SSAC Technical Briefing Note[1]

Sustainable Chemicals[2] - June 2021

Summary

It is timely to consider how Scotland can transition its existing excellent chemicals manufacture base to sustainable feedstocks. Scotland has enviable natural and agricultural resources, although such resources are being competed for by other sectors - particularly in energy. Tactical decisions are needed to map these outcomes and develop them appropriately and strategically, rather than allow this sector to develop organically and at slow place, which is wasteful of financial and human resources. Upskilling and reskilling of the workforce will be important in this transition, while the skills gained may also be transferred to other sectors.

Recommendations/Actions

1) Increased demand for renewable chemicals feedstocks (to replace needs currently met by petrochemicals[3]) has the potential to compete for natural resources with the food and drink, hydrogen, renewable electricity and biomass sectors; the specific demands on natural resourcse need to be quantified and priorities resolved.

2) Where competing demands have been identified (e.g. between renewable chemicals and hydrogen/ sustainable metals / minerals) these need to be transparently acknowledged by each sector.

3) Use the Table to identify areas where more work is needed to refine the renewable chemicals proposition.

4) Using the Table, discuss with renewables sectors a priority of pathfinder activities needed to advance appropriate options.

5) Consider new ways to strengthen the interface between industry, academia and government (previously carried out by Chemical Sciences Scotland), that could play a pivotal role in transition of the renewable chemicals sector.

6) Resource mapping tools have been developed by Scottish Enterprise, Zero Waste Scotland and IBioIC. Refresh and update these to maintain an agile profile of the potential of the sector.

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[1] *A non-exhaustive, non-prioritised set of suggestions and opportunities to exploit sustainable chemicals' manufacture for societal and economic benefits.*

[2] *While* 'chemicals' *can be considered as a continuum including materials such as hydrogen, sustainable metals and minerals, this note focusses on manufacture from renewable feedstocks that can be sourced in Scotland.*

[3] https://www.icis.com/explore/resources/icis-petrochemicals-flowchart/

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The background

Chemical Sciences is a major contributor to the Scottish economy, with ambitious plans for further growth. In 2020[4], its 235 companies delivered 12% of all Scottish manufacturing – with at least £4.4 Bn destined for export (17% of all Scottish exports). The sector supports more than 11,750 direct jobs with 70,000 associated jobs. Its R&D is ranked consistently in the top three in the world.

Currently, our chemicals industry is dependent substantially on raw materials from fossil fuels - principally oil and gas. This explains why much of our industry is nucleated around the petrochemical facilities at Grangemouth. However, 'climate change' and 'climate emergency' are now high profile contemporary concerns. Policies such as the Scottish Government's commitment to net-zero greenhouse gas emissions by 2045 have reinforced the need for reduction of carbon dioxide emissions and carbon capture during chemicals manufacture, and in recognition of the primary locus for petrochemicals have established a Grangemouth Future Industry Board [5]. Scotland's 'Just Transition' Commission, which reported in March 2021 [6], rightly places decarbonisation as a central focus.

In addition, market forces are now also driving sustainability. For example, Unilever has declared a target to remove materials derived from fossil fuels from its cleaning products portfolio by 2030 – part of its overall ambitious 'green' strategy[7]. INEOS has developed a 'bio-attributed' PVC (oil derived from wood pulping for the paper industry) for use in the construction industry[8]. Both examples demonstrate that the market place is ready for bio-based chemicals.

The major and essential component of most chemicals is the element Carbon: 70% (by volume) of chemicals manufactured are composed predominantly of carbon. Hence, this Briefing Note focusses primarily on renewable carbon feedstocks. Decreased extraction and production of fossil fuel will require the chemical industry to find replacement sources for the carbon needed, i.e. to use renewable feedstocks. Our plants and many microbes can supply this.

The disruption caused by the COVID-19 pandemic has reinforced the need for resilience in chemicals manufacturing and localised sourcing of its raw materials. We need to 'onshore' more of our critical manufacturing and Scotland has an abundance of potential renewable feedstocks. The challenge will be to scale up their availability in an appropriate, economically-viable form.

4 https://www.sdi.co.uk/key-sectors/chemical-sciences
5 https://www.theccc.org.uk/publication/reducing-emissions-in-scotland-2020-progress-report-to-parliament/
6 https://www.gov.scot/publications/transition-commission-national-mission-fairer-greener-scotland/
7 https://www.unilever.com/brands/home-care/clean-future.html
8 https://www.biovyn.co.uk/

The opportunity

Industrial Biotechnology (IB) is a disruptive technology. It exploits recent advances in biology to develop new products and processes, with novel properties, that use enzymes or cellular systems in their manufacture. IB can provide '*clean, green*' biological routes to chemical synthesis, instead of the classical chemical processes - which are energy-intensive and often adverse to the environment. IB can broaden the portfolio of feedstocks for the chemicals industry away from traditional fossil fuels to include renewable resources or waste streams (preferred term 'co-products') from other processes.

Scotland is in an enviable position to exploit the opportunity of IB in the context of sustainable chemicals due to:

- its mature, well-developed, well-integrated chemicals sector
- its excellent academic base that has considerable expertise in IB, particularly synthetic biology
- its natural resources, and potential for innovation in biomass production
- the Scottish based Innovation Centre in Industrial Biotechnology (IBioIC), which is supporting the indigenous and international IB industry to harness Scottish Universities' capability to deliver innovative solutions[9]

9 www.ibioic.com

What are the options for sustainable feedstocks to replace fossil fuel sources?

(NB these are illustrative and not exhaustive to provide a starting point for considering issues including overlaps with other sectors)

A. Feedstock option	B. Pros	C. Cons	D. Competing markets	E. Other issues & 'unknowns'
1. Plants, e.g. sugar beet grown on arable land to convert to bioethanol	For example, sugarbeet is suited to the Scottish climate[10]	Concerns about competition with other crops for food production, noting thatbeet, like oilseed rape, is a rotational 'break' crop that restores soil health	Refining sugar beet for human consumption	Likely requirement of 20,000ha of arable land of class 3.1 or better, within a 30 to 60 mile radius of the refinery plant to meet demand for bioethanol for E10 petrol
2. Extract value from wastes and co-products using microbes	IBioIC's 'Biorefinery Roadmap for Scotland'[11] focuses on six key Scottish resources: whisky co-products; municipal solid wastes & food processing wastes;biomass from agriculture;biomass from forestry' biomass from marine; and carbon dioxide[12] (Wastewater could be an additional resource worth considering)	For such streams, much of the technology for the production of chemicals, at scale, is still in early development	Some of the co-products already have value, for example as animal feed - although regulations post-BSE currently limit some of this	Scale of production is limited by the scale of the wastestream, unless it is transported to a central location. Work needs to be done to define the techno-economics of using such co-products at scale

10 https://www.farmersguide.co.uk/sugar-beet-to-return-to-scotland-after-50-years/

11 https://www.ibioic.com/publications-database/biorefinery-roadmap-for-scotland, due to be refreshed in 2022

12 https://www.zerowastescotland.org.uk/sites/default/files/ZWS645%20Beer%20Whisky%20Fish%20Report_0.pdf

3. Products from woody biomass waste (if not included in #2)	85% of Scotland's land is classed as unsuitable for arable crops but it produces substantial biomass (e.g. trees)[13]	The carbon in the biomass is present as cellulose and lignin which need to be broken down physically or enzymatically before they become useful feedstocks. Infrastructure required to valorise cellulose and lignin, and process can be energy intensive.	Harvesting biomass for use as a bioenergy source is currently more attractive economically than for feedstock[14]	Economically, might be better to plant different, faster-growing tree species. However need to consider the impact of different species on our ecosystems.
4. Products from seaweed, an alga that fixes carbon dioxide	Scotland's abundant coastline supports growth of indigenous seaweeds that could be a source of speciality chemicals (e.g. cosmetic and food additives), with the residue turned over to sustainable feedstock.	There has to be a careful balance between preserving and exploiting such an environment. Currently there is a ban on commercial harvesting of wild seaweed, under review[15]	Pharmaceutical products, high end food supplements and animal feed supplements.	Cultivation of seaweed in newly-created 'farms' is a proposition that is gaining momentum[16], and an alternative to harvesting indigenous seaweed

13 https://forestry.gov.scot/
14 https://www.climatexchange.org.uk/media/3609/the-potential-contribution-of-bioenergy-to-scotland-s-energy-system.pdf
15 https://www.gov.scot/publications/seaweed-review-steering-group-scope-of-review/
16 https://www.communitiesforseas.scot/seaweed-cultivation-in-scotland/

5. Carbon dioxide and hydrogen directly, using microbes	Microbes can combine Carbon dioxide with hydrogen to produce the organic carbon needed by the chemicals industry	A non biological route using cobalt phthalocyanine catalyst[17] has been identified but not yet commercialised	Hydrogen can also be used as a fuel and for heating, so competition for this feedstock	Scottish Government published a Policy Statement on Hydrogen in December 2020[18]
6. Methane, using microbes	Microbes can generate biofuels from landfill methane	New infrastructure required	Methane used as energy source for heating, so competition for this feedstock	Technoeconomics of biofuel production versus burning methane for heat is needed to inform policy

17 https://doi.org/10.1038/d41586-019-03563-8
18 https://www.gov.scot/publications/scottish-government-hydrogen-policy-statement/

Ways Forward

Conversion of sustainable feedstocks

Irrespective of the feedstock source in the table above, the next step in the innovation pipeline is to consider how a microbe can be programmed, or an enzyme used, with that feedstock to make a metabolic intermediate that can then be used directly as a chemical building block. This aspect, often termed 'metabolic engineering'and a subset of 'engineering biology'[19], has inputs from synthetic biology and microbial physiology – both of which have considerable strengths in the Scottish academic and SME sectors – and are cornerstones of industrial biotechnology.

How might this develop?

The science

There is a ubiquitous metabolic pathway in microbes, through which most sugar feedstocks are degraded. Yeast is the classic example, and the basis of alcoholic drinks production. However other microbes can use this pathway as an entry point to make more exotic products. For example, the 'ethanol pathway' can be elaborated further to produce biobutanol – a biofuel with physical chemical properties more akin to fossil-derived petroleum than bioethanol, which can also be used as a sustainable form of jet fuel. Understanding how to make bioethanol efficiently paved the way for proof of concept for biobutanol. This model is now a good platform on which to design microbes or modify enzymes to make more complex chemical building blocks and commodity chemicals.

Through synthetic biology, it is now possible to optimise metabolic pathways within a micro-organism to overproduce a particular metabolite through modifying its biology, thus closing the circle from renewable feedstock to sustainable chemical building block.

Mapping an innovation pipeline for sustainable chemicals

The large portfolio of chemicals derived from fossil fuel comes from a relatively small number of chemical building blocks. For example ethylene is currently produced by refining and 'cracking' of oil, and then treatment in various ways to produce plastics in bulk (such as polyethylene, polyvinyl chloride (PVC), polystyrene) and other speciality chemicals. In 2015, recognising that the North Sea oil supply was finite, Scotland agreed to import 'fracked' ethane from the USA to the INEOS plant at Grangemouth[20] in a 15-year contract. This ethane, converted to ethylene, is spawning a new chemical business cluster that can use this secondary feedstock 'over the fence' from INEOS to develop new processes. Scotland thus already has an active, creative ecosystem that is receptive and attuned to developing novel processes.

However, ethane from fracking is still fossil-derived and the Biden administration is less keen on fracking, which may limit ethylene supply in the 2030s. In the interim there is an opportunity to take advantage of the momentum gained with this fossil source to begin to stepwise migrate the manufacture of our chemicals to sustainable feedstocks.

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19 https://www.raeng.org.uk/publications/reports/engineering-biology-a-priority-for-growth

20 https://www.ineos.com/news/ineos-group/ineos-raises-the-roof-on-europes-biggest-ethane-tank-at-grangemouth-in-scotland

Currently Scotland has a poorly-developed industrial bioethanol sector, despite considerable demand for bioethanol which we currently import from abroad. Petrol contains 5% bioethanol (‘E5’) but legislation will move to ‘E10’ (10%) in September 2021 – representing an eventual increase in current demand from 57 M litres to 145 M litres bioethanol[21]. Thus, a Scottish-grown sustainable feedstock could be used as an economic driver to kick-start this entire renewable chemicals sector where there is clear demand – assuring fuel security onshore.

With a route to bioethanol established, expansion of the renewable chemicals portfolio via biobutanol and other speciality chemicals would follow. The geographic focus of chemical production in Scotland enables this and makes it timely now to take one step further and explore the manufacture of such chemicals from sustainable feedstocks.

Training a workforce to enable the new era of sustainable chemical synthesis

Whereas the traditional petrochemical industry is underpinned by the disciplines of chemistry and chemical engineering, these skills need to be augmented with inputs from biology including biochemistry, microbial physiology, synthetic biology, DNA and RNA technologies, data acquisition and mining and biochemical engineering. The university and college sector in Scotland is well placed to deliver such a workforce and retrain existing personnel. The skills are highly transferrable and equally applicable to other growth areas, such as vaccines, therapeutic proteins and diagnostics production. The Scottish Government is already investing in this retraining, amongst which the National Manufacturing Institute for Scotland[22] and the Future Skills Partnership Opportunity North East in Aberdeen[23], that can catalyse this transition.

21 https://www.nnfcc.co.uk/publications/report-sugar-beet-scotland

22 https://nmis.scot/

23 https://www.opportunitynortheast.com/news/2021/future-skills-partnership-launched-to-enhance-digital-skills