The Biorefinery Opportunity

A North East England view

A report on the opportunities for the development of a renewable raw material based process industry in North East England

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nepic

cpi The Centre for Process Innovation ...the future inspired

renew Tees Valley Limited

northeast biofuels

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Strengthened by the existing commercial and technical infrastructure on Teesside, North East England is rapidly establishing itself as major hub for the production of first generation biofuels from both grain and vegetable oils. Production of first generation fuels will continue to develop as technology enables improvement in production performance. As farmers and growers refine their best practices, increased efficiencies in the supply chains will ensure greater economies and lower carbon footprints.

With this as its starting point, the study demonstrates how advanced technologies can produce renewably resourced fuels, energy and platform chemicals. These developments are strategically important if consumer demand for fuels and products - previously derived solely from diminishing fossil hydrocarbons - are to be satisfied. In the future, these demands will be increasing met at least in part from environmentally friendly and sustainable raw materials.

Co-location of plants enables efficient use of the fuel required to produce heat for process chemistry and is fundamental to production integration. In addition, co-products can be utilised as raw materials for down stream conversion into useful products.

Teesside is uniquely placed as the location to pioneer these developments in advanced biofuels production and biorefining and welcomes enquiries from companies and organisations interested in investing and delivering these ideas.

John Reynolds

Introduction

The growth of interest and investment in biomass based processes to produce value added chemicals & fuels led the Regional Development Agency in North East England to seek to understand how it could react to the opportunity.

With the extensive process industry base in the region, represented by its active cluster organisation North East Process Industry Cluster (NEPIC) and with the Centre for Process Innovation (CPI) - the national centre of excellence in process manufacture - situated in the region the agency decided to look at how an integrated complex might develop alongside the existing process plants and what opportunities could exist for linking the new processes with the existing largely petrochemical based operations.

In addition the UK push to develop a biofuels industry has led to significant investment in the region in so called first generation Biodiesel and now Bio-ethanol plants as well as in renewably fuelled power generation. These provide a basis for further development of this very significant business sector in North East England.

With the assistance of the Chemistry Innovation Knowledge Transfer Network (CIKTN) and its partners the National Non-Food Crops Centre, the Bioscience for Business KTN and Trends Business Research (TBR) this review and report has been prepared to provide the basis for further development of a renewable raw material based chemical & process industry in the region. Whilst the precise route to this future remains uncertain the region has the objective of becoming one of the best places to invest in biomass based processes for the development of industrial biotechnology.

The opportunity clearly exists and this report provides recommendations for North East England its industry cluster NEPIC and CPI - with other partners across the UK - to consider in developing the biorefinery concept over the next 5-10 years.

NB – In producing this report a large amount of supporting data and information was assembled by the project team. This is available as a set of appendices to this report. Copies are available by contacting the NEPIC office.

Executive Summary

This study was commissioned to consider the potential strategic impact of biorefining on the process industries in the region.

This study confirms that the North East's unique combination of research and process skills, assets, logistics and business infrastructure, all established to support the traditional chemical industry in the region, can be developed over time to be a competitive centre for biorefining and the associated support activities. The opportunity exists for the North East to develop competitive, and in some areas leading, capabilities for the production of chemicals from renewable feedstocks.

The report identifies the next steps for the North East to develop biorefining as a key element of its forward strategy. It recommends a series of actions, at regional and national level, to develop the necessary technologies, markets, skills, logistics and infrastructure to initiate a large scale biorefinery sector.

It is clearly an option for the region to take no action and allow market forces to prevail. However, given the current global developments in this area both technically and economically, this approach would render the North East ill prepared for the inevitable emergence of biorefining. The existing strengths of the region are not sufficient to ensure investment in biorefining unless action is taken to develop a recognised reputation and the skills, capabilities and markets to compete globally in the production of chemicals from renewable feedstocks. Other parts of Europe and the UK are already taking steps to introduce biorefining.

Answers to key questions

This study was commissioned to address some specific questions listed below.

Question 1: What is a biorefinery, why are they of economic interest and where are they likely to make economic sense in UK/Europe?

A biorefinery is a large scale manufacturing site converting biomass into a range of materials and molecules. Several large studies have concluded that a range of biomass derived materials will have a strategic advantage over petrochemical equivalents in the future due to lower costs and lower environmental impacts. There are several factors that influence the location of biorefineries and biofuel plants including

- Proximity to raw materials such as agricultural, industrial and domestic "waste", specifically grown energy crops, traditional crops (corn, oil seed rape), sugar cane and forestry;
- Access to ports to facilitate imports of biomass and trade in fuels;
- Availability of land, skills, services and infrastructure capable of supporting large-scale process manufacturing;
- Proximity to non-renewable fuel manufacture and blending facilities as an outlet for biofuels;
- Public sector policy support for biorefining and the process industries in general.

The North East possesses sufficient of these features to become a leading location in the UK. Although it is at the northern edge of UK cereal production it has good proximity to forestry. The lack of a complex refinery operation is a disadvantage for fuel production, but the opportunities for process integration are greater because of the diverse chemical operations in the region.

Within the EU the leading locations for attracting biorefinery investment include the coastal sites of Rotterdam and Antwerp together with agricultural and forestry heartland of Europe. The availability of feedstock in volumes for both first and second generation biorefineries favours sites with a surrounding low cost agricultural base.

Question 2: What is the economic case for developing Biorefining in the North East with the associated technology and supply chains?

Driven by subsidies and the requirements for biofuel to be blended into road fuel, the strongest economic case for the North East in the short and medium term is for the production of energy products/fuels. In the long term, better and cheaper technology, higher oil prices and a changing policy landscape will make the production of chemicals and polymers increasingly attractive.

Assessments of Gross Value Added (GVA) show that substantial gains are achievable if the region can initiate projects leading to ca. 1m tes production over the next 20 years. Up to £2.8 bn is potentially available with benefits in manufacturing, agriculture and supply chain operations.

Additional benefits identified by the study include:

- Renewal of the process industries' capital base through new and sustenance investment;
- Substantial additional returns and employment opportunities for the agricultural and forestry sectors;
- A platform for technology and service companies, including licensing technology;
- An expanded port and transport infrastructure;
- Increasing the attractiveness of the region for inward investment;
- Additional opportunities for integration in the region's infrastructure, such as CO_2 capture.

<u>Question 3:</u> Can the existing regional integrated infrastructure and skill base provide promising long term opportunities for supporting a leading position in implementing biorefinery ideas?

North East England has the infrastructure needed and is well positioned to develop biorefining. Some actions are already in hand to address industry skill needs and the growing regional biotechnology industry provides further know-how which will support the industry. As the region's capabilities are focus onto biorefining it will be able to identify and bridge the key skills, knowledge and technology gaps. The establishment of the National Skills Academy for the Process Industries in North East England provides the opportunity to develop the regional and national skills provision to support the industrial biotechnology sector.

<u>Question 4:</u> What strategic value can be added to the NE economy through increased use of sustainable feedstocks and development of novel products and services related to biotechnology and biorefining?

Strategic value added for the North East economy will result from its reputation for responsibility and sustainability and from its capabilities and infrastructure.

Because of these:

- It will attract new and modern process industries to the region;
- It will drive the development of industrial biotechnology in the region;
- It will attract good people and investment and provide an easier growth path for Start-Ups and SME's;
- It will allow participation in significantly growing chemistry-using sectors of the economy and enable new products to be developed and demonstrated locally;
- It will increase sustainability and reduce carbon dioxide emissions thereby developing and reinforcing the competitiveness of the region and supporting the UK in the delivery of its obligations.

<u>Question 5:</u> Can the NE process sector support itself and make a long term contribution to region's Economic Value Add (EVA) in the face of an uncertain energy & raw material supply through developing a biorefining activity?

Although biorefineries will not in the short or medium term displace significant amounts of petroleum as feedstock in outside energy and transport, they will make the region's economy for manufacturing, agriculture and trade more robust in the face of changing feedstock conditions, new market demands for renewable products and policy/regulation changes. The development of novel technologies will secure the region's engineering base.

<u>Question 6:</u> How will the development of a biorefinery affect and be affected by the development of the existing NE industrial base (including service companies), regional capabilities & skills over the next 20 years?

The mutual benefits and opportunities will manifest themselves in a number of ways, particularly:

- The existing research and development activities including CPI (especially the NIBF) and CELS will find their attractiveness to employees and clients enhanced by the proximity of operating pilot and manufacturing plant;
- The sustainable image will attract scientists and engineers to work in the wider industry;
- The industry will provide an opportunity for personnel to remain in the region and for service companies to develop their capacity and capability;
- A revitalised agricultural sector will provide additional employment and GVA opportunities;

- The biorefinery sector will support the development of renewable energy projects as the opportunities process agricultural products expand and generate by-products/waste. The proposed investments in CCS technology represents a further opportunity to lead in the integration of conventional and industrial biotechnology based process manufacture;
- It will stimulate and encourage the development of the academic base;
- It will encourage the generation of SME operations to develop and manage small operating units.

The Major Issues

The current focus for biorefining technologies is the production of road transport **fuel** for blending with diesel or gasoline. This is driven by policy initiatives and financial incentives to both develop this technology and to ensure that it is economically viable.

The production of **chemicals**, the focus of this study, is less well developed. However, a biorefinery can make a range of platform chemicals as well as fuel, and could also extract useful chemicals from the feedstock in a pre-processing step.

There are two major technology routes to achieve this:

a) **Thermochemical** - directly, or via bioOil

b) **Fermentation** - using 1st generation starch/sugar, or 2nd generation lignocellulosic processes

Route (a) has some potential to integrate into the existing Teesside chemical processes although it is currently more suitable, technically and economically, for producing fuels. Route (b) is also has some potential to fit into the existing fuel/chemical cluster but is more likely to be the basis for a future cluster of chemicals and downstream businesses.

Both routes are economically viable for fuel because of subsidies, but less so for platform chemicals where such support is not available. The work done confirms that both routes will be capable of delivering a range of chemicals economically, both as fossil fuel costs rise and new process technologies move along the learning curve. It is however too early to make a firm recommendation on which technology will ultimately prevail. The region should therefore support both approaches.

World scale biorefineries currently produce around 300,000 tonnes/yr product and cost from £150-300m. A facility of this size could be supported by the North East region's agriculture. The strong port infrastructure means that additional raw materials could be imported. Recent work indicates that up to 1m tes of fuels could be produced from available biomass in the UK via a centralised facility. This would be of sufficient scale to make associated chemical manufacture attractive.

Beyond the immediate economic value, a biorefinery sector would contribute to sustainability and greenhouse gas reduction, the development of industrial biotechnology and the continued development of the process sector in the region. It is also essential that the region builds a position in biorefining so that it can participate in the global expansion of this sector when it takes place in the next 20-50 years.

It is predicted that by 2010, US$125 billion worth of chemical sales will involve the use of biotechnology. Already the US is planning investments of over $1 billion in cellulosic biorefineries, a full scale biomass-to-liquid plant is under construction in Germany, a commercial-scale cellulosic biorefinery is now operating in Japan and major projects are underway in several other countries. The demand for biodegradable packaging materials (polymer films) is already significant driven by consumer and regulatory pressures. It is therefore recommended that action is taken to ensure that the currently competitive position is retained.

Regional Action Plan - Recommendations

Developing biorefining as a source of materials for the process industries in the region is a long-term challenge. In the short term economics will favour fuel and energy production rather than chemicals. However, it is important to take action now to continue to particpate in the development of biorefining for fuels and to position the region to be an important player in the future development of platform chemicals from renewable feedstocks which is anticipated to be a major global industry.

North East England should establish a strategy with short, medium and long term goals for biorefining. These should include development of physical assets and the development and exploitation of knowledge in the region to be a leading participant in the global growth of this sector in the EU. The UK is falling behind in the exploitation of biorefinery technology despite the presence of strong capability and industry interest.

Such a strategy will benefit the region, adjoining regions across the north of England and the national economy.

In the next 4 years the northern regions including the North East should aim to attract at least £150m of new investment in biorefinery related activities. In the medium term (i.e. next decade) a stretch target would be to grow this to £1bn, at which point associated service industries might have grown to £100m. An ambitious target for 25 years time would be to install 1m tes of capacity with a cumulative capital investment of £5bn in direct biorefining and associated supply- and demand-side activities.

A total of six recommendations are made which are summarised below.

Recommendation 1: Develop a BioOil Refinery to Demonstrate Thermochemical Biorefining

Establish a second generation bioOil refinery in the region. In the immediate future the market would be power generation as a first step towards production of chemicals. This would establish biorefining in the region, build capability and reputation and demonstrate the economics to the private sector. It would support the region's agriculture and forestry and provide an additional outlet for waste biomass

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Recommendation 2: Develop 2nd Generation Fermentation Capability

2nd generation fermentation and thermochemical routes will be of equal industrial importance so the North East should develop a knowledge and demonstration capability to design processes for platform chemicals based on fermentation of regionally available biomass.

Recommendation 3: Develop Policies to Maximise Carbon Efficiency

Fiscal incentives for power generation and road fuel will increasingly be linked to sustainability. The development of a low carbon infrastructure and measures to reduce industrial carbon emissions per unit of output would be a source of strategic competitive advantage for the region.

Recommendation 4: Develop Sustainable Chemical Industries

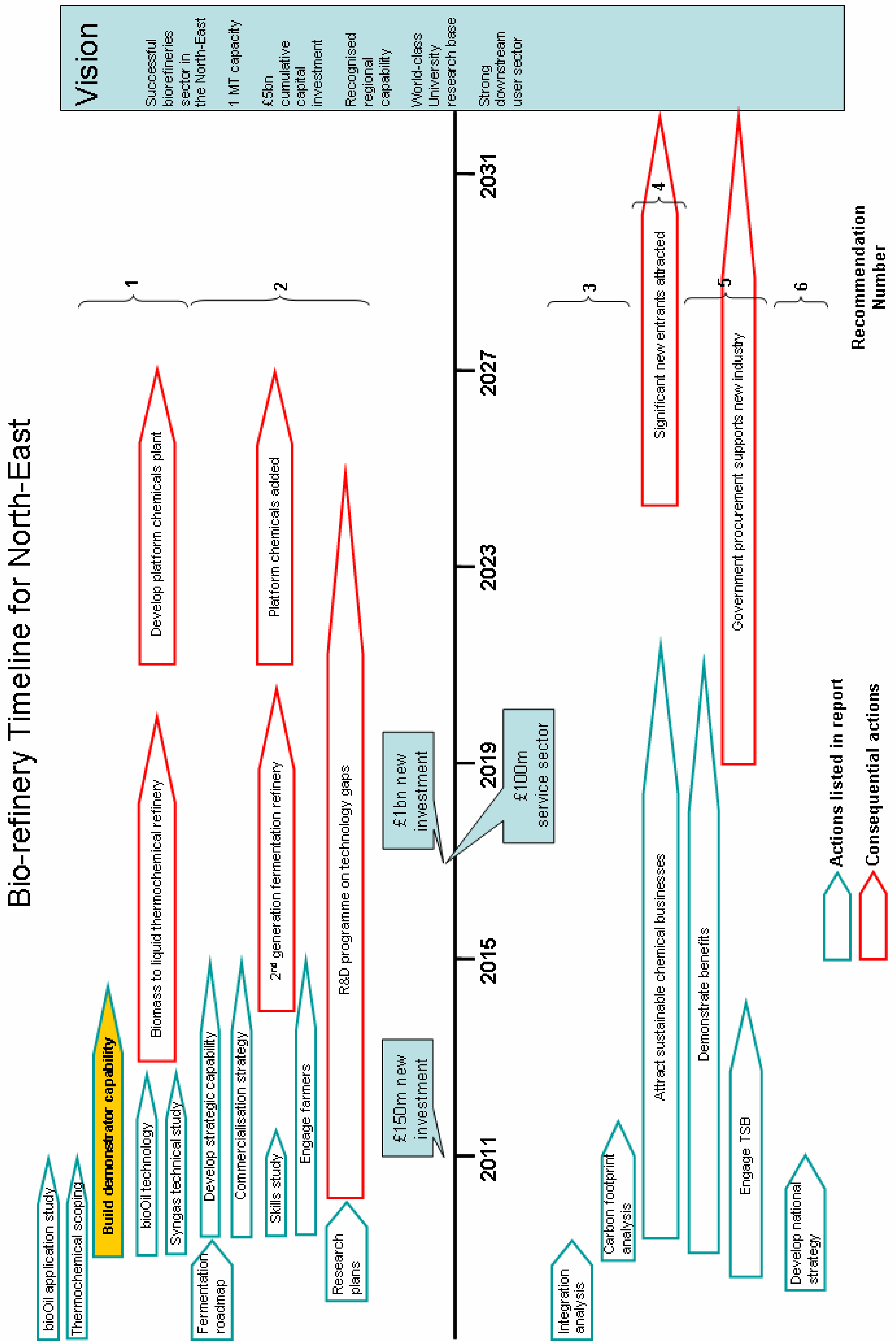
A long term goal is to develop a sustainable chemistries sector in the region based on the products from the portfolio of biorefineries. This will encourage a strategic shift towards businesses that can exploit biorefinery products; including coatings, cosmetics and personal care. The region needs to develop the capability to support such businesses and to actively encourage them. Encouragement through regional and national promotion, developing policies to encourage biorefining, raising awareness of the opportunities and assisting new businesses to establish themselves.

Recommendation 5: Stimulate Demand for Biorefinery Products

Production of most platform chemicals from biomass is not yet economically viable. The region needs to stimulate demand and encourage early investment through policy makers who can use public sector procurement to create initial demand, use regulation to drive a shift towards sustainability and deploy fiscal incentives to encourage early actors.

Recommendation 6: Develop a National Strategy for Biorefineries Linking the Key Regions and Companies

The UK is falling behind in biorefinery technologies. The region should encourage the development of a national biorefinery strategy. The North East region should also urgently and activity work with UK companies and across the other key regions with a direct interest in developing a biorefinery industry (Yorkshire & Humberside, North West & Scotland), supporting the proposed Industrial Biotechnology Innovation & Growth Team (IB-IGT).


Bio-refinery Timeline for North-East
Vision
Successful biorefineries sector in the North-East
1 MT capacity
£5bn cumulative capital investment
Recognised regional capability
World-class University research base
Strong downstream user sector
2011
2015
2019
2023
2027
2031
bioOil application study
Thermochemical scoping
Build demonstrator capability
bioOil technology
Syngas technical study
Biomass to liquid thermochemical refinery
Develop platform chemicals plant
Fermentation roadmap
Develop strategic capability
Commercialisation strategy
Skills study
2nd generation fermentation refinery
Platform chemicals added
Engage farmers
Research plans
R&D programme on technology gaps
£150m new investment
£1bn new investment
£100m service sector
Integration analysis
Carbon footprint analysis
Attract sustainable chemical businesses
Significant new entrants attracted
Demonstrate benefits
Engage TSB
Government procurement supports new industry
Develop national strategy
1
2
3
4
5
6
Recommendation Number
Actions listed in report
Consequential actions

1 Background & Requirements

The fundamental purpose of this study is to consider the strategic impact of biorefineries as a sustainable source of materials for the industries in the North East of England and to make recommendations for developing this capability in the region.

The process industries are critically important to the North East of England, providing 25% of the region's industrial base and impacting over 300,000 people.[1] These industries heavily depend upon oil and natural gas as raw materials.

New "biorefining" technologies are emerging for the use of biomass as an alternative and sustainable feedstock which reduces the dependency on fossil fuel reserves and should lower net carbon dioxide emissions. Biorefining, the production of chemicals from biomass, is generating worldwide interest and is already undertaken for the production of fuels in the UK and overseas.

The fundamental purpose of this study is to consider the strategic impact of biorefining as a source of materials for the North East process industries cluster, both in terms of how it will impact markets and the manufacturing economy itself.

There is a strategic intent to ease the dependence of these industries on raw materials derived from fossil fuels and to reduce greenhouse emissions. It is also imperative, to ensure long term viability, that the region's industry embraces and participates in the deployment of the new industrial and other biotechnologies that are now starting to enter the process industries. Competitive technologies for producing basic chemical building blocks from sustainable raw materials are starting to emerge and it will take a considerable time for a structural shift to take place in the region's industries to exploit them on a large scale. Hence this study to consider the economic case and outline exploitation plans for biorefineries.

[1] Source: www.nepic.co.uk retrieved 6th July 2007

2 Policy & Drivers for Biorefining

The policies driving biorefineries are the needs to reduce greenhouse gas emissions and increase sustainability. This is particularly apparent in the production of road fuels but there is increasing interest as a route to renewably sourced chemicals and materials.

There is an imperative to reduce carbon dioxide emissions and move towards a more sustainable society. Policies at international, European, national and regional levels all reflect this, for example

- The United Nations Framework Convention on Climate Change[2]
- The European Union Climate Change Program[3]
- The UK Climate Change Program[4]
- One NorthEast Regional Economic Strategy[5]

The use of biomass as an alternative source of carbon for energy and materials instead has the potential to reduce both carbon dioxide emissions and the depletion of finite fossil fuels. Consequently there is increasing international interest in the use of these technologies.

Policy makers on both sides of the Atlantic have particularly targeted the use of biomass as a road fuel. For example by 2010 5% (by volume) of UK road transport fuel will need to be derived from a renewable source, and this is expected to increase substantially in future; the EU are considering a target of 10% for 2020[6].

This is having a major impact upon the use of biomass by:

- Creating an imperative for producing road fuel energy products
- Using fiscal instruments to stimulate renewable road fuel production
- Exploiting on very large scale readily available technology for production
- Producing products that can be directly incorporated into road fuels
- Producing crops for sugar, starch and oil that can be transformed into road fuels

This is both creating opportunities and barriers to the development of biorefineries for chemical production. Opportunities arise from the development of the underlying science and technology, particularly in areas of biotechnology and the broader awareness of agriculture and forestry. However, the fiscal incentives and market size of the energy sector makes it far more economically attractive as an outlet than other areas of the process industries.

Security of supply is also an issue, particularly in North America, which is stimulating production of bioethanol for gasoline. There are also economic drivers for very specific products, most notably polylactic acid (a plastic) and 1,3 propanediol; it is cheaper to make from biomass than petroleum

The potential for a new market for agriculture and forestry has not escaped businesses in these sectors. Europe and the US have large agricultural surpluses which is depressing these sectors. The UK alone has the potential to sustainably supply at least 1,000,000 dry tonnes of wood per year and dedicate 1,000,000 ha of land to fuel crops without impacting upon food production.[7]

The biofuel industry in Europe has been led by the biodiesel industry; 85% of world production is in Europe. According to Frost and Sullivan 2006 production was 4m tonnes and will rise to 10m tonnes in 2013. Annual

[2] http://unfccc.int/2860.php
[3] http://ec.europa.eu/environment/climat/eccp.htm
[4] http://www.defra.gov.uk/environment/climatechange/uk/ukccp/index.htm
[5] http://www.onenortheast.co.uk/page/res.cfm
[6] http://ec.europa.eu/energy/energy_policy/doc/07_biofuels_progress_report_en.pdf
[7] UK Biomass Strategy, 2007, Defra

global bioethanol production is currently around 20m tonnes,[8] mainly from Brazilian sugar cane and US corn. European investments are taking place. For example BP, British Sugar and DuPont have recently announced that they will build a 330,000 tonne unit in Hull.[9] Ensus have started constructing a similar sized plant at Wilton which will use wheat.[10]

There is an argument that directly using biomass for power is the most appropriate way to exploit it from the perspective of minimisation of carbon dioxide emissions across the economy as a whole and also minimising investment.

However policy makers are interested in biorefining due to other long term drivers:

- The need for alternative liquid road transport fuels.
- Other technologies are also becoming available for energy without greenhouse gas emissions so biomass can be directed to other uses.
- Increasing corporate and consumer demand for renewably sourced materials with associated market premiums.
- Advances in industrial biotechnology together with increasing oil prices may enable economically superior routes for converting biomass to end products.
- Philosophically, it is preferable to chemically build on the molecular constituents of biomass to make materials than to simply destroy them through power generation.
- Broadening the sectors of the economy that are contributing to increased sustainability.

Accordingly there is increasing interest in the use of biomass as a source of raw materials for the process industries as well as a source of energy. The rewards are potentially large and this is reflected in significant international investment:

- Estimated value to a novel global market by 2030 is US$300 billion
- McKinsey & Co. have predicted that by 2010, US$125 billion worth of chemical sales will involve the use of biotechnology[11]
- The US will invest US$ 1.2 billion in six cellulosic ethanol biorefineries with a further $200 million earmarked to develop small-scale cellulosic demonstration plants.
- A commercial-scale cellulosic biorefinery started operation in Japan during 2007.
- In Europe, Germany, Belgium and France are leading the way by pump-priming with many million euros invested in national programmes. In Germany, the federal government has declared its objective to support the expansion of BTL biorefineries through loan guarantees. Also in Germany, fiscal incentives mean that bioethanol used for the production of E85 and 2nd generation bioethanol as well as BTL will remain tax exempt until 2015. In France, Europe's second largest producer of biofuels after Germany, the publically funded Agence de l'innovation industrielle is providing 50% in aid to a €88million Biohub® R&D programme on renewable chemicals from agricultural raw materials.
- Elsewhere - Brazil is a primary global producer of biofuels and others like China and India are mobilising to take advantage of the new technologies.

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[8] FAOSTAT 2005
[9] http://tinyurl.com/2ne8yq (redirects to BP website at http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7034350)
[10] http://www.ensusgroup.com/about_01.php
[11] www.bio-economy.net/Docs/McKinsey.doc

3 What is a Biorefinery

A biorefinery is a facility that converts biomass into usable products, most often fuel but also chemicals. In the same way that an oil refinery processes crude oil into fuels and chemicals, a biorefinery performs the same task with plant matter.

First generation biorefineries operate by processing the "valuable" parts of a crop such as the grain from wheat and discarding the unwanted parts such as straw and chaff. These are used/disposed of according to normal agricultural practice but we note they can be burnt to produce power where economical to do so. These technologies are established and in industrial use today.

In contrast second generation technology will process the whole plant. This offers two key advantages which lead to higher productivity from a given area of land.

- All the biomass is used in the process resulting in a greater yield of biorefined products from a given agricultural crop.
- The possibility of using a broader range of feedstocks enabling the use of higher yielding plants or products of otherwise unsuitable land.

There are two fundamentally different biorefinery processes, thermochemical and fermentation. Thermochemical processes use heat to convert biomass either into "BioOil" (which can be used for power) or into syngas which can be used for petrochemical manufacture. 1st generation fermentation can convert grain and sugar into ethanol for gasoline and is carried out on a large scale. 2nd generation fermentation processes, which are under development, can convert the whole plant and hence can accept a wider range of biomass and make more productive use of a given agricultural area.

Both technologies have the potential to make other platform chemicals and plants are being built throughout the world. The UK is not developing or exploiting the latest technologies as rapidly as other countries.

Second generation biotechnology is still in the process of development and it will be five to fifteen years before it is fully exploited commercially although a number of plants have been announced in the US. Given its potential for higher yields and broader range of feedstocks it is expected that it will displace many first generation processes over time.

There are two fundamental types of biorefinery technology with different characteristics; the fermentation and thermochemical routes. A third type of biorefining based on chemical transformation is the production of biodiesel which is discussed at the end of this section. Both technologies require energy which can be met by an on-site combined heat and power plant fuelled by residues from the biomass processing.

Biomass is very bulky compared to conventional liquid hydrocarbons, particularly when one considers that only a proportion of the mass can be gainfully transformed. Consequently logistics is very important to the overall biorefinery economics. The presence of a deep water port and associated infrastructure is important to cost-effective handling of raw materials.

3.1 Fermentation

First generation fermentation process, the left hand side of Figure 1 is very widely used to produce bioethanol from sugars and starches. The technology and process is very well established and essentially the same as that used to produce alcoholic spirits. Adaptations are possible to produce other “platform chemicals” (see below).

The second generation fermentation process (right hand side of Figure 1), again primarily aimed at bioethanol and extensively developed in the US, can produce a similar range of “platform chemicals” through the processing of sugars and cellulose and ultimately lignin’s.

The second generation fermentation technologies are still in development and the range and raw materials handled and the proportion of feedstock actually converted to useful products will increase over time. They are more complex and involve more steps than 1st generation processes. Pilot scale and demonstration plants need to be built to prove the technology prior to full scale commercial refining and this process has started in North America and Spain. For example $385m of federal funds are being invested in the US. The first commercial scale production is expected to start in two or three years time. In Japan, the world’s first commercial scale cellulosic biorefinery started operations at the beginning of 2007. The plant has a reported annual operating capacity of 1.4 million litres in 2007 rising to 4 million litres in 2008.

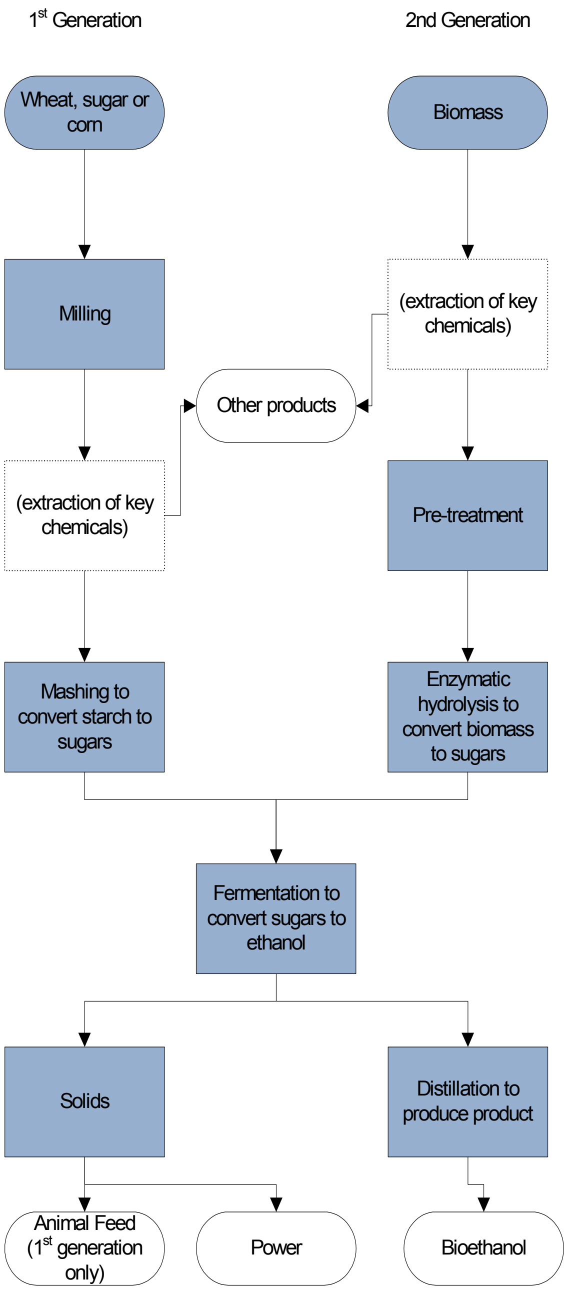

Figure 1: 1st & 2nd Generation Fermentation of Ethanol

The potential for non-renewable greenhouse gas savings from the manufacture of products from 2nd generation plants compared with petrochemical sources varies between 30% and 85%.[12] Second generation technologies provide higher bioethanol/chemical yields per hectare than 1st generation techniques.

Both processes produce solid residues high in proteins. These can be sold into the animal food industry or burnt to power the biorefinery according to their composition and economics.

Fermentation processes have the potential to make a vast range of different chemicals, many with known process routes and applications. However the expectation is that the primary platform chemicals produced from fermentation biorefineries are established platform chemicals with established sources and international markets such as:

- Ethanol
- Succinic acid
- Lactic acid
- 1,3-propanediol
- Butanol

[12] BREW report; executive summary, http://www.chem.uu.nl/brew/

These also have established markets in the following sectors.

- Fuel
- Nutraceuticals
- Personal care and cosmetics
- Elastomers, polymers and adhesives
- Surfactants

It is likely that they, and not their exotic counterparts, would form the primary products and compete with bioethanol for raw materials and production capability.

The processes to ferment rather than extract chemicals are likely to be 1st generation in nature due to the need to develop suitable micro-organisms. The change to second generation will perhaps be later than the adoption of 2nd generation ethanol processes due to the greater challenge of developing suitable micro organisms for the broader range of raw materials.

The fermentation process produces solid co-products and residues. 1st generation co-products from protein crops such as wheat can be used for animal feed and will displace imported soymeal. Other residues can be burnt for power; fermentation facilities require considerable amounts of energy for the distillation and drying processes.

3.2 Thermochemical

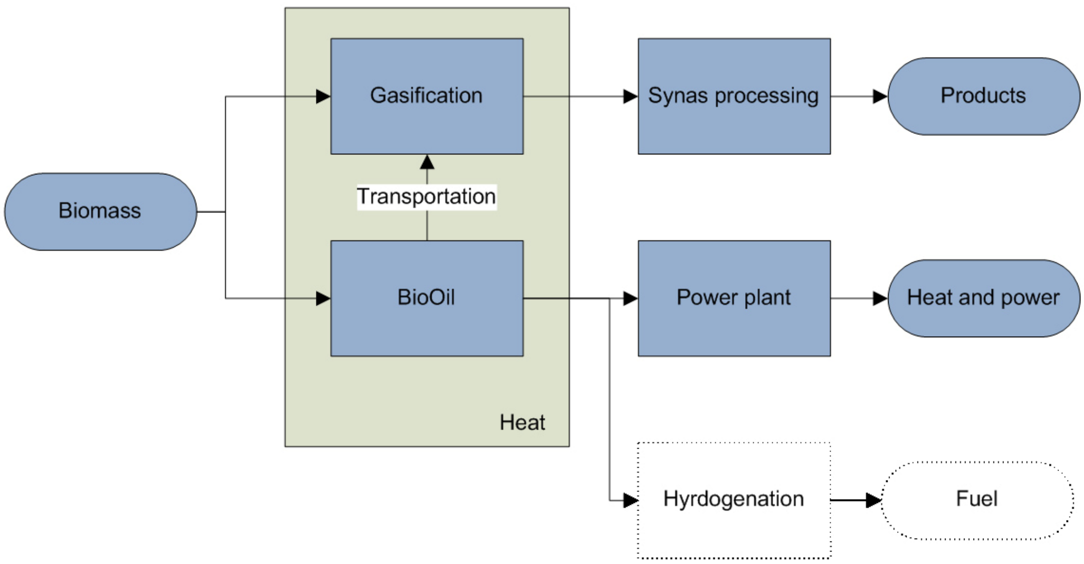

Figure 2: Thermochemical Processes

The thermochemical process Figure 2 is very different from fermentation in that it uses heat to break down the biomass into a gas containing hydrogen and carbon monoxide ("syngas"). This gas can be processed using well established technology widely used in the petrochemical industry.[13] In this sense thermochemical processes provide a biologically sourced substitute for fossil fuel based petrochemicals. The most likely end use is considered to be production of dimethyl ether to be blended into diesel or diesel itself. However it can be converted into other products such as ammonia, methanol and naphtha using well established processes.

2nd generation thermochemical processes are being built. For example Choren claim to have the world's first commercial plant in Freiburg, Germany producing 15,000 tonnes per year of diesel from wood. The costs of the

[13] See Preliminary Screening - Technical and Economic Assessment of Synthesis Gas to Fuels and Chemicals with Emphasis on the Potential for Biomass-Derived Syngas in the bibliography

facility were heavily subsidised through investment support and public loan guarantees.[14] A larger 200,000 tonne plant is in development; this would be the first world scale plant.

Methanol is another established product with a UK market alone of one million tonnes but no operational UK manufacturing. The availability of biomass is such that the scale of production from a biorefinery (say 10^5 tonnes) is likely to be small compared to regional consumption of fossil fuel derived materials (10^6 tonnes) and therefore a thermochemical biorefinery will not displace fossil fuels as the primary raw material feed for the Teesside petrochemical industry.

A different thermochemical technology uses pyrolysis to convert biomass into a dense liquid intermediate known as bioOil. This can be done on smaller units local to the point of production. BioOil can be cost-effectively transported to a central thermochemical unit where further processing takes place via gasification or it can be burnt for heat and power or, in the future, hydrogenated to road fuel. This densification approach reduces the volume of straw by 94%. It should be noted that bioOil has quite different properties from fossil fuel derived oils and cannot be used interchangeably or be simply blended into an oil refinery complex.

These technologies are still being developed with the most advanced plant having a capacity of 36,000 tonnes. This Dynamotive plant processes wood in Canada and facilities twice this size are developing in North America and Australia.[15] Their rate of adoption is determined by commercial and supply chain considerations as well as technical.

Careful consideration has been given to the possibility of extracting valuable chemicals from biomass or bioOil prior to conversion in the biorefinery. In general it is considered that this will not be a primary driver for biorefining and is unlikely to be economic. Extraction would only take place when justified by the marginal economics unless studies into integration and scale-up identify new strategies which can add substantial value.

Identified opportunities include:

- Phenols - phenol, eugenol, cresols, and xylenols, and much larger quantities of alkylated (poly-) phenols
- Levoglucosan
- Hydroxyacetaldehyde
- Acetal
- Furfural and furfurylalcohol

The exception is for the extraction of pharmaceutical products but in this case the commercial activity is driven by the extraction and biorefining would only take place if justified by the marginal cost or as a means of disposal of the biomass.

One can foresee that in the same way that the processing and extraction of chemicals from crude oil increased in sophistication in the 20th century, similar technological evolution will occur in the biorefinery industry in the 21st century.

[14] From http://tinyurl.com/2q6u9y (redirects to http://www.choren.com/dl.php?file=07_05_10_MRudloff_lecture_15th_Biomass_Conference_1.pdf)
[15] www.dynamotive.com

3.3 International Situation

The study identified bioOil and bioethanol projects in many countries including Canada, US, Germany, Japan, China and Finland. Many of these are under construction and due to start in the next few years. Section 5 below demonstrates the strong capability in the UK region but despite this the UK is clearly falling behind. Given the strong presence of the process industries this is a concern.

3.4 Biodiesel via Transesterification

A widely practiced technology already established in the North East of England (with plants owned by D1 Oils and Biofuels Corporation[16]) and throughout the world is the production of biodiesel from vegetable oils. Significant amounts of glycerol are produced as a by-product. Glycerol surpluses are widely anticipated as a result of the increases in biodiesel production and projects are underway to seek new uses for it.[17]

The potential for producing other chemicals via the biodiesel process is likely to be through the use of fatty acids and related substances for the cosmetics industry for which there are long established markets. The biodiesel route involves the production and separation of fatty acid esters and then conversion back to the acid which appears to be more complex than the established process of direct hydrolysis of the same raw materials. If the transesterification route was competitive then the oleochemical industry would already be using it; the chemistry is well known. Although there is clear potential the consultants do not regard this as major opportunity for the region and hence placed greater emphasis on other aspects of biorefining in this study. This is not to diminish the importance of the established biodiesel business in the region; this is to be encouraged.

[16] Renamed as Earls Nook Ltd in August 2007
[17] http://theglycerolchallenge.org/

4 Economics of Biorefining

The economics of biorefineries are driven by incentives related to energy. It is currently viable to build thermochemical processes for bioOil (for power generation) or road transport fuels. 1st generation fermentation routes to bioethanol are also viable and 2nd generation just becoming viable.

Platform chemicals do not have corresponding incentives and at current oil and sugar prices only a few are economically competitive. This situation is changing as energy prices increase and new technology becomes available.

Viable products are likely to be chemicals with established markets and biorefining will need to compete with other routes of production.

The economics of biorefining are very heavily influenced by fiscal incentives to produce power and fuels from non-fossil sources:

- Renewable Obligation Certificates (ROC)
- Climate Change Levy Exemption Certificates (LEC)
- Renewable Transport Fuel Certificates (RTFC)

These are all tradable financial instruments that increase the value of sustainably derived electricity (ROC & LEC) and road fuel (RTFC). Their values are determined by market forces which, in turn, are influenced by the policy of regulators such as Ofgem. The objective is to encourage the development and adoption of new technology and energy sources. To illustrate the impact of the incentives we refer to Figure 3. It can be seen that the product costs of thermochemical biorefinery outputs exceed product values in every case. However once incentives are applied (the third bar) the products become viable; the incentives are serving their purpose.

Electricity from burning biomass simultaneously with fossil fuels is highly attractive at present for energy designated straw or wood from short rotation coppice. Power from bioOil is attractive, particularly from fuel crops in future. The production of dimethyl ether (DME) as a road fuel also becomes significantly more attractive. At present DME is being tested as a niche road fuel and it is likely that the market development would follow that of LPG. Initially it would be used in niche applications or captive markets and then could become more widespread via specially adapted vehicles and distribution infrastructure. Methanol has been extensively researched by fuel companies and it is unlikely that methanol would be used as a biofuel of choice to be blended into gasoline or diesel in Europe.

A key point for the future of biorefining for chemicals is that there are no analogous incentives.

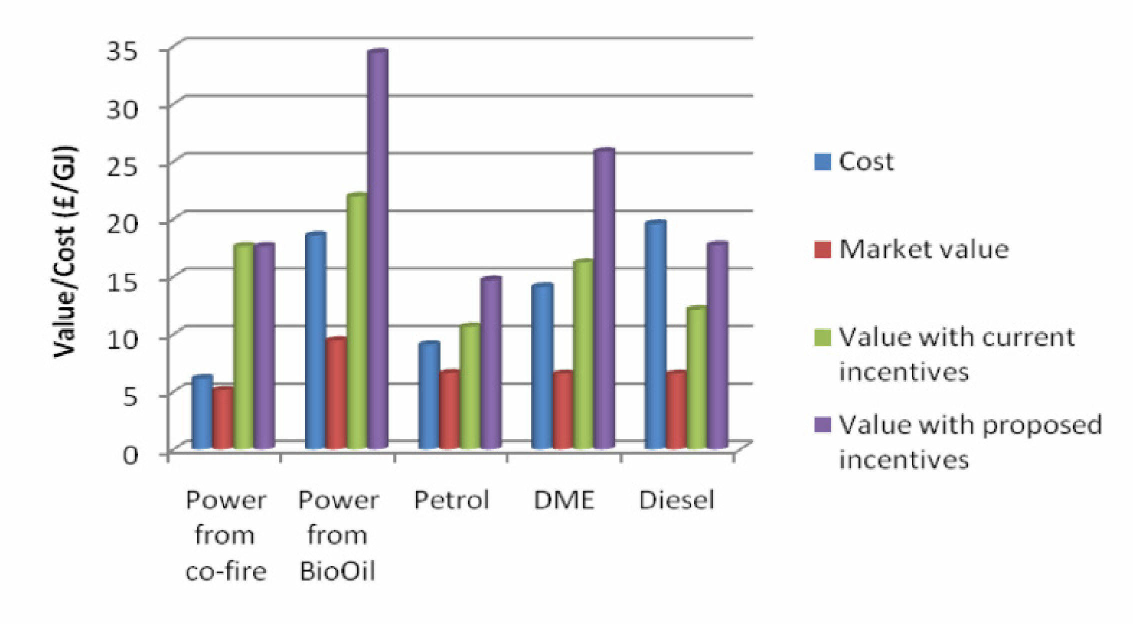

Figure 3: Thermochemical biorefinery product values and costs with and without incentives

The graph refers to diesel manufactured from syngas using the Fischer Tropsch process and petrol is from the hydrogenation of bioOil.

The RFTC incentive is also crucially important for the production of bioethanol from the fermentation process. The economics of production are shown in the "Wheat" line in the figure on the next page. A positive margin is required to make investment worthwhile without incentives and this has not often occurred. However road fuel duty derogations provide a substantial additional incentive making almost always attractive to produce bioethanol from wheat.

A second generation fermentation facility producing bioethanol from wood and straw would probably be sized at around 100,000 tonnes of bioethanol per year. Its economics are also shown in the figure. It shows that second generation technologies are only just becoming economic. As 2nd generation fermentation technology advances and greater operating experience is gained one may anticipate that the gap will continue to close. Further the changes to incentives to reward sustainability may reward the higher productivity per unit of land area possible from 2nd generation technologies.

With regard to the data in both Figure 3 and Figure 4 it is important to note that the nature of the road fuel incentive is changing in 2010 and 2011 to reflect the nature of the carbon savings that may arise and the overall sustainability of the biofuel. The impact could be potentially significant on both thermochemical and fermentation economics. A key unassessed consideration is how it will impact upon the relative economics of 1st and 2nd generation fermentation.

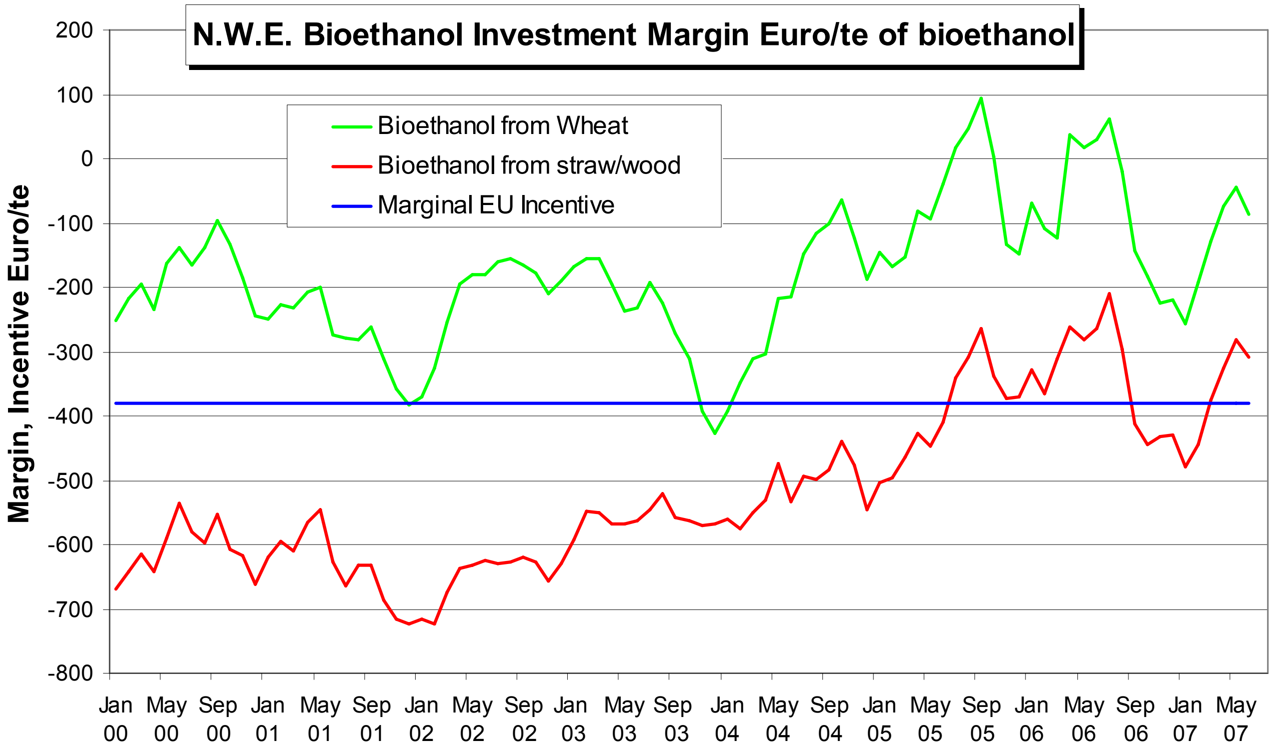

Figure 4: North West Europe bioethanol economics

If the current incentives to produce bioethanol for fuel use continue, then it will continue to be economically viable to convert crops to biofuel. But what are the prospects for platform chemicals from a fermentation biorefinery?

In the absence of subsidies, very few bio-derived platform chemicals can compete with petrochemical alternatives today. However, the situation is not static. The cost of production of a platform chemical depends on the feedstock cost and the cost of conversion. Over time, all these costs are expected to change.

Oil prices will climb as oil production peaks and as the global economy continues to grow impacting both feedstock and processing costs so that the tendency will be for the cost of platform chemicals derived from petrochemical feedstocks to rise over time.

Feedstock prices for 1st generation fermentation routes (sugar and starch) will remain high due to competition with food use, particularly as world population increases; it is unlikely that sugar and starch prices will drop. However 2nd generation processes based on lignocellulosic feedstocks convert more of the primary agricultural productivity into fermentable materials. This will lead to a progressive reduction in feedstock cost per unit of output as the lignocellulosic conversion technologies become more efficient. These process improvements will also lead to a reduction in conversion costs. Overall the tendency is for prices of bio derived platform chemicals to fall.

For each different platform chemical, the crossover point at which it becomes cheaper to produce from plant biomass than from petroleum will vary. For some it is already here. The DuPont/Tate & Lyle joint venture plant for bio-based 1,3-propanediol has been developed because the bio route now has a structural cost advantage compared to the petrochemical route.

Using the above arguments, the BREW report published in late 2006[18] looked at three different scenarios for the substitution of petrochemical commodities with bio-derived the scenarios are shown in the table below.

[18] http://www.chem.uu.nl/brew/

Currently the market matches the medium scenario:

- Oil price > $70 barrel
- Lignocellulosic technologies will definitely be available before 2040
- Biofeedstock costs predicted to be €180 - €218/t sugar
- Average world chemical growth predicted to be 3.5% over next 10 years
- No subsidies expected for bio-derived platform chemicals

Scenario	Low	Medium	High
Oil price	Up to $30 barrel	Up to $66 barrel	Up to $83 barrel
Rate of technology development	Low – technology remains the same	Future technologies from 2040	Future technologies from 2020
Bio-feedstock cost	€400/t sugar	€200/t sugar	€70/t sugar
Chemicals market	0% p.a. growth	1.5% p.a. growth	3% p.a. growth
Subsidies	none	none	1%-5% of product value

Figure 5: Brew report scenarios

Using these scenarios the BREW report predicted which bio-derived platform chemicals would achieve significant market penetration by 2050. Overall for the low scenario they predicted a 15% market penetration against a selected basket of petrochemical platform chemicals. This scenario is dominated by poly-trimethylene terephthalate (PTT) with 100% substitution based on low cost bio-derived 1,3-propanediol. Polylactic acid also achieves a significant market share as does ethyl lactate as a replacement for ethyl acetate.

For the medium scenario total bio production of chemicals is forecast to be 26m tonnes by 2050 representing a market share of 17.5% of 2050 forecast organic chemical production in tonnes. The BREW study considered a basket of 11 commodity chemicals and found that bio derived materials could achieve a volume market penetration of 40% across the basket. Analysis showed that PTT and Nylon-6 would be completely replaced by bioderived PTT with ethyl lactate completely replaced with bioderived equivalent. PET would be substantially replaced by polylactic acid and succinic acid would be almost entirely bioderived (>80% in both cases). PS would be partially replaced by polylactic acid (~50%). Bioderived ethylene, PHA, and butanol would also be economically viable and produced in noticeable quantities (10-50% market shares).

This analysis suggests that a realistic future scenario based on current market trends shows real opportunities for platform chemicals and derivatives from a biorefinery to capture significant market share against the petrochemical alternatives on a purely economic basis.

Major platform chemicals will be bio-derived in the foreseeable future, and there is an opportunity for the North-East to participate in this growth based on existing activities in the biofuels market.

An important point applicable to both fermentation and thermochemical processes is the rapid pace of change in technology and markets. This study presents the best views currently available on current and future economics but history teaches that several factors can materially change the outcomes experienced by businesses.

- New products will lead to new opportunities
- Changing political environment altering the systems of incentives (e.g. amendments to ROCs and RTFCs).
- The development of alternative uses for raw materials (e.g. the diversion of plant oils into biodiesel)
- Variation in agricultural product quality or quantity.

5 The North East Economy

The North East region is well placed to build a biorefinery.

- *Good knowledge and skills base*
- *Raw materials either domestically produced or imported via good port facilities*
- *Strong infrastructure to support process manufacturing*
- *The potential to develop a new renewable chemistry cluster from the strong presence of key sectors*

Biorefining could become a significant economic activity in its own right with potential for 12,000 jobs and up to £4bn of EVA by 2030.

The purpose of this section is to briefly describe the North East economy to address those factors relevant to the biorefinery technologies introduced in the previous section. Namely raw material availability, demand for thermochemical and fermentation products and the technology and services sectors that would engage with biorefineries. This section provides essential contextual background based on background research and deepened and verified by interviews with selected companies to consider the strategic positioning of biorefineries in the regional economy.

5.1 Raw Materials

Raw materials for a first generation biorefinery are likely to be either grown in the region or imported. The major UK crops suitable for biorefining are grain, rapeseed and sugar beet. The North East region is a substantial producer of grain and rapeseed but not sugar beet which is extensively grown in East Anglia. The UK agricultural sector has the potential to supply around 2.8m tonnes of grain annually into biorefineries in addition to satisfying food applications. The North East region currently produces around 500,000 tonnes of grain which could produce 170,000 tonnes of bioethanol from a first generation fermentation plant.

2nd generation biorefineries will use the total biomass from a crop by being able to handle a broad range of plant material. Additional biomass sources would include wood and straw which are already available. New crops such as switch grass and miscanthus are being discussed in this context although the latter does not grow well given current temperatures. 2nd generation technology enables the use of non-food crops and use poor land not currently in agricultural production.

At present it is estimated that the average production of straw from materials amounts to 400,000 tonnes per year in the North East region of which a proportion would be available for biorefining. It is bulky and hence relatively expensive to transport which may provide an economic limit to its availability. This may be overcome in part by local production of bioOil which can be more cost effectively transported. For example the volume of straw is reduced by 94%.

An alternative approach is to import biomass from other locations taking advantage of the deep sea ports in the region. Wheat would be the most likely import.

The North East is a coastal region so it is appropriate to also consider the potential for marine biomass for biorefining. Marine bioresources are recognised as presenting a growing opportunity for new products. For example pharmaceutical products for cancer, microbial infections, UV light damage and chronic inflammatory conditions. They are also potential new cosmetics, food and feed additives, and agrochemicals. Marine organisms are also sources of novel enzymes and biomaterials. However, no full scale marine studies have been carried out and commercialisation routes are not available. Cultivation will be required, either for organisms such as giant kelp (which will require water of suitable depth) or microbial fermentation.

The region has strong capability in its universities and at CPI, but it must be recognised that marine currently presents a research and not commercialisation opportunity.

Another source of biomass is from waste. Materials will arise from a number of sources including the food industry and construction and issues such as availability, composition and seasonality would need to be considered alongside the technical aspects of refining it. The amount of recoverable biomass waste in the UK is considerably in excess if 10m tonnes and represents a substantial opportunity.

5.2 Petrochemical & Fuel Related Manufacturing

The Teesside area of the North East contains an intense cluster of industries that convert raw hydrocarbons both imported and from the North Sea into a wide range of commodity and speciality chemicals. It employs 34,000 people directly and another 280,000 are indirectly dependent upon it.[19]

These sectors operate in highly international markets with global competition and global pricing. For example the methanol facility, despite a UK demand of 1m tonnes and local natural gas, has been mothballed and methanol is imported.

The best way to introduce biomass derived raw materials into this manufacturing complex for non-fuel purposes is to produce one of the existing raw materials or early intermediates from a biorefinery. The closest fit is the production of syngas from the thermochemical route but unfortunately there is not a natural outlet at present, the mothballed methanol facility being the most suitable. An alternative would be to integrate with the proposed clean coal project proposed by Coastal Energy[20] but this is energy, not chemicals related.

The complex is characterised by being highly integrated and using relatively few feedstocks, mostly naphtha, crude oil and natural gas. With the exception of naphtha thermochemical and fermentation biorefineries do not produce these. Naphtha could be produced but is unlikely to be competitive with petrochemical sources and would not be available on the same scale. There is some potential to use syngas from a thermochemical biorefinery to produce methanol (if the plant was reopened), DME (on the mothballed methanol plant) or ammonia. They would require substantial and expensive pre-treatment. These are not viable at the moment. The only economic outlet for biomass derived hydrocarbons would be as road fuel.

An alternative approach is to manufacture bioOil which could be used as a source of fuels rather than as a source of raw materials for chemical manufacturing. Options include:

- Use of bioOil to generate power in suitably modified diesel generators
- Hydrogenation of bioOil to gasoline and diesel
- DME production from synthesis gas via bioOil to blend into diesel
- Gasified to produce syngas, perhaps in the proposed clean coal project
- Extraction of chemicals (as a future option).

5.3 Other Manufacturing

As we have seen the fermentation route produces a range of products suitable for the cosmetic, personal care, nutraceutical and coatings sectors and we therefore consider whether this type of manufacturing is salient in the region and hence the prospects for an emerging cluster sourced from a second generation fermentation biorefinery. Compared to the UK economy as a whole, there are regional strengths in:

- Coatings, elastomers and adhesives
- Polymer manufacture
- Surfactants

Although the general population of cosmetic and personal care firms was found to be lower than expected compared to the UK economy the region hosts two international leaders in the form of Croda and P&G.

[19] Source: NEPIC quoted in Chemistry World v4 n7 July 2007
[20] http://tinyurl.com/2h9257 which redirects to http://www.centrica.com/files/reports/2006cr/index.asp?pageid=273

Extending the analysis to the north of England as a whole only reinforces this conclusion with strong representation in all the identified sectors. This analysis applies from the perspective of both the number of firms and also number of employees employed by those firms.

However North East firms display above average levels of foreign ownership suggesting that key decisions may be taken outside the region and that it is critical that the regional strategy recognises not only do these firms operate in European or global markets but also their decision making also taken from these perspectives. Raw materials and products are also traded on a continental and global basis. These sectors are, however competitive with leading levels of exports and wages. The North East region has the highest new firm formation rates in the key sectors.

Taken together, all this suggests that the North East is a strategically good place for businesses that would use the products from fermentation biorefineries. All the ingredients are in place for the formation of regional or north of England supply chains as fermentation biorefining takes a hold. This will not happen overnight but with leadership from NEPIC, CPI and others there are excellent prospects for new processes and products stemming from fermentation biorefining, initially with simple substitution of renewable feedstocks but more radical innovation in due course. Even without the formation of direct supply chains there is the potential for cluster behaviour to emerge with appropriate and sustained stimulation and leadership.

5.4 Process Technologies

The design, construction and operation of a biorefinery calls upon the same wide range of skills and specialised service companies and the normal chemical and petrochemical process industries and the availability of these skills is crucial to an potential operator and investor. These range from plant design through construction, operation and maintenance through to logistics and professional services. Investors also benefit from suitable sites with utility infrastructure to reduce capital costs and provide process integration. These skills are widely available in the North East.

These factors can be sufficient to justify transport of raw materials and products into and out of a region.

The North East region is very strong in these factors, particularly around the river Tees. The region’s universities and public sector agencies are very supportive of these industries creating significant capability in organisations such as CPI. Thermochemical processes knowledge and expertise is extensive in the region. In addition the biotechnology sector is strong in both industry and academia and the biofuels sector is established. Further, there is a deep sea port with efficient logistics facilitating economic movements of raw materials and products. These are all key strategic strengths generic to all biorefining technologies.

The table below demonstrates that the region has key strengths at all stages in the supply chain for the development and commercialisation of technology as well as raw materials and products.

Stage	NE Organisations / Infrastructure
Research (Academia)	Gasification Fermentation Intensification Agriculture Environment and sustainability Energy
Process Development	Centre for Process Innovation NaREC Johnson Matthey
Process Engineering	Davy Process Technology Aker Kvearner Foster Wheeler K Home International
Manufacturing & Infrastructure	Developed Biomass Supply chain Services (Energy) Infrastructure including proposed carbon capture scheme Established petrochemical & Biofuels Industry Future linked investments include Heavy Oil upgrader & Paper Mills as well as additional polymer capacity. Manufacturing sites & skilled personnel
Raw Material Supply	Agricultural Consortia Forestry Supply Chain Deep water ports
Regional Product Demand	Fuel blenders Polymer manufacturers & processing Coatings Manufacture Consumer Goods Manufacture Automotive Manufacture Pharmaceutical Manufacture
Integrated Cluster Development & Support	NEPIC, Regional Agency and Local Authorities intimately linked and industry focussed

Figure 6: North East capabilities relevant to biorefinery development

The academic skill base in the regions is strong with departments rated 4 or above in key disciplines of chemical engineering, chemistry, biological sciences and agriculture. The development of biorefineries will require a concerted multidisciplinary approach. This will, of course, be undertaken on an international basis but a strong regional axis will strategically strengthen the region.

The Centre for Process Innovation (CPI) has already developed the National Industrial Biotechnology Facility at Wilton on Teesside with the aim of accelerating the practical development and commercialisation of technology.

It also has fermentation capability. A sister organisation, the New and Renewable Energy Centre (NaREC), is developing energy directly from biomass. The region can therefore offer capability from basic research to pilot scale projects in addition to the commercial process development businesses established already in the region.

The region is also active in building links between these organisations to forge a development pipeline. One current manifestation of this strategy is the Energy Technologies Institute that has recently been proposed by Newcastle, Durham and Northumbria universities working jointly with CPI and NaREC to develop a major new institute.

The region therefore contains all the technical capabilities that are needed to both develop and commercialise technology. The challenge is not capability building but to connect and align these individual organisations. This requires a common purpose and objective and the creation of such a common purpose could be led by NEPIC with support from One NorthEast. Such activities would, of course, be linked into national and European technology and sustainability agendas.

5.5 Overall Potential Economic Impact

There are four routes to economic gain through biorefining in the North East region.

- An alternative route to existing products
- New products previously not available
- The provision of knowledge based products and services including technology licensing
- Stimulation of a new mini-cluster with business ancillary to biorefining itself

The region is well poised to capitalise upon the first and third of these and also the second should the opportunities arise in future. The existence of major Biorefineries, particularly from the fermentation route, will stimulate the creation of other ancillary businesses by attracting investors wishing to take advantages of the capabilities in the region and also help entrepreneurs create new businesses. These may interact directly with the biorefinery supply chains but also other businesses with common needs for skills and infrastructure that will be attracted to the region.

This leads to the next question, what is the potential long term impact of biorefining? Despite the lack of immediate fit with the current process industries in the region the potential is large given the strong regional capabilities. It is not unreasonable to speculate the in 25 years the installed capacity in the region may increase by an additional 1m tonnes. The Ensus project alone provides 30% of this and construction has already commenced. The cumulative direct investment may be, say £1.8bn in current money, with comparable indirect investment in the form of infrastructure, logistics, agriculture, forestry, power and downstream industries. The impact of this investment is substantial. It is estimated that this could lead to over 6,000 direct jobs and a total of 29,800 jobs in total in the regional economy. It could directly generate £400m of GVA in the region and a similar amount from indirect stimulation of the economy. If a mini-cluster develops then the total GVA could rise to as much as £2.8b.

At present the only biorefinery related activities in the North East region are the biodiesel plants operated by D1 Oils and Biofuels Corporation and the first generation bioethanol plant being developed by Ensus. Biodiesel and 1st generation bioethanol plants have been announced elsewhere in the UK. At an international level there is a very large amount of biorefining activity taking place for fuels and chemicals and the UK is in danger of being left behind. The North East region, with the strategic capabilities described in this section is very well placed to participate in this industry and establish a UK leadership position.

6 Biorefining in North East England - Summary

The purpose of this section is to compare and consider the merits of both biorefining technologies in the context of the North East of England. This is done using two summary tables on the following pages that present the two routes side-by-side. The conclusions from the comparisons are shown in the box.

- *Both technologies are currently viable and integrate via a biofuels route*
- *Thermochemical has the greatest potential to integrate into the existing process industries as a source of renewable feedstock alongside petrochemicals (not yet attractive for technical and economic reasons) and power (viable now). It does not currently integrate well for non-fuel applications though.*
- *Fermentation is already providing a route to fuels and has the potential to provide renewable materials into other sectors in the region*
- *Second generation fermentation processes, when available, have the potential for increased yields and use of a wider range of biomass materials*
- *The North East region has strong capability to develop both processes*
- *The pace of technological development and changing oil prices make this a particularly inappropriate time for the region to select the preferred process*

Fermentation Biorefinery		
Technology	Use of biotechnology to break biomass down into sugars which can be fermented into bioethanol or source of other platform chemicals.	
	1st Generation	**2nd Generation**
Status	Established – extensively used	In development – 5-10 years from world scale plants
Raw Material	Maize, wheat, sugar beet, sugar cane	Wide range of biomass; wood and straw in short term, specialist crops and waste biomass in longer term
Products	Bioethanol, lactic acid, 1-3 propanediol (today) Succinic acid, butanol, others (future)	
End use	Gasoline personal care, surfactants, polymers	
Integration with North East Process Industries	Bioethanol can be used for fuel blending Close process integration not expected	
Potential fit with regional economy	Bioethanol for fuel blending Polymers, surfactants, coatings and adhesives All products have large established global markets	
World scale plant	300,000 tes £300m	100,000 tes increasing to 300,000tes Forecast £200-500m
Strategic value add for North East	Nucleate a sustainable mini-cluster based on biorefinery products Broaden the process industries away from petroleum increasing their robustness (strategically important for the businesses that serve the sector too) Contribute to developing the NE as a natural location for industrial biotechnology Reinforce the regional capability in industrial biotechnology generally Stimulate the agriculture and forestry resources in the region Stimulate regional companies to consider what opportunities can arise from bio-raw materials (reinforced by regional capability in these technologies) Provide a route to use waste biomass from a wide variety of sources	
Triggers necessary for North East investment	1st generation is already happening with a 300kt plant being constructed by Ensus 2nd generation needs advances in technology to economically produce bioethanol and technology, incentives and economics for other platform chemicals	

Thermochemical Biorefinery	
Technology	Use of heat to partially break down biomass into an oil ("bioOil") or further into syngas which contains carbon monoxide and hydrogen.
	2nd Generation (this is inherently a 2nd generation technology)
Status	Demonstration scale plants up to 15,000 tes 200,000 tes being designed
Raw Material	Any biomass; most plants use wood In longer term a broad range of biomass including new fuel crops
Products	Diesel, naphtha, methanol, DME (dimethyl ether), bioOil and bioOil chemicals (, alcohols, gasoline, lubricants, other chemicals
End use	Fuel, renewable power Chemicals made from ethylene Adhesives, polymers, solvents
Integration with North East Process Industries	Biofuels can be used for fuel blending BioOil for power (via coal gasification plant or otherwise) Close process integration not expected other than by-product naphtha into the cracker
Potential fit with regional economy	Fuel blending, power generation Methanol for biodiesel plant Naphtha for cracker All other products have large established global markets
World scale plant	200,000 tes, £450m (inc. £100m for bioOil plants to feed it)
Strategic value add for North East	Opportunity to further stimulating this sector and agriculture as well as reducing greenhouse gas emissions. Be a starting point for further integration/development of process industries around syngas (e.g. linkage with clean coal etc) Establish first world scale biorefinery in the UK Stimulate regional agriculture Reinforce regional capability in non-fossil power (e.g. the proposed Energy Technologies Institute)
Triggers necessary for North East investment	Leadership to assemble a consortium, carry out feasibility studies and generally champion the development of a project.

7 Implementation Plans & Recommendations

There are six key recommendations that can be taken forward by NEPIC together with One NorthEast and other partners.

1. *A bioOil project for power to demonstrate thermochemical biorefining in the region and provide a platform for further developments*
2. *Develop 2nd generation fermentation capability to exploit this technology as it becomes available*
3. *Develop policies to maximise carbon efficiency*
4. *Stimulate a sustainable chemicals cluster as a source of economic growth*
5. *Stimulate demand for biorefinery products by working with policy makers and business*
6. *Establish a national strategy for biorefining in the UK*

North East England should establish short, medium and long term aspirational goals for biorefining. These should include both physical assets and also the exploitation of the knowledge in the region to service not only regional assets but to be a leading participant in the global growth of this sector.

The benefits of such a strategy will accrue to the region, adjoining regions across the north of England and more generally across the nation. The UK is falling behind in the exploitation of biorefinery technology despite the presence strong capability and industry interest.

In the short term (next 4 years) the region should aim to attract £150m of new investment in biorefinery related activities. In the medium term (i.e. next decade) a stretch target would be to grow this to £1bn at which point associated service supply industries might have grown to £100m. An ambitious target for 25 years time might be to install 1m tonnes of capacity with a cumulative capital investment of £5bn in direct biorefining and associated supply and demand side sectors.

A total of six recommendations are made with implications at regional and national level. Actions to implement the recommendations are presented for each.

Recommendation 1: A BioOil Facility to Demonstrate Thermochemical Biorefining

An immediate goal is to establish a second generation bioOil facility in the region using local or imported agricultural products. In the first instance the products would be used for power generation. The purpose is to build capability and demonstrate economics to stimulate private sector biomass derived power generation. Such a plant would also establish biorefining in the region, albeit still intertwined with energy production. It would support the region's agriculture and forestry and provide an additional outlet for waste biomass as well. Together with the existing biodiesel facilities, proposed bioethanol and clean coal plants and the wood fired power station at Wilton and the proposed Energy Technologies Institute it will build capability and reputation in the region for new process industries based on biomass. Other strategic benefits would include a contribution to the region's sustainability agenda as well as the opportunity for future projects such as chemical extraction or hydrogenation as they become available.

The first steps in this project would be to carry out detailed feasibility studies and technology assessments. Key questions would include:

- Confirming the economics of bioOil for power
- Procuring technology for both bioOil production and power generation
- Selection of feedstocks and location
- The appropriate scale of development
- The best way to minimise waste through burning solid residues

This project could be commissioned by NEPIC but should also involve NaREC and the National Non-Foods Crop Centre for technology and raw material availability. The partnership should include One NorthEast as it will be important to demonstrate commitment to both investors and also technology providers.

Discussions need to be held with neighbouring regions, the North West, Yorkshire and Humber and Scotland on the potential for a coordinate approach to bioOil. BioOil production could be undertaken in these neighbouring regions and the resulting product used to supply a larger plant processing it into other materials or fuels. This increased scale and coordinated approach will increase the range of options available.

Recommendation 2: Develop 2nd Generation Fermentation Capability

This study has concluded that 2nd generation fermentation biorefining will be of equal industrial importance to the thermochemical routes and that North East England should anticipate and engage with this technology accordingly. At present the technology is emerging and commercialisation is commencing. North East England needs to build its academic capability and capitalise upon the National Industrial Biotechnology Facility to establish and demonstrate world class 2nd generation fermentation capability in the region.

The recommended approach is to develop a knowledge and demonstration capability to design processes for platform chemicals from regionally available biomass. This capability would then be used to develop processes for specific chemicals as they became economically viable and industry partners became interested.

The initial focus is likely to be on ethanol as a core commodity product with established markets and value. Additional platform chemicals would be added to the portfolio as markets emerge and they become commercially viable. This may be either by construction of additional plants if a high volume opportunity emerges, or by retrofitting an existing bioethanol plant to extract chemicals from the feedstock or refine and further transform side streams.

Implementation of this recommendation would require a strong consortium and potential partners identifiable today include:

- CPI - the National Industrial Biotechnology Facility
- NEPIC - for industry engagement

- Newcastle University - for research and to align goals in their research departments and renewable energy centre (CREEL)
- One NorthEast - for financial and inward investment support
- Research Councils - for research funding
- Bioscience for Business for research and development of technology
- National Non-Foods Crop Centre - for technology and raw material availability
- Chemistry Innovation KTN and Resource efficiency KTN - for technology and platform chemical exploitation

This will require a substantial, sustained and appropriately resourced program of work. A detailed road-map needs to be created for the development of 2nd generation fermentation biorefineries in North East England. This will describe the market opportunities, the process technologies required, and the capability of the North East to deliver these technologies. This will flush out the key issues, identify the necessary resources and provide a tool for securing the involvement and commitment of the other essential partners.

One can foresee that a pipeline of projects using and developing the National Industrial Biotechnology Facility will emerge from the road-map.

Recommendation 3: Develop Policies to Maximise Carbon Efficiency

The changes to the incentive structures for power generation in the Energy White Paper and the road fuel requirements from 2010 demonstrate that incentives will be increasingly linked to sustainability. The development of a low carbon infrastructure and measures to reduce industrial carbon emissions per unit of output would be a source of strategic competitive advantage for the region.

When considering future biorefineries it is important to plan that there is “no waste, only co-products”. This line of thinking will focus attention on obtaining maximum value/use from every material flow in the system and lead to the identification of uses for things like process water, gases, reaction side streams and solid waste. For example in North East England carbon dioxide could be used for enhanced oil recovery using an appropriate pipeline. This approach needs to apply to the whole supply chain, considering how biomass arises and is transported as well as end use of the actual products. The aim is to be able to identify opportunities across the whole system (not just individual processes within it) to maximise the contribution towards sustainability. This integrated systems approach would be a key differentiator.

Recommendation 4: Develop Sustainable Chemistries Industries

A long term goal is to develop a sustainable chemistries sector in the region building upon the portfolio of biomass facilities and associated products that will emerge from the previous recommendations. There is an opportunity to make the North East the natural location for biorefining in the UK by developing capability. The aim is a strategic shift in the portfolio of businesses towards those in the chemistry using industries that can exploit the products from biorefineries such as coatings, cosmetics and personal care. A key requirement is to develop the capability and capacity of the region.

- Skills - the availability of skilled personnel at all levels for the design, construction and operation of industrial biotechnology. This is to include increasing the skills of established employees as well as industry newcomers.
- Process development - a range of facilities and professional capability to develop industrial biotechnology processes. This has the potential to be a valuable activity in its own right.
- Services - a service sector capable of supporting industrial biotechnology businesses
- Locations - encouraging the strategic development of sites (probably on Teesside) with infrastructure for industrial biotechnology to lower investment costs (e.g. effluent treatment, residual cake processing)
- Supply chains - the availability and logistics infrastructure to handle large volumes of biomass

- Regional promotion - to attract both people and businesses to the region

Other activities can be undertaken more specifically aimed at biorefining.

- The development of regional and national policies strategically designed to encourage biorefining
- Raising awareness in industry and elsewhere on the state of technology and emerging opportunities and capability in the region
- Assisting new businesses with developing technologies, products and markets at all stages in the biorefining supply chain

It is not necessary to form a new cluster organisation or for ONE NorthEast to formally adopt a new cluster but it is important that this thinking is adopted pervasively through the region's strategic planning processes. NEPIC should work in partnership with One NorthEast via a strategic partnership explicitly charges with this agenda. The partnership should involve other bodies such as the agricultural sector and local authorities to develop policies as well as direct funding to develop strategic resources in the region.

This is an ongoing medium term action. Initial target sectors include coating, cosmetics and personal care.

Recommendation 5: Stimulate Demand for Biorefinery Products

Given that the production of most platform chemical from biomass sources is not currently viable it is important to consider ways to stimulate demand to encourage early investment. The emergence of a biofuels industry is a consequence of national and European policies; it has been seen that without these the sector would not be viable. It is therefore important to engage with policy makers and business on a number of levels.

Biorefinery technology and commercialisation is changing rapidly. It is therefore important to raise and maintain awareness of the level and potential of biorefining both as a business opportunity and also a contribution towards sustainability. The target audience needs to include:

- Policy and decision makers, particularly those engaged in the innovation and sustainability areas at both regional and national level
- The business community so that they become aware of current and potential opportunities for routes to current products and also substitution with renewable alternatives.

A useful step would be to commission a series of case studies to illustrate the opportunities that are available and then to promote them. This activity should be undertaken in a coordinated way by organisations acting in concert. These organisations include NEPIC and other chemical initiatives as well as Chemistry Innovation and Bioscience for Business (with NNFCC involvement). The activity needs to be focus on the actual technologies and materials that are becoming available.

It is also important that once interest has been raised that there is a route towards realising the initial concepts. The awareness raising needs to be undertaken in the context of reasonably accessible products and processes and organisations such as NIBF and NNFCC are positioned to assist them (see Recommendation 6).

Policy makers can have a material impact upon demand in several ways operating at different timescales. Options that could be explored would include:

- The use of public sector procurement to create an initial demand for sustainably sourced products
- The use of regulation to drive the shift towards sustainability
- The deployment of fiscal incentives to reward early actors

Specific proposals may need careful consideration and public consultation and as such may not be easy or rapid to advance. However, we observe that the latter two have been instrumental in the emergence of a European biofuels industry.

A first step would be to identify areas where action could usefully be taken. For example the Low Countries facilitated the use of biodegradable hydraulic fluid in waterway locks by funding the draining, cleaning and seal replacement on their waterway infrastructure, these costs being the essential barrier to uptake. An example of the power of public procurement was the stipulation that biodegradeable chainsaw oil was to be used by contractors working for major public bodies; this led to widespread adoption in the industry.

Recommendation 6: Develop a National Strategy for Biorefineries

The UK is currently falling behind many competitor nations in the commercialisation of biorefinery technology and there is a pressing imperative to form a national strategy and also mobilise the relevant and powerful national capability in a coordinated way. The proposed Industrial Biotechnology Innovation and Growth Team (IB-IGT) is a possible vehicle for this providing it is appropriately focussed and engages the relevant people.

There a number of components to the strategy that should be developed.

The **research** strategy needs to engage the academic sector on working on relevant problems. A particularly pertinent one is the development of 2nd generation fermentation technologies suitable for the biomass available in the UK; the international research agenda is available as a starting point.[21] Organisations such as the research councils and NNFCC are particularly important in this process. The scope should include opportunities from marine and waste as well as agricultural biomass.

A **commercialisation** strategy needs to be developed and put in place to ensure that those interested in developing biorefinery processes or products have a means to advance their work. Bodies such as CPI (and the NIBF hosted by them) are critically important, as are industry/academic collaborations through bodies such as CoEBio3.[22] The Royal Society of Chemistry and the Institution of Chemical Engineers should be consulted on this strategy and it is vital that the knowledge transfer networks of Chemistry Innovation and Bioscience for Business are engaged and are supported by the Technology Strategy Board. The KTNs have an important role to play in engaging companies, putting together projects and capitalising upon national and European funding opportunities. Engagement should also take place with the **regions** who promote sustainability, innovation and inward investment agenda. These need to be coordinated and integrated into the strategy too. This is an area where specifically NEPIC and One NorthEast could take a lead.

[21] E.g. Breaking the biological Barriers to Cellulosic Ethanol (A Joint Research Agenda) DOE/SC-0095 http://genomicsgtl.energy.gov/biofuels/2005workshop/2005low_execsumm.pdf
[22] Centre of Excellence for Biocatalysis, Biotransformations and Biocatalytic Manufacture, http://www.coebio3.org/

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