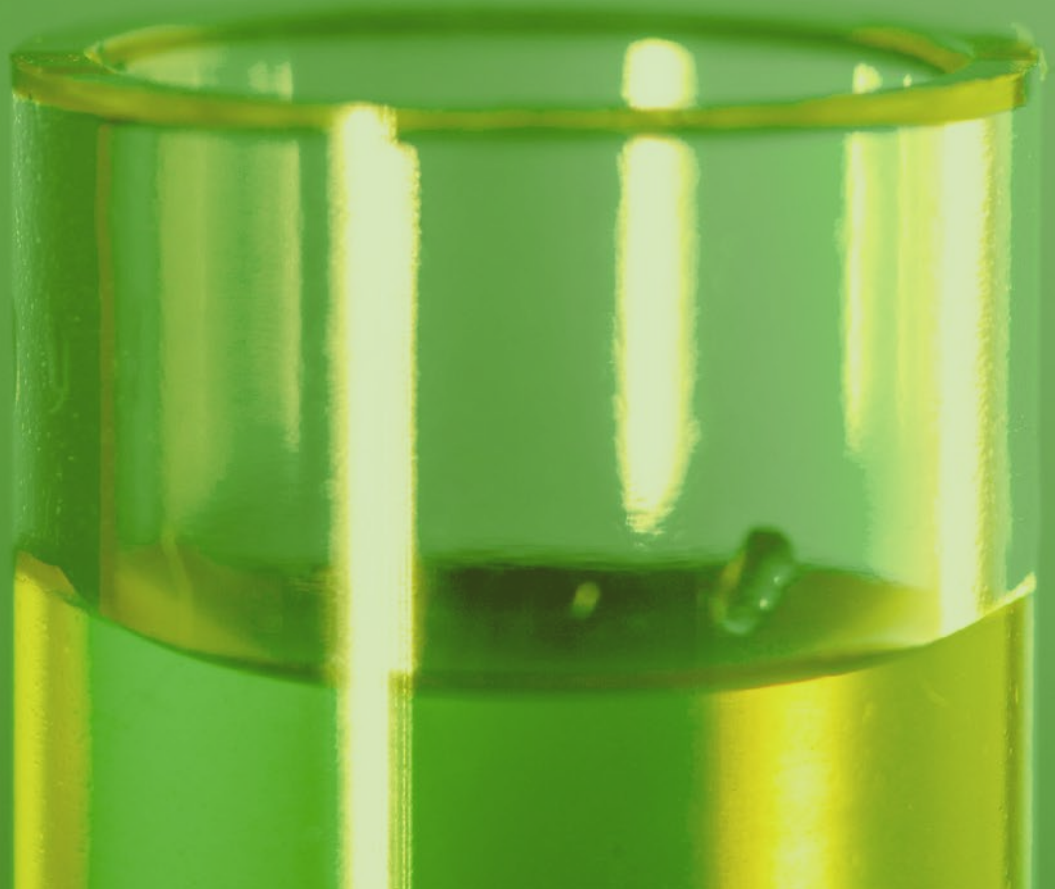
LBNet Lignocellulosic Biorefinery Network

BBSRC bioscience for the future

UKBioChem10

THE TEN GREEN CHEMICALS WHICH CAN CREATE GROWTH, JOBS AND TRADE FOR THE UK

Highlights from a report commissioned by The Lignocellulosic Biorefinery Network (LBNet), a Biotechnology and Biological Sciences Research Council Network in Industrial Biotechnology and Bioenergy (BBSRC-NIBB)



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FOREWORD

Simon McQueen-Mason, LBNet Network Director

Bio-based chemicals – chemicals produced from plants rather than crude oil – represent a dynamic area of innovation in the UK, one that can create growth, trade, investment, and jobs.

Global trends towards sustainability, reduced emissions and landfill avoidance are driving demand for greener products. At the same time, innovators are disrupting the traditional chemicals industry by developing bio-based chemicals which can replace and improve upon oil-based ones.

The UK is already ahead of the game in this disruptive industry. We have world leading research in bio-based chemicals in our universities, startups and corporate R&D. With the right support, we are well positioned to become a leading global bio-based chemicals player in this new sector. Without it, our R&D will probably be commercialised elsewhere.

The UK once had the world's leading chemicals industry, and even now, the industry employs 105,000 people and generates a gross added value of £9bn per year.

Like many industries, chemicals is ripe for disruption, driven by a global move away from using fossil-based carbon reserves. Bio-based chemicals offer the UK the chance to reclaim its world leading position, building new industries out of old ones, creating new jobs, and attracting international investment from major chemical manufacturers and chemical-using industries who want to access our capabilities.

At the same time, this industry will help address climate change and help us move away from an oil-based economy.

The chemicals industry relies on declining reserves of fossil fuels to make materials, many of which have harmful environmental impacts. The buyers of these chemicals – innovative manufacturers in clothing, automotive, aerospace, and packaging to name just a few – want new bio-based chemicals to replace oil-based ones. In some cases, this is about greening supply chains. In others, they want to develop products with new properties, such as biodegradable plastics.

The UK is well placed to benefit from this a growing global market for bio-based chemicals. We have leading biochemical R&D, relevant skills and infrastructure to build the industry, and established supply chains to chemical buyers at home and abroad.

But to ensure that we lead the disruption – rather than have our chemicals industry disrupted by other countries – we need to focus and play to our strengths.

This report identifies ten bio-based chemicals where the UK could focus resources for maximum impact. These all present a clear long-term business opportunity for the UK, driven by a real demand for sustainable chemicals, where the UK already has strong foundations, and where we have the business and research infrastructure to commercialise them. These ten bio-based chemicals are:

01 **LACTIC ACID:** Used to make PolyLactic Acid (PLA), which can form biodegradable plastics

02 **2,5-FURANDICARBOXYLIC ACID (FDCA):** Can be used to make polymers such as PEF, a stronger alternative to PET, which is a fibre used to make plastic bottles, food packaging and carpets

03 **LEVOGLUCOSENONE:** A safer alternative to harmful solvents used in pharmaceutical manufacturing, and also used in flavours and fragrances.

04 **5 HYDROXYMETHYL FURFURAL (HMF):** A versatile chemical with potential to replace chemicals used in plastics and polyesters, and for producing high energy biofuel

05 **MUCONIC ACID:** Derivatives could replace non-sustainable chemicals used in the production of PET and nylon fibres

06 **ITACONIC ACID:** A replacement for petroleum-based acrylic acid, used to make absorbent materials for nappies; and resins used in high-performance marine and automotive components

07 **1,3-BUTANEDIOL (1,3-BDO):** A building block for many high value products including pheromones, fragrances, insecticides, antibiotics and synthetic rubber

08 **GLUCARIC ACID:** Prevents deposits of limescale and dirt on fabric or dishes, providing a green replacement for phosphate-based detergents

09 **LEVULINIC ACID:** Used in the production of environmentally friendly herbicides, fruity flavour and fragrance ingredients, skin creams and degreasers

10 **N-BUTANOL:** Used in a wide range of polymers and plastics, as a solvent in a wide variety of chemical and textile processes and as a paint thinner

The approach draws on the concept of the hugely successful US report, *Top Value Added Chemicals from Biomass*, which was instrumental in bringing a number of chemicals to market. By identifying the most promising bio-based chemical opportunities for the UK, we hope to spur similar support from industrialists, academics and policymakers, which will stimulate innovation and bring competitive advantage to the UK, whilst creating a sustainable future for our chemicals industry.

BIO-BASED CHEMICALS FOR A SUSTAINABLE FUTURE

What are they and why do we need them?

Bio-based chemicals are obtained from plant- or animal-based feedstocks, including sugar, starch, oils and fats, and biomass from crops and organic waste. They are chemicals derived from carbon which has been recently taken out of the air.

In contrast, the chemical industry has traditionally obtained chemicals from materials dug out of the ground, liberating carbon that was sequestered millions of years ago. Most polymers, plastics, textiles, pharmaceuticals and cosmetics are largely derived from oil and gas.

Manufacturing products requires many chemical steps to turn raw materials – traditionally oil or gas - into useful chemicals, combine them, and scale them up to a commercial product.

Many of the chemicals involved in industrial processes can be produced from bio-based sources in a low-carbon, sustainable way. The emerging bio-based chemical industry will be driven by the growing need of companies – pushed by customers and regulators – to use sustainably produced chemicals.

Just as oil underpinned the development of now ubiquitous plastics, textiles, pharmaceuticals and cosmetics in the last century, bio-based chemicals could drive new common and specialist products in the next century from plastic packaging, to face creams to new medicines. Investment and policy support now will allow the UK to be a leader in this important emerging field.

THE INNOVATORS MAKING THE TOP TEN A COMMERCIAL REALITY

ITACONIC ACID
ITACONIX: UK SME CAPTURING MARKET SHARE

Chester-based Itaconix designs and manufactures bio-based ingredients, derived from itaconic acid. These are sold to personal care, homecare and industrial manufacturers, to be used in laundry and dishwasher powders and haircare.

The chemicals give customers in the cosmetics industry a unique opportunity to grow market share amongst buyers who value sustainability. In some cases, they also offer advantages over the petroleum-based chemicals they replace, reducing manufacturing costs and creating new product functionality.

Itaconix has a patented process for producing various bio-based products from itaconic acid. It already makes sales where sustainability or specific functionality provide competitive advantage. They expect such sales to grow with the sustainability agenda, which is driving major consumer product companies, including Unilever, P&G and L'Oreal, to improve product performance whilst replacing traditional ingredients with sustainable alternatives.

CEO Kevin Matthews says:

"The chemicals Itaconix seek to replace represent a multi-billion dollar market. But the challenge for bio-based chemicals is that we are competing with petrochemicals, an industry that has a century of development behind it.

Although in some areas we already come close to petrochemicals on cost, for now bio-based chemicals main selling point is sustainability and functionality. For the industry to really take off, we want to reach a point where bio-based chemicals also outperform petrochemicals on cost."

"I believe that is achievable in many cases, particularly for the chemicals highlighted in this report. Over time, oil prices will naturally rise, and biochemical production costs will go down."

"This could happen a lot quicker if incentives were put in place to help offset the advantage of scale that the petrochemical industry has over us. These could include investment in UK science to develop cost-effective ways to produce key chemicals and their derivativities, and to scale them up; and financial incentives for companies to build infrastructure, such as fermentation and processing plants."

Itaconix

Learn more at
http://itaconix.com

FDCA
BIOME BIOPLASTICS: BIODEGRADABLE PLASTICS FROM SUGARS

Biome Bioplastics is one of the UK's leading developers of natural plastics and aims to produce bioplastics that can ultimately replace oil-based polymers completely. In pursuit of this goal, the company is leading a significant R&D programme to source new organic chemicals for the manufacture of bioplastics that could significantly reduce costs, expand functionality and increase performance.

One avenue to achieving this has seen Biome Bioplastics work closely with academic partners to produce FDCA from natural sugars using enzymes in a bio-catalytic process. First, the bio-based chemical HMF is produced from a sugar dehydration process, then this is turned into FDCA by bio-oxidation. Finally, the FDCA is polymerised to produce a novel polyester co-polymer that are both bio-based and biodegradable.

Having demonstrated this technology at kilogram quantities, Biome Bioplastics is now scaling elements of this process up to tonne scale. It is planned that these new polymers can be used to produce biodegradable food packaging, particularly flexible film.

Since plastics recycling is not always possible, biodegradable plastics will be critical in achieving the government's goal of zero avoidable plastic waste by 2042.

LEVOGLUCOSENONE
CIRCA: INVESTING IN THE UK

Circa is using waste wood to produce levoglucosenone, a building block chemical which can be converted into a diverse range of industrial products, ranging from solvents and crop protection to flavour enhancers.

Founded in 2006 in Australia, Circa has developed and patented a process to produce levoglucosenone. It has recently built pilot and demonstration plants to produce it in commercial scale quantities, and is beginning to see industrial uptake.

Circa were introduced to Professor James Clark, a global authority on Green Chemistry, at the University of York, who suggested levoglucosenone could be easily converted into an industrial solvent. The two embarked upon a collaborative project in York which invented Cyrene™, a solvent with uses in a wide range of manufacturing processes, water filtration, batteries, and even graffiti removal.

Based on the success of this engagement, Circa took the strategic decision to establish a presence in the UK and recruit locally. This allowed it to focus it commercialisation of Cyrene in York, where it had access to world leading expertise and collaborators. This also gives it access to the EU market, where a big demand for green solvents is anticipated as new regulations phase out many existing solvents which are harmful to health.

Fabien Deswarte, Business Development Manager at Circa, says: *"The UK is a very attractive place for companies developing biochemicals, and there is a strong incentive for international companies to invest in developing teams and facilities here. The academic expertise and opportunities for collaborations to advance biochemicals is world class. The UK government's focus on bringing together industry and academia means many academics have strong links to industry and can help make vital introductions. There is a whole system in place here which serves small innovative biochemicals companies like ours very well."*

biome bioplastics

Learn more at
http://biomebioplastics.com

circa

Learn more at
http://www.circagroup.com.au

THE TOP TEN

Through extensive consultation with industry, LBNet has identified 10 chemicals which the UK is in a strong position to develop and commercialise. These were agreed through multiple workshops with experts representing the chemicals industry, biotech startups, academia, government, biotechnology consultants and BBSRC.

The chosen bio-based chemicals were agreed based on: commercial viability, UK strengths to exploit (including research to date, skills, feedstock availability), functionality and sustainability.

The UK's strengths were considered. For example, the UK will struggle to compete with cheaper countries on large scale manufacturing, but its high skill levels present opportunities to manufacture high value bio-based chemicals, to create large volume chemicals which can be licenced for production elsewhere, and to sell UK expertise and consultancy around the world.

Originally, 30 potential high value chemicals were identified by the December 2017 report '*UK Top Bio-based Chemicals Opportunities*', from which a final list of ten were identified, and are presented here.

01

LACTIC ACID

Lactic acid can be used in the production of biodegradable polyesters. These could replace many plastics used in packaging, automotive parts, and textile fibres, allowing products to biodegrade instead of going to landfill. The biodegradability also has high value applications in casing for medicines or medical screws which remain in the body after surgery.

Lactic acid also has uses in food flavouring, detergents and pharmaceutical production. Lactic acid can be produced by fermentation of sugar or starch.

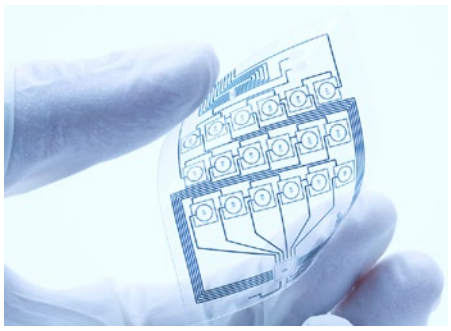
02

2,5-FURANDICARBOXYLIC ACID (FDCA)

FDCA, as a building block for PEF, can offer a sustainable alternative to PET, a non-biodegradable chemical widely used for plastic bottles and food packaging, as well as in carpets, electronic materials and automotive applications.

The UK has academic and commercial activities relating to producing FDCA and developing biodegradable plastics. Leading players include Biome Bioplastics, the Universities of Liverpool, Aston University, University of York, University of Manchester, and Imperial College London.

03



LEVOGLUCOSENONE

Levoglucosenone can be used as a safer and greener alternative to harmful solvents used in pharmaceutical manufacturing. Its derivatives can be used to create flavours and fragrances. It can also be used to create commodity chemicals used to add hardness and flexibility to polyesters.

It is a very high value ingredient obtained from cellulose. Few companies are developing levoglucosenone, and the UK is in a good position to commercialise production. Australian company Circa, which has developed a continuous process to make levoglucosenone from biorefinery waste, is investing in the UK to take advantage of our leading research capabilities.

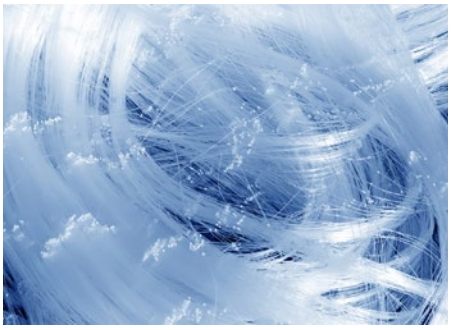
04

5 HYDROXYMETHYL FURFURAL (HMF)

HMF is a versatile chemical which can be converted into many useful compounds which could replace oil-derived polymers, whilst improving durability of products. One such compound (2,5-furandicarboxylic acid) could replace chemicals used in plastics and polyesters. Another (DMF), holds potential as a high energy content biofuel. Others have applications in elastomer, adhesive and coating applications.

Few companies are currently working on HMF globally. The UK has strong research capabilities in HMF, particularly at Imperial College London and the University of Liverpool, and could easily take the global lead.

05



MUCONIC ACID

Muconic acid can be converted to a variety of chemicals and polymers (e.g. caprolactam, terephthalic acid and adipic acid) which could replace non-sustainable benzene and cyclohexane currently used in the production of PET and nylon fibres. These derivatives represent a market of more than US$22 billion, driven partly by growing global demand for nylon in textiles, carpets, and automotive.

Deinove, Myriant, and Amyris have been pursuing bio-based production of muconic acid and conversion to adiptic acid, with many processes demonstrated at lab scale. Well established synthetic biology and polymer science capabilities in UK universities and industry put the UK in a strong position for muconic acid technology development.

06

ITACONIC ACID

Itaconic acid could replace petroleum-based acrylic acid: used in the production of superabsorbent polymers (SAP), which are used to make nappies and personal care products; and unsaturated polyester resins (UPR), used in pipes, gratings and high-performance marine and automotive components.

Its current market is small, but it has potential to tap into a market in excess of £10 billion. UK based Itaconix is one of the leading companies in the development of bio-based polymers from itaconic acid, whilst pioneering R&D work is being carried out at the universities of Nottingham and York. Although several large companies are developing itaconic acid, the technology is at an early stage, leaving room for other innovators to capture share of a growing market.

07

1,3-BUTANEDIOL (1,3-BDO)

1,3-Butanediol (1,3-BDO) is a building block for high value products such as: pheromones, fragrances, insecticides, antibiotics. Conversion to chemicals used in synthetic rubber and specialist resins could open huge market opportunities, with growth expected to be at least 2% per year in the near term. There is growing interest in developing a fermentation route for this chiral chemical in the specific R-form and one that can compete with the relatively high cost of the petrochemical equivalent.

The UK has strong academic expertise and good supply chains for production and sale of 1,3-BDO. UK based CHAIN Biotechnology has developed and patented a Clostridium based technology for fermentation of sugars to produce (R) 1,3-BDO, and plans to develop manufacturing capacity in the UK to serve a growing demand for (R) 1,3-BDO in a ketone ester nutritional product.

08

GLUCARIC ACID

Glucaric acid has many potential applications, both as a building block and in end products. The most important is in detergents, where it prevents deposits of limescale and dirt on fabric or dishes. It could replace phosphate based detergent chemicals, over 4.5 million tonnes of which are sold annually, which are being phased out due to environmental concerns.

Other applications include food ingredients, concrete plasticizers, and corrosion inhibitors. Glucaric acid can be converted into adipic acid which can be used to produce nylon and similar products, potentially accessing a multi-billion pound market.

Glucaric acid can be produced from glucose, but technology has not been scaled to industrial volumes. Several companies are looking into improving production including Rennovia, Johnson Matthey (a UK catalysis powerhouse), Rivertop Renewables and Cargill.

09

LEVULINIC ACID

Levulinic acid can be reacted with other chemicals to produce multiple useful products. These include environmentally friendly herbicides, fruity flavour and fragrance ingredients, a replacement for oil-derived plasticisers (which promote plasticity in synthetic materials), a highly safe solvent for chemical processes, an aid to formulating skin creams, a degreasing chemical, and for diagnosis and treatment of cancer (using photodynamic therapy).

Levulinic acid can be produced from starch or certain sugars. The global market is relatively small, anticipated to reach $19.65 million revenue by 2020. It is attracting interest from chemical companies as a green solvent. Although early days, it is believed there are a number of high value applications which will be tapped by further R&D, which could also be an opportunity for new applications and new players to enter this space.

Biofine, DSM, Segetis, GFBiochemicals are involved in bio-based developments of levulinic acid technology and GFBiochemicals started commercial production of levulinic acid in Italy. Aston University is researching levulinic acid.

10

N-BUTANOL

n-Butanol is used in a wide range of polymers and plastics, and as a solvent in a wide variety of chemical and textile processes. n-Butanol can be produced by fermentation of carbohydrates using Clostridia bacteria. UK based Green Biologics has developed an advanced fermentation process for n-butanol and acetone. Today the company maintains a research base in the UK and operates a commercial fermentation plant in Minnesota, US targeting a range of performance-based markets and applications. For example Green Biologics first “own branded” product is Greenflame™, is a superior naturally formulated lighter fluid that gives clean-burning performance.

The n-butanol market is large, estimated at about 3 million tonnes per year, and likely to grow significantly due to increasing demand for specialty coatings, personal care, food, pharma, nutraceuticals, consumer fuels, and plastics. The UK has a strong academic base and several companies with expertise in the butanol fermentation and is therefore well positioned to take the lead in further development and commercialisation.

HOW TO DELIVER VALUE FROM THE UK'S EARLY LEAD

For now, most of the UK's activities are early stage. Moving from research and lab-scale tests to commercial products is an area where the UK traditionally falls down. To ensure we harness this opportunity, we urge government and business to take the following steps:

FOCUS: This list has been compiled by experts to represent the gold standard in opportunities for the UK's chemical industry. It should be seen as the starting point for focusing resources on exploiting value from these specific bio-based chemicals. Investing in these areas will lead to direct short-term advantage, whilst creating the infrastructure and networks to allow other early stage chemicals to develop successfully.

INCREASED SUPPORT FOR ACADEMIC-BUSINESS COLLABORATIONS: Good partnerships and interactions between SMEs and universities are developing in the UK's bio-based sector, and these are critical in moving chemicals from the lab into manufacturing processes. Existing networks which facilitate these relationships should continue to be supported by government, industry and academia, particularly through BBSRC and EPSRC.

SUPPORT UK SCIENCE CAPABILITY: Research funding focussed on developing cost-effective ways to produce these chemicals and their derivativities, and on ways to scale them up to commercial products, will underpin viable commercial models.

BUILD UK SCALE UP AND TESTING CAPABILITIES: UK companies need technology testing and scale up services, and open access piloting and demonstration facilities. Technology advances in feedstock pre-treatment and the supply of low cost renewable sugars will also be an important enabler for the development of bio-based chemicals. There needs to be further investment in developing easy to access test and scale up facilities for researchers and startups.

INCENTIVISE USE OF BIO-BASED MATERIALS: Policy support should incentivise the development and use of bio-based chemicals to accelerate market uptake. For example, policy could incentivise use of degradable materials or consumer plastics applications. In January 2017 France mandated use of compostable materials for single-use supermarket bags and food packaging, leading to growth in its biomaterials industry. The UK should investigate and implement similar policies designed to promote the bio-based chemicals listed in this report.

Such investment and support for the bio-based chemicals sector would contribute to the sustainable growth of the UK's chemical industry and potentially generate significant value to the UK economy. Growth of the UK's chemical industry by a few percentage points could generate hundreds of millions of pounds in gross added value and thousands of jobs.

ABOUT LBNET

The Lignocellulosic Biorefinery Network (LBNet) is a government-funded body tasked with fostering cross-disciplinary communities in the industrial biotechnology sector. It is an active community of industrial practitioners and leading academics generating economic value by developing novel chemicals, materials and fuels that use lignocellulosic biomass as an alternative to petroleum-derived inputs.

The LBNet is one of 13 collaborative Networks in Industrial Biotechnology and Bioenergy set up by the Biotechnology and Biological Sciences Research Council (BBSRC NIBB) to boost interaction between academia and industry, and promote the translation of that research into benefits for the UK. For more information, visit **www.lb-net.net**

To see the report *UK Top Bio-based Chemicals Opportunities*, commissioned by the Lignocellulosic Biorefinery Network (LBNet), on which these highlights are based, visit **http://bit.ly/topbiobased**

For more information, and to keep up to date with UKBioChem10's progress, please contact Veronica Ongaro, LBNet Manager, at **veronica.ongaro@york.ac.uk**

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