The Bioeconomy Consultants NNFCC

Tees Valley as a Biorefinery Cluster

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A report for Tees Valley Combined Authority

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Executive Summary

This report summarises the opportunities for biorefinery development in the Tees Valley Combined Authority area. It is supplemented by a larger appendix report providing more detail on the underpinning data and evidence gathered and generated in support of this report and the assessment it contains. The two should be read in conjunction where more detail on the underlying assumptions and assessment is required.

This report includes an assessment of current biomass resources in the North East region, prospects for biomass imports and the current potential for syngas and pyrolysis deployment. Existing biobased interests in the region are identified along with the policies affecting future deployment.

The most promising opportunities for biobased chemical integration are examined, taking account of opportunities provided by existing assets and chemical processing chains in the regional chemical cluster. The prospects for UK competitiveness in developing bio-ethylene derivatives is discussed.

Existing bioenergy assets in the region have helped to develop regional biomass supply chains based on arable crops, woody biomass and waste streams, but further development will be limited by reducing support for further deployment of renewable heat, power and fuels.

The Tees Valley has an identified domestic biomass resource of around 1.1 million tonnes, the majority of which is contained in waste streams. However, the varied composition of this collated resource will affect the ability to utilise it in advanced conversion systems, particularly where large volumes of feedstock are required to serve bulk chemical markets. However, the region is developing as a significant hub for biomass import that could expand to accommodate an increase in local demand for biomass.

Thermochemical processes such as pyrolysis and gasification are capable of utilising a wide range and mix of feedstocks compared to primarily biochemical conversion processes. This offers potential to expand the palate of bio-based chemical feedstocks available on Teesside. However, for both pyrolysis and gasification exploitation to date has mainly been for heat and power applications. Opportunities for further refinement of pyrolysis oils to bio-based chemicals (i.e. through conventional refinery plants) needs further research and examination. Gasification of biomass to fuels and chemicals remains a difficult prospect, but the waste to syngas to methanol pathway is showing promise and expansion currently at scales of up to 30 million litres. The biological conversion of syngas (from biomass gasification) to chemicals is a significant area of ongoing R&D with supporting expertise available within the CPI on Teesside.

Based on an understanding of current gaps in UK production, current technical feasibility, stage of development, market potential, commercial interest and relevance to interest in the Teesside chemical cluster, a list of potential candidate bio-derived chemicals was reviewed and ranked. Priorities for development were identified as:

High priority:	HDPE, MEG
Medium-high priority:	MMA, ethylene oxide
Medium-low priority:	higher TRL: lactic acid, propylene glycol, acetone, succinic acid, propanediol. lower TRL: isobutylene, butanediol, isoprene, adipic acid, paraxylene,
Lower priority:	propylene

Several of the most promising opportunities rely on the derivation of ethylene from bioethanol. Teesside has the potential to produce up to 180 tonnes of bioethylene from the total bioethanol output from Ensus, which equates to just less than half of the ethylene demand for SABIC's LDPE plant on Teesside.

Ethylene price is highly dependent on feedstock costs. Current European bioethanol prices suggest an EU bio-ethylene price of around £1300-$1600 which would be competitive with many global producers, other than Brazil and India. However, the UK bioethanol industry survives in the face of such competition due to tariff protection provided by the EU Single Market. Current uncertainty around future UK trade agreements is likely to lead to uncertainty for such markets, making investment difficult.

The analysis concentrates on relatively large-scale opportunities by looking for opportunities for integration with existing interests and assets on Teesside. There are a myriad of potential niche and other biobased chemicals that could potentially be produced on Teesside but for which there is currently no clear supply chain or potential offtake identified. In such cases the Tees Valley Region needs to make an appropriate, broad and attractive case to attract relevant technology companies to the region.

The degree of local industry interest in the highlighted opportunities and ability and willingness to adapt needs further examination with relevant supply chain interests, along with more detailed analysis of the business case for each opportunity.

Any development will require investment support and work is required to build the case for this. A hurdle to this is the absence of co-ordinated UK and EU policy to promote biobased chemicals.

Biobased materials have to provide commercial advantages in production and/or use to be successful, including credentials that brand owners are prepared to pay a premium for. Outside the EU, public procurement programmes like the US

Biopreferred Programme have been adopted to successfully stimulate uptake of biobased products. The rationale supporting this is that it supports innovation, creates domestic employment (particularly in rural areas) and adds value to the domestic economy while reducing use of fossil resources. To date the EU has not sought to adopt a similar EU-wide scheme. Its approach has been to develop demand by addressing standards and labelling requirements and to review opportunities for public procurement through activities such as the Lead Market Initiative (LMI). One of the LMI's expert groups recently recommended that the Commission should work towards development of a Bio-based Materials Directive.

In the UK, in 2015 the UK Government published a white paper "Building a High Value Bioeconomy: Opportunities from Waste" detailing the UK vision, current steps and policies in place to support bioeconomy development. To date, support has primarily focussed on research and technology development supported by funding programmes such as the Industrial Biotechnology (IB) Catalyst.

With the support of mandates and subsidies for low carbon energy, the North East has developed significant biomass heat and power capacity and biofuels production capacity, ensuring that biomass supply chains are well developed in the region. Changing policy priorities suggests that further development of all of these sector will be limited, but the established industry presence offers opportunities for diversification.

Given the identified opportunities for bio-based chemical derivatives from ethanol, any possible change to EU biofuels policy could affect investment appetite. To address concerns over use of crops for fuel, the EU has decided to cap the contribution (to mandatory Renewable Energy Directive targets) permitted from crop-derived biofuels to 7% of 2020 EU transport fuel energy demand. Post 2020, the Commission has expressed a wish to "remove support for crop-derived biofuels" which would affect the market for fuels from Ensus in its current form. Brexit adds further complication in terms of future access to EU and other markets. The UK Department for Transport (DfT) has set out plans to 2030 that includes retention of support for crop-based biofuels to a limited level, against which the UK biofuels industry is looking for a cap of no less than 5%, and encouragement to deploy E10 (10% ethanol/petrol blend) to provide sufficient market headroom. A long-delayed DfT consultation on this is pending, its outcome will determine the UK's long-term policy on support for biofuels to 2030.

The UK's close involvement with the EU has supported development of the bioeconomy sector, both in terms of overarching policy and initiatives as well as through direct support provided through relevant EU funds, with the most important being the Horizon 2020 R&D programme and European Structural and Investment (ESI) Funds used to support regional actions and support for business. EU policy has helped to create markets (directly in the case of biofuels and bioenergy), build supply chains, support relevant R&D and provide numerous relevant networking, knowledge exchange and business support opportunities. The BREXIT decision raises uncertainty around future access to such opportunities that could hamper UK aspirations for a bio-based economy.

A further problem for Teesside is that comparison with other biorefinery site offerings suggests the Teesside offering as it stands is not unique. There are comparable European and North American interests offering similar facilities: integrated chemical and service facilities equipped with biomass hubs (for either food or non-food feedstocks), port and other logistics facilities, access to research and development resources and skilled staff. The Teesside offer therefore needs to be well articulated, strongly backed and marketed to attract potential inward investment and to provide the right offering to emerging innovative companies in the sector.

The UK Industrial Biotechnology sector, a key enabling sector of the bioeconomy, is relatively small, fragmented and primarily made up of SME's which hampers development. Clustering activities in the Tees Valley region could attract and support innovative developing companies in the region.

Several actions are suggested to further develop and validate the highlighted bio-based chemical opportunities and improve the attractiveness of Teesside's offering to industry interests, including:

- Encouraging and supporting investment in feedstock collection (virgin biomass feedstocks) and in waste recycling and refinement to improve accessibility to the large waste resource on Teesside.
- Work with industry interests to ensure there is a supportive policy regime for existing bio-based industries on Teesside, which will be particularly important in the face of uncertainty stemming from the BREXIT decision, to maintain sectors that could underpin future bio-based chemical production on Teesside.
- Validate existing Teesside interests in the potential bio-based chemical opportunities available and willingness to take opportunities forward, identifying any barriers to development.
- Building the 'offering' for Teesside as a place for bio-based industries, though cases for investment support and incentives to attract relevant business interests.
- Networking and awareness raising of the Teesside offer amongst other regional and national bio-based initiatives and in centres supporting enabling technologies for bio-based industries.

Contents

1 Introduction

The bioeconomy encompasses the production of food, feed, bioenergy and bio-based products, in the case of the latter two, with the aim of reducing reliance on fossil feedstocks. According to a recent Capital Economics report, the direct activities of the bioeconomy currently contributes £36.1bn (GVA) to the UK economy and provides 600 thousand jobs. Development of the bioeconomy, particularly through wider application of biotechnology, is seen as an important driver of future innovation and growth opportunities in the UK.

Central to the expansion of the bioeconomy is the development of biorefineries. In the same way that an oil refinery processes crude oil into fuels and chemicals, biorefineries perform the same task with plant-derived or bio-based waste matter, processing biomass into a range of useful products including chemicals, materials and energy. Understanding the potential for biorefinery development requires a balanced assessment of feedstock accessibility, supply chain capability, technology readiness and market demand for biorefinery products.

There are a number of different potential pathways though which biomass in its various forms can be directed to deliver value-added chemical and material products – see Figure 1. There are two distinct subclasses that are relevant to Teesside, defined by biomass conversion processes

- The 'thermochemical biorefinery', and in this case the 'syngas platform', where biomass is subject to high pressure and extreme heat in a gasifier, where it is combusted in a low oxygen environment to produce syngas which can then then cleaned and modified using biological or catalytic processes to produce fuels, alcohols or a range of base chemicals (ethylene, propylene, butadiene).

- The 'sugar platform' – where biomass is fractionated by physical, chemical and biological means into its main structural components and conversion of these into individual sugar monomers to serve as fermentation or chemical feedstocks, with residual lignin used as either a fuel source or as an intermediary for other chemical feedstocks.

The Tees Valley hosts an internationally recognised and strategically important chemical process industry cluster that has emerged and developed from former ICI assets. Over three key sites in the region (Wilton International, Seal Sands/North Tees and Billingham) it offers a range of integrated service offerings to gas and petrochemical interests as well as deep water port access. The UK chemical sector faces intense competition from overseas interests. The TVCA area itself hosts companies with global interests in chemical and product manufacture. The Tees Valley has benefitted from the development of major biofuel interests in the region and investment being made into biomass power generation.

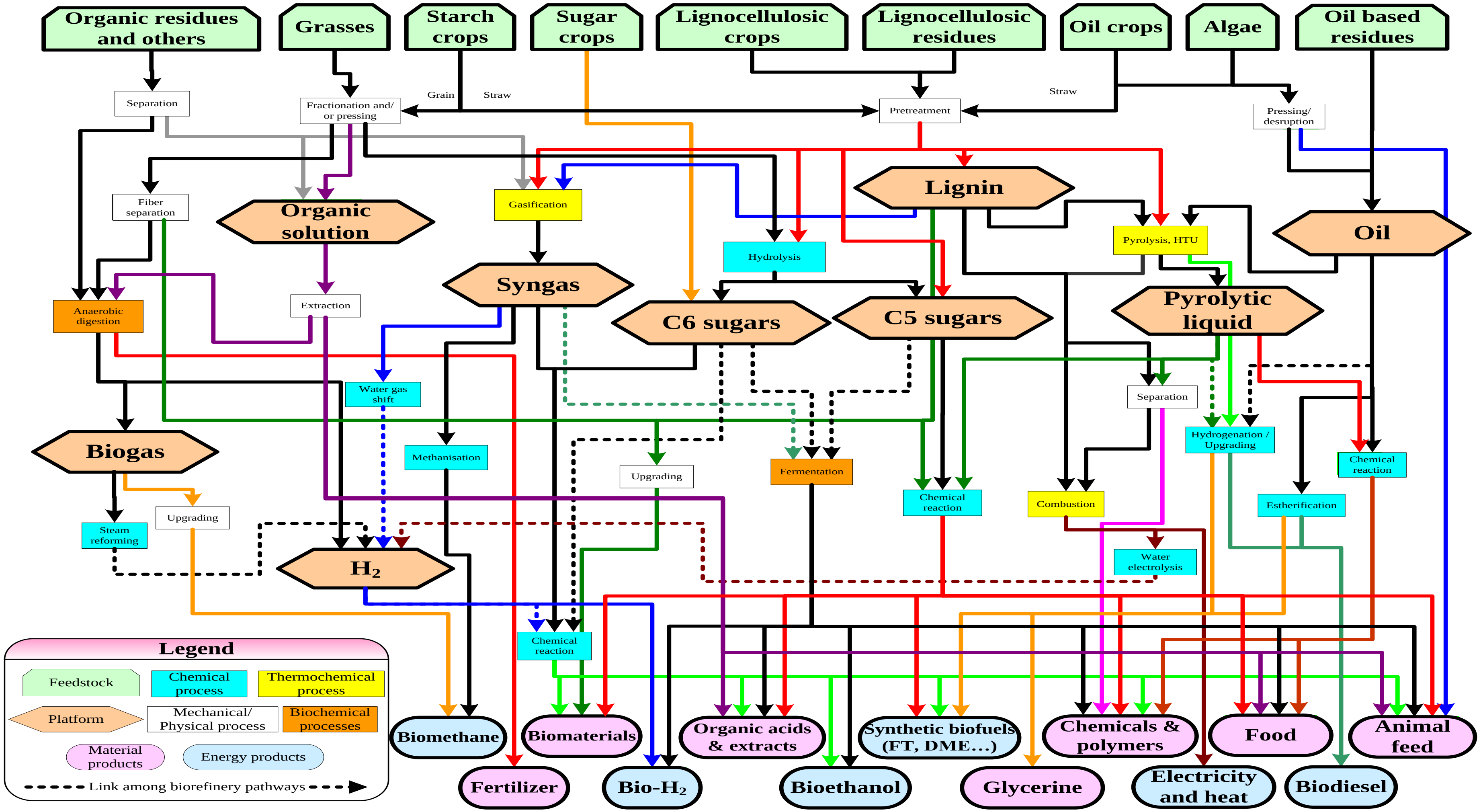

Figure 1. Schematic representation of possible options for biorefining biomass into chemical feedstocks (source: IEA Bioenergy Task 42, Biorefinery classification system)

Tees Valley Combined Authority (TVCA) is keen support developments to both protect the future of current interests on Teesside and identify new opportunities for further growth and development to benefit the regional economy. TVU wishes to understand the potential for further integration and development on Teesside through exploitation of emerging biobased processing industry opportunities.

1.1 Project aims

The aim of this project is to provide a critical assessment of the potential for development of process industry opportunities around the use of bio-based processing and use of renewable raw materials in the Tees Valley Enterprise Zone.

The project has the following objectives;

- To understand the nature of the process industry in the TVCA area and current biorefining activities,
- To identify opportunities for the development of a biorefinery offering synergies with existing industrial activities,
- To provide recommendations for biorefining technology and project development in the TVCA area.

1.2 Approach

The project was carried out as a desk-based project, incorporating structured data searches, stakeholder interviews and information analysis. The project was delivered as three actions comprising:

- a landscape mapping exercise, identifying regional feedstock and industry resources and interests, mechanisms supporting innovation, policies and current sources of funding
- a horizon scan of possible opportunities linked to regional capabilities
- an opportunity analysis
    - ranking the possible options
    - using international case studies to identifying the factors that have influenced the siting of recent bio-based developments
    - providing recommendations for action and development

1.2.1 Landscape Mapping

This action built a 'landscape map' of the TCVA area in relation to biorefining and the existing process industry. This provided a picture of:

- current commercial biorefining activities in the region,
- current key process industry value chains in the region,
- the regions bio-feedstock potential (internal and imported),
- regional technical knowledge base
- regional business support networks and funding sources.

1.2.2 Horizon scan

Based on the landscape exercise, the potential opportunities for biorefinery development in the Tees Valley region were outlined, based on an understanding of the opportunities available and technology readiness levels while taking account of:

- existing infrastructure available in the TVCA area and potential for adding value or repurposing
- existing chemical sector interests and market sectors of interest that could enable uptake

This included an assessment of the potential for novel feedstocks (syngas and CO_2[1])

1.2.3 Opportunity assessment

Drawing on the findings from the above actions the relative strengths of different opportunities for bio-based chemicals were mapped, taking account of

- technology readiness,
- market price to feedstock cost ratio,
- size of the potential bio-based market opportunity available,
- the status of current commercial interest,
- relevance to interests and capabilities on Teesside.

The output was used to define the most promising opportunities for Teesside and the basis for further examination of business potential for Teesside to compete globally for such opportunities.

The key findings were used to develop recommendations for the region identifying the key actors and next steps.

[1] The opportunities for carbon capture and use have been examined in a parallel project "CO2 utilisation opportunities in the Tees Valley" by CO2Chem, The Carbon Dioxide Utilisation Network (led by Katie Armstrong at Sheffield University)).

2 Feedstock resource

2.1 Arable resource

The North East region holds just under 7% of the UK's agricultural area and 4% of the UK's cropped area, representing just under 150,000 ha, of which 77% is in cereals and produced just under 600,000 tonnes of wheat in 2015. The bulk of this resource lies to the North and North West of the Tees Valley.

2.2 Virgin non-food and waste biomass

Table 1. Biomass arising's in the North East region (Tees Valley, Durham, Northumberland and Tyne and Wear) (NNFCC estimates from resource analysis and waste data derived from Environment Agency data on treatment of permitted wastes in the North East region)

Source	Key Type	tonnes	Total resource (tonnes)
Virgin biomass (sustainably sourced)	Softwood harvest residues	67,000	132,000
	Agricultural straw	62,000	
	Other	2,000	
Waste and processing residues	Municipal biowastes	507,000	1,064,000
	Collected green waste	154,000	
	Digestate from Anaerobic Digestion	137,000	
	Wood waste	133,000	
	Agri and food processing residues	85,000	
	Waste water dry solids	48,000	
	Other	<1,000	

In the North East as a whole there are over 1.1 million tonnes annually of non-food crop bio feedstock arisings in various forms as detailed above.

Accessible, and sustainably-sourced[2] virgin biomass resources represent a relatively small proportion of this resource and this fraction is dominated by straw (after accounting for other uses in the livestock sector[3]) and forest harvest residues (sawdust, branches, tops and thinnings) from softwood. Efforts and investment would be required to stimulate collection and collation of these residues which are widely dispersed and would otherwise simply be left in-situ.

The biggest potential single source of biomass is the biological fraction of municipal solid waste (MSW) collected by local authorities and other wastes collected from industry, where typically in the case of MSW around 50% of the material collected is of biological origin. This fraction can be accessed (to varying degrees of separation depending on the technologies employed) through material recycling facilities (MRF's). For example, MRF's can produce refuse derived fuels (RDF) from sorted waste for power generation. In the North East around 192,000 tonnes of waste is treated in MRF's (including 27,000 tonnes in Redcar and Cleveland, 18,000 tonnes in Stockton on Tees and 16,000 tonnes in Hartlepool).

The Tees Valley has more waste to energy capacity than surrounding Local Authorities. In recent years, up to 390 ktpa of MSW has been combusted in the North East, all in the TVCA area[4]. This is set to expand with the Wilton 11 plant from 2016 which will consume around 430,000 tonnes per annum of residual waste (from recycling operations) arising from Municipal Waste collections on Merseyside, which will be transported to the site by rail. Wilton 10 consumes around 80-120,000 tonnes of waste wood collected locally from a range of sources including outside the Tees valley region, this comprises only part of a total feedstock requirement of 300,000 tpa for the plant.

With the exception of wood wastes, that are typically reused in wood panel manufacture and as shavings for animal bedding, many of the remaining wastes listed in Table 1 are currently composted before being applied to land, as this reduces material going to landfill and contributes to Council recycling targets. This can act as a barrier to access. In addition collection and treatment of wastes are typically linked to long term contracts which can lock-up waste resources for considerable time.

It is difficult to gain a clear picture on waste arisings and eventual use or disposal routes as the picture is complicated by regional importation and by the potential for double counting between different assessments (i.e. accounting for treatment through MRF's and then further treatment of sorted wastes by composting or landfill

[2] Around one third of straw and forest harvest residues should be retained in situ to help maintain soil carbon balance, soil health and provide other environmental benefits in the case of forest harvest residues.
[3] While the North East has a net regional surplus of straw, much is baled and removed to supply straw deficits in nearby Scottish markets. 62,000 tonnes represents the straw tonnage that could be collected for other uses if collection rates were increased and not the total amount that is currently collected (which is around 390tpa).
[4] One North East assessment of NE England's waste to energy industrial solutions. https://www.uk-cpi.com/wp-content/uploads/2012/09/WasteTechnologiesStudyONENorthEast.pdf

etc.). The relevant data currently needs to be gleaned from a number of sources where the quality and method of data capture differs and needs to be checked against multiple sources.

According to the Environment Agency, which collates information on transfer of 'permitted' wastes, around 490 thousand tonnes of non-hazardous biological material enters landfill annually in the North East (2014 data). This is mainly classed as wastes and water treatment waste (dry solids from waste water treatment) along with 129 thousand tonnes arising from municipal waste collection. A further 400,000 tonnes of biological wastes are recycled to land each year (2014 data). Very little agri and food processing waste or paper and card now reach landfill as a result of segregated collections.

The amount of biological material entering landfill from water treatment is likely to decline as more investment is made into treated sludge, to render it suitable for land application. This has increased in popularity as fertiliser prices have increased.

Clearly there is a significant volume of waste material available for use that could be diverted from landfill without impact on other sectors. However diverting from composting operations may prove more difficult if this works against the waste hierarchy, to which councils are required to adhere as this links to recycling targets imposed by Central Government. However, ensuring that use as a feedstock complements current recycling actions (and provides enhanced environmental benefits) should help to 'unlock' this resource for use.

2.3 Biomass imports

Table 2. Current and planned port biomass handling capacity

Port	Approx. current biomass import	Biomass capacity 2015-
Port of Tyne	1mtpa (2013)	2 mtpa y
Teesport (PD Ports)	-	2.5 mtpa

Support for the UK biomass power sector, particularly by large-scale coal to biomass conversions, has rapidly ramped up UK demand for imported woody biomass. The Tees Renewable Energy Plant planned by MGT for Teesport and the planned Lynemouth conversion to the north of Teesside will stimulate demand for around 4 million tonnes of biomass. Both the Port and Tyne and Teesport are investing in logistics and storage infrastructure to handle this alongside supply for other inland plants such as Drax. The NE region is set to become the UK's most important for biomass reception, handling, transport and storage.

Most of the biomass for MGT will be imported from the Southern US (though Enviva). The US and Canada currently account for around 80% of UK wood pellet import, the balance supplied from Europe and Baltic States.

2.4 Biomass demands for chemical production

Drawing on commercial and pilot plant examples, Table 3 provide estimates of feedstock demands for a few example bio-based chemicals, including current 1st generation commercial bioethanol production for comparison.

While regional feedstock availability will have some bearing on siting of plants, the capacity to import biomass both domestically and externally, means that this is not necessarily a defining issue.

Bioethanol producer Ensus, currently consumes 1m tonnes of wheat on Teesside when running at full capacity, primarily sourced from locally grown and other UK sourced wheat. Converting the plant wholly to lignocellulosic feedstock would create a biomass demand of 1.4 million tonnes. Given the scale of such an undertaking it may be possible to convert in stages where 1st generation and advanced production trains could be run in parallel to take advantage of common processing equipment and infrastructure. Alternatively import of biomass could be considered to supplement local and domestic supplies.

Smaller scale commodity chemical intermediary production provides a closer fit with available regional biomass resources, particularly where conversion efficiencies are high and commercial scales of production are more conservative than those for products like biofuels.

2.5 Key points for virgin and waste feedstocks

Domestic virgin biomass resources represent a relatively small biomass resource in the region (130kt), dominated by straw and forest harvest residues. Investment would be required to stimulate collection and collation of these dispersed residues.

While it is difficult to be definitive on the exact volumes of waste arisings by sector in the North East, a significant volume of bio-based waste is still entering landfill (490 kt) that could be put to other uses, but this will require processing, sorting and stabilising actions to optimise its use.

A significant additional volume of biological waste material is recycled to land in the NE region (400kt), actions to encourage consideration for use as a feedstock, and ensuring this is compatible with the waste hierarchy and Council recycling plans could help to increase access to this resource.

Table 3. Example feedstock requirements

100 kt dry wood	Via conventional ABE process	10,000 t butanol 5,000 t acetone 1,000 t ethanol
100 kt dry wood	Lignocellulosic sugar extraction and fermentation	39,000 t lactic acid
100 kt dry wood	Gasification and Fischer Tropsch	16,000 t FT diesel 4,000 t naptha
100 kt dry wood	Lignocellulosic sugar extraction and yeast fermentation	22,000 t ethanol
100 kt wheat grain	Yeast fermentation	31,000 t ethanol

Notes:

The ABE process has historically been commercial, lignocellulosic-fed ABE process is at industrial development stage.

Lactic acid production is commercialised from starch/sugar resources, lignocellulosic-fed production is in industrial development.

Wood gasification is at demonstration stage but not currently commercial.

Lignocellulosic ethanol from straw is at early commercial development stage, Ineos Bio have been trialling green waste.

While there is a large regional waste resource available, its composition is highly variable and this can be a barrier to use, even in thermochemical transformation processes that are more feedstock agnostic than chemical and biological processes.

Investment in advanced 'clean' MRF's utilising a mix of mechanical and biological treatments to separate and stabilise waste fractions can help to improve and refine bio-based waste streams. Autoclaving treatments (using high pressure steam) for example (emerging but not commonly encountered) can produce a highly refined stable biological 'flock' material of primarily lignocellulose (with some other contaminants depending on the degree of separation achieved) suited to use with biological treatments. However, energy inputs are high, and it involves batch-scale modular processing. Resulting feedstocks are therefore likely to be supplied at a cost, rather than securing a gate fee for further processing/disposal.

Commercial scale chemical intermediary production provides a closer fit with the identified availability of regional non-food biomass resources, but the regional resource should not be viewed as a constraint. The NE region and Teesport in particular will become an important hub for biomass import to the UK, paving the way for additional supply chains. The success of Ensus in securing very large volumes of wheat shows that local supply constraints do not hamper development when working with the right supply chain partnerships.

3 Future feedstock opportunities

3.1 Pyrolysis oil

Pyrolysis or bio-oils are produced by heating biomass feedstocks to around 400-650°C in the absence of oxygen. The resulting 'raw' oil produced is acidic, contains water, is difficult to store and transport and can be corrosive to engines and refinery processing equipment. However, a number of research groups and companies are attempting to produce a stable bio-oil compatible with existing refinery technology and/or that can be converted into advanced biofuels.

Current developments target production of a mix of heat, power and bio-oil for use as a fuel, replacing heavy fuel oil. 'Upgrading' pyrolysis oil provides the potential for expanding uses. However upgrading technologies (hydrogenation, hydro-deoxygenation) require large-scale plants and significant capital and are technically difficult. Teesside has a resource of low-carbon hydrogen, which could in theory be an asset to reduce the carbon footprint of pyrolysis oil derivatives, but this is predicated on these being successfully developed.

After upgrading, pyrolysis oil can potentially be used in many different ways, including being fed directly into a conventional refinery to make renewable transportation fuels, or used as a blend-stock for bunker or marine fuels.

It is not yet clear what the potential issues would be for normal operation of such refineries (i.e. on the balance of outputs) and much research is still required to address these concerns.

Commercial demonstration plants are at the 30-90kt of pyrolysis oil stage, primarily producing unrefined pyrolysis oils for use in heat and power applications. Development is hindered by the current technical risk and economic uncertainty inherent in such technologies currently.

The leading developer is Ensyn, producing heating fuels and chemicals. Ensyn has been using pyrolysis oil for refinery co-processing to produce drop-in advanced fuels and is currently expanding plant developments to capitalise on its technology. Current plans are for development of a 10 million gallon 'green-fuel' facility in Port Cartier, Quebec utilising 65,000 tonnes of wood harvest residues.

3.2 Syngas

Syngas, or synthesis gas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide and often some carbon dioxide. It can be produced by gasification of fossil fuels and biomass.

Syngas may be burned directly in gas engines to produce power and heat; used to produce methanol and hydrogen; or following significant clean up to remove tar and contaminants, converted via the Fischer–Tropsch process into synthetic fuel. Emerging technology is also examining the potential for fermenting syngas to produce alcohols.

Gasification is an established technology in the fossil fuels sector, but the variability of biomass feedstocks, especially waste feedstocks has led to problems in exploitation at scale.

Several waste gasification processes have been proposed, but few have yet been built and tested. Where biomass is concerned, most of these have been directed to heat and power production as power demand in gasification and clean-up is significant and the downstream technology and opportunities are viewed as more risky propositions by investors. At present there are only a few industrial scale biomass gasification plants. The most successful to date have been fed with wood chip providing a relatively stable and predictable feedstock. Scales of 14-32MW have been developed to date as pilot plants, but most are much smaller demonstration units.

Air Products plasma gasifier on Teesside was designed for waste treatment to deliver heat and power. However, following ongoing teething troubles it's likely that the plant will be repurposed towards a more conventional technology.

One of the leaders in conversion of bio-derived syngas to fuels and materials is Ineos Bio with a demonstration facility in Vero Beach, Florida, USA. The facility is designed to convert waste biomass and residual municipal waste into bioethanol, via fermentation of the syngas stream, producing heat and power as co-products. The unit is capable of producing 24 ktpa of bioethanol. It has taken sometime to address process and unexpected contaminant problems, and current status is unclear after difficulties restarting production in 2015 after an outage to address syngas clean up. Ineos Bio recently (September 2016) put up its ethanol business for sale, including its Vero Beach asset, citing changes in the US market for ethanol and a wish to refocus on the company's core strategic objectives.

Enerchem, a Canadian company is another leading player in the sector. Its Alberta biofuel facility, commissioned in 2014, converts post-sorted MSW, via gasification and catalysis of the resulting syngas, into 30 million litres (10 million gallons) per annum of methanol (and downstream to ethanol). In a consortium partnership development, Enerchem now plans to build a waste-to-methanol plant in either the Port of Rotterdam or in Delfzijl, to evaluate and test a number of prospective waste streams. The methanol will be converted into chemicals such as acetic acid, thickening agents and dimethyl ether. Discussions are ongoing over another plant in Qingdao, China. Scales of deployment are still relatively small compared to a world-scale 1st generation biofuel plant, capable of producing 400 million litres per annum. Lanzatech have also been successful in converting CO into chemicals (see next section)

The technology has been proven with fossil-fuels at large scale, but scale-up in the biomass sector has proven difficult to date. With the exception of Enerchem and Ineos that both have projects at commercial development stage, much development in this sector to date is still at an early pilot stage. The economic viability of the process has to be proven at scale and the durability of processes demonstrated.

Previous studies[5] of the potential for synthesis gas production on Teesside identified the problems that biomass poses for gasification technologies and the difficulties in developing smaller Fischer-Tropsch facilities in the 15-150ktpa scale range. Production of such advanced fuels faces a number of economic hurdles compared to the production of methanol for example.

3.3 CO and CO_2

In a study of the potential for carbon capture in the Teesside Valley, The Teesside Collective identified that up to 2.8 mtpa of CO_2 could be captured from just four companies in Teesside: The key emitter was SSI Redcar Steelworks, but this plant closed in autumn 2015.

LanzaTech is currently trialling processes involving biological conversion of carbon to products through gas fermentation. This includes demonstration stage trials on the

[5] DRD Consultants (Whitburn and Mallinson) 2007 report "Teesside Synthesis Gas" for renew Tees Valley Limited.

capture of CO from steelmaking for ethanol production (15,000 gallon per annum scale in new Zealand, 300mtpa in China (BaoSteel Mill, Shanghai & Shougang Steel Mill)) and for butanediol (BDO) production. The first European plant is currently being developed with steel company ArcelorMittal in Ghent, Belgium, with plans to produce 47,000tpa of ethanol in the €87 million plant. In contrast, it is not clear how far CO_2 capture and fermentation has progressed.

With the loss of the SSI steel plant on Teesside, a key source of CO emissions (from off gas) has disappeared and there is no longer a surplus of CO on Teesside as it is used in ammonium nitrate production by GrowHow on Teesside.

These opportunities represent a low-carbon technology where the carbon captured originates from fossil sources rather than biological resources. Resulting fuels and products would be termed 'low carbon' rather than renewable or bio-based.

A new approach to polymer processing is to combine traditional chemical feedstocks with CO_2 to synthesise polymers and high value chemicals, typically using zinc-based catalysts. Typical polymers produced to date include polypropylene carbonate (PPC) and polyethylene carbonate (PEC).

In the US Novamer has been developing its CO2-based polypropylene carbonates (PPC) and polyethylene carbonates (PEC) that contain between 43% and 50% CO_2 by weight, using its own proprietary catalyst system to transform 'waste' CO2 into polyols. It's not clear how clean the waste gas stream needs to be.

It is likely that most CO_2 streams would require some degree of clean-up prior to use, however the potential is significant. The global polypropylene market is around 45Mt, substituting all of this with renewable PPC would see 22.5 Mt CO_2 used as feedstock annually. Polymers created in part from CO_2 could replace traditional petroleum based plastics such as polypropylene, polyethylene, polystyrene and polyvinyl chloride. However, with no additional stand-out benefit they will have to compete on price with existing materials unless the carbon sequestration aspect is valued.

The technology is still at an early development phase and the key interests are in the 'low cost' packaging materials sector, so acceptance will be strongly cost driven for large scale applications. A parallel project[6] is being funded by TVCA looking in more detail at the specific opportunities offered by use of CO_2 on Teesside.

3.4 Key points on future feedstocks

Development of pyrolysis and gasification technologies for syngas production are being hindered by the current technical risk and economic uncertainty inherent in these technologies. There are few commercial exemplars to date to encourage investment, but of these the Enerchem process based on catalytic conversion of

[6] 'CO2 utilisation opportunities in the Tees Valley' is being delivered by CO2Chem, The Carbon Dioxide Utilisation Network (led by Katie Armstrong at Sheffield University)).

syngas to methanol is now deploying commercially, albeit at scales of around 30million litres.

While Teesside has processing capabilities of a scale capable of upgrading pyrolysis oils, and potentially access to low-carbon hydrogen, the current opportunities for upgraded pyrolysis oils are limited by current areas of market application. Similarly regarding opportunities for utilising biobased methanol on Teesside, there is no clear offtake compared to other sites involved in the current technology roll-out by Enerchem and its project partners, which favour existing partner sites.

Capture and use of CO and CO_2 offers some potentially interesting opportunities for Teesside however the technology is still at a relatively early development phase.

4 Existing bio-based interests

4.1 Biomass power and heat

Table 4. Operational and planned large scale biomass power and heat projects in the North East.

Company	Location	Biomass Type	Feedstock requirement tonnes (2020)	Capacity MW	Technology
Operational plants					
Sembcorp - Wilton 10	Wilton, Redcar	virgin/ recovered wood UK	300,000	35	Dedicated biomass (CHP)
Veolia Energy-Dalkia Biomass Energy Centre	Chilton, Durham	Waste wood	120,000	17.5	Dedicated biomass (CHP)
Developing plants					
MGT Tees Renewable Energy Plant	Teesport, Teesside	Imported wood pellets	2,000,000	300	Dedicated biomass (CHP)
Glennmont Partners - Renewable Energy Plant	Port Clarence, Billingham, Teesside	Waste Wood	250,000	40	Dedicated biomass
Energetický a průmyslový holding,	Lynemouth	Imported wood pellets	2,000,000	330	Coal conversion to biomass
Estover Energy	Cramlington, Northumberland	Local forestry by-products	200,000	27	Dedicated biomass CHP
Sunrise Renewables Ltd	Hudson Dock East, Sunderland	Waste wood	25,000	9	Dedicated biomass

The regions current biomass demand for large scale heat and power of 420 ktpa, will soon be boosted significantly by developments at Teesport and Lynemouth. If all planned plants come to fruition, biomass demand for power and heat in the North

East will rise to 4.8 million tonnes, 415kt of which either already, or plans to come from waste wood resources. The bulk of the remainder will be addressed via imported wood pellets.

Much of the development of this sector to date has been driven by government incentives for biomass power generation. Government appetite to continue to support this sector has waned. Support for dedicated biomass power plants under current funding mechanisms (Renewables Obligation) places a cap on the generating capacity that will be supported. It's probably too late now for new applications to be accredited under this scheme as it will close in April 2017. The replacement Contracts for Difference mechanism will not support dedicated biomass generation, but combined heat and power (CHP) projects would be supported. However it's commonly difficult to find heat demands large enough to support large CHP projects. As a tendering scheme with only limited auctions (and currently uncertainty over when these will happen and what technologies will be eligible) the appetite for new biomass projects is limited at the present time.

4.2 Energy from waste

Much of Tees Valley's residual waste stream goes to an Energy from Waste facility in Haverton Hill, Teesside operated by SITA UK (now owned by Suez), with a capacity capable of dealing with 390,000 tonnes of municipal waste per year, which draws in waste from outside the Tees Valley region.

Air Products (AP) established a 50MW advanced plasma gasifier on the Seal Sands complex, the largest of its kind in the UK. Plans to develop a second gasifier were recently scrapped. The aim was to gasify[7] heterogeneous wastes into high-energy syngas that can be used for power and heat generation.

Gasification is an important potential route from biomass resources to production of transport fuels and materials, such as diesel, gasoline, naphtha, methanol, ethanol and other alcohols, and syngas fermentation routes to ethanol. As 'advanced conversion technologies' such technologies would be supported under the CfD mechanism supporting low power generation.

In a blow to such developments, in April 2016 AP announced that it was pulling out of the energy generation business, in part due to the need for further significant technology investment in the gasification technology. The facility is currently seeking a buyer.

[7] In the gasification process, biomass is heated in an atmosphere with limited oxygen, which leads to volatilisation of the biomass rather than combustion, leading to production of a mix of simple gasses, primarily CO, H2 and some CO2, plus small amounts of methane and nitrogen. The preponderance of these species in the syngas mix varies depending on the feedstock and technology used. Gasification of biomass produces a 'raw' producer gas, which can then be cleaned of contaminants and tars to increase its fields of application. The resulting clean 'syngas' contains predominantly hydrogen and carbon monoxide.

Development of biomass gasification at such scales has been beset with problems. The topic of syngas is discussed further in section 3.2 .

4.3 Anaerobic digestion

In the North East there are currently 8 operational AD plants that are taking farm and/or food waste and a further 10 in the development pipeline, with a power generating capacity of 24MW. There has been an increasing move in recent years to biomethane injection into the gas grid (where green gas credits can be generated). In the North East there is one established (Newton Aycliffe, Durham) and one planned (Hartlepool) biomethane injection plant that will provide 1000Nm3/hr. Together the North East's biogas and biomethane output amounts to 25x106 Nm3 of gas per year, or about 1% of the North East's regional natural gas consumption. The waste water sector will add to this resource as it increasingly turns to AD to process waste water solids to enable land application now that disposal to sea is no longer an options.

AD facilities currently consume around 100ktpa of food waste and 46ktpa of crops in the region, but very little crop waste (straw). This will only increase by a small amount as remaining plants in the development pipeline are commissioned.

Northumbrian Water has been particularly active in investing in Anaerobic Digestion to treat waste water and sewage sludge. Northumbrian Water has two advanced thermal hydrolysis AD plants, one at Howdon on Tyneside and the other at Bran Sands, Tees Port, Middlesbrough. It is planned that the former will supply green methane to the national gas grid and the latter may follow. Together they will process around 300,000 tonnes of wet sludge.

Support for AD plants is provided under the Renewables Obligation (large plants) and through the Feed-in-Tariff mechanism, with further support from the renewable heat incentive for heat applications. In both cases the amount of support on offer has been gradually eroded, and the development pipeline will slow significantly once the current (and capacity restricted) tranche of plants are awarded support.

4.4 Biofuel production

Ensus Limited, operates one of the largest bioethanol production plants in Europe. Based on the Wilton International site, it has an annual production capacity of 400 million litres (314kt) of bioethanol, produced from fermentation of 1 million tonnes of grain crops, primarily wheat and maize. The plant has suffered from a number of technical issues in reaching full capacity and until recently was on 'temporary shutdown' due to competition pressures in the biofuel market.

Greenergy is Europe's largest manufacturer of biodiesel from waste vegetable oils and tallow, with a plant based at Seal Sands, capable of producing 250,000 tonnes of biodiesel (the UK's largest)) and a 2nd at Immingham. The move to use of mainly waste oils and fats as feedstocks was prompted by changes in UK policy within the

Renewable Transport Fuels Obligation (RTFO) which currently double rewards fuels made from wastes. Up to 27,000 tonnes per annum of glycerol is produced as a by-product at full capacity. Crude glycerol can be used as a renewable fuel, or cleaned and upgraded for higher value food and non-food applications.

Growing concern over the impact of using crops for fuel and associated impacts on land use change has tempered European political ambitions for biofuel development. The EU recently decided to cap the contribution of crop-derived biofuels to 7% of 2020 EU transport fuel demand (on an energy basis). Post 2020, the European Commission has expressed in communications a wish to "remove support for crop-derived biofuels". The exact implications of this have yet to be discussed and formalised. Brexit adds further complication. It appears the Department for Transport (DfT) want to provide certainty for investors by setting out plans to 2030, which includes retention of the RTFO and most likely support for crop-based biofuels (though to a limited level 'or cap' which has yet to be revealed). The biofuels industry is looking for a cap of no less than 5% to provide sufficient market headroom. Ensus and Vivergo together have the capacity to deliver 5% of the current UK petrol (gasoline) energy demand.

The DfT will soon (anticipated autumn 2016) consult with industry and affected stakeholders on amending the Renewable Transport Fuel Obligation (RTFO) to account for these agreements which will determine the UK's policy on support for biofuels out to 2030.

The market for waste oils for biofuel is likely to remain strong and for import potential to grow from current 400 million litres.

4.5 Support for biobased chemicals

The preceding sections highlight the support available to promote the development of bio-based energy applications, but development of biorefineries and biobased chemicals and materials is currently less directly supported.

There is currently no direct product subsidy or mandated market to encourage chemical or material substitution of fossil-derived with bio-derived materials, a common feature throughout the EU. The sector is being driven by end-user needs that demand products with either improved performance or a 'better' environmental profile to meet a direct need or brand-owner aspiration.

Outside the EU, public procurement programmes like the US Biopreferred Programme have been adopted to successfully stimulate uptake of biobased products. The rationale supporting this is that it supports innovation, creates domestic employment (particularly in rural areas) and adds value to the domestic economy while reducing use of fossil resources. To date the EU has not sought, and has no plans currently to adopt a similar EU-wide scheme. Its approach has been to develop demand by addressing standards and labelling requirements and to review opportunities for public procurement through activities such as the Lead Market Initiative (LMI) and establishing 'expert groups'. The expert group on bio-based products recently made a number of recommendations to the Commission to promote use of bio-based products, but again much of this focusses on awareness raising actions, but does include a recommendation to work towards development of a Bio-based Materials Directive.

In 2015 The UK Government produced a white paper "Building a High Value Bioeconomy: Opportunities from Waste", that details the UK vision for, and current steps and policies in place to support bioeconomy development in the UK. Responsible departments include; the new Department for Business, Energy and Industrial Strategy (BEIS) and Defra. The former brings together previous government interests in business and innovation with those of energy which may help to foster a more cohesive approach to policy development going forward.

UK government support for the bioeconomy has to date primarily focussed on supporting research and technology development and interests in the life science and biotechnology sector, for example through R&D funding programmes such as the Industrial Biotechnology (IB) Catalyst. The BBSRC has identified support for Industrial Biotechnology, along with synthetic biology as a key priority in its 5yr strategic plan, primarily focussing on building capability and critical mass and to increase opportunities for collaboration with industry. There is a recognised need for more basic and strategic research in the sector to underpin innovative routes of chemical manufacture. Innovate UK, the main bridge-funder for 'applied research' in the UK, does not specifically target biorefineries and the bioeconomy as priority areas in its latest strategic delivery plan and therefore support through its programmes is likely to be more fragmented across its priority themes (emerging and enabling technologies, manufacturing and materials, health and life sciences).

Without a significant driver, the UK Industrial Biotechnology sector remains relatively small, fragmented and primarily made up of SME's. Cluster activities could provide access to a range of services important for developing companies in the region including:

- sharing of facilities to scale up ideas
- shaping and providing access to regional funding to support technology development and investment through co-ordination and linking of shared regional interests.
- accessing business support and connection services
- lowering costs for start-up by accessing cluster facilities
- Establishing networks to encourage contact with co-located companies to benefit from industry know-how and skills and facilitate links to high quality science/technology researchers and expertise.

Premiums are available for some products but these are very product and market segment dependent, so premiums for the same product can vary depending on the end use value placed on the credentials. Biobased plastics for example trade at a premium over non-biodgradable alternatives. Such products are chosen for corporate social responsibility reasons or to address a specific environmental or technical requirement (which may be imposed). Most of the Green Premium price findings are in the range of 10 to 20% for bio-based intermediates, polymers and compounds[8], but can be higher in specific cases. Premiums of up to 30% have been paid for 100% bio-derived HDPE for example. In the absence of any policy incentives, Green Premium prices are very important for the market introduction of bio-based products, but are clearly very variable and influenced by end user willingness or ability to pay.

The implications of the BREXIT decision have yet to be clarified. In the interim negotiation period it is 'business as usual'. The European Commission has made clear that EU law continues to apply to and within the UK including the eligibility of UK legal entities to participate and receive EU funding. The UK government has also announced that, as a minimum, it will guarantee support for EU R&D grants awarded up to 2020 to build confidence amongst EU partners that UK academics will receive funding to maintain participation in projects when the UK leaves the EU. Impacts beyond 2020 are less certain and subject to BREXIT deal negotiations.

There are a variety of relevant EU R&D funds with the most important being the £80bn Horizon 2020 programme. In the field of economic development, European Structural and Investment (ESI) Funds provide assistance aimed at improving the economic development of poorer regions of the EU, reinforcing competitiveness and promoting co-operation between regions. In the UK, the relevant ESI Funds are the European Regional Development Fund (ERDF), European Social Fund (ESF) and the European Agricultural Fund for Rural Development (EAFRD).

In relation to biorefinery and enabling technology development, EU structural funds are currently being used in the UK to support lowered cost access to R&D facilities and expert advice and support. Examples include support to access pilot-scale facilities and support to gain access to analytical support and evaluation work.

The results of negotiation may have implications for loss of future access to research and development opportunities including Horizon 2020 programmes and more broadly for relevant networking activities. However, there may also be opportunities for the UK to maintain a foothold if domestic funding is made available to support involvement. The following additional EU initiatives are all helping to support development of the biobased economy:

ERA-NET - Provides funding of calls for transnational research and innovation in selected areas with high European added value and relevance.

[8] Nova Institute, Green Premium prices along the value chain of bio-based products. Available via: www.bio-based.eu/markets

Interreg Programmes - stimulate cooperation activities between EU regions, funded by the European Regional Development Fund.

Sustainable Process Industry through Resource and Energy Efficiency (SPIRE) – is a public private partnership under H2020 that aims to develop innovation to reduce energy use and use of fossil resources in process industries.

Biobased Industries Public Private Partnership (BBI) - A public private partnership providing €3.7 billion investment in bio-based innovation from 2014-2020 under Horizon 2020.

Vanguard Initiative - develops interregional cooperation to support clusters and regional eco-systems to focus on specific areas of specialisation. This includes an initiative to develop interregional cooperation on innovative use of non-food Biomass, which focusses on demonstration and pilot actions (Scotland is currently a partner).

Loss of access to such programmes in terms of the funding, networking and knowledge exchange opportunities they provide would impair the UK's ability to develop against its bioeconomy aspirations.

4.6 Key points for existing bio-based interests

The North East has developed significant biomass heat and power capacity and benefitted from the development of biofuels production in the region. This will ensure that biomass supply chains are well developed and the respective knowledge on handling and storage will benefit other sectors looking to secure feedstock and associated handling expertise.

Changing priorities in energy policy away from biomass-based technologies suggests that further development of the sector will be limited in the near term. But the established industry presence offers opportunities for diversification.

There is much less direct support for biobased chemicals and materials. Promotion to date has focussed on actions to support innovation and promote market pull. Willingness to pay premiums has been important in stimulating biobased polymer markets.

5 Key chemical interests in the Tees Valley

The Tees Valley Chemicals Cluster encompasses a number of interlinked sites including Wilton International, Seal Sands and the Billingham Chemicals site, which have developed around the deep water port facilities on Teesside and the proximity to North Sea oil and gas. This led to the development of oil and gas refineries and co-location of downstream chemical interests. As a result the area benefits from integration of power and heat supplies, pipeline networks for chemical and gas transport, facilities for chemical and gas storage and investment in transport logistics for onward dispatch.

However, UK refining capacity has been declining for a number of years, to the point where the UK is now a net importer of petroleum products. In addition low cost by-products of gas fracking threatens to further undermine traditional oil and gas refining.

Teesside is home to one of the world's largest naphtha steam crackers (Olefins 6, owned by SABIC). This is in the process of being modified into a gas cracker, which will take (principally imported) shale gas by-products as feedstock (ethane, butane and propane) with an output production capacity of 865ktpy of ethylene (along with 400 ktpy of propylene and 100 ktpy of butadiene), primarily destined for polymer production, improving product output from the cracker. The resulting decline in aromatic BTX outputs (Benzine, Toluene and Xylene isomers) arising from this change is likely to result in the closure of Sabic's Aromatics Division.

The historical context means key chemical interests are focussed on polymer production and intermediaries. In the past this also including the production of aromatics for polyurethanes and nylon, but this has been closed down so interest in this area is limited. The Wilton site is dominated by SABIC's investment into Low Density Polyethylene (LDPE), the largest such plant in the world. Polyethylene terephthalate (PET) is also manufactured at large scale on Teesside by the Korean-owned Lotte Chemical UK.

Elsewhere on Teesside, Ineos Nitriles make the raw materials for Nylon (adiponitrile). Lucite International, now part of the Mitsubishi Group, are the biggest producers in the world of MMA (methyl-methacrylate), the precursor of acrylic polymers.

Outside of biofuel plants, all of the industrial plants in the Teesside Chemicals Cluster are currently associated with gas or mineral oil feeds. The move to greater use of ethane, butane and propane as feedstocks for steam reforming could lead to a shortage of what to date have been cheap supplies of C4 organic chemicals such as butadiene and butanediol. A number of international interests (Gevo, Butamax, Genomatica, GranBio, Rhodia, Cobalt Technologies, Green Biologics, Microvi, Myriant and BioAmber) are looking at bio-based alternatives to fill what they see as the potential business gap.

Invista has divested itself of interest in nylon on Teesside, but it maintains an R&D presence in Wilton and is currently looking at bio-based technologies, with links to CPI in the region and other external commercial interests. It has key interests in gas fermentation to chemicals, and plans to commercialise technology by 2018, focussing on the production of nylon intermediates. It also provides technology licencing and know-how for polyester, polyurethane and nylon production processes through Invista Performance Technologies.

A table of key capabilities, interests and linkage within the Teesside chemical cluster is provided in the supplementary appendix report (see table 3). In additional to the steam cracker, there is a steam methane reformer producing syngas (32ktpa H_2) primarily for aniline production (Huntsman) and significant gas storage capacity (0.1-0.2million m^3 of underground storage).

6 Support for innovation in the region

Given the history of petrochemical processing on Teesside, it has a well-developed infrastructure to support development with a focus on the chemical processing industry including;

- The Centre for Process Innovation (CPI) is technology innovation centre that provides access to scale-up facilities and uses market knowledge and technology understanding to develop and prototype products and processes. It is part of the UK's Advanced Manufacturing Technology Innovation Centre (Advanced Manufacturing Catapult). CPI provides expertise in biomass processing, refining and product recovery.

  CPI encompasses a number of specialist facilities including:

  - The national industrial biotechnology facility, which can take a manufacturing concept to commercial readiness. It contains pilot facility and a demonstrator plant capable providing up to 10,000 litres of fermentation capacity and associated upstream and downstream processing capabilities.
  - An anaerobic digestion development centre
  - A gasification development facility. The fermentation of carbon rich gases is an emerging technology of increasing commercial interest. CPI brings together critical competences of expertise in thermochemical processing and gas fermentation along with facilities for gasification and fermentation.

- Five universities (Durham University, Newcastle University, Northumbria University, the University of Sunderland, Teesside University), provide an important resource and partner to the process Industry, with technology, engineering and science departments underpinning the sector that are rated 5-star in their research and teaching capabilities. Key relevant interests include:

  - The Technology Futures Institute at Teesside University (support to process engineering)
  - Centre for Synthetic Biology and the Bioeconomy (Newcastle University)

  - Centre for Bacterial Cell Biology (Newcastle University)
  - Biopharmaceutical and Bioprocessing Centre (Newcastle University)

The region also has well developed cluster support through the 500-member North East Process Industry Cluster (NEPIC) which provides technical, funding and business advice to investors and regional businesses. NEPIC partners with its Local Enterprise Partnerships, TVCA and the North East LEP to attract investment and develop partnerships with other European chemical industry location to help foster the development of chemical process industries on Teesside.

6.1 Key points for supporting innovation

The above organisations and networks are important for two key reasons

- The bioeconomy sector is fragmented and represented by relatively few interests currently, most of which are SME's. There is a need to identify and support the development of many more innovative ideas into companies that can help to grow the bioeconomy and these need support to network and find ways of reducing hurdles to development.

- There is a need to develop an offering to potential external interests to consider locating in the Tees Valley. The ability to demonstrate the presence of key skill bases, supporting technologies and opportunities for networking with like-minded companies is a key attraction.

Tees Valley Combined Authority, the Northeast LEP and others with an interest in stimulating inward investment of bio-based industries onto Teesside also need to make contact with relevant initiatives and key centres outside the region, to work in partnership to identify potential companies and innovative ideas and attract them to Teesside.

These include:

- The Biorenewables Development Centre and the Biovale Initiative centred on York. Teesside could offer growing-on and incubation space for companies developing out of such initiatives.

- BioPilotsUK which has just been launched in the UK to link the 5 key open access industrial Biotechnology pilot plant centres in the UK, of which CPI is a Founding Member. Again this could provide a source of innovative companies and ideas looking for space to develop.

There are also a number of more academic initiatives with interest in bioeconomy related science that it may benefit to have links with including:

- Doctoral training centres

  - EPSRC Centre for Doctoral Training in Sustainable Chemical Technologies at the University of Bath (with a focus on developing new molecules, materials, processes and systems).

  - EPSRC Centre for Doctoral Training in Bioenergy at the University of Leeds. (Interest includes anaerobic digestion, energy from wastes, next generation technologies, bioenergy carbon capture and storage including chemical looping).

The Tees Valley would also benefit from developing links with initiatives in enabling technology areas, such as synthetic biology, as a source of potential future innovative company interests looking for help and support to develop. Centres of specific interest include:

- SynbiCITE the Innovation and Knowledge Centre (IKC) for Synthetic Biology funded by the UK Research Councils was established as the UK's national centre for the commercialisation of synthetic biology. It is based at Imperial College, London and hosts a mix of academic institutions and industrial partners.

- Centres of Excellence in Synthetic Biology

  - SYNBIOCHEM – Manchester Synthetic Biology Research Centre for Fine and Speciality Chemicals

  - Warwick Integrative Synthetic Biology Centre (WISB)

7 Opportunities for bio-based chemical development on Teesside

7.1 Key potential opportunities for integration of bio-based processing

Taking a broad account of the existing relationships and capabilities on Teesside, the key possible opportunities for development of biorefineries within the chemicals cluster on Teesside can be summarised as

a) Opportunities to utilise existing biobased resources in the region (primarily bioethanol as the most commercially developed) or

b) Opportunities to repurpose existing infrastructure (primarily fermentation facilities) to produce bio-based products,

To either;

1) Provide bio-based drop-in (like for like) replacement feedstocks for chemicals produced in the cluster, or

2) address emerging gaps in UK chemical production, or

3) create new bio-based business opportunities on Teesside

7.2 Emerging gaps in UK production of chemical intermediates

Through increasing global economic pressure, it has become increasingly difficult for the UK chemicals sector to maintain production of a range of different chemical intermediates that are important to its manufacturing base. The UKTI is involved in an exercise to broadly map gaps in chemical supply chains that exist or are emerging in the UK to identify where intervention may be required. A draft copy of the assessment to date was supplied for use in this project.

This identified a subset of 22 candidate chemicals, where production in the UK would strengthen the UK chemical and manufacturing base, which could justify government intervention. NNFCC reviewed this subset to identify those chemicals that could be produced from a known bio-based pathway, based on an understanding of the state of development of biobased production chains. This identified 7 chemicals for further evaluation, listed in Table 5.

7.3 Industrial biotechnology options

Production of bioethanol from sugar and starch feedstocks, as well as some fine chemicals and pharmaceutical molecules, is commercialised at a global scale. Ethanol can be converted to ethylene relatively easily, a key chemical intermediary in conventional chemical supply chains.

Processes for bioethanol production from starch and sugar have been optimised. However, feedstock costs are a significant part of the production cost and interest has moved to exploit the sugars in cellulose and hemicellulose materials (lignocellulose) contained in biological wastes and by-products.

Accessing the glucose and pentose sugars contained in biomass requires pre-treatment to break down and weaken the bonds of parent cellulose and hemi-cellulose with lignin. Further enzyme treatment is required to breakdown the cellulose and hemicellulose into its constituent sugar monomers. Common treatments include thermo-chemical approaches (typically steam hydrolysis with or without the presence of weak acids). Lignin is produced as a by-product which can be recycled and burnt for heat generation, or for derivation of chemicals (vanillin is commonly cited as a potential target however the market size is limited) but opportunities to date have been relatively limited.

In both cases, the aim is extraction of sugars that can either be fermented by microorganisms to produce a range of products for further exploitation or (after purification) extracted for chemical conversion.

Development of cost-effective commercial-scale processes for extraction of lignocellulosic materials are still at the early commercial scale. Examples include Europe's first cellulosic ethanol plant using Beta Renewables Proesa technology at Crescentino in Italy, capable of producing 40 ktpa. Which is relatively small compared to Ensus' production of up to 314 ktpa using conventional grain fermentation technology.

US Department of Energy and follow-up work has identified what they see as the most promising biobased chemical opportunities in term of technology readiness and likely market impact[9]. Key chemicals from fermentation highlighted include ethanol, isoprene, lactic acid, hydroxypropionic & succinic acid.

There are already ethanol interests on Teesside. In the case of the other chemicals listed above, there are no obvious routes for direct substitution on Teesside, though Chemoxy Fine Chemicals does offer to produce succinic acid as part of its portfolio of contract chemical production. These therefore represent potential new opportunities to repurpose existing fermentation capacity on Teesside should the opportunity arise, though with a need for further investment and clarification of the business case for development in the UK.

NNFCC is aware of a number of other biobased chemicals and process being developed that could provide opportunities for ethanol conversion or repurposing fermentation facilities. These are listed in Table 5.

7.4 Options considered but dismissed currently

7.4.1 Thermochemical biomass conversion

Thermochemical dissociation of biomass can provide a pyrolysis oil that could potentially be fed into existing oil refinery infrastructure, to deliver a wide palette of materials capable of directly substituting for fossil-C derived materials. However, there remain a number of problems around scale-up beyond a few tens of thousands of tonnes per annum and questions around compatibility with existing refinery processes. It's questionable whether any significant impact could be achieved in a short to medium timescale.

Gasification of biomass to syngas yields biogenic carbon that can feed fermentation systems to provide ethanol and given time and further technical development could probably deliver a number of other primary chemical feedstocks. However, the technology of gasification is emerging and commercial examples are limited. The ability to scale-up successfully when using biomass feedstocks (particularly mixed wastes) also needs to be demonstrated.

[9] Bozell J.J. and Petersen G. (2010) Technology development for the production of biobased products from biorefinery carbohydrates – the US department of Energy's "top 10" revisited. Green Chem., 2010 **12**, 539-554.

The potential for catalytic conversion of syngas to methanol is gaining ground based on success demonstrated by Enerchem and this is an area that needs watching. The opportunities for direct integration of such technology on Teesside needs further examination

7.4.2 Metabolite extraction

Plants provide a range of materials including, waxes, oils, fibres, flavour, fragrance and pharmaceuticals for industrial and medicinal use and markets are relatively mature. One area of growth has been the production of biodiesel from Fatty Acid Methyl Esters (FAME) from vegetable oil feedstocks. Fatty acid esters have been used as industrial feedstocks for decades in detergent, solvent and lubricant sectors and opportunities for further expansion are limited, so there are limited opportunities for repurposing biodiesel plants. However the glycerol by-product does provide opportunities, particularly for use of lower grade materials.

7.5 Long list of opportunities

Drawing on current priority gaps in UK chemicals production, key chemical products produced on Teesside and an understanding of which bio-based chemicals and their derivatives can be produced either from existing facilities on Teesside, or by repurposing facilities on Teesside, a first long list of possible opportunities was drafted to identify potential areas of synergy (see Table 5). This identified 19 chemicals as a focus for further examination.

Table 5. Key opportunities and common linkages on Teesside

	UKTI identified gap in UK supply chain -	Bio ethanol derivatives	Opportunities for repurposing fermentation capabilities to bio-based key markets	Opportunities for substitution into existing supply chains in Teesside
1	**acetone**		acetone-butanol-ethanol (ABE process) (nButanol)	ABE process compliments existing bioethanol production (**Ensus**)
2	**mono ethylene glycol** (MEG)	mono ethylene glycol (*for polyesters*)		**Lotte** (PET producer) (MEG is one of the monomers for PET production.
3	**ethylene oxide**	ethylene oxide (polyesters & surfactants)		
4	**high density polyethylene**	ethylene (and derivatives)		ethylene (**Sabic** (LDPE & ethylene derivatives)
5	**propylene glycol**			
6	**adipic acid**		adipic acid (nylon 6,6 precursor (but no longer primary route))	
7	**xylenes** (ortho and para-xylene) (for terephthalic acid & PET production)		Isobutanol and derivatives [The monomers of PET are ethylene glycol and terephthalic acid, terepthalic acid production is more difficult – routes possible from isobutanol and onwards via paraxylene, or by chemical catalytic conversion of sugars]	Possible precursor for terepthalic acid for **Lotte** PET production, *(Lotte currently imports PTA to UK)*
8		**1,2 dichloroethane** (for PVC)		no PVC interest on Teesside
9		**propylene**		
10			**butanediol**	

	UKTI identified gap in UK supply chain -	Bio ethanol derivatives	Opportunities for repurposing fermentation capabilities to bio-based key markets	Opportunities for substitution into existing supply chains in Teesside
11			**hydroxypropionic acid** (used in P(3-HP) production)	
12			**isobutylene** for isobutylene rubber. Global Bioenergies Interest)	
13			**isoprene** (used to produce cis-1,4-polyisoprene a synthetic rubber)	
14			**lactic acid**	(Plaxica have a pilot LA plant at Wilton and a tie up with Invista) However, this is via a chemical route
15			**methyl methacrylate** (monomer for plexiglass)	methyl methacrylate (**Lucite International**)
16			**propanediol**	
17			**succinic acid**	**Chemoxy Fine Chemicals** on Teesside have a limited interest
18			**glutamic acid** (produced via fermentation)	acrylonitrile (**Ineos Nitriles** key output) [2-step chemical transformation from glutamic acid]
19				**aniline** (**Huntsman**) exported for polyethylene

Further detail on the rationale for selection of the above chemicals, possible routes of bio-based derivation, current and potential use, current market size and value, current stage of development and key industry interests is presented in Table 5 in the appendix report.

8 Ranking of bio-based chemical opportunities

The prospective chemicals of interest were ranked to identify the most promising on the basis of techno economic attractiveness (state of technical development for bio-based routes of derivation and ability to provide a reasonable financial return) versus market opportunity and interest (reflecting scale of global market opportunity, current levels of commercial interest, and relevance of interests and ease of incorporation on Teesside).

Techno economic attractiveness index was based on

- Technology readiness level (0-7, based on oil and gas industry definitions of TRL's (API 17N))
- Scoring of calculated product to feedstock cost (£/t sugar) break-even ratios (based on nominal price of wheat-derived C6 sugar (wheat at £130/tonne)) to reflect minimum level of process efficiency required to cover feedstock cost

Market opportunity and interest index was based on:

- Estimate of likely scale of market exploitation from 100's to millions of tonnes per annum (1-4 ranking)
- Current commercial interest index (0-3 ranking (undeveloped to competing commercial interests))
- Regional relevance index (0-4 ranking (no specific interest to opportunity for direct substitution)).

Scores and ranking were summed to provide a techno economic attractiveness index and a market opportunity and interest index for each chemical. The results of this are shown below.

A few chemicals stand out as ranking less well, but with most separating out more significantly in terms of size of market opportunity (reflecting the size of the market available, currently levels of commercial interest in developing bio-based feedstocks and relevance to Teesside (which is unsurprising as part of the original selection criteria)) rather than in terms of techno economic attractiveness (reflecting TRL level and price of output over C6 sugar feedstock cost). The general trend is summarised in Table 6 below.

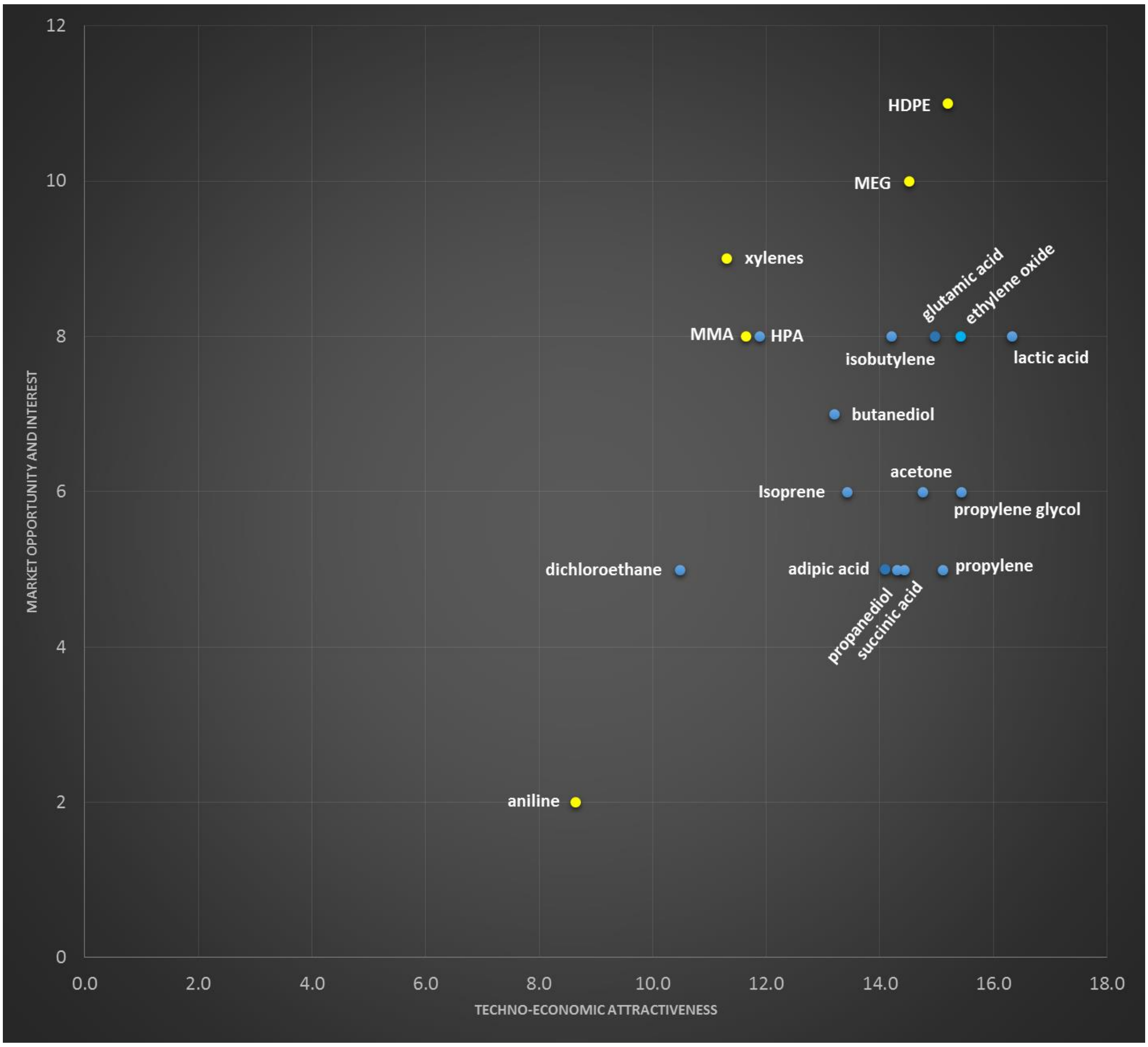

Figure 2. Market opportunity and techno-economic attractiveness rankings of biobased opportunities. Yellow markers indicate opportunities for substitution within chemical industries based on Teesside, or intermediaries with derivatives offering opportunities for substitution

Table 6. Prioritised opportunities based on outcomes demonstrated in Figure 2, and indication of ability to integrate with existing infrastructure and chemical interests on Teesside

	Opportunity (UKTI UK supply gaps highlighted)	Bioethylene derivative	Repurposed fermentation (direct or via intermediary fermentation product (shaded)	Chemical or catalytic derivation	Direct opportunity for substitution on Teesside	Indirect opportunity for substitution on Teesside	
Increasing market attractiveness, technical readiness and compatibility with interests in Teesside	HDPE				✓✓✓		(Sabic interests in PE)
	MEG				✓✓✓		MEG monomer for PET (with terephthalic acid) (Lotte interest)
	Xylenes (paraxylene)		*	*	✗	✓✓	*via isobutanol or catalytic conversion from sugar – possible biobased terephthalic acid precursor (possible Lotte interest)
	lactic acid				✗	✓	Plaxica pilot plant at Wilton (but chemical route)
	ethylene oxide				✗	✗	
	glutamic acid				✗	✓	Possible precursor for acrylonitrile (Ineos interests) direct fermentation or chemically via bio-propylene
	isobutylene		*	*	✗	✗	*via isobutanol derived by fermentation
	HPA				✗	✗	
	MMA		*		✓✓✓		*Via itaconic acid or methacrylic acid. (Lucite interest)
	butanediol				✗	✗	
	propylene glycol			*	✗	✗	*From glycerine or lactic acid
	acetone				✗	✓	ABE process would integrate with existing bioethanol infrastructure for ethanol fraction, also see propylene
	isoprene				✗	✗	
	propylene	*			✗	✗	* or via n-butanol (ABE process)
	succinic acid				✗	✓	Chemoxy have some capability to supply on bespoke contracts
	propanediol				✗	✗	
	adipic acid				✗	✗	No polyamide interests on Teesside
	dichloroethane				✗	✗	
	aniline				✓✓		Huntsman export

8.1 High priority opportunities

HDPE, MEG

As opportunities that address strategic gaps identified by UKTI, and with the potential for direct integration into existing Teesside interests, HDPE (Sabic) and MEG (Lotte) are key candidates for further examination of the business case and regional interest. As bioethanol derivatives, much of the required infrastructure is in place in Teesside reducing the investment need and hurdles to development.

8.2 Medium-high priority opportunities

MMA

MMA is of interest due to potential Lucite interest on Teesside, but bio-based MMA is at a relatively early stage of development and exploitation, which will delay roll out until the technical and business case is proven.

Ethylene Oxide

The dehydration of ethanol to ethylene is simple and the equipment to undertake this is present on Teesside. Therefore it would be relatively simple to take bioethanol from Ensus to produce ethylene oxide. This is already commercialised in Asia and is emerging in the US. Identified as a production gap in the UK, but business case needs further examination.

8.3 Medium-low priority opportunities

There are a number of emerging and recently commercialised examples of fermentation derived products that could potentially be produced on Teesside through the re-purposing of existing fermentation facilities. There are differences in the degree of current technical development and in the potential scale of market opportunity available reflected in the overall rankings.

Paraxylene

Paraxylene is of interest as a precursor for bio-based terephthalic acid for PET production, but further work is required to commercialise the process. A number of key brand owners are investing in this technology currently to produce fully bio-based PET. Further examination of the local interest of Lotte and possible business case is required. Costs of conventional PX are lower than for the majority of chemical opportunities considered here reducing the potential margin over costs. However, the drive of brand owning end users for fully-bio-based PET could drive premiums.

For the following there is no specific interest identified on Teesside:

Lactic acid, propylene glycol, acetone, succinic acid, propanediol

In the above cases the biobased routes of derivation are proven and moving to early or full commercial production

Isobutylene, butanediol, isoprene, adipic acid

In the above cases, biobased routes of derivation are proven but require further development to move to full commercial production.

As a flammable gaseous products, fermentation of isobutylene and isoprene will be more difficult for conventional fermentation equipment and there would be a need for appropriate ATEX-rated facilities to address safety requirements (particularly for isobutylene), increasing Capex costs.

8.4 Lower priority opportunities

Propylene

Derivation of propylene from bioethylene is possible, but bio-based routes from isopropanol and n-butanol are also currently being pursued. Further technical development is required to prove the commercial business case as the sector is at an early stage of development. Ineos currently has interests in propylene.

8.5 Monitor development

Glutamic acid

Ranked highly in this exercise, primarily because it is an amino acid that has already been commercially developed at large scale for the food sector. However industrial use remains limited and derivatives are largely theoretical in nature and need to be tested and developed commercially.

Hydroxypropanoic acid

Offers opportunities for repurposing fermentation equipment, but bio-based production is at a very early stage of development and there are no specific interest on Teesside.

8.6 Dismiss

Dichloroethane, Aniline

At current prices, the low price of dichloroethane means it would be difficult to generate a high margin over feedstock costs and there is no specific interest on Teesside. Aniline lacks a clear biobased production route and significant development work would be required to establish this.

9 Potential for Teesside to compete on bioethylene

Several of the most promising opportunities rely on the derivation of ethylene from bioethanol. Bioethylene is currently being produced in Brazil and India from ethanol. Price is highly dependent on feedstock costs but moves to utilise lignocellulosic sugar will help decouple feedstock ethanol costs from food crop prices and increase competitiveness with Brazilian, Indian and Chinese bioethylene (Table 7).

Estimated production costs of bioethylene vary globally with bioethanol feedstock accounting for around 60% of the cost (one tonne of bioethylene requires 1.74 tonnes of hydrated bioethanol) and crop feedstock accounts for 60-75% of the cost of bioethanol.

Table 7. Estimated costs of bioethylene production (2013 prices)[10]

Country and feedstock	$/tonne
Brazil and India (Sugarcane)	1200
China (sweet sorghum)	1700
US (corn)	2000
EU (Sugar beet)	2600
US Lignocellulosic	1900-2000

It is anticipated that ongoing work to reduce the costs of lignocellulosic technologies will reduce costs of bioethylene in the future. Sugar feedstock costs (in terms of £/t sugar in the feedstock) range from being 30-60% lower in lignocellulosic feedstocks than those of grain and sugar-beet fed plants[11]. Ongoing development of cellulosic ethanol for the biofuels sector could provide wider benefits in opening up the technology to provide cheap fermentation feedstocks for a wide range of industrial biotechnology applications.

The bioethylene prices in Table 7 take into account the different support measures for bioethanol production at work in different countries, for which there is not a level playing field. Trade barriers and tariffs can restrict bioethanol imports to protect domestic production. However, where end product costs are strongly influenced by feedstock price, manufacturers will typically locate where the cheapest resources can be found. Trade barriers to protect UK or European interests in the biofuel sector

10 IEA-ETSAP and IRENA Technology Brief 113, 2013. Production of bioethylene

11 These are highly influenced by assumptions around feedstock costs, composition and fuel conversion efficiency.

are unlikely to help the bio-based materials sector. The key objective in the EU is to reduce feedstock costs.

Imports of bioethanol from outside the EU (except for a few favoured trading nations with bilateral free-trade agreements) face a €0.192/litre import duty, which can account for around a third of the final price for ethanol imported into the EU. This helps to favour and protect domestic production. Prices for ethanol within the EU have been falling in recent years due to the opening up of tax-free imports and falling demand for EU product (in part due to ongoing shift to dieselisation of the transport fleet) which has helped to increase EU competitiveness with global market bioethanol prices.

Global conventional ethylene prices are at a low of around $1000/tonne which poses a further hurdle to market entry with like-for-like substitutions. Bioethylene derivative markets are likely to require either a premium or preferential market access unless bioethylene can be produced at close to the global ethylene price, which Brazil and China are close to achieving.

GHG emissions for bioethylene production (from sugar cane) can be up to 40% lower than those for conventional fossil ethylene. The value placed on this is dependent on the objectives of the end user, which will influence the level of any premium that can be borne. Bio PE has been sold at a premium of up to 30% over conventional PE by Braschem.

A key issue going forward affecting confidence in the UK market for bioethylene is how the BREXIT decision will affect future UK trade relations and associated tariff levels. A deal which means the UK maintains access to the existing EU single market is likely to provide a more protected market for UK bioethanol and bioethylene production, while outside of this the UK could be exposed to extremes as varied as complete protection to complete open access to imports depending on individual trade deals with different trading partners or trading blocks.

9.1 Potential for substitution

Ensus has a bioethanol production capacity of 314 tonnes, directing all of this to ethylene production would produce around 180 tonne of bioethylene, which would put it in current world-class scales of operation. This would represent around 21% of the ethylene output from SABICS new gas cracker and equates to just under half the feedstock required for its 400 ktpa LDPE plant.

The degree of SABIC interest in bio-based feedstock would need to be ascertained, and the ability to feed-in external supplies of bioethylene examined. The output of the new gas cracker will be closely tied to SABICS LDPE interests and so the business case would need to be very strong to disrupt this integrated investment, unless alternative uses for the fossil ethylene could be found.

9.2 Potential for re-purposing assets

A number of the medium-priority opportunities rely on repurposing fermentation equipment to deliver new molecules. While the basic fermentation equipment may be suitable, the specific requirements of the fermentation microorganisms to deliver optimum efficiency and the different characteristics of the metabolites that need to be removed from the fermentation broth mean that significant re-tooling and assessment of existing equipment design parameters would likely be required. Again this is likely to require investment and needs to be based on a robust business case.

9.3 Key points for highlighted opportunities

There are a number of emerging bio-based chemical opportunities that the chemicals industry in Teesside could potentially take advantage of, including both opportunities for integration with current supply chains and for repurposing facilities to enter new markets. Both of these routes entail risk and require a robust business case for investment along with a strong clear market offtake driver which will take time to develop.

A concern is future EU biofuels policy and what impact this could have on bioethanol sector interests. Due to concern over use of crops for fuel, the EU has capped the contribution (to mandatory Renewable Energy Directive targets) permitted from crop-derived biofuels to 7% of 2020 EU transport fuel energy demand. Post 2020, the Commission has expressed a wish to "remove support for crop-derived biofuels". Brexit adds further complication to this in terms of relevance and access to markets. The UK Department for Transport (DfT) wants to provide certainty for investors and has set out plans to 2030 that includes retention of support for crop-based biofuels to a limited level. The UK biofuels industry is looking for a cap of at least 5%, and encouragement to deploy E10 (10% ethanol/petrol blend) to provide sufficient market headroom. A long-delayed DfT consultation on this is pending, its outcome will determine the UK's long-term policy on support for biofuels to 2030. An option for UK biofuel producers looking to the medium to long-term is to examine options for conversion to use of lignocellulosic feedstocks, a technology which is at early commercial stages of deployment

Current uncertainty around future trade and tariff levels will increase uncertainty in the near term and is likely to put a hold on investments around bioethylene production. There is a role to ensure that the needs of the Chemical Industry on Teesside are heard in Central Government to protect opportunities for future development.

In addition to policy uncertainty, the level of industry interest in the highlighted opportunities needs to be tested to ascertain what the chemicals industry on Teesside sees as the barriers to development and/or needs to support development. Investment into current fossil fuel chains may be such that diversion to other opportunities may be constrained.

There will be a need for investment in research, partnership building, and down the line re-tooling and investment in equipment. The investment requirements will be significant, running into £millions. TVCA and others supporting inward investment in the region need to start to build the case for a significant investment fund to support such developments and reduce private investment risk.

The foregoing analysis concentrates on relatively large-scale opportunities, in part driven by the focus looking for opportunities for integration with existing interests and assets on Teesside. There are a myriad of potential niche and other biobased chemicals of varying complexity that could potentially be produced on Teesside but for which there is currently no clear supply chain or potential offtake identified. In such cases the Tees Valley Region needs to make an appropriate 'bid' or offering for hosting the relevant technology companies identifying the advantages that Teesside has to offer.

The development of supply chains for biobased chemicals also provides the opportunity for developing chemical extractive markets to co-exist with biorefinery operations, but it is the existence of the primary biobased chemical business that will grow the former and where efforts should focus.

10 Learning from existing examples

To assess the attractiveness of the wider Teesside offering, example case studies were sought of initiatives supporting the development of bio-based clusters and the driving factors behind their development. This included review of potential competitor offerings and examples of recent bio-based chemical developments. More detail on each case study is available in the appendix report.

10.1 Matrìca, Sardinia, Italy

Matrica was established in 2011 as a joint venture between Novamont and Versalis (ENI) (Italy's largest chemical company) to convert a failing petrochemical facility into an integrated green chemistry complex to develop a state-of-the-art range of bio-based products sourced from an integrated agricultural production chain.

The driver for the development was political pressure initially by the chemical engineers' union and the Sardinian community, including regional mayors and authorities. Together they forced the central government to make ENI commit to finding an alternative to simply shutting down the Porto Torres petrochemical plant.

This led to a €500 million investment in site development. The new site includes a Research Centre, incorporating an analytical laboratory and 7 pilot plants. The Centre operates in synergy with Novamont's research centres where many of the relevant the technologies were developed and also addresses relevant research sectors for Versalis. A further €200 million has been invested in R&D.

10.2 Port of Rotterdam

The Port of Rotterdam has set out to establish itself as the "gateway for biobased industry in Europe". Rotterdam is the largest port in Europe, with facilities for inland shipping, rail, pipeline and roads to mainland Europe. It boasts one of the largest renewable hubs in the world. Rotterdam Port currently has 6 biofuel plants, 4 biopower plants, 3 biobased chemical companies, and 8 edible oil/agri food companies. The port has capacity for deep-sea shipments, transport and storage for solid and liquid biomaterials, through 8 agri/biomass terminals and 10 large scale tank storage facilities. There are 14 bio-based industrial companies providing integration through supply of feedstocks, products and by-products with each other and other sectors on site.

Knowledge and innovation are provided by 3 world leading Universities, and the regions processing facilities support a pool of skilled labour.

The strategy to develop a bio-based cluster involves many partners, largely coordinated by the Port of Rotterdam Authority. 80 hectares of dedicated reclaimed land have been assigned to biorenewable chemicals production.

10.3 Sarnia-Lambton Hybrid Chemistry and Energy Cluster

Canada's Sarnia-Lambton refining and petrochemical centre (SLRPC) in Ontario provides a hub for several large petrochemical refineries, which has led to the development of integrated company relationships and the development of an extensive logistics infrastructure, providing good road, rail and international sea connections via the St Lawrence Seaway. The complex hosts a number of global chemical companies.

The Sarnia-Lambton Hybrid Chemistry and Energy Cluster encompasses several business, industrial and research parks in the locality and a number of additional support facilities including; Bioindustrial Innovation Canada - the Canadian national centre for the commercialisation of large-scale industrial biotechnology. In addition there are training facilities to build process industry and engineering skills. A new Bio Industrial Park has been established within the cluster, with integrated service provision of water, steam, power, rail and port facilities.

BioAmber has sited its pilot 30,000tpa biosuccinic acid pilot plant in the Bio Industrial Park, deriving dextrose from co-located Comet Biorefining (lignocellulosic biomass refining) in which BioAmber has an equity stake. BioAmber is a US company which has developed some of its technology in Europe under licence.

Government backing is very important for these new industries, BioAmber received support for its US$125m pilot plant from a number of public sources totalling $52m[12]

[12] http://www.theobserver.ca/2016/03/13/bioamber-and-comet-receive-huge-government-support

Canada promotes itself as offering low investment and capital costs and has taken steps to reduce tax burdens on non-resident investors.

As well as succinic acid, BioAmber has licenced technology to produce 1,4-butanediol (BDO) and tetrahydrofuran (THF) derived from succinic acid. A further 2 biosuccinic acid plants are planned, including plans for moving to BDO and THF production in 2018 (based on work with Johnson Matthey Davy Technologies in the UK who provide the catalysts and UK plant tests). BioAmber is looking for government loans to support this expansion. Locations under consideration for expansion include Louisiana, on the Mississippi in the US and sites close to the existing Sarnia Plant in Canada.

10.4 Croda – Ethylene Oxide

Following the cessation of ethylene oxide production by Dow at its Wilton site in 2010. Croda decided to exit the Wilton site. A key issue was the short timescale within which Croda needed to act to protect its business interests. Croda re-assessed its position across facilities in Asia, India, Europe and the US and its facility at Atlas Point in the US was identified as the site best placed to replace capabilities lost at Wilton.

Ethylene oxide is difficult and hazardous to transport. To reduce risk exposure, Croda took the strategic decision to derive ethylene oxide onsite from ethanol. As a result the site is being developed to convert between 10 and 14 million gallons of bioethanol each year into ethylene oxide. As a site which also derives 75% of its energy from renewables this also fits with the company's ethos and long-term sustainability goals. Croda's ethanol-to-ethylene oxide facility will be one of just two or three developed worldwide to serve its material needs

10.5 Avantium - furan dicarboxylic acid

Avantium, based in Amsterdam, is a spin-out from Royal Dutch Shell with advanced catalysis skills. Over the last 10 years it has been developing furanics technology, converting plant-based sugars into chemical building blocks including furanics. Avantium has developed polyethylene furanoate (PEF), a 100% biobased alternative to the well-known PET (which is partially renewable (consisting of terephthalic acid combined with monoethylene glycol)). Brand–owners including Coca-Cola, together with Danone and ALPLA are looking for ways to substitute existing PET bottles with a 100% green alternative and have invested in Avantium.

Avantium has signed an agreement with Mitsui to commercialize PEF in Asia, but as a stepping stone to that Avantium has developed a Joint Venture with BASF to site its reference plant in Antwerp on a BASF site. The rationale for this it that it provides access to:

- BASF's experience and credibility in market development as well as commercial and large scale production of intermediates and polymers

- the Antwerp 'Verbund system' of BASF (designed to provide intelligent interlinking of production plants, energy flows and infrastructure to reduce its raw material and energy use)
- 'world class' infrastructure for chemical operations at the heart of the Benelux chemical cluster
- logistics and raw materials sourcing

In addition, the proximity to its Amsterdam headquarters and the Geleen Pilot Plant was important along with EU support provided for flagship projects, though the latter was viewed to be a complimentary benefit rather than a key driver.

10.6 Key points from case studies

While the Teesside cluster may look an attractive proposition to attract inward investment, it is not unique. There are comparable offerings from other European and North American interests offering similar facilities, as well access to research and development resources and skilled staff. Any offering therefore needs strong marketing and backing.

Political pressure to stimulate investment has been an important stepping stone to some developments. Visions around the 'Northern Powerhouse' and the recently completed independent report led by Lord Heseltine "Tees Valley: Opportunity Unlimited" may provide the impetus. Investment incentives have helped to lure in companies developing bio-based chemicals, many of whom are global operators and so have a pick of the opportunities available.

Linkage to existing infrastructure and facilities is an important factor in decision making over site selection. The biomass import facilities and existing bioethanol plant should be important selling points in any offering.

Gaining investment support is a critical issue for the sector, as an emerging sector biorefinery development and industrial biotechnology is viewed as a high risk for private investment. There are a number of funding schemes that businesses in the North East can access (see appendix report section 11), while the pots themselves may seem large the individual awards and loans are typically relatively small, from a £ few tens of thousands to £1-2 million and typically represent seedcorn funding. This is negligible compared to capital grants offered to attract BioAmber to Canada for example and work with central government is required to address this deficit to be ready for any opportunity that may arise.

11 Next steps

Feedstocks

Regional domestic virgin biomass wood resources represent a relatively small resource in the region and there is existing infrastructure that could be used to help improve recovery, particularly of straw residues. A relatively small investment would help to build collection of regional wood residues, which otherwise are likely to be left in-situ.

Action	Timescale
Consider a relatively small investment in biomass collection from forestry harvest operations in the region to incentivise increased rates of collection. This could support existing biomass demands in the region until other markets develop to help build local supply chains	1-2 years

The most abundant source of biomass in the North East is contained in waste streams, with much still entering landfill (though this will decline over time as waste separation rates increase and costs of landfill increase)

Action	Timescale
Actions to increase waste separation would increase the biomass resource available on Teesside and could help to provide a more consistent feedstock for energy from waste facilities, including the currently struggling Plasma Gasifier facility. Investment in more intensive 'clean' material recycling facilities will provide a more consistent and refined biomass output. The business case for further investment and possible partnerships should be examined	1 year

With regard to thermochemical (pyrolysis and syngas) and opportunities for use of CO and CO2 as feedstocks, TVU needs to keep a watching brief on developments and develop an attractive offering for technology holders.

Support for existing bio-based interests

Existing biobased interest on Teesside are driven by the low-carbon and renewable energy agenda and are dependent on government support and actions to maintain their market. Current uncertainty around the government position on biofuels could affect plants like Ensus.

Action	Timescale
Regional Authorities and Ensus need to engage with the planned Department for Transport consultation (end of 2016) on amendments to the Renewable Transport Fuel Obligation to ensure Ensus has sufficient market headroom and licence to operate beyond 2020	1-2 months

Action	Timescale
In maintaining biofuel interests beyond 2020, support and engagement with Ensus should be initiated to examine interest in, and capacity to adopt cellulosic feedstocks as a next-steps development phase	Within 6 months

New bio-based opportunities

All of the identified highest priority opportunities result from integration to a greater or lesser degree with existing assets and interests in the chemicals cluster on Teesside, particularly building on bioethanol and the potential for bioethylene production as an intermediary. Further work and discussion is required with these interest to understand their level of interest in the highlighted opportunities, their concerns and ability to support investment.

Action	Timescale
Ascertain SABIC and Ensus interests in commercialising the production of bioethylene on Teesside, and linked interest of Lotte for PET production. Examine SABIC ability to incorporate bioethylene within existing business plans and possible alternative business plans to accommodate use.	3 months plus follow up assessment
Action	
Ascertain Lucite interest in bio-based MMA and development needs to progress (anticipate 5+ year to any development)	3 months, plus follow up
Action	
Examine Lotte interest in bio-based paraxylene for PET and development needs to progress (anticipate 5+ year to any development)	3 months, plus follow up

Ethylene oxide, lactic acid, propylene glycol, acetone, succinic acid, propanediol, isobutylene, butanediol, isoprene and adipic acid are all potential candidates for new opportunity development on Teesside, though with no current interests on site.

Action	Timescale
Examine Ensus interest in repurposing options for fermentation trains and associated limitations and work to assess business case for any specific areas of interest	3 months + 4 months for detailed business case

Dealing with uncertainty and risk

Impact of BREXIT decisions on trade tariffs for bioethanol, bioethylene and derivative products could have a significant impact on the competitiveness of UK industry in this sector. The UK needs confidence to be able to operate.

Action	Timescale
Ensure that the needs of the Chemical Industry on Teesside are heard in Central Government to protect opportunities for future development.	2+ years to post-BREXIT

Support for capital investment

There will be a need for investment in research, partnership building, and down the line re-tooling and investment in equipment and plant. The investment requirements will be significant, running into £millions

Action	Timescale
TVCA and others supporting inward investment in the region need to start to build the case for a significant investment fund to support such developments and reduce private investment risk	2+ years for 1st phase 3+ for 2nd aimed at capital projects

The Teesside 'offer'

While the Teesside cluster may look like an attractive offering, it is not unique. There are comparable offerings from other European and North American interests. The Teesside offer to bio-based business needs strong marketing and backing.

Action	Timescale
Develop a strong clear offering and brand for the Tees Valley Chemical Cluster and potentially a biobased cluster offering and support this via promotional activities with strong case studies of the benefits	1 year
Action	
Develop working relationships and linkage with other regional initiatives in the Bioeconomy Sector (e.g. Biovale) and in specialist centres for enabling technology areas (e.g. synthetic biology) as a means of targeting and attracting companies with a potential interest in the Teesside offering.	3-6 months to identify areas of potential cooperation
Action	
Develop economic incentives for siting plants and investing in biobased developments on Teesside, building on the 'Northern Powerhouse' concept and impetus generated by the recent "Tees Valley: Opportunity Unlimited" review led by Lord Heseltine	1 year + deployment

NNFCC

NNFCC is a leading international consultancy with expertise on the conversion of biomass to bioenergy, biofuels and bio-based products.

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