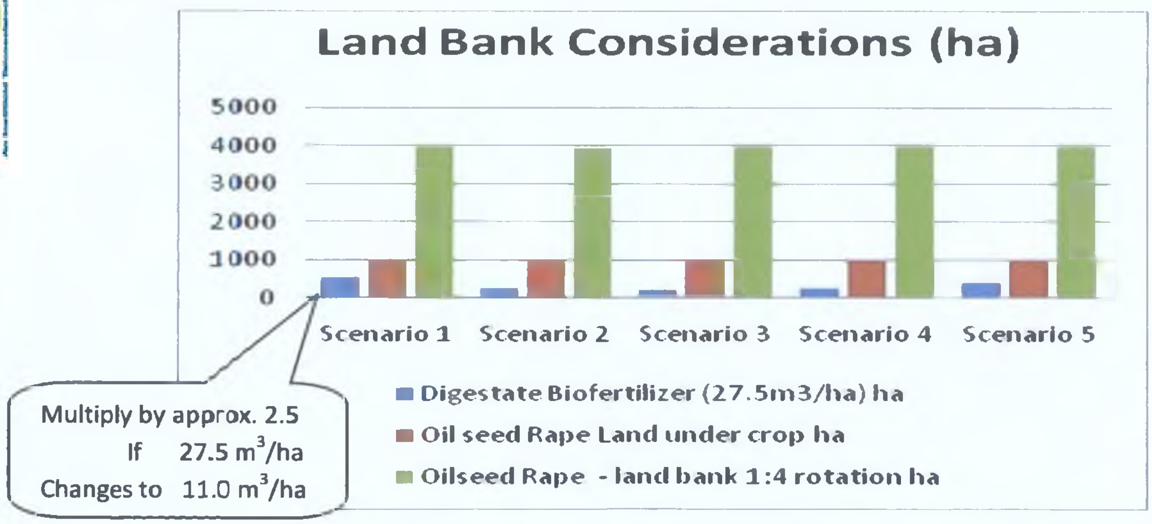


Figure 10.3 Land bank requirements compared in the Bioenergy Park

As can be seen in figure 10.3 above, the significant landbank requirement is based on the OSR 4 year rotational crop demand. In comparing like with like, the sugar beet crop is also a 4 year rotational crop. In 2006, the area under cultivation for sugar beet was in the order of 31,000 ha in Ireland. Consider then 10 Bioenergy Parks and the landbank requirement based on the cultivation area of OSR, this equates to 9840 ha or 32% of the sugar beet land bank requirement. This implies that from a national perspective that the landbank required is available.

10.2.5 Bioenergy Park Viability

Upon review of the Bioenergy Park business case the net margin over a 20 year plant life time is unfavourable and low. Margins of between 3 and 9 % are poor and will not encourage investment.

In figure 10.4 the graph presents capital costs, operational costs and percentage margin. Operational costs are almost double the capital costs. While both the straw pelleting plant and the anaerobic digester operate in profit, the biodiesel plant operates at a loss in excess of € 1.2 million (Table 10.5). This a sizable sum to absorb and casts a shadow of doubt over the inclusion of biodiesel production facility within the Bioenergy Park System. The reason for the high operational cost can be attributed to raw material costs, in particular OSR. At € 500/ tonne the viability of the Park is challenged. Even with onsite energy generation supplied 'free' to the biodiesel plant the operation costs are significant.

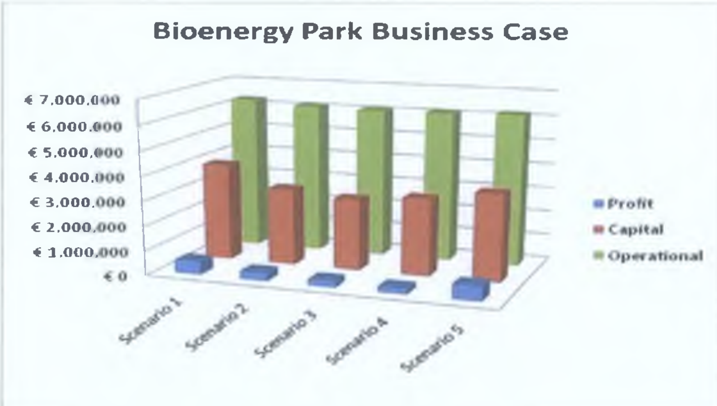


Figure 10.4 Costs associated with the Bioenergy Park

Furthermore, the business case has assumed that both the biodiesel and straw pelleting plants operate to design specification and therefore losses are not incorporated into the matrix.

Bioenergy Park Business Case		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Bioenergy Park Capital Costs		€	€	€	€	€
Anaerobic Digestion	Euro	2560234	1718535	1496123	1731757	2134548
Biodiesel (Capacity 2592 t/an)	Euro	723315	723315	723315	723315	723315
Straw Pellets (Capacity 12000t/an)	Euro	674250	674250	674250	674250	674250
	Total	€ 3,957,799	€ 3,116,100	€ 2,893,688	€ 3,129,322	€ 3,532,113
Bioenergy Park Operating Costs						
Anaerobic Digestion	Euro	399434	240415	201513	242773	316858
Biodiesel Fixed	Euro	4864237	4864237	4861132	4861132	4861132
Straw Pellets Fixed	Euro	1017275	1017275	1017275	1017275	1017275
	Total	€ 6,280,945	€ 6,121,926	€ 6,079,920	€ 6,121,180	€ 6,195,265
Bioenergy Park Net Profit						
Anaerobic digester Net Profit	euro	427657	217139	136149	109282	476377
Biodiesel Net Profit	euro	-1262797	-1262797	-1262132	-1262132	-1262132
Straw Pellet Net Profit	euro	1370605	1370605	1370605	1370605	1370605
	Total	[illegible]5,465	€ 324,947	€ 244,622	€ 217,755	[illegible],850
% Net Margin		8	5	4	3	9

Table 10.5 Bioenergy Park Business Case Scenario 1-5

The production performance generally is less than design specifications. It is expected that the biodiesel plant will operate between 95% to 99% efficiency, based on information on GRO Oil and EcoOla performances. In the case of straw pelleting however, this level of efficiency is highly unlikely. On the plant tour to view Soma technology, the expectation of the plant manager was a productivity level of 1.5 t/h, even though the plant design specification was 2.5 t/h.

Based on the results, a comparison scenario is required to investigate the impact of reducing the capacity of biodiesel within the Bioenergy Park system. Scenarios 6 & 7 investigate a reduced capacity biodiesel plant and its impacts on the output of the Bioenergy Park system. Scenarios 8, 9 and 10 subsequently challenge the impact of reduced production output of both the biodiesel and straw pellet plants against the design specification.

10.3 Scenarios 6 & 7, the scale up to a bundle of ten Bioenergy Parks

Scenarios 6 and 7 investigate the potential of a bundle of ten Bioenergy Parks operating at capacity. Feedstock ratios are similar in both scenarios and are therefore considered a constant. The feedstock values are based on the median range. The systems are in balance from an electrical energy point of view. The difference however between scenario 6 and 7 is that the design capacity of the biodiesel plant is reduced by 50% in scenario 7. The capital requirement has also been adjusted so that the business case can be examined in tandem.

Bioenergy Park Production Output	Capacity (tonnes) Max capacity	Scenario 6 med FS value	Scenario 7 med FS value
Biodiesel Fixed (t)	2952	29500	14750
Straw Pellets (t)	12000	120000	120000
Anaerobic Digestion Feed Stock (t)		150000	278000
Glycerin - from Biodiesel Process	%	2	1
Pig Slurry	%	64	65
Cow Slurry	%	20	20
Sewage Sludge	%	14	14
Total % (Should not be > 100%)		100	100

Table 10.6 Bioenergy Park Inputs - Scenario 6 &7

The impact of reducing the biodiesel capacity has a number of effects within the system.

1) Reducing the biodiesel production results in an overall reduction in renewable energy generation in the Bioenergy Park. There will also be an inherent loss of income, however this is married with a reduction in raw material costs and subsequent OSR land bank requirements. In addition the overall Bioenergy Park thermal and electrical demand on the plant is reduced.

2) By reducing the biodiesel capacity the resultant by-product of glycerine is also reduced by 50%. As glycerine has a high value in terms of methane production this feedstock loss has a significant impact on the energy production potential of the anaerobic digester in the Bioenergy Park system.

3) In order to compensate for the lost energy production potential afforded by the glycerine the feedstock quantity had to be increased. The comparison between feedstock tonnes in scenario 6 versus scenario 7 is 150000 to 278000 tonnes respectively or a 54% increase in feedstock. The knock on impact of this volume increase is reflected in the land bank requirement and is investigated in section 10.3.4

The importance of glycerine as a feedstock cannot be overstated. In the literature review it was reported that glycerine could be added by up to 5% without having a negative impact on the biology of the digester. Given the impact identified above, at all times the anaerobic digester should be supplied with a feed stock of 5% glycerine to maximise the energy potential within the Bioenergy Park.

10.3.1 Electrical and Thermal Energy Balance

Having reduced the biodiesel plant capacity by 50% in scenario 7, the thermal demand is thus reduced by 50% in comparison to scenario 6. As discussed in 10.2.1 above, there is a disparity in the thermal and electrical demand of the Bioenergy Park.

Bioenergy Park Energy Provision			
Electrical Demand MWh		**Scenario 6**	**Scenario 7**
Straw Pellet Production	MWh	8810	8810
Oil Press Production	MWh	1486	743
Biodiesel Production	MWh	838	419
Total Electrical Parasitic Demand	MWh	11134	9972
AD Net Electrical Supply	MWh	11143	10022
% Electrical Energy Supplied	%	100	100
Thermal Demand MWh		**Scenario 6**	**Scenario 7**
Straw Pellet Production	MWh	0	0
Oil Press Production	MWh	2333	1167
Biodiesel Production	MWh	1319	659
Total Thermal Parasitic Demand	MWh	3652	1826
AD Net Thermal Supply	MWh	10000	8994
% Thermal Energy Supplied	%	274	493

Table 10.7 Electrical and Thermal Energy Balance Scenario 6 & 7

Thus as the thermal demand is further reduced then the situation of over-supply of thermal energy is even more pronounced in this scenario 7 (Table 10.7). The thermal supply is at 493% and obviously then over-supplied by 393%.

10.3.2 Bioenergy Park Outputs

With respect to the carbon emission reduction potential, scenario 7 resultant carbon emission reduction is down 13% on scenario 6. This is not surprising however given the fact that the biodiesel capacity has been reduced by 50%. The renewable energy generated and the cars fuelled have to be adjusted also in respect to the biodiesel capacity reduction. Table 10.8 presents the Bioenergy Park Outputs for the given scenarios.

Bioenergy Park Output		Scenario 6	Scenario 7
Reduced Carbon Emissions tCO2	tCO_2	311240	269857
Renewable energy generated GJ Straw pellets and Biodiesel	GJ	2894754	2469069
Tonnes of Oil Equivalent Straw pellets and Biodiesel	toe	68355	58178
Homes Heated - Straw Pellets (5.2 t/home/year)	Homes	23400	23400
Avg. cars fueled - Biodiesel (1.91 t/car/year)	Cars	15281	7641
Electrical generation potential MWh Straw pellets and Biodiesel	MWh	241200	205800

Table 10.8 Bioenergy Park Outputs Scenario 6 & 7

10.3.3 National Targets Achieved

National targets achieved for scenario 6 are as discussed in the previous section (10.2.3). In the case of scenario 7 however, the impact of the 50 % biodiesel reduction in capacity will impact the plants regarding delivery against the biofuel target of 5.75%. In scenario 6, 14% of the national biofuel target could be achieved, while only 7% can be achieved in scenario 7. All other national impacts remain the same as scenario 6 and therefore as reported in section 10.2.3.

10.3.4 Landbank Considerations

The land bank requirement for scenario 6 and 7 are calculated in table 10.9. The land bank required for spreading digestate / biofertilizer has increased from 5304ha in scenario 6 to 9730 ha in scenario 7. This is as a result of the increase of feedstock requirements to combat the energy loss as a result of the loss of the available glycerine by 50% in scenario 7.

Bioenergy Park Land Bank Considerations		Scenario 6	Scenario 7
Digestate Biofertilizer (27.5m³/ha)	ha	5304	9730
Oil seed Rape Land under crop	ha	9833	4917
Oilseed Rape - land bank 1:4 rotation	ha	39333	19667

Table 10.9 Land Bank Considerations Scenario 6 & 7

A reduced OSR requirement automatically impacts the land bank demand for crop cultivation by 50% from scenario 6 to 7. Yet the lead requirement in terms of the land bank requirement is still the 4 year rotational crop consideration. Table 10.9 above identifies a range difference between the two scenarios of 19667 to 39333 ha. Again at its maximum of circa 39,000 ha, this land bank is comparable to the once cultivated sugar beet land bank of Ireland (31,000 ha).

10.3.5 Bioenergy Park Viability

In the results to date, the performance for scenario 7 is poor relative to scenario 6. The adverse results include a loss in carbon emission reduction potential, reduction in the total renewable energy produced, increase in feedstock quantity required and an increased landbank to spread the digestate. But in examining the business case (table 10.10) and interesting result appears. The profit margin in case of scenario 6 is equal to 8%, but scenario 7, even with the loss of income of 50% of the biodiesel, makes a profit margin of 29%.

Bioenergy Park Business Case		Scenario 6	Scenario 7
Bioenergy Park Capital Costs		€	€
Anaerobic Digestion	Euro	9875967	14180149
Biodiesel	Euro	7233150	2416575
Straw Pellets	Euro	6742500	6742500
	Total	23851617	23339224
Bioenergy Park Operating Costs			
Anaerobic Digestion	Euro	2229178	3533667
Biodiesel Fixed	Euro	48611320	24345660
Straw Pellets Fixed	Euro	10172750	10172750
	Total	61013248	38052077
Bioenergy Park Net Profit			
Anaerobic digester Net Profit	euro	4276538	7884804
Biodiesel Net Profit	euro	-12621320	-6350660
Straw Pellet Net Profit	euro	13706050	13706050
	Total	5361268	15240194
% Net Margin		8	29

Table 10.10 Bioenergy Park Business Case Scenario 6 & 7

The reason for this appreciable margin increase is directly related to the raw material cost of OSR. While the biodiesel plant still operates at a loss, this loss can now be absorbed by the business as a whole. Arguably the removal of the biodiesel plant from the system could be justified from a financial point of view, but care must be taken to recognise the synergies between the three processes.

1) The impact of reducing the biodiesel by 50% automatically reduces the available glycerine by same quantity.

2) The result of this 50% reduction of glycerine has a significant impact on the energy production potential of the anaerobic digester.

3) The scale of the digester had to be increased in capacity by 54% to combat the energy loss.

4) Reduction in annual OSR crop cultivation reduces the potential alliance between the arable farmers as the biofertilizer requirements are reduced and land required to handle the increased tonnage of biofertilizer is dramatically increased. In the case of scenario 6 and 7 the digestate quantity has approximately doubled and at the same time the cultivated area has halved from scenario 6 to 7.

5) The biodiesel process is the major thermal energy user within the system. The impact of reducing the biodiesel production capacity by 50% results in further increases in thermal energy oversupply.

The business case showing a 29% profit margin is favourable to the investor, while the environmentalist and renewable energy provider will be disappointed in the reduced potential as discussed. Thus the balancing act between competitiveness, environment and security are demonstrated in scenario 7.

10.4 Scenarios 8, 9 and 10

Scenarios 8, 9 and 10 are designed to investigate two issues.

Firstly the impact of high, median and low values feed stock is considered. Scenario 8, 9 and 10 considers the low, median and the high feed stock value respectively.

Secondly, the impact of the reduced productivity of the straw pellet plant and the biodiesel plant versus design criteria is investigated.

In the three scenarios both the straw pelleting plant and the biodiesel plant operate at the same output, i.e. 7200 tonnes of straw pellets and 1800 tonnes of biodiesel per annum (see table 10.11). The plants are balanced from an electrical energy point of view. The feed stocks percentage mix is as close as reasonably possible.

Bioenergy Park	Capacity (tonnes)	Scenario 8	Scenario 9	Scenario 10
Production Output	Max capacity	low FS value	med FS value	hi FS value
Biodiesel Fixed (t)	2952	1800	1800	1800
Straw Pellets (t)	12000	7200	7200	7200
Anaerobic Digestion Feed Stock (t)		17500	9000	5300
Glycerin - from Biodiesel Process	%	1.03	2.00	3.40
Pig Slurry	%	65.00	64.00	64.00
Cow Slurry	%	20.00	20.00	20.00
Sewage Sludge	%	14.00	14.00	13.00
Total % (Should not be > 100%)		**100**	**100**	**100**

Table 10.11 Bioenergy Park Inputs Scenarios 8, 9 & 10

In balancing the electrical demand, the feedstock volumes required changed considerably between the three scenarios (table 10.11). Scenario 8 required 17500 tonnes of low value feedstock whereas scenario 10 only required 5300 tonnes to deliver the same energy potential. The median feedstock value (Scenario 9) required 9000 tonnes of feedstock in order to fuel the integrated processes within the plant. The impact from a design perspective is that the design capacity required is in the region of 9000 +/- 15% based on these results. Other impacts include;

1. As feedstock throughput in the anaerobic digester plant increases the parasitic energy demand increases reducing the overall productivity and energy yield of the digester to the Bioenergy Park.

2. Increased feedstocks result in increased land bank requirements to spread the biofertilizer/ digestate.

3. Increased quantity of organic waste matter processed through the plant.

4. Additional fee paying feedstocks could increase plant income

5. Additional biofertilizer generation could increase plant income, market dependent.

In the scenarios 8, 9 and 10, three feedstocks were considered in the mix (pig slurry at 65%, cow slurry at 20% and sewage sludge at 14%). As was discussed in chapter 3.0 and chapter 7.0 and presented in the results of scenario 1-5 results, the energy potential varies from feedstock to feedstock. This consideration together with the complication of high, median and low energy yield values range demonstrates the need for the matrix, so that many scenarios can be investigated in order to find the best energy potential from mixed feedstock within an Bioenergy Park location.

10.4.1 Electrical and Thermal Energy Balance

The energy balance results are displayed in table 10.12. As expected, in all cases there is a thermal energy oversupply. The resultant thermal energy over-supply is similar in all three scenarios at 173%. The issue of thermal and electrical demand as discussed in 10.2.1 apply in these three scenarios also.

Bioenergy Park Energy Provision				
Electrical Demand MWh		Scenario 8	Scenario 9	Scenario 10
Straw Pellet Production	MWh	529	529	529
Oil Press Production	MWh	91	91	91
Biodiesel Production	MWh	51	51	51
Total Electrical Parasitic Demand	MWh	670	670	670
AD Net Electrical Supply	MWh	679	674	676
% Electrical Energy Supplied	%	101	101	101
Thermal Demand MWh		Scenario 8	Scenario 9	Scenario 10
Straw Pellet Production	MWh	0	0	0
Oil Press Production	MWh	142	142	142
Biodiesel Production	MWh	80	80	80
Total Thermal Parasitic Demand	MWh	223	223	223
AD Net Thermal Supply	MWh	609	605	607
% Thermal Energy Supplied	%	273	272	272

Table 10.12 Bioenergy Park Energy Balance Scenario 8, 9 & 10

10.4.2 Bioenergy Park Outputs

The Bioenergy Park outputs are the same for each of the three scenarios with the exception of carbon emission reduction potential. Even with the feedstock quantities the carbon emissions results are not significantly different between scenarios 8, 9 and 10.

This can be explained as the carbon reduction is calculated on the methane yield and not quantity of feedstock processed. The range as presented in table 10.13 is from 18647 to 18959 t CO_2 reduced. In terms of the national reduction target of 64 Mt CO_2 the variance is slight and not worth considering on the scheme of things.

Bioenergy Park Output		Scenario 8	Scenario 9	Scenario 10
Reduced Carbon Emissions tCO_2	tCO_2	18647	18779	18959
Renewable energy generated GJ Straw pellets and Biodiesel	GJ	174551	174551	174551
Tonnes of Oil Equivalent Straw pellets and Biodiesel	toe	4122	4122	4122
Homes Heated - Straw Pellets (5.2 t/home/year)	Homes	1404	1404	1404
Avg. cars fueled - Biodiesel (1.91 t/car/year)	Cars	932	932	932
Electrical generation potential MWh Straw pellets and Biodiesel	MWh	14544	14544	14544

Table 10.13 Bioenergy Park Outputs Scenario 8, 9 & 10

10.4.3 National Targets Achieved

Again the biofuel target of 5.75% is calculated based on 2006 figures of diesel consumption in transport and equates to 144 ktoe. Ten Bioenergy Parks as described in scenario 8, 9 and 10 could potentially supply up to 9 % of Irelands biofuel obligation in relation to diesel oil requirements in transport.

The 2006 consumption of oil for home heating was 2295 ktoe in Ireland. Based on straw pellet output of 72000 t per Bioenergy Park, 10 parks could replace 1.3% of this oil with renewable energy from waste straw.

10.4.4 Landbank Considerations

Bioenergy Park Land Bank		Scenario 8	Scenario 9	Scenario 10
Digestate Biofertilizer (27.5m3/ha)	ha	626	318	186
Oil seed Rape Land under crop	ha	600	600	600
Oilseed Rape - land bank 1:4 rotation	ha	2400	2400	2400

Table 10.14 Bioenergy Park Land Bank Requirements Scenario 8, 9 & 10

In scenario 8 there is a match between the land bank required to cultivate the annual crop for biodiesel (600 ha) and the land bank required to spread the digestate/ biofertilizer (626 ha).

Between the three scenarios there is a significantly different requirement when considering the digestate/ biofertilizer, 186 ha to 626 ha from high feedstock value to low feedstock value.

However, as before, the oilseed rape cultivation land bank requirement when the four year rotation is consideration is still the overriding factor in calculating the land bank (Table 10.14) (2400 ha).

10.4.5 Bioenergy Park Viability

In consideration of the business case for scenarios 8, 9 and 10 the results are poor. Scenario 8 and 9 while positive are very low in margin and scenario 10 is negative. This is an interesting result as scenario 10 is the high value feedstock and one would have expected that with a reduced capital that the results would have been more favourable.

Bioenergy Park Business Case			Scenario 8	Scenario 9	Scenario 10
Bioenergy Park Capital Costs			€	€	€
Anaerobic Digestion		Euro	2802403	1897622	1391170
Biodiesel	(Capacity 2592 t/an)	Euro	723315	723315	723315
Straw Pellets	(Capacity 12000t/an)	Euro	674250	674250	674250
		Total	€ 4,199,968	€ 3,295,187	€ 2,788,735
Bioenergy Park Operating Costs					
Anaerobic Digestion		Euro	448161	272766	183685
Biodiesel Fixed		Euro	3076045	3076045	3076045
Straw Pellets Fixed		Euro	705275	705275	705275
		Total	€ 4,229,480	€ 4,054,085	€ 3,965,005
Bioenergy Park Net Profit					
Anaerobic digester Net Profit		euro	501485	256329	145092
Biodiesel Net Profit		euro	-880045	-880045	-880045
Straw Pellet Net Profit		euro	727453	727453	727453
		Total	€ 348,893	€ 103,738	-€ 7,499
% Net Margin			8	2	0

Table 10.15 Bioenergy Park Business Case Scenario 8, 9 & 10

The contributing factors are;

1. The biodiesel plant is operating at 60% capacity. While this reduces the net income, it also reduced the available glycerine for use in the anaerobic digester as a feed stock
2. The straw pelleting plant is operating at 60% capacity, this represents the expected rather than the design output of the plant, based on the visit to Soma Technology. The net result is that a 40% decrease straw pellet output thus a reduced income from the sale of the pellets.
3. The feedstocks are greatly increased from the high, medium and low values. The result is that greater quantity of gate fees can be collected and where biofertilizer reaches a market value then fees can be collected here also. Hence the reason why scenario 8 looks more favourable than scenarios 9 and 10.

10.5 Summary

As mentioned in the introduction of this chapter, the opportunity to explore scenarios in the matrix is endless. Finding the best fit Bioenergy Park will depend on a number of variables external to the plant's control. A summary of the findings underline the potential opportunities and roadblocks facing the Bioenergy Plant project as it is translated from concept in to reality.

The key findings are:

1. Carbon emission reductions potential is marginal based on delivery against the national target.
2. Cost effective production of renewable energy, particularly in the case of biodiesel, is dependant on raw material prices. In the current climate biodiesel production is unfavourable given the cost of OSR. However the removal of the biodiesel plant as part of the system could effectively break the synergies.
3. Given the land bank requirements, a key integration is that of the agricultural community. The Bioenergy Park is dependant on the supply of raw material, OSR, straw and slurries together with a land bank requirement for spreading digestate from the local agricultural community.
4. Glycerine is identified as a key feedstock for the anaerobic digester
5. Feed stocks availability, quality and consistency are critical to managing the energy balance of the Bioenergy Park
6. Thermal energy oversupply is a key issue or exploitation opportunity in the Bioenergy Park.
7. Nine of the ten scenarios showed unfavourable results from a business case point of view. Scenario 7 demonstrates however, that the system can prove viable both in terms of economics and environmental sustainability. Getting the balance right is critical.

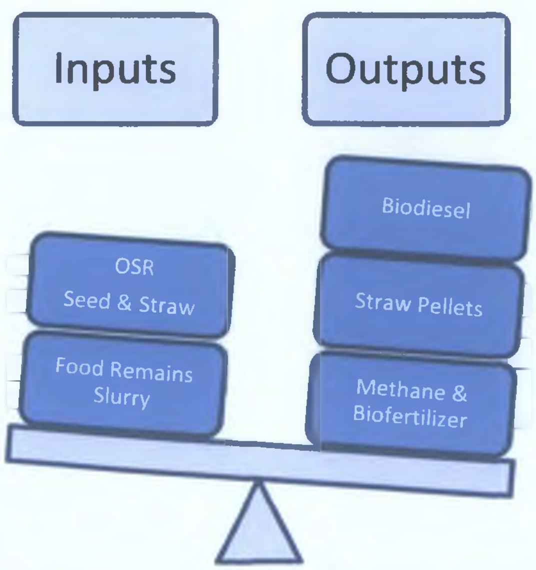


Figure 10.5 Bioenergy Park - getting the balance right.

11.0 Discussion

Ensuring sufficient, reliable and environmentally responsible supplies of energy at prices reflecting market fundamentals is a challenge for our countries and for mankind as a whole." (SEI-4, 2008). The concept of the Bioenergy Park embraces these fundamentals, however the tensions created in achieving sustainable energy generation are reflected in the results of the 'Integration Matrix' as documented in chapter 10.0. This chapter discusses the analysis of the synergies of the following;

- Business case success or failure
- Feedstocks and surrounding impacts
- Thermal energy oversupply
- Combustion of Straw
- Energy Generation Potential
- Carbon emission reduction potential of the Bioenergy Park.

11.1 Business case success or failure

In order to translate concept into reality, investment is key. In the business case results, (chapter 10.0), of the 10 selected scenarios investigated only one showed promise, scenario 7, where a 29% profit margin was calculated. Scenario 10 showed a negative percentage margin and the remaining 8 scenarios showed profit margins ranging between 2 and 9%. There are a number of points to be discussed regarding the businesses case analysis of a Bioenergy Park.

- Raw material costs
- Collection and distribution costs
- Straw pellet income potential
- Potential financial support mechanisms available to the set up of a Bioenergy Park in Ireland.

11.1.1 Raw mate rial costs

At the projected cost of € 500 /tonne, the cost of the oil seed rape tips the balance of viability for the Bioenergy Park. Scenario 7 had a biodiesel plant capacity reduction of 50% relative to the other scenarios, this reduced the losses incurred significantly and these reduced losses were absorbed by the income generated from the other processes within the Bioenergy Park system. From an investment point of view, actively including a loss making process (biodiesel production) within a new business model would not be acceptable. On the other hand, the removal of the biodiesel process from the Bioenergy Park concept would unravel the plants synergies in respect to thermal energy consumption, glycerine generation and land bank integration as discussed in chapter 10.0 section 3.

11.1.2 Collection and distribut ion costs

Collection and distribution costs were not included as part of the financial consideration in the matrix development. It was assumed that goods were supplied from a local network and subsequent to production, were distributed to a local market. Where collection and distribution costs are incurred beyond the local radius (10 km) the costs could seriously impact on the profit margins of between 1% and 29% as documented in the results chapter.

11.1.3 Straw pellet income potential

The matrix considers that straw pellets are of a similar quality to wood pellets thus the calculated value in the matrix is equivalent market value to that of wood pellets. However, given the observations made on the Czech tour, the quality of the straw pellets was by far inferior to wood pellets and this is perceived as an issue regarding market penetration and income potential. Currently, Carroll, 2007, (Teagasc), is conducting research on the pelleting of alternative biomass. This study will be critical to Bioenergy Park developers, if straw pellets are to access the wood pellet market and realise the income potential going forward.

11.1.4 Financial support mechanisms

No consideration has been made to the financial implications of grant aid, tax incentives or other government funding mechanisms in relation to a Bioenergy Park scenario within the matrix. Chapter 1 indicated how the Bioenergy Park can deliver on a number of the National Climate Change Strategy points (Chapter 1, Box 1.2). There are both direct and indirect benefits which provide incentives for the development of the Bioenergy Park concept. The relevant capital and operational incentives are outlined in box 11.1 below.

Capital and operational development incentive	Box 11.1

- Support for Combined Heat and Power projects
- Support for waste-to-energy projects under REFIT scheme
- Tax incentives for investment into renewable energy systems
- Sustainable Energy Ireland, Enterprise Ireland and Environmental Protection Agency grant support schemes.

11.2 Feedstocks - the full picture

The matrix was configured to allow a more accurate calculation on energy yield potential based on individual feedstock characteristics. The scenarios 1-5 demonstrated the dramatic effect of changing the feed mix ratios based on the median value. Scenarios 8, 9 and 10 considered the low, median and high value of the same feedstock mix and highlighted the impact this had on plant capacity requirements to deliver the same energy needs. In the context of the results presented in chapter 10.0 there a number of items to be discussed on the topic of feedstocks.

These are;

- The limitations of the matrix,
- Critical feedstocks such as glycerine
- Site selection based on feedstock availability and energy generation potential,
- Land spreading within the law.

11.2.1 **Matrix limitations**

1. Integration 'BP Live' reflects the median feedstock value only and does not present the high and low range values automatically.
2. Some feedstocks did not have a range defined in the original table (Appendix 5.1) and thus could not be extrapolated in relation to low, median and high values. This possibly distorts the energy generation potential when making comparisons.

3. The Integration Matrix is developed so that a multitude of scenarios can be investigated within the context of the eleven feedstocks as defined. Five scenarios were presented to challenge the potential, the opportunity to explore is within the scope of the Integration Matrix.

11.2.2 **Glycerine as a key feedstock**

Glycerine as a key feedstock and is critical to the success of the Bioenergy Park. The energy value of glycerine as derived within the matrix was supplied by an anaerobic digestion design company (Weltech Biopower). It is clear that a feedstock such as glycerine should be added to maximum level of 5% to boost the energy yield by 20% as documented. Thus where the Bioenergy Park can not supply the full quota of glycerine, it should be purchased as a supplementary feedstock

11.2.3 Site selec tion and based on the availability and nature of slurries and feedstocks

The fundamental criteria to be considered when identifying a viable site for a Bioenergy Park as defined and these include;

- Land productivity, farming type and density
- Nature and location of slurries and organic feedstocks
- Sensitive catchments areas in relation to digestate and its water pollution potential
- Infrastructure, access and distribution to site and market
- Interest in the Bioenergy Park concept

Appendix 1.13 considers the most appropriate geographical location to site a Bioenergy park based on land use, farming activity and feedstock resource potential. The counties identified with the most potential for the location of a Bioenergy Park are Cork, Galway, Tipperary, Kilkenny and Meath. In locating a site, the feed stocks availability, quality and consistency of supply will be critical to the performance to the anaerobic digester, the Bioenergy Park engine. Given the learnings of the characteristic of individual feedstocks, designers will require a more accurate estimation of the energy potential of local feeds stocks so that design structure, capacity, mixing, and retention time and storage requirements will be sized appropriately.

11.2.4 Land spreading within the law

The constraints identified in respect of land spreading the resultant biofertilizer/ digestate are critical when considering site location. Chapter 5.0 explored the issues regarding the use of animal by-products as a feedstock and the impact this has on the control of digestate. The summary of land spreading of digestate is documented in box 11.2 below. The limitation of the integration matrix is that the spread rate is defined as 27.3 m^3 per hectare for all feedstocks and it is from this value that the land bank requirement is calculated. This may be significantly different dependant on feedstock type, land use and soil type.

Box 11.2

In the implementation of the Nitrates Directive a number of factors need to be considered.

- ✓ A rule of thumb of 11m^3 for pig slurry per hectare for grass land and 27.3m^3 for crops can be land spread. Cattle slurry can be spread at a rate of 33m^3 per hectare of land.
- ✓ Where sewage sludge is part of the feed stock, consideration of heavy metals and maximum load of 2 tonnes dry matter per hectare can be applied to land.
- ✓ Where catering waste is part of the feedstock, a restriction of grazing of 21 days is applied and this is extended to 60 days for pigs.
- ✓ Where category 3 material is part of the feedstock a 12 month ban on the production of feed crops (animal or otherwise) and in addition a 3 year ban on grazing is applied.

11.3 Energy generation - thermal energy oversupply addressed

In the results chapter, of the 10 scenarios investigated the oversupply of thermal energy in the minimum was 172 % and reached an extreme of 393 % oversupply in the case of scenario 7. This generation of excess thermal energy is an unfortunate result of the disparity in the demand and the supply of energy flows within the Bioenergy Park system. Clearly, the generation of this significant quantity of thermal energy, effectively a waste, has exploitation potential and thus requires further investigation. In addition, the calculations of the biodiesel thermal demand were based on the figures supplied in the GroOil case study. Estimations were made that potentially overstate the thermal demand of the plant (chapter 7.0 section 7.2.4).

The matrix considered one-dimensional energy supply and demand dynamics. In reality, the digester will be a 24-7 operation with fluctuating energy demands based on process flows and hygienization step activities. Both the biodiesel and the straw pelleting operations will more than likely be restricted to a production pattern of 12 hours.

Finding solutions for the use of the excess thermal energy would create another integration dynamic thus complicate further the site selection criteria. Rethinking the energy generation mechanisms within the Bioenergy Park site may be worth considering. There a number of solutions to the thermal supply and these include the following;

- District heating
- Partnership with an industrial (thermal) consumer
- Restructuring the energy generation system to prevent the production of excessive thermal energy

11.3.1 District h eating

In Europe, a typical use of thermal energy from anaerobic digesters is the district heating option to the local communities. An Irish example of such a district heating system is the anaerobic digester operating in the Camphill Community, Ballytobin, Co. Kilkenny. The digester is supplied by four local dairy farms. The biogas production is estimated at 600m^3 per day. The biogas is burned in either an 85 kW or a 200 kW hot water boiler to supply the community district heating system (Healion, 2005).

11.3.2 Partnership with a thermal consumer

By linking the Bioenergy Park with a high thermal energy user that requires low grade thermal energy, could provide a solution to the excess thermal energy issue. Appendix 1.14 investigates Glanbia Dairy (Ballytore) as an industrial plant for such a partnership and identifies a number of additional potential synergies between the two operations. These are outlined below in box 11.3.

Glanbia Dairy (Ballytore) - A perfect match for a Bioenergy Park system	Box 11.3

- High consumption of electrical and thermal energy
- User of diesel in transport and boiler fuel
- Waste water treatment plant
- Sewage sludge generation
- Established land bank and nutrient management plan
- Access to main distribution route. (N7 and N8)
- Large site with development potential on adjoining land
- Agri trading activity on site which includes grain drying and grain storage facility
- On-site weigh bridge.
- Located in an arable region with access to grain cultivation potential slurries and feedstocks.

11.3.3 Recon figure the energy generation within the process

In the initial stages of the Bioenergy Park development, it would be prudent to investigate the actual maximum demand requirements and the off peak requirements before committing to fixed energy generation process and plant. This study would facilitate greater decision making in designing the most appropriate energy generation solution further maximising the energy generation potential of the Bioenergy Park rather than designing a known oversupply issue of thermal energy and an inherent energy loss into a new system. It is worth noting that Murphy-1, 2005, has argued that in order to maximise income potential from biogas that the best value is in its use as a transport fuel. The potential revenue from biogas for electricity, CHP and transport is equal to € 0.15/ m^3, € 0.19/ m^3 and € 0.47 m^3 respectively.

11.4 Straw combustion and emissions

In chapter 4.0, research documented issues regarding the emissions generated during the combustion process of straw. The section concluded that straw pellets can be used as an alternative fuel to wood pellets with a number of considerations.

1 Specially adapted burners are required when using agri-pellet fuel in respect of combustion and emissions control.

2 There are approved burners on the market for the combustion of straw pellets.

3 Emissions can be abated using additives and smart design for domestic boilers.

4 The approval of fuel, for a specific burner type, is the responsibility of the burner manufacture and not the role of the fuel supplier. However, a close relationship with innovative burner specialists could prove a positive synergy.

11.5 Renewable energy production potential

The concept of the Bioenergy Park is that the raw material for the processes is supplied locally. Secondly, the anaerobic digester is the energy generator on site. These two conditions place constraints on the size, capacity and resultant renewable energy production potential per site. The 'Integration Matrix' has been designed to reflect the smaller plant capacity as these are more realistic in terms of local provision of materials that can be produced in an environmentally sustainable way. The land bank required to produce one tonne of biodiesel is circa 3 hectares, this increases to 12 hectares when crop rotation is considered. Depending on the geographic location and farming activity this will restrict the biodiesel output. Availability of waste straw is less restrictive, however supply volumes will determine the possible energy generation potential on a site. Results showed that at a capacity of 2952 tonnes of biodiesel and 12000 tonnes of straw pellets where the output of ten Bioenergy Parks are bundled together that 14% of the National Biofuel target can be achieved and 2.1% of the home heating oil can be replaced with carbon neutral fuel based on 2006 total energy consumption figures.

11.6 Carbon emission reduction potential

The potential carbon emission reduction associated with the Bioenergy Park as calculated is marginal (0.48% to 0.58%) when measured against the national carbon emission reduction target of 64 million tonnes of CO_2. The carbon emission reduction potential as documented in the matrix is guideline of the Bioenergy Park potential. Having reviewed N. D. Mortimer, 2003, it is clear that a full life cycle analysis study of an actual operating Bioenergy Park is required to truly calculate the carbon emission reduction potential of a given plant.

11.7 Summary of discussion

While the potential of the Bioenergy Park is real, both the results chapter and the discussion above have demonstrated that the balance of success and failure is on a knife edge. Detailed design and planning to maximise the potential synergies is essential to ensure a successful project.

12.0 Conclusion

The purpose of this study was to develop a software tool to analyse the possible synergies of integrated renewable energy processes in a Bioenergy Park. The synergies do not simply lie in the obvious categories such as one site, one environmental impact assessment, one planning application, one distribution network, one land bank and so on. They are much more intricate and involve a fine balance between processes operating together to maximise the energy generation potential of the Bioenergy Park.

In keeping with the principle of local environmental sustainable supply, the 'Integration Matrix' is designed with a biodiesel plant capacity of 2952 tonnes, straw pellet capacity of 12000 tonnes and the anaerobic digester is sized appropriately to supply the total energy needs of the Bioenergy Park system.

The 'Integration Matrix' demonstrated that the feedstock energy yield potential is based on the parameters of quality, consistency and availability of feedstocks types in a given location.

Glycerine, the main by-product of the biodiesel process, is identified as a significant feedstock, having a high energy generation potential when added in small quantities (<6%) to the anaerobic digester. Through the literature review, it was observed that glycerine could only be added up to a maximum of 6%, before the micorflora of the digester reacts negatively.

Of the 10 scenarios investigated the oversupply of thermal energy in the minimum was 172 % and reached an extreme of 393 % oversupply in the case of scenario 7. This generation of excess thermal energy is an unfortunate result of the disparity in the demand and the supply of energy flows within the Bioenergy Park system. This potential remains unexploited in the context of the Bioenergy Park as described.

When bundled together, the output of ten local Bioenergy Parks can supply from 7 to 14% of the National Biofuel target.

Ten Bioenergy Parks could generate sufficient straw pellets to replace 2.1% of home heating oil, based on 2006 National oil consumption figures.

The carbon emission reduction potential of ten bundled Bioenergy Parks is marginal (0.48%) when measured against the national targets carbon emission reduction targets of circa 64 million tCO_2. The carbon emission reduction potential as documented in the matrix is guideline of the Bioenergy Park potential. A life cycle analysis based on a recognized standard methodology (ISO 14040:2006 and 14044:2006) must be applied to and operational Bioenergy Park to truly evaluate its carbon emission reduction potential

Given the landbank requirements, a key integration is that of the Bioenergy Park with the agricultural community. The Bioenergy Park is dependant on the supply of raw materials, OSR, straw and slurries together with a land bank requirement for the spreading of digestate. Without the continuous support and integration of the local community the Bioenergy Park system will fail.

In the business case results of the 10 selected scenarios investigated only one showed promise, scenario 7 where a 29% profit margin was calculated. A positive profit margin can be achieved however, clever integration and site location in close proximity to material supply and market access is key to the success of the Bioenergy Park.

The main loss driver within the matrix is the raw material cost of oil seed rape At € 500 /tonne, this cost tips the balance of viability for the Bioenergy Park. A possible directional change in relation to biodiesel and its function as a key process within the Bioenergy Park operation may be required, but care must be taken to replace its synergy potential with other complimentary processes and feedstock materials. It is worth noting that the cost of a barrel of oil was $ 26 US dollars in 2003 and reached record costs of $126 dollar a barrel by May 2008 and further predictions of $ 170 per barrel by year end have been reported (RTE, 2008). This ever increasing cost of fossil fuel oil imports could turn the tables for biodiesel as viable process within the system.

The study concludes that based on the results generated from the 'Integration Matrix' the option of a Bioenergy Park, as described, has a role to play in ensuring a local supply of renewable energy that is reliable and environmentally responsible and at prices reflecting market fundamental, in the Irish context.

13.0 Recommendation

There are a number of key areas which require further research and development and these are as follows;

1. Research in the area of 'Super' feedstocks - such as glycerine
2. Simplifying the Animal By-Products Directive and the Nitrates Directive in an Integration Matrix
3. Exploitation of the thermal energy over supply
4. Straw combustion and pellet structure issues
5. Life Cycle Analysis of a Bioenergy Park
6. Development of a software tool to investigate the possible synergies in and Integration waste to energy processing site

13.1 Research in the area of 'Super' feedstocks - such as glycerine

Glycerine was identified as a valuable feedsock in this study. There could be many more wastes or process by- products with equal energy generation potential and these need to be identified and researched so that the energy yield potential of these organic wastes could be realized in the Irish context. This research should include glycerine as a feedstock and maximize its percentage inclusion. In addition, a database of feedstock values and feedstock mixes could then be established that give a specific, rather than a general range for each site. This type of study would provide the best possible scientific knowledge on which a Bioenergy Park developer could base his site selection criteria and balance the energy generation potential more accurately.

13.2 Development of an Integration Matrix to simplifying the Animal By-Products Directive and the Nitrates Directive

There is also a need to simplify the Animal By-Products Directive and Nitrate Directive requirements on a site by site basis. The matrix could be designed to integrate the constraints of the feedstock mix and marry the legislative restrictions imposed on the spreading of digestate together with the nutrient load requirements for effective soil/nutrient management in a specific location. This new dimension of the matrix would allow an accurate assessment of actual landbank requirement in a specified area, just by a click of a button, thus simplifying the Animal By-Products Directive and Nitrate Directive requirements.

13.3 Energy generation - thermal energy oversupply addressed

The generation of excess thermal energy is an unfortunate result of the disparity of the demand and supply energy flows within the Bioenergy Park system. Further research is required to maximise this energy potential. This could involve engineering out the generation of the excessive oversupply, finding a thermal hungry renewable energy process to absorb the thermal energy or indeed finding a suitable client or partner to utilize the thermal energy.

13.4 Straw combustion and pellet structure issues

Further research on the topic of boilers and boiler-fuel combustion has commenced (2008) in University College Dublin (UCD), where engineers are investigating emissions using test rig boilers. This work is being conducted in partnership with the EPA. Teagasc is also investigating alternative biomass characteristics such as ash levels, chlorine levels among others in consideration of propagation, harvesting and combustion of alternative fuel crops. Teagasc is also studying the production of high quality straw pellet investigating the use of various additives and material blends. These pieces of work will identify the next phase of boiler design for Agri-pellets and emission testing of new pellet blends.

13.5 Life Cycle Analysis to determine the true Carbon Emission Reduction Potential

A life cycle analysis study of an actual operating Bioenergy Park is required to truly calculate the carbon emission reduction potential of a given plant. This study should be based on a recognized standard methodology such as the procedures of life cycle assessment (LCA) as set out in the International Standards Organization (ISO) in the standards denoted as ISO 14040:2006 and 14044:2006. This study would provide a systematic approach and template for all further Bioenergy Parks LCA evaluations.

13.6 Development of a software tool to investigate the possible synergies in and Integration waste to energy processing site

The concept of the Bioenergy Park Integration matrix could be developed in the context of and Integrated Waste Management site with a view of maximising the potential of a number of different operations where the focus is energy generation and environmental sustainability. This study would need a partnership between a waste management company an Educational body and support form a funding body such as the EPA.

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Appendix 1.0

Disk containing 'Integration Matrix' file – Microsoft Office Excel®
(Software Version 2007)

Appendix 1.1	**Bioenergy Park Integration Matrix©**
Index	Index of Bioenergy Park Integration Matrix
BD Cap	Biodiesel Capital Quotation
BD Bus	Biodiesel Production Business Case with OSR cost consideration
BD Scen	Biodiesel Bioenergy Park displaying Integration Live and 10 scenarios
SP Cap	Straw Pellet Capital – combining Soma and Ekopress quotation
SP Bus	Straw Pelleting Business Case with Output Capacity Options considered
SP Scen	Straw Pellets Bioenergy Park displaying Integration Live and 10 scenarios
AD FSCal	Anaerobic Digestion Feedstock calculations – High, Medium and Low Values
AD Cap	Anaerobic Digestion Capital and Operational Costs -model extrapolated
AD Scen	Anaerobic Digestion Bioenergy Park displaying Integration Live and 10 scenarios
BP-Live	Bioenergy Park Integration Live, setting out put and cost and income variables
BP- 1-10	Bioenergy Park Integration - displaying Integration Live and 10 scenarios

Appendix 1.2 Bioenergy Park Integration Matrix Live 'BP Live'

Bioenergy Park	Integration Live	
Biodiesel (Max capacity 2952 tonne)	0	t
Straw Pellets (Max capacity 12000 tonne)	0	t
Anaerobic Digestion Feed Stock	0	t

Select Feedstock Make-up

Glycerin - from Biodiesel Process	#DIV/0!	%
Pig Slurry	0.00	%
Cow Slurry	0.00	%
Food Remains	0.00	%
Sewage Sludge	0.00	%
Chicken Slurry	0.00	%
Whey	0.00	%
Leaves	0.00	%
Wood Shavings	0.00	%
Straw	0.00	%
Garden Waste	0.00	%
Total % (Should not be > 100%)	#DIV/0!	

Bioenergy Park Financial Output	Euro	
Capital Cost	1397565	€
Net Profit	#DIV/0!	€
% Margin	#DIV/0!	%

Please Check Variables - Scroll Down

Back to the Index

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Investigate Scenarios

Straw Pellets	1 tonne
Reduced tCO_2 emissions	1.5
GJ of energy	17.0
TOE	0.4
Homes Heated (5.2 t/home/year)	0.195
Electrical generation potential MWh	1.42

Biodiesel	1 tonne
Reduced tCO_2 emissions	2.41
GJ of energy	28.86
TOE	0.69
Homes Heated (5.2 t/home/year)	0.19
Avg. cars fueled (1.91 t/car/year)	0.518
Electrical generation potential MWh	2.40
Oil Press Parasitic Thermal Demand kWh	79.10
Oil Press Parasitic Electrical Demand kWh	50.36
Biodiesel Parasitic Thermal Demand kWh	44.70
Biodiesel Parasitic Electrical Demand kWh	28.42

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Bioenergy Park Power Supply		
Total Electrical Demand	0	MWh
Anaerobic Digestion Supply	#DIV/0!	MWh
%Electrical Energy Supplied	#DIV/0!	%
Total Thermal Demand	0	MWh
Anaerobic Digestion Supply	#DIV/0!	MWh
% Thermal Energy Supplied	#DIV/0!	%

Bioenergy Park Output	Biofuel	
Reduced Carbon Emissions	#DIV/0!	tCO_2
Renewable energy generated	0	GJ
Tonnes of Oil Equivalent	0	TOE
Homes Heated - Straw Pellets	0	Homes
Avg. Cars Fuelled - Biodiesel	0	Cars

Land Bank Requirement	Hectares	
Digestate Biofertilizer - Land bank	#DIV/0!	ha
Oilseed Rape - Land bank	0	ha
Bioenergy Park - Radius (Absolute).	0.00	km

Commodities		
Oil Seed Rape (local delivered)	500	€/t
Straw (local delivered)	65	€/t
Methanol	475	€/t
ESB Electricity Supply kWh	0.15	€/t
Thermal Electricity Supply kWh	0.12	€/t

Finished Products	Income Potential	
Biodiesel	880	€/t
Straw Pellets	210	€/t
Glycerin	90	€/t
Rape Cake	170	€/t
Bio-Fertilizer	15	€/t

Income from Feed stocks	Income Potential	
Pig Slurry	0	€/t
Cow Slurry	0	€/t
Food Remains	100	€/t
Sewage Sludge	100	€/t
Chicken Slurry	0	€/t
Whey	100	€/t
Leaves	0	€/t
Wood Shavings	0	€/t
Straw	0	€/t
Garden Waste	0	€/t

Appendix 1.3 Bioenergy Park Integration Matrix Scenario 1-10 ‘ BP 1- 10 Part (1)

Bioenergy Park	Capacity (tonnes)	Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Production Output	Max capacity	med FS value	med FS value	med FS value	med FS value	med FS value	med FS value	med FS value	med FS value	low FS value	med FS value	hi FS value
Biodiesel Fixed (t)	2952	0	2952	2952	2950	2950	2950	29500	14750	1800	1800	1800
Straw Pellets (t)	12000	0	12000	12000	12000	12000	12000	120000	120000	7200	7200	7200
Anaerobic Digestion Feed Stock (t)		0	15000	7600	6000	7700	11000	150000	278000	17500	9000	5300
Glycerin - from Biodiesel Process	%	#DIV/0!	1.97	3.88	4.92	3.83	2.68	1.97	0.53	1.03	2.00	3.40
Pig Slurry	%	0.00	64.00	57.00	59.00	0.00	0.00	64.00	65.00	65.00	64.00	64.00
Cow Slurry	%	0.00	20.00	20.00	20.00	73.16	68.20	20.00	20.00	20.00	20.00	20.00
Food Remains	%	0.00	0.00	0.00	0.00	0.00	15.00	0.00	0.00	0.00	0.00	0.00
Sewage Sludge	%	0.00	14.03	14.30	8.50	0.00	14.00	14.03	14.03	14.00	14.00	13.00
Chicken Slurry	%	0.00	0.00	0.00	0.00	23.06	0.00	0.00	0.00	0.00	0.00	0.00
Whey	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leaves	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wood Shavings	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Straw	%	0.00	0.00	5.00	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Garden Waste	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total % (Should not be > 100%)		#DIV/0!	100	100	100	100	100	100	100	100	100	100

Bioenergy Park Business Case		Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Bioenergy Park Capital Costs		€	€	€	€	€	€	€	€	€	€	€
Anaerobic Digestion	Euro	0	2560234	1718535	1496123	1731757	2134548	9875967	14180149	2802403	1897622	1391170
Biodiesel (Capacity 2592 t/an)	Euro	723315	723315	723315	723315	723315	723315	7233150	2416575	723315	723315	723315
Straw Pellets (Capacity 12000t/an)	Euro	674250	674250	674250	674250	674250	674250	6742500	6742500	674250	674250	674250
	Total	€ 1,397,565	€ 3,957,799	€ 3,116,100	€ 2,893,688	€ 3,129,322	€ 3,532,113	€ 23,851,617	€ 23,339,224	€ 4,199,968	€ 3,295,187	€ 2,788,735
Bioenergy Park Operating Costs												
Anaerobic Digestion	Euro	0	399434	240415	201513	242773	316858	2229178	3533667	448161	272766	183685
Biodiesel Fixed	Euro	281995	4864237	4864237	4861132	4861132	4861132	48611320	24345660	3076045	3076045	3076045
Straw Pellets Fixed	Euro	237275	1017275	1017275	1017275	1017275	1017275	10172750	10172750	705275	705275	705275
	Total	€ 519,270	€ 6,280,945	€ 6,121,926	€ 6,079,920	€ 6,121,180	€ 6,195,265	€ 61,013,248	€ 38,052,077	€ 4,229,480	€ 4,054,085	€ 3,965,005
Bioenergy Park Net Profit												
Anaerobic digester Net Profit	euro	#DIV/0!	427657	217139	136149	109282	476377	4276538	7884804	501485	256329	145092
Biodiesel Net Profit	euro	-281995	-1262797	-1262797	-1262132	-1262132	-1262132	-12621320	-6350660	-880045	-880045	-880045
Straw Pellet Net Profit	euro	-237275	1370605	1370605	1370605	1370605	1370605	13706050	13706050	727453	727453	727453
	Total	#DIV/0!	€ 535,465	€ 324,947	€ 244,622	€ 217,755	€ 584,850	€ 5,361,268	€ 15,240,194	€ 348,893	€ 103,738	-€ 7,499
% Net Margin		#DIV/0!	8	5	4	3	9	8	29	8	2	0

Appendix 1.3 Bioenergy Park Integration Matrix Scenario 1-10 ' BP 1- 10 Part (2)

		Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
% Electrical Energy Supplied												
Electrical Demand MWh												
Straw Pellet Production	MWh	0	881	881	881	881	881	8810	8810	529	529	529
Oil Press Production	**MWh**	**0**	**149**	**149**	**149**	**149**	**149**	**1486**	**743**	**91**	**91**	**91**
Biodiesel Production	MWh	0	84	84	84	84	84	838	410	51	51	51
Total Electrical Parasitic Demand	**MWh**	**0**	**1114**	**1114**	**1113**	**1113**	**1113**	**11134**	**9972**	**670**	**670**	**670**
AD Net Electrical Supply	MWh	#DIV/0!	1115	1119	1129	1115	1126	11143	10022	679	674	676
% Electrical Energy Supplied	%	#DIV/0!	100	100	101	100	101	100	100	101	101	101
Thermal Demand MWh												
Straw Pellet Production	MWh	0	0	0	0	0	0	0	0	0	0	0
Oil Press Production	**MWh**	**0**	**234**	**234**	**233**	**233**	**233**	**2333**	**1167**	**142**	**142**	**142**
Biodiesel Production	MWh	0	132	132	132	132	132	1319	659	80	80	80
Total Thermal Parasitic Demand	**MWh**	**0**	**365**	**365**	**365**	**365**	**365**	**3652**	**1826**	**223**	**223**	**223**
AD Net Thermal Supply	MWh	#DIV/0!	1000	1004	1013	1000	1011	10000	8994	609	605	607
% Thermal Energy Supplied	%	#DIV/0!	274	275	277	274	277	274	493	273	272	272
Bioenergy Park Output		Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Reduced Carbon Emissions tCO_2	**tCO_2**	**#DIV/0!**	**31131**	**30792**	**30757**	**30995**	**31063**	**311240**	**269857**	**18647**	**18779**	**18959**
Renewable energy generated GJ Straw pellets and Biodiesel	GJ	0	289533	289533	289475	289475	289475	2894754	2469069	174551	174551	174551
Tonnes of Oil Equivalent Straw pellets and Biodiesel	**TOE**	**0**	**6837**	**6837**	**6836**	**6836**	**6836**	**68355**	**58178**	**4122**	**4122**	**4122**
Homes Heated - Straw Pellets (5.2 t/home/year)	Homes	0	2340	2340	2340	2340	2340	23400	23400	1404	1404	1404
Avg. cars fueled - Biodiesel (1.91 t/car/year)	**Cars**	**0**	**1529**	**1529**	**1528**	**1528**	**1528**	**15281**	**7641**	**932**	**932**	**932**
Electrical generation potential MWh Straw pellets and Biodiesel	MWh	0	24125	24125	24120	24120	24120	241200	205800	14544	14544	14544
Land Bank Hectares		Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Digestate Biofertilizer (27.5m3/ha)	**ha**	**#DIV/0!**	**530**	**265**	**208**	**267**	**384**	**5304**	**9730**	**626**	**318**	**186**
Oil seed Rape Land under crop	**ha**	**0**	**984**	**984**	**983**	**983**	**983**	**9833**	**4917**	**600**	**600**	**600**
Oilseed Rape - landbank 1:4 rotation	**ha**	**0**	**3936**	**3936**	**3933**	**3933**	**3933**	**39333**	**19667**	**2400**	**2400**	**2400**
Bioenergy Park - Radius Absolute.		Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Digestate Biofertilizer (27.5m3/ha)	**km**	**#DIV/0!**	**1.30**	**0.92**	**0.81**	**0.92**	**1.11**	**4.11**	**5.57**	**1.41**	**1.01**	**0.77**
Oil seed Rape Land under crop	**km**	**0.00**	**1.77**	**1.77**	**1.77**	**1.77**	**1.77**	**5.59**	**3.96**	**1.38**	**1.38**	**1.38**
Oilseed Rape - landbank 1:4 rotation	**km**	**0.00**	**3.54**	**3.54**	**3.54**	**3.54**	**3.54**	**11.19**	**7.91**	**2.76**	**2.76**	**2.76**

Appendix 1.4 Anaerobic Digester Feedstock Calculations - Integration Matrix ‘ ADFSCal’ Part (1)

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Characteristics and operational parameters of agricultural waste digesters Steffen et al 1998

Extrapolated to give: x= 1000 kg biomass or 1 tonne of Biomass

Feed Stock	Total Solids TS%	Volatile solids (% of TS)	Volatile Solids Kg [Cal- per x kg of Biomass]	C:N Ratio	Biogas Yield M3/kg VS	Retention time (days)	CH4 content %	Biogas Yield M3 / 1t of Biomass	CH4 Yield M3 in 1t of Biomass	Tonnes Of Methane	GWP= tCO2	Biogas m3@70% methane
Pig Slurry	5.5	75	41.25	3 to 10	0.375	30	75	15	11.60	0.011	0.200	14
Cow Slurry	8.5	80	68	6 to 20	0.25	25	65	17	11.05	0.012	0.219	18
Food Remains	10	80	80	not Avail	0.55	15	75	44	33.00	0.032	0.568	41
Sewage Sludge	*12*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*22.5*	65	*17.5*	11.38	0.013	0.226	19
Glycerin	*1*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*70*	*838*	586.60	0.601	10.815	838
Chicken Slurry	20	75	150	3 to 10	0.475	30	70	71	49.88	0.051	0.920	71
Whey	3	87.5	26.25	not Avail	0.875	6.5	70	23	16.08	0.016	0.296	23
Leaves	80	90	720	30 to 80	0.2	14	55	144	79.20	0.103	1.858	183
Wood Shavings	80	95	760	511	0.2	30	55	152	83.60	0.109	1.962	193
Straw	70	90	630	90	0.4	30	55	252	138.60	0.181	3.252	321
Garden Waste	65	90	585	100 to 150	0.35	19	55	205	112.61	0.147	2.643	261

Table1 Median values

Characteristics and operational parameters of agricultural waste digesters Steffen et al 1998

Extrapolated to give: x= 1000 kg biomass or 1 tonne of Biomass

Feed Stock	Total Solids TS%	Volatile solids (% of TS)	Volatile Solids Kg [Cal- per x kg of Biomass]	C:N Ratio	Biogas Yield M3/kg VS	Retention time (days)	CH4 content %	Biogas Yield M3 / 1t of Biomass	CH4 Yield M3 in 1t of Biomass	Tonnes Of Methane	GWP= tCO2	Biogas m3@70% methane
Pig Slurry	3	70	21	3 to 10	0.25	30	70	5	3.68	0.004	0.068	5
Cow Slurry	5	75	37.5	6 to 20	0.2	25	55	7.5	4.13	0.005	0.097	10
Food Remains	10	80	80	not Avail	0.5	15	70	40	28.00	0.029	0.516	40
Sewage Sludge	*12*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*22.5*	*65*	*17.5*	11.38	0.013	0.226	19
Glycerin	*1*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*70*	*838*	586.60	0.601	10.815	838
Chicken Slurry	10	70	70	3 to 10	0.35	30	60	25	14.70	0.018	0.316	29
Whey	1	80	8	not Avail	0.8	6.5	60	6	3.84	0.005	0.083	7
Leaves	80	90	720	30 to 80	0.1	14	55	72	39.60	0.052	0.929	92
Wood Shavings	80	95	760	511	0.1	30	55	76	41.80	0.054	0.981	97
Straw	70	90	630	90	0.35	30	55	220.5	121.28	0.158	2.846	281
Garden Waste	60	90	540	100 to 150	0.2	19	55	108	59.40	0.077	1.394	137

Table2 Least values taken from Steffen et al table

Characteristics and operational parameters of agricultural waste digesters Steffen et al 1998

Extrapolated to give: x= 1000 kg biomass or 1 tonne of Biomass

Feed Stock	Total Solids TS%	Volatile solids (% of TS)	Volatile Solids Kg [Cal- per x kg of Biomass]	C:N Ratio	Biogas Yield M3/kg VS	Retention time (days)	CH4 content %	Biogas Yield M3 / 1t of Biomass	CH4 Yield M3 in 1t of Biomass	Tonnes Of Methane	GWP= tCO2	Biogas m3@70% methane
Pig Slurry	8	80	64	3 to 10	0.5	30	80	32	25.60	0.023	0.413	28
Cow Slurry	12	85	102	6 to 20	0.3	25	75	30.6	22.95	0.022	0.395	29
Food Remains	10	80	80	not Avail	0.6	15	80	48	38.40	0.034	0.619	42
Sewage Sludge	*12*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*22.5*	*65*	*17.5*	11.38	0.013	0.226	19
Glycerin	*1*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*not Avail*	*70*	*838*	586.60	0.601	10.815	838
Chicken Slurry	30	80	240	3 to 10	0.6	30	80	144	115.20	0.103	1.858	126
Whey	5	95	47.5	not Avail	0.95	6.5	80	45	36.10	0.032	0.582	39
Leaves	80	90	720	30 to 80	0.3	14	55	216	118.80	0.155	2.788	275
Wood Shavings	80	95	760	511	0.3	30	55	228	125.40	0.163	2.943	290
Straw	70	90	630	90	0.45	30	55	283.5	155.93	0.203	3.659	361
Garden Waste	70	90	630	100 to 150	0.5	19	55	315	173.25	0.226	4.065	401

Table3 Highest values taken from Steffen et al table

Appendix 1.4 Anaerobic Digester Feedstock Calculations - Integration Matrix ' ADFSCal' Part (2)

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Characteristics and operational parameters of agricultural waste digesters Steffen et al 1998

Extrapolated to give:

Feed Stock	MJ equivalent /1t of Biomass	L petrol Equivalent/ 1t of Biomass	TOE Tonne of Oil Equivalent / 1t of Biomass	Electrical Energy Generated @30% Conversion Methane KWh	CHP Elect KWh	CHP Thermal KWh	Electrical kWh Parasitic Demand / tonne of biomass	Available Electrical kWh / tonne biomass	Thermal kWh Parasitic Demand / tonne of biomass	Available Thermal kWh / tonne biomass	% Fibre / 1T of biomass	%Liquor /1T of biomass
Pig Slurry	289	9	0.0069	25	38	43	4	34	13	30	2.75	97.25
Cow Slurry	366	11	0.0087	31	48	55	5	43	16	38	4.25	95.75
Food Remains	821	25	0.0196	70	107	123	11	96	37	86	5.00	95.00
Sewage Sludge	377	11	0.0090	32	49	57	5	44	17	40	6.00	94.00
Glycerin	16760	511	0.4003	1425	2179	2514	218	1961	754	1760	0.50	99.50
Chicken Slurry	1425	43	0.0340	121	185	214	19	167	64	150	10.00	90.00
Whey	459	14	0.0110	39	60	69	6	54	21	48	1.50	98.50
Leaves	3665	112	0.0875	312	477	550	48	429	165	385	40.00	60.00
Wood Shavings	3869	118	0.0924	329	503	580	50	453	174	406	40.00	60.00
Straw	6415	196	0.1532	545	834	962	83	751	289	674	35.00	65.00
Garden Waste	5212	159	0.1245	443	678	782	68	610	235	547	32.50	67.50

Table1 Median values

Characteristics and operational parameters of agricultural waste digesters Steffen et al 1998

Extrapolated to give:

Feed Stock	MJ equivalent /1t of Biomass	L petrol Equivalent/ 1t of Biomass	TOE Tonne of Oil Equivalent / 1t of Biomass	Electrical Energy Generated @30% Conversion Methane KWh	CHP Elect KWh	CHP Thermal KWh	Electrical kWh Parasitic Demand / tonne of biomass	Available Electrical kWh / tonne biomass	Thermal kWh Parasitic Demand / tonne of biomass	Available Thermal kWh / tonne biomass	% Fibre / 1T of biomass	%Liquor /1T of biomass
Pig Slurry	105	3	0.0025	9	14	16	1	12	5	11	1.50	98.50
Cow Slurry	191	6	0.0046	16	25	29	2	22	9	20	2.50	97.50
Food Remains	800	24	0.0191	68	104	120	10	94	36	84	5.00	95.00
Sewage Sludge	377	11	0.0090	32	49	57	5	44	17	40	6.00	94.00
Glycerin	16760	511	0.4003	1425	2179	2514	218	1961	754	1760	0.50	99.50
Chicken Slurry	572	17	0.0137	49	74	86	7	67	26	60	5.00	95.00
Whey	149	5	0.0036	13	19	22	2	17	7	16	0.50	99.50
Leaves	1833	56	0.0438	156	238	275	24	214	82	192	40.00	60.00
Wood Shavings	1935	59	0.0462	164	251	290	25	226	87	203	40.00	60.00
Straw	5613	171	0.1341	477	730	842	73	657	253	589	35.00	65.00
Garden Waste	2749	84	0.0657	234	357	412	36	322	124	289	30.00	70.00

Table2 Least values taken from Steffen et al table

Characteristics and operational parameters of agricultural waste digesters Steffen et al 1998

Extrapolated to give:

Feed Stock	MJ equivalent /1t of Biomass	L petrol Equivalent/ 1t of Biomass	TOE Tonne of Oil Equivalent / 1t of Biomass	Electrical Energy Generated @30% Conversion Methane KWh	CHP Elect KWh	CHP Thermal KWh	Electrical kWh Parasitic Demand / tonne of biomass	Available Electrical kWh / tonne biomass	Thermal kWh Parasitic Demand / tonne of biomass	Available Thermal kWh / tonne biomass	% Fibre / 1T of biomass	%Liquor /1T of biomass
Pig Slurry	560	17	0.0134	48	73	84	7	66	25	59	4.00	96.00
Cow Slurry	571	17	0.0136	49	74	86	7	67	26	60	6.00	94.00
Food Remains	840	26	0.0201	71	109	126	11	98	38	88	5.00	95.00
Sewage Sludge	377	11	0.0090	32	49	57	5	44	17	40	6.00	94.00
Glycerin	16760	511	0.4003	1425	2179	2514	218	1961	754	1760	0.50	99.50
Chicken Slurry	2520	77	0.0602	214	328	378	33	295	113	265	15.00	85.00
Whey	790	24	0.0189	67	103	118	10	92	36	83	2.50	97.50
Leaves	5498	168	0.1313	467	715	825	71	643	247	577	40.00	60.00
Wood Shavings	5804	177	0.1386	493	754	871	75	679	261	609	40.00	60.00
Straw	7216	220	0.1724	613	938	1082	94	844	325	758	35.00	65.00
Garden Waste	8018	245	0.1915	682	1042	1203	104	938	361	842	35.00	65.00

Table3 Highest values taken from Steffen et al table

Appendix 1.5 Integration Matrix Anaerobic Digestion Capital ' ADCap'

Anaerobic Digestion Capital Costs

Capital Costs in Euro				Operation Costs in Euro			
	Feed Stock m3/year	2008			Feed Stock m3/year	2008	
Integration Live	0	€ 0		Integration Live	0	€	-
Scenario 1	15000	€ 2,560,234		Scenario 1	15000	€	399,434
Scenario 2	7600	€ 1,718,535		Scenario 2	7600	€	240,415
Scenario 3	6000	€ 1,496,123		Scenario 3	6000	€	201,513
Scenario 4	7700	€ 1,731,757		Scenario 4	7700	€	242,773
Scenario 5	11000	€ 2,134,548		Scenario 5	11000	€	316,858
Scenario 6	150000	€ 9,875,967		Scenario 6	150000	€	2,229,178
Scenario 7	278000	€ 14,180,149		Scenario 7	278000	€	3,533,667
Scenario 8	17500	€ 2,802,403		Scenario 8	17500	€	448,161
Scenario 9	9000	€ 1,897,622		Scenario 9	9000	€	272,766
Scenario 10	5300	€ 1,391,170		Scenario 10	5300	€	183,685

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Figure 5.7 Equation to calculate capital and running costs

Running c $y = 1.8*0.124 \times \chi^{0.746}$

Figure 5.7 Equation to calculate capital and running costs. (Poliafico, 2007)

Where χ is the cubic meters of feedstock.

y is the cost in '000 Euros

Reference
ANAEROBIC DIGESTION:
DECISION SUPPORT SOFTWARE
Submitted by: Project Supervisor:
Marco Poliafico, M Eng Dr. Jerry D. Murphy

Appendix 1.6 Anaerobic Digestion – Scenario 1 (representative sample of extrapolation of feedstock Scenarios) Integration Matrix' ADScen'

Scenario 1 Median Value from Steffen et al report

Feed Stock	Total Solids TS%	Feed Stock Tonnes	CH4 content %	Biogas Yield M3 /tonne	Biogas Yield M3	CH4 Yield M3	Tonnes Of Methane	GWP= tCO_2	Biogas m3@70% methane	MJ Energy equivalent	TOE Tonne of Oil Equivalent	Electrical Energy @30% Conversion kWh	CHP Elect kWh	CHP Thermal kWh
Glycerin	*1*	*295*	70	*838*	*247378*	173164	177	3193	247378	4947552	118	420542	643182	742133
Pig Slurry	6	*9600*	75	15	*144000*	108000	103	1858	134400	2688000	64	228480	349440	403200
Cow Slurry	9	*3000*	65	17	*51000*	33150	37	658	54923	1098462	26	93369	142800	164769
Food Remains	10	*0*	75	44	*0*	0	0	0	0	0	0	0	0	0
Sewage Sludge	*12*	*2105*	65	*18*	*36829*	23939	26	475	39662	793235	19	67425	103121	118985
Chicken Slurry	20	*0*	70	71	*0*	0	0	0	0	0	0	0	0	0
Whey	3	*0*	70	23	*0*	0	0	0	0	0	0	0	0	0
Leaves	80	*0*	55	144	*0*	0	0	0	0	0	0	0	0	0
Wood Shavings	80	*0*	55	152	*0*	0	0	0	0	0	0	0	0	0
Straw	70	*0*	55	252	*0*	0	0	0	0	0	0	0	0	0
Garden Waste	65	*0*	55	205	*0*	0	0	0	0	0	0	0	0	0
Total Tonnes Feedstock		14705	640	1779		338253	344	6185	476362	9527248	228	809816	1238542	1429087

Feed Stock	Electrical kWh Parasitic Demand	Available Electrical kWh	Thermal kWh Parasitic Demand	Available Thermal kWh	% Fibre / 1t of biomass	%Liquor /1t of biomass	Tonnes of Biofertilizer to spread	Gate fee Income Potential	Fertilizer Income Potential	Total Income Potential	Land Bank (ha) Required *(27.3t/ha)*
Glycerin	64318	578864	222640	519493	1	100	294	0	4406	4406	11
Pig Slurry	34944	314496	120960	282240	3	97	9336	0	140040	140040	342
Cow Slurry	14280	128520	49431	115338	4	96	2873	0	43088	43088	105
Food Remains	0	0	0	0	5	95	0	0	0	0	0
Sewage Sludge	10312	92808	35696	83290	6	94	1978	210450	29673	240123	72
Chicken Slurry	0	0	0	0	10	90	0	0	0	0	0
Whey	0	0	0	0	2	99	0	0	0	0	0
Leaves	0	0	0	0	40	60	0	0	0	0	0
Wood Shavings	0	0	0	0	40	60	0	0	0	0	0
Straw	0	0	0	0	35	65	0	0	0	0	0
Garden Waste	0	0	0	0	33	68	0	0	0	0	0
Total Tonnes Feedstock	123854	1114688	428726	1000361	178	923	14480	210450	217207	427657	530

Appendix 1.7 Biodiesel Capital Costs Integration matrix ' BD Cap'

Capital Costs for Oil press and Biodiesel plant equipment	£	€	Exchange rate 9/4/08
Oil Press System	Cost	Cost	1.227
Screen	2000	2454	
Seed cleaner	40000	49080	
KEK PO 500 Press x 2	94000	115338	
AMA VERSIS1000 pressure leaf filter	40000	49080	
Siemens controls	19000	23313	
Compressor	10000	12270	
System Fully Automated	24000	29448	
Total Cost for 0.36 t/hr oil press system	229000	280983	
Source:sales@feedservices.co.uk) quotation Feb 2008			
	Back to the Index		
Biodiesel: Twin Auto FuelMa 8400 L/Day (24hrs)			
FuelMatic Project site survey and installation definition	750	920.25	
Pre Heat Module - Input Oil 1300 liters	9500	11656.5	
FuelMatic Twin Reactor Tanks	23800	29202.6	
FuelMatic Glycerin Separator	7700	9447.9	
FuelMatic Biodiesel Purification Module Twin Column 900l/h	18500	22699.5	
FuelMatic PLC Control Panel Twin System	38000	46626	
Base plate for Twin Reactor FuelMatic	5750	7055.25	
Twin FuelMatic Installation and Site work pre commissioning	6500	7975.5	
Twin FuelMatic Commissioning and First Year Maintenance	5500	6748.5	
Total Cost for 0.38 t/hr biodiesel system	116000	142332	
Dave Abbott (dave@greenfuels.co.uk) quotation Dec 2007			
Biodiesel for oil seed rape - total capital cost	345000	423315	

Appendix 1.8 Biodiesel Business Case – Integration Matrix 'BD Bus'

Costings on Biodiesel Feed service and Greenfuel (combination) 0.36t/hr						2592 t/year
Back to the Index	Option 1 (OSR € 300/t)		Option 2 (OSR € 450/t)		Option 3 (OSR € 500/t)	
Capital	ESB	Bioenergy Park Supply	ESB	Bioenergy Park Supply	ESB	Bioenergy Park Supply
Equipment	423315	423315	423315	423315	423315	423315
Land and Buildings (estimate)	200000	200000	200000	200000	200000	200000
Running Capital	100000	100000	100000	100000	100000	100000
Total	723315	723315	723315	723315	723315	723315
Annual capacity - Biodiesel Tonnes	2592	2592	2592	2592	2592	2592
Oilseed Rape 2592 t x3 (3 tonnes OSR = 1 t biodiesel) at €300 or €450 or €500/ t	2332800	2332800	3499200	3499200	3888000	3888000
Electricity:202.58 kWh/t @ 0.15 € x 2592						
Thermal energy:202.58 kWh/t @ 0.15 € x 2592	78763	0	78763	0	78763	0
Wages (Industrial average) 6x€400*50	120000	120000	120000	120000	120000	120000
Methanol @ € 0.60/ l Added at 28 l/t (Thamiriroj's 2007)	43546	43546	43546	43546	43546	43546
5 Year depreciation	84663	84663	84663	84663	84663	84663
Interest on Capital @5% for 5 years	36166	36166	36166	36166	36166	36166
Maintenance and office (est.)	20000	20000	20000	20000	20000	20000
20 year depreciation	21166	21166	21166	21166	21166	21166
Operating Cost	2737103	2658340	3903503	3824740	4292303	4213540
Break even price / tonne	1055.98	1025.59	1505.98	1475.59	1655.98	1625.59
Biodiesel Income @ €880/tonne	2280960	2280960	2280960	2280960	2280960	2280960
Glycerol price €90/ tonne	23328	23328	23328	23328	23328	23328
Rapeseed Cake price € 170 / t	881280	881280	881280	881280	881280	881280
Total Income	3185568	3185568	3185568	3185568	3185568	3185568
Net Income	448465	527228	-717935	-639172	-1106735	-1027972
Margin %	14	17	-23	-20	-35	-32
MOT Relief Realized	**Option 1**	OSR@€300	**Option 2**	OSR@€450	**Option 3**	OSR@€500
Add MOTRelief €0.368/ L or € 323.84/t	839393	839393	839393	839393	839393	839393
Biodiesel Income @ €880/tonne	2280960	2280960	2280960	2280960	2280960	2280960
Glycerol price €90/ tonne	23328	23328	23328	23328	23328	23328
Rapeseed Cake price € 170 / t	881280	881280	881280	881280	881280	881280
Total Income	4024961	4024961	4024961	4024961	4024961	4024961
Net Income	1287858	1366621	121458	200221	-267342	-188579
Margin %	32	34	3	5	-7	-5
Land Bank Requirement						
Hectares of set crops 1)	864	864	864	864	864	864
Land bank required ha 2)	3456	3456	3456	3456	3456	3456
Straw yield tonnes @ 1:0.98 Seed/straw	2540.16	2540.16	2540.16	2540.16	2540.16	2540.16
	1) Area under cultivation			2) Crop set 1: 4 year rotation		

Appendix 1.9 Biodiesel Scenarios considered - Integration Matrix ' BD Scen' part (1)

Costings on Biodiesel Feed service and Greenfuel (combination) 0.36t/hr											
Back to the Index	Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Capital											
Equipment	423315	423315	423315	423315	423315	423315	4233150	2116575	423315	423315	423315
Land and Buildings (estimate)	200000	200000	200000	200000	200000	200000	2000000	200000	200000	200000	200000
Running Capital	100000	100000	100000	100000	100000	100000	1000000	100000	100000	100000	100000
Total	€ 723,315	€ 723,315	€ 723,315	€ 723,315	€ 723,315	€ 723,315	€ 7,233,150	€ 2,416,575	€ 723,315	€ 723,315	€ 723,315
Annual capacity - Biodiesel Tonnes	0	2952	2952	2952	2952	2952	29500	14750	1800	1800	1800
Oilseed Rape Cost (3 tonnes OSR = 1 t biodiesel)	0	4428000	4428000	4428000	4428000	4428000	44250000	22125000	2700000	2700000	2700000
Electricity ESB (78.78 kWh/t)	0	34884	34884	34884	34884	34884	348602	174301	21271	21271	21271
Thermal energy (123.8 kWh/t)	0	43855	43855	43855	43855	43855	438252	219126	26741	26741	26741
Wages (Industrial avg) 6x€400*50	120000	120000	120000	120000	120000	120000	1200000	600000	120000	120000	120000
Methanol (At 11% addition)	0	154242	154242	154242	154242	154242	1541375	770688	94050	94050	94050
5 Year depreciation	84663	84663	84663	84663	84663	84663	846630	423315	84663	84663	84663
Interest on Capital @5% for 5 years	36166	36166	36166	36166	36166	36166	361658	120829	36166	36166	36166
Maintenance and office (est.)	20000	20000	20000	20000	20000	20000	200000	200000	20000	20000	20000
20 year depreciation	21166	21166	21166	21166	21166	21166	211658	105829	21166	21166	21166
Operating Cost	€ 281,995	€ 4,942,975	€ 4,942,975	€ 4,942,975	€ 4,942,975	€ 4,942,975	€ 49,398,174	€ 24,739,087	€ 3,124,056	€ 3,124,056	€ 3,124,056
Bioenergy Park Operating Costs	€ 281,995	€ 4,864,237	€ 4,864,237	€ 4,864,237	€ 4,864,237	€ 4,864,237	€ 48,611,320	€ 24,345,660	€ 3,076,045	€ 3,076,045	€ 3,076,045
Bioenergy Park Break even price	#DIV/0!	€ 1,648	€ 1,648	€ 1,648	€ 1,648	€ 1,648	€ 1,648	€ 1,651	€ 1,709	€ 1,709	€ 1,709
Bioenergy Park Biodiesel Income	€ -	€ 2,597,760	€ 2,597,760	€ 2,597,760	€ 2,597,760	€ 2,597,760	€ 25,960,000	€ 12,980,000	€ 1,584,000	€ 1,584,000	€ 1,584,000
Bioenergy Park Rapeseed Cake Income	0	1003680	1003680	1003680	1003680	1003680	10030000	5015000	612000	612000	612000
Total Income	0	3601440	3601440	3601440	3601440	3601440	35990000	17995000	2196000	2196000	2196000
Net Income	-281995	-1262797	-1262797	-1262797	-1262797	-1262797	-12621320	-6350660	-880045	-880045	-880045
Margin - at Bioenergy Park Price	#DIV/0!	-35.06	-35.06	-35.06	-35.06	-35.06	-35.07	-35.29	-40.07	-40.07	-40.07
Net Profit at Bioenergy Price	-€ 281,995	-€ 1,262,797	-€ 1,262,797	-€ 1,262,797	-€ 1,262,797	-€ 1,262,797	-€ 12,621,320	-€ 6,350,660	-€ 880,045	-€ 880,045	-€ 880,045

Appendix 1.9 Biodiesel Scenarios considered - Integration Matrix ' BD Scen' part (2)

Costings on Biodiesel Feed service and Greenfuel (combination) 0.36t/hr											
Back to the Index	Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Oil Press Production Electrical demand (kWh)	0	148663	148663	148663	148663	148663	1485620	742810	90648	90648	90648
Biodiesel Production Electrical demand (kWh)	0	83896	83896	83896	83896	83896	838390	419195	51156	51156	51156
Total Electrical Parasitic Demand (kWh)	0	232559	232559	232559	232559	232559	2324010	1162005	141804	141804	141804
Oil Press Production Thermal demand (kWh)	0	233503	233503	233503	233503	233503	2333450	1166725	142380	142380	142380
Biodiesel Production Thermal demand (kWh)	0	131954	131954	131954	131954	131954	1318650	659325	80460	80460	80460
Total Thermal Parasitic Demand (kWh)	0	365458	365458	365458	365458	365458	3652100	1826050	222840	222840	222840
Glycerol Produced (tonnes) Feedstock for AD	0	295	295	295	295	295	2950	1475	180	180	180
Reduced tCO_2 emissions	0	7114	7114	7114	7114	7114	71095	35548	4338	4338	4338
GJ of energy	0	85195	85195	85195	85195	85195	851370	425685	51948	51948	51948
TOE	0	2037	2037	2037	2037	2037	20355	10178	1242	1242	1242
No of Car fueled per year	0	1529	1529	1529	1529	1529	15281	7641	932	932	932
Electrical generation potential MWh	0	7085	7085	7085	7085	7085	70800	35400	4320	4320	4320
Land Bank Requirement	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
Hectares of set crops (set area per yr)	0	984	984	984	984	984	9833	4917	600	600	600
Land bank required ha (1 in 4 rotation)	0	3936	3936	3936	3936	3936	39333	19667	2400	2400	2400
Straw yield tonnes @ 1:0.98 Seed/straw	0	2893	2893	2893	2893	2893	28910	14455	1764	1764	1764

1) Crop set rotation not considered
2) Crop set 1: 4 year rotation

Appendix 1.10 Straw Pellets Capital - Integration Matrix 'SPCap'

Eko-Press Process	KWh/t	Price €	Soma Quote	KHz/t	KWh/t	Additional Plant Requirement
Crusher	11	6500	Crusher			
Hammer Mill and Cyclone	11	7500	Hammer Mill			
Belt conveyor	1.5	4300	Belt conveyor			
Impulse dust filter	1.1	18000	**Impulse dust filter**	1.1	1.1	18000
Cyclone	0.75	4200	**Cyclone**	0.75	0.75	4200
Rotary drum screen	1.5	4750	Rotary drum screen			
Magnet separator		1950	Magnet separator			
Bucket conveyor	1.5	3750	Bucket conveyor			
Buffer	0.5	2650	buffer			
Pellet press	92.95	65000	pellet press			
Bucket conveyor	1.5	3750	Bucket conveyor			
Cooler	1.1	21250	**Cooler**	1.1	1.1	21250
Grade screening	1.5	10650	**Grade screening**	1.5	1.5	10650
Fan	11	3750	**Fan**	11	11	3750
Screw conveyor	1.1	3750	**Screw conveyor**	1.1	1.1	3750
Dust filter net		21250	**Dust filter net**			21250
Bucket conveyor	1.5	3750	**Bucket conveyor**	1.5	1.5	3750
Buffer	0.5	2650	**buffer**	0.5	0.5	2650
Weighing a packing	3.5	35000	**Bulk Storage**			35000
Electrical cabinet		7350	Electrical cabinet			
Steel Frame		18760	**Quoted Elect demand**	165	165	
Fit and commission		30000	Fit and commission			
			Quoted cost	**250000**	**250000**	**250000**
Cost in Euro		**280510**	**Additional +Quote**			**374250**
Electrical Demand /hr	143.5		Electrical Demand /hr	183.55	183.55	
Expected Out Put t/h	1		Expected Out Put t/h	2.5	1.5	
Electrical Demand /t	**143.5**		**Electrical Demand /t**	**73.42**	**122.37**	

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Soma Original Quote - Jan 2008		
Crusher		
Hammer Mill		
Belt conveyor		
Rotary drum screen		
Magnet separator		
Bucket conveyor		
buffer		
pellet press		
Bucket conveyor		
Electrical cabinet		
Fit and commission		
	Euro	
Quoted cost	250000	250000
Electrical Demand kWh	165	
Expected Out Put tonne/hour	2.5	
Electrical Demand kWh/tonne	**66**	

Hours	Days	Weeks	Total Hours Available	Tonnes Produced	Electrical Demand MW/h
16	6	50	4800	7200	528.624
24	5	50	6000	9000	660.78
24	7	50	8400	12600	925.092

a) Electrical demand per hour = 183.55 kWh
b) Expected output = 2.5 t/hr
c) Electrical energy demand per tonne = 73.42 t/hr

Appendix 1.11 Straw Pellet Business Case - Integration Matrix ' SPBus'

Costings on Soma (combination) 1 Pellet Press system						
Back to the Index	Option 1		Option 2		Option 3	
Capital	ESB	Bioenergy Park Supply	ESB	Bioenergy Park Supply	ESB	Bioenergy Park Supply
Equipment	374250	374250	374250	374250	374250	374250
Land and Buildings	200000	200000	200000	200000	200000	200000
Running Capital	100000	100000	100000	100000	100000	100000
Total	674250	674250	674250	674250	674250	674250
Feed Stock 2.5t/hr x16x6x60 12000tonns@60 euro/tonne	474000	474000	720000	720000	1260000	1260000
Electricity:73.4 kWh/t @ 0.15 € x 12000	86979	0	132120	0	231210	0
Wages (Industrial average)	90000	90000	90000	90000	135000	135000
5 Year depreciation (equipment)	74850	74850	74850	74850	74850	74850
Interest on Capital @5% for 5 years	33712.5	33712.5	33712.5	33712.5	33712.5	33712.5
Maintenance and office	20000	20000	20000	20000	20000	20000
20 year depreciation (equipment)	18712.5	18712.5	18712.5	18712.5	18712.5	18712.5
Operating Cost	798254	711275	1089395	957275	1773485	1542275
Tonnage	7900	7900	12000	12000	21000	21000
Break even price	101.04	90.03	90.78	79.77	84.45	73.44
Balcas current price / tonne	210	210	210	210	210	210
ESB @ 6.5euro /GJ (15GJ (9%aw)	97.5	97.5	97.5	97.5	97.5	97.5
Margin - at Balcas Price	108	133	131	163	149	186
Margin at ESB price - delivery not inc.	-4	8	7	22	15	33
Net Profit at Balcas price	**860746**	**947725**	**1430605**	**1562725**	**2636515**	**2867725**
Net Profit at ESB price	**-28004**	**58975**	**80605**	**212725**	**274015**	**505225**

Appendix 1.12 Straw Pellet Scenarios 1-10 - Integration Matrix ' SPScen' Part (1)

Bioenergy Park Capital and Operating Costs - Line Capacity 12000 tonne/ annum											
Back to the Index	Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Tonnage Produced	**0**	**12000**	**12000**	**12000**	**12000**	**12000**	**120000**	**120000**	**7200**	**7200**	**7200**
Capital	Bioenergy Park Supply	Bioenergy Park Supply	Bioenergy Park Supply	Bioenergy Park Supply	Bioenergy Park Supply	Bioenergy Park Supply	Bioenergy Park Supply	Bioenergy Park Supply	Bioenergy Park Supply	Bioenergy Park Supply	Bioenergy Park Supply
Equipment	374250	374250	374250	374250	374250	374250	3742500	3742500	374250	374250	374250
Land and Buildings	200000	200000	200000	200000	200000	200000	2000000	2000000	200000	200000	200000
Running Capital	100000	100000	100000	100000	100000	100000	1000000	1000000	100000	100000	100000
Total Capital Costs	**674250**	**674250**	**674250**	**674250**	**674250**	**674250**	**6742500**	**6742500**	**674250**	**674250**	**674250**
Cost Per Tonne of Feed Stock	65	65	65	65	65	65	65	65	65	65	65
Feed Stock Total Cost	0	780000	780000	780000	780000	780000	7800000	7800000	468000	468000	468000
Electricity:73.4 kWh/t @ € 0.15 € (ESB)	*0*	*132120*	*132120*	*132120*	*132120*	*132120*	*1321200*	*1321200*	*79272*	*79272*	*79272*
Wages (Industrial average)	90000	90000	90000	90000	90000	90000	900000	900000	90000	90000	90000
5 Year depreciation (equipment)	74850	74850	74850	74850	74850	74850	748500	748500	74850	74850	74850
Interest on Capital @5% for 5 years	33712.5	33712.5	33712.5	33712.5	33712.5	33712.5	337125	337125	33712.5	33712.5	33712.5
Maintenance and office	20000	20000	20000	20000	20000	20000	200000	200000	20000	20000	20000
20 year depreciation (equipment)	18712.5	18712.5	18712.5	18712.5	18712.5	18712.5	187125	187125	18712.5	18712.5	18712.5
Operating Cost - ESB Charge	237275	1149395	1149395	1149395	1149395	1149395	11493950	11493950	784547	784547	784547
Bioenergy Park Operating Costs	**237275**	**1017275**	**1017275**	**1017275**	**1017275**	**1017275**	**10172750**	**10172750**	**705275**	**705275**	**705275**
Bioenergy Park Break even price	#DIV/0!	95.78	95.78	95.78	95.78	95.78	95.78	95.78	108.96	108.96	108.96
Bioenergy Park Pellet price / tonne	210	210	210	210	210	210	210	210	210	210	210
Margin - at Bioenergy Park Price	#DIV/0!	119	119	119	119	119	119	119	93	93	93
Net Profit at Bioenergy Price	**-€ 237,275**	**€ 1,370,605**	**€ 1,370,605**	**€ 1,370,605**	**€ 1,370,605**	**€ 1,370,605**	**€ 13,706,050**	**€ 13,706,050**	**€ 727,453**	**€ 727,453**	**€ 727,453**
Electrical demand to AD (kWh)	0	881040	881040	881040	881040	881040	8810400	8810400	528624	528624	528624

Appendix 1.12 Straw Pellet Scenarios 1-10 - Integration Matrix ' SPScen' Part (2)

Bioenergy Park Capital and Operating Costs - Line Capacity 12000 tonne/ annum

Back to the Index	Integration Live	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Tonnage Produced	0	12000	12000	12000	12000	12000	120000	120000	7200	7200	7200
Output represented in Key Equivalents											
Reduced tCO2 emissions	0	17832	17832	17832	17832	17832	178320	178320	10699.2	10699.2	10699.2
GJ of energy	0	204338.4	204338.4	204338.4	204338.4	204338.4	2043384	2043384	122603.04	122603.04	122603.04
TOE	0	4800	4800	4800	4800	4800	48000	48000	2880	2880	2880
Homes Heated (5.7 t/home/year)	0	2340	2340	2340	2340	2340	23400	23400	1404	1404	1404
Electrical generation potential MWh	0	17040	17040	17040	17040	17040	170400	170400	10224	10224	10224
Land Bank Requirement	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
Hectares of set OSR crops (biodiesel)	0	984	984	984	984	984	9833	4917	600	600	600
Land bank required ha (biodiesel)	0	3936	3936	3936	3936	3936	39333	19667	2400	2400	2400
Rape Straw yield (tonnes) @ 1:0.98 Seed/straw	0	2893	2893	2893	2893	2893	28910	14455	1764	1764	1764
Additional Straw required (tonnes)	0	9107	9107	9107	9107	9107	91090	105545	5436	5436	5436
Additional ha of crops required Wheat/Barley yield 13 t /ha	0	701	701	701	701	701	7007	8119	418	418	418
Land bank required hectares (100% availability of produce)	0	3936	3936	3936	3936	3936	39333	19667	2400	2400	2400

Appendix 1.13 (part 1) **Site Location based on resource availability only**

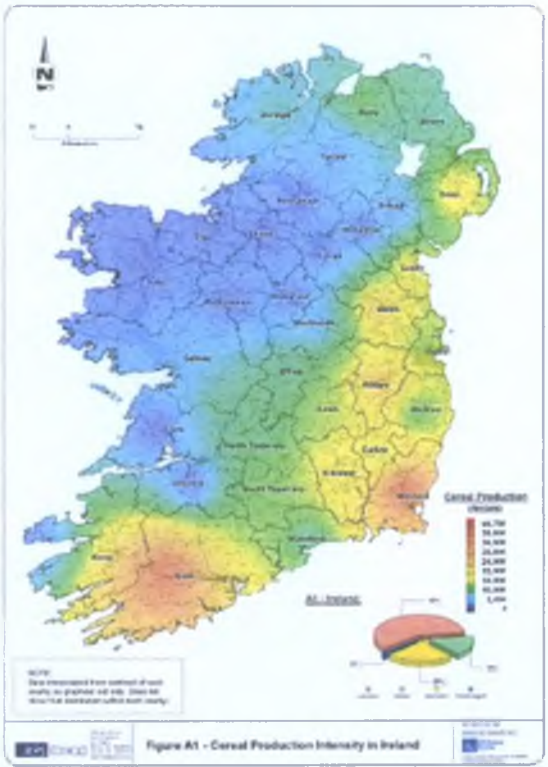


Fig : Spatial distribution of Cereal Production
Source: (SEI-2, 2003),

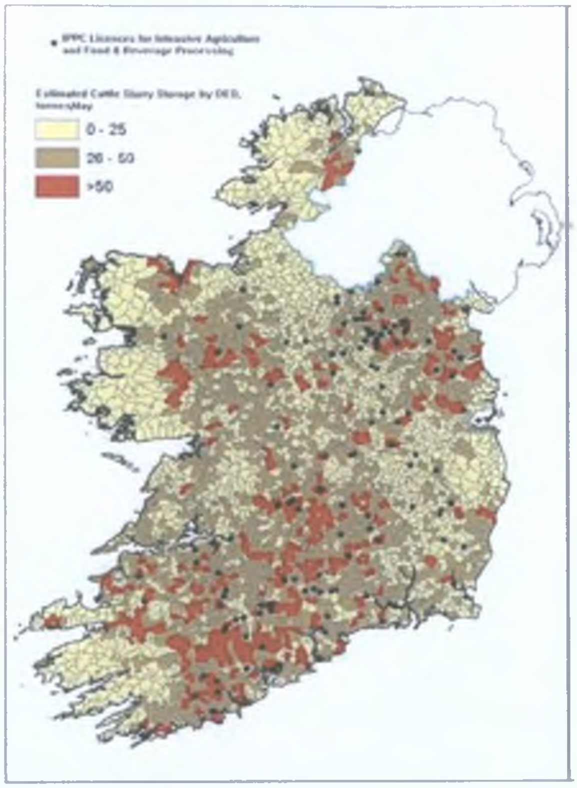


Fig: Spatial distribution of Cattle Slurry and EPA licensed Agriculture and Food Processing Sites
Source: (EPA-1, 2005)

Fig: Decision Support Locating Anaerobic Digestion

Source: (Poliafico, 2007)

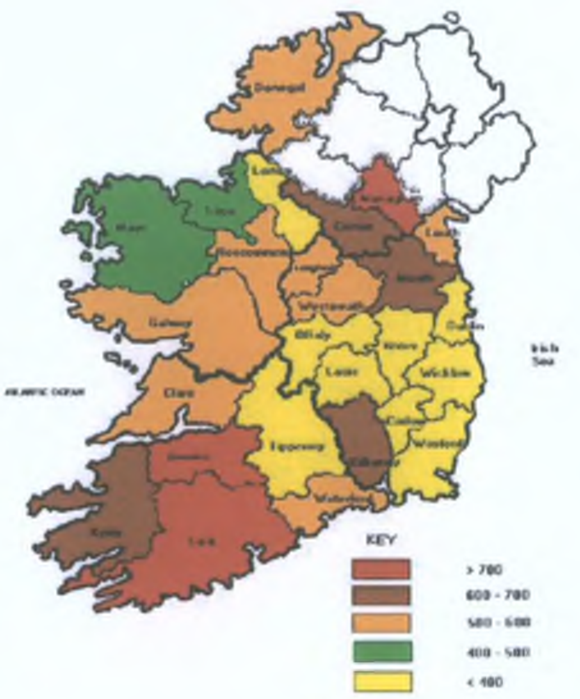


Fig: Regional Weighting for potential sites for CAD. (Fehily, Timoney Report, 1998).
Source: (Mahony, 2002)

Appendix 1.13 (Part 2)

Sow & Pig numbers in 2005 (Teagasc, 2008)				Tillage land by county (Murphy, 2007)			
County	Rating	Total Sow / Pig	Slurry m3/ annum	% of Land Tilled in County	Land Tilled Hectares	Rating	County
Cork	1	180,213	2757259	63	470,307	1	Cork
Cavan	2	181,925	2783453	46	271,586	2	Galway
Tipperary	3	95,463	1460584	63	267,097	3	Tipperary
Waterford	4	57,561	880683	88	204,195	4	Meath
Westmeath	5	44,165	675725	83	195,134	5	Wexford
Longford	6	42,690	653157	92	169,446	6	Waterford
Kilkenny	7	36,660	560898	80	164,427	7	Kilkenny
Limerick	8	30,255	462902	27	146,510	8	Mayo
Laois	9	29,340	448902	79	138,168	9	Westmeath
Wexford	10	28,802	440671	65	128,972	10	Offaly
Kerry	11	27,665	423275	48	127,983	11	Limerick
Meath	12	27,108	414752	68	115,440	12	Kildare
Offaly	13	23,055	352742	53	106,624	13	Wicklow
Monaghan	14	22,200	339660	42	102,929	14	Roscommon
Donegal	15	21,750	332775	21	99,998	15	Donegal
Wicklow	16	19,230	294219	30	94,737	16	Clare
Kildare	17	17,125	262013	20	91,772	17	Kerry
Mayo	18	15,920	243576	46	82,057	18	Sligo
Leitrim	19	14,995	229424	48	81,850	19	Laois
Carlow	20	13,374	204622	56	70,605	20	Monaghan
Roscommon	21	11,130	170289	78	70,018	21	Carlow
Clare	22	7,320	111996	83	67,586	22	Louth
Louth	23	5,800	88740	69	63,580	23	Dublin**
Sligo	24	5,385	82391	59	61,554	24	Longford
Galway	25	3,365	51485	23	43,145	25	Cavan
Dublin**	26	500	7650	3	4,489	26	Leitrim
TOTAL	462	962,996	14733839	** Approx. 20% of Dublin is urban land			

Site location in Ireland based on resource potential for a Bioenergy Park

Tillage – Cork, Galway, Tipperary, Meath, Wexford, Waterford, Kilkenny (Murphy, 2007)
Pigs - Cork, Cavan, Tipperary, Waterford, Westmeath, Longford, Kilkenny (Teagasc, 2008)
CAD - Cork, Cavan, Limerick, Galway, Tipperary and Roscommon (Poliafico, 2007)
CAD - Cork, Limerick, Monaghan, Kilkenny, Meath and Cavan (Mahony, 2002)

Common Counties:

Cork, Galway, Tipperary, Kilkenny and perhaps Meath.

Appendix 1.14

Case Study – to investigate industrial partnership with a Bioenergy Park

Glanbia plc was formed following the merger of two of Ireland's major co-operatives, Avonmore and Waterford in 1998. World wide Glanbia plc employ 3926 people and had a turnover of 2206.57 million euro in 2007. In Ireland, Glanbia Dairies focuses its efforts on the fast moving consumer goods market, operating sectors, fresh dairy products, nutritional beverages, cheese, soups, sauces and spreads. Glanbia Agri-trading operates a network of 61 agribusiness units in Ireland, supplying farming supplies including seed and fertilizer and trading facility for grain. This section of the portfolio forms a key link with its 5700 dairy farmer supply base.

The Glanbia Ballitore dairy is located in Ballitore, County Kildare The site serves two separate Glanbia business entities. The second business is a grain trading operation and agribusiness sales and retail outlet. The Ballitore dairy plant operates a liquid milk processing and packing facility processing more than 200 tonnes of milk per day.

Energy Usage

The energy usage at the plant is approximately 6,000,000 kWh of electricity to power the plant on annual basis. The duty boiler is fired on marked gas and uses an estimated 416,000 liters of oil per annum. The site has two boilers to supply steam heat for processing 24 hours a day, 365 days a year. The boiler ratings are 2800 kg/h and 200 kg/hr with thermal input of 2.406 MW and 2.1 MW respectively. The energy consumption table below provides the actual energy consumption on site for 2006 and 2007 showing a 7% reduction in electrical consumption and a 10% in thermal consumption year on year.

Energy Consumption	kWh 2006	kWh 2007
Ballytore Electricity	5,731,537	5,344,812
Ballytore Oil	4,271,831	3,844,827
	Source Glanbia plc. 12/03/2008	

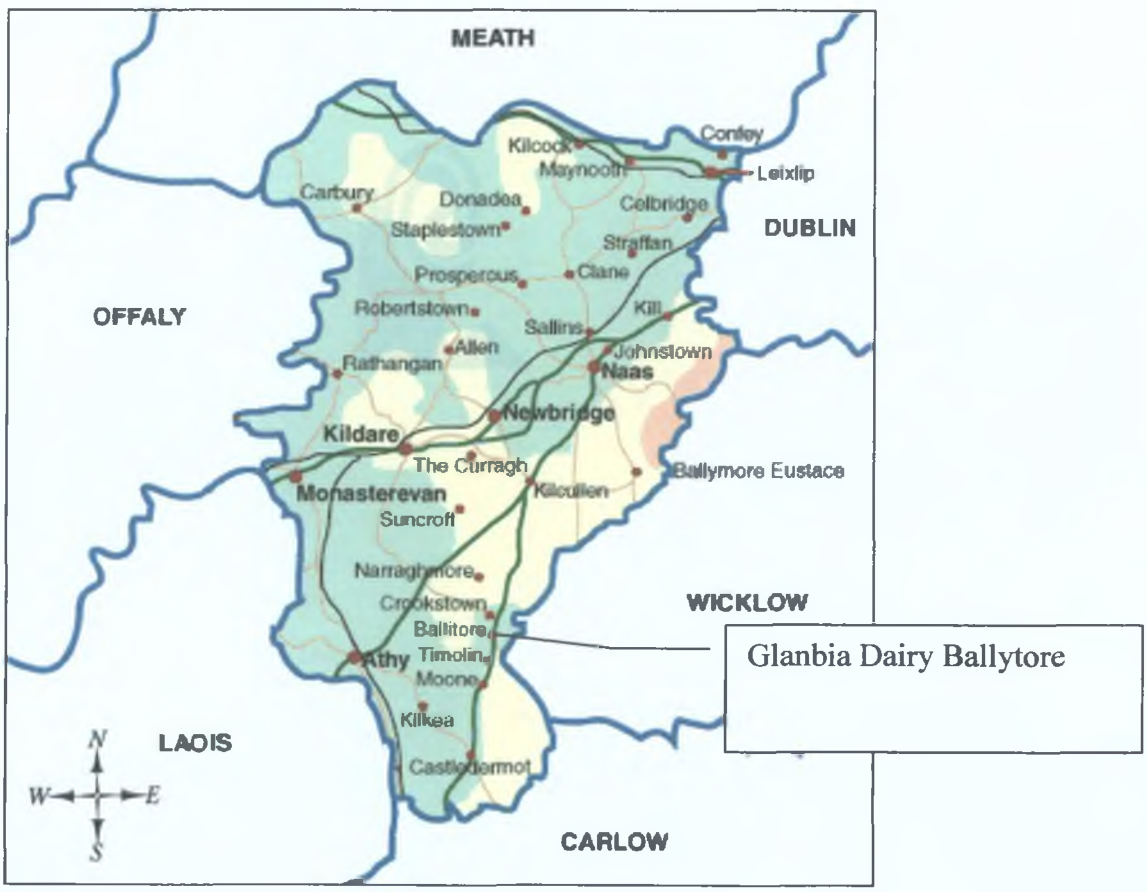
Waste and Waste Waters

The onsite canteen and the maintenance department produce 9.3 m^3 of waste oil annually. This waste is disposed of by a licensed waste contractor. Waste water produced from the plant operations is diverted to the on site waste water treatment plant. The waste water is treated by aerobic oxidation ditch prior to discharge to the River Greese. A volume of 440 m^3 is discharged on a daily basis. Emission limit values has been specified in the Trade Effluent discharge license issued by Kildare County Council. Dairy waste water treatment process generates a sludge waste product. In 2005, Ballytore dairy plant produced 116.6 m^3/ month or cumulatively to 1399.2 tonnes/annum of waste water treatment sludge.

The sludge is processed in accordance with a nutrient management plan, the code of practice of Good Agricultural Practice and other relevant legislation and guide lines. In accordance with the nutrient management plan, a land bank of 86.73 hectares are contracted to Glanbia. 97% of this land is fit for use with respect to land spreading dairy waste water treatment sludges.

Ballytore is considered to be a representative 'perfect match' for a Bioenergy Park system because of the following determinants:

- High consumption of electrical and thermal energy
- User of diesel in transport and boiler fuel
- Waste water treatment plant
- Sewage sludge generation
- Established land bank and nutrient management plan
- Access to main distribution route. (N7 and N8)
- Large site with development potential on adjoining land
- Agri trading activity on site which includes grain drying and storage facility
- Onsite weigh bridge.
- Located in an arable region with access to slurries and feedstocks.



Appendix 3.1

Quality of the Biodiesel is in compliance with ASTM D-6751 and EN 14214 Standards

No.	Specification	ASTM D-6751	EN 14214	BiodieselMach fuel specification
1	Methyl esters content, %	-	>96.5	97.9
2	Density at 15C, kg/m3	-	860-900	882.4
3	Viscosity at 40C, sq.mm/s	1.9-6.0	3.5-5.0	4.24.
4	Closed vessel flashpoint, degrees C	>130	>120	161
5	Sulfur, mg/kg	<0.05 (%)	<10	0.016
6	Cetane number	>47	>51	52
7	Sulfated ash, % (m/m)	<0.02	<0.02	0.01
8	Water content by weight, %	<0.05	<0.05	0.01
9	Copper strip test	<No. 3	Class 1	Compliant
10	Acid number, mg KOH/g	<0.8	<0.5	0.22
11	Methanol content by weight, % (m/m)	-	<0.2	0.1
12	Monoglycerides by weight, % (m/m)	-	<0.8	0.6
13	Diglycerides by weight, % (m/m)	-	<0.2	0.1
14	Triglycerides by weight, % (m/m)	-	<0.2	0.13
15	Free glycerine by weight, % (mm)	<0.02	<0.02	0.01
16	Total glycerine content, % (m/m)	<0.24	<0.25	0.25
17	Iodine number	-	<120	61
18	Phosphorus content mg/kg	<0,001%	<10	10
19	Group I metal content (Na, K)	-	<5.0	-
20	Group II metal content (Ca, Mg)	-	<5.0	-
21	Maximum carbonating ability, %	-	0.3	0.03

Source:www.biodieselmach.com

Appendix 3.2

Quotation

green fuels

Quote - Twin Auto FuelMatic
This is a sample quotation only.

Order No. 1603
Order Date 18/12/2007
Customer Ref.
Account Ref. SSFM001

Item	*Product Code*	Product Description	Net Price £ GBP
1	*0202*	**FuelMatic Project site survey and installation definition** Define scope of supply and site infrastructure requirements and connections	750.00
2	*0212*	**Pre Heat Module - Input Oil 1300 litres** Function: to preheat oils to reaction temperature via electric imersion heater Model: PH 800 Capacity: holding capacity 1,300 litres: designed to heat 800 litres in 30 minutes. Electrical loading :2 x 12kw heater element ; 0.5 kw 3 phase pump unit	9,500.00
3	*0222*	**FuelMatic Twin Reactor Tanks** Function: Transesterification of used or fresh vegetable oil Model: 14000AB Capacity: Typical batch per reactor = 350 Ltrs per hour. Electrical power : 0.5 kw 3 phase pump unit Construction: 304 Grade Stainless Steel insulated reactor tanks, baffles, ATEX approved electric pumps Semi automatic reactors mounted on load cells for digital oil measurement. Integrated batch counters for precise methylate and methanol dosing.	23,800.00
4	*0232*	**FuelMatic Glycerine Separator** Function: Separation of glycerine from biodiesel Model: GS 35 Capacity: maximum of 35 l/minute Electrical power : 0.5kw 1 phase pump unit Construction: Mild steel construction fully insulated Standard unit	7,700.00

Quotation

green fuels

Quote - Twin Auto FuelMatic
This is a sample quotation only.

Order No. 1603
Order Date 18/12/2007
Customer Ref.
Account Ref. SSFM001

Item	*Product Code*	Product Description	Net Price £ GBP
		Reduction of £1,800 if glycerine discharge is operated manually (not recommended)	
5	*0242*	**FuelMatic Biodiesel Purification Module Twin Column 900l/h** Capacity: up to 21,600 litres / day : holding tank capacity 1,300 litres	18,500.00
6	*0256*	**FuelMatic PLC Control Panel Twin System** Function: To control the various processes to produce biodiesel from vegetable oils in a fully automatic process to enable 24 hour operation Allows for : Fail safe monitoring of process - if a controlled unit fails - system shuts down Auto fill of preheat tank from feedstock Monitoring of oil temperature in pre-heat system Auto fill of oil reactor to desired pre-set volume Auto dosing of methanol and methylate Auto batch cycle with auto transfer to glycerine separator Auto glycerine drain function Auto discharge of separator to buffer tank (level controls in separator) Auto flow control of fuel through Amberlite™ BD10Dry column c/w level control Auto temperature control of heater in buffer tank Flow meters mounted for monitoring of glycerine and finished fuel Full dial in facilities for remote operation Construction: touch screen operated PLC controlled panel with Data logging -	38,000.00
7	*0272*	**Baseplate for Twin Reactor FuelMatic** Function: To provide suitable containment ; secure mounting , integration of the system and easy relocation Construction: Fabricated from mild steel	5,750.00

Quote - Twin Auto FuelMatic
This is a sample quotation only.

Order No. 1603
Order Date 18/12/2007
Customer Ref.
Account Ref. SSFM001

Item	*Product Code*	Product Description	Net Price £ GBP
8	*0281*	**Twin FuelMatic Installation and Sitework pre commissioning** All installation, connection and pipe work associated with Green Fuels supplied equipment	6,500.00
9	*0283*	**Twin FuelMatic Commissioning and First Year Maintainance** co-ordinated with other project suppliers and site infrastructure to agreed Commissioning protocol	5,500.00
10	*0295*	**Delivery of a FuelMatic** This will be quoted for approximately 14 days before the final completion of the equipment	0.00

Appendix 4.1

Straw availability in Ireland an value as a Renewable Energy Resource

SEI **16PJ = 4500GWh**	P = 10 ^{15,} T=10 ^{12,} G= 10 ^{9,} M= 10^{6} **1 PJ = 281.25GWh** **1GJ=281.25kwh** **1MJ=0.28125kWh**
Straw Calorific value of 13.5MJ/kg @20% moisture **Straw Cal value of 13500MJ/tonne**	

COS Data	2005	2005	2006	2007	units
Irish Straw Resource					
From COS 2005 @10 availability		346335	387239	338157	tonnes
10% of Straw Tot Cal@ 13500MJ/t Value @ 20% moisure	13500	4675523271	5227721486	4565122586	MJ
10% of Straw Tot Cal PJ		4.7	5.2	4.6	PJ
KWH from10% of total straw value	0.28125	1314990920	1470296668	1283940727	kWh
If ALL of the 10% Available straw Was used it would equate to ..		1315	1470	1284	GWh
To Burn Biomass for electrical production - conversion rate is estimated at 29% but can be as low as 10% Edenderry claim a conversion rate of 38%	30%	394	441	385	GWh

Appendix 4.2 List of Boilers presented at the Bioenergy Conference, Oakpark, Carlow 2007 (Part 1)

Company Name	www	Contact	Products	Brand	Range
Darionti Energy Ireland	www.ecotec.net	023 42728	Oats burner with ash discharge	Agrotec- agroline 20	90-95%
	www.verner.cz	042 491465024	wood pellets Alternative pellets corn, maize,wheat, oats, rye, triticale	Range of boilers	
Prime energy solutions	www.primeenergysolutions.ie	0906 490642	wood pellets Alternative pellets corn, maize,wheat, oats, rye, triticale	Isabella pellet stove Benekov prime boiler range benekov multifuel boilers	
Atlantic industries ireland	www.justsen.dk		Wood , peat, grain and husk		
Darionti Energy Ireland	www.woodheat.ie	023 42728	Wood Pellet Boiler	Ecotec varmessystem	20kw 300kw
Timber Pro	www.timberpro.ie	469249392	Wood Chips Wood Pellet Wood Briquettes		
Alternative Heat	www.alternativeheat.co.uk	0044 28 43770700	Wood Pellet Boiler Stoves		
Stafford Fuels ltd	www.greenerfuels.ie		Wood Briquettes	Ecoflame	
Firestixx ireland ltd	www.firestixx.org	085 1217521	Pellet Barbecue- Grusy Wood pellets	Firestixx	
Rural Generation Ltd	info@ruralgeneration.com	0044 28 71358215	KWB Wood pellet boiler		92%
Greenword	www.greenwoodfurnace.com		Timber Furnace Greenwood 100 Greenwood 200 Greenwood 300		
Sustainable energy systems	www.sustainableenergysystems.ie	074 9551286	Domestic Wood Gasifier	Herlt	84-88%
Evergreen Energy	www.eta.co.at www.evergreenergy.ie	087 2497814	Wood Chips Wood pellets	ETA HACK 20-90kW	
Kraft & warme aus Biomasse Gmb	www.kwb.at	0043 31156116	Wood pellet Wood Chip	KWB Multifire 15-100kw	

Appendix 4.2 (part 2)

Company Name	www	Contact	Products	Brand	Range
Eco Heat Ltd	www.herz-feuerung.com	059 39626 0043 33332411	Wood Pellets	Herz - pelletstar biocontrol	10 kw 60kw
Eco-Energy Centre	www.froeling.com	053 9146382	Chipped wood boiler Pellet boiler log boiler	froling	28 110kW
Palazzetti	www.palazzetti.it		Wood pellet	Ecofire range	
Choice heating solutions	choiceheating@eircom.ie	087 2754012	fuel systems Wood logs		
Gerkro heating technology	www.gerkros.ie	062 71105	Wood pellet boilers Wood log	Cosyman Executive 15kw Woodpecker boilers	
KOB	www.koeb-schaefer.com	043 55746770	Wood log Wood chip		
Glas	www.glas.ie	056 7728255	Wood Pellets boiler	HDG Pelletmasters 15 -25	
Stockers	www.stoker.ie	076 6709134	Wood Chip Wood Pellet boiler	Stoker 20-125kw	
www.heatmerchants.ie	www.wodtke.com	0049 70717003	Wood pellet boilers	Range of boilers	
Ecotherm	www.thermorossi.com		Wood Pellet boiler		
www.woodenergyltd.co.uk	www.binder-gmbh.at	0845 0707338	Wood Chip Wood Pellet boiler Wood log boilers	Binder	
www.hevac.ie	www.janfire.com	14191919	Wood pellet boilers	janfire	
Filtrex renewable energy systems	www.filtrex.ie	18071220	wood pellet, wood chip boilers	Endress german boiler herz wo heizung.da herz	
P&H Energy	www.ph-energy.dk	049 8548000	Wood chip wood pellets		
Imperative Energy	www.imperativeenergy.ie	049 8548000	Wood chip wood pellets		
Maple marketing ltd	www.heatmaster.ie	021 4968388	Wood pellet boilers	Mescoli	
Clear power	www.clearpower.ie		wood boiler		
Clear power	www.heizomat.de		wood boiler		

Appendix 4.3 Balcas Site Tour

Balcas is one of Britain and Ireland's largest wood products suppliers, and has an annual turnover of £65 million. The Group has 700 direct employees with an additional 300 people engaged in forestry and haulage. All timber used by Balcas is sitka spruce from managed forests. One of the issues Balcas had was the disposal and management of waste sawdust from the on-site activities. After much research into technology solutions, wood pelleting was considered a means of not only reduced waste disposal bills and vehicular movement from the site but also a way of converting waste into a carbon neutral fuel. Pellet production thus facilitated compliance with the renewable energy fuel obligation while producing a valuable commodity adding to the company's bottom line.

Balcas's innovative bio-energy initiative has resulted in replacing 42 MW energy from fossil fuel production and replacing it with energy from waste wood, which is carbon neutral.

Pelleting Plant Technology

A site tour was conducted in October 2007. The process technologies used can be identified as follows: intake screw feed rotary conveyor, a screening system, drying system, hammer mill, conditioning, pellet pressing, cooling, sieving, storage and dispatch. Photographs were not permitted during the site visit, however the recording of key plant equipment brand names was permitted and equipment details were researched through the internet following the tour.

Fig 4.9 Intake screw conveyor (CPM)

Fig 4.10 Screening (CPM)

Intake screw feed rotary conveyor (Fig 4.9) transfers raw material at uniform feed rates to the screen. The rotary conveyor has variable speed drives for rate adjustment. Champion (CPM) whirly screeners (Fig 4.10) are designed for screening and sieving. Access and change over of screens is designed to be quick and efficient. SWISS COMBI belt dryer (Fig 4.11) operates at low-temperature drying system reducing the moisture of the saw dust from 50% to <12% in a cost efficient manner.

Features include

- Low electrical energy consumption
- Low emission values
- Utilization of low-temperature energy
- Gentle drying for optimal product quality
- Automatic operation
- Low maintenance costs
- High operational reliability

Fig 4.11 Swiss Combi belt dryer

Moisture levels must reach the target of 12% before the material can be moved forward into the hammer mill. An on-line moisture scanner is installed to control the process. A Champion hammer mill (Fig 4.12) pound and grind the

saw dust into fine particulates. Pelleting material must have average particle size of 0.5 to 0.7 mm, with no particles > 1 – 1.5 mm. The Champion hammer mill is a high-efficiency mill, capable of fine-grinding fibrous materials.

4.12 Hammer Mill

Figure 4.13 Conditioning with direct steam

In order for wood pellets to maintain form through transport and storage the naturally present adhesive, called lignin, needs to be conditioned before the pellet press (Fig 4.13). CPM pellet mills (Fig 4.14) are highly efficient and built for 24-7 production and driven by up to 800 horsepower.

Features of the CPM press mill include:

- Positive direct gear -a 98% energy transfer with less energy wasted
- Segmented die clamps ensuring no alignment problems & quicker die changeovers
- Metal-to-metal seals keeps dust/steam inside the pelleting chamber
- Stand-alone oil lubrication system

Fig 4.14 CPM Pellet press

Pellets are cooled to improve pellet hardness and storage stability. Airflow enters the cooler via discharge gate and leaves the cooler from the air outlet. The discharge air contains moisture and wood dust, which are separated in a highly efficient cyclone. After discharge, the product will be passed over a sieve to ensure a clean and dust-free high quality product. Pellets are then either dispatched in bulk or sent to the bagging plant for packing.

The pelleting plant was installed in 2005, at a cost of £ 15 million, with the capacity of 55,000 tonnes of pellets per annum. The pelleting operation is 24-7 year round, processing twelve tonnes of waste sawdust per hour and producing six tonnes of finished product pellets.

Eight employees are directly involved in the pelleting process with a further operator per shift for the bagging process. The Balcas pellet is branded as Brites. Balcas *brites* can be used in commercial applications as well as in the domestic market. Wood pellets provide a high specific energy fuel that is 20% cheaper than heating oil at its current cost (Keelagher, 2007). The environmentally-friendly pellet fuel produced generates enough heat to keep 10,000 homes warm throughout the year.

The success of Balcas Brites has been such that in order to have continuity of supply, production capacity had to be supplemented with pellets from Germany (Pellet@tlas, 2008). Balcas are currently investing £ 25 million in a pelleting plant in Scotland which will have a capacity of 100,000 tonnes per annum. Balcas intend to supply the Cork area from Scotland, as it cheaper and more environmentally friendly to transport into Cork harbour than to use road transport from Enniskillen. Balcas also hope to penetrate the English market from its Scottish plant (Keelagher, 2007).

Appendix 4.4 Soma Engineering Site tour

Soma-Engineering Technology, a Czech company, recently designed a 'specialist' line of products to add to their core business of printing press manufacture. The Soma engineering team focused on providing an engineering solution for a cost effective, small scale, pelleting press system as an extension of its machinery portfolio. Ekover pelleting systems were launched on the market in 2007. Eight pelleting systems were on order by the end of 2007. Two systems were up and running in the Czech Republic and supplying straw pellets into a local power station by December 2007. The pelleting system is designed for the following raw material:

- straw of cereals and oil bearing plants and hay
- secondary products from mills and malt houses, (bran, barley, malted husks)
- secondary products from cereal distillery by-product

Company SOMA Engineering now boasts to being *a supplier of the complete technological solution of the machinery producing ecological fuel from the renewable sources*. Czechtrade, in conjunction Soma Engineering invited a contingent to tour the Soma Engineering plant and two straw pellet operations in Czech Republic in December 2007. The party included A J Navratil, Glen Ryan of Eco-Heat.net, Michael Butler, technical engineer of Biopower plc. and Michael Holland director of Biopower plc and the author.
Of the two operating sites visited on the Czech Republic tour, the first was in operation for one week and the second had three weeks production completed.

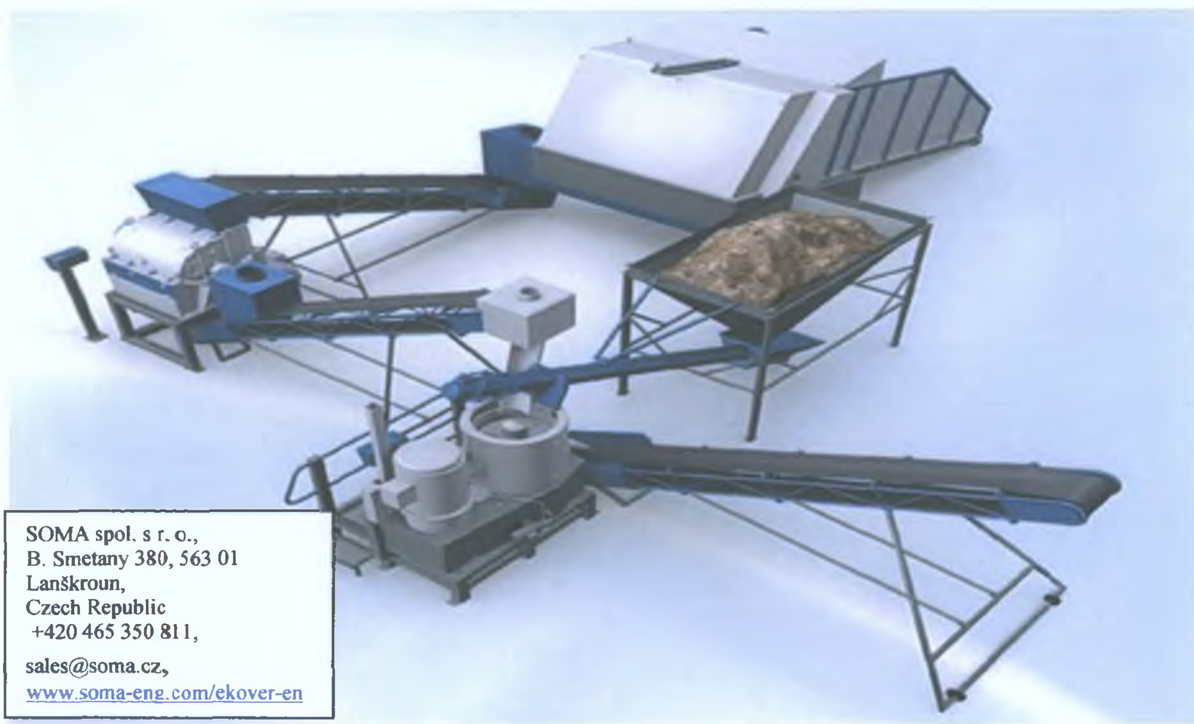


Figure 4.15 Soma Engineering Technology

Process Description

The first stage in the process is the infeed conveyor (Fig 4.16). The system is designed as a slow moving conveyor that feeds into a rotating drum with 'combine harvester' teeth. The teeth chop the bale and forward feed to a hammer and press. The infeed conveyor is sized to take two bales either large square or large round bales.

Figure 4.16 InFeed Conveyor

The conveyor is a very simple chain system with links that are similar to current farm systems so spare parts are easy to locate in Ireland. The hammer mill (Fig.4.17) receives the chopped material from the infeed conveyor via a small covered transfer conveyor. Parts are easy to change out, minimising down time. Heat is generated at this point of the process Ideal moisture level is 10 to 12%. Where straw is too dry, water can be added before the chopping stage by injecting a fine spray into the transfer conveyor. Optimum moisture will improve efficiency and through put.

Figure 4.17 Hammer Mill

Figure 4.18 Inside the pellet press

Figure 4.19 Material feed to a pellet press

The pellet press (Fig 4.18) receives the hammered material and using rotating wheels compacts the material through the die. The die size dictates the pellet size and durability. Increased die depth will improve durability and pellet structure. But will also reduce throughput. Figure 4.19 depicts the feed material flowing into the pellet press on line. Die depth ranges from 60mm, 30mm, 15mm. Die life time 2-3000 tonnes and costs four thousand euros per die. Figure 4.20 displays a die on the work shop floor.

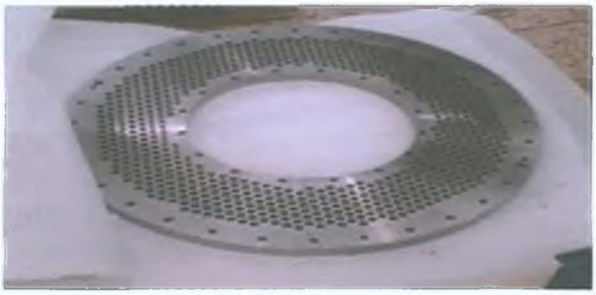


Fig 4.20 Die head on shop floor

Fig 4.21 Straw Pellet – hot off the line

Once the pellets are pressed, they are then conveyed via a screw auger to the dispatch silo. The pellets are cooled using ambient air flow, cooling the pellets in-transit to the silo.
Dust load from a health and safety point of view was thought to be considerable and would need further attention. Environmental noise was thought to be insignificant – similar to noise created by grain drying and other such farm activities. The line output was at 1.5 tonnes /hour, one tonne per hour less than the design specification of 2.5 – 3 tonnes/hour.
Soma Engineering provided a quote of € 250,000 euro (Box 4.2) for their line as viewed and documented above.

Soma Quotation - Jan 2008 **Box 4.2**

Source: (Ryan-Purcell, 2008)

	Euro
Quoted cost	250000
Electrical Demand kWh	165
Expected Out Put tonne/hour	2.5
Electrical Demand kWh/tonne	66

Appendix 5.1

WELtec BioPower GmbH
Zum Langenberg 2
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Preliminary Yield estimation*

20.02.2009

(Technical part)

Substrate quantity:	Substrate p.a.	Dry matter	Biogas m³/t	Sum biogas
Sewage sludge 4% DM	15.000 t/a	6,00%	16 m³/t	330.750 m³
Pig slurry 6% DM	7.500 t/a	6,00%	22 m³/t	164.025 m³
Glycerin	500 t/a	92,00%	838 m³/t	419.067 m³
Dairy wastes 30% DM	3.500 t/a	30,00%	168 m³/t	587.412 m³
Food Waste w/ medium fat 16% DM	3.500 t/a	16,00%	57 m³/t	200.239 m³
		2,00%		
Total quantities	30.000 t/a			1.701.493 m³

Size of the digester — Ø Methane part: 57,77%

Digester 2.008 m³ — Quantity: 2,0 — Diameter: 20,17 m — Net volume: 3.564 m³ — Height: 6,20 m — Surface area base plate: 320 m²

Digesting volume: 3.564 m³

Calculated fermentation time	43 days	
Expected average dry matter	6,01%	
Expected putrid space load in the main fermenter	2,12 (kg oDM/(m³*d))	
Necessary final waste tank with a storage time of	13 weeks:	7087 m³

Conditions of the generator

Expected daily biogas yield	4.662 m³/d
Expected daily methane yield	2.697 m³/d
Expected firing thermal output	1.111,32 kW
Calculated electrical connection	434,53 kW

Generator datas

	Quantity	Power/unit	η electr.	η therm.	Oil cons.	Biogas cons.
Gas - CHP 536 kW	1	536 kW	0,391	0,388	0,00%	236,00 m³/h

Function hours per year	7.102	Extent of use Ø	81,07%

* The gas and methane yields are based on substrate studies. In a real system, these values could be quite different from the theoretical values.

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Unsere Lieferungen erfolgen zu unseren allgemeinen Geschäftsbedingungen
SWIFT-Code DEUTDE HB 290

Preliminary Yield estimation*

20.02.2001

Economical points

Income	€/kWh	electr. [kWh]	
Income through the biogas electricity sales	0,12 €	3.806.441	456.772,69 €
Total income		**Sum:**	**456.772,69 €**

Costs			
Management	4,0 hours/day with	10,00 €/h	14.600,00 €
Maintenance / Insurance	0,015 € / kWh produced	about	57.096,61 €
Additional electricity requirement	5,00% / kWh produced	0,14 €/kWh	26.645,09 €
		Total costs:	98.341,70 €

Earnings/costs before writing-off and financial costs and taxes **358.431,20 €**

* Simplified yield estimation, which actual results can deviate substantially

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Unsere Lieferungen erfolgen
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[illegible]

Appendix 5.2 : Extracts from :

STATUTORY INSTRUMENTS

S.I. No. 378 of 2006

European Communities

(Good Agricultural Practice for Protection of Waters) Regulations 2006

SCHEDULE 4

Articles 13, 17 and 19

PERIODS WHEN APPLICATION OF FERTILISERS TO LAND IS PROHIBITED

1. *In counties Carlow, Cork, Dublin, Kildare, Kilkenny, Laois, Offaly, Tipperary, Waterford, Wexford and Wicklow, the period during which the application of fertilisers to land is prohibited is the period from –*
   - *(a) 15 September to 12 January in the case of the application of chemical fertiliser*
   - *(b) 15 October to 12 January in the case of the application of organic fertiliser (other than farmyard manure)*
   - *(c) 1 November to 12 January in the case of the application of farmyard manure.*
2. *In counties Clare, Galway, Kerry, Limerick, Longford, Louth, Mayo, Meath, Roscommon, Sligo and Westmeath, the period during which the application of fertilisers to land is prohibited is the period from –*
   - *(a) 15 September to 15 January in the case of the application of chemical fertiliser*
   - *(b) 15 October to 15 January in the case of the application of organic fertiliser (other than farmyard manure)*
   - *(c) 1 November to 15 January in the case of the application of farmyard manure.*
3. *In counties Cavan, Donegal, Leitrim and Monaghan, the period during which the application of fertilisers to land is prohibited is the period from –*
   - *(a) 15 September to 31 January in the case of the application of chemical fertiliser*
   - *(b) 15 October to 31 January in the case of the application of organic fertiliser (other than farmyard manure)*
   - *(c) 1 November to 31 January in the case of the application of farmyard manure.*

Table 7 Amount of nutrient contained in 1m^3 of slurry

Livestock type	Total Nitrogen (kg)	Total Phosphorus (kg)
Cattle	5.0	0.8
Pig	4.2	0.8
Sheep	10.2	1.5
Poultry – layers 30% DM	13.7	2.9
For the purposes of calculation, assume that 1m^3 = 1000 litres = 1 tonne.		

Table 10 Determining nitrogen index for tillage crops

Continuous tillage: - crops that follow short leys (1-4 years) or tillage crops			
Nitrogen Index			
Index 1	Index 2	Index 3	Index 4
Cereals Maize Vegetables receiving less than 200 kg/ha nitrogen	Potatoes Oil Seed Rape Leys (1-4 years) grazed or cut and grazed. Any crop receiving dressings of organic fertiliser Vegetables receiving more than 200 kg/ha nitrogen	Swedes grazed in situ	
Tillage crops that follow permanent pasture			
Index 1	Index 2	Index 3	Index 4
Any crop sown as the 5th or subsequent tillage crop following permanent pasture	Any crop sown as the 3rd or 4th tillage crop following permanent pasture. If original permanent pasture was cut only, use index 1	Any crop sown as the 1st or 2nd tillage crop following permanent pasture (see also Index 4). If original permanent pasture was cut only, use index 2	Any crop sown as the 1st or 2nd tillage crop following very good permanent pasture which was grazed only

Table 15 Annual maximum fertilisation rates of phosphorus on grassland (cut only, no grazing livestock on holding)

Phosphorus Index	1	2	3	4
	Available Phosphorus (kg/ha) [1]			
First cut	40	30	20	0
Subsequent cuts	10	10	10	0

[1] The fertilisation rates for soils which have more than 20% organic matter shall not exceed the amounts permitted for Index 3 soils.

Table 16 Maximum fertilisation rates of nitrogen on tillage crops

Nitrogen Index	1	2	3	4
Crop	Available Nitrogen (kg/ha)			
Winter Wheat[1]	190	140	100	60
Spring Wheat[1, 2]	140	110	75	40
Winter Barley[1]	160	135	100	60
Spring Barley[1]	135	100	75	40
Winter Oats[1]	145	120	85	45
Spring Oats[1])	110	90	60	30
Potatoes: Main crop	170	145	120	95
Potatoes: Early	155	130	105	80
Maize	180	140	110	75
Oilseed Rape	225	180	160	140

[1] Where proof of higher yields is available, an additional 20kg N/ha may be applied for each additional tonne above the following yields;

Winter Wheat - 9.0 tonnes/ha Spring Wheat - 7.5 tonnes/ha
Winter Barley - 8.5 tonnes/ha Spring Barley - 7.5 tonnes/ha
Winter Oats – 7.5 tonnes/ha Spring Oats – 6.5 tonnes/ha

The higher yields shall be based on the best yield achieved in any of the three previous harvests, at 20% moisture content.

[2] Where milling wheat is grown under a contract to a purchaser of milling wheat an extra 30 kg N/ha may be applied

Table 17 Maximum fertilisation rates of phosphorus on tillage crops

Crop	Phosphorus Index			
	1	2	3	4
	Available Phosphorus (kg/ha) [1]			
Wheat	45	35	25	0
Barley	45	35	25	0
Oats	45	35	25	0
Potatoes: Main crop	125	100	75	50
Maize	70	50	40	0
Oil Seed Rape	35	30	20	0

[1] The fertilisation rates for soils which have more than 20% organic matter shall not exceed the amounts permitted for Index 3 soils.

Appendix 5.3 **National impact of local biodegradable waste into energy via AD**

In 2006, the Department of the Environment, Heritage and Local Government published the 'National Strategy for Biodegradable Waste' as directed by the article 5 of the Council Directive 1999/31/EC (Landfill Directive) (EPA-2, 2008). The Strategy proposes a number of methods to facilitate the diversion of biodegradable municipal waste from landfill. With 1995 as the baseline year, Ireland is restricted to land-filling no more than 75% of the equivalent total weight of biodegradable municipal waste produced. This target is planned to be further reduced to 50% by 2013 and 35% by 2016 (Table 5.7).

Table 5.7 Targets for biodegradable waste diversion from landfill

Baseline

		Quantity generated (tonnes)
1995		1,289,911

Targets

Target Year	Landfill Directive Target	Maximum quantity allowed to be landfilled (tonnes)
2010[45]	75% of quantity generated in 1995	967,433
2013[45]	50% of quantity generated in 1995	644,956
2016	35% of quantity generated in 1995	451,469

Current position

		Quantity landfilled (tonnes)
2004		1,304,426
2005		1,307,570
2006		1,422,432

Source: (EPA-2, 2008)

Ireland is currently at risk of not reaching its targets. In the annual report for 2005, the Controller and Auditor General noted the "*possibility of EU financial penalties arising from any such failure*". Given the fact that Ireland has availed of a four year 'period of grace' where targets were postponed, it is unlikely that the European courts will be lenient in this matter.

Quantity of biodegradable waste produced

Biodegradable municipal waste is mainly composed of food and garden waste, wood, paper, cardboard and textiles. Approximately 74% of the household and commercial waste managed in Ireland in 2006 was biodegradable. Organic (food and garden) waste accounted for 36% of the total biodegradable municipal waste generated.

The EPA estimate that circa 2.3 million tonnes of biodegradable municipal waste was generated in Ireland in 2006 (Table 5.8). Approximately 62% of this was land filled and the balance was recovered. The main route for the recycling of organic (food and garden) waste is composting.

Table 5.8 Biodegradable municipal waste generation and management

Material	Gross quantity available (tonnes)	Quantity landfilled (tonnes)	National landfill rate (%)	Quantity recovered (tonnes)	National recovery rate (%)
Wood	219.317	15,480	7.1	203.837	92.9
Paper and cardboard	1,063.841	475,285	44.7	588.556	55.3
Organics	819.919	[39]755,194	92.1	64.725	7.9
Textiles	186.325	176,474	94.7	9.851	5.3
Total	**2,289.401**	**1,422.432**	**62.1**	**866,969**	**37.9**

Source : (EPA-2, 2008)

In 2006, there were over 40 operational composting facilities in the Republic of Ireland, and circa 65 ktonnes of organic waste was processed through these 40 plants (EPA-2, 2008). Of note is the fact that anaerobic digestion was not featured in the report.

The National impact of digesting organic waste locally

Consider a central anaerobic digester, with a feed stock capacity of 100,000 tonnes per annum of organic matter. If the digester operated with a feedstock ratio of 25% food remains and 75% agricultural waste, then this equates to 25,000 tonnes of food remains diverted from land fill, or an increase in the percentage of organic material recovered from 7.9 to 10.9 % , when the figures from table 5.8 are applied.

Appendix 11.1 The final word.

In the words of author and activist, Rick Bass,

" *The water begins to rumble and froth and slap at the boat in angry little whitecaps. I realize with a grim sort of triumph that I'm now in water sufficiently fast and wild enough that I can no longer turn back ...... I'm committed.*" **Rick Bass**