The Role of Biomass and Biorefineries in a Sustainable Future

James Gaffey

GMIT
GALWAY-MAYO INSTITUTE OF TECHNOLOGY

Masters of Science in Environmental Systems

Department of Mechanical and Industrial Engineering /

Department of Building and Civil Engineering

Galway-Mayo Institute *of* Technology

2010

The Role of Biomass and Biorefineries in a Sustainable Future

Author

James Gaffey

A THESIS SUBMITTED FOR THE MASTERS OF SCIENCE IN ENVIRONMENTAL SYSTEMS,
AT THE COLLEGE OF ENGINEERING,
GALWAY MAYO INSITUTE OF TECHNOLOGY, IRELAND

Supervisor

Dr. Patrick Walsh

DEPARTMENT OF MECHANCIAL AND INDUSTRIAL ENGINEERING /
DEPARTMENT OF BUILDING AND CIVIL ENGINEERING
GALWAY-MAYO INSITUTE OF TECHNOLOGY, IRELAND

SUBMITTED TO THE GALWAY MAYO INSITUTE OF TECHNOLOGY, SEPTEMBER 2010

GMIT
GALWAY-MAYO INSTITUTE OF TECHNOLOGY
INSTITIÚID TEICNEOLAÍOCHTA NA GAILLIMHE-MAIGH EO

DECLARATION OF ORIGINALITY

September 2010

The substance of this thesis is the original work of the author and due reference and acknowledgement has been made, when necessary, to the work of others. No part of this thesis has been accepted for any degree and is not concurrently submitted for any other award. I declare that this thesis is my original work except where otherwise stated.

(Signature of Candidate)

James Grafton

Name of Candidate

(Candidate)

(Signature of Supervisor)

Name of Supervisor

(Supervisor)

Abstract

Some of the biggest issues facing humanity in the 21st century include energy security, global warming and resource scarcity. These issues will affect every nation and Ireland is no exception. There is much research underway to uncover technologies that will allow the world to overcome such problems, but none offer the flexibility of biomass. Unlike other sustainable technologies, which offer a solution to one or at most two of the above problems, biomass as demonstrated by the author, can play a part in mitigating all of the above problems. It has been known for some time that biomass can be used in various ways as a form of renewable energy, but with the development of biorefineries biomass can be used to produce material as well as fuel products.

In this report the author has looked at the viability and benefits of biomass, bioenergy and biorefining in Ireland. The author has demonstrated that such technologies when implemented correctly are sustainable from an economic, environmental and societal point of view. The author has shown in this thesis that abundant supplies of biomass make biorefineries a viable business opportunity in Ireland and has shown how a number of biorefinery scenarios have the potential to be extremely profitable. The author has evaluated the profitability of material product-based biorefineries as well as fuel product-based configurations. The author demonstrated that value-added co-products help to make biorefineries profitable even when excise-relief is not granted on biofuels.

In this thesis the author has revealed some of the problems that bioenergy and biorefineries have had to overcome to date and examines challenges that remain for bioenergy and biorefining, and looks at the future opportunities for biofuels.

This report concludes that biomass and biorefining has exciting business potential while offering unique opportunities to mitigate the problems of the future.

Acknowledgements

The author would sincerely like to thank thesis supervisor Dr. Patrick Walsh for all the generous guidance during the course of this thesis.

The author would also like to thank his family and partner for all their love and encouragement.

Table of Contents

List of Figures

List of Tables

1. Introduction

The energy crises of the 1970s should serve as warning of the dangers of over-reliance on other nations particularly politically unstable nations for something as essential as our energy supply. In 1973 global oil prices tripled as a result of a temporary Arab oil-embargo on the western world. These prices doubled again when the Iranian Shah was dethroned in 1979, catapulting the world into economic recession. The geo-strategic landmines associated with oil were revisited in the recent Russian-Georgian conflict and remain a constant threat to our energy security. From an energy security point of view, Ireland has placed herself in a very delicate position. The country relies heavily on imported oil, as does most of Europe, with little or no alternatives in place, should that oil tap be turned of for any reason. The following are some facts and figures relating to Irelands energy security issues, according to IIEA (2010):

- Ireland's current energy mix is 96% reliant on fossil fuels
- Ireland has the 4th largest fossil fuel dependency in the EU
- Energy imports constitute 90% of Ireland's total energy use, at an estimated cost of €6bn to the Irish exchequer annually
- Ireland has just 11 days gas supply storage compared to an EU average of 60 days

According to the International Energy Agency (IEA)(2010a) In 2007 Ireland was producing 1.41 Mtoe of it's own energy as opposed to the 14.18 Mtoe that had to be imported. According to IEA (2007) the main sources of our home produced energy were from coal and peat, gas, hydro, solar/geothermal and combustible renewables and waste. Of imported fuel the bulk is made up of petroleum products, crude oil, gas and coal/peat. Under circumstances in which our energy supply was to be "turned off" the nation would essentially be closed for business. According to the Ecology Foundation (2010) "In June 2008 a supply disruption resulted in a 35% reduction in gas supply in Western Australia, which had immediate repercussions for businesses and householders alike. Energy was rationed and many businesses were affected, forcing many workers to take their annual leave early, while others lost their jobs. Businesses bore the brunt of the supply shortage with households remaining largely unaffected". The long-term economic cost was estimated to be AU$1.8bn dollars. This is something that Ireland could scarcely afford to happen in the current economic climate, but it is something that the country will inevitably have to deal with given her over dependence on imported fossil fuels.

Increasing energy security through investment in renewable infrastructure will in the long term make energy more affordable for Irish companies thereby increasing the future competitiveness of Irish companies over international rivals. The amount of bottom line cash spent on energy in industry is phenomenal. The figure varies from low energy intensive to high intensive industries, but according to PRlog (2006) energy costs can consume up to 65% of heavy industry budgets. There is much talk recently about how Irish companies lack competitiveness due to high labour costs, but reducing energy costs would be a huge factor in increasing the competitiveness of the country and increasing inward investment from foreign companies and more importantly, helping indigenous companies to thrive.

As things stand, Ireland now has to compete for fossil fuel supplies with a growing number of newly industrialized countries. Even if the availability of fossils were to remain the same, Ireland would have to fight harder and pay more for its energy supply due to an increasing global population and increasing number of emerging nations. But the imminent threat of "peak oil" makes it even more important for Ireland to address her issues of energy security. Exploiting a resource more quickly than this resource can be replaced is unsustainable for a prolonged period. From a financial point of view, scarcity of a resource usually results in a price increase in that particular resource. This has already been seen in the case of fish, phosphorous and other resources that have been depleted due to unsustainable human practices. Vaccari (2009) showed how in the United States phosphorous went from costing $21 per ton to $113 per ton, while at the same time production of phosphorous in the US began to decline. In oil terms the phrase "peak oil" has been coined to describe this. This is the point at which oil extraction peaks and there follows a terminal decline in extraction of oil, which will see prices soar. This is very different to oil crises of the 1970s where price hikes were driven by temporary embargos on the western world by Arab nations. These "peak oil" price hikes would be severe and permanent. Campbell & Laherre (1998) claim that three times as much oil was used as was discovered in the 1990s and this doesn't allow for the possibility that oil-producing countries may be artificially inflating their reserves in order to increase export quotas or for other financial reasons. In the early years of this century there was a sense that we may have already been in a period of peak oil as oil rose to

$147.30 in July 2008(Reuters, 2009). However due to the recent economic crisis the prices have declined (although not to low prices of the 1980s and 1990s). Despite this, most economist and environmentalists agree that peak oil is almost upon us, and these prices in addition to price hikes that result from geo-political incidents (most of the worlds oil is in unstable regions) will make it more difficult for a country like Ireland to meet her energy requirements.

Investment in non-fossil fuel based infrastructure can help Ireland to increase, in a sustainable manner, its energy security and competitiveness while also mitigating the future impacts of peak oil. But it will also help Ireland to meet its obligations in relation of climate change and global warming. The issues of climate change and energy are inextricably linked. Currently, energy primarily derived from fossil fuels, generates electricity, runs our transport systems and heats our homes and factories. But the CO^2 emissions released from the burning of such of fuels are the main driver of human induced climate change. CO^2 is one of the primary greenhouse gases and "atmospheric CO^2 concentrations have increased from 280ppm in 1750 to 383ppm in 2007" and "approximately 75% of this increase is due to CO^2 emissions from fossil fuel combustion" (Myhre, *et al* 2009). This belief is driven by the fact that the increase in emissions coincides with the period that has followed the industrial revolution and increasing use of fossil fuels by humans. In a 2007 report the Intergovernmental Panel on Climate Change (IPPC) stated "Atmospheric concentrations of CO^2 (379ppm) and CH^4 (1774 ppb) in 2005 exceed by far the natural range over the last 650,000 years"(IPCC 2007). The temperature of the earth's surface has increased by 0.74 degrees Celsius within the last century, and virtually all climate policymakers feel that this trend of global warming is set to continue if humans attempt to maintain current rates of fossil fuel consumption. The threat of climate change has been internationally accepted, although getting unanimous agreement on solution to the problem remains elusive. According to the IPCC achieving a low to moderate climate impact will require that CO^2 concentrations stabilize at or below 450ppm by 2100. This in turn will require that global per capita emissions reduce to around 0.6 tC (tonnes of carbon) from the current average of around 1.2 tC. But as Ireland has been emitting approximately 10 tCO^2/capita per year in the last decade (IEA 2009) she has a huge amount of work to do to reduce these emissions (although the economic recession has greatly helped to reduce emissions). According to Rajan (2004) "in the spirit of the ''differentiated responsibilities'' clause of the UNFCCC, the US and other industrialized countries may have to reduce their emissions towards these levels (0.6 tC) as early as possible to allow developing countries a brief period where they could increase their emissions to accommodate their needs of social and economic development". So we can assume that Ireland, as a developed nation, will bear quite a burden from any international climate change agreement that can be reached. Even without an imminent international agreement, Ireland as a EU country already has ambitious targets to achieve in the areas of renewable energy and energy security, energy efficiency and climate change.

Increasing the amount of renewable and clean energy should be of imminent national importance, in order to:

- Increase energy security
- Increase competitiveness
- Mitigate climate change
- Reduce revenue lost on mechanisms such as carbon trading and fines from not meeting targets

The next chapter will look at policies and technologies, which may help to facilitate this
As mentioned above, oil and energy is not the only limiting resource facing us in a world with a rapidly growing population. Fish and phosphorous have been mentioned, but there are many resources which are in limited supply. Resources likely to be in short supply in coming decades range from metals to food and include resources that are derived from oil such as chemicals and plastics. Changing the way humans recklessly consume resources is essential in coming decades, but even if this is achieved alternative sources of essential resources will still be necessary to cope with low resource stockpiles and high population. Resource scarcity in addition to the previously mentioned global warming and energy security is another one of the key challenges facing humanity in coming decades.

This thesis will examine the policies that have been set out thus far to help mitigate the above crises. The author will then look at the role that biomass can play in helping to mitigate these crises, with particular reference to Ireland. The author will describe the workings of a biorefinery and discuss the role that an integrated biomass processing facility might play in a addressing the crises set out here. The author will assess the viability of such a facility in Ireland and assess the facility under the three pillars of sustainability, economic, environmental and social. Under economic sustainability, the author will use an original costing method to calculate the economic sustainability of a number of hypothetical biorefineries over their lifespan. The author will then assess the potential of environmental impacts in an environmental sustainability analysis. Finally the author will look at the potential of the biorefinery to meet the needs of the local community under the social sustainability analysis. The author will finally assess the opportunities for and challenges facing biofuels and biorefineries going into the future.

2. Policy

2.1 International Policies

It is broadly agreed that climate change and energy security are some of the greatest issues of our time and getting an agreed and binding policy internationally is seen as the greatest hope of addressing these issues. However, with the exception of the Kyoto Protocol, climate change and energy policies and agreements still tend to be national or continental but not global agreements.

The Kyoto Protocol was the global communities' first attempt to reduce greenhouse gas emissions. The Kyoto Protocol (1998) was adopted in December 1997, but only entered into force in February 2005. The Protocol contained legally binding emissions targets for highly industrialized countries known as Annex 1 countries. Under the targets these industrialized countries were required to reduce their emissions by 5.2% below that of 1990 emission levels by 2012. Although the 5.2% reduction of industrialized nations emissions was the overall aim of the agreement, different targets were allocated to individual nations based on economic security thereby allowing some countries to increase their greenhouse gas emissions. The European Union (E.U.) had 15 member states in 1997 and has a combined emission reduction target of 8% below 1990 levels, which has to be achieved between 2008 and 2012. Within the European Union, targets differ among the member states ranging from a 28% reduction from Luxembourg to a 27% increase by Portugal. The target imposed on Ireland was to limit its annual average emissions to 13% above 1990 levels over the period 2008 to 2012.

More recently the Copenhagen "Accord" was a failed attempt in 2009 to agree a legally binding successor to the Kyoto Protocol, which expires in 2012. The "Accord" was drafted by 193 countries, with participating countries agreeing to submit targets by the end of January 2010 committing to economy-wide emissions reductions up to 2020.

Clean renewable energy will play a large role in any serious attempt to develop a low carbon society, which is less dependent on fossil fuels. The biggest International advisory body on energy issues is the International Energy Agency. "The International Energy Agency (IEA) is an intergovernmental organisation which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens" (IEA 2010). Although initially founded to co-ordinate measures in oil supply emergencies, it has expanded to advise on energy security, environmental protection and economic development. Member states mostly consist of OECD (Organisation for Economic Co-Operation and Development) countries although there is also regular communication with non-member states, particularly those states with high-energy production or consumption (e.g. China). The agency regularly releases documents promoting energy efficiency and renewable technologies, and is a driving force in attempting to commercialise these new technologies.

Since the Kyoto Protocol a number of important policies, directives and schemes have been launched internationally to help address the issues of global warming and energy security. A summary of these can be viewed overleaf in table 2.1:

Area/country	**Greenhouse gas reductions target**	**Energy efficiency target**	**Carbon trading**	**Renewable energy target**
European Union 	20% by 2020 50% by 2050	Increasing energy efficiency to reduce consumption by 20% by 2020	EU – European Trading Scheme	20% of total energy consumed by 2020, and 10% of biofuels in vehicle fuel consumption by 2020
United States 	17 % carbon emissions by 2020, 83% by 2050	Reducing gasoline usage by 20% between 2007 and 2017. 25% greater efficiency in light bulbs between 2012 to 2014	Cap and trade plan approved in 2009	Targets only within selected states
China 		20% reduction in energy intensity between 2006 and 2010	Pilot emissions trading scheme planned 2010-2015	15% renewable energy by 2020

Australia 	5% below 2000 levels by 2020 if done on a unilateral basis, or 15% below 2000 levels if other countries make similar commitments		Emissions Trading Scheme in 2010	20% electricity energy renewable by 2020
United Kingdom 	20% by 2010 compared with 1990 levels	20% increase by 2020	EU European Trading Scheme	10% renewables by 2010

Table 2.1: Summary of International Energy and Climate Change policies/incentives

2.2 E.U. Policy

As an E.U. member state, Ireland already has ambitious energy and climate change targets to meet, as summarized below:

Area/country	Greenhouse gas reductions target	Energy efficiency target	Carbon trading	Renewable energy target
European Union 	20% by 2020 50% by 2050	Increasing energy efficiency to reduce consumption by 20% by 2020	EU – European Trading Scheme	20% of total energy consumed by 2020, and 10% of biofuels in vehicle fuel consumption by 2020

Table 2.2: Summary of E.U. Energy and Climate Change policies/incentives

In 2000 the European Union produced a green paper entitled – "Towards a European strategy for the security of energy supply". This outlined the dependence of the EU on external energy sources and the vulnerability arising from this. Over the next few years other important directives were published by the EU such as 2002/91/EC on the energy performance of buildings. The Directive on Electricity Production from Renewable Energy Sources was issued in 2001. The main aim of this Directive was for the EU to generate a total of 22% of its electricity from renewable sources i.e. green electricity, by 2010, in order to comply with the Kyoto Protocol. This equated to a target of 13.2% green electricity for Ireland. In 2000 the European Union also launched the European Climate Change Programme (ECCP) to help to develop a strategy that would allow the EU to meet its Kyoto targets. The EU has decided to work as a unit to meet its emissions targets. The ECCP developed the European Union Greenhouse Gas Emission Trading Scheme (EU ETS) under the 2003 Emission Trading Directive, through which countries can either make these savings within their own country, or they can buy these emissions reductions from other countries which are still required to meet their own emission targets. Those companies which exceed emission limits without purchasing the necessary credits to cover this will face fines, while for those companies who achieve emissions below their limit there is the incentive of being able to sell these unused emission quotas to struggling companies. The scheme also includes Norway and Switzerland. In March 2006 a green paper entitled "A European strategy for sustainable, competitive and secure energy" was revealed by the commission. On the back of this green paper, "Energy for a changing world"(2007) containing the first proposal for the policy was published in January 2007. These proposals include:

- a cut of at least 20% in all greenhouse gas emissions from all primary energy sources by 2020 (compared to 1990 levels), with a cut in carbon emissions of 50% by 2050
- minimum of 10% use of biofuels by 2020
- that a European Strategic Energy Technology Plan be launched to promote development of technology that can increase our sustainability and reduce our emissions
- develop better relations with EU neighbours and develop an Africa-Europe Energy partnership to help them seize opportunities of being a renewable energy supplier.

Arising out of the above proposals came the European Union Climate and Energy package which was adopted by the European Parliament in December 2008. The package includes the "three 20 targets" of:

- reducing greenhouse gas emissions by 20% by 2020 (this could increase to a 30% reduction target, instead of 20% -- but only if other developed countries make comparable efforts)
- increasing energy efficiency in order to reduce energy consumption by 20% by 2020
- ensuring renewable energy accounts for at least 20% of total energy consumed by 2020, and 10% of biofuels in vehicle fuel consumption by 2020 (ECE 2010)

To help ensure that the reductions in greenhouse emissions will be met, fewer emission allowances will be granted under the EU ETS after 2013. Binding national agreements are intended to help countries to reach their renewables targets, and while these targets vary from country to country (to achieve an average 20% renewables target throughout the EU), each country must achieve at least 10% renewable fuels in transport.

2.3 Domestic Policy and Targets

Nationally a number of policy documents have been set out to ensure Ireland meet its targets set out by the EU, and to address Irelands energy security and climate change issues.

Irelands National Climate Change Strategy 2007-2012

The National Climate Change Strategy details how the government will achieve its climate change targets through a combination of flexible mechanisms offered within the Kyoto Protocol as well as existing and proposed emission reduction measures. The Irish Government committed to the European Commission in the National Allocation Plan to purchase European Union Allowances of up to €18.035 million over the period 2008 – 2012, with the National Treasury Management Agency acting as purchasing agent for the state. Another method by which, industrial countries can exceed their targets is by offsetting carbon emissions through the Protocol's Clean Development Mechanism (CDM) which allows them to purchase carbon credits from developing countries by investing in renewable projects, with the effect of reducing GHG emissions in those countries. Under the national development plan 2007 – 2013 the Irish government has allocated €270 million towards the clean development mechanism. For every tonne of GHG emissions avoided through the investment in developing countries, Ireland can offset an equivalent tonne of emissions through receiving an allowance, moving the country ever closer to her emissions reduction target. Prior to 2008, it seemed that Ireland was exceeding its emissions' allowances, and was potentially running up a debt in emissions' penalties under the Kyoto agreement. According to the ESRI (2009), due to the current economic recession Ireland is now likely to meet its Kyoto Protocol commitments as set out for 2008-2012.

Ireland's Energy Efficiency Action Plan (2009-2020)

Published in May 2009 Ireland's Energy Efficiency Action Plan, considers the main strategies outlined in the Government White Paper and the National Strategy on Climate Change (both referred to earlier) but focuses more on the government commitment to achieving an EU target of 20% reduction in energy demand by 2020. This 20% reduction in energy demand stems from the EU's ambitious Energy Efficiency Action Plan published in 2006, where Ireland agreed to a shared goal of achieving a 20% energy saving for Europe by 2020. To highlight the government's commitment it has decided to lead by example and has challenged the public sector to achieve a 33% reduction in public sector energy over the same period. The purpose of the National Energy Efficiency Action Plan is to identify policies and measures to help us achieve the 20% target by 2020, (31,925 GWh).

Irelands Renewable Energy Plan

While under sustained pressure to meet European and International emission targets Ireland also has the added problem of energy security. Increased introduction of sustainable forms of energy will increase national energy security, while at the same time moving the country to a low-carbon economy and helping to meet climate change targets. At present 90% of Irelands Energy is imported at a cost of €6 Billion a year. 90% of our gas is imported through twin interconnections from Scotland, which is fed by the trans-Siberian pipeline. To address the vulnerability of this supply the Irish Government has published a number of policy frameworks, strategies and action plans.

In October 2006, the government published an Energy Policy Green Paper, "Towards a Sustainable Energy Future for Ireland" projecting the government's goals of "ensuring safe and secure energy supplies, promoting a sustainable energy future, and delivering economically efficient prices to Irish consumers". This was followed in 2007 by an Energy

Policy White Paper "Delivering a Sustainable Energy Future for Ireland", which sets out the Government's Energy Policy Framework 2007-2020. The White Paper highlights three actions that need to be achieved:

- Security of Supply
- Sustainability of Energy
- Competitiveness of Energy Supply

Under each action is a range of strategic goals that will each contribute towards fulfilling this action. These goals are broad ranging from energy efficiency to preparedness in dealing with energy disruptions, to job creation in the energy sector. But throughout the paper much emphasis is placed on the importance of renewable energy in a sustainable energy future. Goals that are directly associated with renewable energy include:

- Enhancing the Diversity of Fuels for Power Generation
- Accelerating the Growth of Renewable Energy Sources
- Promoting the Sustainable Use of Energy in Transport
- Delivering an Integrated Approach to the Sustainable Use of Bioenergy Resources

As stated above, 20% of EU energy consumption must come from renewable sources by 2020. However, as some countries are very advanced in this area while others are lagging well behind. Different targets have been set for each Member State, in order to achieve an average 20%. Ireland has a proposed target of 16%. Ireland has set out its strategy on how to achieve this target through increasing the quantity of renewable energy used for electricity, heat and transport.

Electricity

A target of 15% renewable share in the electricity sector by 2010

A target of 40% renewable share in the electricity sector by 2020

This 40% will account for 11% of total energy use across all sectors

Heating

A target of 5% renewable share in the heating sector by 2010

A target of 12% renewable share in the heating sector by 2020

This 12% will account for 3% of total energy use across all sectors

Transport

A target of 4% renewable share in the transport sector by 2010

A target of 10% renewable share in the transport sector by 2020

This 10% will account for 2% of total energy use across all sectors

Achieving these targets will ensure that the 16% target will be met.

3.0 Role of Bioenergy and Biomass in a Sustainable Future

A sustainable future must be looked at under the headings of economic, environmental and societal sustainability. These are known as the three pillars of sustainability. From an economic point of view, it has already been mentioned how energy security and competitiveness can be increased through the development of renewable energy sources and infrastructure. From an environmental point of view development of energy, which is not fossil based, is essential to mitigating climate change. It is also important to ensure our means of utilizing natural resources are sustainable and won't result in further resource shortages. From society's point of view it is important that people are allowed to live fulfilled lives.

Biomass is an important natural resource and can be a renewable resource when properly managed, replanted and not over exploited. It is widely acknowledged that biomass can make a large contribution to our energy needs. Indeed before the age of fossil fuels, much of our energy was derived from biomass, and this has led a recent renaissance in attempting to maximize the potential of biomass for energy. However modern utilization of biomass for energy purposes has come a long way from simple combustion (which is still widely used), to manufacture of advanced transport fuels and use in electricity generation. In recent times it has also been shown that biomass has the potential to provide us with sustainable materials, based which are currently manufactured from a variety of finite resources, in a facility called a biorefinery. Therefore biomass may be able to play a role not just in our future energy sustainability as bioenergy and biofuels but also in our future materials sustainability.

3.1 What is Biomass?

According to the SEAI "Biomass refers to land and water-based vegetation, organic wastes and photosynthetic organisms". Common examples are wood, grasses, crops, agricultural waste and municipal waste. Biomass is perhaps the most versatile renewable energy source, and can be used to meet transport, heating and electricity needs. Biomass can also be used to produce material products in a biorefinery. Biomass can be regarded as a sustainable energy source from an environmental point of view." Energy from biomass and waste is often referred to as bioenergy. When plant material is burned for energy purposes carbon dioxide is released. However, because plants absorb carbon dioxide during their life cycle, the net emissions of carbon dioxide are zero. In this way, wood is said to be carbon neutral"(SEAI). According to Hendrick & Black (2009), "it is environmentally sound and economically prudent to use wood biomass for energy production, particularly in applications such as heating where there is a high energy efficiency". As discussed in Chapter 2 Ireland has the ambitious target of having to ensure that 16% of its energy consumed comes from renewable energy, and biomass and bioenergy will be central to achieving this. According to the SEAI "at present, most biomass use is from burning industrial wood wastes to produce heat. Approximately 2% of Ireland's energy supply comes from renewable resources and 1.3% of this is from biomass". As can be seen from the chart biomass use is much lower than other EU countries:

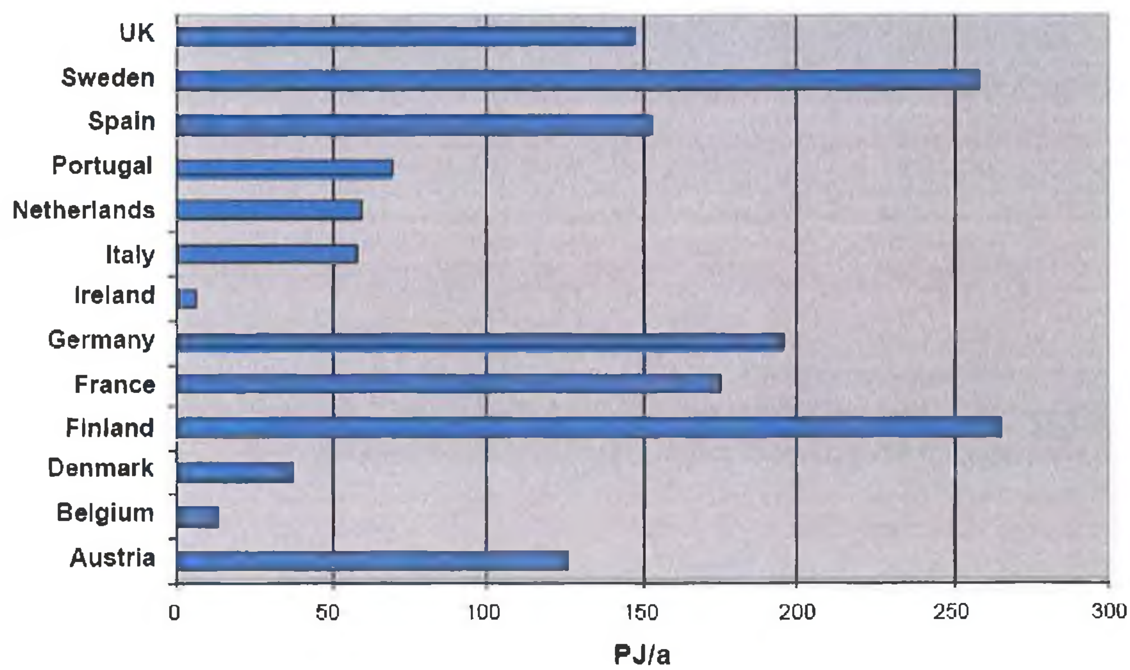


Figure 3.1: Use of Biomass in European Countries (SEAI)

The role that biomass will play in meeting our renewable energy targets are dealt with by DCMNR (2007).

- Of the 40% renewable share in the electricity sector by 2020 33% must come from bio-energy

- Bioenergy must comprise a 12% share in the heating sector by 2020
- Bioenergy in the form of biofuel will comprise a 10% renewable share in the transport sector by 2020

3.2 Ireland's Sustainable Future

In Ireland, the Sustainable Energy Sub-Programme will provide €276 million in the sustainable energy sector during the 2007-2013 period. A substantial portion of the investment has been directed towards the large-scale development of wind energy and to a lesser extent biomass and bio-fuels.

It is hoped that research and investment in renewable and sustainable energy, infrastructure and technology may help the three pillars of sustainability to be met. From a point of view of developing green energy, which increases our energy security and competitiveness whilst helping to meet climate change targets, most commentators believe that a combination of a number of natural energy sources rather than one energy source is likely to be the best solution. If the aim is to replace only a small amount of fossil fuel energy with energy from renewable sources then one source might suffice. However a country like Sweden, where 43 percent of the energy supply comes from renewable energy understands the importance in utilizing diverse energy sources. "In 2003, green electricity certificates were introduced in Sweden to encourage the use of renewable energy. To be certified green, the electricity has to come from wind power, wave power, solar energy, geothermal energy, biofuels or small hydroelectric plants" (Sweden.se).

It is through investment in such a wide variety of energy technologies and infrastructure that Sweden has managed to ensure that almost half its energy is coming from clean, cheap and renewable sources. The importance of utilizing this variety of technologies is well demonstrated below:

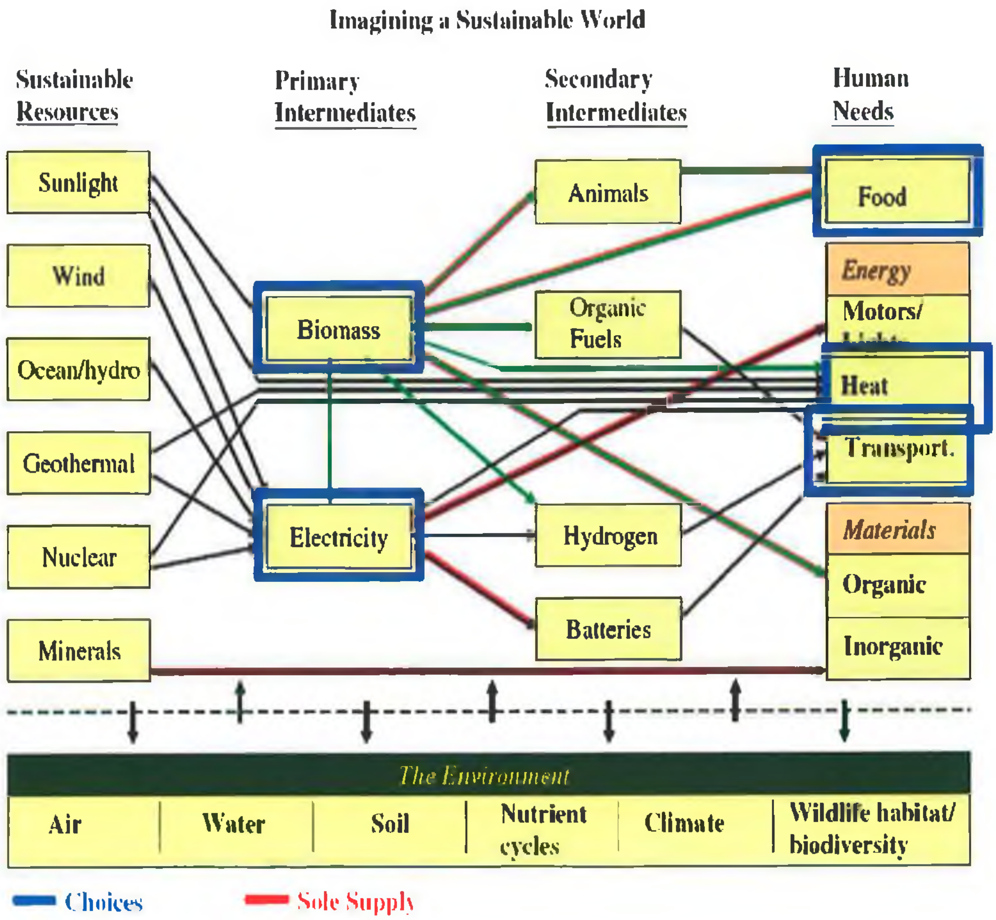


Figure 1. Pathways from potentially sustainable resources to human needs.

Figure 3.2: Biomass in a sustainable future (Lynd *et al*, 2009)

According to SEAI (2010) Ireland generated 14.4pc of its electricity from renewable sources in 2009, and has already reached the government target for 2010 to have 15pc of its electricity produced from renewable sources (although the EU target for Ireland was only 13.2%). According to Minister Eamon Ryan "we are on track to meet our 2020 target to have 40pc of Ireland's electricity produced from renewable energy". He added that Ireland loses €6bn abroad in the importation of fossil fuels yearly and "Harnessing the power of the wind and sun in Ireland reduces this bill as well as carbon emissions, benefiting the economy as well as the environment" (SEAI 2010)

While achieving this target is good news, it really must be kept in perspective that 15% of electricity from renewable energy is quite unimpressive compared with the inroads that countries like Sweden have made. In 2007 renewable energy accounted for 2.8% of Ireland's primary energy supply according the Ecology Foundation (2010). And the breakdown of this energy is shown below. The SEAI report (2010) shows that the total contribution of renewable energy to primary energy demand in 2009 based on provisional data had grown to 4.4%.

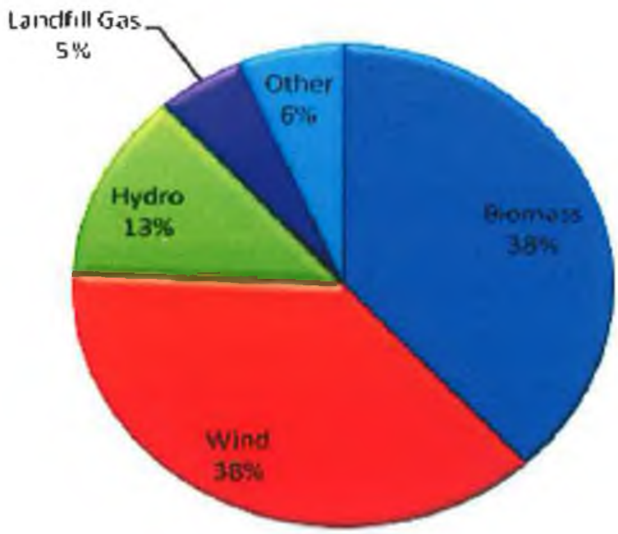


Figure 3.3: Breakdown of Renewable Energy in Ireland (Ecology Foundation, 2010)

While 15% of electricity came from renewable sources, still only 4.4% of all energy came from renewable technology which means that a greater effort needs to be made in increasing the quantity of renewable energy used in heating and transport in particular. To emphasize this, figures from the Central Statistics Office show that in 2006 a massive 41% of all energy consumed was consumed in the transport sector, with residential sector being the next biggest consumers. There is no silver bullet to addressing these issues, but rather the solution involves maximising the potential of all available resources in this respect just as Sweden have.

Sector	**1995**	**2000**	**2005**	**2006**
Transport	29.8	37.7	39.8	41.4
Residential	27.7	23.3	23.4	23.0
Industry	24.7	23.5	20.9	20.6
Agriculture	4.2	2.9	2.7	2.5
Services	13.6	12.6	13.3	12.5

Total	**100.0**	**100.0**	**100.0**	**100.0**

Table 3.1: Energy Use by Sector in Ireland (CS0 2010)

3.3 Biomass to Transport Energy

In relation to the transport energy problem, it appears that Ireland is going *down the road* of electric cars. This decision was made with the knowledge that in Europe, more than 80 % of car journeys average below 20 km and Europeans drive less than 40 km per day, well within the driving range of electric vehicles, which is currently limited to around 200 kilometres. Recharging a battery can take from 3 to 8 hours, assuming a conventional plug-in to the electric grid, but given that vehicles are parked an average of 95 % of the time, this should not pose a problem if charging points are widely available. Earlier this year it was announced that over the next two years, the ESB would install 1,500 roadside and kerbside charging points throughout the country. They will also facilitate the installation of some 2,000 charging points in homes. Today's battery costs have a price premium of €15,000 to €40,000. As technological progress is made and economies of scale begin to kick in, this could decrease to under €10,000 in the mid-term and €5,000 in the longer-term. Grants of €5,000 euro have been made available in Ireland to incentivize buyers to consider electric cars. Of course there is bound to be some fear and scepticism among the general public about the reliability of these cars and the fact that time and effort must be made in charging these vehicles, but the reality is that a shift away from the status quo is a must. A major environmental and economic advantage of electric vehicles is their energy efficiency. "With a tank-to-wheel efficiency in the range of 60 to 80 %, they outperform conventional cars four-fold" (European Energy Agency 2010). The electric car is able to convert a much higher proportion of energy in its battery to motion compared to extremely inefficient internal combustion engine with can waste up to 70% of the energy burned. According to Goodall, (2010) "a light electric car travelling at 40mph uses about 7 kilowatts of power. At current UK electricity prices the cost of this is about 80 pence per hour. Even a highly fuel efficient small petrol car will cost three or four times that amount at current UK petrol prices of over 1.20 per litre". Over time this saving will compensate the owner for the initial high capital cost of the car. And with the prospect of more and more energy being supplied to the grid from renewable sources, this does indeed appear to be much more economically and environmentally sustainable than our current system. If Ireland does adopt electric cars as a means of developing a cleaner transport system, this will not make biofuels redundant as one may think. Obviously there is still going to be a necessity for people to travel long distances as certain times. In some occupations such a courier, delivery, mail etc. this will be needed everyday, and taking to 3-8 hours off during the middle of a trip is not an option. According to DCMNR (2007) "CIE transport companies are mandated to move as soon as possible towards a 5% blend in all their existing diesel fleet". Electric cars are not really a solution for these scenarios, and conventional engines will most likely continue to be used here. Even the general public will need options when longer trips are necessary. For instance, electric vehicles could be used for short distances and daily trips, while a supplementary conventional or hybrid vehicle (rented or owned) could be used for occasional longer journeys.

Getting people to buy into such technologies could be a slow process, not to mention the initial expenses involved in upgrading to an electric car and it will also take quite a lot of time before infrastructure such as charging stations will be made available, especially in rural areas. While hugely optimistic plans are in place to have 250,000 electric cars on the road in Ireland, this, if it happens, will still only be fraction of the total vehicle count, with the remainder using conventional engines. All this means that there will still be a large energy market for biofuels.

There is also the aforementioned legal driver from the EU that a target of 10% of transport fuel must be from biofuels by 2020, and from July of this year that figure must be 4% in Ireland. The target was intended to be 5.75% but to achieve this about 85 to 90 per cent of the biofuels would need to be imported mostly from Brazil. Minister for Energy Eamon Ryan indicated that the 2010 target was dropped from 5.75% to 4% to give Ireland's biofuels industry time to ramp up and develop new methods of production, clearly a nod to the preference of using locally grown sustainable biofuels such as those produced from a lignocellulosic biorefinery (Rechargenews, 2009).

To help achieve the 10% target by 2010, The Bioenergy Action Plan, published in 2007, set out future policy for biofuels in Ireland, including the formal decision to introduce an obligation type scheme that has recently been passed by the Oireachteas. Under the Energy (Biofuel Obligation and Miscellaneous Provisions) Bill 2010, all petrol and diesel sold in Ireland will have to include at least 4.166% biofuel. The government sees this as a pathway towards ensuring the 10% by 2020 target (gradually increasing the current percentage of biofuels imported to meet this quota often offer minimal environmental improvements over fossil fuels.

With no excise-relief in place, domestically produced biofuels will, according to the IRBEA (2010), now have to pay excise duty of 37 c/l, just like fossil fuels. Tom Bruton, president of the Irish Bioenergy Association, highlighted serious concerns he had about the new scheme including the lack of incentive for and prioritization to indigenous biofuel producers. “A similar scheme in the UK has led to 89 per cent of biofuels being imported” (Irish times 2010). He claims the 4% obligation by 2010 could, given the right circumstances be met by indigenous suppliers. At present, indigenous groups account for about 30 per cent of all biofuels supplied in Ireland. And this could fall to 15 per cent under the new scheme.
However, in the author’s opinion it is not all doom and gloom for indigenous biofuel suppliers. While it’s widely expected that the cost of producing biofuels is likely to decrease going forward with technology developments, in the case of fossil fuels the opposite is almost certain to happen due to resource scarcity. The target of 10% biofuels by 2020 is in the author’s opinion likely to increase further beyond 2020, and by this stage policy is likely to dictate that biofuels must be derived in a sustainable manner, reducing the importation of unsustainably produced biofuel imports. So there is a future market for biofuels in Ireland, but the extent to which biofuels increase our energy security and reduce our carbon emissions will be influenced by government policy. Prioritising indigenous companies will increase Irelands energy security, and prioritising more sustainable biofuels will do more to reduce our carbon footprint. To the author there appears to be a contradiction in government policy on one hand reducing its targets in order to ramp up Irelands biofuels industry, while at the same time initiating a scheme, which allows and even encourages Irish fuel companies to meet their biofuels quota by importing biofuels, with questionable sustainability.

3.4 Biomass to Heat and Electricity Energy

A target of 40% of electricity consumption being from renewable sources by 2020 has been set by the Department of Energy. The ESB and Bord na Móna have been tasked to work with the biomass sector to develop the potential of co-firing (with biomass) at the three state-owned peat burning power stations (Knaggs & O’Driscoll 2008) The Irish government has established a target for biomass to contribute up to 30% of energy input at peat stations by

2015, and this should help hugely in the achievement of 33% of renewable electricity coming from bio-energy by 2020. According to the national climate change plan "achievement of this target could reduce emissions from peat stations by 900,000 tonnes per annum by 2015". The report estimates that 30,000 ha of indigenous energy crops could replace every 10% of this peat which is co-fired.

To facilitate reaching this target of 40% renewable energy in electricity, the government has launched the Renewable Feed In Tariff (REFIT) as an incentive to renewable energy suppliers to connect to the grid. To meet the 40% target it is envisaged that a generating capacity in the order of 5800MW's is required to be installed. As well as supporting On-shore Wind developments and Biomass Combined Heat and Power (CHP) plants the REFIT scheme has now extended to the categories of Anaerobic Digestion, high efficiency CHP, Ocean Energy and Off-shore Wind.

The REFIT facilitates the negotiation of Power Purchase Agreements (PPA) between renewable energy generators and electricity suppliers for periods of 15 years. The PPA is a contractual agreement between the electricity generator and a licensed supplier obliging the latter to purchase the eligible electricity from a new renewable energy powered electricity generation plant selected under competition by the Department of Communication Energy and Natural Resources (DCENR) at fixed prices (DCENR 2009). The REFIT enables negotiation of PPPA between the renewable energy generators and the electricity suppliers over a 15-year period by setting a compensation mechanism for suppliers purchasing green energy. The REFIT 2009 sets the following compensation rates for suppliers purchasing green energy:

Generation Type	Compensation Rate
➢ Anaerobic Digestion	12c/kWh
➢ Biomass	12c/kWh
➢ Ocean	22c/kWh
➢ Off-Shore Wind	14c/kWh

(Since 2010 the REFIT compensation rates for anaerobic digestion and biomass are now up to 15c/kWh).

It is hoped that a target of 12% renewable share of biomass in the heating sector is achieved by 2020. According to DCMNR (2007) "The Environmental Protection Agency (EPA) has identified a potential 0.5 million tonnes of wood residues available each year for energy recovery. This quantity would have an equivalent energy value of approximately 256 million litres of home heating oil (kerosene) or some 200,000 tonnes of oil equivalent (toe). This represents one quarter of total kerosene consumption in Ireland in 2004". The plan details steps to help achieve the 12% such as:

- Expansion of the Greener Homes Scheme to provide support for residential consumers to adopt renewable technologies for heating. This scheme encourages people to install renewable energy heating systems to their homes. The scheme launched in September 2006 was to run for a period of five years. Grants were made available to homeowners, which contributed to the initial costs of installing renewable energy heating systems, largely biomass based, in the home, making them more attractive than traditional form of central heating
- Expansion of the commercial Bioheat Scheme to include a combination of renewable technologies including woodchip. This scheme is for commercial renewable heat technologies enables companies and small businesses to obtain grants for the installation of wood chip and wood pellet boilers in large buildings and commercial premises.
- The Combined Heat and Power (CHP) programme which provides grants for the installation of CHP units. These units generate electricity at the site where the electricity is used, and can simultaneously use the heat from the electricity generating process (this will be of added benefit in helping to achieve electricity targets too).

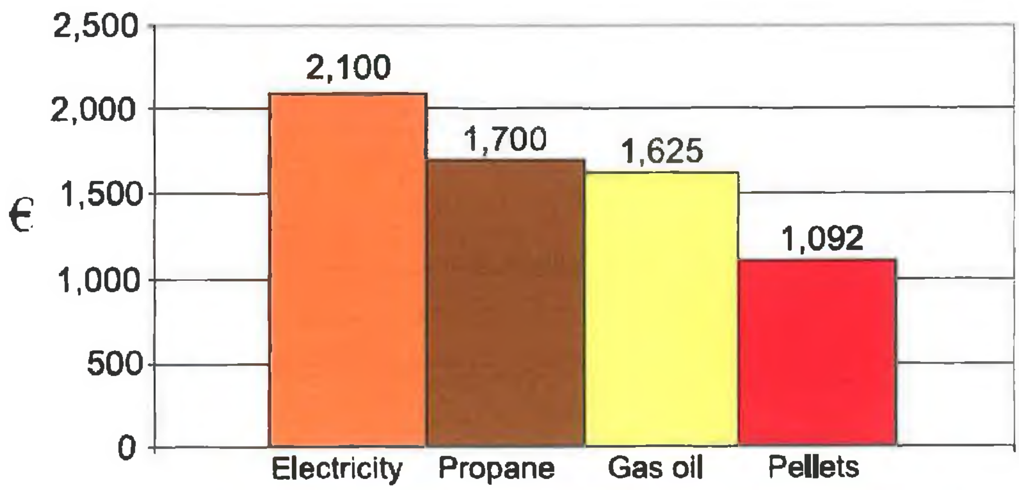


Figure 3.4: Economic comparisons of wood pellets and other heating sources (Knaggs & O'Driscoll 2008)

As can be seen above, there is the additional cost advantage of using wood pellets for home heating, as opposed to electricity, propane and gas oil. This was from a study undertaken in France in 2007 (Knaggs & O'Driscoll 2008). Biomass appears to be more economically sustainable as well as environmentally so.

3.5 Biomass in Production of Material Products

In a world where the population is estimated to peak at approximately 8 billion by 2050, it would seem reasonable to suggest that oil will not be our only limiting resource. Biomass has the potential for deriving the raw materials, which may be in short supply in the future. According to the DCMNR (2007) "the potential of extracting high value biochemicals could ultimately be a significant benefit to Ireland for use in the chemical and pharma industries that play such a significant role in Ireland's economic well being". The introduction referred to the shortage of phosphorous as a vital fertilizer in coming decades. Biorefineries offer a solution for replacement phosphorous and many other dwindling but vital resources in future. The potential for this will be examined more in the next chapter.

4.0 Biorefineries

DCMNR (2007) states "Biorefining is the industrial application of oil refining technology to biomass for the purpose of extracting energy carriers, high value biochemicals and fibres". Biorefineries are facilities, which support 'the sustainable processing of biomass into a spectrum of marketable products and energy' (IEA Bioenergy 2009). This facility is based on ideas associated with the petrochemical industry as indicated below.

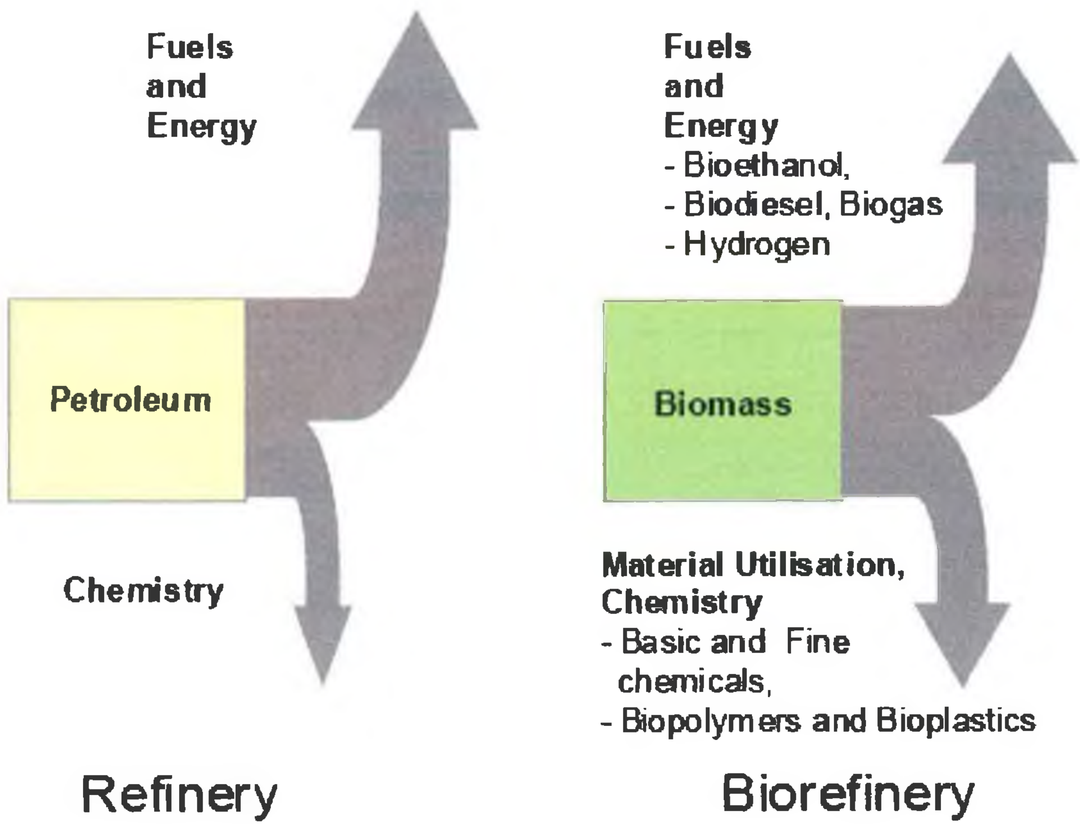


Figure 4.1: Comparison between Petrol Refinery and Biomass Biorefinery (Kamm 2007)

Task 42 by IEA Bionenergy (2009) emphasizes that biorefineries may exist as a concept, a facility, a process, a plant, or even a cluster of facilities. The word "processing" in the above definition usually involves a combination of a number of different treatments or processes including mechanical pre-treatments (extraction, fractionation, and separation), thermochemical conversions, chemical conversions, enzymatic conversions, and microbial fermentation (both aerobic, anaerobic) conversions. The processes that will be utilized will vary depending on feedstocks used and products sought. Due to the vast number of potential feedstocks and the large number of potential products from each feedstock, there is no one size fits all approach to biorefineries. On the contrary biorefineries tend to be quite experimental and individualistic, with pioneers looking to find the most effective biorefinery from an economic and environmental point of view. Many existing biorefineries, (particularly second and third generation biorefineries) are still very much in the pilot phase. Due to the complex and individualistic nature of biorefineries IEA Bionenergy (2009) outlines a system to help "identify, classify and describe the different biorefinery systems, viz: **platforms, products, feedstocks,** and conversion **processes**".

4.1 Products

As well as having the potential to provide sustainable and relatively clean transport fuel, biorefineries have the potential to provide additional co-products. Research is ongoing to ensure that biorefineries are developed with the aim of maximizing all feedstock used in the facility and not just that proportion that will be used to produce fuels. Utilizing residual material to manufacture value-added material co-products for sale will make the biorefinery more cost effective. Currently it appears that biorefineries will be energy driven, with co-products used simply to utilize residual material. With energy security problems and the imminent threat of peak oil, it would be reasonable to assume that biorefineries will be most profitable with energy as a primary output. However in time as other natural resources come under threat, we may see biorefineries with a more material product-driven focus. Potential material products include:

- Animal feed
- Biomaterials
- Chemicals and Polymers
- Food
- Glycerine
- Organic Acids

According to Mac Lachlan & Pye (2007)"With the new era of high oil prices many companies are now searching for renewable sources of commodity chemicals, chemical intermediates, polymers, adhesives, and coatings, as well as performance additives in plastics, lubricants, and resins". If over time our energy needs are fully met in new and innovative ways, biorefineries could one day become completely product-driven facilities. Some potential scenarios for this will be examined in chapter 7.

4.2 Processes

As mentioned above a combination of a number of different treatments or processes are likely to be used in a biorefinery. IEA Bioenergy (2009) has identified 4 main subgroups of processes:

1. Mechanical/physical (e.g., pressing, pre-treatment, milling, separation, distillation), which do not change the chemical structure of the biomass components, but they only perform a size reduction or a separation of feedstock components.
2. Biochemical (e.g., anaerobic digestion, aerobic and anaerobic fermentation, enzymatic conversion), which occur at mild conditions (lower temperature and pressure) using microorganisms or enzymes.
3. Chemical processes (e.g., hydrolysis, transesterification, hydrogenation, oxidation, pulping), where a chemical change in the substrate occurs.
4. Thermochemical (e.g., pyrolysis, gasification, hydrothermal upgrading, combustion), where feedstock undergoes extreme conditions (high temperature and/or pressure, with or without a catalytic mean).

Whether a process is to be used and the extent to which it will be used will depend on the particular biorefinery set up or configuration. For example, the first step in a lignocellulosic biorefinery is usually to separate out the major constituents of the feedstock, cellulose, hemicellulose and lignin, which can then be further processed in individual streams. This is mechanical/physical process. Pretreatment is followed by hydrolysis on the cellulose and hemicellulose components using acid or enzymes to produce sugars. This is a chemical process. These can be fermented to produce a dilute product from which ethanol can be derived. This can be referred to as biochemical processing. Thermochemical processing can also be used to produce fuel and energy. The difference between thermochemical and biochemical processing being that high temperatures are involved but again a process of pretreatment is involved, followed by a thermochemical processes including combustion (to generate heat and stream to drive turbines), gasification (convert biomass into fuel gas or synthesis gas) or pyrolysis (e.g. fast pyrolysis) to produce a number of fuel and chemical products. Chemicals can be produced when processes like hydrolysis and pyrolysis are applied to a particular component stream. Most biorefinery configurations will incorporate a number of different processes.

4.3 Feedstocks

Feedstock is the raw material/biomass converted into marketable products and/or energy in a biorefinery. Many biorefineries are defined by the feedstock they use and named as such. The Feedstock used will determine the processes required to achieve the desired product. These feedstocks may be obtained from a number of sectors as outlined by IEA Bioenergy (2009):

- Agriculture (dedicated crops and crop residues).
- Forestry (wood, short-rotation poplar, logging residues).
- Industry (process residues and wastes) and domestic activities (organic residues).
- Aquaculture (algae, seaweed)

"A further distinction is made between those feedstocks which come from dedicated crops, produced on agriculture or forestry land or in aquatic systems, and those that come from residues, from agricultural, forestry and industrial activities" (Cherubini, F *et al* 2009a). These feedstocks can be primary, secondary or tertiary depending on their source as described by Wright below:

Primary biomass is produced directly by photosynthesis and includes all terrestrial plants now used for food, feed, fibre and wood fuel. All plants in natural and conservation areas (as well as algae and other aquatic plants growing in ponds, lakes, oceans, or artificial ponds and bioreactors) are also considered primary biomass

Secondary Biomass includes residues and by-product streams from food, feed, fibre, wood, and materials processing plants. Secondary biomass feedstocks differ from primary biomass feedstocks in that the secondary feedstocks are a by-product of processing of the primary feedstocks.

Tertiary biomass includes post consumer residues and wastes, such as fats, greases, oils, construction and demolition wood debris, other waste wood from the urban environments, as well as packaging wastes, municipal solid wastes, and landfill gases.

The composition and characteristics vary between different feedstocks; there is therefore the need to employ different processes. Goodall (2008), discussing the challenge of producing cellulosic ethanol using secondary feedstock compared to corn ethanol using primary feedstock, states "whereas corn starch needs relatively little encouragement to break in sugars and then ethanol, cellulose is very stable" before going on to discuss the complexity of lignocellulosic material.

4.4 Platforms

According to IEA Bioenergy (2009) "The platforms (e.g. C5/C6 sugars, syngas, biogas) are intermediates which are able to connect different biorefinery systems and their processes". Generally the number of platforms is an indication of system complexity, and conversion of these platforms to marketable products can be carried out using the different processes described above, although in some cases platforms themselves may be marketable products themselves.

Cherubini et al (2009a) identified that the most important platforms which can be recognized in energy-driven biorefineries are the following:

- "Biogas (a mixture of mainly CH4 and CO2), from anaerobic digestion.
- Syngas (a mix of CO and H2), from gasification.
- Hydrogen (H2), from water-gas shift reaction, steam-reforming, water electrolysis and fermentation.
- C6 sugars (e.g., glucose, fructose, galactose: C6H12O6), from hydrolysis of sucrose, starch, cellulose and hemicellulose.
- C5 sugars (e.g., xylose, arabinose: C5H10O5), from hydrolysis of hemicellulose and food and feed side streams.
- Lignin (phenylpropane building blocks: C9H10O2(OCH3)n), from the processing of lignocellulosic biomass.
- Pyrolysis liquid (a multicomponent mixture of different size molecules), from pyrolysis.
- Oil (triglycerides: RCOO-CH2CH(-OOCR')CH2-OOCR") from oilseed crops, algae and oil based residues.
- Organic juice (made of different chemicals), which is the liquid phase extracted after pressing of wet biomass (e.g., grass).
- Electricity and heat, which can be internally used to meet the energy needs of the biorefinery or sold to the grid".

4.5 Biorefinery Set-up Examples

While many biorefinery configurations are the subject of research and only exist on pilot scale, there are some examples of commercial plants. Commercial examples to date are usually first generation biorefineries, but over the last few years more second-generation biorefineries are becoming commercialized. 1st generation biorefineries are based on direct utilization of classical forms of agricultural biomass (Biorefinery CRIP 2009a). This biomass includes; rape seed, sunflower, soybean, and other oily crops which can be converted into biodiesel, and corn, sugar cane and wheat or other sugary or starchy crops which can be converted into bioethanol.

"The class of bio-organics from 2nd generation biorefinery is defined as that which utilizes Lignocellulosic biomass as a raw material. The principal advantage of this class of biorefinery is recovery of the most abundant source of renewable carbon on the planet"(Biorefinery CRIP 2009b). Examples of biomass used in second-generation biorefineries include; straw, wood waste, and dedicated crops like miscanthus.

A couple of examples will now be presented to show the typical set-up of some biorefineries, and also showing how feedstock, process, platform and products can be used to describe the biorefiney.

4.5.1 First-Generation Biorefinery

The biorefinery featured below is a commercial bioethanol producing biorefinery from Germany and is owned by the Crop Energies Group. This biorefinery has been classified by IEA Bioenergy (2009) as a "C6 Sugar Biorefinery for bioethanol and animal feed from sugar and starch crops". It can be described as being first generation because it is based on direct utilization of classical forms of agricultural biomass. Figure 4.2, below, describes the biorefinery set up. The classification title contains the type of feedstock, platforms and products but does not contain the type of processes used. However the processes are featured on the accompanying diagram. It can be seen that unlike the sugar beet feedstock, the starch crops feedstock require mechanical fractionation and enzymatic hydrolysis to isolate the C6 sugars, and the C6 sugars from both products are fermented to produce the products. This shows that a biorefinery is capable of processing more than one feedstock.

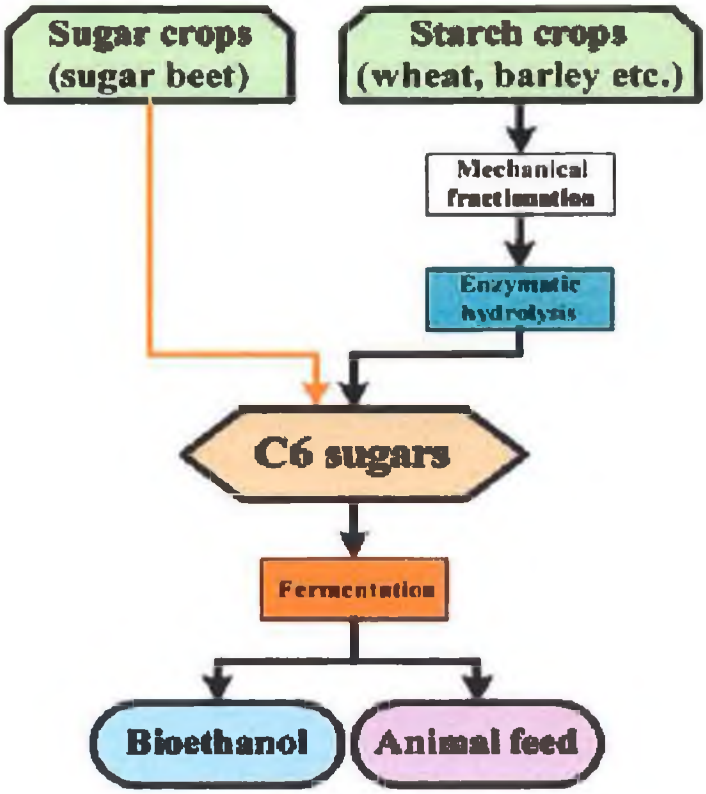


Figure 4.2: First-Generation Biorefinery example (IEA Bioenergy 2009)

The pathway for converting starch to bioethanol is more complex than sugar beet. According IEA Bioenergy (2009) "Ethanol production from cereals containing starch takes place in five stages:

- milling the cereals, meaning mechanical crushing of the cereal grain to release the starch component
- heating and addition of water and enzymes for conversion into fermentable sugars
- fermentation of the mash using yeast, whereby the sugars are converted into ethanol
- distillation and rectification, i.e. concentration and cleaning the ethanol produced by the distillation by removing by-products
- drying (dehydration) of the ethanol".

From the diagram it can be seen that sugar beet forgoes the first two stages above, this is due to the fact that sugar beet does not require processing to extract sugars, unlike starch crops.

4.5.2 Second-Generation Biorefinery

The next biorefinery featured below is a pilot plant located in Denmark and owned by Inbicon, a subsidiary of Dong Energy. It is classified as a C5/C6 Sugars and Lignin biorefinery for bioethanol, animal feed, electricity and heat from lignocellulosic residues that are in this case straw. It can be classified as a second generation biorefinery as it utilizes lignocellulosic biomass as a raw material/feedstock. Biofuels generated globally from lignocelluloses are estimated at about 30 EJ/year, compared to the total energy used world wide of over 400 EJ/year (McKendry 2002). This type of biorefinery involves a change in the bioconversion step. According to Biopact (2007a) instead of only using easily extractible sugars, starches or oils as in the previous situation, these techniques allow for the use of all forms of lignocellulosic biomass. While the biomass can be more inexpensive than that of first generation biorefineries, the problem is that lignocellulosic biorefineries currently face is a lack of inexpensive proven technology that can process biorefinery feedstocks to products in a manner that makes them competitive with existing market fuels and products. As lignocellulosic feedstock is readily available and low cost, it should be possible to ensure its products are competitive if the technology issue can be overcome. The problem is that Lignocellulosic materials are more complex to break down than the starch present in traditional biofuel feedstocks like sugarbeet, and therefore require more advanced pretreatment and conversion processes than those used in the production of first generation biorefineries.

The greater number of platforms present here are indicative of a more complex biorefinery than the previous example. The three platforms are lignin, C6 sugars from cellulose and C5 sugars from hemicellulose. Straw and all lignocellulosic biomass contain lignin, cellulose and hemicellulose. These platform components will be referred to more in the coming chapters. Currently most second-generation biorefineries use the biochemical route referred to earlier, to produce biofuels through fermentation. This pathway yields 'cellulosic ethanol' or bioethanol.

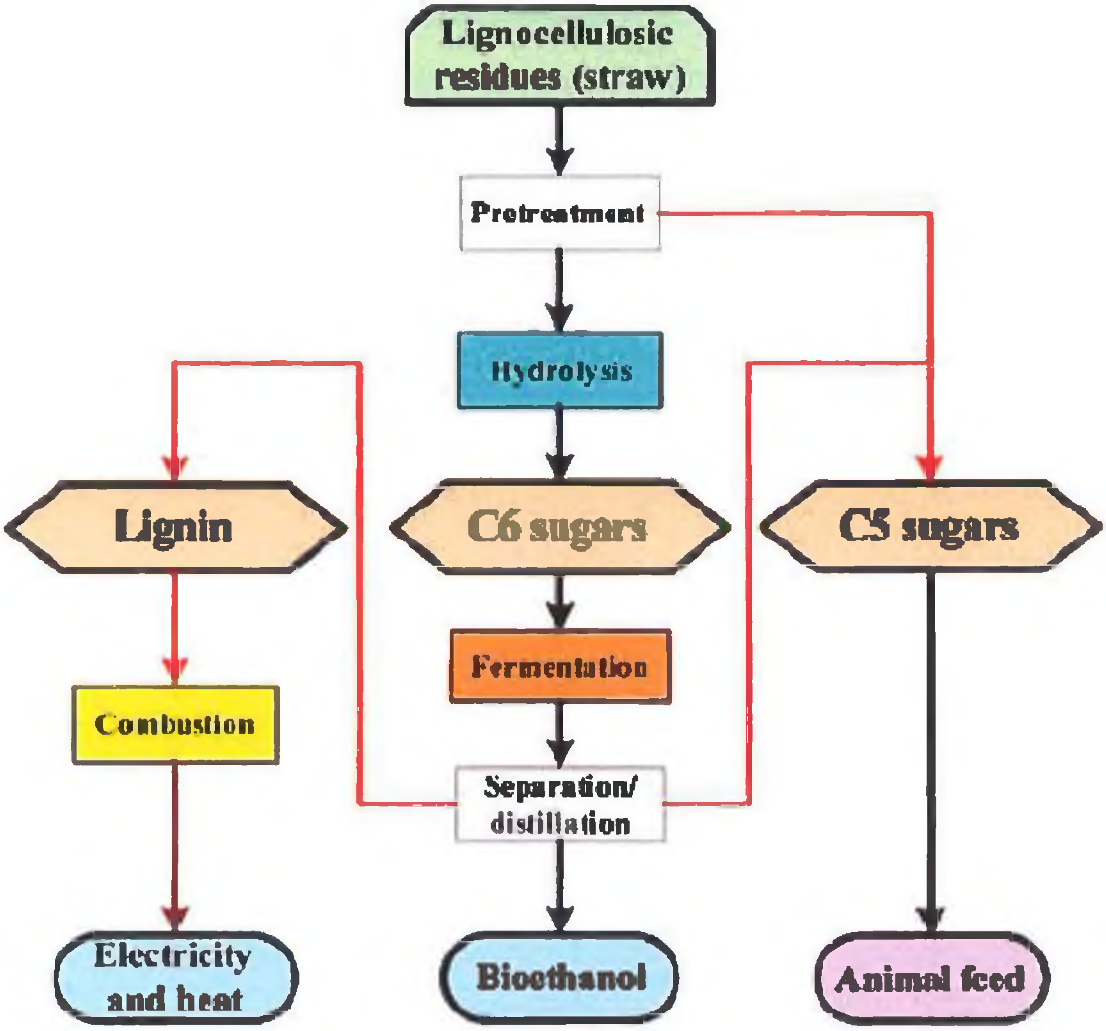


Figure 4.3: Second-Generation Biorefinery example (IEA Bioenergy 2009)

As can be seen in figure 4.3 the lignin component of the feedstock can be combusted to form electricity and heat, but in many second generation biorefinery scenarios the waste streams from the lignin, cellulose and hemicellulose components are collectively gathered and converted to biogas through which electricity and heat can be generated. For this reason, biomass CHP plants can be integrated as part of the biorefinery increasing the overall efficiency of plant and providing heat and electricity from otherwise residual material. This will be discussed more in chapter 6. Biogas is also an established platform under the task 42 classification system.

A more in-depth look at the relationship between first and second-generation biorefineries will be examined in Chapter 8.

Economic Analysis

To assess the viability of biorefineries, particularly in Ireland, this thesis will now examine some hypothetical biorefinery configurations and attempt to test their feasibility as much as possible. Chapter 6 will look individually at some potential products that could be produced from the selected biorefinery feedstock, and chapter 7 will look at potential biorefinery configurations in which the biorefinery is set up to produce a combination of these products. After assessing the predicted revenue from the combination of products and deducting all costs incurred including cost of facility, production and feedstock, it will be possible to assess the predicted economic sustainability of the biorefinery. Chapter 5 will now look at the selection of the most suitable biorefinery and biorefinery location in terms of feedstock availability, as well as costs incurred by a biorefinery as

Data used in the economic analysis will be based on the limited but best available information at the time of print.

5. Biorefinery Cost and Set-up

There will be a number of costs incurred by the biorefinery such as:

- Facility cost (payback duration on this cost will vary depending on profitability)
- Cost of debt (will vary depending on payback duration)
- Feedstock cost (incurred throughout lifespan)
- Production cost (incurred throughout lifespan)
- Labour cost (incurred throughout lifespan)

The main factors in determining the configuration of the biorefinery will be feedstock (dependent on availability) and desired products.

5.1 Biorefinery Facility Cost

In order to assess the economic viability of a biorefinery it is important to know the cost of feedstock and process against the potential market value of the products. However it is also necessary to take into account the capital cost of the biorefinery. These costs are substantial. According to Hayes, "The problems associated with getting commercial biorefineries off the ground are their high capital costs (as is often the case for a first-generation facility) and the risks associated with any new technology. Investors/lenders will not invest in, or lend money to, technologies with these levels of risk unless the debt is guaranteed by a strong credit rating, such as from a government". As biorefineries are highly individualistic it is difficult to get an average capital cost of biorefinery, in addition to this, capital cost will vary with scale of facility and maturity and commercialisation of technology. In his paper "State of Play in Biorefining Industry" Hayes gives an insight into the capital cost of a number of existing and soon to exist biorefineries. According to this paper an Abengoa plant using corn to produce ethanol in Lacq in the south of France with a capacity for 200,000 tons of bioethanol from corn and wine alcohol had a total capital cost of 180 million euro. Abengoa are also constructing a corn/cellulosic ethanol plant in Kansas USA at a cost of $330 million to produce 379 million (M) litres of ethanol per year with 57 million litres coming from lignocellulosic feedstock (corn stover) and 322 million litres coming from starch. Iogen, a Canadian company are building a commercial scale biorefinery, which will process agricultural residues, principally waste straw and cost over $200m. According to the report there were varying estimates of capacity and output; "An earlier press release indicated that

the facility would be fed by approximately 400,000 tons of straw (apparently Iogen has sourced 320 farmers for this supply) and produce around 170m litres of ethanol per year. However the notes associated with the Department of Energy grant scheme stated that the facility would use 700 tons of agricultural residues per day (about 255,000 tons per year) to produce 68m litres of ethanol per year". These are wildly differing estimates, and this may result from the fact that estimating yields on such a large scale can be a difficult task, compared with pilot or laboratory situations.
Abengoa Bioenergia is currently arranging financing for a plant in Rotterdam, which will have capacity of 480 million litres a year and require investment of 500 million euros.

In 2000, start-up of the first Bioethanol facility in Spain with an initial production capacity of 100 M litres/year currently 150 M litres/year), required a €93.8 M investment. The start-up cost of the second Bioethanol facility in Spain (Bioetanol Galicia), with a 126 M liters/year production capacity (currently 176M litres/year), required a €92.1 M investment. (Abengoa, 2006). From these figures it is possible to draw a pattern that currently the capital cost is proportional to the amount of ethanol output and will as consequence also be proportional to the quantity of feedstock input. Currently it appears that capital cost is currently slightly less than 1 euro for every litre of ethanol produced in a typical year of operation. However the biorefineries listed in these examples are on a large scaled of upwards of 100 million litres of ethanol produced per year. From the study carried out by Deverall, et al (2009a) it has been established that Ireland may struggle to meet the feedstock requirements of such a large-scale biorefinery using a single feedstock source. So this study will assume that the biorefinery has a feedstock requirement equivalent to that of a 40 million litres per year ethanol biorefinery (the biorefinery in question must not necessarily produce ethanol, but will have the same feedstock requirements as that of a 40 million litres per year ethanol biorefinery. This biorefinery cost will also include the cost of an integrated biomass CHP facility that will utilize residual material. It is unclear whether the references listed above include the cost of such a facility for residual waste utilization in their set up costs, but if the reader feels that the CHP plant should be taken individually then the figures can be adjusted accordingly.

So it will be assumed from the above examples and pattern that a 40 million-litre biorefinery will require a €40 million capital cost, €10 million of which will come from private investment, with the other €30 million being loaned. This can be covered through revenue over the expected 25 year lifespan of the biorefinering but due to recurring interest charged it will make sense to cover this debt as quickly as possible.

5.2 Feedstock Availability, Feedstock Selection and Production Costs

With energy security a central driver behind biorefineries it would defeat the purpose to design a biorefinery, which requires a non-local feedstock. Importing feedstock from another country will not address Irelands energy security issues, and excessive transportation of feedstock will not help Irelands attempts to reduce carbon emissions. A study carried out by Deverell *et al.* (2009a) examined the potential availability of three feedstocks wheat, sugarbeet and straw around 9 locations in Ireland. The study assumed that the maximum radius within which indigenously grown feedstock's could be sourced was 100 Km from the biorefinery facility and that the ethanol plant would have an annual output of 200 million liters per annum. The study found that while none of the feedstocks could by themselves meet the demands of a large-scale biorefinery, "combining wheat and straw (multi stream plant) as the feedstock would result in feedstock demands being met at one inland location". The report claims "New Ross port can potentially supply the greatest amount of feedstock from domestic wheat and straw requiring only 14% or 28 million liters to be produced from imported wheat". All other feedstock combinations failed to meet requirements of a large-scale biorefinery, which may be seen as a concern. It must also be appreciated that while economies of scale can be economically beneficial, there are drawbacks in utilizing a primary feedstock like wheat or other food crops to make up for the shortfall in straw availability, in order to feed such a large-scale biorefinery. These impacts will be examined more in section 8.1. From that point of view a number of medium sized biorefineries that solely utilize the available straw may be preferable to a single large biorefinery utilizing wheat and straw. The study carried out by Deverall *et al.* (2009a) offers a visual summary of the available straw in 9 locations across Ireland, displayed below.

Figure 6. Modeled availability of straw around each location.

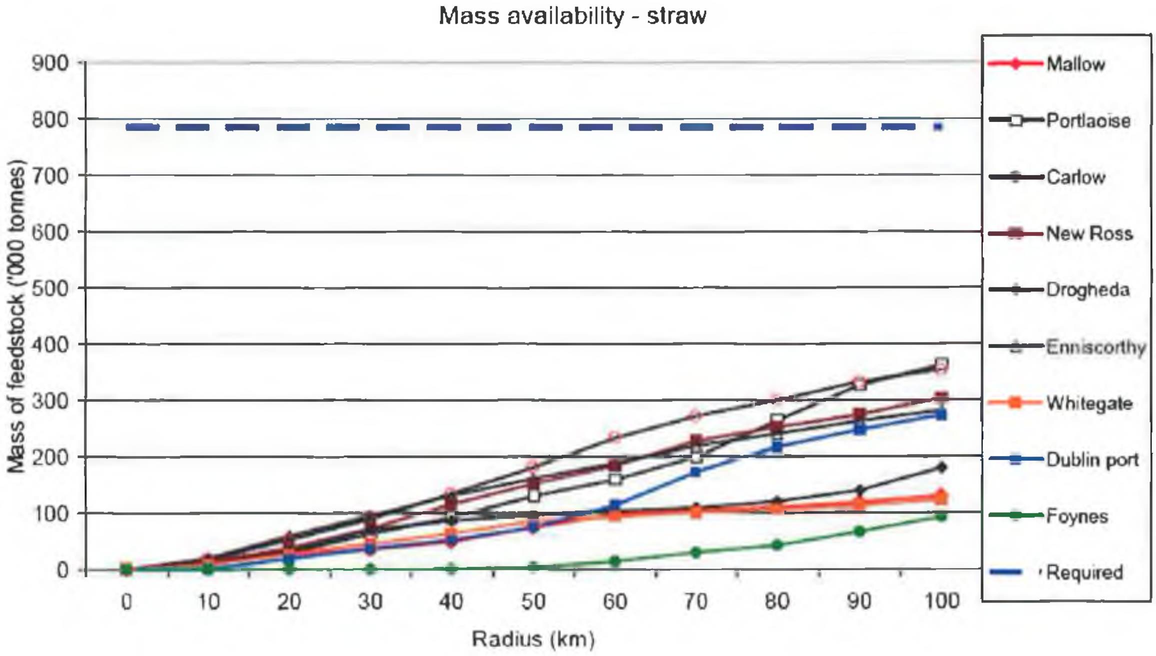


Figure 5.1: Availability of Straw around nine examined Locations in Ireland (Deverell *et al.* 2009a)

Figure 5.1 shows that five of the locations have 250,000 plus tonnes of straw available within a 100 km radius. 100 km was taken as a maximum distance for collection of feedstock for logistical, economical and environmental reasons. Ideally, it might be best to chose a biorefinery location closest to a large urban population where demands for products and energy is likely to be high, and a few of these locations such as Portlaoise and Carlow are in the vicinity of Dublin.

We must take into account however that not all straw specified in the above study will be readily available for use in a biorefinery. According to DCMNR (2007) "Ireland's agricultural sector creates significant quantities of dry residues, principally straw, which can be combusted to produce electricity, heat or both. Total straw production in Ireland is of the order of 1 .1m to 1.4m tonnes. Current uses are animal bedding and ploughing back".

Allowing for the fact that a percentage of total straw available in Ireland will not be available for use in a biorefinery, we can assume from the study by Deverell *et al.* (2009a), that by combining the yields provided by the various eastern locations (Dublin Port, Portlaoise and

Carlow) a medium scale (40 M litres ethanol per year) east coast biorefinery should be feasible from a feedstock supply perspective. One might also be feasible for the southern region again by combining the yields provided by individual locations.

Aside from availability another reason for choosing straw as a feedstock is economic potential. In a separate study Deverell *et al* (2009b) carried out an economic assessment on five biomass-to-ethanol production pathways using straw as the feedstock in one scenario. Straw was found to be the most promising option from an economical point of view. The above study indicates a straw price of €41/t (+/- 7 euro) and specifies an ethanol yield of 255 l/t. This straw price is backed up by Hamelinck *et al.* (2004) who claim that "Given the depressed state of the market in recent years, it is likely that amounts up to or exceeding 100 ktonne could be bought for 25 €/tonne in the field, i.e before baling and bale collection. The cost of these operations is estimated at about 15 €/tonne, giving a total of 40 €/tonne before road transport". Using these figures it is possible to calculate the cost in feedstock per year;
If one ton of straw produces 255 litres (see above), then to produce 40,000,000 litres:
40,000,000/255 = 156,862.74 tons of straw is required
So assuming a straw price of €41/t, it is possible to estimate the yearly cost of feedstock to be
156,862.74 x 41 = **€6,431,372**

According to Deverell *et al* (2009b) "the main factor affecting the cost, and therefore competitive- ness of most biofuels is the cost of the feedstock, which generally constitutes some 60–85% of the total production cost". Taking these figures (60-85%) and the feedstock cost per year as calculated above it can be assumed that the total production cost will be between €10,718953.33 and €7,566320 per year. So an average yearly cost of **€9.14 million** for feedstock and production (including labour) can be expected. For the first year of the biorefinery, this 9.14 million will be loaned, which when added to the 30 million loan in building the facility will bring total loan to 39.14 million plus interest.

Cost of Production

Cost of production, including cost of labour has been covered covered under feedstock cost above and is approximately €2.7 million annually (€9.14M - €6.43M). This production cost will be considered across all biorefinery scenarios. It is necessary to use the figure as an approximation across all biorefinery configurations in this analysis as many of biorefinery products studied within, are as yet only being produced at laboratory level and so reliable costs of production especially on a commericial scale are unavailable for some products. So while there may be available costs of production for bioethanol, such production costs do not exist for some other products. For this reason it will be assumed that production costs over time will be similar across all biorefinery scenarios.

Energy costs are also considered under this cost of production, though some of the required thermal energy in for the biorefinery may be provided by biogas produced from the residual waste stream. This biogas can be used to produce electricty for market, but also can produce heat energy as a by-product which may be utilized for some of the heat-intensive processes such as thermochemical processing.

Cost of Transport

Deverell *et al* (2009b) state that "Transport costs are also determined and it is assumed that the feedstock producer incurs those costs", so this will be included in feedstock cost covered above.

5.3 Repayment of Debt

As mentioned above, €39.14 million plus interest will be borrowed prior to year one for the building of the facility and production costs for year one. Due to recurring interest charged this debt should be paid back as quickly as possible, but this will depend on the profitability of the biorefinery in question. An example of how debt would be repaid over a ten-year period is included below.

Yearly Loan Amortization Schedule

If the business borrows €39,140,000.00 at a stated interest rate of 3.41% per annum for ten years and is scheduled to pay it off in equal annual payments over the ten-year time period. Since it's in the form of equal annual payments and the balance is €39,140,000.00 with a ten-year term, the principal paid yearly will be €3,914,000.00.

Year	Beginning Balance[4]	Total Payment [3]	Interest Paid[2]	Principal Paid[1]	Ending Balance[5]
1	€39,140,000	€5,248,674	€1,334,674	€3,914,000	€35,226,000
2	35,226,000	5,115,206.6	1,201,206.6	3,914,000	31,312,000
3	31,312,000	4,981,739.2	1,067,739.2	3,914,000	27,398,000
4	27,398,000	4,848,271.8	934,271.8	3,914,000	23,484,000
5	23,484,000	4,714,804.4	800,804.4	3,914,000	19,570,000
6	19,570,000	4,581,337	667,337	3,914,000	15,565,000
7	15,565,000	4,444,766.5	530,766.5	3,914,000	11,742,000
8	11,742,000	4,314,402.2	400,402.2	3,914,000	7,828,000
9	7,828,000	4,180,934.8	266,934.8	3,914,000	3,914,000
10	3,914,000	4,047,467.4	133,467.4	3,914,000	-0-

Table 5.1: Yearly loan amortization example

1: Equal payments paid each year as specified by the bank.

2: Interest payments are calculated as follows: Beginning Balance X .0341 = Interest Paid

3: Total payment is calculated by: Interest Paid + Principal Paid

4: Beginning balance is reduced by the amount of the **principal payment only** each year.

5: Ending Balance = Beginning Balance – Principal Paid

€7,337,603.90 - total interest paid in ten years term @ 3.41% per annum from €39,140,000.00 principal.

While it is important to pay off the yearly debt as early as possible to eliminate recurring interest charges, it is also important that some of the yearly profit be held back and in reserve for unforeseen events etc. In calculating the debt repayment period the author has decided that after production costs are deducted from yearly gross revenue, half the remaining revenue will be used to pay the yearly debt with the remaining half being kept in reserve.

6.0 Potential Biorefinery Value-added Co-products

Much of the research emphasis in relation to straw and other lignocellulosic biorefineries has centred on how best to maximize production of ethanol from such biorefineries. However, as Ireland and other countries seem to be prioritising electric cars as the mode of transport for the future, it allows time to reappraise how best to use these biorefineries. For example, might it be better to forget about energy production altogether and simply focus on production of materials, like polymers, biomaterials etc.? It has also been mentioned that despite the commitment to large-scale production of electric cars, it still seems inevitable that some of the products of lignocellulosic biorefineries will be fuel products. Ireland are after all mandated by the EU to source 10% of its transport fuels from renewable sources by 2020, and from July of this year that figure must be 4% in Ireland. In addition to biorefinery fuel products being essential to meeting these targets, it also must be appreciated that a world where most/all of personal transport is carried out in electric cars is quite a long way off and a market for biofuels exists. It also seems to make environmental sense to ensure that a percentage of the products of a biorefinery will be motor fuel product/products, as it should reduce dependence of fossil fuels.

But as mentioned before, with such a rapidly growing population we can expect resources other than oil to become in short supply too. As some of these limited resources can be provided as by-products in a biorefinery, it seems to make sense to ensure part of a biorefinery is product-based, particularly where those products are currently based on finite resources. In chapter 7 the author will look at the economic viability of a number of biorefinery configurations both material products based, fuel based, and combinations of both. The following fuel and material products will be looked at in a number of scenarios;

- Bioethanol
- Biobutanol
- Lactic Acid
- Biohydrogen
- Furfural
- Carbon Fibres
- BTX

- Lignin Pellets
- Biogas

Some of the products listed are further along the road towards commercialisation than others, however this analysis will be carried out with an eye towards the future and focusing on the potential of these products to generate revenue with production costs being approximately equal across all biorefinery scenarios. Quoted market values are based on current markets but products may well increase in value with time due to scarcity of resources.

The composition of straw as analysed by McKendry (2002) indicates a cellulose content of 33–40% and a hemi-cellulose content of 20–25%, therefore, a total polysaccharide content of 53–65% is potentially available for fermentation by a suitable organism. A 15-20% share is made up of lignin, with the remaining percentage being minor constituents like wax. The products listed above will come from the cellulose, hemicellulose and lignin components of straw. So the basic biorefinery configuration will be somewhat similar to the lignocellulosic biorefinery discussed in chapter 4, with C5, C6 sugars and lignin (as well as biogas) being the main platforms, but with different co-products produced which will determine the process deployed. For each product, a predicted yield from straw and market value will be presented as determined by the author from the best available data at time of publication.

Biogas will be generated in each scenario to create heat and electricity from the residual cellulose hemicellulose and lignin components once the necessary components to produce the other products have been removed.

6.1 Products using the Cellulose Constituents

As cellulose is largest component of straw the author will now look at some of the products that can be derived from this constituent;

- Bioethanol
- Biobutanol
- Lactic Acid

Bioethanol

Bioethanol is the most common biofuel and is an example of one potential fuel product from the cellulose and or hemicellulose content of lignocellulosic material. This fuel which can be used as a replacement for petrol, or blended with petrol, has been produced from primary feedstocks like sugarbeet and corn, for decades, but can be manufactured in a more sustainable way using second generation feedstocks, such as the straw used in this biorefinery. This is also known as cellulosic ethanol as it is derived from lignocellulosic material. In Section 8.2 the pros and cons of first and second-generation biofuels will be examined. Bioethanol fuel mixtures have "E" numbers, which describe the percentage of ethanol in the mixture by volume; for example, E85 is 85% ethanol and 15% petrol. Blends of bioethanol with petrol are variable, but can generally be as low as 5% (E5) all the way up to 95% (E95). In Ireland following implementation of The Energy (Biofuel Obligation and Miscellaneous Provisions) Bill 2010, all petrol and diesel sold in the Republic will have to include at least 4.166% biofuel. In ethanol terms this would result in an E4/E5 mixture (NORA 2010). According to the U.S. Department of Energy (DOE) (2009) "While ethanol delivers less energy than gasoline on a gallon-for-gallon basis, today's vehicles are designed to run on gasoline blended with small amounts of ethanol (10 percent or less) with no perceptible effect on fuel economy". Some flexible fuel vehicles are capable of running on pure hydrous ethanol (E100) or blended with any combination of E20 to E25 petrol. According to U.S. DOE (2009) "Flex-fuel vehicles designed to run on higher ethanol blends (E85 or 85 percent ethanol) do experience reduced miles per gallon, but show a significant gain in horsepower".

In an effort to see how competitive bioethanol could be with fossil fuels, Deverell *et al*, (2009b) carried out an economic assessment on five biomass-to-ethanol production pathways using straw as the feedstock in one scenario. As has been mentioned in chapter 5, straw was found to be the most promising option of all five biomass to ethanol scenarios with a price of €41/t and yield of 255l/t. Deverell *et al.* (2009b) acknowledge that these prices will be complicated by the fact that technologies are not yet fully mature and the demand for straw in other sectors such as bedding for livestock and compost for mushroom growers.

Production and Yield: The most common means of producing ethanol and the one used here is through cellulolysis processes, which involve hydrolysis on pretreated lignocellulosic materials, and using enzymes to break cellulose into simple sugars such as glucose. This is followed by fermentation and distillation processes. Alternatively gasification can be used to convert lignocellulosic biomass into gaseous carbon monoxide and hydrogen. These gases can be converted to ethanol by fermentation or chemical catalysis. The author suggests that neither of these processes seem to have reach full maturity and efficiency and technological barriers still remain for both. One barrier inhibiting the efficiency of the fermentation process is enzyme cost. The cellulase enzyme required for conversion of lignocellulosic material to ethanol cost around 15-20 cents/gallon as opposed to 2-4 cents/gallon for amylase used in starch to ethanol process for first generation bioethanol. It is hoped that in future enzymes with better and better efficiencies can be available at lower and lower costs. Producing enzymes onsite may also lower costs. Biofuels Digest (2010) says that producers have reduced the cost of production of cellulosic ethanol below USD 2.00 per gallon, or 50 cents (37 euro cents) per litre. According to Biofuels Digest (2010) "in Denmark, Novozymes has announced that productivity increases with its new Cellic CTec2 enzymes have brought enzyme costs down to 50 US cents per gallon, and will enable the biofuel industry to produce cellulosic ethanol at a price below USD 2.00 per gallon for the initial commercial-scale plants that are scheduled to be in operation in 2011".

Bioethanol can be produced from both the cellulose and hemicellulose constituents of straw and other cellulosic matter. The composition of straw as analysed by McKendry (2002) indicates a cellulose content of 33–40% and a hemi-cellulose content of 20–25%, therefore, a total polysaccharide content of 53–65% is potentially available for fermentation by a suitable organism. So cellulosic ethanol can be created from the cellulosic component of straw (36.5%), the hemicellulose component (22.5%) or both (59%). From the above study by Deverell *et al* (2009b) it is stated that straw yields 255 l/t and this seems like a safe assumption as it is verified by Washington state university (2001) who stated "The assumed yield is 69 gallons of ethanol per ton of straw". 69 gallons is equivalent to 261 litres, although there are reports that Iogen's process yields about 75 gallons of ethanol per ton of straw.

Market Value: Due to the difficulty in getting accurate prices at which cellulosic ethanol and other biorefinery fuel products will be sold to the suppliers, or the market value of these products, the analysis will base its figures on current market petrol prices along with the fuel density of the fuel in question. So while cellulosic ethanol has a fuel density of 19.6 MJ/l, petrol has an energy density of 32 MJ/. Current petrol prices in Ireland are about €1.30, so ethanol can expect to achieve a market value of (1.30 x 19.6/32) €0.796/litre. This also seems to be good price to compete with imported ethanol from countries like Brazil. A study carried out by Cooley-Clearpower Research (2006) stated that the market value of Brazilian ethanol in Ireland excluding VAT and excise is almost 0.68 euro/l, rising to almost €0.82/l when VAT is added. While Ethanol from Brazil can be produced at costs as low as €0.25 per litre, when margin, transport and import duty are added, the cost rises significantly. There is a lot of controversy about importing biofuels from overseas due to the unsustainable production of first generation biofuels (which will be examined in section 8.2), so it is therefore important to ensure that indigenous ethanol is as competitive with imported ethanol as possible. While the €1.30 figure for petrol includes excise duty, the figure of €0.796/l for ethanol will be considered a market value without the inclusion of excise as it is already competitive with Brazilian ethanol at €0.82/l (The Biofuels Obligation Scheme ensures that the main competition for indigenous ethanol will be imported ethanol (such as Brazilian ethanol) and not fossil fuels).

BioButanol

Butanol or Biobutanol is another potential product from both the cellulose and hemicellulose constituents of straw. "The current market for butanol is largely industrial, for use as a plasticizer or solvent" (Ethanol Today 2007). But butanol can also be an effective transport fuel. "Butanol is a cleaner and superior fuel extender/oxygenate than ethanol with octane numbers 113 and 94 as compared with that of 111 and 94 for ethanol" (Qureshi *et al.* 2007). Butanol has a fuel density of 29.2 MJ/L. Ethanol with a fuel density of 19.6 MJ/L cannot achieve the same energy levels as butanol. In practice the effectiveness of butanol may actually rival or overtake petrol, as butanol has a strong power and torque content, drivers may use a lighter foot on the accelerator and hold a higher gear longer. As a consequence, fuel efficiency could approximately match that of petrol.

Butanol can replace petrol to any percentage up to 100, however, so far it has been shown that yields of butanol from straw are quite low. According to Ethanol Today (2010) analysis done by the National Renewable Energy Lab, show that most of the advantages of butanol come from its properties as a fuel, not from current production technology.

Processes and yield: Biobutanol can be produced by fermentation of biomass by the A.B.E. Process (named such because it produced Acetone, Butanol, and Ethanol in roughly 6:3:1 ratios) with quite low yields as mentioned above, but according Butylfuel LCC (2010) "ButylFuel, LLC has developed a process which makes fermentation derived butanol more economically viable and competitive with current petrochemical processes and the production of ethanol". This patent is a fermentation-based process, which claims to extract higher yields than was traditionally the case, but commercial success of this technology remains to be proven. "Traditionally, low yields - in the 15 to 25 percent range - have plagued butanol production" (Ethanol Today 2007), so a yield of 20% will be assumed for this analysis. This estimate can be further verified by the following statement "Theoretically, one metric tonne of sugar will yield 648.2 litres of ethanol or 508.1 litres of butanol" (Szulczyk 2010). (Assuming the densities are 0.789 kg per litre for ethanol and 0.8091 kg per litre for butanol). This shows that butanol yield is approximately 80% that of ethanol and assuming an ethanol yield of 255l/ton per tonne we can say that approximately or slightly more than 200 l/ton of butanol can be produced (20%).

Market Value: With an energy density of 29.2 MJ/l it can in theory achieve approximately 90% of the work achieved by the same amount of petrol (energy density 32 MJ/). So if it is assumed for butanol as with cellulosic ethanol above, that market price will be based on energy density, then when petrol prices are €1.30 at the petrol pump, butanol will be €1.19/litre.

Lactic acid

Rather than producing fuels, it is also possible to produce material products from the cellulose constituent of straw. According to Garde *et al.* (2001), "lactic acid is an important chemical used in a wide variety of applications, being primarily used in the food industry as an acidulent, preservative and for the production of emulsifying agents". This journal states other uses as being in production of cosmetics and pharmaceuticals as well as use in textile finishing and metal etching. It also points out a large potential for use as a precursor for biodegradable polylactic acid production, "by co-polymerization with other functional monomers, specific properties can be obtained making it possible to substitute many existing petroleum-derived polymer products".

Production and Yield: In terms of lactic acid yield from straw, according to Maas *et al.* (2008), "711 g lactic acid was produced out of 2,706 g lime-treated straw, representing 43% of the overall theoretical maximum yield". This represents 260g/kg of straw or a yield of 26%. This was achieved through a fermentation process using Bacillus coagulants.

Market Value: Market price of lactic acid can be highly variable. "Lactic acid from €0.70 to €3 a kilo, spans food and feed grade to the higher pharma grade" (Foodnavigator 2005). According to Tejayadi & Cheryan (1995) the current market price of lactic acid in 1988 was $1.60-$. 2.20/kg. The average of these figures is $1.90, adjusting for inflation since 1988 would leave a market price of $3.40 or €2.75kg in 2009.

6.2 Products using the Hemicellulose Constituents

As hemicellulose is the second largest component of straw the author will now look at some of the products that can be derived from this constituent;

- Bioethanol (examined above)
- Biobutanol (examined above)
- Biohydrogen
- Furfural

Biohydrogen (from hemicellulose component)

According to Kaparaju *et al.* (2009), "one alternative prospect for utilization of hemicellulose is to produce biohydrogen. Biohydrogen production of sugars through anaerobic fermentation is recognized as a very promising, environmentally friendly and feasible process". Cherubini *et al.* (2009a) states "Biohydrogen can be used both as an energy carrier and as an important auxiliary chemical for various processing technologies". Biohydrogen (Bio-H^2) is simply hydrogen that has been produced biologically and offers the same opportunities as hydrogen. Hydrogen is used in the petrochemical industry for hydrodealkylation, hydrodesulfurization, and hydrocracking, all methods of refining crude oil for wider use. It is also used in the food industry, to hydrogenate oils or fats, which permits the production of margarine from liquid vegetable oil and is also used as a reducing agent for metal ores. It is often said to be one of the clean fuels with greatest potential going into the future. There are however, some barriers to recognising the potential of the hydrogen market. Prototype hydrogen vehicles have been developed, but there is currently no significant infrastructure for distributing hydrogen as a transport fuel, and in-vehicle storage capacity is still an issue. In addition, hydrogen fuel cells are expensive to produce and fragile, and have a relatively short service life.

Production and Yield: According to Dowaki *et al.* (2006)"Using the moving-bed gasifier, 0.047 kg-H2/kg-biomass material (purity: 99.99%) can be produced due to a gasification process".) But are using fermentation processes, Kaparaju *et al.* 2009, looking at the potential of biohydrogen production from hemicellulose in an integrated biorefinery found that "hydrogen yield from wheat straw hydrolysate (xylose) was around 178.0 ml-H2/g-sugars (0.0178 kg H2/kg) lower than the yield of 334.7 ml-H2/g-sugar which was converted from xylose by using the extreme thermophile of C. saccharolyticus (Kadar *et al.* (2004). This lower yield was due to the fact that the main part of sugars in straw (glucose) had previously been utilized in ethanol production, so only the remaining sugars were used". Pretreated wheat straw was the most energetically efficient for biogas production. Since the biorefinery configurations examined here may be producing bioethanol and butanol in addition to biohydrogen, the lower yield of 0.0178 kH2/kg will be assumed.
Market Value: With an energy density of hydrogen between 120 and 142 MJ/kg (average 131 MJ/kg) gasoline has energy density 32 MJ/L. so if petrol prices are €1.30, then bio-H^2 will be 1.30 x (131/32) = €5.32/kg.

Furfural (from hemicellulose component)
Another means of utilizing the hemicellulose content of straw is to use it for the production of furfural a derivative of xylose with a broad spectrum of industrial applications, such as the production of plastic, pharmaceuticals, and agrochemical products.

Production and yield: according to Mamman *et al.* 2008, the production of furfural is usually based on acid-catalyzed hydrolysis of hemicellulose, however this method is susceptible to poor activity and/or selectivity, difficulty in separation of reaction products, corrosion hazards, and generation of large amounts of neutralization waste. So, acid hydrolysis to isolate xylose/pentoses, followed by cyclodehydration of the isolated product to Furfural using solid acid catalysts, will be used to minimize loss of FF as a result of resinification and or condensation." The potential furfural yield for typical feedstock is expressed in terms of kg of furfural per metric ton of dry biomass. It is reported to be 220 for corncobs, 170 for bagasse, 160 for cornstalks, 160 for sunflower hulls, and approximately

150–170 for hardwoods" (Mamman *et al.* 2008). Since cornstalks contain a hemicellulose content of 27% (Ahmed & Zhu 2006), similar to the 25% of straw assumed in this analysis, a similar yield of furfural can be assumed for straw (i.e. 160 kg/ton).

Market Value: According to Win (2005) "Current world production of furfural is about 250,000 t/a, at a stable price of $1,000/t".
And this price is verified by Hayes *et al.* who state that "the current market price of furfural is approximately $1/kg compared with prices in 1990 of $1.74/kg for furfural and $1.76/kg for furfuryl alcohol. They add that "EU and US import tariffs are placed on furfural from China, these being designed to lessen this effect of this price differential but market prices are still highly dependent on Chinese supply". $1/kg currently converts to €0.81/kg.

6.3 Lignin-Based Products

Since lignin constitutes up to 30% of the weight and 40% of the fuel value of biomass it can be used to increase fuel production but given the right technology production of material products may offer greater income than energy. The author will describe the following potential products of this contitutent;

- Carbon Fibres
- BTX (Benzene Toluene Xylene)
- Lignin Pellets

Carbon fibres (CF)

Carbon fibre, a material consisting of extremely thin fibres composed mostly of carbon atoms, is often used to reinforce composite polymers According to Kadla *et al.* (2002) "carbon fiber composite products are routinely used in sports equipment, marine products, construction, and the automotive industry. Carbon fibre has a number of benefits such as low weight, high tensile strength, chemical inertness, thermal and dimensional stability. According to Brodin (2009) the major drawback of CF is its high production cost. Growth in demand was about 10% annually from 2002 to 2006 (Brodin 2009), but this could increase considerably if the cost can be lowered In spite of this the demand. Since the raw material accounts for 45-60 % of the total cost of CFs according to Lindgrin (2009), lignin is an attractive alternative, due to its availability and comparably low cost. There are environmental benefits of increasing the use of lignin based carbon fibres. Using lignin in the carbon fibre manufacturing process improves raw material availability, decreases raw material sensitivity to petrol cost, and decreases environmental impacts. Using carbon fibre-reinforced plastics as opposed to steel panels can make vehicles more lightweight, reducing fuel requirement. However, the technology used in CF production may be less mature than some of the more obvious options of lignin utilization.

Production and yield: Gasification processes would facilitate production of carbon fiber precursors from lignin and may make the recovery and storage of large amounts of lignin commercially attractive (Compere *et al.* (2001). According to Compere *et al.* (2001) whose studies involved the spinning of a range of lignin-blend fibres that can be oxidized, carbonized, and graphitized, "production of carbon fibre precursor from renewable and recycled materials is feasible. The yield of fibre appears to be approximately 50%". Additionally, the availability of high temperature process heat from biogas may decrease carbon fibre process costs.

Market value: according to Robert E. Norris Jr., leader of ORNL's Polymer Matrix Composites Group "The cost to purchase commercial-grade carbon fiber is between $8 and $10 per pound, the goal is to reduce that figure to between $3 and $5 per pound " (Norris 2006).

Allowing for the conversion factor of 2.2 for pounds to kg

$8-10 per pound = 2.2 x $8-10 = $17.60 –20 per kg.

However according to Compere *et al.* (2001) "For the automotive industry to benefit from carbon fiber technology, fiber production will need to be substantially increased and fibre price decreased to $7/kg". "The industry, as a part of the Partnership for a New Generation of Vehicles, has estimated that a carbon fiber price of $7/kg would make use in passenger vehicles attractive. This would require significant reductions in both feedstock and production costs"(Compere *et al.* (2001)). So while current market prices would see carbon fiber fetch well in excess of $7/kg or €5.67, it will be assumed from the above articles that lignin based carbon fibers will be sold at that low price to attract a large market.

Benzene, Toluene, Xylene (BTX)

Lignin is the only renewable source of an important and high-volume class of compounds—the aromatics. These include BTX and phenol. Benzene, toluene, and xylene (BTX) are very important petrochemical raw materials for polymer and other petrochemical syntheses. According to Timken & Angevine (1997) "The worldwide demand for BTX has grown constantly. BTX can be made by a number of different methods, for example, by synthesis from C2 and C3 olefins or, in a refinery, by distillation and extraction from a refinery stream, typically from a reformer". As petroleum resources become more depleted and prices increase, direct and efficient conversion of lignin to discrete molecules or classes of high-volume, low-molecular weight aromatic molecules will be an attractive option and a big challenge. According to Holladay *et al.* (2007) "technology developments may lead to two sets of compound classes. One of these, which would arise from aggressive (i.e., non-selective) depolymerization in the form of C-C and C-O bond rupture, is aromatics in the form of BTX plus phenol and includes aliphatics in the form of C1 to C3 fractions Of course, there is the possibility of forming some C6-C7 cycloaliphatics as well. These products could be easily and directly used by conventional petrochemical processes". The same paper also points out that technology remains a challenge. "Development of the required aggressive and non-selective chemistries is part of the long-term opportunity but is likely to be achievable sooner than highly selective depolymerizations".

Yield and Market value: In relation to potential yield of BTX from lignin, the study by Holladay *et al.* (2007) carried out by looked at a number of scenarios for utilizing the residual lignin after the carbohydrate portion of biomass was used to generate 60 billion litres of bioethanol. Based on an assumption that 60 billion gallons of fermentation ethanol will require 0.75 billion tons of biomass and that biomass is composed of 30% lignin there will be 225 million tons of lignin to be utilized in each scenario. In one scenario looked at by Holladay, et al, (2007) (Scenario 3), lignin is converted to simple aromatic chemicals (BTX) using gasification. Under this scenario 12.7 billion gallons (48 billion litres) of BTX are produced at a value of $24.9 billion. Assuming this "value" refers to market value, then it is possible to work out a market value of BTX of (24.9/12.7) $1.96 per gallon BTX, or €0.41/litre. It is also possible therefore to calculate the yield as (48 billion/225 million) 211 l/ton. Kaiser & Hanselmann (1982) showed that aromatic chemicals could also be produced through anaerobic microbial conversion of lignin monomers.

Lignin Pellets

One of the more obvious uses for lignin is to convert it to lignin pellets which can be burned in boiler, in the same manner as wood pellets. The main advantage that lignin pellets offer over traditional wood pellets is a higher calorific value, this will allow greater work to be done, it can also mean less demanding storage requirements for the consumer. According to Knaggs & O'Driscoll (2008) "In 2006, just over 1,000 tonnes of wood pellets were recorded as being imported into Ireland. This market is likely to grow as demand for renewable fuel increases".

Production and yield: The wood pelleting process involves milling and reduction of particle size, and then conditioning with dry steam and water to the required temperature and moisture content to activate the binding ability of lignin and to achieve the correct malleability. The pellets are then compressed to the correct compaction ratio and cooled until hardened. "The energy consumed to operate the pellet mill and heat the steam corresponds to 2.5-3% of the energy content of wood" (SEAI 2004). In terms of yield, it can be assumed that virtually all the lignin constituents can be palletized.

Market value: Globally the market price of wood pellets is highly variable;

- in the Austrian market between €140-150 per ton without delivery and around €170 per ton including delivery,
- in the Swedish market around ~ €215 per ton (€44 per MWh) Bulk delivery and ~€230 per ton (€47 per MWh) sack delivery.
- in the US market anywhere from $120-200 per ton and averages $150" (SEAI 2004)

In Ireland, pellets purchased at the average €170 per ton are competitive with average energy costs of oil. At approx. 22 MJ/kg, lignin has a higher calorific value that air-dry wood (15 MJ/kg). This means that lignin pellets will do the same work as regular wood pellets discussed above, while consuming less fuel. As the above prices are related to wood pellets, which have a lower calorific value, it can be assumed that lignin pellets will fetch higher prices. Walsh (2010, pers. comm..) has estimated that his company should be able to sell lignin pellets at approximately €200 per tonne, which taking into account the market value estimates for wood pellets and allowing for increased energy potential of lignin pellets seems like a reasonable estimate.

6.4 Biogas Production from Residual Matter

According to the European Biomass Association (2010), biogas as a secondary energy carrier can be produced out of many different kinds of organic materials and its options for utilisation can be equally versatile. Biogas can be used to generate electricity, heat and biofuels. The remaining fermentation residues can be used, for example as a fertiliser. "In Sweden biogas is converted to a transport fuel by scrubbing out non-methane gases. Typically 1Nm ^{3} of biogas will replace 0.6 litres of petrol (Murphy 2005).
In April 2005 "1Nm ^{3} of biogas will generate 2kWh of electricity which will generate a revenue of €0.14 (allowing €0.07/kWh from biogas" (Murphy 2005). As will be shown this revenue has increased to between €0.085 and €0.15/kWh depending on the quantity of biogas produced and the process used.

Each biorefinery configuration examined in the chapter 7 will assume the production of biogas from the residual streams. According to Kaparaju *et al.* (2008) "A sustainable solution for removal of the residual organic matter in the effluents from bioethanol and biohydrogen processes is to convert them to biogas and use the residual effluents as fertilizers on agricultural soil". Biogas, which consists mainly of methane and carbon dioxide, is the product after anaerobic digestion of a wide biomass, and it essentially the waste product of microorganisms used during fermentation. Each biorefinery scenario studied will use its residual waste stream to produce biogas in a digester in anaerobic conditions. The biogas will be then be transferred to an integrated Combined Heat and Power (CHP) facility where it will be used to generate electricity for market and heat for the biorefinery processes.

Production and yield: According to Walsh (2010, pers. Comm..), 20% residues from a straw biorefinery may be considered available for biogas production. If the total yearly feedstock to the Biorefinery is 156,862.74 tons of straw as indicated previously and according to Walsh (2010, personal communication) 20% residues will be available for Biogas then 31,373 tons or 31,273000 kg/VS will be available.

In terms of biogas yield from this quantity in an integrated straw biorefinery, Kaparaju *et al.* (2008) showed that the effluents from both bioethanol and biohydrogen processes produced methane with the yields of 0.324 and 0.381 m^3/kg volatile solids (VS) added, respectively. The average yield of 0.3525 m3/kgVS will be assumed. So if 0.3525m^3 methane can be produced from 1kgVS then;

31,273000 will produce 11,023,733m^3 methane (31,273000 x 0.3525)

According to Kofman (2010) Natural gas (1,000 m^3) produces thermal energy of 39 GJ or 10.83 MWh) per m^3 of methane. So 11,023,733 m3 will produce:

119,387,028 kWh thermal energy per year (11,023,733m^3 x10.83)

However," Each cubic meter (m^3) of biogas contains the equivalent of 6 kWh of calorific energy. However, when we convert biogas to electricity, in a biogas powered electric generator, we get about 2 kWh of useable electricity, the rest turns into heat which can also be used for heating applications" (Electrigaz 2010). Since methane is the main proportion of biogas responsible for producing electricity and heat, we can assume from this that a third of the methane calculated above can be used to produce electricity. Therefore 39,795,676 kWhe (119,387,028 kWh/^{3}) or 39,797 MWhe will be available for conversion to electricity. As there are 8,760 hours in a year, it means that the CHP will require approximately a 5MWe specification.

Market value: The guaranteed support price (REFIT) will range from 15 cent per kilowatt hour to 8.5 cent an hour depending on the technology deployed.

The tariffs, when CHP are in high efficiency mode, are as follows

Biomass CHP ≤1500kW 14c/kWh

Biomass CHP >1500kW 12c/kWh

Since this biorefinery production of electricity from methane will be well in excess of 1500 kWh the 12 c/kWh tariff will apply. Therefore it can be envisaged that using our biorefinery residues to produce electricity could generate revenue of up to €4,775,481 (39,795,676 x €0.12).

This figure will be assumed for each biorefinery scenario. However, this figure is very much an approximation, and in reality it will vary with each biorefinery. Actual availability of residual biomass for biogas production will vary with each biorefinery.

In order to meet the generous tariff of €0.12/kWh it is important for the CHP plant to demonstrate it is in high efficiency mode. As can be seen in figure 6.1 below, for the CHP plant to be efficient it must find a means of utilizing its heat component in the form of steam as well as selling or using the electricity it generates. Finding a use for the heat generated by steam will not be incredibly difficult in these biorefineries given that many of the processes used will require heat to varying degrees. In order for a plant to qualify for the feed-in tariff a required efficiency must be achieved. According to DCENR (2009);

"High Efficiency CHP means Electricity generating plants harnessing energy from biomass for the simultaneous production in one process of thermal energy and electrical energy where –

i) in the case of cogeneration units of the types of pressure turbines, turbines with heat recovery, internal combustion engines, microturbines (meaning a co-generation unit with an installed capacity below 50 kWe), sterling engines and fuel cells shall have an overall annual energy efficiency capability of at least 75%

ii) in the case of cogeneration units of the types of combined cycle turbines with heat recovery and steam condensing extraction turbines, shall have an overall annual energy efficiency capability of at least 80%".

So depending on the technology deployed, the plant will need to ensure over 75% or 80% efficiency to qualify for the tariff. Looking at potential technologies that could be deployed;

- Gas Turbine; Gas turbine plants use the waste heat in the flue gas (methane) of gas turbine
- Steam Turbine; Steam turbine plants use high pressures and temperatures, boilers and other equipment and must be designed and manufactured to a high specification. This is expensive and according to the WDC (2008) CHP units using steam turbines are usually economical only above 2 MWe technology (which suits our specification).
- Organic Rankine Cycle (ORC); Instead of using steam, an Organic Rankine Cycle (ORC) uses an alternative substance with more favourable thermal properties. The alternative substance, usually a silicone, drives a turbine but at lower temperatures and pressures. As a result, WDC state that ORC units (from approximately 200 kWe up to 5 MWe) are usually more cost-effective than steam turbines

- Gasification; While steam engine and ORC systems typically convert less than 20% of the input energy to electrical power, biomass gasification systems have electrical efficiencies of up to 33%, making it potentially extremely profitable.
- Stirling Engines; Stirling engines are used usually on a smaller scale and with low electrical efficiency (typically ~ 12%), so will not be considered.

Some of these technologies will be able to ensure that the CHP facility reaches the 75/80% efficiency needed to qualify for the €0.12/kWh tariff, however it is not really possible to determine the most suitable biorefiney as it will be dependent on the individual biorefinery in question. For example a biorefinery scenario which uses one or a number of thermochemical conversion is likely to significantly higher heating requirements than those which don't deploy such technologies, and such a biorefinery may opt to use a technology which is more effective at converting the heat energy into work than electricity conversion. Similarly, a biorefinery which is configured to secure an ultra high efficiency and energy security may retain all the energy produced from biogas for its own onsite use. As a result of these reasons the €4,775,481 figure, which can generated from producing electricity from biogas and waste residues will be assumed, but may in some case be lower that this.

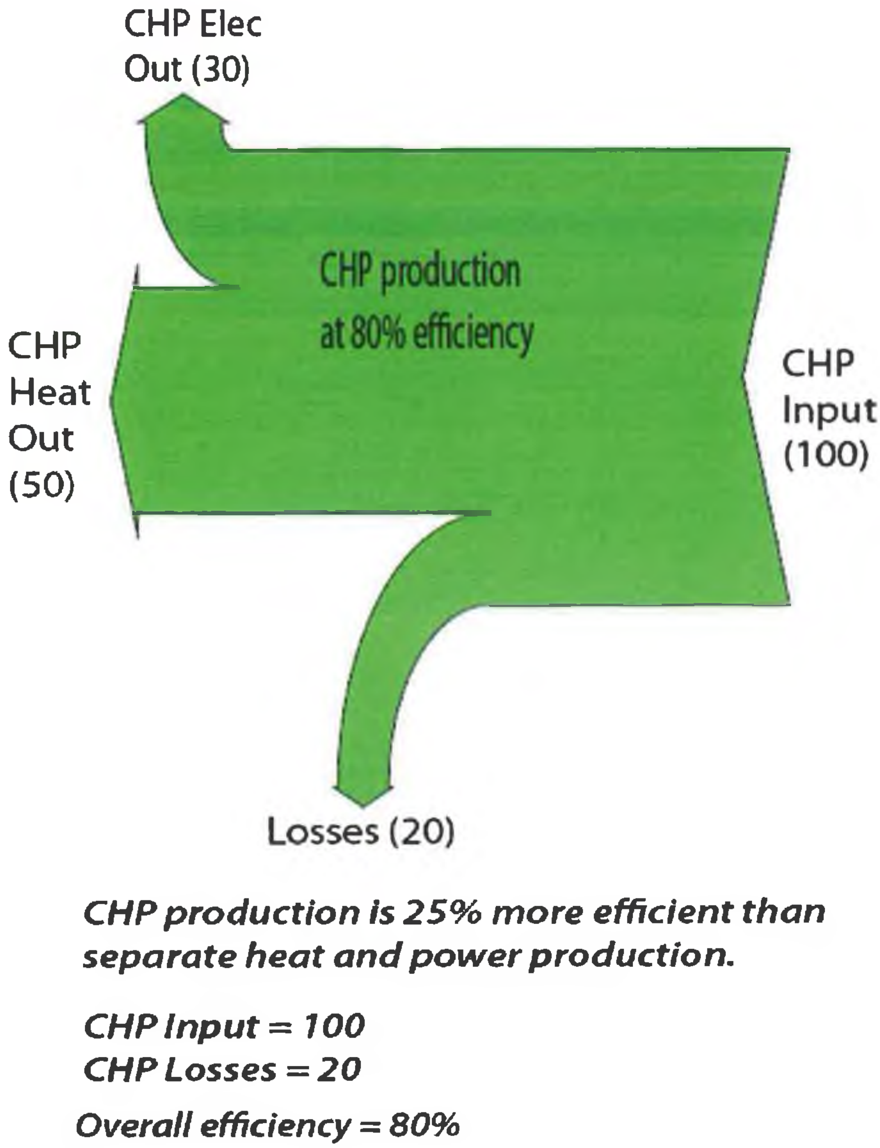


Figure 6.1 Efficiency requirements of CHP (Dennehy *et al.* 2010)

7. Biorefinery Configuration Examples

Having previously, decided upon an appropriate raw material (straw), having determined our biorefinery costs and having examined a number of potential co-products, this chapter will look at five potential biorefinery scenarios or configurations where the biorefinery is set out to produce a combination of products. All of the scenarios will produce some of the products examined in the previous chapter:

- Bioethanol
- Biobutanol
- Lactic Acid
- Biohydrogen
- Furfural
- Carbon Fibres
- BTX
- Lignin Pellets
- Biogas

Five biorefinery configurations will be examined as displayed in figure 7.1 below:

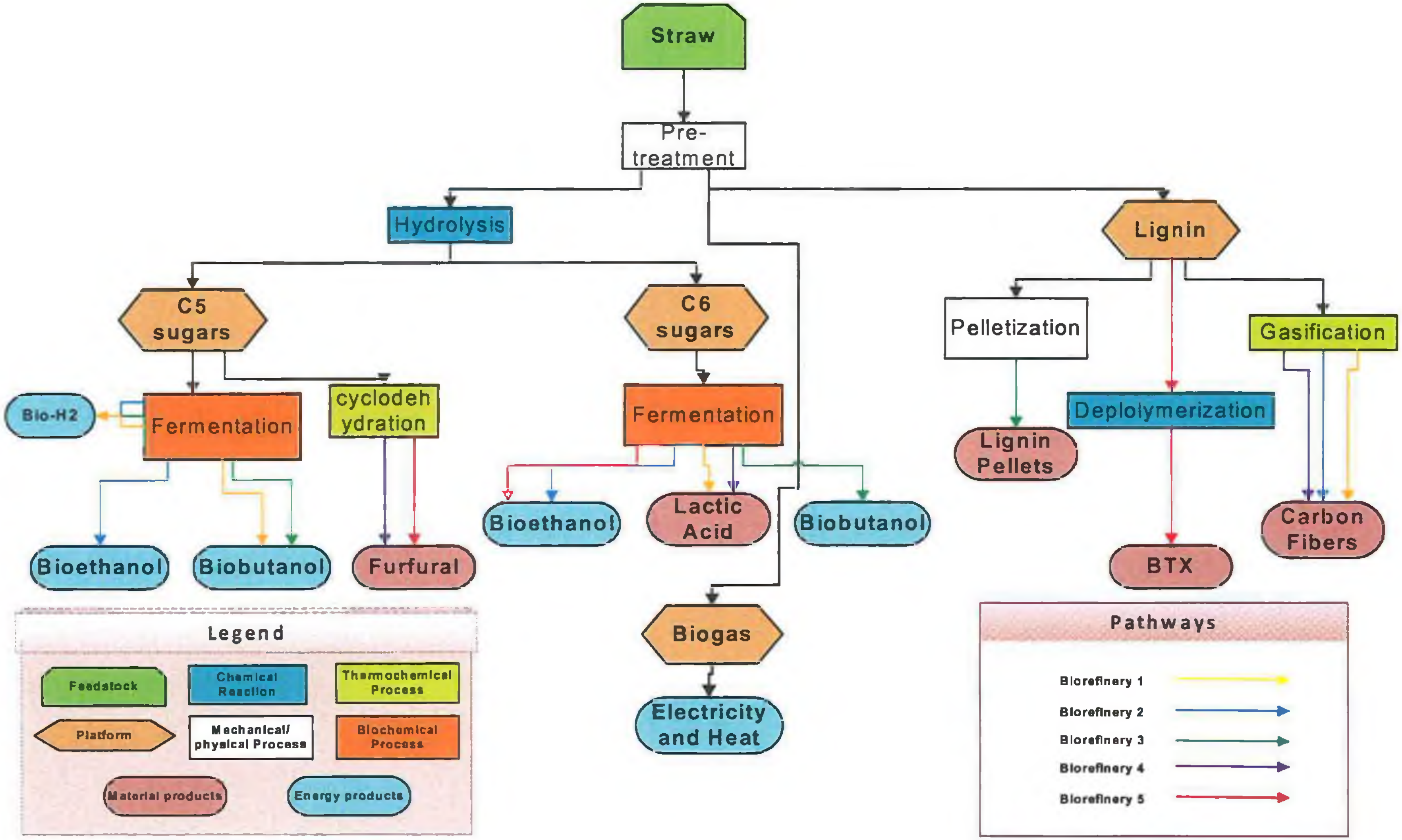


Figure 7.1: Summary of Biorefinery Configurations

As indicated in chapter 6, some of the products listed are further along the road towards commercialisation than others, however this analysis will be carried out with an eye towards the future and focusing on the potential of these products to generate revenue with all things being equal, including production costs.

In this chapter the author will assess the predicted revenue from the combination of products in each scenario and deduct all costs incurred including costs of facility, production and feedstock, which have been determined in chapter 5. These costs will be assumed to be equal across all five biorefinery scenarios. While biorefineries are extremely individualistic, the study by Hayes in chapter 5 shows a similar cost pattern is emerging across many biorefineries, and this will be expected to continue as greater technological advances are made across different co-product scenarios. By deducting these expected costs from potential revenue, it will be possible to assess the economic sustainability of the biorefinery. Since market value was the only available source of information on revenue potential, a number of deductions have to be made by the author, initially for VAT at 21%. Once VAT has been deducted from the gross revenue 30% of the remaining revenue will be deducted for the supplier, as €0.79/l represents market price and a commission for the supplier must be included within that price. In real life terms this figure would be negotiated between producer and supplier, so it cannot be clearly defined. However 30% seems like a generous commitment depending on the profitability of the product. This estimate can be adjusted in future if this mark-up estimate becomes more clearly defined for each product in question.

As mentioned earlier due to the planned introduction of excise duty to be payable on biofuels later this year under the Biofuels Obligations Scheme, a second economic assessment will be carried out on each biorefinery to accommodate this scenario (with the exception of the material product biorefinery where excise will not be applicable). In an economic assessment of ethanol, Deverell *et al.* (2009b) produced a sensitivity analysis with showed that with price of straw is assumed as €41/t it was projected that production will be uneconomical with or without excise when petrol pump prices are below €0.75/litre. Production was economical without excise when petrol pump prices are above €0.75/litre and economical with excise when petrol pump prices are above €1.31/litre (study assumed excise at €0.44/l). This indicates the importance that excise can play in the competitiveness of biofuels (particularly with fossil fuels).

According to IRBEA (2010) "biofuels will now have to pay excise duty of 37 c/l". In this assessment when excise duty is payable it will be added on to the market value of biofuel products initially, so in the case of bioethanol it will mean that the excise (€0.37) will be added to the market value (0.79 euro) so that the new market value will be €1.16. According to Sunday Business post (2002), "in Ireland, Vat at 21% is not just charged on the base price of fuel but on the total price after the government excise duty is added". So tax at 21% will be calculated on the market value of the biofuel once the excise is added on (1.16euro). So the tax in the case of bioethanol will be calculated as (€0.79 (market value) + €0.37 (excise)) x 0.21 (vat). Once VAT has been deducted from the gross revenue, 30% of the remaining revenue will be deducted for the supplier. Only once these deductions have been made can the €0.37/l excise be removed from our calculations, with the remainder being profit.

As shown previously the different fuel products generate different revenue potential based on fuel potential, so an excise duty of 37c/l will represent a different proportion of each products market value and so too will the tax on this excise. Ultimately the customer will foot the bill for this excise payment. The issue of competitiveness with fossil fuels is not a major problem since the Biofuels Obligation Scheme demands that biofuels be incorporated by suppliers of fossil fuels. The issue of competitiveness with foreign biofuels is more concerning, but by ensuring that bioethanol with excise relief will have a market value of €0.79/l versus Brazilian ethanol at €0.82/l (also with excise relief), there is a strong ability to deal with the additional excise. In addition to €0.37/l being added to Irish Biofuels, this will also be added to foreign biofuels, meaning that bioethanol in these biorefinery scenarios maintain competitiveness, and retain their market but will be forced to pay higher tax (as tax is placed at 21% on market value + excise).

Full calculations will be shown within text for the first biorefinery configuration with and without excise relief. For the remaining configurations full calculations can be found in appendix, with only a brief summary (Accumulated revenue and payback period) displayed within this chapter.

7.1 Biorefinery 1 Analysis with Excise Relief

(C5/C6 Sugars and lignin biorefinery for biobutanol, biohydrogen, lactic acid, carbon fibres and biogas from straw (with excise relief)

The first straw biorefinery scenario evaluates the production of Biohydrogen and Biobutanol using the C5 sugars, lactic acid from C6 sugars, carbon fibres from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. This scenario assumes excise relief on fuels produced. Table 7.1 below, is a method for calculating the gross revenue potential of the biorefinery. This method displays the amount of feedstock that will be available for use in producing a particular product as well as the expected yield of the product. The quantity of the product can thus be calculated. This yield quantity will then be multiplied by the market value to determine the gross revenue potential.

	Required feedstock percentage	Yield	Market value	Gross Revenue Potential
Biobutanol *(using C5 sugars)*	20-25% (35,295 tons)	20%	1.19 euro/litre	35,295000kg x .2 = 7,059,000 litres @ 1.19 euro/l = 8,400,210 euro
Biohydrogen	20-25% (35,295 tons)	0.0178 kg H2/kg	5.32 euro/kg	35,295000 x 0.0178 = 628,251kg x 5.32 euro/kg = 3,342,295
Lactic Acid	33-40% (57,255 tons)	26%	2.75 euro/kg	57255000x .26 =14,886,300 kg @ 2.75 euro/kg =40,937,325
Carbon fibres	15-20%(27,450)	50%	5.67 euro	1372500kg x5.67euro = 7,782075
Biogas to electricity	20% (31,373 tons)	(0.3525 m3/kgVS) x (10.83/kwh/3)	12/c kWhe	4,775,481

Table 7.1: Calculation of market potential of each product when excise relief is granted

Having calculated the gross revenue potential of each product it was necessary to make deductions for VAT at 21% and allowing the supplier a 30% mark-up on what remains. The table below calculates the revenue once these deductions have been made. This will calculate the net revenue (excluding deductions for debt and production costs) for a biorefiney scenario when excise is not payable on fuel products.

	Gross Revenue	**VAT** *(Gross Revenue @ 21%)*	**Revenue after Tax***(Gross Revenue – VAT)*	**Mark-up for Supplier** *(Revenue after Tax@ 30%)*	**Total Deductions** ***(VAT + Mark up for Supplier)***	**Net Revenue** *(Gross Revenue – Total Deductions)*
Biobutanol *(using C5 sugars)*	8,400,210	1,764,044	6,636,166	1,990,850	3,754,894	4,645,316
Biohydrogen	3,342,295	701,882	2,640,413	792,124	1,494,006	1,848,289
Lactic Acid	40,937,325	8,596,838	32,340,487	9,702,146	18,298,984	22,638,341
Carbon Fibres	7,782,975	1,634,425	6,148,550	1,844,565	3,478,990	4,303,985
Biogas	4,775,481	0	0	0	0	4,775,481
Total						€38,211,412

Table 7.2: Estimated revenue potential of the biorefinery after deductions have been made for VAT and supplier mark-up

Having calculated a net revenue of 38,211,412 euro per year it is then necessary to calculate the loan payback of 39.14million plus interest. For economic reasons the loan will be repaid in the shortest time practicable. While it is important to pay off the yearly debt as early as possible to eliminate recurring interest charges, it is also important that some of the yearly profit be held back and in reserve for unforeseen events etc. In calculating the debt repayment period the author has decided that after production costs are deducted from yearly gross revenue, half the remaining revenue will be used to pay the yearly debt with the remained half being kept in reserve. Due to the great profitability of this biorefinery as indicated by the calculations above, 3years was the chosen payback term. This is displayed below:

Year term calculation for debt payment

	Gross revenue	38,211,412
Less	Production cost	9,140,000
		29,071,412
Multiply	For debt allocation of 50%	0.50
		14535706
Then:		
	Loan amount	39,140,000
Divide		14535706
	Years	2.693 **3 years**

Table 7.3: Year term calculation for debt repayment

The loan amortization schedule is represented in the table below and will be paid over 3 years

Year	Beginning Balance	Total Payment	Interest Paid	Principal Paid	Ending Balance
1	39,140,000	14,381,341	1,334,674	13,046,667	26,093,333
2	26,093,333	13,936,449	889,783	13,046,667	13,046,667
3	13,046,667	13,491,558	444,891	13,046,667	0

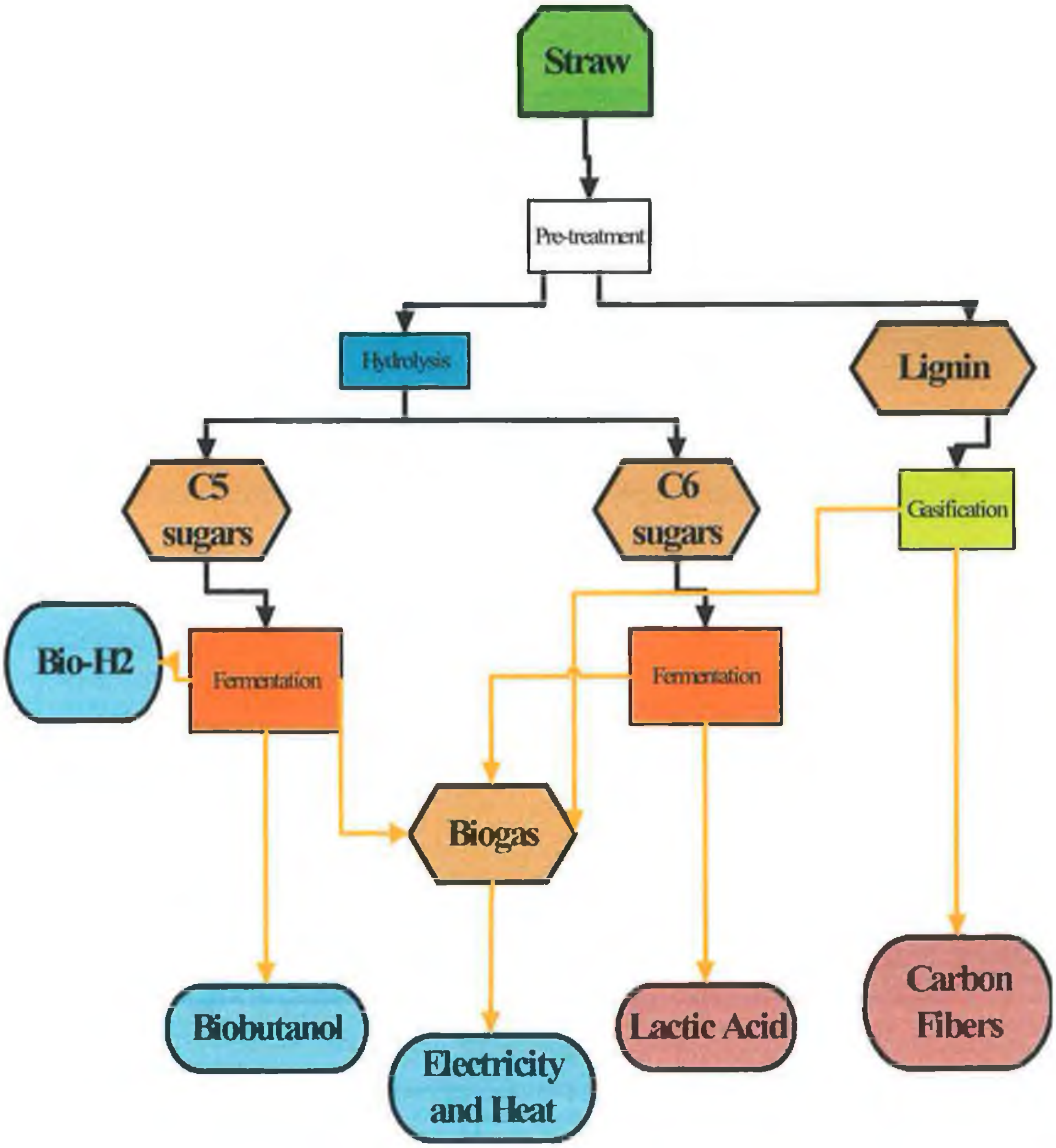
Table 7.4: Loan Yearly Amortization Schedule

Once this schedule was established it was possible to calculate the potential revenue of biorefinery after all costs had been removed. For the first 3 years of the biorefinery these costs consisted of loan amortization plus yearly production costs of 9.14 million (VAT and supplier mark-up have previously been deducted, and these are deducted from gross revenue. For every year thereafter the only remaining cost to be deducted is the production cost (9.14 million), except for the final years balance, which does not require a deduction for production costs.

As can be seen from the table below, the accumulated revenue of the biorefinery over its life span of 25 years will be euro 694,115,952 after all costs have been reduced. This means that an average profit of 27.76 million can be generated every year with a payback period of 3 years.

Year	Gross Revenue	Loan Amortization	Production Cost	Total Cost	Revenue Balance
1	38,211,412	14,381,341	9,140,000	23,521,341	14,690,071
2	38,211,412	13,936,449	9,140,000	23,076,449	15,134,963
3	38,211,412	13,491,558	9,140,000	22,631,558	15,579,854
4	38,211,412	0	9,140,000	9,140,000	29,071,412
5	38,211,412	0	9,140,000	9,140,000	29,071,412
	↓				↓
23	38,211,412	0	9,140,000	9,140,000	29,071,412
24	38,211,412	0	9,140,000	9,140,000	29,071,412
25	38,211,412	0	0	0	38,211,412
Accumulated Revenue					**€694,115,952**

Table 7.5: Projected Accumulated Revenue over lifespan of 25 years



C5/C6 Sugars and lingin biorefinery for biobutanol, biohydrogen, lactic acid, carbon fibers and biogas from straw (with excise relief)

Accumulated Revenue (minus costs); €694,115,952
Payback period; 3 years

Figure 7.1: Accumulated Revenue and Payback

7.2 Biorefinery 1 analysis without Excise Relief

(C5/C6 Sugars and lignin biorefinery for biobutanol, biohydrogen, lactic acid, carbon fibres and biogas from straw (without excise relief))

	Required feedstock percentage	**Yield**	**Market value with excise (+0.37)**	**Revenue potential** (Excise included)	**Excise payable @ 0.37 litre**
Biobutanol (using C5 sugars)	20-25% 35,295	20%	1.19 + 37 = 1.56 euro/l	35,295000kg x .2 = 7,059,000 litres @ 1.56euro/l = 11,012,040euro	7,059,000 x 0.37 = 2,611,830
Biohydrogen	20-25% (35,295)	0.0178 kg H2/kg	(5.32 +37)= 5.69	35,295000 x 0.0178 = 628,251kg x 5.69 euro/kg = 3,574,748	628,251kg x 0.37 =232,453
Lactic Acid	33-40% (57,255 tons)	26%	2.75 euro/kg	57255000x .26 = 14,886,300 kg @ 2.75 euro/kg =40,937,325	0
Carbon fibres	15-20% (27,450)	50%	$7 per kg 5.67 euro	1372500kg x5.67euro = 7,782075	0
Biogas to electricity	20% (31,373 tons)	(0.3525 m3/kgVS) x (10.83/kw h/3)	12/c kWhe	4,775,481	0

Table 7.6: Calculation of market potential of each product when excise is added

The table below calculates the revenue once excise, VAT on excise and 30% mark-up for the supplier have been deducted. This will calculate the net revenue (excluding debt and production) for a biorefiney scenario where excise is payable on fuel products.

	Gross Revenue	**VAT** *(Gross Revenue @ 21%)*	**Revenue after Tax** *(Gross Revenue – VAT)*	**Mark-up for Supplier** *(Revenue after Tax@ 30%)*	**Excise**	**Total Deductions** *(VAT + Mark up for Supplier + Excise)*	**Net Revenue** (*Gross Revenue –* Total Deductions)
Biobutanol *(using C5 sugars)*	11,012,040	2,312,528	8,699,512	2,609,853	2,611,830	7,534,212	3,477,828
Biohydrogen	3,574,478	750,640	2,823,838	847,151	0	1,597,792	1,976,686
Lactic Acid	40,937,325	8,596,838	32,340,487	9,702,146	232,453	18,531,437	22,405,888
Carbon Fibres	7,782,075	1,634,236	6,147,839	1,844,352	0	3,478,588	4,303,487
Biogas	4,775,481	0	0	0	0	0	4,775,481
Total							**€36,939,371**

Table 7.7: Estimated revenue potential of the biorefinery after deductions have been made for excise, VAT on excise and supplier mark-up

The debt payback period is calculated at 3 years as indicated below;

	Year term calculation for debt payment		
	Gross revenue	36,939,371	
Less	Production cost	9,140,000	
		27,799,371	
Multiply	For debt allocation of 50%	0.50	
		13899686	
Then:			
	Loan amount	39,140,000	
Divide		13899686	
	Years	2.816	**3 years**

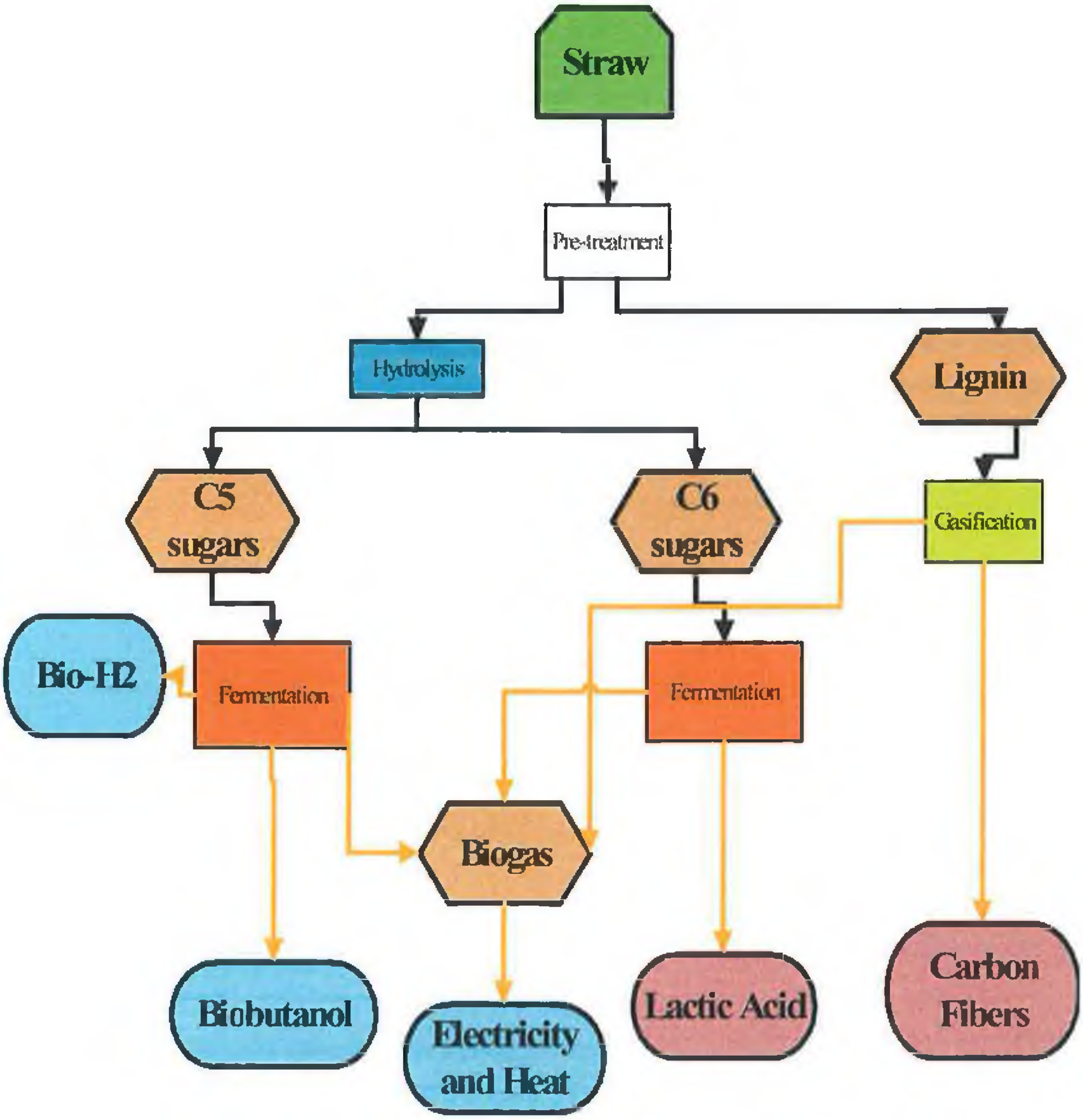
Table 7.8: Year term calculation for debt payment

Year	Beginning Balance	Total Payment	Interest Paid	Principal Paid	Ending Balance
1	39,140,000	14,381,341	1,334,674	13,046,667	26,093,333
2	26,093,333	13,936,449	889,783	13,046,667	13,046,667
3	13,046,667	13,491,558	444,891	13,046,667	0

Table 7.9: Loan Amortization Schedule

Year	Gross Revenue	Loan Amortization	Production Cost	Total Cost	Revenue Balance
1	36,939,371	14,381,341	9,140,000	23,521,341	13,418,030
2	36,939,371	13,936,449	9,140,000	23,076,449	13,862,922
3	36,939,371	13,491,558	9,140,000	22,631,558	14,307,813
4	36,939,371	0	9,140,000	9,140,000	27,799,371
5	36,939,371	0	9,140,000	9,140,000	27,799,371
	↓				↓
23	36,939,371	0	9,140,000	9,140,000	27,799,371
24	36,939,371	0	9,140,000	9,140,000	27,799,371
25	36,939,371	0	0	0	36,939,371
Accumulated Revenue					**€662,314,927**

Table 7.10: Projected Accumulated revenue over lifespan of 25 years



C5/C6 Sugars and lingin biorefinery for biobutanol, biohydrogen, lactic acid, carbon fibers and biogas from straw (without excise relief)

Accumulated Revenue (minus costs); €662,314,927

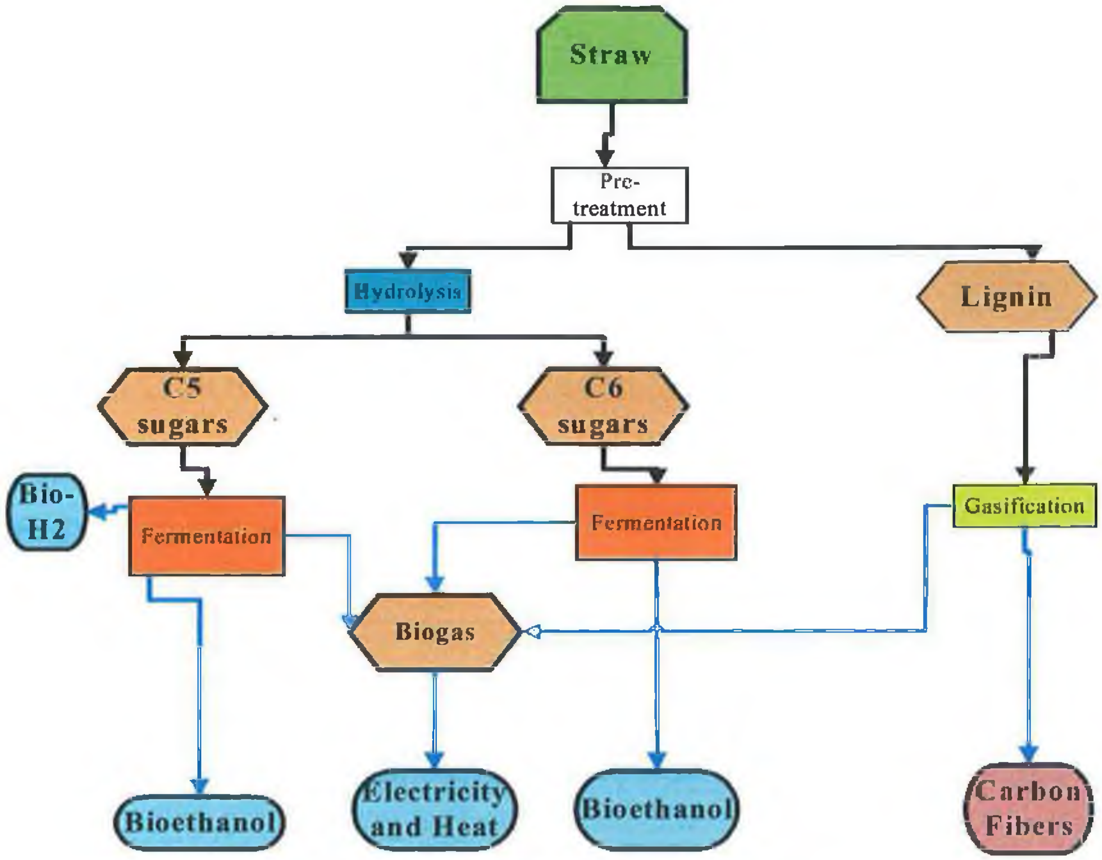
Payback period; 3 years

Figure 7.2 Accumulated Revenue and Payback

7.3 Biorefinery 2 Summary with Excise Relief

(C5/C6 Sugars and lignin biorefinery for bioethanol, biohydrogen, carbon fibres and biogas from straw (with excise relief))

The next straw biorefinery scenario evaluates the production of Biohydrogen and Bioethanol using the C5 sugars, with bioethanol also being produced from the C6 sugars, carbon fibres from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise relief is assumed on fuel products (see Appendix 1 for calculations).



C5/C6 Sugars and lingin biorefinery for bioethanol, biohydrogen, carbon fibers and biogas from straw (with excise relief)

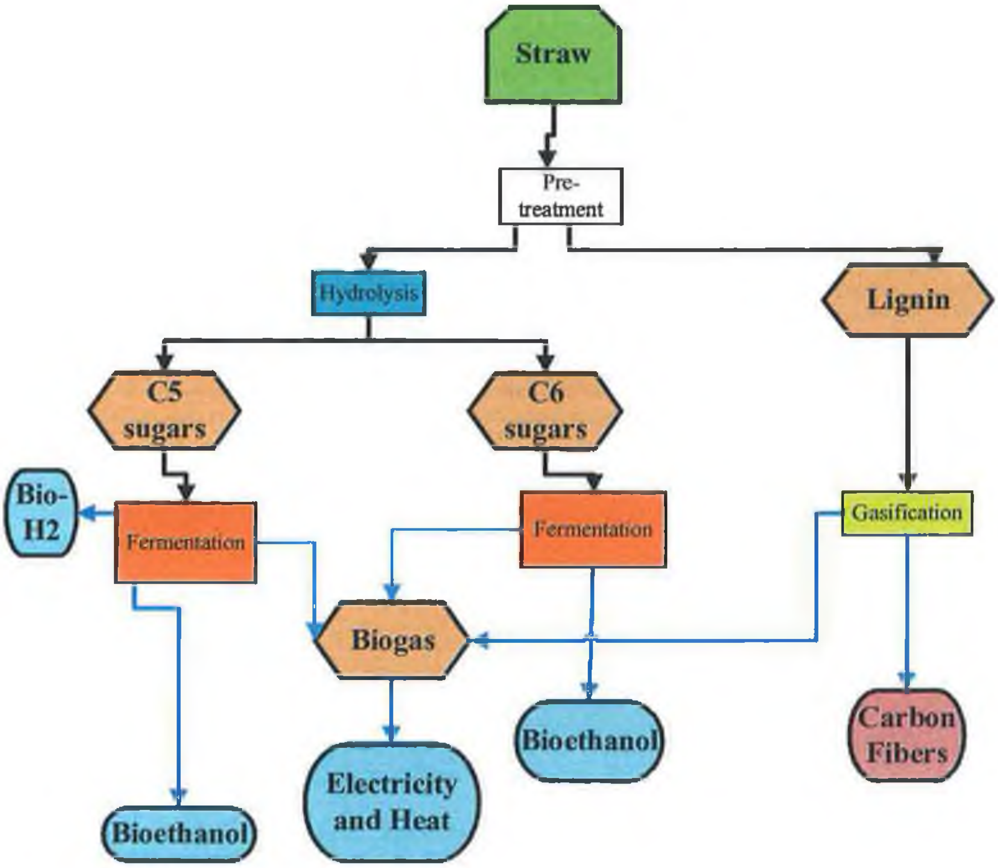
Accumulated Revenue (minus costs); €267,777,516
Payback period; 6 years

Figure 7.3: Accumulated Revenue and Payback

7.4 Biorefinery 2 Summary without Excise Relief

C5/C6 Sugars and lignin biorefinery for bioethanol, biohydrogen, carbon fibres and biogas from straw (without excise relief)

The biorefinery below scenario evaluates the production of Biohydrogen and Bioethanol using the C5 sugars, with bioethanol also being produced from the C6 sugars, carbon fibres from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise is assumed payable on fuel products (see Appendix 2 for calculations).



C5/C6 Sugars and lingin biorefinery for bioethanol, biohydrogen, carbon fibers and biogas from straw (without excise relief)

Accumulated Revenue (minus costs); €164,913,793

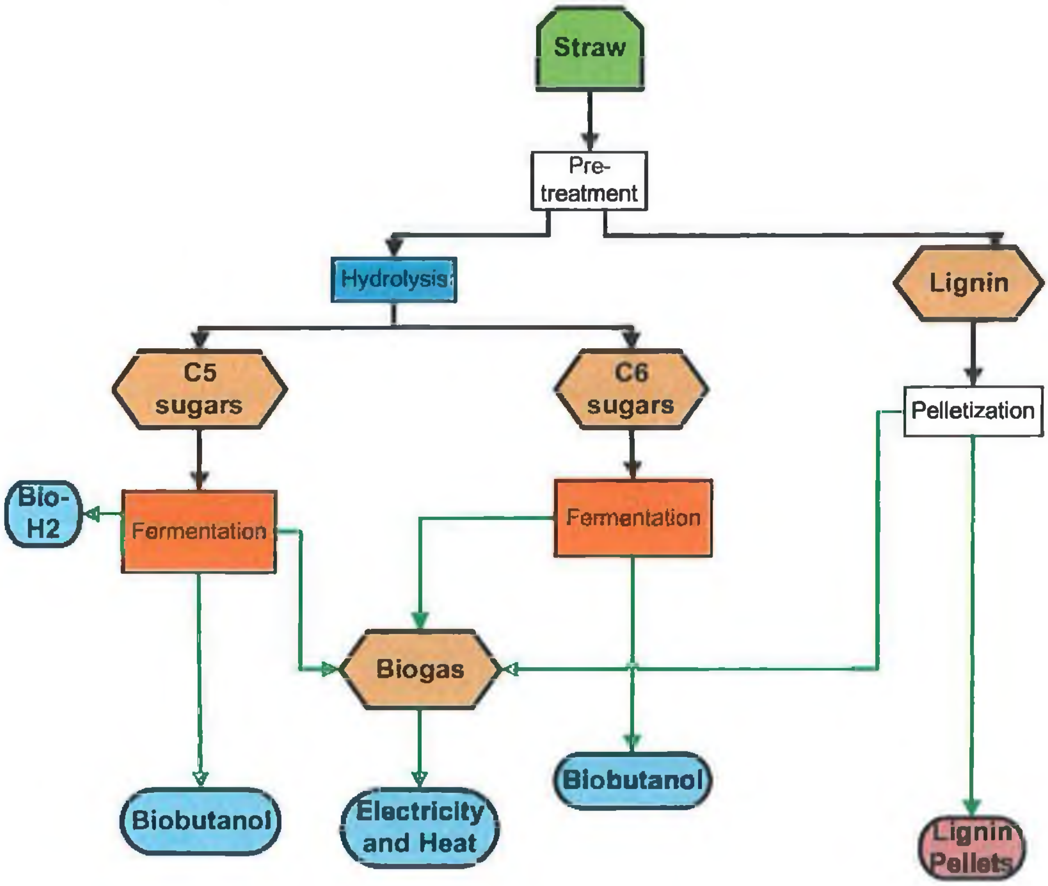
Payback period; 10 years

Figure 7.4: Accumulated Revenue and Payback

7.5 Biorefinery 3 Summary with Excise Relief

(C5/C6 Sugars and lignin biorefinery for biobutanol, biohydrogen, lignin pellets and biogas from straw (with excise relief))

The next biorefinery scenario evaluates the production of Biohydrogen and Biobutanol using the C5 sugars, with biobutanol also being produced from C6 sugars, and the lignin component pelletized into lignin pellets, with the residual matter being used to generate electricity (and heat) from biogas. Excise relief is assumed on fuel products. (See Appendix 3 for full calculations).



C5/C6 Sugars and lingin biorefinery for biobutanol, biohydrogen, lignin pellets and biogas from straw (with excise relief)

Accumulated Revenue (minus costs); €282,839,816

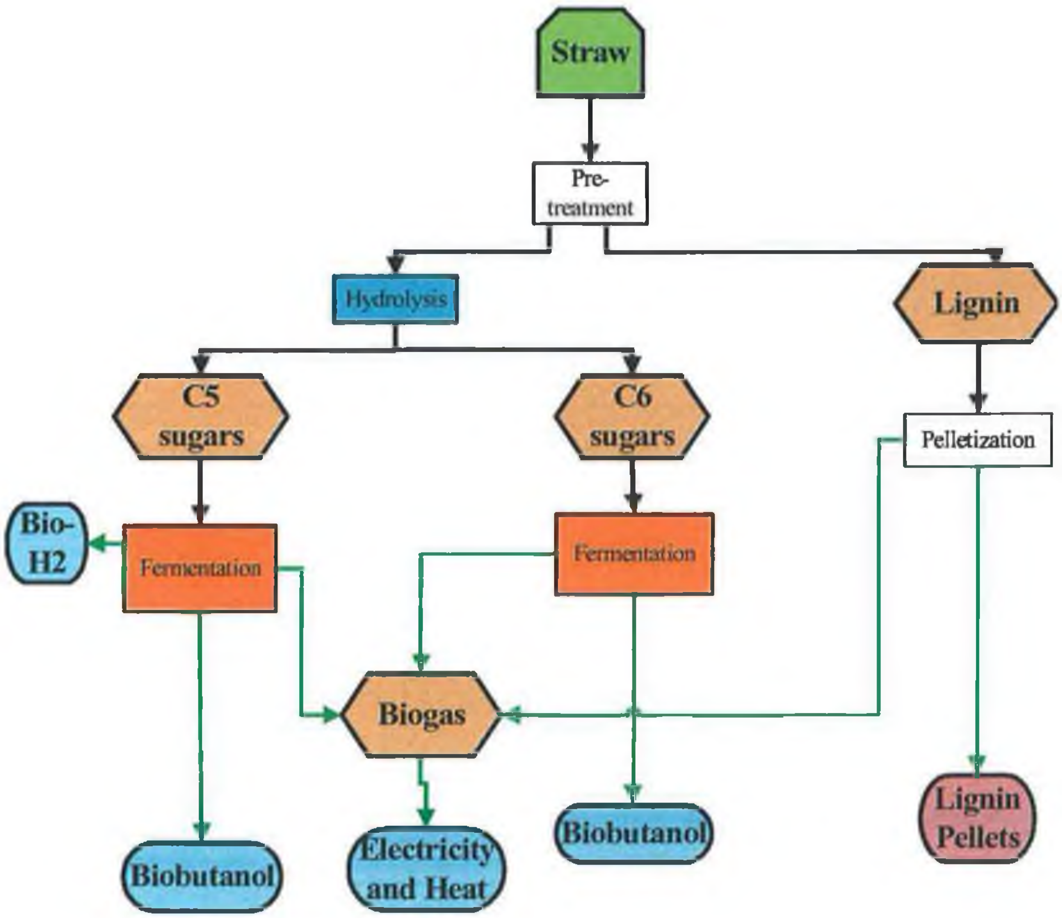
Payback period; 6 years

Figure 7.5: Accumulated Revenue and Payback

7.6 Biorefinery 3 Summary without excise relief

(C5/C6 Sugars and lignin biorefinery for biobutanol, biohydrogen, lignin pellets and biogas from straw (without excise relief))

The next biorefinery scenario evaluates the production of Biohydrogen and Biobutanol using the C5 sugars, with biobutanol also being produced from C6 sugars, and the lignin component pelletized into lignin pellets, with the residual matter being used to generate electricity (and heat) from biogas. Excise is assumed payable on fuel products. (See Appendix 4 for calculations).



C5/C6 Sugars and lingin biorefinery for biobutanol, biohydrogen, lignin pellets and biogas from straw (without excise relief)

Accumulated Revenue (minus costs); €202,371,917

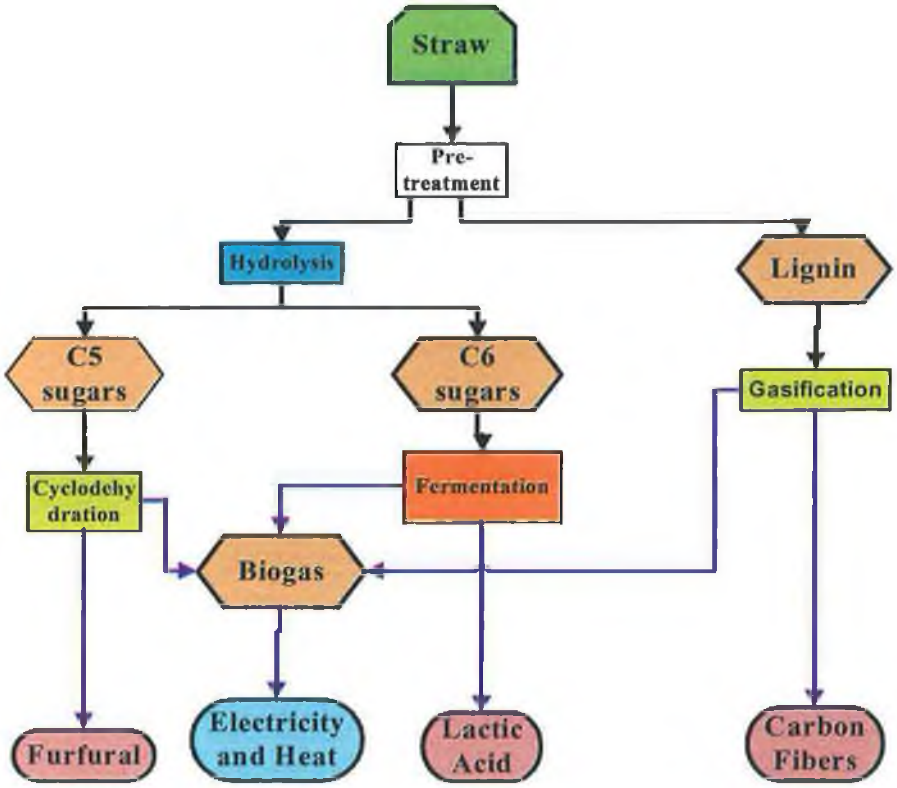
Payback period; 8 years

Figure 7.6: Accumulated Revenue and Payback

7.7 Biorefinery 4 Summary

(C5/C6 Sugars and lignin biorefinery for furfural, lactic acid, carbon fibres and biogas from straw (Product Based Biorefinery – excise not applicable)

The next straw biorefinery scenario evaluates the production of furfural using the C5 sugars, lactic acid from C6 sugars, carbon fibres from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise relief is not applicable as fuel products with the exception of biogas are not produced. (See Appendix 5 for calculations).



C5/C6 Sugars and lingin biorefinery for furfural, lactic acid, carbon fibers and biogas from straw (Product Based Biorefinery – excise not applicable)

Accumulated Revenue (minus costs); €595,014,577

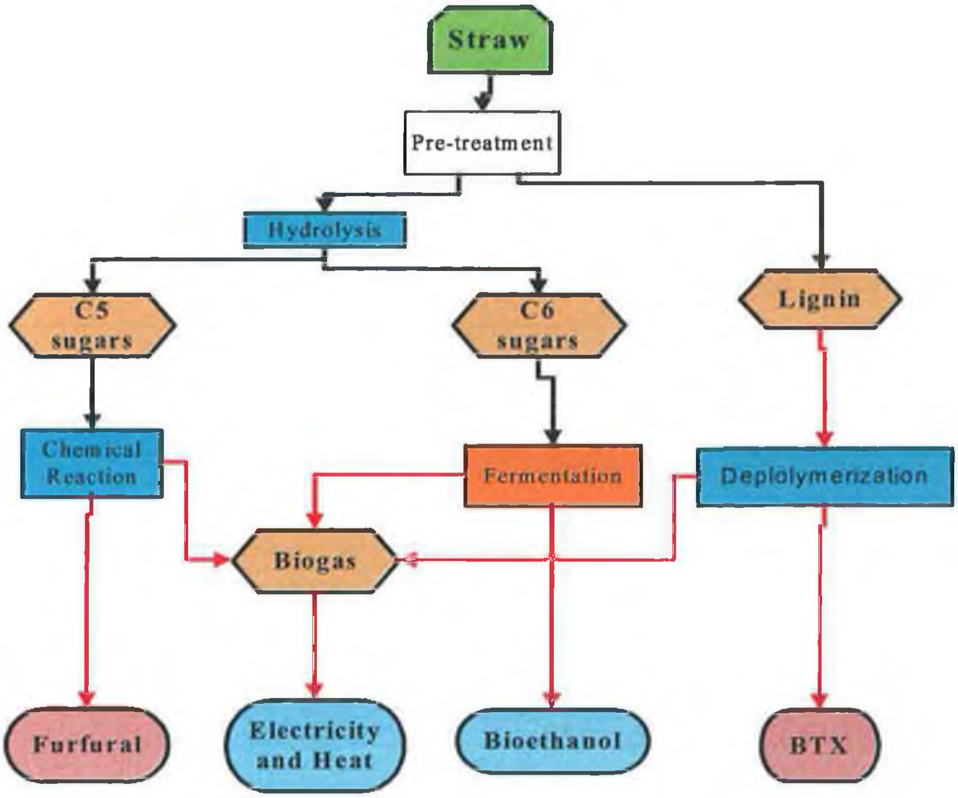
Payback period; 3 years

Figure 7.7: Accumulated Revenue and Payback

7.8 Biorefinery 5 Summary with Excise Relief

(C5/C6 Sugars and lignin biorefinery for furfural, bioethanol, BTX and biogas from straw (with excise relief))

The final straw biorefinery scenario evaluates the production of furfural using the C5 sugars, bioethanol from C6 sugars, BTX from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise relief is assumed. (See Appendix 6 for Calculations)



C5/C6 Sugars and lingin biorefinery for furfural, bioethanol, BTX and biogas from straw (with excise relief)

Accumulated Revenue (minus costs); €107,225,657

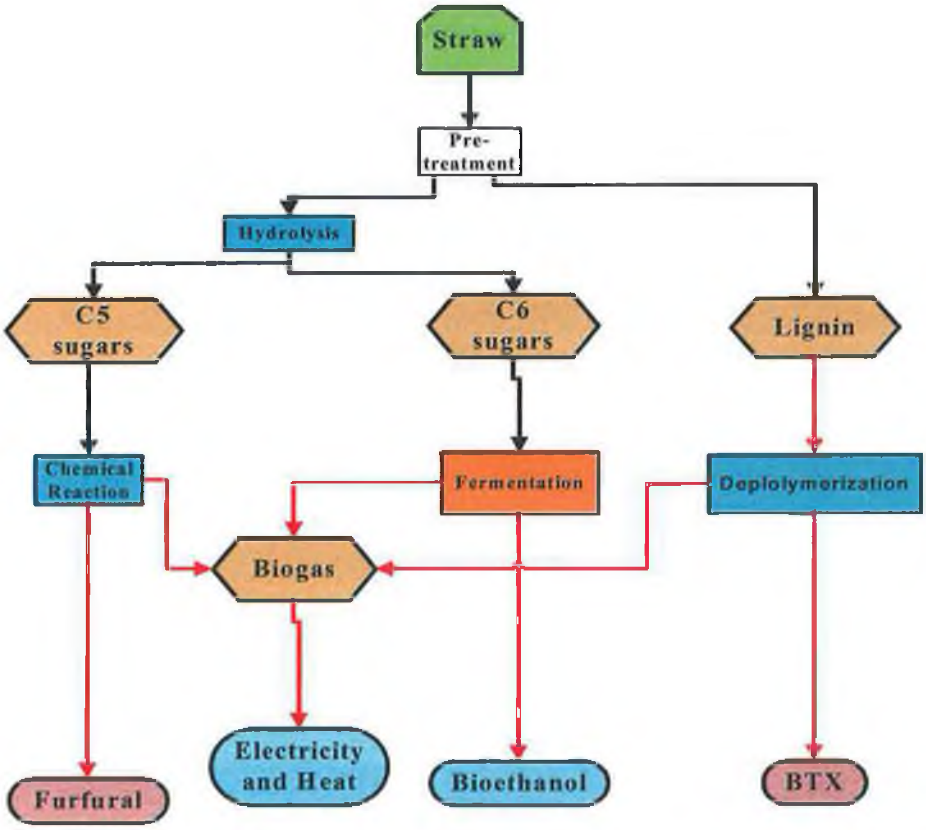
Payback period; 13 years

Figure 7.8: Accumulated Revenue and Payback

7.9 Biorefinery 5 Summary without Excise Relief

(C5/C6 Sugars and lignin biorefinery for furfural, bioethanol, BTX and biogas from straw (without excise relief))

The final straw biorefinery scenario evaluates the production of furfural using the C5 sugars, bioethanol from C6 sugars, BTX from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise is assumed payable on fuel products. (See Appendix 7 for full calculations)



C5/C6 Sugars and lingin biorefinery for furfural, bioethanol, BTX and biogas from straw (without excise relief)

Accumulated Revenue (minus costs); €40,185,887

Payback period; 23 years

Figure 7.9: Accumulated Revenue and Payback

7.10 Summary of Biorefinery Configuarations Economic Analysis

All biorefinery scenarios show the potential of being profitable to varying degrees depending largely on the co-products selected. The “C5/C6 Sugars and lignin biorefinery for biobutanol, biohydrogen, lactic acid, carbon fibres and biogas from straw (with excise relief)” shows the greatest potential in terms of profitability. The “C5/C6 Sugars and lignin product-based biorefinery for furfural, lactic acid, carbon fibres and biogas from straw” is unaffected by the introduction of excise on transport fuels. Biorefineries, which produce higher density fuels like butanol and biohydrogen, are less affected by the introduction of excise than those producing bioethanol.

8.0Sustainability of biorefineries from an economic, environmental and social point of view

As mentioned earlier, the idea of a sustainable future must be looked at under the headings of economic, environmental and societal sustainability. These are known as the three pillars of sustainability. So in order for a technology such as biorefinery to be genuinely considered sustainable, it is important to assess it's contribution and performance under each of these pillars. In this chapter the author will also examine the contribution that a biorefinery can make to Irelands overall renewable energy capacity.

8.1 Economic Sustainability

Chapter 7 has demonstrated the potential of biorefineries to be economically sustainable. Much of the criticism that has been aimed at indigenous bioenergy in recent years is associated with the lack of competitiveness with fossil fuels without excise relief. The new Biofuels Obligations regulations means that indigenous biofuels no longer need to compete with fossil fuels, as all fossil fuel supplies must now contain a biofuel quota of 4.166%. Rather, indigenous biofuels will now have to compete with biofuels produced in other countries. As shown in this report, by delivering bioethanol and other biofuels at a price that competes with international biofuels, indigenously produced biofuels will be back in control of the biofuels market in Ireland. This of course is not always easy to do, especially with the end to excise relief on biofuels under the Biofuels obligation scheme. To facilitate this, the profits made from the production of bioethanol may be quite small or minimal. This could really impinge on the profitability of small suppliers who focus only on biofuel production. But from a biorefinery point of view the effects are likely to be less severe. The fuel supplies from a biorefinery can be sold at a very competitive cost with the co-products produced adding value to the biorefinery and ensuring profitability (as could be seen in some of the scenarios in chapter 7). With this strategy, over time foreign biofuel producers will find it very difficult to produce and deliver biofuels at a rate that competes with those produced by second-generation biorefineries. Unlike biorefineries however, smaller indigenous producers will not have the same flexibility of reducing their production costs and profit margins on bioethanol to corner their share of the market. This emphasizes the importance of value-added biorefinery co-products particularly in a difficult and competitive market. From the scenarios in chapter 7 it can be seen that value-added and sustainably-derived co-products such as lactic acid, carbon fibers can significantly enhance the profitability of a biorefinery, which can still contribute significant quantities of renewable energy. Should further excise-relief steps be put in place for producers of indigenous biofuels in future then it will be possible to reassess the biorefinery configuration, however as mentioned already sustainably-derived materials might be just as important as sustainably derived fuels in the future world.

The economic assessment of the previous chapter shows how biorefineries can be not only viable, but extremely profitable in Ireland. The assessment does it's best to formulate a costing scenario based on the as yet, limited data available to the public on the cost of establishing and operating a second generation biorefinery. These figures can be adapted as more reliable and consistent figures become available. One may estimate the establishment of a biorefinery facility as being greater than that estimated in this report, but if that is the case, many of the most profitable scenarios in chapter 7 still have plenty of scope to accommodate extra costs. In any case, any inaccuracies are likely to be balanced out over time, as aspects of biorefining become less expensive. Like any new technology, second generation biorefinery technology and processing has started off quite high, but will become more efficient and affordable as it develops. While many of the products examined in these biorefinery scenarios may not be fully commercialized in terms of cheap and efficient production, technological advancements in getting to the stage of second-generation biofuels indicate that further progress is extremely likely. And while not all of the products examined in chapter 6 have a current market that is as obvious as the bioethanol market, biorefineries are future thinking and adaptable technologies with an almost infinite amount of co-products, and it is important to examine future as well as current markets. It is also important that one does not underestimate the selling power of sustainably produced and "green products" in coming decades. Already ecolabelling is used in the EU (part of a broader EU Action Plan on Sustainable Consumption and Production and Sustainable Industrial Policy adopted by the European Commission on 16 July 2008) to help consumers to identify products, which are considered green based on their environmental impacts throughout their life cycle. Although the scheme is currently voluntary there is an expectation that this will not be the case in the future. Demand for such products is likely to intensify due to changing government and industry policies as well increasing customer awareness. In future, products that do not meet the ecolabel standard may be banned from trading within the EU market.

8.2 Environmental impacts of biomass and bioenergy utilization

The EC Biofuels directive 2003/30/EC demands from the member states that a share ("Reference Percentage") of 10% of fossil fuels sold on their transportation markets should be replaced by biofuels by 2020. But to many, biofuels create some controversy when discussed as an environmentally sustainable energy.

Traditionally biofuels have been manufactured by processing sugar, starch or oil from food-based crops such as sugarbeet and corn using conventional technology. These first generation biofuels and associated biorefinery systems have a number of problems. According to Cherubini & Jungmeier (2009) "the main advantages of first generation biofuels are due to the high sugar or oil content of the raw materials and their relatively easy conversion into biofuel, while the disadvantage is the competition with food and feed industries for the use of biomass and agricultural land". So there is the ethical question of using food crops to produce energy in a world where many people don't have food to survive. Brown (2009) said last year that "A fourth of this year's U.S. grain harvest—enough to feed 125 million Americans or half a billion Indians at current consumption levels—will go to fuel cars. Yet even if the entire U.S. grain harvest were diverted into making ethanol, it would meet at most 18 percent of U.S. automotive fuel needs. The grain required to fill a 25-gallon SUV tank with ethanol could feed one person for a year". For this reason food crop ethanol has gained notoriety in some circles. Hijacking food crops for biorefinery usage results in price hikes in food and starvation for many. So there is also the issue of would-be biofuel producer paying food prices for first generation biorefinery feedstock. Food prices are open to extreme fluctuations as has been seen numerous times throughout history often resulting from poor crop yields in a particular year, and given the growing population and food demand the trend for high food prices will almost inevitably continue. So in addition to the ethical concerns, there are huge question marks over the economic stability of first generation biofuels.

In addition to these concerns is the environmental concern that the life cycle savings in CO^2 and other greenhouse gas emissions when compared with fossil fuels has been the subject of criticism, with claims that savings are minimal. While such systems will reduce our dependency on imported oil according to Goodall (2008) they require "large inputs of fossil fuel energy to produce the fertilizer, look after the growing crop and process the grain into sugars and then ethanol. Moreover, when it breaks down chemically in the soil, artificial fertilizer produces a small amount of nitrous oxide, a greenhouse gas over 300 times more powerful than carbon dioxide". Cherubini & Jungmeier (2009) state that most Life Cycle Assessments (LCA) carried out so far indicate that it is environmentally beneficial to use first generation ethanol as a substitute for petrol in transport, however, "considering other environmental aspects (acidification, eutrophication, ozone depletion, etc.) and including land use change effects in GHG balances, biofuels substituting fossil fuels may lead to increased negative impacts". According to U.S. DOE (2009) ethanol produced from corn only results in about a 20% reduction in GHG emissions relative to petrol.

A combination of the above factors has resulted in criticism of biofuels over the last ten years, however the EU, United States and the IEA, continued with enthusiastic support for biofuels. Bioenergy experts knew that enhancing first generation technologies would eventually lead to breakthroughs in more advanced and sustainable bioenergy sources. In defence of the EU's persistence with first generation biofuels European Commissioner for Agriculture and Rural Development Mariann Fischer Boel stated, "Until now, biofuels have been produced by processing agricultural crops. The challenge is to further develop the technologies for biofuels based on different feedstocks such as lignocellulosic materials and waste. This needs the short-term improvement of existing technologies but also the development of more advanced biofuels, for which the environmental and economic gains are expected to be higher"(Boel 2006). According to Goodall (2008) "Biofuels made from simple starchy and sugary molecules in food are just the first stage in the exploitation of biological materials for use as petrol and diesel replacements. The next generation of biofuels will not use the seeds of wheat and maize to make petrol replacements; they will use much more complicated molecules contain in wood and agricultural wastes". This is referred to as second-generation biorefining, which has already been exemplified in the five straw-based biorefinery configurations studied in the last chapter. Second-generation biorefining pursues a more sustainable path than the traditional biofuel production methods, by using biomass consisting of the residual non-food parts of current crops, like stems and leaves, as well as other non food crops like switch grass and miscanthus. Waste from industry such as woodchips and pulp can also be used. These are referred to as lignocellulosic biomass. This obviously resolves the ethical concerns about diverting the food crops away from the food chain for energy use. It will also remove the huge susceptibility to fluctuating food prices, and as this material is already growing in abundance naturally there will be less demands on land space, less deforestation and greater co2 savings versus traditional biofuel feedstocks.

According to Bryant (2009), ethanol from cellulose reduces green house gas emission by 90 percent, when compared to gasoline and in comparison to corn-based ethanol which decreases emissions by about 20 percent (Agricultural Marketing Resource Centre 2009). The potential greenhouse gas savings from second-generation cellulosic ethanol versus corn ethanol and gasoline can be seen in figure 8.1 below. Achieving such high savings will be somewhat dependent on using some of the energy from the residual biomass constituents (e.g. lignin) in the production process. To that end, careful decision may need to be made on whether to use residual streams for energy or material purposes.

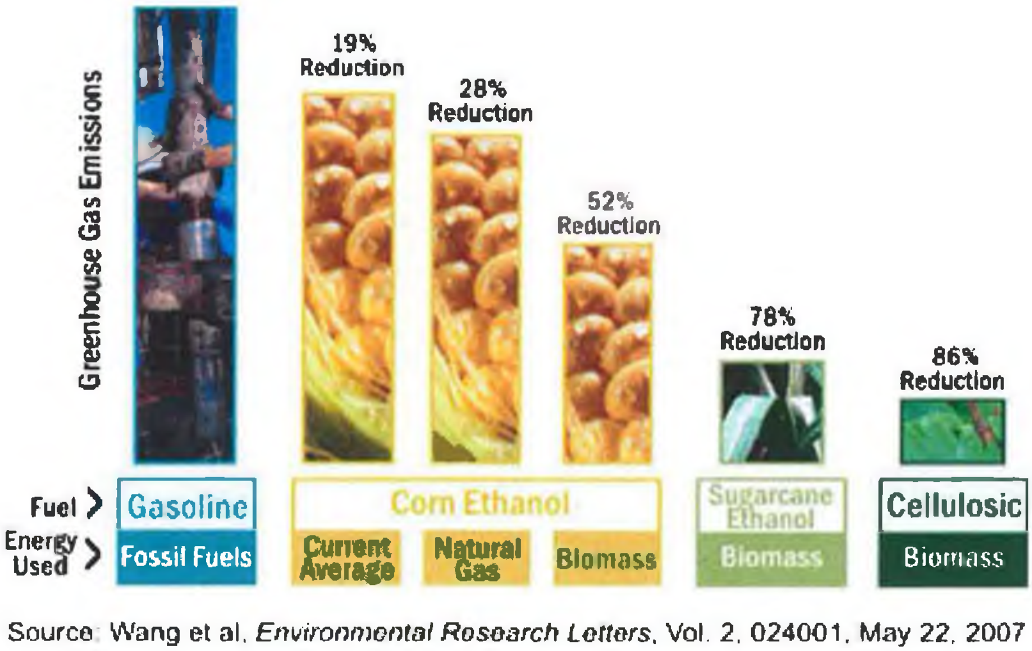


Figure 8.1: Comparison of Greenhouse gas savings between cellulosic ethanol and corn ethanol (U.S. D0E 2009)

While there are question marks over the total CO^2 savings and environmental benefits that can be achieved through the use of dedicated crop feedstocks in first-generation biorefineries, second-generation biorefineries have been more positively received in this regard. Whereas first-generation biorefineries require that more and more land be set aside for corn and starch crops, feedstock for second generation biorefineries is made up of residues from current plant and crops and other agricultural wastes, and as such does require deforestation or further land to be set aside. According to Cherubini *et al* (2009b) "Unlike dedicated bioenergy crops, biowaste and residues are not produced specifically for use as an energy resource. They are the result of economic activity and production of goods in almost all sectors of the economy". When the Life Cycle Assessment was carried out on a second-generation biorefinery concept producing bioethanol bioenergy, and chemicals from switchgrass, Francesco Cherubini et al found that it was "an effective option for mitigating climate change, reducing dependence on imported fossil fuels, and enhancing cleaner production chains based on local and renewable resources" but says that "the provision of biomass with sustainable practices is then a crucial point to ensure a renewable energy supply to biorefineries".

When Cherubini & Ulgiati (2009) carried out a broader study "Crop residues as raw materials for biorefinery systems" they found that "significant GHG and fossil energy savings are achieved when the biorefinery system is compared with a fossil reference system. GHG savings are in the range of 50% while non-renewable energy savings go beyond 80%". While these benefits are impressive Cherubini *et al* (2009b) emphasizes two particular concerns with the use of lignocellulosic residues as feedstock, first that "the removal of forestry or agricultural residues from land can reduce carbon storage in carbon pools like soil, dead wood or litter, and can deplete soil nutrients" and secondly that "the creation of a market for biomass residues or by-products, giving an additional income stream, can make the production of the main commodity (such as timber) economically more attractive, leading to expansion of this land use, which may have negative environmental impacts (for example, if native forests are replaced)". However the latter may have a positive effect on climate change, through the production of more wood products for substitution of more environmentally damaging materials.

The environmental benefits and impacts of biorefineries were studied by Cherubini & Jungmeier (2009). In their life cycle assessment they compared biorefineries with a fossil reference system and the results shown in figure 8.2 below show significant savings in greenhouse gas emissions, but greater acidification and eutrophication issues. So while second generation biofuels and biorefineries are a hugely positive step in an environmental sense, correct management practices and government policies will be essential in ensuring their environmental sustainability. Potential for further environmental benefits appear to be on the way with the development of third and fourth generation biorefineries, which will be examined later.

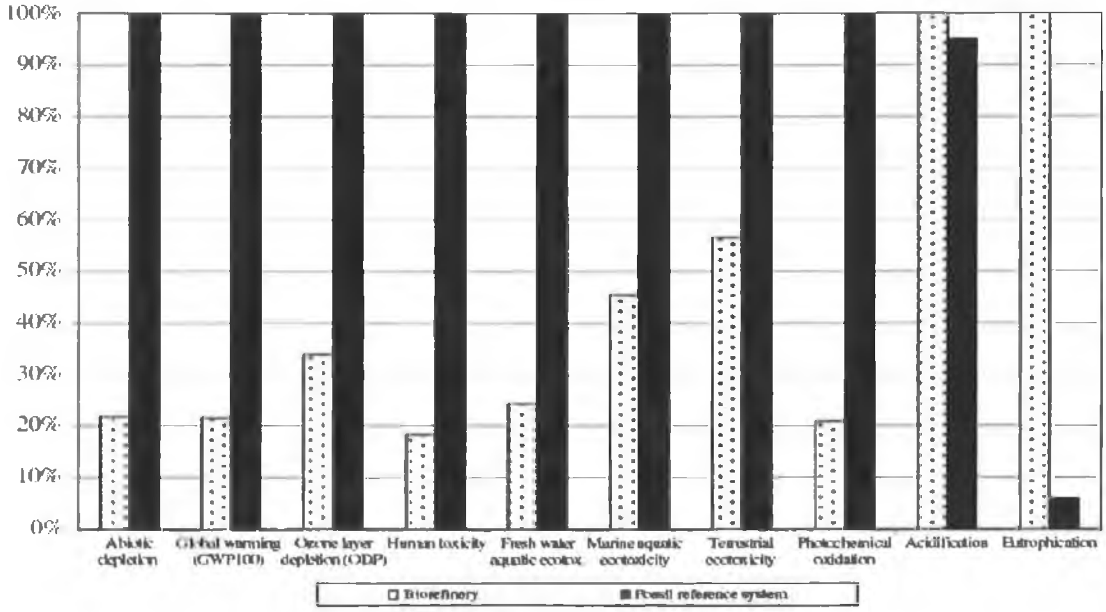


Figure 8.2: Impact Assessment of Biorefinery over life cycle versus fossil reference system (Cherubini & Jungmeier (2009))

Sadly the recent Government introduced Biofuels Obligation Scheme in Ireland, which demand that a particular quota of biofuels be present in each litre of fossil fuel sold, do not specify that the make up of that biofuel be derived in a sustainable manner. The fuel companies are authorized to blindly choose their suppliers. This means that if it is more affordable to buy biofuels from a suppler in a country where rainforests (which sequester carbon) are cut down to make space for biofuel crop-growing land, then they are free to buy biofuels produced in such a manner. This is seen by the author as a missed opportunity to promote biofuels made using sustainable practices.

8.3 Role of biomass and biorefining in a sustainable society

Biorefineries are expected to contribute to an increased competitiveness and prosperity by responding to the need to supply a wide range of bio-based products and energy in an economically, socially, and environmentally sustainable manner. Unlike other proposed renewable technologies, which are designed to meet one particular need of society, such as provision of heat or electricity, biomass is very flexible and can meet a variety of needs. As has been mentioned, the next century will see an increasing number of natural resources become scarcer due to over consumption. Biorefineries will play a role in helping society to find alternatives for these depleting resources. Future biorefineries may be focused towards providing supplies of phosphorous or plastics as society demands. Adequate food availability is a must for any society and it has already been stated that second generation biorefineries will not impinge on existing food supplies, nor will it result in higher food prices.

According to IEA Bioenergy (2009), "biorefineries show promise both for industrialized and developing countries. New competencies, new job opportunities and new markets are expected to be realized while the development of biorefineries will contribute to the realization of renewable energy, environmental and rural development goals". Such opportunities are vital particularly in the current economic climate. According to the Irish Times (2010), a study carried out by National Suicide Research Foundation found that "unemployment was associated with a two-to-threefold increased risk of suicide and undetermined death in men and a four-to-sixfold increase in women during this period" (www.irishtimes.com). Biorefineries have the potential to create jobs particularly in rural communities, which have been most seriously affected by the downturn in the economy. According to Biopol, a study carried out by Ecofys shows that "1 job is created per each 1000 ton of newly installed biomass processing capacity"(Biopol 2009). This refers to indirect jobs. These jobs can range from those involved in the supply chain to clients. Given that the processing capacity of the biorefinery in the 40,000-litre ethanol biorefinery scenario is for 157,000 tons of straw, this means that the biorefinery scenarios covered in section 7 each have the potential to create 157 indirect jobs. There will obviously be a considerable amount of jobs created within the biorefinery itself, as well as jobs created during the construction phase and for any associated research activities. Farmers who are currently struggling in the current economic climate may be able to gain income by collecting and selling potential feedstock, which would otherwise be disposed. Many of these facilities may decide to create future jobs in the shape of research positions to look at future opportunities. According to Biopol (2009) "biorefineries strengthen farmers' jobs through contracting of raw materials. Farmers have greater diversity and more resilience for their production".

8.4 Ability of Biorefinery to increase energy security

The early chapters of this thesis looked at energy security in addition to competitiveness and global warming as being one of the main drivers for renewable energies including biofuels. It is possible to assess the degree to which a biorefinery scenario can help increase the energy security of the country, by converting its fuel output to Ktoe (kilotonnes of oil equivalent) and viewing this figure in light of Irelands 2009 Provisional energy balance. Take for example one scenario, the biorefinery that produced 40 million litres of bioethanol;

The first step is to convert the yearly output of 40 million litres to tonnes.

Ethanol has a density of 0.789 tonne/cubic meter

So; 1 tonne / 0.789 = 1.27 cubic meter

and 1.27 cubic meter = 1270 litres

So:

40,000,000/1270 = 31,496 tons of ethanol

and since 1 t bioethanol = 0.64 toe we can calculate that the energy output from the biorefinery over one year will be;

20,157 toe

or 20.16 ktoe

To put this figure into perspective, the contribution from renewable energy to TPER was 168 ktoe (thousands of tonnes of oil equivalent) in 1990 rising by over 107% (5% per annum) to 391 ktoe in 2005. Reflecting the rapid growth of renewable energy sources, most particularly wind in the last few years, the increase in 2005 was 26% (DCMNR 2007). In 2005, 1 .3 million litres of biofuels were placed on the market compared with petrol consumption of 8.074 billion litres and diesel consumption of 6.588 billion litres

(Bio-Nett 2010). 20.16 ktoe makes a sizeable contribution to the total renewable energy produced in 2005 391 ktoe, and not forgetting that this only takes into account the ethanol produced at the biorefinery. There may also be significant contributions if biogas and biohydrogen are produced simultaneously.

9.0 Future of Biomass and Biorefining

This study examined the economic potential of different biorefineries on an all-things-being-equal basis, but also acknowledges that there are technological barriers in commercialising some of the scenarios discussed. Much research in how to maximize the potential of biorefineries is currently underway. Many existing biorefineries have a link to research facilities either onsite or offsite. The challenges going forward include making processes more efficient, gaining more products from less biomass, realizing the potential of alternative feedstocks, and in the case of lignocellulosic biorefineries, finding innovative ways to utilize the residual and minor constituents of biomass. Aside from productivity and economic sustainability, new technologies will also seek to further enhance environmental sustainability. There are many exciting possibilities regarding the role biorefineries will play in the future and which products they will seek to replace, and some of the challenges for biorefineries in the future are examined below.

9.1 Second generation biofuels

Figure 9.1: Second Generation Biofuels (Biopact (2007b)

Improvements to be made in relation to second-generation biofuels are likely to associated with processing techniques. The biorefineries contained in this report used a biochemical method of processing biofuels, but use of a thermochemical route is also likely to be pursued in future. According to Biopact "The thermochemical route converts biomass via processes such as gasification and fast-pyrolysis. Gasification allows for the production of very clean synthetic biofuels, by liquefying the syngas via Fischer-Tropsch synthesis -

combined, this pathway is known as 'biomass-to-liquids' (BTL). It remains relatively energy intensive, but the integration of processes promises increased efficiency. In fast-pyrolysis, biomass is rapidly heated (450-600°C) in the absence of air to yield a heavy fuel oil type liquid - bio-oil or pyrolysis oil - that can be further refined into a range of designer fuels".

This thesis has looked at how lignocellulosic biorefineries might utilize the cellulose, hemicellulose and lignin components of feedstock, in this case straw. However aside from these major components, lignocellulosic feedstock contains up to 15-20% of minor constituents. When one considers the amount of feedstock being processed in a biorefinery, this 15-20% is a considerable quantity of feedstock, which in the case of straw consists the following components:

- Suberin/Cutin
- Waxes
- Phenolic acids
- Proteins
- Pigments
- Polar lipids
- Inorganics

It will be a challenge going forward to see how these components can be utilized to add value to the biorefinery in much the same way as lignin utilization has done. This will make the biorefinery more efficient and profitable. University of York has already looked at extraction of wax from straw in a biorefinery situation. According to Deswarte et al. (2005) "Wheat straw, like many other plants, is known to contain a significant quantity of wax (ca. 1% by weight); wax is normally made up of a mixture of primarily long chain fatty acids and fatty alcohols, sterols and alkanes". Waxes extracted can be used in the production of cosmetics, personal care products and polishes. As plant waxes are traditionally extracted by volatile organic solvents like hexane, chloroform, dichloromethane and benzene which co-extracted some of the other unwanted minor constituents mentioned above such as polar lipids, as well as having environmental and toxicological impacts, alternative low environmental impact and non toxic extraction methods are preferable. To achieve this Deswarte, et al, (2005) looked at the selective extraction/fractionation of waxes from agro-residue wheat straw by liquid and supercritical CO2. The study showed that while the organic solvents provided a complete extraction of wheat straw wax it was unselective with less than 50% of wax present in total extract. However, hexane was most selective solvents giving a 70% weight yield of wax compared to total extract. Using supercritical and liquid CO^2 as solvents proved to be completely selective to the desired waxes over a range of conditions, and in seeking optimum conditions for maximum yields the study determined that 99.9% of the total extractable wax could be recovered after ca. 100 min while 99.0% could be isolated after less than 70 min. "Most significantly, we have demonstrated that by adjusting the supercritical/liquid CO2 conditions, the waxes can be fractionated into more valuable products. For example, at relatively low pressures, the extract contains a high proportion of alkanes (useful as insect semiochemicals) whereas at higher pressures the extracts contain a high proportion of fattyalcohols (used as cholesterol reducing agents)"(Deswarte *et al.* (2005)).

9.2 Third generation biofuels

Fig. 9.2: Third Generation Biofuels (Biopact (2007b)

Rather than improving the fuel-making process, third-generation biofuels seek to improve the feedstock. According to Biopact, scientists have recently designed eucalyptus trees with a low lignin content, which allows for easier conversion into cellulosic ethanol (Biopact 2007c). Scientists have designed poplar trees with lower lignin content to make them easier to process. Researchers have already mapped the genomes of sorghum and corn, which may allow genetic agronomists to tweak the genes controlling oil production.

Third-generation biofuels seek to improve yields through improving the feedstocks themselves instead of the processes. Designing oilier crops, for example, could greatly boost yields. According to Biodiesel Magazine (2010) "Third-generation or advanced feedstocks include those sources that promise to generate greater than 500 gallons of oil per acre per year, namely palm oil and algae oil as examples. Corn, soybean and camelina yield 18, 48, and 62 gallons of oil per acre, respectively. Rapeseed and jatropha yield 127 and 202 gallons of oil per acre. Palm oil alone yields 635 gallons of oil per acre. But conservative projections are that oil harvested from algae will yield values much higher than all of these; between 5,000 and 10,000 gallons of oil per acre have been speculated. Still, there is no successful commercial demonstration of biodiesel from algae oil apart from a few laboratory samples ".

Third generation biofuels should help to alleviate the concern over competing land use or required land use changes that exist in production of first-generation and possibly second-generation biofuels. According to Nigam & Singh (2010) "on the basis of current scientific knowledge and technology projections, third-generation biofuels specifically derived from microbes and microalgae are considered to be a viable alternative energy resource that is devoid of the major drawbacks associated with first and second-generation biofuels".

In using microbes as a source of biofuel recent studies by Xiong *et al.* (2008), have shown that some microbial species such as: yeast, fungi and microalgae can be used as potential sources for biodiesel as they can biosynthesise and store large amounts of fatty acids in their biomass. Zhu *et al.* (2008) have reported that lipids produced in microbial biomass can be utilized for biodiesel production while working on the production of microbial biofuel from waste molasses.

As mentioned above, biofuels from algae is considered an area of huge potential due to anticipated high yields. Microalgae can produce lipids, proteins and carbohydrates in large amounts over short periods of time. These products can be processed into both biofuels and valuable co-products. However as shown by Pulz *et al.* (1998) the production of lipids, proteins and carbohydrates may be limited by available sunlight due to diurnal cycles and the seasonal variations; thereby limiting the viability of commercial production to areas with high solar radiation". Ideally for efficient oil production algae should be able to accumulate more than 30% of their cell weights in oils. The conversion technologies for utilising microalgae biomass can be separated into two categories according to Nigam & Singh (2010):

- Thermochemical, - thermal decomposition of organic components to fuel products direct combustion, gasification, thermochemical liquefaction and pyrolysis and
- Biochemical conversion - energy conversion of biomass into other fuels includes anaerobic digestion, alcoholic fermentation and photobiological hydrogen production

9.3 Fourth generation biofuels

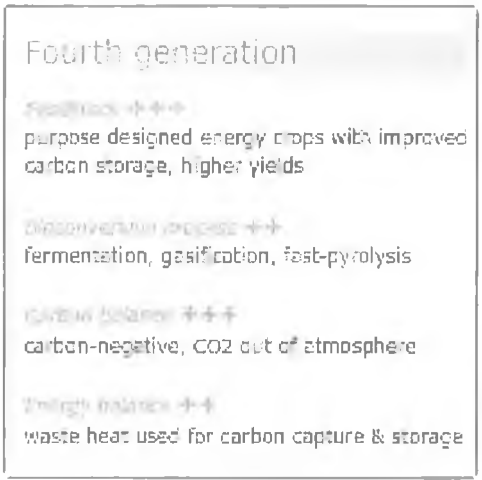


Fig. 9.3: Fourth Generation Biofuels (Biopact 2007b)

One definition of a fourth generation biofuel is crops that are genetically engineered to consume more CO2 from the atmosphere than they'll produce during combustion later as a fuel. Another definition is genetically engineered crops similar to the ones just mentioned but combined with synthesized microbes that will convert the biofuels produced into even more efficient fuel. For example a plant could be grown then converted into a fuel, which is then exposed to a microbe that changes it directly into gasoline. Yet another definition is genetically modified or synthesized microbes that convert CO^2 in the atmosphere directly into usable fuels (Renewable Energy Resource 2010). So it is evident that no clear definition for fourth generation exists as such, but it can be assumed that this category will cover biofuels created from processes other than first-generation ethanol and biodiesel, second generation cellulosic ethanol, and third generation biofuels such as algae biofuel. And some of these processes might include pyrolysis, gasification, upgrading, solar-to fuel and genetic manipulation of organisms to secrete hydrocarbons (Green Tech Media Research 2010).

As indicated above much of the research is focused on attempting to produce biofuels, which have a net carbon negative affect on the atmosphere, as compared with previous generations and other renewable energies, which will at best be carbon neutral. To achieve this, the development of crops that sequester more CO2 than normal plants will be necessary and the production process would be coupled to carbon capture and storage techniques. Before, during or after the bioconversion process, the carbon dioxide is captured by utilizing so-called pre-combustion, oxyfuel or post-combustion processes. This gas can then be sequestered. According to Biopact (2008) a number of crops have been developed which show potential for use in such scenarios, such a eucalyptus tree that stores more CO2 and grows less lignin but more cellulose, and a hybrid larch that sequesters up to 30% more CO2.

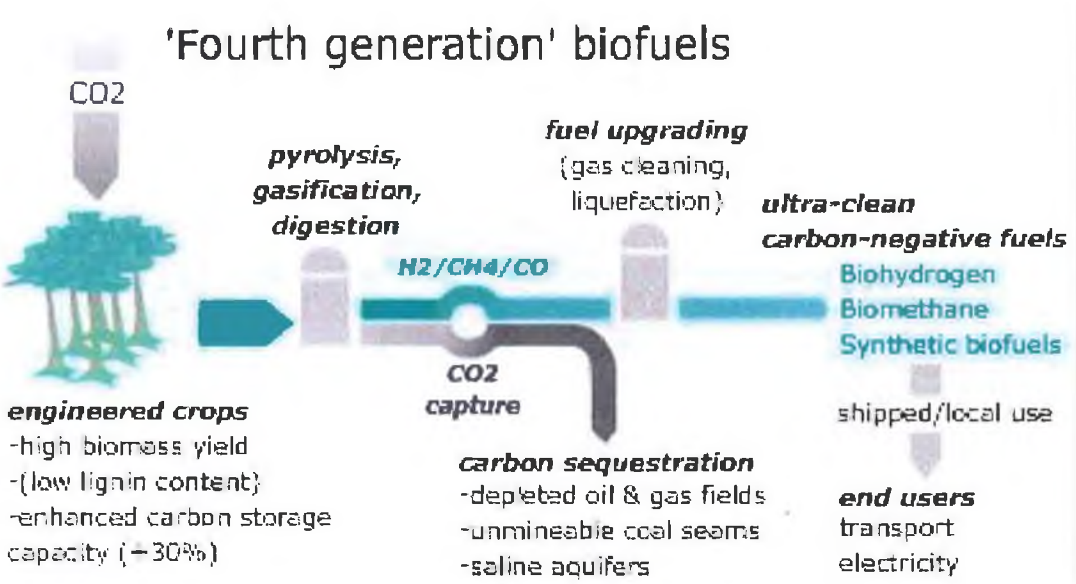


Figure 9.4: Summary of fourth generation biofuels (Biopact 2007b)

9.4 Keeping our resource sustainable

The important role that biomass will play in meeting our renewable energy targets in transport, heating and electricity was discussed in chapter 3. Of course, the sustainability of bioenergy is dependent on ensuring that a continuous supply of biomass. The growing demands on biomass sources into the future will mean not merely sustaining current available biomass, but actually growing these resources. Forestry in addition to being an important supply of lignocellulosic biomass also sequesters carbon and can help Ireland to reduce its emissions. Ireland in recent decades has increased its forestry resources. According to Hendrick & Black (2009) since 1985 there has been a rapid expansion in private sector afforestation until 4-5 years ago when it began to tail off. These trends are displayed in figure 9.5 below:

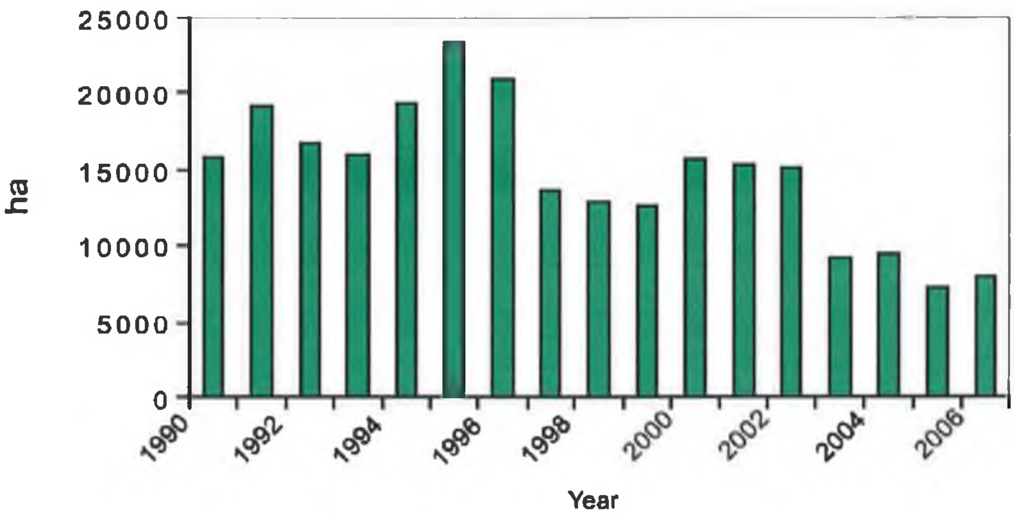


Figure 9.5: Annual Afforestation rate in Ireland 1990-2007 (Hendrick and Black 2009)

According to Coford Projections to 2020 indicate that a supply of 4 million green tonnes of biomass will be required per annum to meet Irish government targets for biomass use. It is unlikely that the forest sector could supply more than half of this volume. These targets highlight the need for a substantial increase in the rate of afforestation, allied to increased wood fibre output from short rotation forestry, coppice and harvesting residues. "Sustaining wood fuel production beyond 2020 is dependent on a continuation of policy measures and on the level of afforestation over the next two decades. Wood fuels are mainly sourced from young forests. A balanced age class structure is therefore a

prerequisite for sustained supply of wood fuel. To provide a sustainable biomass supply, an annual afforestation programme of at least 10,000 ha per year needs to be put in place for an extended period of up to two decades. If annual afforestation rates continue to fall below 10,000 ha per annum, wood fuel supply will not be sustainable in the long term and government biomass targets will not be attained" (Knaggs & O'Driscoll (2008)).
As the straw biorefinery scenarios in this thesis have demonstrated there are other sources of potentially renewable biomass that could be available to help meet the targets set out in the bioenergy action plan. According to Irish Independent (2008) "more than 70,000 hectares of bio-energy crops will be required by 2015 to help Ireland meet its renewable electricity and heat targets". These include crops such as willow and miscanthus. But according to Teagasc's Barry Caslin in the same article "the biggest problem with the energy crops at the moment is the supply chains do not exist". To incentivise farmers to participate in this supply chain and thus help ensure the sustainability of the supply chain the Bionenergy Scheme was introduced on a pilot phase in 2007. Approximately 800 hectares of willow and miscanthus were planted under phase I. The scheme, which in 2008 was introduced in full, rewards farmers for planting supplies energy crops by providing a grant of up €1,450 per hectare, with areas planted with willow and miscanthus also qualifying for an EU Energy Crops premium, the National Energy Crop premium of €80 per hectare and adjusted payments under the REPS and Disadvantaged Areas Scheme (DAFF 2008).

Given the important role that biomass looks set to play in our future, it is important to make sure that this resource is protected. If biomass is to help protect us from the devastating effects of climate change and resource scarcity, then we must protect the biomass supply from the affects of climate change and resource scarcity. Forward planning of biomass supplies and sustainable forestry will be essential in ensuring adequate availability of biomass. It will be necessary to take into account future project weather trends to determine our future supplies. According to Hendrick & Black (2009) "Forecasted changes in Ireland's climate will have a significant influence on the productivity of managed forests and woodlands. Given the long term nature of forestry, the selection of suitable provenances or genotypes and adaptable management practices under future climate change scenarios are essential for sustainable forestry in Ireland".

9.5 Maximizing co-product potential

As mentioned throughout the document, biorefineries will in future be faced with the task of maximizing co-product potential to meet a variety of needs. From the point of view of providing energy products, biorefineries will seek to provide higher density unblended biofuels, which, will be designed for the automotive industry of the future. Biorefineries will also be required to meet the needs of other markets, which will be under threat due to resource scarcity. This in inevitable under current circumstances, and will be even more inevitable as the populations peaks toward the midpoint of the century. It might be unclear which products will be most under threat, but it can be assumed that any products dependent on the petrochemical industry, such as plastics and some chemicals will need an alternative source in future. So too will resources of fertilizers which will be used to help feed a growing population. The Pacific Northwest Laboratory (2004) on behalf of the U.S. Department of Energy carried out a study on the top value-added chemical product candidates from biomass (sugars and synthesis gas). The report identifies twelve building block chemicals that can be produced from sugars via biological or chemical conversions. The twelve building blocks listed in figure 9.6 can be subsequently converted to a number of high-value bio-based chemicals or materials. The report also acknowledges that technical barriers exist between commercialization.

Building block	Direct use of building block	Potential uses of derivatives
1,4 succinic, fumaric and malic acids		Solvents, fibres such as lycra
2,5 furan dicarboxylic acid	PET analogues with new properties (bottles, containers)	New polyesters and nylons
3 hydroxy propionic acid		Sorona fibres, use in contact lenses
Aspartic acid	Salts for chelating agents. Sweeteners	New area
Glucaric acid		Solvents. Nylons.
Glutamic acid		Monomers for polyesters and polyamides
Itaconic acid	Co-polymers in styrene-butadiene polymers	Solvents. New polymer opportunities
Levulinic acid		Fuel oxygenates, solvents
3-hydroxybutyrolactone	Intermediate for high value pharma compounds	Solvents
Glycerol	Personal care products, pharmaceuticals, food and beverages	Resins for use in insulation, polyester fibers, antifreeze
Sorbitol		Water soluble polymers, PET-like polymers
Xtlitol/arabinitol	Non-nutritive sugars, unsaturated polyester resins (UPR)	UPRs, new opportunities

Table 9.6: Twelve building block chemicals that can be produced from sugars via biological or chemical conversions (Pacific Northwest Laboratory, 2004)

10. Conclusions

This report began by looking at the main theoretical driving factors and associated policies for developing renewable energy and sustainable technologies and practices;

- Energy security
- Competitiveness
- Global warming
- Sustainable material resources

Throughout the report the author has attempted to examine how bioenergy and biorefineries might help in providing a solution to the problems facing us, with a particular focus on Ireland. The report has outlined the role that biomass can play in meeting energy and material requirements going forward, helping to resolve some of the drivers outlined in the introduction. The author highlighted the Governments ambitions for biomass to play a large role in transport, electrical and heat energy going forward. The report has examined the potential of biorefinery facilities to provide energy solutions as well as material product solutions in an extremely efficient and high-tech manner. The author has shown how biorefineries can help the government to meet it's transport fuel targets, while using an integrated CHP facility to help meet heating and electricity targets through the use of biomass residues and biogas. The author also looked at the role that biorefineries could play in supplying materials, which are currently based on finite sources.

The author has found that Bioenergy and Biorefineries are not the solution to the drivers outlined in the first chapter but that they can form part of the overall solution when coupled with other technologies and practices. When developed correctly biofuels and biorefineries can be sustainable in every way. The author suggests that the most effective way of producing biofuels and bioenergy in an economically sustainable fashion is to produce them within an integrated biorefinery, where co-product produced from residual streams can add value.

The author looked at the viability of setting up a biorefinery in Ireland beginning with feedstock availability, and was able to show that considering straw only as a feedstock, a medium-sized biorefinery would be feasible on the east coast as well the potential for a second one on the south coast. The author highlights other feedstock supply chains that are developing and emphasises that this is essential for the sustainability and future development of biofuels and biorefineries in Ireland.

Having determined the feasibility of a medium-sized straw biorefinery on the east coast, the author then set about assessing bioenergy and biorefineries in particular under the three pillars of sustainability, economic sustainability, environmental sustainability and social sustainability.

To begin the process of determining economic sustainability the author developed 5 straw biorefinery configurations each configured to produce a range of different co-products. Some of these configurations were primarily energy-product based others were primarily market-product based. The author determined the economic potential of each biorefinery by estimating the revenue potential of the combination of co-products and deducting all costs incurred. The author found that all 5 biorefinery configurations examined showed potential for profitability. However the degree to which a biorefinery was profitable was hugely dependent on the biorefinery configuration and the choice of co-products. Some of the configurations show enormous economic potential, and highlight the huge revenue potential of material products in addition to energy products. In the analysis of economic sustainability the author also shows appreciation for the fact that from a technology point of view there are challenges ahead, but also points out that technology will become more affordable as technological advancements are made. The author both compliments and criticizes the role government policy plays in ensuring the economic viability of biofuels in Ireland. In one context the Governments new Biofuels Obligations Scheme 2010 help biofuel producers by ensuring that fossil fuel supplies such as petrol and diesel contain a 4.166% quota of biofuels. On the other hand the regulations remove excise relief, thereby making it more difficult for indigenous biofuel producers to compete with Brazil and other international suppliers. The author feels this problem is most likely to affect smaller indigenous biofuel-only suppliers who unlike biorefinery producers may not have the luxury of value added co-products. The author has shown how value-added co-products make biorefineries more flexible and capable of dealing with international competitors. The author has shown the ability of biofuels and biorefineries to increase energy security, but fears that indigenous biofuel producers may suffer at the hands of these regulations, being unable to compete with international competitors. Unless indigenous biofuel suppliers are supported, Ireland will not address her energy security issues.

From an environmental point of view the author has shown the benefits of second-generation biofuels and biorefineries (such as the straw-based biorefineries examined) over first-generation technologies and fossil fuels, with up to 90% reduction in greenhouse gas savings. The author highlights that such high savings will only be achieved if correct environmental practices and high efficiencies are observed. The author points out some of the environmental concerns surrounding change of land-use and advises that steps must be taken to ensure environmental sustainability at all stages from cultivation of feedstock to burning of final product. This report also shows the potential for future technologies to have even less impacts on the environment, to the point of becoming "carbon negative". Again the author is critical of the Government Biofuels Obligation Scheme 2010, which while specifying a mandatory quota of biofuels in all fuels also allows suppliers to blindly choose their biofuel producer. There is no specification that biofuels be second-generation or produced in a sustainable manner. But certainly when biomass and biorefineries are utilized using the correct practices, they offer considerable benefits over fossil fuels and can do so in a manner that is environmentally sustainable.

From the point of developing a sustainable society, biomass and biorefineries can offer much potential of meeting the needs of local communities. Not only can these technologies supply the local community with a vast array of material and energy products in a sustainable and local manner, but they have the potential to provide long-term direct and indirect employment to the local community. These facilities provide a new market for local farmers, stimulating the community while offering a secure supply of resources.

The author has also shown that even one medium-sized biorefinery, such as the straw biorefinery scenarios examined, when properly configured, can make a significant contribution to Ireland total renewable energy stockpile. So in addition to the economic, environmental and social benefits, biorefineries can play a large role in meeting Irelands energy targets.

The author concluded by looking at the potential for biorefineries going forward, examining technical issues as well as resource challenges. The author examined:

- Processing issues associated with second-generation biofuels
- Third-generation biofuels

- Fourth-generation biofuels
- Ensuring sustainable biomass resources
- Maximizing co-product potential

While acknowledging that some barriers still remain for biofuels and biorefineries into the future, it also seems inevitable that some of the technology and infrastructure is currently more expensive due to its infancy and this is likely to become more affordable over time. With cheaper production costs will come potentially cheaper market value in stark contrast with oil prices, which seem set to rise. Therefore biorefineries are one mechanism of enabling Ireland to supply cheaper fuel, minimizing the effects of cheap oil and ensuring Irelands competitiveness with her neighbours.

It is clear from the analysis within this report that the flexibility of biomass, through biofuels and biorefineries can play a major role increasing energy security, increasing competitiveness, mitigating anthropogenic global warming and providing material resources. But as has also been demonstrated in this report, biofuels and biorefineries are not just noble ventures; but they are viable and provide real economic opportunities for entrepreneurs willing to take a chance.

References

Abengoa Activity Report (2006) http://www.globalclearinghouse.org/infradev/assets%5C10/documents/Abengoa%20-%20Activity%20Report%202006_v1%20(2006).pdf (Accessed on 17th June 2010).

Agricultural Marketing Resource Centre (2009) http://www.agmrc.org/renewable_energy/ethanol/efficiency_and_environmental_improvements_of_corn_ethanol_production.cfm (Accessed on 4th July 2010).

Ahmed A. & Zhu J. Y. – (2006) cornstalk as a source of Fibre and Energy (Wisconsin, United States).

Biodiesel Magazine (2010) http://www.biodieselmagazine.com/article.jsp?article_id=4158 (Accessed on 13th July 2010).

Biofuels Digest (2010)

<http://biofuelsdigest.com/bdigest/2010/02/15/novozymes-announces-2-per-gallon-cellulosic-ethanol-will-arrive-in-2011-dramatic-enzyme-breeakthrough/ >(Accessed on 19th July 2010).

Bio-Nett (2010) D16 Biofuel Strategies http://www.bape.com.pl/LinkClick.aspx?fileticket=2IEfWJ1x9VI%3D&tabid=168&mid=546 (Accessed on 15th July 2010).

Biopact (2007a) http://news.mongabay.com/bioenergy/2007/07/in-depth-look-at-biorefinery-concepts.html (Accessed on 14th July 2010).

Biopact (2007b) http://news.mongabay.com/bioenergy/2007/10/quick-look-at-fourth-generation.html (Accessed on 15th July 2010).

Biopact (2007c) (http://news.mongabay.com/bioenergy/2007/10/quick-look-at-fourth-generation.html (Accessed on 15th July 2010).

Biopact 2008 http://news.mongabay.com/bioenergy/2008/03/new-study-shows-way-to-fourth.html (Accessed on 15th July 2010).

Biopol (2009) - Report with the assessment results concerning the impactof biorefineries on rural development, employment and environment, 2009 http://www.biorefinery.nl/fileadmin/biopol/user/documents/PublicDeliverables/BIOPOL_D_2_2_3_-_Final_120609.pdf (Accessed on 17th July 2010).

Biorefinery CRIP (2009a) http://www.biorefinery.ws/en/bio_1stgen.html(Accessed on 3rd June 2010).

Biorefinery CRIP (2009b) http://www.biorefinery.ws/en/bio_2ndgen.html (Accessed on 3rd June 2010).

Boel M., F. 2010 "(http://www.publicservice.co.uk/feature_story.asp?id=6067 (Accessed on 4th August 2010).

Brodin I., (2009) Chemical Properties and Thermal Behaviour of Kraft Lignins

Fibre and Polymer Technology KTH Royal Institute of Technology, Stockholm, Sweden.

Brown, L., R. (2009) – Could food shortages bring an end to civilization for Scientific American, United States.

Bryant C. 2009 http://www.pi.energy.gov/documents/11-Cynthia_Bryant.pdf (Accessed on 5th June 2010).

Butylfuel LCC (2010) www.butanol.com (Accessed on 5th June 2010).

Campbell C., & Laherre, J. (1998) End of Cheap oil - *Scientific American.*

Cherubini, F., Jungmeier, G., Wellisch, M., Willke, T., Skiadas, I., Van Ree, R., de Jong, E. (2009a)"(Toward a Common cCassification Approach for Biorefinery Systems).

Cherubini F., Bird, N. D., Cowie A., Jungmeier G., Schlamadinger B. & Woess-Gallasch S. (2009b) Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations.

Cherubini F. & Jungmeier, G (2009) LCA of a Biorefinery concept producing Bioethanol, Bioenergy, and Bhemicals from Switchgrass.

Cherubini F., & Ulgiati S. (2009) Crop residues as raw materials for biorefinery systems – A LCA case study.

Compere A. L., Griffith W. L., Leitten Jr., C., F. & Shaffer J., T. (2001) Low Cost Carbon Fibre From Renewable Resources (Oak Ridge National Laboratory United States).

Cooley-Clearpower Research (2006) Ethanol Production Evaluation Study – Cork County Council (2006).

CS0 (Central Statistics Office) (2010) <http://www.cso.ie/statistics/energy_consumption_sector.htm>2010 (Accessed on 11thJuly 2010).

DAFF (Department of Agriculture, Fisheries and Food) (2008) BIOENERGY SCHEME FOR WILLOW AND MISCANTHUS (2nd round) 2008 http://www.teagasc.ie/forestry/docs/financial_info/TERMSANDCONDITIONSBIOENERGYSCHEME2008.pdf (Accessed on 12th July 2010).

DCENR (Department of Communication Energy and Natural Resoruces) Biofuels Obligation Scheme – Regulatory Impact Assessment

http://www.dcenr.gov.ie/NR/rdonlyres/26358B8D-1DC7-4B0F-B697-2F2FEDA32F46/0/BiofuelsObligationRIAJuly09.pdf (Accessed on 29th June 2010).

DCENR (Department of Communications Energy and Natural Resources) (2009)

REFIT (Renewable Energy Feed-In Tariff) (Additional Categories) <http://www.dcenr.gov.ie/NR/rdonlyres/3B13ECAA-9351-41E0-8B44-7C02E98E4F50/0/AdditionalREFITcetegories.pdf > (Accessed on 5th June).

DCMNR (Department of communications, Marine and Natural Resources) (2007)

Bioenergy Action Plan for Ireland 2007.

Dennehy E., Barriscale A., Howley M. & O'Gallachoir B., (2010) Combined Heat and Power in Ireland 2010 Update for the SEAI.

Deverell, R. ,McDonnell, K., Devlin, G., (2009a) Potential Bioethanol Feedstock Availability Around Nine Locations in the Republic of Ireland (Department of Biosystems Engineering, Agriculture and Food Science Building, University College Dublin).

Deverell, R., McDonnell, K., Ward, S., Devlin, G., (2009b) An economic assessment of potential ethanol production pathways in Ireland (Department of Biosystems Engineering, Agriculture and Food Science Building, University College Dublin).

Deswarte F. E. I., Clark J., Hardy J. & Rose P. (2005) The fractionation of valuable wax products from wheat straw using CO2 for University of York, UK.

Dowaki K., Ohta T., Kasahara Y., Kameyama M., Sakawaki K., & Mori S., (2006) An economic and energy analysis on bio-hydrogen fuel using a gasification process.

ECE (European Commission Environment) (2010) Energy Energy and Climate Package http://ec.europa.eu/environment/climat/climate_action.htm (Accessed on 20th July 2010).

Ecology Foundation (2010) Report on Energy Security- Ireland on the Edge 2010.

EEA (European Energy Agency) (2010) <http://www.eea.europa.eu/articles/the-electric-car-2014-a-green-transport-revolution-in-the-making> 2010 (Accessed on 14th June 2010).

Electrigaz (2010) http://www.electrigaz.com/faq_en.htm(Accessed on 12th June 2010).

ESRI (Economic and Social Research Institute) (2009)http://www.finfacts.ie/irishfinancenews/article_1017283.shtml (Accessed on 12th June 2010).

Ethanol today (2007) http://www.ethanol.org/pdf/contentmgmt/March_07_ET_secondary.pdf (Accessed on 5th July 2010).

European Biomass Association (2010) A Biogas Roadmap for Europe http://www.aebiom.org/IMG/pdf/Brochure_BiogasRoadmap_WEB.pdf (Accessed on 17th July 2010).

Food Navigator (2005) http://www.foodnavigator.com/Financial-Industry/Lactic-acid-price-rise-at-Purac (Accessed on 12th July 2010).

Garde A., Jonsson G., Schmidt A., & Ahring B., (2001) Lactic Acid production from wheat straw hemicellulose hydrolysate by lactobacillus pentosus and Lactobacillus brevis, Garde, A., 2001 Denmark.

Goodall, C., (2008) Ten Technologies to Fix Energy and Climate (Green Profile, Great Britain).

Green Tech Media Research (2010) http://www.gtmresearch.com/report/third-and-fourth-generation-biofuels(Accessed on 8th July 2010).

Hamelinck, C., van den Broek, R., Rice, B.,Gilbert, A. Ragwitz, M. & Toro, F.

(2004) The Liquid Biofuels Strategy Study for Ireland for SEAI.

Hayes D.J. State of Play in Biorefining Industry for University of Limerick http://www.carbolea.ul.ie/files/State_of_Play.pdf (accessed 2nd June).

Hayes, D., J., Ross, J., Hayes, M., Fitzpatrick, S., The Biofine Process: Production of Levulinic Acid, Furfural and Formic Acid from Lignocellulosic Feedstocks

http://www.carbolea.ul.ie/files/HFHR_Chapter%204_FINAL.pdf (Accessed on 27th May 2010).

Hendrick E. & Black K., Climate change and Irish Forestry *(2009) COFORD* Connects, Ireland.

Holladay, J., E., Bozell, J., J., White, J., F., Johnson, D., (2007) - (Top Value-Added Chemicals from Biomass Volume II—Results of Screening for Potential Candidates from Biorefinery Lignin) Prepared for the U.S. Department of Energy.

IEA (International Energy Agency) (2007) Energy Policies of IEA countries, Ireland 2007 Review (France).

IEA (International Energy Agency) (2009) CO2 Emissions from Fuel Combustion – Highlights http://www.iea.org/co2highlights/CO2highlights.pdf

(Accessed on 28th July 2010)

IEA (International Energy Agency) (2010)a http://www.iea.org/stats/indicators.asp?COUNTRY_CODE=IE(Accessed on 12th June 2010).

IEA (International Energy Agency) (2010b) <http://www.iea.org/about/index.asp> (Accessed on 21st July 2010).

IEA (International Energy Agency) Bioenergy (2009) IEA Bioenergy Task 42 Biorefinery. International Energy Agency.

IIEA (Institute of International and European Affairs) (2010); http://www.iiea.com/events/irelands-future-energy-security (Accessed on 17th July 2010).

IPPC (Intergovernmental Panel on Climate Change) (2007) Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report DRAFT COPY. Valencia, Spain.

IRBEA (Irish Bioenergy Association) (2010a) <http://www.irbea.org/index.php?option=com_content&task=view&id=538&Itemid=1> (Accessed on 12th July 2010)

Irish Independent 2008 http://www.independent.ie/farming/ploughing-championships/farmers-urged-to-grow-energy-crops-1481737.html(Accessed on 4^{th} June 2010).

Irish Times (2010) <http://www.irishtimes.com/newspaper/ireland/2009/1110/1224258481755.html> (Accessed on 5^{th} June 2010).

Irish Times (2010)http://www.irishtimes.com/newspaper/ireland/2010/0607/1224272004743.html(Accessed on 13^{th} July 2010).

Kádár Z., de Vrije T., Van Noorden G., Budde M., Szengyel Z., Reczey K., & Claasen P. (2004) Yields from Glucose, Xylose, and Paper Sludge Hydrolysate during Hydrogen Production by the Extreme Thermophile Caldicellulosiruptor saccharolyticus. Applied Biochemistry and Biotechnology.

Kadla J.,F., Kubo S.,Venditti R., A., Gilbert R.,D., Compere A., L. & Griffith W. (2002) Lignin-based carbon fibres for composite fiber applications United States.

Kaiser J., P. & Hanselmann K., W. (1982) Aromatic chemicals through anaerobic microbial conversion of lignin monomers.

Kamm B., 2007 Biobased products from lignocellulose sources (Research Institute biopos, Germany) <www.forestplatform.de/download.php?id=155 > (Accessed on 15^{th} June 2010).

Kaparaju P., Serrano M, Thomsen A., B., Kongjan P., & Angelidaki I., Bioethanol, biohydrogen and biogas production from wheat straw in a biorefinery concept (2009) Denmark.

Knaggs G., & O'Driscoll E (2008) an overview of the irish wood-based biomass sector (COFORD, Ireland).

Kofman P., D. (2010) Units, conversion factors and formulae for wood for energy http://www.coford.ie/iopen24/pub/COFORD-Connects/ht21.pdf (accessed on 17th July 2010) for COFORD, Ireland.

Lindgrin K., (2009) Potential Lignin Applications Beyond Energy

http://innventia.co.uk/upload/9581/NWBC%202009%20Lindgren%20Potential%20lignin%20applications%20beyond%20energy.pdf (Accessed on 27th June 2010).

Lynd L., Larson E., Greene N., Laaer M., Sheehan J., Dale B., McLaughlin S., & Wang M., (2009) The Role of Biomass in America's Energy future: framing the Biofuels, Bioproducts and Biorefining Analysis (Volume 3, Issue 2).

Maas, R., H., Bakker, R., Jansen M., Visser, D., de Jong, E., Eggink, G., Weusthuis, R., (2008) Lactic acid production from lime-treated wheat straw by **Bacillus coagulans**: neutralization of acid by fed-batch addition of alkaline substrate (Agrotechnology and Food Sciences Group, Wageningen University and Research Centre).

MacLachlan R. &,Pye E. K. (2007) Biorefining the Future: Modern Biorefineries Refined and Redefined.

McKendry, P. (2002) Energy production from biomass (Part 1): overview of biomass.

bioresource Technology. Bioresource Technology (Applied Environmental Research Centre Ltd – Colchester UK).

Murphy J.D. (2005) Biomass, Biogas, Biofuels and Energy http://www.irishscientist.ie/2005/contents.asp?contentxml=05p53.xml&contentxsl=is05pages.xsl (Accessed on 19th June 2010) The Irish Scientist 2005 Year Book.

Myhre, G., Alterskjær, K.& Lowe, D.(2009) A fast method for updating global fossil fuel carbon dioxide emissions. Centre for International Climate and Environmental Research—Oslo.

Nigam P. S. & Singh, A. (2010) Production of liquid biofuels from renewable resources.

NORA (National Oil Reserves Agency) http://www.nora.ie/biofuels/biofuels_obligation_scheme.476.476.html (Accessed on 18th July 2010).

Norris R., E. 2006 <http://www.futurepundit.com/archives/003300.html>(Accessed on 31st May 2010).

Mamman A., S., Lee J., M., , Kim Y., C., Hwang I., T.,Park N., J., Hwang Y., K.,Chang J., S.,& Hwang J., S., (2008) Furfural: Hemicellulose/xylose derived biochemical (Biofuels, Bioproducts and Biorefining Volume 2 Issue 5).

Pacific Northwest Laboratory (2004) "Top value-added chemical product candidates from biomass (sugars and synthesis gas) for Department of Energy, United States,

Prlog (2006) <http://www.prlog.org/10001075-energy-costs-consume-upto-65-of-heavy-industry-budgets.html> (Accessed on 12th July 2010).

Pulz O. & Scheinbenbogan K. (1998) Photobioreactors: design and performance with respect to light energy input. Adv Biochem Eng/Biotechnol.

Qureshi N., Saha B.C., & Cotta M. A., (2007) Butanol production from wheat straw by simultaneous saccharification and fermentation using Clostridium beijerinckii: Part II—Fed-batch fermentation United States.

Rajan, S., C.,2004 Climate change dilemma: technology, social change or both?: An examination of long-term transport policy choices in the United States. Tellus Institute, USA.

Recharge news (2009) http://www.rechargenews.com/energy/biofuels/article198442.ece) (Accessed on 29th May 2010).

Renewable Energy Resource (2010) (http://renewableenergyresource.net/renewable-energy-sources/fourth-generation-biofuels (Accessed on 11th July 2010).

Reuters 2009 <http://www.reuters.com/article/idUSTRE58M40T20090923> (Accessed on 7th June 2010).

SEAI (Sustainable Energy Association of Ireland). REIO Biomass Factsheet Sustainable Energy Ireland
<http://www.seai.ie/uploadedfiles/RenewableEnergy/REIOBiomassFactsheet.pdf>
(Accessed on 17th June 2010).

SEAI (2004)
http://www.seai.ie/Renewables/Bioenergy/Wood_Energy/Fuels/Pellets/Preliminary_Study_of_Pellet_Production_in_Ireland.pdf (Accessed on 17th June 2010).

SEAI (2010) Report on Renewable Energy in Ireland 2010 update
<http://www.businessandleadership.com/leadership/news/article/22923/)/>(Accessed on 17th July 2010).

Sunday Business Post 2002
http://archives.tcm.ie/businesspost/2002/01/27/story567686728.asp(Accessed on 5th June 2010).

Sweden.se (2010) <http://www.sweden.se/eng/Home/Society/Sustainability/Facts/Energy>

(Accessed on 17th June 2010).

Szulczyk K. (2010) Which is a better transportation fuel – butanol or ethanolhttp://ken-szulczyk.com/E-books/Butanol.pdf (Accessed on 5th June 2010).

Tejayadi, S. & Cheryan, M.,(1995) Lactic acid from cheese whey permeate. Productivity and economics of a continuous membrane bioreactor.

Timken H., K., C, & Angevine P., J., (1997) Production of benzene, toluene, and xylene (BTX) from FCC Naphtha.

U.S. DOE (Department of Energy) (2009) Ethanol Myths and Facts
http://www1.eere.energy.gov/biomass/ethanol_myths_facts.html (Accessed on 5th July 2010).

Vaccari D.A., (2009) Phosphorous – a looming crisis. Scientific American.

Walsh, P (2010) Personal Communication (GMIT & Biospark).

Washington State University (2001) Washington university energy program ; Wheat Straw for Ethanol Production in Washington: A Resource, Technical, and Economic Assessment 2001 http://www.energy.wsu.edu/documents/renewables/WheatstrawForEthanol.pdf (Accessed on 5th June2010).

WDC (Western Development Commission) (2008) Biomass CHP Market Potential in the Western Region An assessment http://www.bioxl.ie/index.php?option=com_docman&task=cat_view&gid=36&Itemid= (accessed on 18th June).

Win, D., T. (2005) -Furfural – Gold from Garbage http://www.journal.au.edu/au_techno/2005/apr05/vol8no4_abstract04.pdf (Accessed on 5th June 2010).

Wright, L., US DOE http://cta.ornl.gov/bedb/feedstocks/Primary_Feedstock_Detail.shtml (Accessed on 13th June 2010).

Wright, L., US DOE
http://cta.ornl.gov/bedb/feedstocks/Secondary_Feedstock_Detail.shtml

(Accessed on 13th June).

Wright, L., US DOE (Accessed on 13th June.

2010)http://cta.ornl.gov/bedb/feedstocks/Tertiary_Feedstock_Detail.shtml (Accessed on 13th June 2010).

Xiong W, Li X, Xiang J, Wu O. (2008)High-density fermentation of microalgae Chlorella protothecoides in bioreactor for Microbiodiesel Production.

Zhu LY, Zong M.H. & Wu H. (2008) Efficient lipid production with T. fermentas and its use for biodiesel preparation. *Bioresource Technology.*

Bibliographies

DCMNR 2007 (Department of Communications, Marine and Natural Resources) Delivering a Sustainable Energy Future for Ireland the energy policy framework 2007-2020 http://www.dcenr.gov.ie/NR/rdonlyres/54C78A1E-4E96-4E28-A77A-3226220DF2FC/27356/EnergyWhitePaper12March2007.pdf (Accessed on 20th June 2010).

DEHLG (Department of Environment Health and Local Government) (2007) Irelands National Climate Change Strategy 2007-2012 http://www.environ.ie/en/Publications/Environment/Atmosphere/FileDownLoad,1861,en.pdf (Accessed on 20th June 2010).

Euopean Union (2000) Green Paper - Towards a European Strategy for the Security of Energy Supply http://ec.europa.eu/energy/green-paper-energy-supply/doc/green_paper_energy_supply_en.pdf (Accessed on 17rd June 2010).

European Union (2007) Energy for a changing world (2007) http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/07/38&format=HTML&aged=0&language=EN (Accessed on 20th June 2010).

United Nations (1998) Kyoto Protocol to the United Nations Framework Convention on Climate http://unfccc.int/resource/docs/convkp/kpeng.pdf (Accessed on 3rd June 2010).

Appendix Section

Appendix 1: Biorefinery 2 Analysis with Excise Relief

(C5/C6 Sugars and lignin biorefinery for bioethanol, biohydrogen, carbon fibres and biogas from straw (with excise relief)

The next straw biorefinery scenario evaluates the production of Biohydrogen and Bioethanol using the C5 sugars, with bioethanol also being produced from the C6 sugars, carbon fibres from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise relief is assumed on fuel products.

	Required feedstock percentage	Yield	Market value	Revenue potential
Bioethanol *(using C6 sugars only)*	33-40% (57,255 tons)	255 l/ton (25.5%)	0.79 euro/l	57,255x255 = 14599930 litre @ .79 euro/l = 11,533945
Bioethanol *(using C5 only)*	20-25% (35,295)	255 l/ton (25.5%)	0.79 euro/l	35,295x255=9,000,255@0.79/l = €7,110178
Biohydrogen	20-25% (35,295)	0.0178 kg H2/kg	5.32 euro/kg	35,295000 x 0.0178 = 628,251kg x 5.32 euro/kg = 3,342,295
Carbon fibres	15-20%(27,450)	50%	5.67 euro	1372500kg x5.67euro = 7,782075
Biogas to electricity	20% (31,373 tons)	(0.3525 m3/kgVS) x (10.83/kwh/3)	12/c kWhe	4,775,481

Table shows calculation of market potential of each product when excise relief is granted

	Gross Revenue	**VAT** *(Gross Revenue @ 21%)*	**Revenue after Tax** *(Gross Revenue – VAT)*	**Mark-up for Supplier** *(Revenue after Tax@ 30%)*	**Total Deductions** *(VAT + Mark up for Supplier)*	**Net Revenue** *(Gross Revenue – Total Deductions)*
Bioethanol *(using C6 sugars only)*	11,533,945	2,422,128	9,111,817	2,733,545	5,155,673	6,378,272
Bioethanol *(using C5 only)*	7,110,178	1,493,137	5,617,041	1,685,112	3,178,250	3,931,928
Biohydrogen	3,342,295	701,882	2,640,413	792,124	1,494,006	1,848,289
Carbon Fibres	7,782,975	1,634,425	6,148,550	1,844,565	3,478,990	4,303,985
Biogas	4,775,481	0	0	0	0	4,775,481
Total						**€21,237,955**

Table shows the estimated revenue potential of the biorefinery after deductions have been made for VAT and supplier mark-up

The debt payback period is calculated at 6 years as indicated below:

	Year term calculation for debt payment	
	Gross revenue	21,237,955
Less	Production cost	9,140,000
		12,097,955
Multiply	For debt allocation of 50%	0.50
		6048978
Then:		
	Loan amount	39,140,000
Divide		6048978
		6.471
	Years	**6 years**

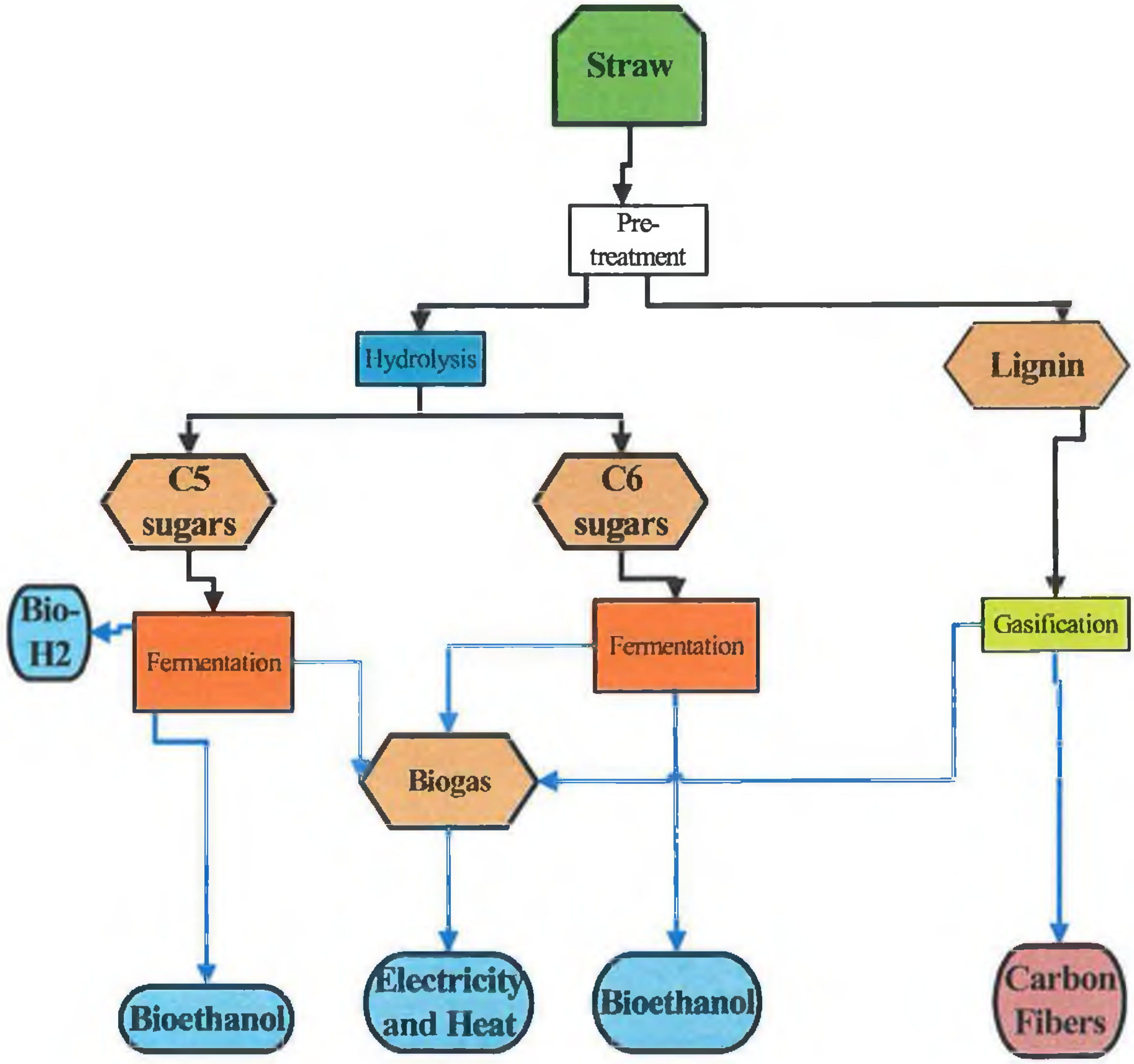
Year term calculation for debt repayment

Year	Beginning Balance	Total Payment	Interest Paid	Principal Paid	Ending Balance
1	39,140,000	7,858,007	1334674	6,523,333	32,616,667
2	32,616,667	7,635,562	1112228.334	6,523,333	26,093,333
3	26,093,333	7,413,116	889782.6689	6,523,333	19,570,000
4	19,570,000	7,190,670	667337.0034	6,523,333	13,046,667
5	13,046,667	6,968,225	444891.3379	6,523,333	6,523,334
6	6,523,334	6,745,779	222445.6724	6,523,333	0

Loan amortization schedule

Year	Gross Revenue	Loan Amortization	Production Cost	Total Cost	Revenue Balance
1	21,237,955	7,858,007	9,140,000	16,998,007	4,239,948
2	21,237,955	7,635,562	9,140,000	16,775,562	4,462,393
3	21,237,955	7,413,116	9,140,000	16,553,116	4,684,839
4	21,237,955	7,190,670	9,140,000	16,330,670	4,907,285
5	21,237,955	6,968,225	9,140,000	16,108,225	5,129,730
6	21,237,955	6,745,779	9,140,000	15,885,779	5,352,176
7	21,237,955	0	9,140,000	9,140,000	12,097,955
8	21,237,955	0	9,140,000	9,140,000	12,097,955
	↓				↓
23	21,237,955	0	9,140,000	9,140,000	12,097,955
24	21,237,955	0	9,140,000	9,140,000	12,097,955
25	21,237,955	0	0	0	21,237,955
Accumulated Revenue					**€267,777,516**

Projected Accumulated revenue over lifespan of 25 years



C5/C6 Sugars and lingin biorefinery for bioethanol, biohydrogen, carbon fibers and biogas from straw (with excise relief)

Accumulated Revenue (minus costs); €267,777,516
Payback period; 6 years

Accumulated Revenue and Payback

Appendix 2: Biorefinery 2 Analysis without Excise Relief

(C5/C6 Sugars and lignin biorefinery for bioethanol, biohydrogen, carbon fibres and biogas from straw (without excise relief))

	Required feedstock percentage	Yield	Market value with excise (+0.37)	Revenue potential (Excise included)	Excise payable @ 0.37 litre
Bioethanol (using C6 sugars only)	33-40% (57,255 tons)	255 l/ton (25.5%)	0.79 + 0.37 = 1.16 euro/l	57,255x255 = 14599930 litre @ 1.16 euro/l = €16,935,918	14599930 litre x 0.37 = 5,401,974
Bioethanol (using C5 only)	20-25% (35,295)	255 l/ton (25.5%)	1.16 euro/l	35,295x255=9,000,255 @1.16/l = €10,440,295	9,000,255 l x0.37 = 3,330,094
Biohydrogen	20-25% (35,295)	0.0178 kg H2/kg	(5.32 +37)= 5.69	35,295000 x 0.0178 = 628,251kg x 5.69 euro/kg = 3,574,748	628,251kg x 0.37 =232,453
Carbon fibres	15-20% (27,450)	50%	$7 per kg 5.67 euro	1372500kg x5.67euro = 7,782075 x0.7 = 5,447,452	0
Biogas to electricity	20% (31,373 tons)	(0.3525 m3/kgVS) x (10.83/kwh/3)	12/c kWhe	4,775,481	**0**

Table shows calculation of market potential of each product when excise is added

The above biorefinery scenario evaluates the production of Biohydrogen and Bioethanol using the C5 sugars, with bioethanol also being produced from the C6 sugars, carbon fibers from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise is assumed payable on fuel products.

	Gross Revenue	VAT *(Gross Revenue @ 21%)*	Revenue after Tax *(Gross Revenue – VAT)*	Mark-up for Supplier *(Revenue after Tax@ 30%)*	Excise	Total Deductions *(VAT + Mark up for Supplier + Excise)*	Net Revenue *(Gross Revenue – Total Deductions)*
Bioethanol *(using C6 sugars only)*	16,935,918	3,556,543	13,379,375	4,013,813	5,401,974	12,972,329	3,963,589
Bioethanol *(using C5 only)*	10,440,295	2,192,462	8,247,833	2,474,350	3,330,094	7,996,906	2,443,389
Biohydrogen	3,574,478	750,640	2,823,838	847,151	232,453	1,830,245	1,744,233
Carbon Fibres	7,782,075	1,634,236	6,147,839	1,844,352	0	3,478,588	4,303,487
Biogas	4,775,481	0	0	0	0	0	4,775,481
Total							**€17,230,180**

Table shows the estimated revenue potential of the biorefinery after deductions have been made for excise, VAT on excise and supplier mark-up

The debt payback period is calculated at 10 years as indicated below:

	Year term calculation for debt payment		
	Gross revenue	17,230,180	
Less	Production cost	9,140,000	
		8,090,180	
Multiply	For debt allocation of 50%	0.50	
		4045090	
Then:			
	Loan amount	39,140,000	
Divide		4045090	
	Years	9.676	**10 years**

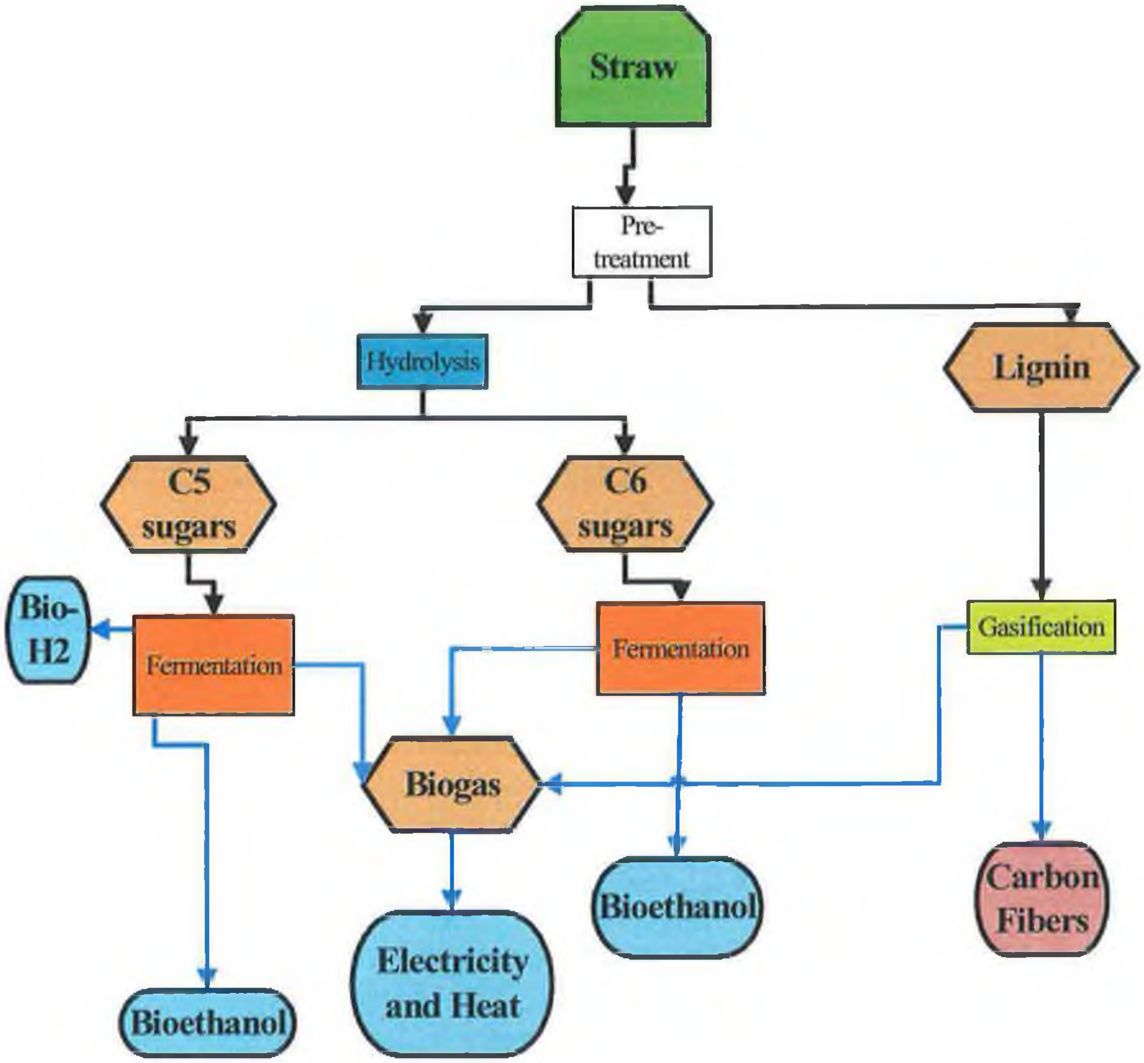
Year term calculation for debt payment

Year	Beginning Balance	Total Payment	Interest Paid	Principal Paid	Ending Balance
1	39,140,000	5,248,674	1334674	3,914,000	35226000
2	35,226,000	5,115,207	1201206.6	3,914,000	31312000
3	31,312,000	4,981,739	1067739.2	3,914,000	27398000
4	27,398,000	4,848,272	934271.8	3,914,000	23484000
5	23,484,000	4,714,804	800804.4	3,914,000	19570000
6	19,570,000	4,581,337	667337	3,914,000	15656000
7	15,656,000	4,447,870	533869.6	3,914,000	11742000
8	11,742,000	4,314,402	400402.2	3,914,000	7828000
9	7,828,000	4,180,935	266934.8	3,914,000	3914000
10	3,914,000	4,047,467	133467.4	3,914,000	0

Loan yearly amortization schedule

Year	Gross Revenue	Loan Amortization	Production Cost	Total Cost	Revenue Balance
1	17,230,180	5,248,674	9,140,000	14,388,674	2,841,506
2	17,230,180	5,115,207	9,140,000	14,255,207	2,974,973
3	17,230,180	4,981,739	9,140,000	14,121,739	3,108,441
4	17,230,180	4,848,272	9,140,000	13,988,272	3,241,908
5	17,230,180	4,714,804	9,140,000	13,854,804	3,375,376
6	17,230,180	4,581,337	9,140,000	13,721,337	3,508,843
7	17,230,180	4,447,870	9,140,000	13,587,870	3,642,310
8	17,230,180	4,314,402	9,140,000	13,454,402	3,775,778
9	17,230,180	4,180,935	9,140,000	13,320,935	3,909,245
10	17,230,180	4,047,467	9,140,000	13,187,467	4,042,713
11	17,230,180	0	9,140,000	9,140,000	8,090,180
12	17,230,180	0	9,140,000	9,140,000	8,090,180
	↓				↓
23	17,230,180	0	9,140,000	9,140,000	8,090,180
24	17,230,180	0	9,140,000	9,140,000	8,090,180
25	17,230,180	0	0	0	17,230,180
Accumulated Revenue					**€164,913,793**

Accumulated revenue over lifespan



C5/C6 Sugars and lingin biorefinery for bioethanol, biohydrogen, carbon fibers and biogas from straw (without excise relief)

Accumulated Revenue (minus costs); €164,913,793

Payback period; 10 years

Accumulated Revenue and Payback

Appendix 3: Biorefinery 3 Analysis with Excise Relief

(C5/C6 Sugars and lignin biorefinery for biobutanol, biohydrogen, lignin pellets and biogas from straw (with excise relief)).

The next biorefinery scenario evaluates the production of Biohydrogen and Biobutanol using the C5 sugars, with biobutanol also being produced from C6 sugars, and the lignin component pelletized into lignin pellets, with the residual matter being used to generate electricity (and heat) from biogas. Excise relief is assumed on fuel products.

	Required feedstock percentage	Yield	Market value	Revenue potential
Biobutanol *(using C5/C6 sugars)*	53-65% (92548 tons)	20%	1.19 euro/litre	92548000 kg x.2 = 18,509,600 @ 1.19/litre = 22,026,424 x 0.7 = 15,418,496
Biohydrogen	20-25% (35,295)	0.0178 kg H2/kg	5.32 euro/kg	35,295000 x 0.0178 = 628,251kg x 5.32 euro/kg = 3,342,295
Lignin pellets	15-20% (27,450)	100% approx	200euro/tonne	27,450 x 200 euro = 5,490,170
Biogas to electricity	20% (31,373 tons)	(0.3525 m3/kgVS) x (10.83/kwh/3)	12/c kWhe	4,775,481

Table shows calculation of market potential of each product when excise relief is granted

	Gross Revenue	VAT *(Gross Revenue @ 21%)*	Revenue after Tax *(Gross Revenue –VAT)*	Mark-up for Supplier *(Revenue after Tax@ 30%)*	Total Deductions *(VAT + Mark up for Supplier)*	Net Revenue *(Gross Revenue – Total Deductions)*
Biobutanol *(using C5/C6 sugars)*	22,026,424	4,625,549	17,400,875	5,220,262	9,845,812	12,180,612
Biohydrogen	3,342,295	701,882	2,640,413	792,124	1,494,006	1,848,289
Lignin pellets	5,490,170	1,152,936	4,337,234	1,301,170	2,454,106	3,036,064
Biogas to electricity	4,775,481	0	0	0	0	4,775,481
Total						**€21,840,447**

Table shows the estimated revenue potential of the biorefinery after deductions have been made for VAT and supplier mark-up

The debt payback period is calculated at 6 years as indicated below:

	Year term calculation for debt payment		
	Gross revenue	21,840,447	
Less	Production cost	9,140,000	
		12,700,447	
Multiply	For debt allocation of 50%	0.50	
		6350224	
Then:			
	Loan amount	39,140,000	
Divide		6350224	
	Years	6.164	**6 years**

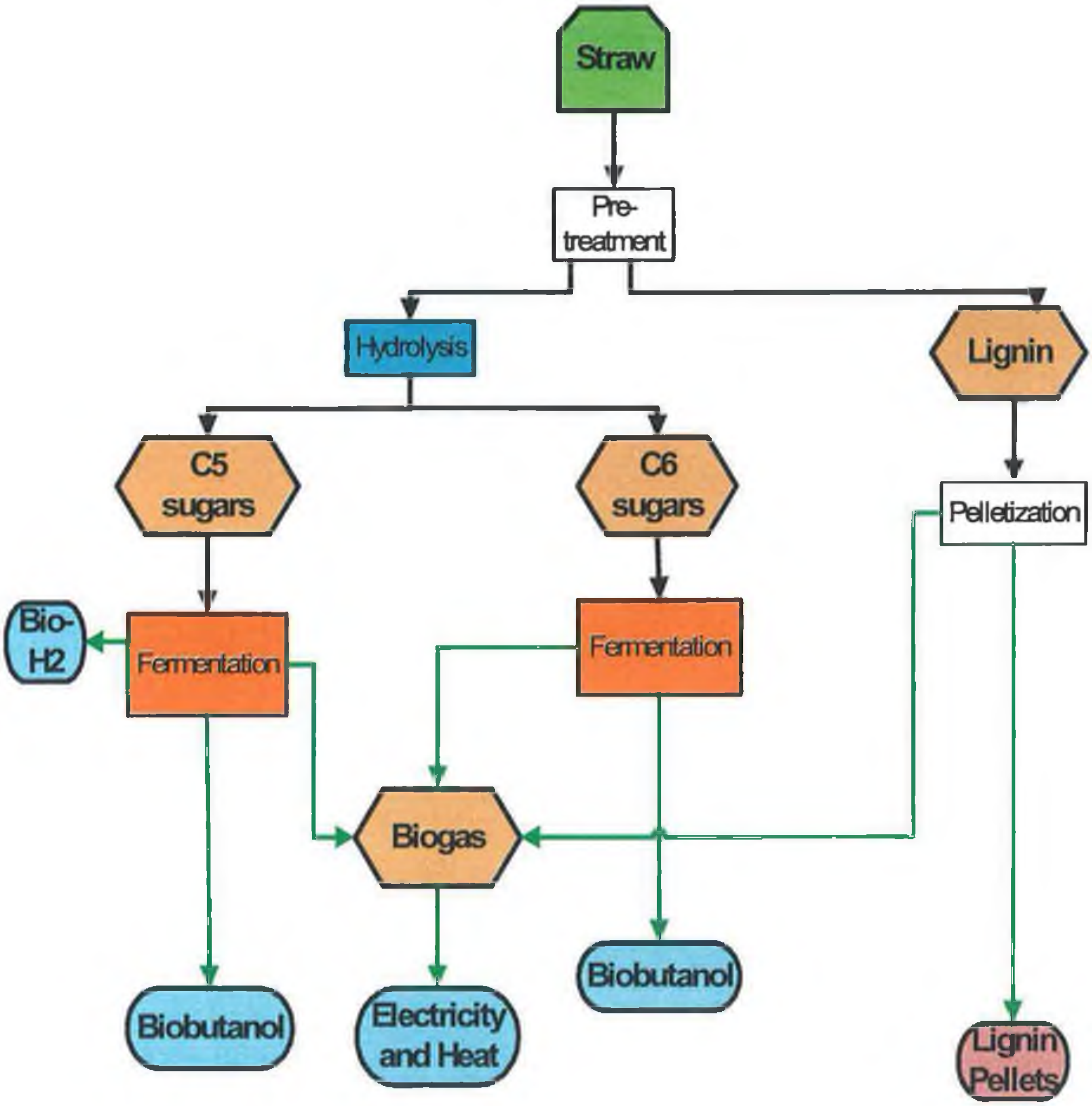
Year term calculation for debt repayment

Year	Beginning Balance	Total Payment	Interest Paid	Principal Paid	Ending Balance
1	39,140,000	7,858,007	1334674	6,523,333	32,616,667
2	32,616,667	7,635,562	1112228.334	6,523,333	26,093,333
3	26,093,333	7,413,116	889782.6689	6,523,333	19,570,000
4	19,570,000	7,190,670	667337.0034	6,523,333	13,046,667
5	13,046,667	6,968,225	444891.3379	6,523,333	6,523,334
6	6,523,334	6,745,779	222445.6724	6,523,333	0

Loan yearly amortization schedule

Year	Gross Revenue	Loan Amortization	Production Cost	Total Cost	Revenue Balance
1	21,840,447	7,858,007	9,140,000	16,998,007	4,842,440
2	21,840,447	7,635,562	9,140,000	16,775,562	5,064,885
3	21,840,447	7,413,116	9,140,000	16,553,116	5,287,331
4	21,840,447	7,190,670	9,140,000	16,330,670	5,509,777
5	21,840,447	6,968,225	9,140,000	16,108,225	5,732,222
6	21,840,447	6,745,779	9,140,000	15,885,779	5,954,668
7	21,840,447	0	9,140,000	9,140,000	12,700,447
8	21,840,447	0	9,140,000	9,140,000	12,700,447
	↓				↓
23	21,840,447	0	9,140,000	9,140,000	12,700,447
24	21,840,447	0	9,140,000	9,140,000	12,700,447
25	21,840,447	0	0	0	21,840,447
Accumulated Revenue					**€282,839,816**

Accumulated revenue over lifespan



C5/C6 Sugars and lingin biorefinery for biobutanol, biohydrogen, lignin pellets and biogas from straw (with excise relief)

Accumulated Revenue (minus costs); €282,839,816

Payback period; 6 years

Accumulated Revenue and Payback

Appendix 4: Biorefinery 3 Analysis without Excise Relief

(C5/C6 Sugars and lignin biorefinery for biobutanol, biohydrogen, lignin pellets and biogas from straw (without excise relief)).

The next biorefinery scenario evaluates the production of Biohydrogen and Biobutanol using the C5 sugars, with biobutanol also being produced from C6 sugars, and the lignin component pelletized into lignin pellets, with the residual matter being used to generate electricity (and heat) from biogas. Excise is assumed payable on fuel products.

	Required feedstock percentage	**Yield**	**Market value with excise (+0.37)**	**Revenue potential (excise included)**	**Excise payable @ 0.37 litre**
Biobutanol *(using C5/C6 sugars)*	53-65% (92548 tons)	(20%)	1.19 + 37 = 1.56 euro/l	92548000 kg x.2 = 18,509,600 @ 1.56/litre = 28,874,976	18,509,600 x 0.37 = 6,848,552
Biohydrogen	20-25% (35,295)	0.0178 kg H2/kg	(5.32 +37)= 5.69	35,295000 x 0.0178 = 628,251kg x 5.69 euro/kg = 3,574,748	628,251kg x 0.37 =232,453
Lignin pellets	15-20% (27,450)	100% approx	Ireland 200euro/ton	27,450 x 200 euro = 5,490,170	
Biogas to electricity	20% (31,373 tons)	(0.3525 m3/kgVS) x (10.83/kwh/3	12/c kWhe	4,775,481	

Table shows calculation of market potential of each product when excise is added

	Gross Revenue	VAT *(Gross Revenue @ 21%)*	Revenue after Tax *(Gross Revenue – VAT)*	Mark-up for Supplier *(Revenue after Tax@ 30%)*	Excise	Total Deductions *(VAT + Mark up for Supplier + Excise)*	Net Revenue *(Gross Revenue – Total Deductions)*
Biobutanol *(using C5/C6 sugars)*	28,874,976	6,063,745	22,811,231	6,843,369	6,848,522	19,755,636	9,119,340
Biohydrogen	3,574,478	750,640	2,823,838	847,151	232,453	1,830,245	1,744,233
Lignin pellets	5,490,170	1,152,936	4,337,234	1,301,170	0	2,454,106	3,036,064
Biogas to electricity	4,775,481	0	0	0	0	0	4,775,481
Total							**€18,675,118**

Table shows the estimated revenue potential of the biorefinery after deductions have been made for excise, VAT on excise and supplier mark-up

The debt payback period is calculated at 8 years as indicated below:

	Year term calculation for debt payment		
	Gross revenue	18,675,118	
Less	Production cost	9,140,000	
		9,535,118	
Multiply	For debt allocation of 50%	0.50	
		4767559	
Then:			
	Loan amount	39,140,000	
Divide		4767559	
	Years	8.210	**8 years**

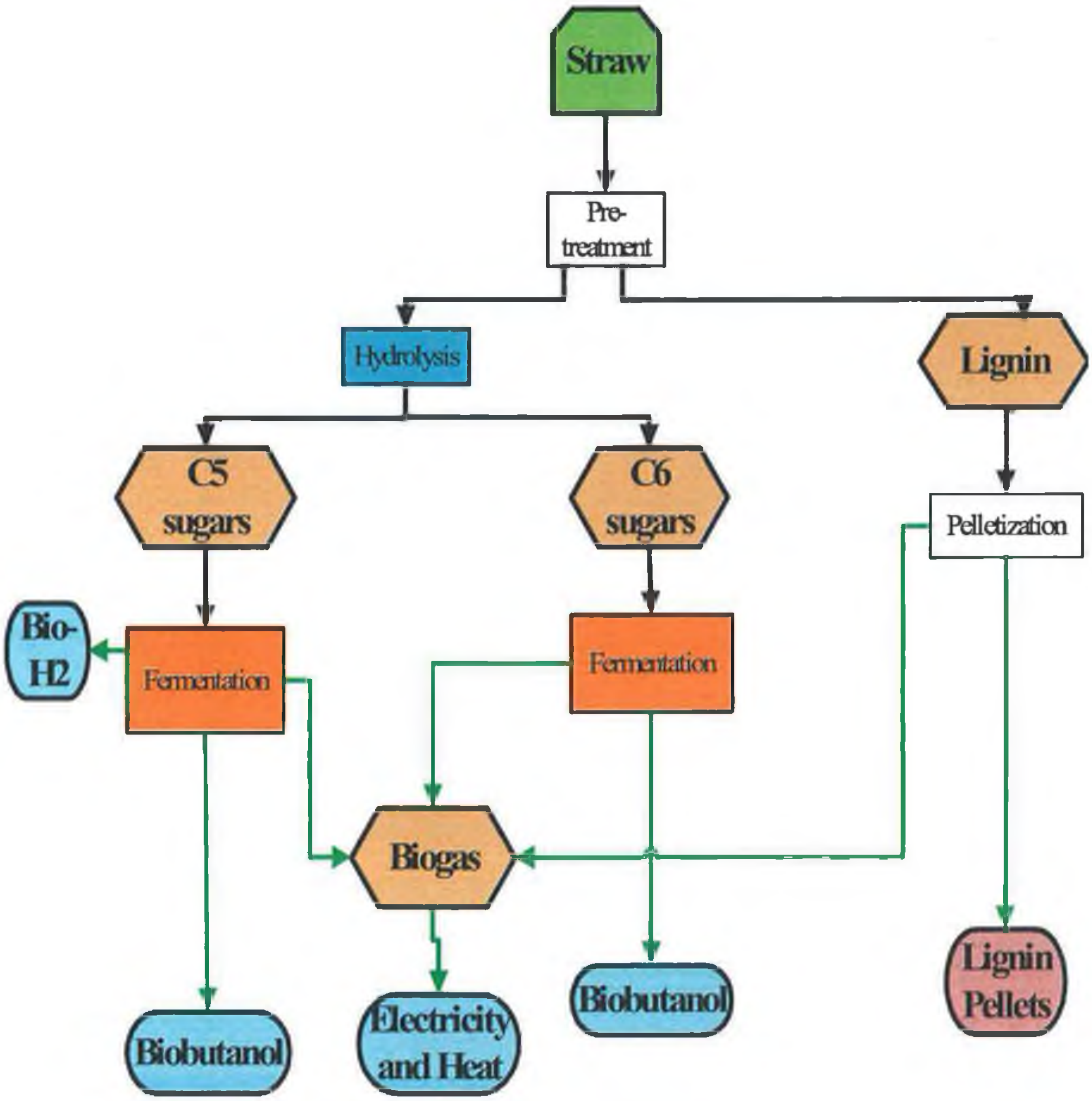
Year term calculation for debt payment

Year	Beginning Balance	Total Payment	Interest Paid	Principal Paid	Ending Balance
1	39,140,000	6,227,174	1334674	4,892,500	34,247,500
2	34,247,500	6,060,340	1167840	4,892,500	29,355,000
3	29,355,000	5,893,506	1001006	4,892,500	24,462,500
4	24,462,500	5,726,671	834171	4,892,500	19,570,000
5	19,570,000	5,559,837	667337	4,892,500	14,677,500
6	14,677,500	5,393,003	500503	4,892,500	9,785,000
7	9,785,000	5,226,169	333668.5	4,892,500	4,892,500
8	4,892,500	5,059,334	166834.25	4,892,500	0

Loan yearly amortization schedule

Year	Gross Revenue	Loan Amortization	Production Cost	Total Cost	Revenue Balance
1	18,675,118	6,227,174	9,140,000	15,367,174	3,307,944
2	18,675,118	6,060,340	9,140,000	15,200,340	3,474,778
3	18,675,118	5,893,506	9,140,000	15,033,506	3,641,613
4	18,675,118	5,726,671	9,140,000	14,866,671	3,808,447
5	18,675,118	5,559,837	9,140,000	14,699,837	3,975,281
6	18,675,118	5,393,003	9,140,000	14,533,003	4,142,115
7	18,675,118	5,226,169	9,140,000	14,366,169	4,308,950
8	18,675,118	5,059,334	9,140,000	14,199,334	4,475,784
9	18,675,118	0	9,140,000	9,140,000	9,535,118
10	18,675,118	0	9,140,000	9,140,000	9,535,118
	↓				↓
23	18,675,118	0	9,140,000	9,140,000	9,535,118
24	18,675,118	0	9,140,000	9,140,000	9,535,118
25	18,675,118	0	0	0	18,675,118
Accumulated Revenue					**€202,371,917**

Accumulated revenue over lifespan



C5/C6 Sugars and lingin biorefinery for biobutanol, biohydrogen, lignin pellets and biogas from straw (without excise relief)

Accumulated Revenue (minus costs); €202,371,917

Payback period; 8 years

Accumulated Revenue and Payback

Appendix 5: Biorefinery 4 Analysis

(C5/C6 Sugars and lignin biorefinery for furfural, lactic acid, carbon fibres and biogas from straw (Product Based Biorefinery – excise not applicable))

The next straw biorefinery scenario evaluates the production of furfural using the C5 sugars, lactic acid from C6 sugars, carbon fibres from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise relief is not applicable as fuel products with the exception of biogas are not produced.

	Required feedstock percentage	**Yield**	**Selling price**	**Revenue potential**
Furfural	20-25% (35,295)	160 kg/ton	0.81 euro/kg	35295 x 160 = 5647200 kg x0.81 = 4, 574232
Lactic Acid	33-40% (57,255 tons)	26%	2.75 euro/kg	57255000kg x 0 .26 = 14,886,300 kg @ 2.75 euro =40,937,325
Carbon fibres	15-20% (27,450)	50%	5.67 euro	1372500kg x5.67euro = 7,782075
Biogas to electricity	20% (31,373 tons)	(0.3525 m3/kgVS) x (10.83/kwh/3)	12/c kWhe	4,775,481

Table shows calculation of market potential of each product (excise relief not applicable)

	Gross Revenue	VAT *(Gross Revenue @ 21%)*	Revenue after Tax *(Gross Revenue –VAT)*	Mark-up for Supplier *(Revenue after Tax@ 30%)*	Total Deductions *(VAT + Mark up for Supplier)*	Net Revenue *(Gross Revenue – Total Deductions)*
Furfural	4,574,232	960,589	3,613,643	1,084,093	2,044,682	2,529,550
Lactic Acid	40,937,325	8,596,838	32,340,487	9,702,146	18,298,984	22,638,341
Carbon Fibres	7,782,975	1,634,425	6,148,550	1,844,565	3,478,990	4,303,985
Biogas to electricity	4,775,481	0	0	0	0	4,775,481
Total						**€34,247,357**

Table shows the estimated revenue potential of the biorefinery after deductions have been made for VAT and supplier mark-up

The debt payback period is calculated at 8 years as indicated below:

	<u>Year term calculation for debt payment</u>		
	Gross revenue	34,247,357	
Less	Production cost	9,140,000	
		25,107,357	
Multiply	For debt allocation of 50%	0.50	
		12553679	
Then:			
	Loan amount	39,140,000	
Divide		12553679	
	Years	3.118	**3 years**

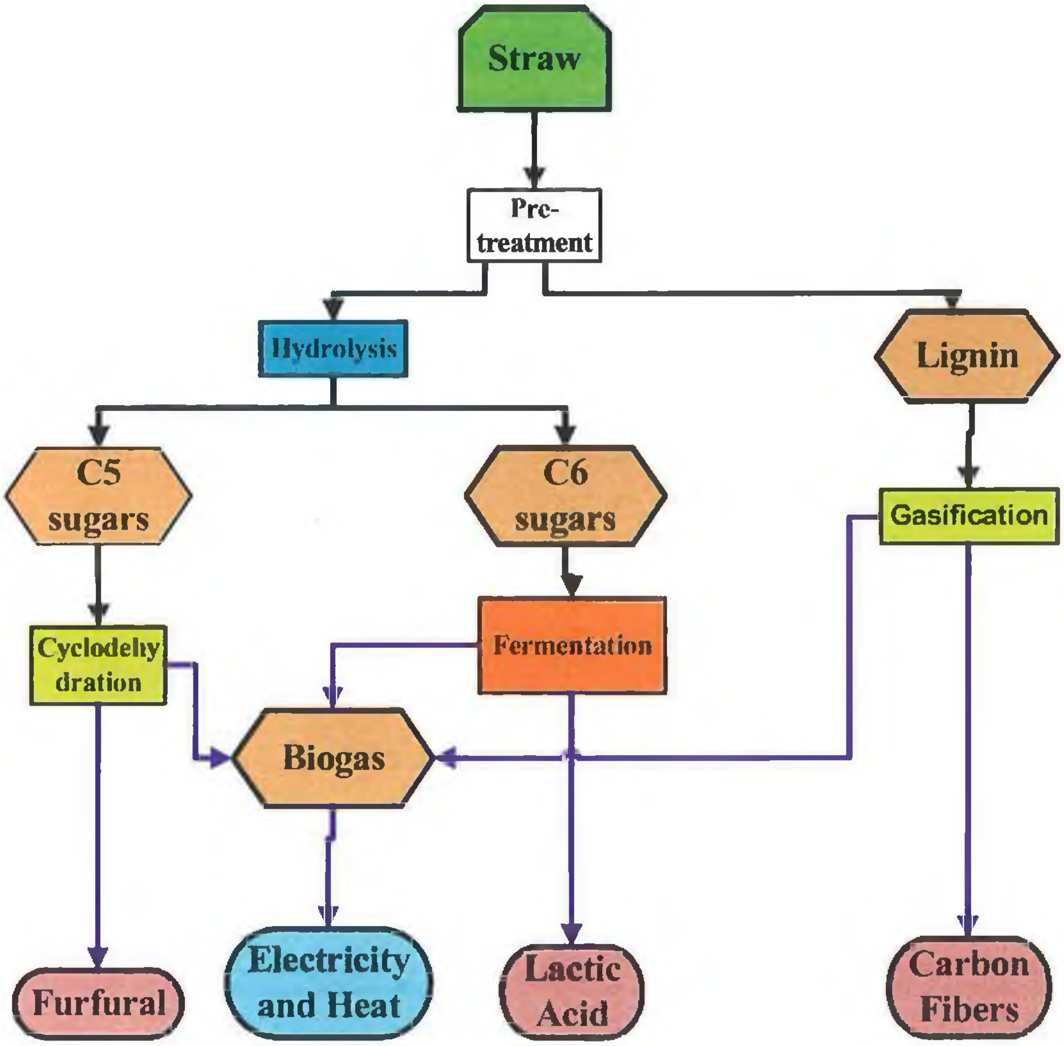
Year term calculation to debt payment

Year	Beginning Balance	Total Payment	Interest Paid	Principal Paid	Ending Balance
1	39,140,000	14,381,341	1334674	13,046,667	26,093,333
2	26,093,333	13,936,449	889783	13,046,667	13,046,667
3	13,046,667	13,491,558	444891	13,046,667	0

Loan Yearly Amoritization Schedule

Year	Gross Revenue	Loan Amortization	Production Cost	Total Cost	Revenue Balance
1	34,247,357	14,381,341	9,140,000	23,521,341	10,726,016
2	34,247,357	13,936,449	9,140,000	23,076,449	11,170,908
3	34,247,357	13,491,558	9,140,000	22,631,558	11,615,799
4	34,247,357	0	9,140,000	9,140,000	25,107,357
5	34,247,357	0	9,140,000	9,140,000	25,107,357
	↓				↓
23	34,247,357	0	9,140,000	9,140,000	25107357
24	34,247,357	0	9,140,000	9,140,000	25107357
25	34,247,357	0	0	0	34247357
Accumulated Revenue					**€595,014,577**

Accumulated Revenue over Lifespan



C5/C6 Sugars and lingin biorefinery for furfural, lactic acid, carbon fibers and biogas from straw (Product Based Biorefinery – excise not applicable)

Accumulated Revenue (minus costs); €595,014,577

Payback period; 3 years

Accumulated Revenue and Payback

Appendix 6: Biorefinery 5 Analysis with Excise Relief

(C5/C6 Sugars and lignin biorefinery for furfural, bioethanol, BTX and biogas from straw (with excise relief))

The final straw biorefinery scenario evaluates the production of furfural using the C5 sugars, bioethanol from C6 sugars, BTX from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise relief is assumed.

	Required feedstock percentage	Yield	Market value	Market potential
Furfural	20-25%	160 kg/ton	0.81 euro/kg	35295 x 160 = 5647200 kg x0.81 = 4, 574232
Bioethanol (using C6 sugars only)	(35,295) 33-40% (57,255 tons)	255 l/ton (25.5%)		57,255x255 = 14599930 litre @ .79 euro/l = 11,533945
BTX	15-20% (27,450)	211.68 l/ton	0.41 euro/l	27,450 x 212 = 5819400x0.41 euro/l= 2,385,954 euro
Biogas to electricity	20% (31,373 tons)	(0.3525 m3/kgVS) x (10.83/kwh/3)	12/c kWhe	4,775,481

Table shows calculation of market potential of each product when excise relief is granted

	Gross Revenue	**VAT** *(Gross Revenue @ 21%)*	**Revenue after Tax** *(Gross Revenue –VAT)*	**Mark-up for Supplier** *(Revenue after Tax@ 30%)*	**Total Deductions** *(VAT + Mark up for Supplier)*	**Net Revenue** *(Gross Revenue – Total Deductions)*
Furfural	4,574,232	960,589	3,613,643	1,084,093	2,044,682	2,529,550
Bioethanol *(using C6 sugars only)*	11,533,945	2,422,128	9,111,817	2,733,545	5,155,673	6,378,272
BTX	2,385,954	501,050	1,884,904	565,471	1,066,521	1,319,433
Biogas to electricity	4,775,481	0	0	0	0	4,775,481
Total						**€15,002,735**

Table shows the estimated revenue potential of the biorefinery after deductions have been made for VAT and supplier mark-up

The debt payback period is calculated at 13 years as indicated below:

	Year term calculation for debt payment		
	Gross revenue	15,002,735	
Less	Production cost	9,140,000	
		5,862,735	
Multiply	For debt allocation of 50%	0.50	
		2931368	
Then:			
	Loan amount	39,140,000	
Divide		2931368	
		13.352	
	Years		**13 years**

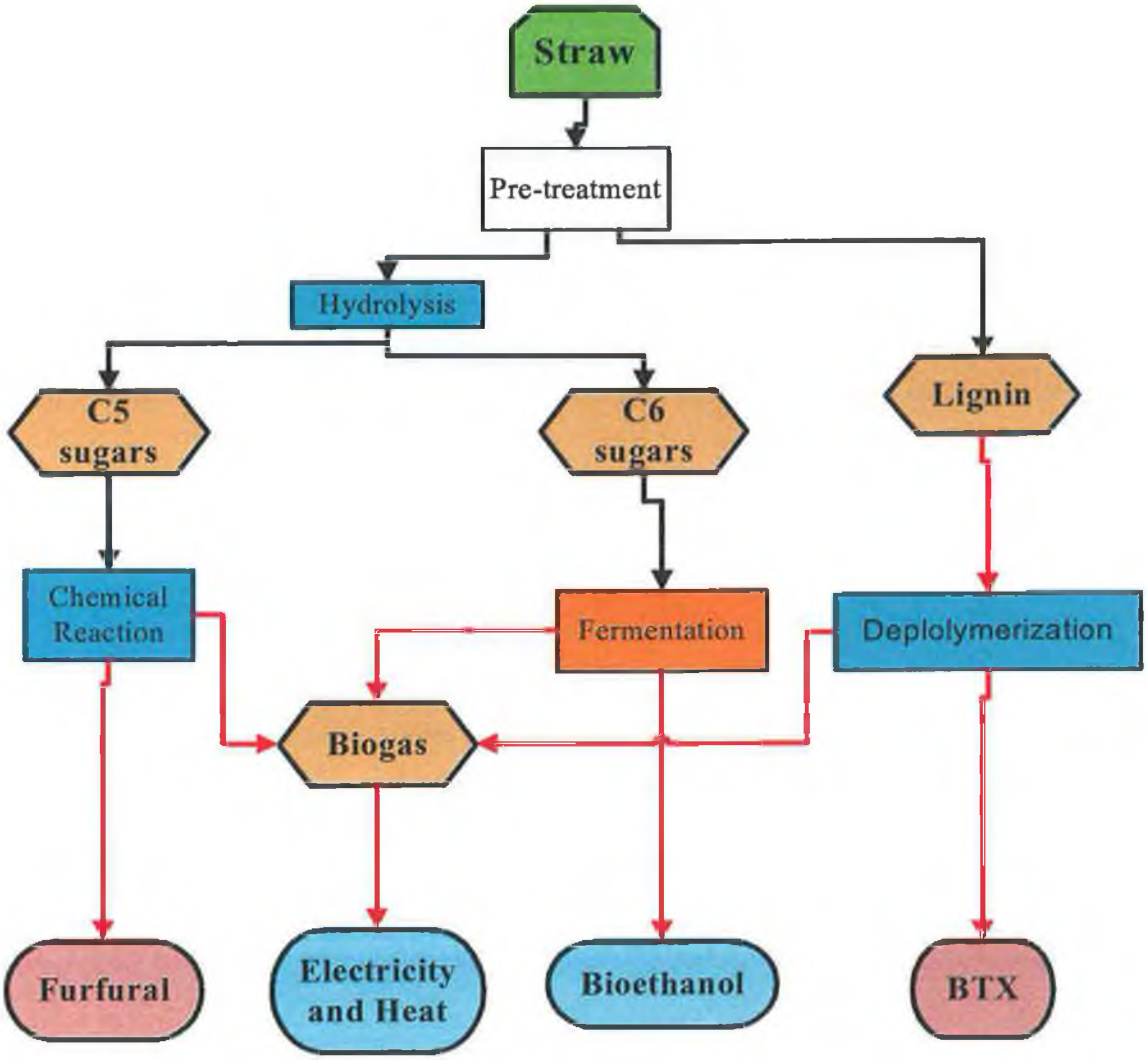
Year term calculation for debt repayment

Year	Beginning Balance	Total Payment	Interest Paid	Principal Paid	Ending Balance
1	39,140,000	4,345,443	1,334,674	3,010,769	36,129,231
2	36,129,231	4,242,776	1,232,007	3,010,769	33,118,462
3	33,118,462	4,140,109	1,129,340	3,010,769	30,107,692
4	30,107,692	4,037,442	1,026,672	3,010,769	27,096,923
5	27,096,923	3,934,774	924,005	3,010,769	24,086,154
6	24,086,154	3,832,107	821,338	3,010,769	21,075,385
7	21,075,385	3,729,440	718,671	3,010,769	18,064,615
8	18,064,615	3,626,773	616,003	3,010,769	15,053,846
9	15,053,846	3,524,105	513,336	3,010,769	12,043,077
10	12,043,077	3,421,438	410,669	3,010,769	9,032,308
11	9,032,308	3,318,771	308,002	3,010,769	6,021,538
12	6,021,538	3,216,104	205,334	3,010,769	3,010,769
13	3,010,769	3,113,436	102,667	3,010,769	0

Loan yearly amortization schedule

Year	Gross Revenue	Loan Amortization	Production Cost	Total Cost	Revenue Balance
1	15,002,735	4,345,443	9,140,000	13,485,443	1,517,292
2	15,002,735	4,242,776	9,140,000	13,382,776	1,619,959
3	15,002,735	4,140,109	9,140,000	13,280,109	1,722,626
4	15,002,735	4,037,442	9,140,000	13,177,442	1,825,293
5	15,002,735	3,934,774	9,140,000	13,074,774	1,927,961
6	15,002,735	3,832,107	9,140,000	12,972,107	2,030,628
7	15,002,735	3,729,440	9,140,000	12,869,440	2,133,295
8	15,002,735	3,626,773	9,140,000	12,766,773	2,235,962
9	15,002,735	3,524,105	9,140,000	12,664,105	2,338,630
10	15,002,735	3,421,438	9,140,000	12,561,438	2,441,297
11	15,002,735	3,318,771	9,140,000	12,458,771	2,543,964
12	15,002,735	3,216,104	9,140,000	12,356,104	2,646,631
13	15,002,735	3,113,436	9,140,000	12,253,436	2,749,299
14	15,002,735	0	9,140,000	9,140,000	5,862,735
15	15,002,735	0	9,140,000	9,140,000	5,862,735
	↓				↓
23	15,002,735	0	9,140,000	9,140,000	5,862,735
24	15,002,735	0	9,140,000	9,140,000	5,862,735
25	15,002,735	0	0	0	15002735
Accumulated Revenue					**€107,225,657**

Accumulated revenue over lifespan



C5/C6 Sugars and lingin biorefinery for furfural, bioethanol, BTX and biogas from straw (with excise relief)

Accumulated Revenue (minus costs); €107,225,657

Payback period; 13 years

Accumulated Revenue and Payback

Appendix 7: Biorefinery 5 Analysis without Excise Relief

(C5/C6 Sugars and lignin biorefinery for furfural, bioethanol, BTX and biogas from straw (without excise relief))

The final straw biorefinery scenario evaluates the production of furfural using the C5 sugars, bioethanol from C6 sugars, BTX from the lignin component, with the residual matter being used to generate electricity (and heat) from biogas. Excise is assumed payable on fuel products.

	Required feedstock percentage	**Yield**	**Selling price** With excise (+0.37) for fuels	**Revenue potential**	**Excise payable @ 0.37 litre**
Furfural	20-25% (35,295)	, 160 kg/ton	0.81 euro/kg	35295 x 160 = 5647200 kg x0.81 = 4, 574232	
Bioethanol (using C6 sugars only)	33-40% (57,255 tons)	255 l/ton (25.5%)	0.79 + 0.37 = 1.16 euro/l	57,255x255= 14,600,025 @1.16/l = 16,936,029 euro	14,600,025 l x0.37 = 5,402,009
BTX	15-20% (27,450)	211 l/ton	$1.96/gallon $0.51/l 0.41 euro/l	27,450 x 212 = 5819400x0.41 euro/l= 2,385,954 euro	
Biogas to electricity	20% (31,373 tons)	(0.3525 m3/kgVS) x (10.83/kwh/3)	12/c kWhe	4,775,481	

Table shows calculation of market potential of each product when excise is added

	Gross Revenue	**VAT** *(Gross Revenue @ 21%)*	**Revenue after Tax** *(Gross Revenue – VAT)*	**Mark-up for Supplier** *(Revenue after Tax@ 30%)*	**Excise**	**Total Deductions** *(VAT + Mark up for Supplier + Excise)*	**Net Revenue** (*Gross Revenue – Total Deductions*)
Furfural	4,574,232	960,589	3,613,643	1,084,093	0	2,044,682	2,529,550
Bioethanol *(using C6 sugars only)*	16,936,029	3,556,566	13,379,463	4,013,839	5,402,009	12,972,414	3,963,615
BTX	2,385,954	501,050	1,884,904	565,471	0	1,066,521	1,319,433
Biogas to electricity	4,775,481	0	0	0	0	0	4,775,481
Total							**€12,588,079**

Table shows the estimated revenue potential of the biorefinery after deductions have been made for excise, VAT on excise and supplier markup

The debt payback period is calculated at 23 years as indicated below;

	Year term calculation for debt payment		
	Gross revenue	12,588,079	
Less	Production cost	9,140,000	
		3,448,079	
Multiply	For debt allocation of 50%	0.50	
		1724040	
Then:			
	Loan amount	39,140,000	
Divide		1724040	
	Years	22.702	23 years

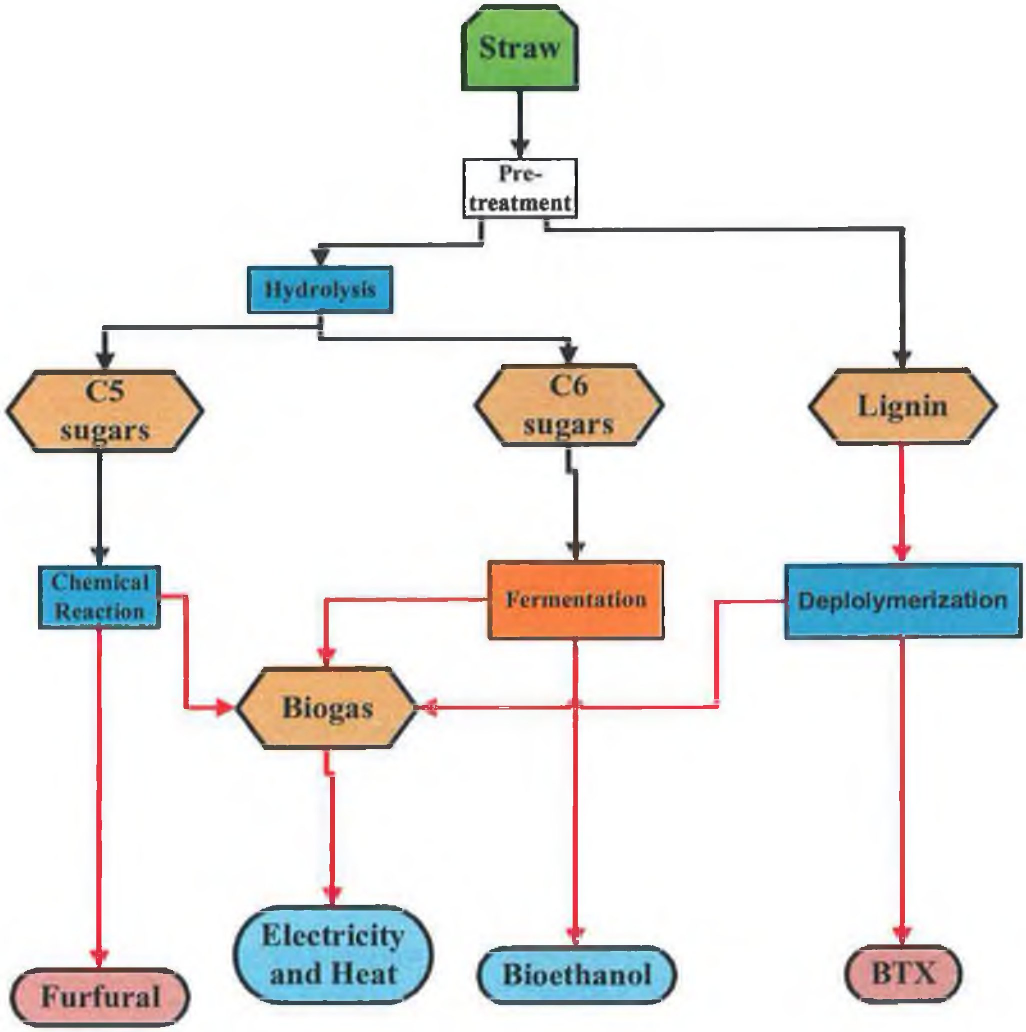
Year term calculation for debt repayment

Year	Beginning Balance	Total Payment	Interest Paid	Principal Paid	Ending Balance
1	39,140,000	3,036,413	1,334,674	1,701,739	37,438,261
2	37,438,261	2,978,384	1,276,645	1,701,739	35,736,522
3	35,736,522	2,920,355	1,218,615	1,701,739	34,034,783
4	34,034,783	2,862,325	1,160,586	1,701,739	32,333,043
5	32,333,043	2,804,296	1,102,557	1,701,739	30,631,304
6	30,631,304	2,746,267	1,044,527	1,701,739	28,929,565
7	28,929,565	2,688,237	986,498	1,701,739	27,227,826
8	27,227,826	2,630,208	928,469	1,701,739	25,526,087
9	25,526,087	2,572,179	870,440	1,701,739	23,824,348
10	23,824,348	2,514,149	812,410	1,701,739	22,122,609
11	22,122,609	2,456,120	754,381	1,701,739	20,420,870
12	20,420,870	2,398,091	696,352	1,701,739	18,719,130
13	18,719,130	2,340,061	638,322	1,701,739	17,017,391
14	17,017,391	2,282,032	580,293	1,701,739	15,315,652
15	15,315,652	2,224,003	522,264	1,701,739	13,613,913
16	13,613,913	2,165,974	464,234	1,701,739	11,912,174
17	11,912,174	2,107,944	406,205	1,701,739	10,210,435
18	10,210,435	2,049,915	348,176	1,701,739	8,508,696
19	8,508,696	1,991,886	290,147	1,701,739	6,806,957
20	6,806,957	1,933,856	232,117	1,701,739	5,105,217
21	5,105,217	1,875,827	174,088	1,701,739	3,403,478
22	3,403,478	1,817,798	116,059	1,701,739	1,701,739
23	1,701,739	1,759,768	58,029	1,701,739	0

Loan yearly amortization schedule

Year	Gross Revenue	Loan Amortization	Production Cost	Total Cost	Revenue Balance
1	12,588,079	3,036,413	9,140,000	12,176,413	411,666
2	12,588,079	2,978,384	9,140,000	12,118,384	469,695
3	12,588,079	2,920,355	9,140,000	12,060,355	527,724
4	12,588,079	2,862,325	9,140,000	12,002,325	585,754
5	12,588,079	2,804,296	9,140,000	11,944,296	643,783
6	12,588,079	2,746,267	9,140,000	11,886,267	701,812
7	12,588,079	2,688,237	9,140,000	11,828,237	759,842
8	12,588,079	2,630,208	9,140,000	11,770,208	817,871
9	12,588,079	2,572,179	9,140,000	11,712,179	875,900
10	12,588,079	2,514,149	9,140,000	11,654,149	933,930
11	12,588,079	2,456,120	9,140,000	11,596,120	991,959
12	12,588,079	2,398,091	9,140,000	11,538,091	1,049,988
13	12,588,079	2,340,061	9,140,000	11,480,061	1,108,018
14	12,588,079	2,282,032	9,140,000	11,422,032	1,166,047
15	12,588,079	2,224,003	9,140,000	11,364,003	1,224,076
16	12,588,079	2,165,974	9,140,000	11,305,974	1,282,105
17	12,588,079	2,107,944	9,140,000	11,247,944	1,340,135
18	12,588,079	2,049,915	9,140,000	11,189,915	1,398,164
19	12,588,079	1,991,886	9,140,000	11,131,886	1,456,193
20	12,588,079	1,933,856	9,140,000	11,073,856	1,514,223
21	12,588,079	1,875,827	9,140,000	11,015,827	1,572,252
22	12,588,079	1,817,798	9,140,000	10,957,798	1,630,281
23	12,588,079	1,759,768	9,140,000	10,899,768	1,688,311
24	12,588,079	0	9,140,000	9,140,000	3,448,079
25	12,588,079	0	0	0	12,588,079
Accumulated Revenue					**€40,185,887**

Accumulated revenue over lifespan



C5/C6 Sugars and lingin biorefinery for furfural, bioethanol, BTX and biogas from straw (without excise relief)

Accumulated Revenue (minus costs); €40,185,887

Payback period; 23 years

Accumulated Revenue and Payback