The organic waste gold rush: optimising resource recovery in the UK bioeconomy

Resource productivity in the UK bioeconomy requires integrated technologies and strategies in which wastes from one sector become a resource for another. This policy note highlights emerging technologies designed to maximise resource recovery from organic wastes and the policy interventions that are needed to promote a circular bioeconomy.

Overarching recommendation

The use of organic waste in the bioeconomy has the potential to contribute towards the UK's strategic goals of clean growth, resource security and reducing use of fossil fuels. To deliver this, the government should adopt a whole-system and inter-departmental approach to maximise benefits across environmental, social and economic domains. Policy and regulations should encourage industrial synergies and an increase in the diversity of resources recovered from organic waste in order to be able to respond to future resource demands.

Resource recovery for a sustainable bioeconomy

- The bioeconomy refers to the use of renewable biological resources to replace fossil resources in products, processes and services[1]. This includes: nutrients to substitute conventional inorganic fertilisers, organic precursors of chemicals currently synthesised from fossil fuels (such as plastics and pharmaceuticals), and biofuels (such as hydrogen and natural gas).

- The use of organic wastes as a resource to fuel the bioeconomy can contribute towards ensuring that the transition from fossil to bio-based resources is sustainable. Residues and waste waters from the bioeconomy industry also contain potentially useful organic and chemical resources which could be better exploited.

- The greatest environmental, social and economic benefits of resource recovery from organic wastes are associated with the displacement of fossil fuel derived chemicals and materials[2], and the combined products of nutrients and energy from anaerobic digestion[3].

- Organic wastes offer multiple resources that can be exploited most efficiently by technologies working in synergy with each other. In order to develop cascades of organic waste resource throughout the bioeconomy, industrial symbiosis between waste producers, bioeconomy technologies and end markets should be promoted.

- Policies, regulation and taxation should incentivise resource recovery approaches that maximise system wide benefits across multiple domains, including economic, environmental, social and technical value. This requires understanding the complexity of the current and future resource requirements, and the potential for emerging technologies to contribute to maximising resource recovery.

- Policies and regulations should align across departments in order to deliver the overarching strategic aims of the UK government. These include pledges set out in the BEIS 'Clean Growth' strategy[4] and Defra's '25 year plan for the environment'[5], and commitments made to the international community for clean growth and sustainable resource use.

The organic waste hierarchy

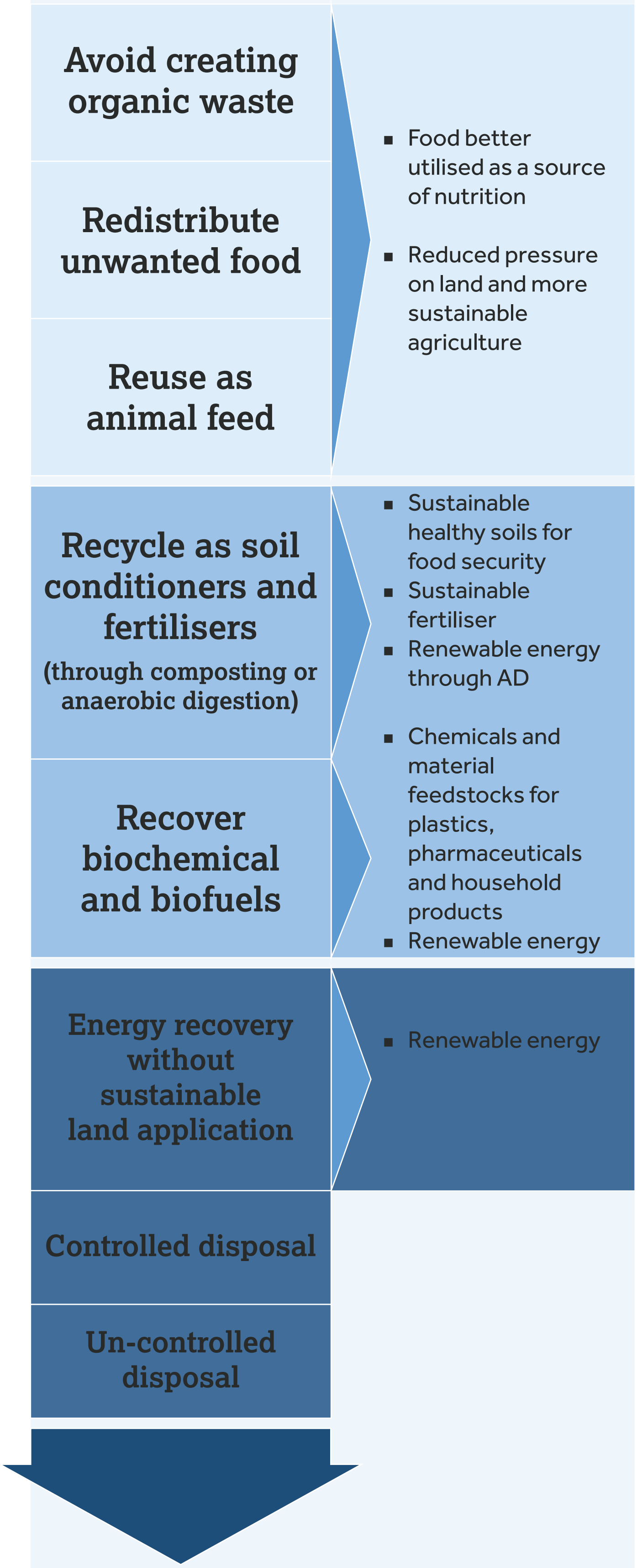

Figure 1: The organic waste hierarchy highlighting the benefits offered at each level.

The importance of organic wastes in the bioeconomy

- The bioeconomy could provide an alternative and renewable source of chemicals and materials currently manufactured from fossil fuels (including plastics, pharmaceuticals and household chemicals), along with the generation of renewable energy[1]. Reduced reliance on fossil fuels can contribute towards the UK's clean growth objectives and resource security, along with reducing the need to exploit fossil fuel reserves that have high economic, environmental and societal costs.

- The importance of the bioeconomy is reflected in the Industrial Strategy[6] and the ongoing development of a strategy to grow the UK bioeconomy[7]. These strategies need to be balanced with ensuring that growth in the bioeconomy does not exert unsustainable pressures on land, particularly for food production and natural capital provided by the environment[8]. In order to achieve a sustainable bioeconomy the use of organic resources must be optimised: from food to feed to nutrients, chemicals, materials and then energy (Figure 1).

- Organic wastes can provide a significant feedstock for the UK bioeconomy. While the reduction of avoidable organic waste is a priority, a number of waste streams are likely to persist. In the UK, these include industrial and domestic food waste, residues from agriculture, forestry and gardens[8] and organic waste streams from sewage, municipal solid waste and industrial processes[9].

- Investments into different options for using organic wastes are driven by government policy and resource demand, in addition to technology readiness. Policies should look to promote recovery pathways that maximise environmental, social and economic benefits. These include the production of chemicals and materials currently obtained from fossil fuels[2] and the combined products of nutrients and energy from anaerobic digestion[3].

Resource Recovery from Waste programme

'Resource Recovery from Waste' (RRfW) is a research programme funded by the Natural Environment Research Council, Economic and Social Research Council and Defra. It envisions a circular economy in which waste and resource management contribute to clean growth, human well-being and a resilient environment.

The programme has worked to develop a range of technologies and approaches to maximise the value obtained from organic wastes.

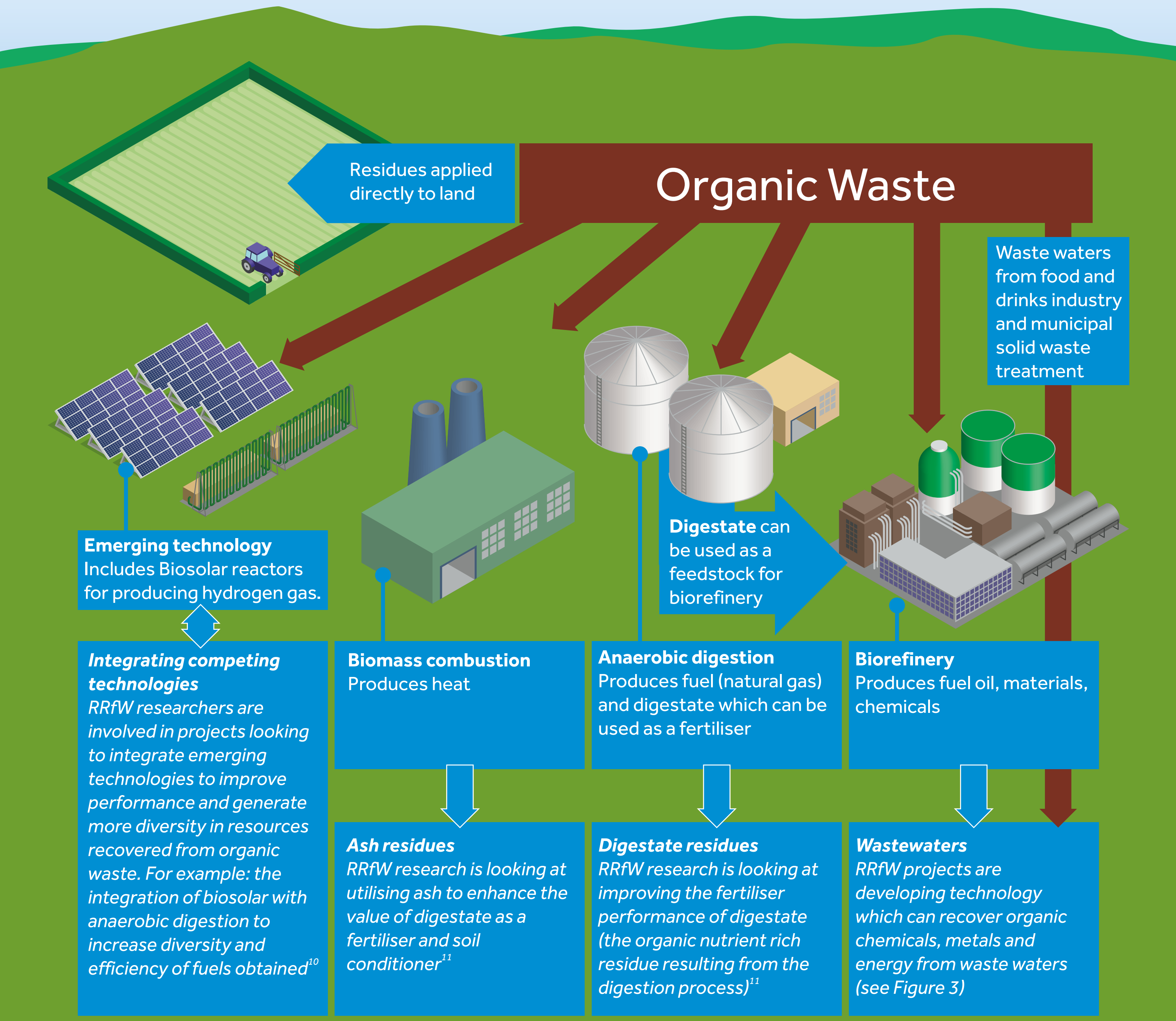

Figure 2: This figure presents some (but by no means all) of the bioeconomy technologies with potential to use organic waste. These processes in themselves create waste, which can be feedstocks for other processes or present a further opportunity for resource recovery. This figure highlights the areas where the RRfW programme is working to maximise the value obtained from organic wastes.

Making the most of organic wastes

Optimising the mix of resource recovery options

- How organic wastes are used is a complex question; there are multiple, often competing, demands for resources from biomass (Figure 2) . These include production of fuels, power, materials, chemicals and nutrients. Resource demands are constantly evolving as new technologies emerge and industrial processes are decarbonised. For example, hydrogen is a critical feedstock in a number of industries and demand is likely to grow due to its expanding use as a fuel[12]. Current hydrogen production relies heavily on fossil fuels but the generation of biohydrogen from organic wastes and wastewaters is a potential route for decarbonising the resource. Innovation in this area has been hindered as organic waste has become locked into established technologies; however, potential routes for integrating emerging technology into existing infrastructure are available[10]. Investment in a diversity of resource recovery options should be encouraged in order to promote a sustainable and responsive circular bioeconomy.

- Integrated biorefineries provide the opportunity to optimise production of resources including biofuels, chemicals and materials. Prioritising high value, low volume products (i.e. food and pharmaceutical ingredients > chemical > material > biofuel > energy) in integrated biorefineries provides opportunities for economic independence (analogical to crude oil refinery and petrochemical industries)[13]. Only ~5% (by mass) recovery of high value low volume product along with recovery of bulk product from organic wastes could enhance the triple-bottom-line (economic, environmental and social) sustainability of the industrial process[13,14]. The TESARREC™ software (developed in the RRfW programme) uses a 'Life Cycle Sustainability Assessment' approach to evaluate the triple-bottom-line of processes and products.

- Models that can process the complexity of resource flows and the interconnections between different domains of value (economic, social, environmental and technical) can inform and support decision making in resource recovery. The RRfW programme has developed a modelling framework "CVORR" which looks to optimise value created across these multiple domains whilst accounting for resource use and flows within a complex system [15,16]. Models such as "CVORR" will be valuable for informing future resource and waste use in the bioeconomy.

Making the most of organic wastes

Recovering organic resources from waste water

- There are increasing volumes of industrial waste waters which contain a complex but dilute mix of organic components and metals. These waste streams include those from food and drink processing, biorefineries, municipal solid waste and sewage treatment.

- Technologies such as bio-electrochemical systems offer the potential for remediation and simultaneous recovery of elemental, inorganic and organic resources present at low concentrations in waste streams[18] (Figure 3) . Whilst many of these systems are currently in the lower levels of technology readiness, they have the potential to be integrated into existing waste and bioeconomy infrastructure.

- Regulation controlling pollutant and contaminant levels in residual waste streams can be used to drive innovation in technologies for resource recovery. Such regulation offers environmental and economic win-wins in terms of decontamination of water and organic waste whilst obtaining valuable resources, such as metals, chemicals and energy in the process[19].

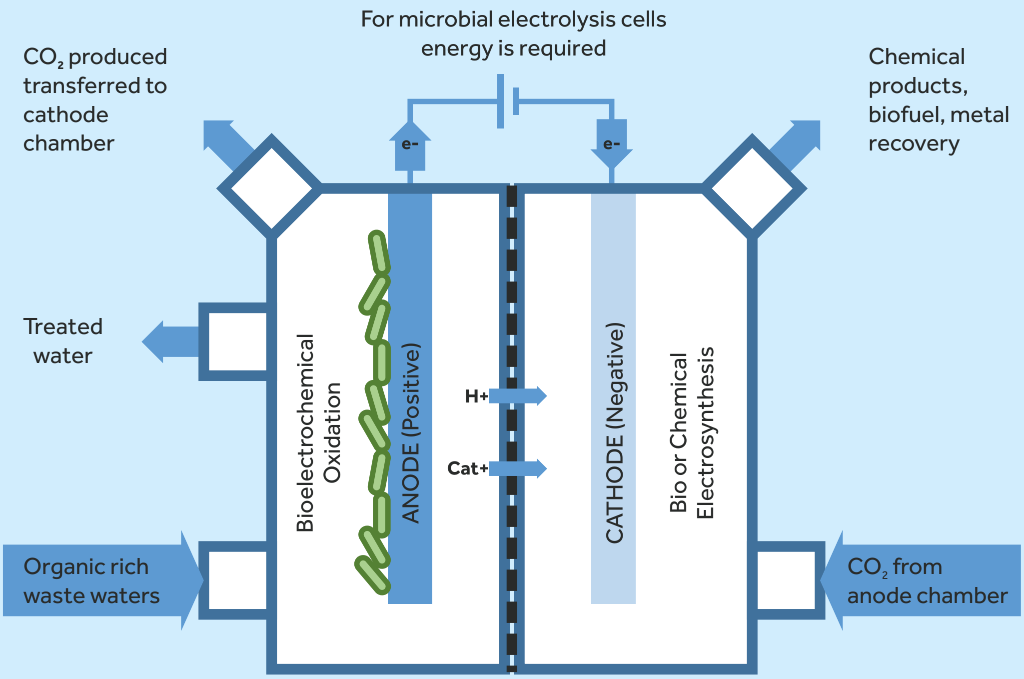

Figure 3: Overview of a microbial electrolysis cell in which an external voltage drives the formation of high value products and fuels from organic wastes. The resources recovered depend upon the configuration of the cell and the waste materials used. Whilst these cells require an external power source they can be linked to other forms of renewable energy as an option for transforming solar or wind energy into potential energy in the form of gas and fuels. Adapted from Shemfe et al[17].

Optimising organic resource recovery for sustainable land use

- Anaerobic digestion (AD) produces heat and natural gas, stabilises organic matter and enhances nutrient availability in the remaining organic matter (digestate). This nutrient-rich digestate is an effective agricultural fertiliser[20], reducing reliance on energy intensive conventional fertilisers, and recycling nutrients and organic matter back into the soil.

- The growth of the UK AD industry has primarily been driven by policy objectives focused on delivering increases in renewable energy generation (the Renewable Heat Incentive and Feed-In Tariffs) while reducing landfilling of biodegradable wastes (Landfill Tax and EU Landfill Directive). In order to capitalise on the multi-dimensional value of AD, the co-benefits of heat, gas and fertiliser production should be incorporated into one business model, with policy incentives for both energy and fertiliser products[11].

- In order to develop the market for fertilisers derived from waste streams, regulatory and commercial challenges need to be overcome. Proposed revisions to the EU fertiliser regulations[21] offer potential for the development of an EU wide market for bio-based fertilisers. These revisions will level the market opportunities for alternative fertilisers from organic materials including digestate. There is potential for these to be extended to other waste streams including ash, struvite from wastewater treatment and biochar[22]. This revised directive embodies a shift to a more flexible regulatory mind-set which values the nutrient and additional agronomic value in waste materials, whilst still maintaining environmental protection. The UK government should engage with this process and ensure that regulation of waste materials is designed with a circular economy in mind post-Brexit.

- Incentivising farmers to use digestate and compost in place of conventional fertilisers could stimulate the UK market for alternative organic derived fertilisers in agriculture. This could be supported by joined up, cross-departmental policy as benefits from such incentives will contribute to strategies within both Defra (agriculture, resources and waste) and BEIS (clean growth, bioeconomy).

What does this mean for policy?

- **Long-term policy direction is important for guiding future innovation and infrastructure investments, however, decision-making should also be informed by the future strategic resource needs of the UK.** There is competition between different technologies for access to organic waste streams, which is likely to grow as positive steps are taken to reduce food waste. Policy should look to incentivise diversity in the mix of resources obtained from organic wastes, using the waste hierarchy as a guiding principal.

- **Many government departments currently focus on financial cost-benefit approaches or on one environmental parameter (e.g. carbon emissions) in decision-making[23]. This needs to be adapted to account for new modelling approaches that integrate a range of metrics across social, environmental, economic and technical domains.** Utilising modelling approaches incorporating these multiple values, and interactions between them, will provide a more comprehensive assessment of the impacts associated with resource and waste management decisions in the bioeconomy.

- **The government should fund a comprehensive programme of business support to disseminate essential knowledge and skills to companies throughout the UK and promote industrial symbiosis.** Future bioeconomy and waste infrastructure needs to be adaptable to emerging technologies in order to maximise on the opportunities for high value resource recovery from organic wastes. Industrial symbiosis networks could promote the integration of complementary systems and sharing of biowastes from one industrial process that are valuable feedstocks for another recovery process. Formal governance of such networks has been shown to strengthen knowledge transfer and resource flows between organisations[24].

- **There is a need to have joined up, cross-departmental policy in resource use to promote circular economy practices across Defra (agriculture, resources and waste) and BEIS (bioeconomy, energy and climate change).** Ensuring that policies, regulations and incentives align across departments will help work towards the overarching strategic aims of the UK government, and the international community, for clean growth and sustainable resource use.

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This policy note was written by Rachel Marshall, Jhuma Sadhukhan, Lynne E. Macaskie, Kirk T. Semple, Anne P. M. Velenturf and Juliet Jopson as part of a Policy Impact project (https://rrfw.org.uk/projects/policy-impact-project/) funded by the Natural Environment Research Council, a faculty impact grant awarded by Lancaster University and the Resource Recovery from Waste programme (grant code CVORR NE/L014149/1). We are grateful for the input and feedback from RRfW researchers.

Resource Recovery from Waste
University of Leeds, Leeds LS2 9JT.
Web: https://rrfw.org.uk/

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