OPPORTUNITIES REPORT

Global Health

Closing the protein loop

Making sure the supply of food continues to keep up with humanity's appetite will mean meeting many challenges. We think one of these is recycling sources of protein that are currently wasted and looping them back into the food supply.

Overview

This paper outlines the key challenges and opportunities that we see for future developments in protein recycling.

We have become far better at avoiding waste going to landfill over the past 20 years – roughly half of both household and commercial waste in the UK is now recycled and only a quarter goes to landfill.[1] But not all recycling is the same, and this is particularly true of waste food. Waste food can be composted, fermented or fed to animals – or we can find ways to eat it ourselves.

Our research focuses on the challenges and opportunities facing efforts to repurpose waste protein for human consumption. This is arguably the most difficult, but also the most valuable form of food recycling.

This report identifies three key areas in which we think there are significant opportunities for changing the way that we eat:

- supporting the creation of new technologies (including developing ways of processing currently inedible waste into food we can and want to eat);
- supporting the creation of a functioning market (including increasing public acceptance);
- learning from the past by rediscovering, reimagining and promoting traditional food production and processing methods that use waste products in a culturally acceptable manner.

The context

Feeding the world has been a challenge for all of human history. The dramatic population explosion of the 20th century was fed through a combination of expanding agriculture's

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[1] Department for Food and Rural Affairs (2016) 'UK Statistics on Waste' London: DEFRA

footprint on the land[2] – and expanding its use of resources. Increased use of freshwater resources for irrigation, industrial-scale monoculture of novel, highly productive crop varieties, factory farming and the fertiliser- and pesticide-driven Green Revolution greatly increased the production of food per hectare (trebling wheat productivity over 50 years[3]), but at the cost of environmental degradation and resource depletion.

With the world's population set to grow to 9.7 billion by 2050,[4] we need to be smarter about our food production system if we are to avoid either significant hunger or needless environmental damage.

Protein is a particularly difficult piece of this puzzle. It is nutritionally important, crucial for maintaining a well-functioning human body. However, protein is present in relatively small quantities in most of the easy-to-grow cereals and vegetables that form the backbone of our diet.

While starvation and chronic hunger have fallen dramatically,[5] malnutrition – including a lack of protein in the human diet – remains an issue in parts of the developing world, and is a contributory factor towards stunting.[6] Meanwhile, production of protein-rich food remains highly inefficient.

Much of our protein comes from a handful of sources: soy, livestock and fish. All of these are environmentally problematic. Soy is grown in huge monocultures, with just three countries (the US, Argentina and Brazil) providing the lion's share, over 85% of world production.[7] Livestock production is wasteful (using up more feed than it produces in food), often cruel, and has serious negative externalities running from antibiotic resistance[8] to climate change.[9] Overfishing is depleting wild-caught fish stocks, while aquaculture still relies on unsustainable feed, causes pollution and destroys habitats.

In parallel to the growing need for food, and the unsustainable methods we currently use to produce protein, the world has a huge food waste problem.

There are inefficiencies at every stage in the value chain – in the farm, in food processing plants, in shops, in the home – and food that could feed people is lost. WRAP (the Waste and Resources Action Programme) estimates that food waste in the UK amounts to 10

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[2] World Bank (1961-2013) 'Agricultural land (% of land area)' Available from http://data.worldbank.org/indicator/AG.LND.AGRI.ZS?end=2013&start=1961&view=chart&year=1974 [Accessed 5 October 2016]
[3] Food and Agriculture Organization (1961-2013) 'Yield of commodity in selected country – world, 1961-2013' Available from http://faostat3.fao.org/browse/Q/QC/E [Accessed 5 October 2016]
[4] United Nations (2015) 'World population projected to reach 9.7 billion by 2050' Available from http://www.un.org/en/development/desa/news/population/2015-report.html [Accessed 5 October 2016]
[5] Food and Agriculture Organization (2016) 'The State of Food Insecurity in the World 2015' Available from http://www.fao.org/hunger/key-messages/en/ [Accessed 5 October 2016]
[6] Ghosh, S., Suri, D., and Uauy, R. 'Assessment of protein adequacy in developing countries: quality matters. *Br J Nutr* 2012 Aug; 108 Suppl 2:S77-87
[7] WWF (2016) 'Soy is everywhere' Available from http://wwf.panda.org/what_we_do/footprint/agriculture/soy/facts/ [Accessed 5 October 2016]
[8] Lance B Price (2015) 'The antibiotics in our food' Available from https://longitudeprize.org/blog-post/antibiotics-our-food [Accessed 5 October 2016].
[9] Rob Bailey, Antony Froggatt and Laura Wellesley (2014) 'Livestock – Climate Change's Forgotten Sector.' London: Chatham House

million tonnes per year, and that 60% of this is avoidable. Waste in the home makes up over two thirds of this.[10]

So what does recycling look like in practice?

Not all recycling is the same. There are two similar hierarchies of waste that are widely used, Moerman's Ladder[11] and Lansinck's Ladder[12], both of which distinguish the different uses to which waste products can be put.

Moerman's Ladder, applied to food waste, is as follows:

	Example
1. Prevention	Buy only the food you need, avoid waste
2. Use for human food	Donate excess food to food bank
3. Recycling/conversion for human food	Extract protein from whey to make ricotta
4. Recycling/conversion for use in animal feed	Use broken or stale crisps as pig feed
5. Raw materials for industry	Use in cosmetics or industrial chemicals
6. Fertiliser with energy co-production	Composting/digesting with heat and/or biogas recovery
7. Fertiliser without energy coproduction	Composting
8. Energy production	Anaerobic fermentation
9. Burning as waste	Incineration (may include generation of energy)
10. Dumping	Landfill

As a general rule, any stream of waste should be used at the highest possible level of this hierarchy, as this is the most efficient use. Composting, burning or turning edible food into biogas is a huge waste of a valuable resource. Feeding it to animals is far better but still nowhere near as efficient as feeding it to people – for instance cattle convert only about a sixth of what they eat into body mass[13] – and turning food waste into animal feed in any case faces many of the same problems (around food safety, for instance) as feeding it to humans.

And while preventing wastage of food at the top two levels (prevention, and reuse as human food) is relatively simple, as the food does not need to undergo any kind of transformation, the third is less straightforward.

Transforming currently neglected waste streams of protein that are not suitable for eating in their unprocessed form – such as the leafy tops of sugar beet, sludge from potato

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[10] WRAP (2016) 'Estimates of Food Surplus and Waste Arisings in the UK' Available from: http://www.wrap.org.uk/sites/files/wrap/UK%20Estimates%20May%2016%20%28FINAL%20V2%29.pdf [Accessed 5 October 2016]
[11] Walter Leal Filho and Marina Kovaleva (2015) 'Food Waste and Sustainable Food Waste Management in the Baltic Region.' Heidelberg: Springer, p24
[12] Voedselverspilling.com (2010) 'Ladder van Moerman' Available from: http://www.voedselverspilling.com/laddervanmoerman.aspx [Accessed 5 October 2016]
[13] Dan Shike (2013) 'Beef Cattle Feed Efficiency' Available from https://web.archive.org/web/20161006093420/http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1027&context=driftlessconference [Accessed 6 October 2016]

processing or the by-products of brewing and dairy processing – into safe, palatable and nutritious foods means solving a number of challenges. But it is valuable as it creates new sources of food that people can eat out of products that are currently underused.

There are some interesting start-ups working in this space – for instance ReGrained (protein from brewery by-product); Sir Kensington's (mayonnaise from hummus by-product); and Renewal Mill (high-protein flour from soy milk by-product). There are also edible by-products of non-food industrial processes, such as the yeast produced by Alternative Fuel Corporation's biofuel manufacturing.

But aside from powdered whey protein, a refined and processed by-product of cheese manufacture, which is widely used in food manufacturing and as a bodybuilding supplement, these are not yet mainstream commodity products.

Meanwhile there are many other promising streams of waste protein that are untapped, or underexploited – from sources as varied as blood from slaughterhouses (a high-protein product that is currently largely turned into fertiliser) and sludge from potato processing.

The challenges facing protein recycling

There are several challenges in making these products ubiquitous.

There is not currently a fully functional market for them. There are technological difficulties in developing some of these products. There is also a range of cultural and legal barriers to their wider use.

Market failure

Aside from whey protein, the market does not currently support the widespread use of recycled protein in human diets. Valuable sources of waste end up being used lower down Moerman's Ladder than they need to be, with excess food from supermarkets often being used to make biogas in anaerobic digesters[14] and high-protein products from slaughterhouses (such as blood, feathers and bones) typically going into fertiliser or animal feeds.[15]

The market is simply not configured for most of these products. It's not always clear what waste streams are available, what they are currently being used for, and what the commercial viability of a product might be.[16] What relationships do exist in the field are generally ad-hoc, such as brewers selling their spent grain to local farms as animal feed. The situation is not helped by the products often being in inconvenient locations – such as urban microbreweries – and there being natural variation in quality and quantity between suppliers and batches.

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[14] BBC News (2015) 'Viewpoint: The supermarkets' guilty secret about unsold food' Available at: http://www.bbc.co.uk/news/magazine-34708775 [Accessed 5 October 2016]
[15] David Meeker and CR Hamilton (undated) 'An overview of the rendering industry'. Available from: http://assets.nationalrenderers.org/essential_rendering_overview.pdf [Accessed 6 October 2016]
[16] Karen Smith (undated) 'Current and future processing of whey ingredients.' Wisconsin Center for Dairy Research. Slide 67. Available from: http://oregondairy.org/wp-content/uploads/2014/04/4-2014-ODI.pdf [Accessed 6 October 2016]

There is a lack of established intermediaries or standards for products which would allow them to be traded as commodities.

There is even a lack of shared language around these – widely-understood names for some of the different raw ingredients are missing, and the vocabulary to describe products made from them, for instance whether they are ‘recycled’, ‘upcycled’, ‘second life’, ‘closed loop’ or ‘circular food’, is inconsistent.

This is despite clear customer demand for more sustainable food products,[17] and the existence of labels such as ‘organic’ or ‘fair trade’ that support the marketing of other desirable products.

Technological barriers

For many streams of waste protein, there are technological challenges that lie in the path towards them being large-scale solutions.

For some products, the challenge is in processing them. For instance, acid whey (the acidic by-product of strained Greek-style yoghurt production), as well as having somewhat lower protein content than the whey that comes from cheese production, produces an extremely sticky and difficult-to-handle residue when dehydrated[18]; for others such as spent grain from breweries or blood from slaughterhouses, the by-product spoils very quickly, requiring rapid refrigeration or dehydration.

Achieving consistency in products is another technical challenge, which is particularly problematic for those products which will be sold as standardised commodities (ingredients such as powders or flours sold on for use in other products), which need to have highly predictable properties and minimal variability between batches. Natural ingredients often have a degree of variability. This is particularly the case for by-products, which can come from a range of slightly different sources – for instance, spent grain from breweries producing different types of beer, whey from different types of cheese production (or different animals’ milk), or different varieties of plant.

Ensuring that products remain traceable in long supply chains is not straightforward and is in part a technological challenge. The origins of the ingredients, for instance country of origin, or whether they come from GM or organic agriculture, may be obscured. How they have been treated, for instance acrylamide build-up from excessive heat treatment or aflatoxin from mould, may be hard to trace. Cross-contamination with other foods such as allergens, or animal products in vegetarian ingredients (animal rennet in whey protein, for instance) is easier to envisage than in a product with a short supply chain between farm and fork. Recycled foods may therefore require more extensive testing, and new or more sophisticated methods of tracing batches through numerous stages in the value chain. The 2013 horsemeat scandal in Europe demonstrated how long and obscure some of the value

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[17] J Sainsbury plc (undated) ‘Sainsbury’s 20 by 20 Sustainability Plan.’ London: J. Sainsbury plc. Available from: https://www.j-sainsbury.co.uk/media/373272/sainsbury_s_20_by_20_sustainability_plan.pdf [Accessed 5 October 2016]

[18] Eric Hamilton (2015) UW researcher seeks ways to extract components of acid whey. *Milwaukee Wisconsin Journal-Sentinel* Available from: http://archive.jsonline.com/business/uw-researcher-seeks-ways-to-extract-components-of-acid-whey-b99546480z1-320523582.html [Accessed 5 October 2016]

chains in the food sector are, to the extent that food safety bodies had to conduct DNA tests on ready meals to determine what they actually contained. A related issue is labelling, outlined later in this paper.

Finally, developing recipes that can transform waste products into palatable food is a technological challenge as well as a gastronomic one. Some of these ingredients will need processing in order to make them palatable – whether that is through separation, filtration, grinding into particles, blending into smooth pastes, eliminating unpleasant flavours, or ensuring that the mechanical properties (mouthfeel, stickiness, viscosity, elasticity, etc.) contribute to the finished product in a desirable way.

Cultural, legal, safety and regulatory barriers to acceptance

There are a number of obstacles to introducing novel foodstuffs into the market – the history behind the acceptance of the sweetener Stevia being one example. Before any novel food is approved for use, it must be rigorously assessed for safety. Stevia demonstrates the years of testing and research often needed before entering the market. Throughout this process, a number of conflicting conclusions were made by various bodies regarding whether it was safe to eat, before it was finally approved and regulated as a food additive in the EU in 2011. The development of Quorn – protein from a single-celled fungus – saw similar barriers to its acceptance during development.[19] Although some recycled foods will not be subject to these rules, others, if their manufacture is sufficiently different from traditional foods, may be.

What is deemed to be normal or acceptable by society is another barrier to widespread consumption of novel recycled foods. Chickens are widely eaten around the world, for instance – but dogs are not; cheese is common in Europe but rare in China. Food is subject to many such cultural preferences – and these will need to be taken into account when developing, testing and marketing new products based on recycled protein.

Related to these preferences are food taboos, some of which are deeply ingrained in various cultures and traditions. For example Islamic and Jewish dietary laws will almost certainly conflict with some recycled foods that contain (or could be cross-contaminated with) meat, dairy and blood.

Traceability and labelling are also factors to consider in the introduction and acceptance of recycled foodstuffs. Food ingredients are required to be listed on their packaging, but how these regulations would apply to recycled foods – where the origin, nutritional makeup and consistency between batches may be less reliable than in other products – is not straightforward. Would customers accept products that obscure the origins or nutritional content of their food?

There are also issues around health, and public perception of health. Food recycling solutions are often likely to be highly processed, which is usually perceived to be unhealthy.

Additionally, recycled protein would be replacing some already well known and trusted food stuffs – for instance meat, dairy or eggs – and may be perceived as an inferior substitute.

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[19] See Robert Bud, *The Uses of Life*, Cambridge: Cambridge University Press, 1993

Perception is also related to how these items are marketed. For instance, Hampton Creek, a food start-up known for its eggless alternative to mayonnaise ‘Just Mayo’, was issued a warning letter by the Food and Drug Administration in 2015 accusing them of false labelling, as the legal definition of mayonnaise in the US requires eggs as an ingredient. This resulted in Hampton Creek having to make some changes to their product’s label. Protein recycling company Sir Kensington’s makes a mayonnaise-style condiment using aquafaba (the protein-rich water leftover after cooking chickpeas to make hummus), but has to market their product as ‘Fabanaise’.

This demonstrates that recycling food companies need to be careful in regards to how they advertise their product, and that it is not seen to be misleading.

Opportunities

The challenges facing the recycling of protein are not intractable. Not all proteins will be suitable for recycling into the food chain – for instance, food safety issues around variant Creutzfeldt-Jakob Disease mean it is unlikely that proteins derived from discarded parts of cattle could ever be permitted, even in animal feed. But in many cases, it is a matter of solving social or technological challenges – and in identifying the opportunities that innovation would bring.

Support the creation of new technologies

Creating new foods is likely to require the development or refinement of technology, in order to extract, purify or process waste foods into proteins.

Some of these will have to be highly tailored to specific foods being produced. For instance, the requirements for filtration or separation equipment will be different for waste streams that have different properties. Isolating protein from spent grain – a solid – is not the same as isolating it from acid whey – a liquid. Identifying the key priorities for technological development in this field will mean identifying which key sources of protein are particularly worthy of being exploited and solving the specific technological problems they face.

Other technological requirements are likely to be more widely needed, such as efficient, reliable and mobile dehydration equipment (many sources of waste protein are both highly perishable and have high moisture content).

One area which would be particularly valuable for recycled proteins would be technology that permits rapid, accurate and low-cost testing, both of nutritional content and potential contaminants. As recycled proteins are likely to have passed through longer supply chains, and to have undergone multiple transformations, the chances of both variation between batches, and unexpected contaminants within them, are relatively high. Easier testing would support both public confidence and regulatory compliance.

Related to this is a way of tracking batches of food through complex supply chains, giving consumers and regulators the confidence that they know what is in a product that is on sale. This would help consumers verify whether the content of their food meets their requirements – for instance whether it meets organic, halal or kosher standards; whether whey protein was sourced from a dairy that uses animal rennet; what country ingredients were produced in; whether animal products come from free-range or sustainable sources – and solve two risks of food recycling: that it can obscure the origin of ingredients, and that this obscurity can allow fraudulent practices to flourish.

Blockchain technology, a way of running a distributed, trusted and permanent database of transactions, may be one promising way of doing this. Although developed for cryptocurrency transactions such as bitcoin, blockchain has been successfully used to form the backbone of Everledger, a fraud detection service that tracks diamonds. It could be used to provide a permanent record of how different batches of food have worked their way through the supply chain.

Support the creation of a market

Even with the best technology in the world, recycled protein will not make an impact unless it finds a market.

This is partly an issue of public and regulatory acceptance: the sector will have to find opportunities to educate and inform the public about the value of recycled protein, as well as to pre-empt public and regulatory concerns through openness about supply chains and ingredients.

It is partly an issue of standardisation and commoditisation. Developing standards for the quality and nutritional content of key recycled protein ingredients – including what these ingredients are called – would help shift the market away from small, ad-hoc arrangements between suppliers and users, and create a larger and more efficient market to sell into. Many food ingredients – vegetable oils, cereals, even coffee – are highly standardised commodities and can therefore be reliably traded in bulk with confidence that the goods delivered will be precisely as specified.

Finally, it is an issue of policy. Food production is not a free market: both in Europe and North America, farming is heavily subsidised, and this has profound impacts on how food is produced, what food is produced and how it is priced. Subsidies for soy and meat production, combined with tariff barriers for some agricultural imports and export, mean a complex market in which recycled proteins have to compete. In particular, this system means that some products (soy, and hence meat that is fed on soy, for instance[20]) are sold at below production cost. Recycled proteins, as well as alternative proteins such as insect meal, face an uneven competitive playing field in many markets – and have to find the opportunities to thrive in this environment.

So, successful recycled proteins need to seize the opportunity to create markets – for instance by creating brands and standardised names, marketing themselves as sustainable products that can charge a premium, and develop into commodities that are widely traded and widely used.

Learn from the past

Innovation doesn't just mean cutting edge science and technology being applied to a problem. In food technology, there is a lot that can be learned from the past, rediscovering,

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[20] EWG (2015) 'Soybean subsidies in the United States totalled $31.8 billion from 1995-2014'. Available from: https://farm.ewg.org/progdetail.php?fips=00000&progcode=soybean [Accessed 5 October 2016]

repurposing or reimagining old-fashioned ways of working – from a time when food was treated as far more precious than it is now.

There are traditional foods that are made of recycled protein.

Black pudding is made from pig's blood and oatmeal – but its manufacture uses only a small fraction of the total production of blood from slaughterhouses, most of which ends up as blood and bone meal (often used as a fertiliser).

Italian ricotta, Corsican brocciu and Scandinavian caramelised cheeses like geitost are not, strictly speaking, cheeses, as they are not made of milk. They are made by cooking whey, the protein-rich liquid left over when curds are drained in cheese production.

Other traditional cheeses including cottage cheese and Dorset blue vinney are made from the skimmed milk left over after cream is removed to make butter.

Seitan – a meat-like substance made from gluten, widely eaten in China and Japan – is made by separating the protein (gluten) from starch in wheat flour. Although it is not waste protein – seitan is actually the desired product and starchy water is the waste product – this, like the popularity of tofu, shows that highly processed protein extracts, produced by traditional means, can be popular.

So one valuable area which innovative companies could work in, would be to rediscover lost or obscure foodstuffs and manufacturing techniques – and either reintroducing them, or learning from the processes involved in their manufacture.

As well as supporting traditional food culture, these techniques may find an easier path to public and regulatory acceptance. Reviving a traditional food could be more popular with consumers than developing a highly processed protein powder.

Possible challenge prizes

- Ingredient prize: for developing a technology that is able to cost-effectively recover protein from a currently underutilised waste source
- Marketing prize: for developing and successfully marketing a recycled protein product, garnering public and regulatory acceptance
- Traceability prize: for developing an online system that can accurately, trustworthily, verifiably and cost-effectively trace the ingredients through the long supply chains required for recycled protein products
- Testing prize: for developing lower-cost methods of testing the nutritional content or allergen risk of a batch of recycled protein product

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