Circular Economy Scotland

green alliance...

in partnership with

scdi Scottish Council for Development and Industry

Summary

Rising resource risks and the growing recognition of the economic value being lost in waste have raised business interest in the circular economy. These trends are feeding a more interventionist approach to resource policy in countries as diverse as the US, China, Germany, Japan and Korea. This analysis shows how Scotland could help to make its economy more circular, by assessing potential opportunities in three exemplar sectors, and developing these into a wider suite of lessons for government as a whole.

The analysis draws on Green Alliance's experience of working with the businesses in the UK's Circular Economy Task Force. It also derives from a programme of engagement with the businesses and political actors in Scotland's oil and gas, food and drink and finance sectors, which we have undertaken with the Scottish Council for Development and Industry (SCDI).

We draw out scenarios based on the interaction between opportunities and all decision makers' appetite for risk, desire for government intervention and the political will to act. As such, recommendations for action in specific sectors are presented as a menu of options.

However, the wider lessons for government focus on how Scotland might capture the biggest circular economy opportunities. Scotland is already ahead in resource efficiency opportunities, particularly for materials. As such, it is well positioned to capitalise on its high social connectedness and policy leadership on low carbon technology to develop and pilot more innovative, valuable, and ambitious circular economy business models and technologies. To enable this to happen, we conclude that **Scotland needs a targeted, challenge-led innovation strategy** run by institutions empowered to drive technically risky, but potential big win circular economy pilot projects.

Because Scotland is a relatively small country, this strategy will be more likely to succeed if targeted towards innovations that will help Scotland's key sectors adapt to a more resource constrained world.

Scotland's existing innovation institutions could fulfil this role, if politicians provide a mandate for them to be bold, bearing in mind that innovation inevitably leads to failures as well as successes.

Summary: circular economy opportunities in three Scottish sectors

	Less radical		More radical
Oil and gas	Better metal alloy separation to improve recycling	Improved asset reuse, within the industry and in related sectors	Reuse of existing pipelines for a carbon capture and storage network
Food and drink	Food redistribution and anaerobic digestion for energy	Biorefining: improved fermentation to produce chemicals	Biorefining: extraction of specialist chemicals from separated feedstocks
Finance	More recyclate, but not more reprocessing leads to limited investment	More circular economy infrastructure and piloting in Scotland	Scottish private finance of circular economy infrastructure abroad

Introduction

What is a circular economy?

At its best, a circular economy restores old products, parts and materials back to their original use in a way that uses the least resources to deliver the same function.

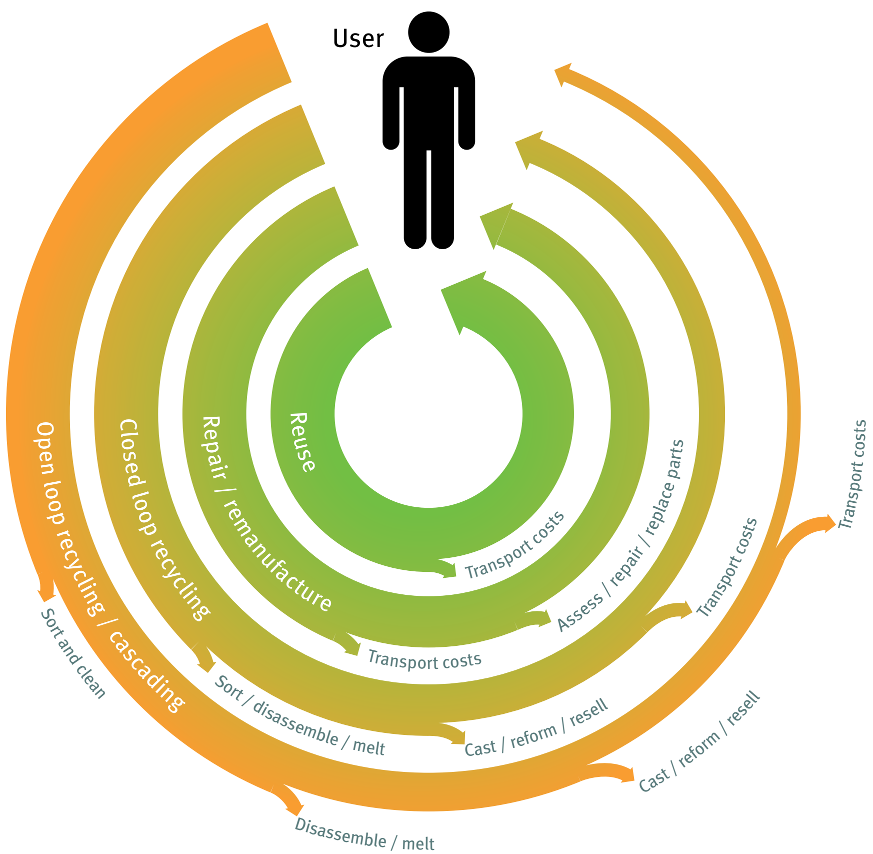
Ideally, this means direct reuse of products, which preserves both the highly engineered character of a product and its useful function. Where a product needs repair or reconditioning before it can be used again, remanufacturing preserves the most value. These are the tightest 'loops' within a circular economy.

The next best route is recycling, which can be closed or open loop. Closed loop recycling turns products into materials that can be used to create the products they were recovered from: examples include glass bottle to glass bottle or specialty alloy to specialty alloy recycling. In contrast, open loop recycling, or downcycling, creates material suitable only for lower value applications. For example, glass bottles can be used for construction aggregate and specialty alloys can be downcycled into bulk metals. Although lower value, this avoids the use of new materials.

Achieving a more circular economy will mean governing differently. More collaboration, both within and across sectors, needs to be underpinned by more entrepreneurial institutions, whether led by the state or industry.

Our analysis of three key sectors in Scotland shows which circular economy opportunities might be possible, given a range of different technical, political and social drivers.

Keeping value in a circular economy



Scotland's unique characteristics

Scotland has a suite of opportunities and challenges, derived from its particular political climate, policies, institutions and scale.

Politics and policy

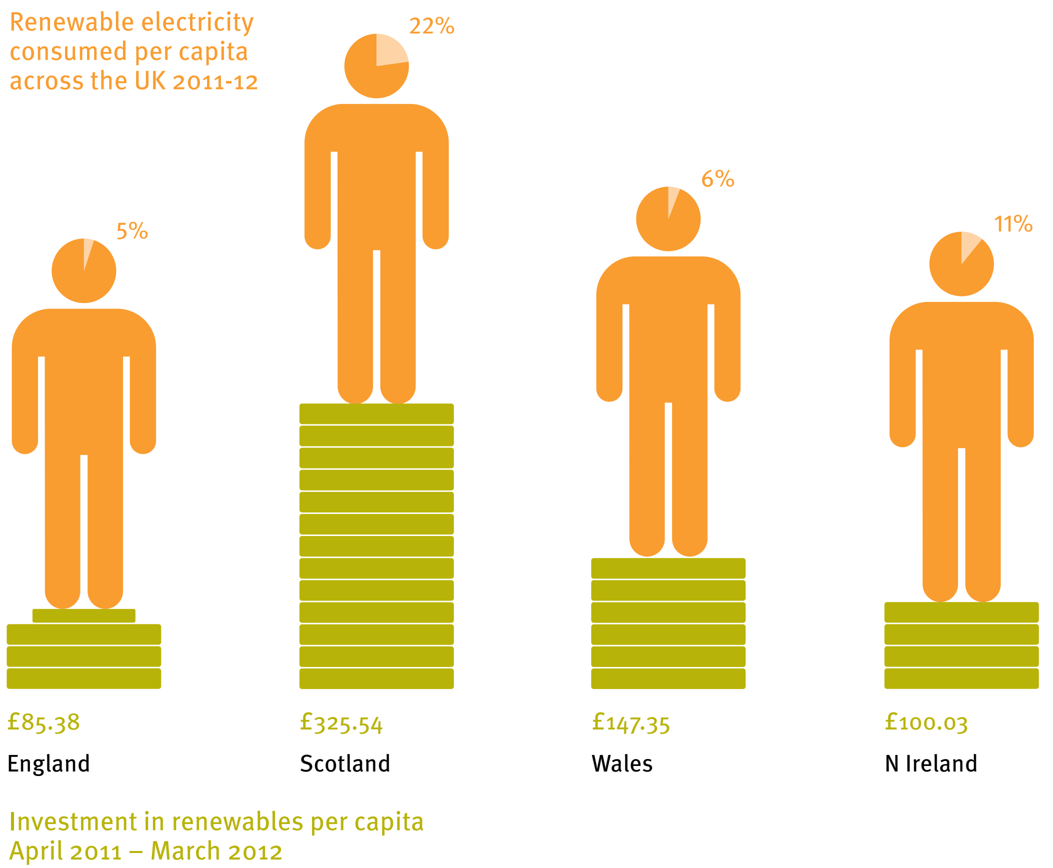
Scottish politics and policy has featured a consistent narrative in favour of renewables and on the value of industrial strategy. This has helped to de-risk investment in both on and offshore wind. Similarly, Scotland's Zero Waste regulations have been more comprehensive and targeted than other parts of the UK. But more co-ordination and targeted policy will be needed to secure supply chain collaboration and investment in a circular economy.

Institutions

Scotland has many institutions which could help to develop and commercialise new technologies and business practices in a circular economy.

Notably, its new innovation centres could build on international innovation policy experience to bring forward technologies and business models for the circular economy; Scotland's enterprise agencies have the opportunity to play a co-ordination and funding role in bringing new technologies and start ups out of the lab and into the market; and Scotland's trade bodies and cross sectoral convenors, such as the SCDI, can help to diffuse innovative ideas and promote collaboration.

Scottish policy has pushed renewables development ahead of the rest of the UK

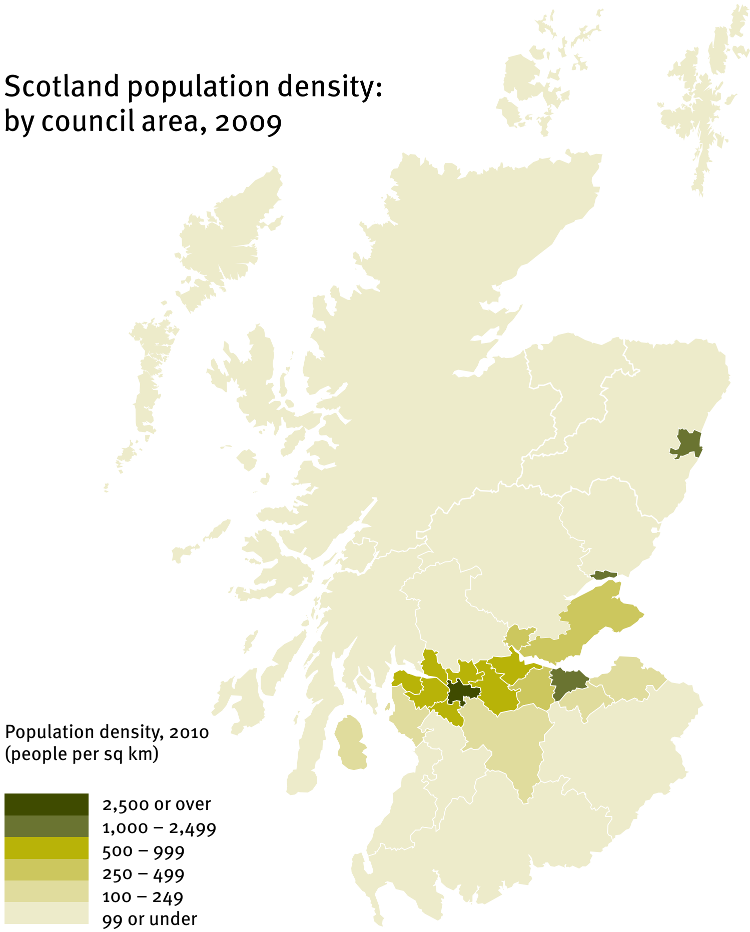


Scale and geography

Scotland has an economies of scale challenge. Low population density outside the central belt limits large scale reprocessing, meaning that the opportunities are likely to be in high value reuse and remanufacturing loops, or greater separation of higher value materials.

Scotland's relatively small size has an upside, however, in greater social connectedness. Concentration of economic activity in a few, highly networked sectors lowers the cost of collaboration and increases the viability of cross sectoral projects and resource use.

Scotland population density: by council area, 2009



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How could Scotland's key sectors benefit from the circular economy?

The analysis presented here focuses on three sectors: oil and gas, food and drink, and finance. These were drawn from the growth sectors targeted by the Scottish Government Economic Strategy.

The examples we give are all deliverable, but the main goal of our analysis has been to understand what governance and policy changes might be required to achieve a circular economy more widely in Scotland. Each section identifies opportunities, ranging from the least radical options to the most radical: which serve to reflect how far away the business models and technology choices needed are from the current situation.

The final section outlines the lessons from the analysis, to inform the Scottish government's approach to its future circular economy roadmap.

Key sector
Oil and gas

The oil and gas sector is a large user of materials and a major economic force in Scotland. It's also, essentially, a linear, extractive business but, even so, there are significant circular economy opportunities.

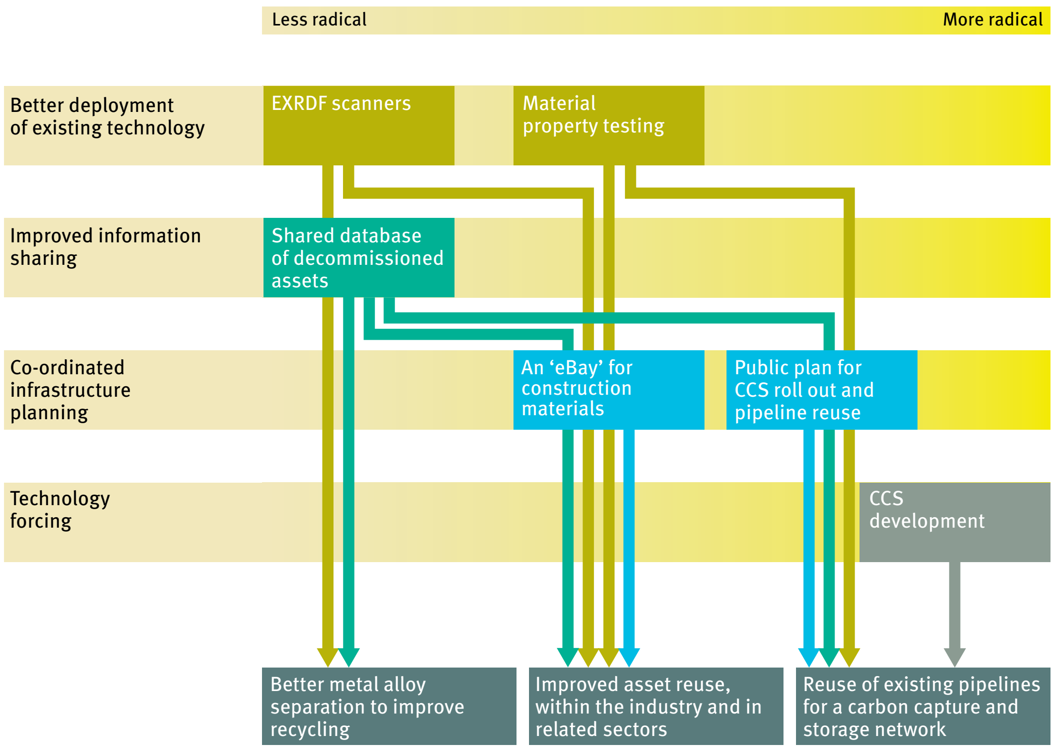
Decommissioning of offshore assets is expected to involve spending £10 billion over the next decade, and £35-50 billion by 2040.[1] It will transport 405,000 tonnes of material onshore between 2013 and 2022, with opportunities for improved recycling and enhanced reuse.[2]

Perhaps the biggest opportunity is reusing infrastructure for carbon capture and storage (CCS). This technology will be needed to decarbonise industry and would help to decarbonise the power sector. The UK has a strong combination of engineering skills and appropriate geology to lead its development.

The benefit of better value recovery would not only be felt by the oil and gas industry. An estimated 60 per cent of the cost of decommissioning "will ultimately be borne by the government through tax relief."[3] This suggests that a government-industry partnership would make sense.

Extracting maximum value from a circular economy approach for the oil and gas industry will require multiple interventions. The graphic right outlines how interventions in four domains might foster different outcomes.

Potential circular economy interventions for the Scottish oil and gas industry



Least radical: better alloy separation

Oil rigs use a large amount of high grade steel and other specialist alloys. These take a lot of energy and sometimes rare materials to make. Although recycling rates are high, it is unclear whether the value of these alloys is preserved when rigs are decommissioned.

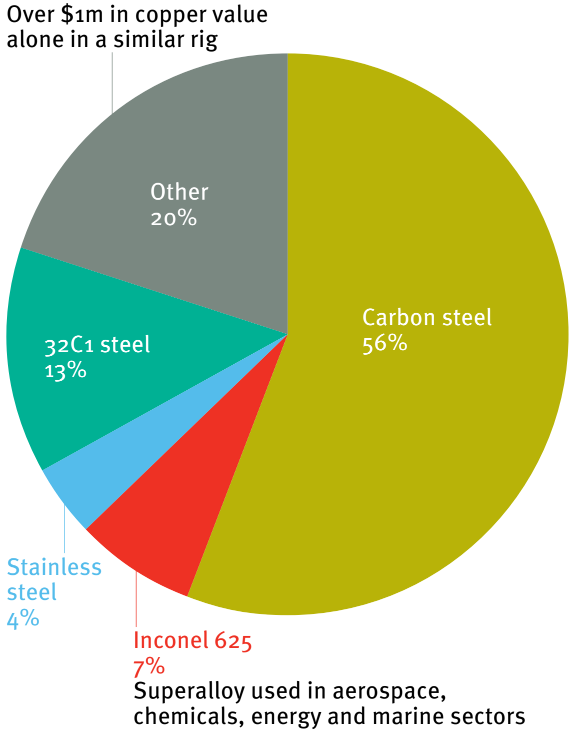
Alloy content matters. Alloys are tuned to deliver very specific material characteristics: hardness, ductility, malleability, corrosion resistance, etc. When several alloys are mixed together, these properties are lost. Although a few alloying agents can be readily separated when mixed, many cannot.[4] As a result, recyclers must dilute alloys with virgin metal so they don't affect the properties of recycled steel, and then add new agents to recreate new alloys. This process wastes energy and materials.

The least radical circular economy option for the oil and gas sector is to separate high quality metal alloys better, enabling more effective recycling. This is an incremental improvement as the decommissioning process already includes some metal grade information. The large tonnages of the metals involved mean that specialist recycling should be viable, creating an industrial opportunity.

Some decommissioining reports identify alloys and quantities of material, including X60/65 microalloy steel (contains niobium); duplex stainless steels (22-25% chromium); titanium; and Cu-Ni alloys. This allows an estimation of value: Hutton contained $1 million in copper alone[6], and duplex steel, which this rig has in abundance, is nearly double the price of mild steel.

However, decommissioning reports don't always produce detailed information, which can be as generic as 'steel' or as detailed as the alloy grade. This means it's unclear how much specialist recycling is happening. Better information sharing would ensure that all materials are recovered in the best possible way.

Materials in the Schiehallion rig[5]



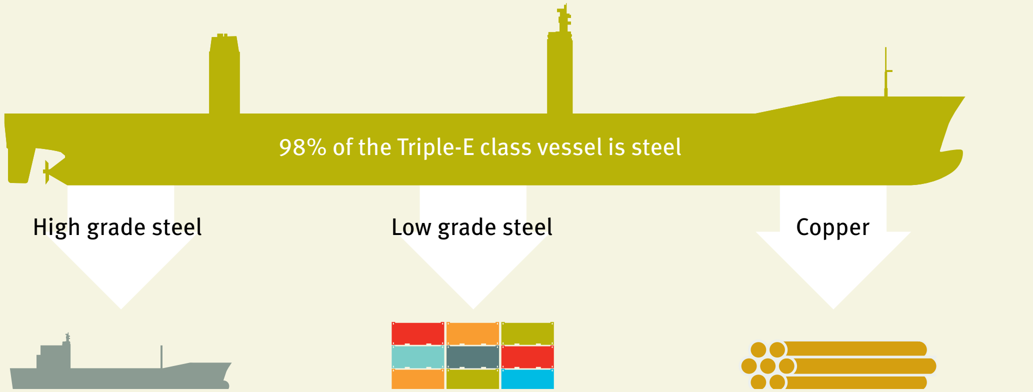
How to make it pay: examples from the car and shipping industries

The car industry has developed a business model which could be adopted by oil and gas companies. Car manufacturers contract with metal recyclers to maintain ownership over metals used in autocatalysts, which they use in the next generation of cars. This creates an incentive to separate which guarantees material supply for manufacturers and enables better recycling. Large integrated oil and gas companies could explore this for specialist metals.

The shipping industry provides an example that's closer to home. Maersk uses many of the same materials as the oil and gas industry. It provides a good proxy for what the oil and gas industry could do with its assets. Maersk's ability to categorise and separate different alloys means it's likely to sell scrap metals for ten per cent more than unseparated steel.[7] This reduces the energy needed for recycling and demand for virgin materials.

A recyclable ship

The Triple-E class will be designed for future safe and sound recycling. A new 'Cradle-to-Cradle' passport will be developed which will list the materials used to build the vessel, where they are located and how they can be correctly disassembled and recycled.



How new technology can help

New technology makes identifying specific alloys straightforward. Handheld EDXRF scanners, which have only become available recently, are:

- able to distinguish between thousands of alloys in less than ten seconds;[8]
- inexpensive relative to overall decommissioning costs, with a payback period of under one year for a recycler;
- already used by some specialist recyclers.[9]

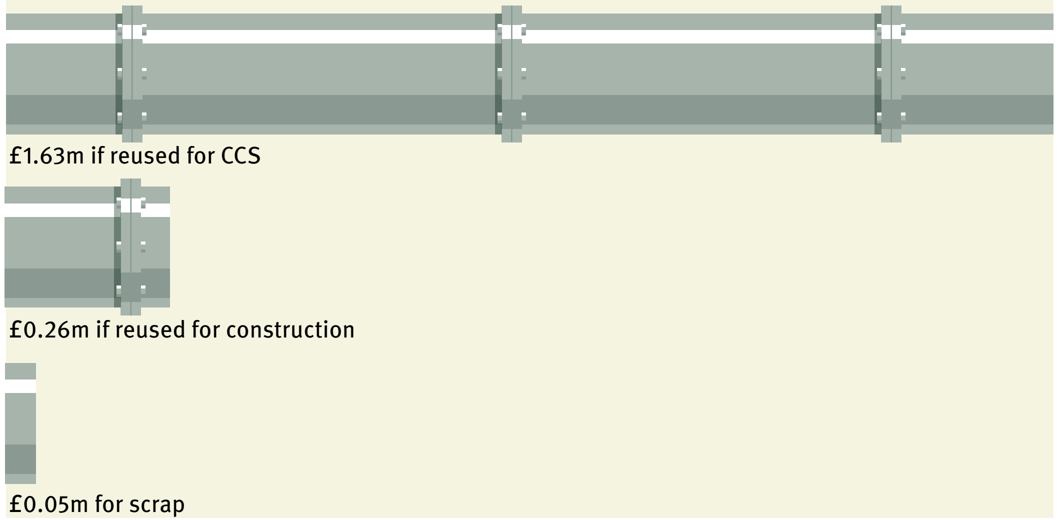
Local authority recycling contracts split the profits from better separation between the recycler and local authority seller. Cheaply available separation technology means that oil and gas companies could insist that decommissioning companies separate the alloys and share the additional revenue gained from better separation.

More radical: reusing assets

Reuse is much more valuable than recycling. This is because reuse preserves some or all of the function of the product. In the case of pipelines, reuse could be worth five times the scrap value of the steel, or even more, if reusing the pipelines means that new pipelines do not have to be built. But reuse is uncommon in the North Sea.

In the US, reuse and remanufacturing of heavy equipment used in the oil and gas industry was worth \$7.7 billion in 2011. Demand for reused equipment rose 50 per cent between 2009 and 2011.[11] Opportunities to reuse motors, engines, valves and other industrial equipment exist in other sectors abroad, including construction and farming. But reuse companies need to know what's available at least a year in advance to be able to find a suitable buyer.

Reusing pipelines (values per km)[10]



If pipelines and steel can't be reused within the industry and are not valuable enough to export, products could be diverted to construction. This already happened in the construction of London's 2012 Olympic stadium, which used surplus pipelines as structural steel. Importantly, the steel used was not guaranteed for its structural suitability but the Olympic Delivery Authority was able to test the steel cost effectively to ensure it would not fail. Similar measures could be taken to ensure all UK safety regulations are respected, but this and other experience shows that reuse is compatible with strong health and safety rules.

A similar process could be used for decommissioned oil and gas industry assets, but would require more visibility when the assets are brought ashore; this could be provided through an 'ebay' style portal for reusable materials and changes to the way decommissioning is undertaken.

Another option is to reroll steel plate and cut it into rebar for construction. This is common practice in Indian shipbreaking, but is less ideal as it uses more materials and energy in processing.

Further examples of oil and gas industry steel reuse[12]

From gasholder to office, Naaldwijk, the Netherlands

BedZed's reused girders, London

Most radical: direct reuse for carbon capture and storage

Pipelines could readily be repurposed to transport CO_2 instead of gas, this would eliminate the cost of removing them. This is technically straightforward: pipeline and platform age, fatigue life and existing corrosion are all known, although confidential. The proposed Peterhead CCS project already incorporates pipeline reuse.

The cost of pipelines is a significant fraction of the cost of CCS: "an integrated transport and storage network… promises the biggest contribution to cost reduction for CCS in due course" according to Mott Macdonald.[13] Reusing infrastructure as part of an integrated network would reduce costs further.

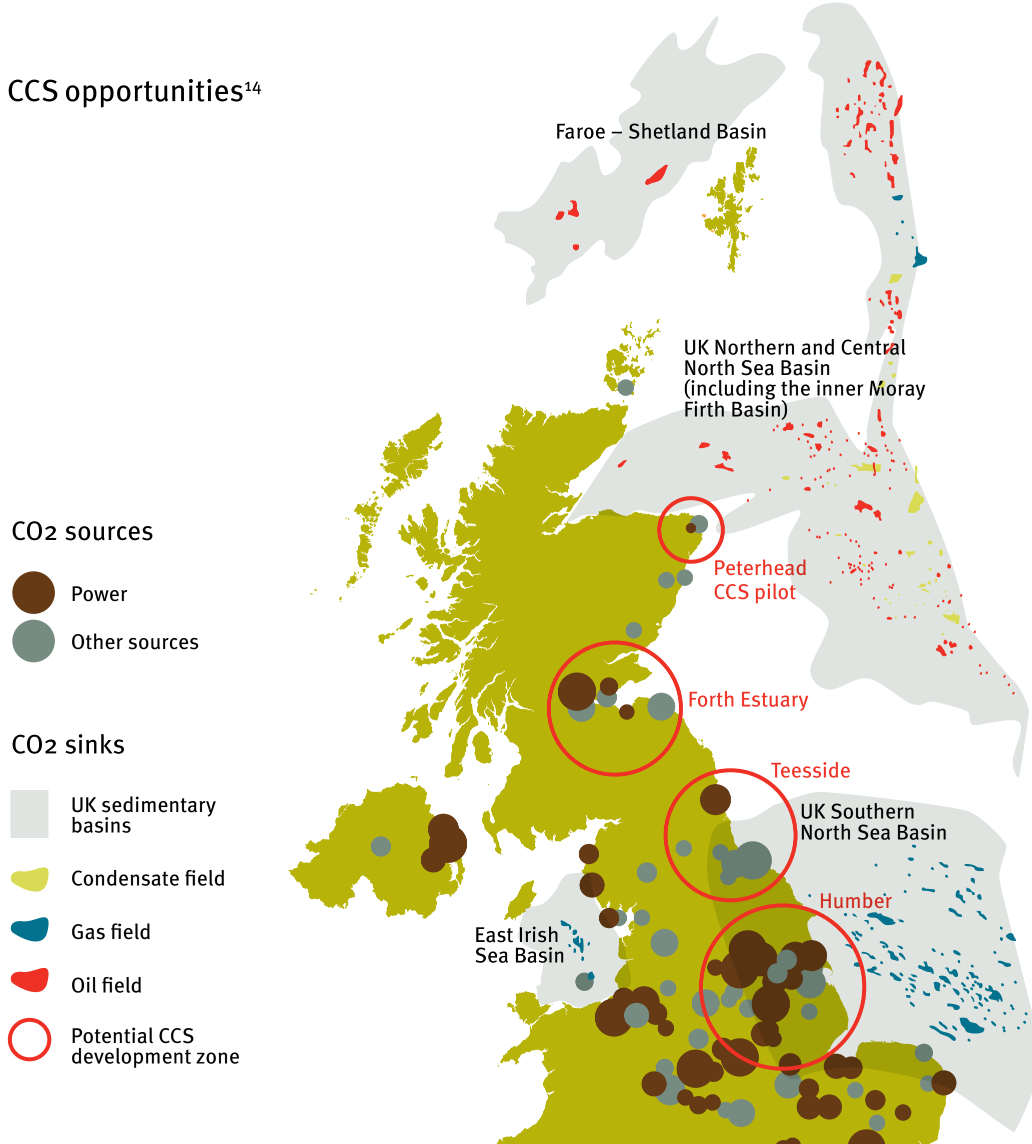
For this to be a viable option, masterplanning is necessary to link up multiple sources of CO_2. Fortunately, Scottish and UK sources are reasonably well clustered. In the medium term, there is plenty of demand for CO_2 storage from across the EU, making the knowledge and skills acquired by going early on CCS networks in Scotland valuable to a wider market. Given the constraints on onshore CO_2 storage, Scotland might also be able to sell storage space under the North Sea if its network is readily accessible.

For pipeline to be reused in this way, collaboration across the oil and gas industry and a plan for CCS roll-out are needed. The industry itself has come up with a suitable mechanism for this in the Wood Review, although it is currently intended for more extraction. It has two elements:

- an industrial strategy, for setting an agreed industry-wide goal;
- a regulator to enforce collaboration to achieve the goal.

Many of the details are similar, including 'the shared use of infrastructure' and the creation of 'hubs and clusters' bringing different companies together and jointly using transport and processing infrastructure. This framework could easily be adapted to take up the better recycling, reuse and CCS opportunities outlined here.

CCS opportunities[14]



Key sector
Food and drink

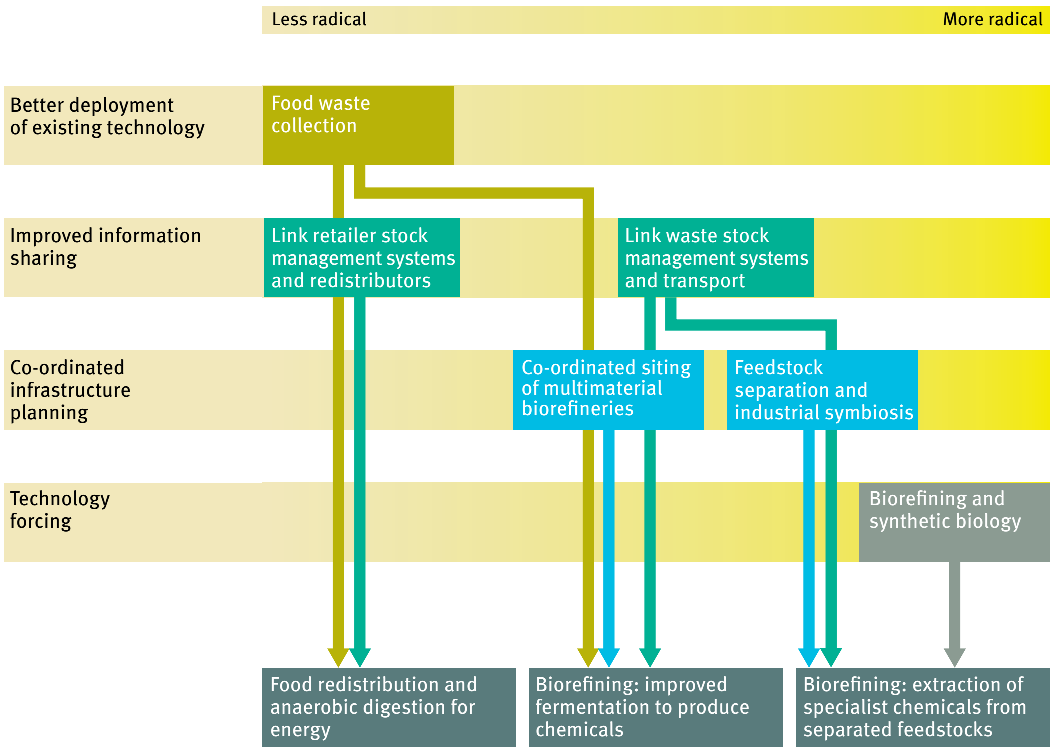
Scotland has a strong food and drink sector, producing waste and byproducts which, if captured and processed effectively, could be more valuable and resource efficient. New technology and much greater co-ordination across sectors will be required to maximise the opportunity.

The size of the prize is likely to be substantial even if improvements are incremental: better use of biowaste is estimated to be worth €1 billion per year to the Netherlands.[15] This value largely comes from better application of existing technologies, largely through the anaerobic digestion of animal waste. A similar figure, scaled down for the size of the economy, is likely to be possible for Scotland.

But creating more value will mean developing biorefining, a process of capturing valuable chemicals from biomass. However, doing so is complicated by a number of factors: water content limits the transport of many materials and feedstock is perishable and sometimes seasonal. Also, biorefining is not yet commercially proven, and requires much greater interaction between companies in very different sectors

Nevertheless, Scotland has a range of research centres and start ups working on overcoming these technical and economic challenges. Government assistance with co-ordination and innovation policy is likely to be needed to realise more of these advanced opportunities. We outline here three scenarios showing how intervention might influence which ones are realised.

Potential circular economy interventions for the Scottish food and drink sector



Least radical: redistribute edible food and anaerobically digest all waste

Under any scenario, even with only limited collaboration and technological innovation, ensuring that edible food is consumed should be top priority. The two main preconsumer sources of food waste are:

- **Supply chains:** 45-60 kilotonnes of food in Scottish supply chains could be redistributed to people each year, with an approximate value of £50 million.[16]
- **In-field food losses:** WRAP estimates that three megatonnes of food is wasted prior to harvest across the UK every year.[17] FAO data suggests root and tuber crops, fruit and vegetables and fish are the major areas of loss.[18]

Improving food redistribution

Food redistribution could be facilitated by extending supermarket distribution IT. Food in supermarket supply chains is well tracked. In contrast, redistributed food only tops up stocks at food banks rather than replacing the food ordered from wholesalers, because the food banks don't know how much redistributed food will be available in advance. Better information and more notice would mean these charities could count on redistributed food and buy less food to feed the same number of people. Integrating Fareshare (and others) into food retailers' supply chain management systems would reduce their costs and enable more efficient food redistribution.

Digital gleaning

Gleaning describes an old practice of volunteers helping to harvest food which would otherwise not be harvested. It has been an informal activity, reliant on volunteers in the local community. eBay has already enabled unwanted products to be reused by linking buyers and sellers. A similar system could work for fruit and vegetables, with farmers advertising the availability of their surpluses. The costs of such a system would be modest, and even a small increase in the use of harvested food could be significant.

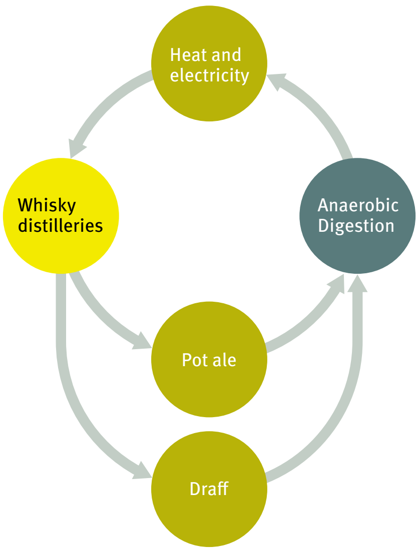
Anaerobic digestion

As a way of recovering the value from waste food, anaerobic digestion (AD) is proven, financially supported and requires only limited collaboration. Digesting all the food waste in Scotland would save £23 million in avoided landfill costs, and gain £27 million of value from generated energy. AD could produce 337GWh of biogas which is about 0.5 per cent of Scottish heat demand by 2020.[19] Given existing good practice and policy in Scotland, this is likely to become the norm. AD of other biodegradable wastes would increase biogas production and the value captured for the economy.

More radical: Biorefining

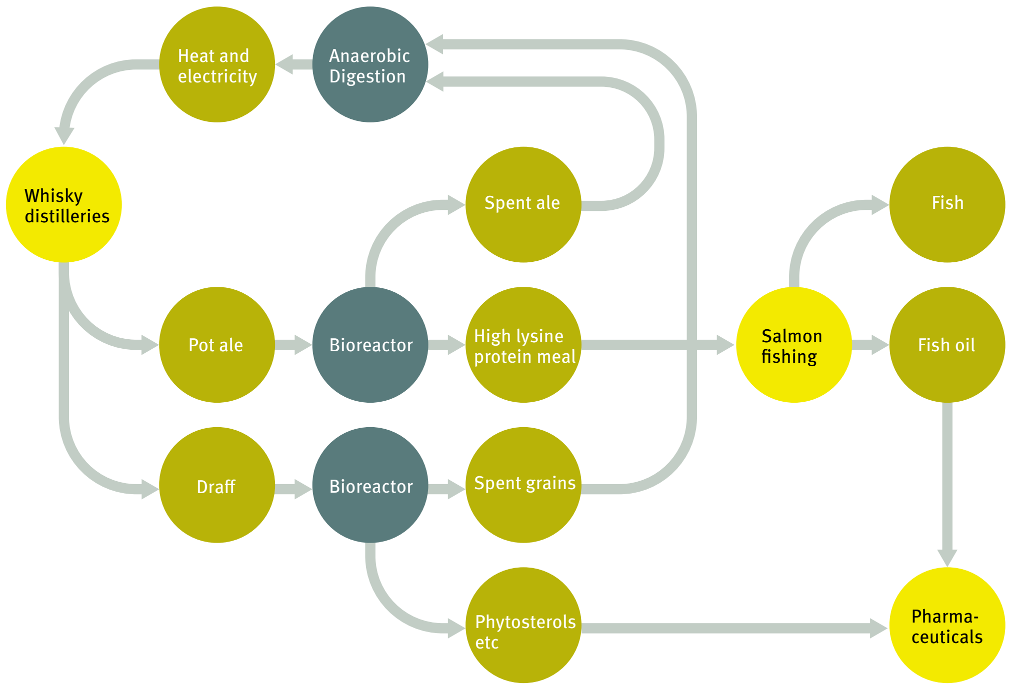
A single sector approach: whisky

Developing a circular economy approach for one sector is possible, but has limitations. For example, acting on its own, the whisky industry is improving resource productivity by capturing heat and electricity from its byproducts.



A multi-sector approach: whisky, fish and pharma

By contrast, working across sectors enables higher value products to be captured from wastes and byproducts. In the example below, the whisky industry could still capture heat and electricity, but by biorefining these prior to AD, can extract two additional, valuable products: protein meal for fish farming, which displaces fish meal and is worth around £1,500 per tonne, compared to the £50 per tonne for pot ale syrup;[20] and phytosterols, which help to manage cholesterol levels.



Two ways of biorefining

Capturing higher value products can be done in two ways:

Conversion: Fermentation of cellulose, hemicellulose or lignin to create platform chemicals. This builds on existing work done for second generation biofuels. Fermentation by specialist bacteria creates the precursors to bioplastics, including PLA, PEF and others.[21] These plastics may have properties that are better suited to food storage than fossil fuel derived plastics and consequently should have market value in addition to their green credentials. They are also worth more than energy, such as bioethanol or biogas. In theory, the process to create them is tolerant of multiple, different inputs and able to produce multiple, different outputs. This means it should be more resilient to feedstock and market risk than single output plants, like first generation biofuel plants. However, there are few examples of commercial platform chemicals plants, making this a more radical bioeconomy option than anaerobic digestion.

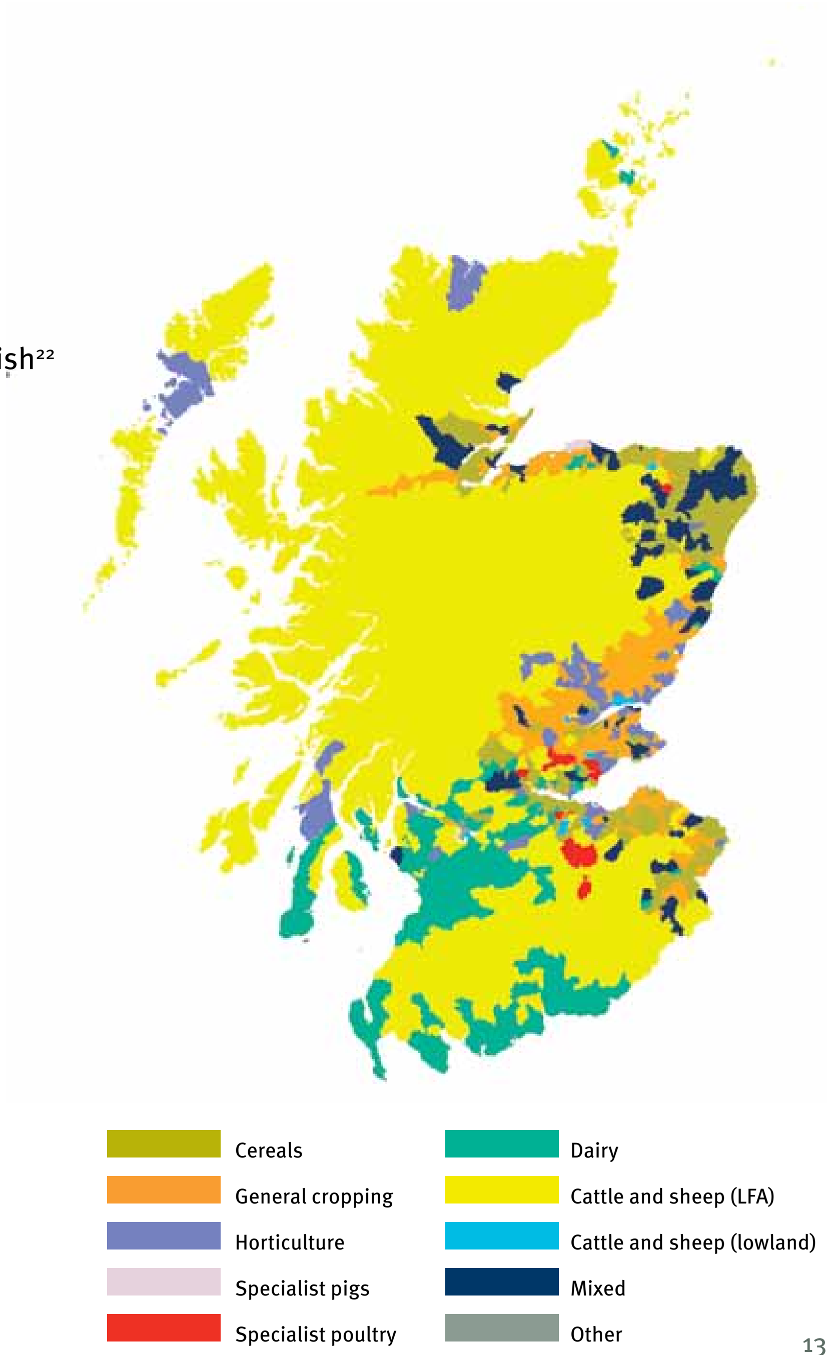
Extraction: existing chemicals made by plants are extracted and purified. Compared to fermentation, outputs are more valuable but there is much more technology, feedstock and market risk, making this the most radical bioeconomy option. Several feedstocks are available in Scotland, including whisky byproducts, for phytosterols and protein; potato hulm, for chaconine and solanine for pesticides; and some fish waste, for omega 3 oils.

The challenges for biorefining

Transport and the availability and seasonality of feedstock

The Scottish government collects very detailed data on production, as illustrated by the detailed map of farming types shown on the right, but there is currently no equivalent for waste and byproducts, which makes it harder to get an overview of the opportunities available. Scottish Enterprise is analysing feedstocks to inform business and government; this should provide a basis for brokering opportunities and an analysis of infrastructure lock-in risk.

Farm type by parish[22]



Infrastructure lock-in risk

Some bioeconomy opportunities may allow for evolutionary change in infrastructure. For example, extracting proteins from whisky pot ale, as described above, improves AD gas or liquid biofuel yield, so these processes don't compete for feedstock.

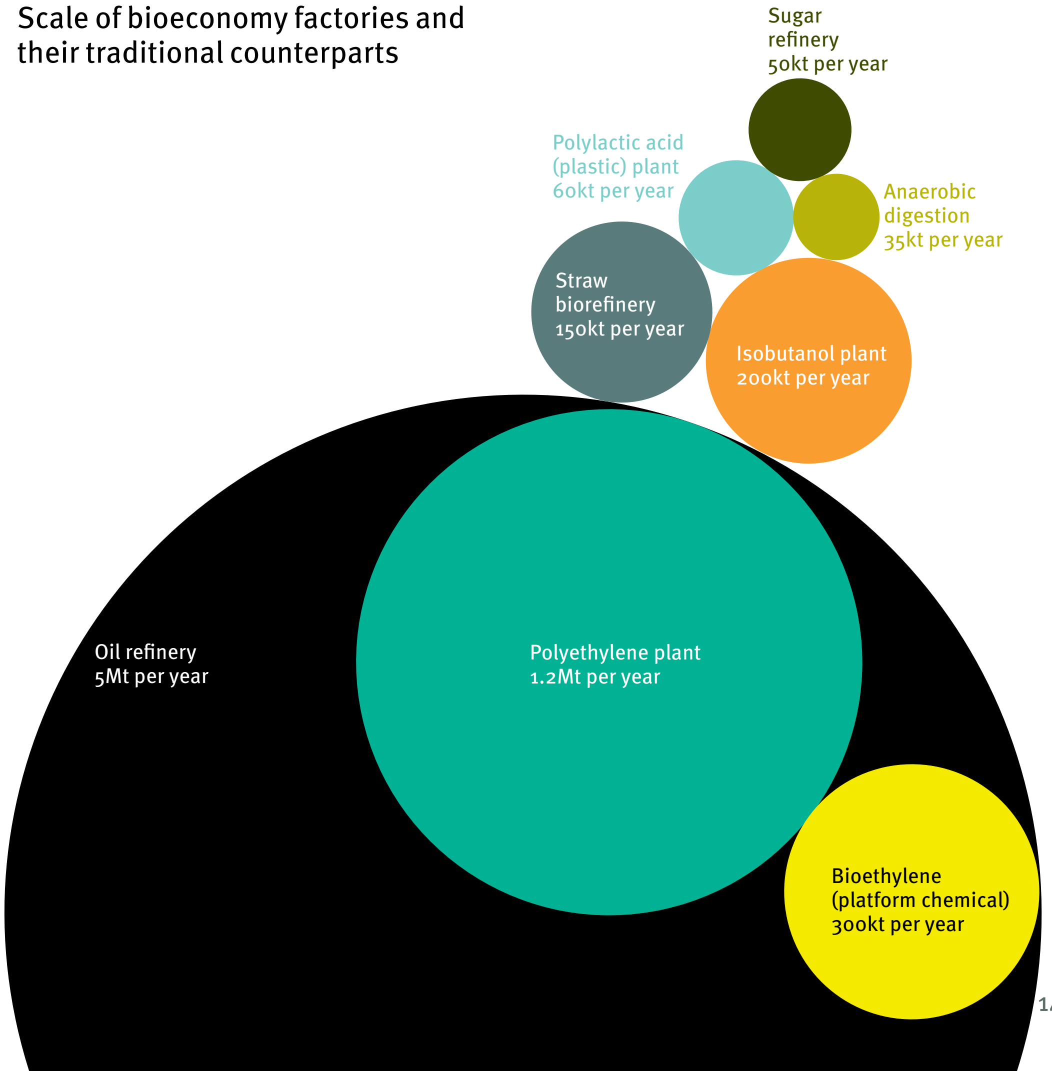
But other opportunities are subject to feedstock competition and infrastructure incompatibility, creating create lock-in risks. For instance:

- converting biomass into platform chemicals relies on substantially the same feedstock as AD;
- pot ale syrup production competes with AD and protein recovery technologies for feedstock;
- the scale of production for different systems varies, affecting transport networks and the number of supply chain actors. Rough scales for different technologies are shown on the right.

By comparison, 9-13Mt of total biological byproducts and wastes are thought to be available in Scotland.[23] There's a choice between larger, lower value, more flexible technologies which are nearer to market, such as biofuels, and higher value, but more inflexible ones, which carry more technological risk.

Scotland only has enough feedstock for one, or perhaps two, biofuel plants able to scale up to compete with fossil fuels. In contrast, a larger number small scale plants could be more resilient to changing economic conditions. This may mean that higher value, low volume options are preferable, but these are likely to need intervention to achieve.

Scale of bioeconomy factories and their traditional counterparts



The importance of brokering

Many of the challenges outlined above can be eased by using Scotland's institutions as brokers, to match feedstock with potential users; to help address transport challenges and lock-in risk; or to support the financing of new projects.

Brokering is most important at smaller scales, both of geography and business. For example, just 200 of the 1,200 food and drink manufacturers in Scotland have revenues over £1 million. These SMEs are likely to require assistance to access high value recovery opportunities.

There are two strategies for brokering:

Area based: this is likely to make most sense in Scotland's more remote locations, especially on islands. This brokering role could be fulfilled by local authorities, though they would need to work across the municipal and commercial waste divide to maximise opportunities.

Sector based: for high value, higher volume feedstocks. Examples include fallen stock from salmon farms, to recover fishmeal and fish oils; protein recovery and platform chemicals from the higher volume whisky distilleries; and biorefining from forestry by-products.

Effective brokering needs to be guided by an assessment of technology maturity and the scale of operation required by different biorefining processes. Indicative thresholds could help to inform the scale for collection and convening.

The table on the right is an overview of these main challenges to extracting more value from biowaste, and the possible interventions to overcome them.

Challenges and interventions for biowaste

Challenge	Intervention
Transport	Big business can organise this independently, but remote regions and SMEs will need brokers
Availability and seasonality of feedstock	Feedstock assessment, which Scottish Enterprise is undertaking
Infrastructure lock-in	Outline assessment of the fit of different feedstocks with technologies
Finance	Overview of how subsidy, waste regulations and fossil fuel price projections affect bioreactors
Durability of the market for outputs	Leave to the market to assess

Key sector
Finance

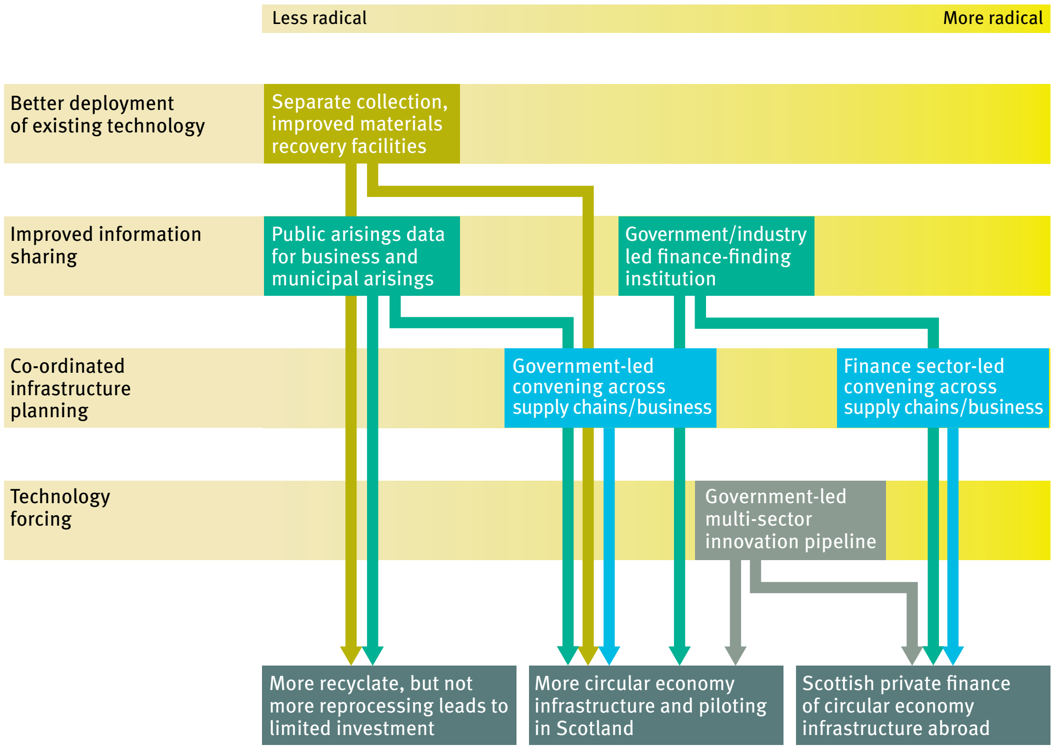
The finance sector does not produce or consume large quantities of resources, but is a key enabler for the circular economy. Understanding how finance can play a part in the circular economy in Scotland means seeing the circular economy is an innovation process, which has two key elements:

Co-ordination: high value opportunities, via reuse or remanufacturing, need designers, manufacturers, retailers and logistics companies to work together to make and move products.

Technology: achieving technology innovation requires new means to share information about a product's lifetime, repair, and function, along with new technologies to reprocess, redesign and remanufacture.

To illustrate how these two needs might be addressed together, so that more circular economy infrastructure can be financed, three scenarios are outlined on the right which capture a range of possible interventions and outcomes.

Potential circular economy interventions for the Scottish finance sector



Existing policy may hamper circular economy finance opportunities

There is significant finance available for the resources sector, but it is focused on energy from waste (EfW) technologies. Interviews we conducted with finance professionals in Scotland suggest this is not because the finance community believes EfW maximises value recovery. Rather, investment takes place because of subsidy; for example through financial support for pyrolysis and gasification; PPP contracts; and feedstock guarantees, via local authority contracts.

Although recycling captures more value from materials, fluctuations in the market value of recycled plastics are seen as risky, compared to the stable returns created through subsidy. Getting finance for higher value circular loops will require a reassessment of current policy. The German government's assessment for biobased materials concludes that "market distortion hinders the competitiveness of producers of materials [rather than energy] from biomass… which are not counteracted by taxes on fossil carbon sources as a raw material."[24]

Closed loop recycling, reuse, biorefining and remanufacturing should not need to be subsidised once scaled up but, where there is competition for feedstock or finance, public policy should be adjusted to enable these technologies to compete.

Because of its scale, Scotland may need to work with other governments to address existing market incentives: for example, there is strong demand for refuse derived fuel in other parts of Europe, and UK policy favours biomass for energy.

Different support systems for energy and materials in Germany.[25]

Instruments	Biofuels	Biogas for electricity	Wood pellets for electricity or heating	Material use, bio based products
Tax incentives	Yes	(Yes)	Yes	No
Quotas (biofuels, RED)	Yes	Yes	Yes	No
EEG (electricity/heat)	Yes	Yes	Yes	-
Emissions trading (ETS)	Yes	Yes	Yes	No
Market introduction schemes or special market regulations	Yes	Yes	Yes	Yes (but largely expired) (for lubricants, insulation and bioplastic packaging)
Others (eg rural development scheme)	Yes	Yes	Yes	No (CAP reform proposal 2011: Yes)
Research and development	Yes	Yes	Yes	Yes

Least radical: incremental improvements to circular economy finance

As in previous scenarios, limited collaboration and technological innovation mean that much of the value of the circular economy can't be captured, or in this case, can't be financed.

In the case of biobased feedstock, anaerobic digestion is a proven technology, viable at small scale, supported by subsidy and Scotland's zero waste regulations to improve feedstock availability. This makes it the most bankable circular economy option, suggesting improved feedstock separation would enable the finance community to support more AD. In contrast, finance for projects with marginally higher technical risk is unlikely to be available without further intervention: even relatively less risky ethanol producers, like Ineos Bio and Vireol Bio-energy, have located their plants in the US to take advantage of locally available grants and tax rebates rather than achieving finance to develop their technologies in the UK.[26]

In the case of abiotic materials, better sorting might also enable incremental improvement in financing of circular economy infrastructure. The scale of feedstock required for closed loop plastics reprocessing, and WEEE or large scale metal recycling, means that investors have a bias for projects closer to large sources of arisings, ie locations outside Scotland. Scotland's existing strategy of improving sorting, if extended, might enable smaller scale, feedstock specific recycling plants to be built in Scotland. For example, Biffa Polymers in Redcar switched from mixed plastics to single stream polypropylene, which makes its relatively small scale, just 20,000 tonnes per year, economically viable.[27]

There are also data driven, sector-specific opportunities. Feedstock risks could be reduced by identifying a range of potential suppliers through much more detailed, publicly available data on arisings, collected across municipal, commercial and industrial sectors. This would enable venture capital and private equity finance to more readily arrange for the feedstock needed to enable more circular economy infrastructure to be built.

The recently announced Scottish Materials Brokerage Service could fill these data gaps, especially if data about commercial and industrial waste is included. To capture the very high value options, it would ideally need to provide more specific information about materials than existing European Waste Codes data.

There is, of course, no guarantee that the infrastructure using Scottish materials would be built in Scotland. Instead, due to scale and geography challenges, feedstock exports for some materials may make the most financial sense.

Overall, this least radical approach is likely to see limited investment as the finance community focuses on easier opportunities elsewhere. However, Scotland would benefit from capturing more value from exported materials.

More radical: infrastructure and innovation

Improving access to finance

The clear conclusion from our discussions with finance professionals is that the finance sector is very unlikely to seek out higher risk, higher value activities alone. Achieving either more infrastructure in Scotland or, more optimistically, a more adventurous Scottish finance sector which funds circular economy infrastructure projects abroad needs much more intervention.

A finance finding institution

A minimal intervention would be to create or support an institution to match existing cleantech investors with those seeking funding. This could increase the quantity and quality of interaction in the sector and reduce fragmentation, enabling business links to be made across supply chains. It would improve new entrants' understanding of finance, and make finding suitable finance easier.

EcoConnect, a not-for-profit company, Scottish Enterprise and Highlands and Islands Enterprise, and Zero Waste Scotland have all performed aspects of this role, but not comprehensively or at scale. More importantly, the evidence of effective matchmaking institutions elsewhere, like the London Waste and Recycling Board, is that they need to be able to fund innovative companies directly to leverage significant private finance.

The government could consider supporting these organisations or creating a new institution with a mandate to link investors, which could also provide or co-ordinate co-funding where appropriate.

Government led financing

Finance finding would help projects that are close to being financed already. But these projects are dominated by low value combustion and downcycling, with limited investment in the higher value circular loops we have described. This is because the returns are uncertain and many of the risks are binary: unproven technologies may or may not scale up; feedstock availability is uncertain; the durability for a market for remanufactured and reused goods is viewed with scepticism; and there can be a large number of supply chain actors who need to co-operate.

These risks can't be priced, and can determine the success or failure of a project, driving away most investors. In the UK, according to the LSE's Growth Commission, investment is already "heavily skewed towards property and buildings, rather than equipment, innovation and new technologies" due to lower perceived risks in property.[28] In this context, a more active institution, pursuing targeted innovation to deliver a circular economy, will be needed.

Using innovation institutions

Really driving innovation with suitable funding requires specialist institutions, directed to commercialising circular economy opportunities. It is likely that leadership would need to come from the state. As Professor Mariana Mazzucato outlines in *The entrepreneurial state*, "Not only has government funded the riskiest research, whether applied or basic, but it has indeed often been the source of the most radical, path-breaking types of innovation." Her research shows that these innovations happened not just through funding, but by "envisioning the opportunity space… and overseeing the commercialisation process."[29] The business model and co-ordination needed to deliver a circular economy requires path-breaking innovations to be fostered through commercialisation.

If led by the state, these institutions – which would have to encompass a broader set of goals than simply providing finance – would almost inevitably seek to secure investment in Scotland, though it would be constrained by Scotland's scale (see page five).

Finland's Tekes innovation agency is a highly relevant model which combines foresight, strategic steer and risk capital. A Scottish version of Tekes could help to diffuse circular economy finance lessons to project developers and financiers interested in investing in Scotland.

This model could also, in a very optimistic scenario, develop exportable expertise in circular economy project development and finance.

Lessons for Scotland

The circular economy presents two types of opportunity, which each require a different approach:

Resource efficiency opportunities, characterised by the **diffusion** of near commercial or established technologies, and increased collaboration within broadly established business models. In our sector analyses, examples of these included:

- metal alloy separation to improve recycling; and
- the expansion of biowaste feedstock analysis to improve AD viability.

Circular economy opportunities, characterised by **innovation**, to establish and commercialise novel technologies, and by some degree of business model integration along supply chains and between sectors. In our sector analyses, these included:

- business model integration: steel reuse in construction, extending supermarket distribution systems to food redistributors; and
- new technology: CCS and biorefining to create chemicals or extract proteins and other valuable products.

Learning from energy policy

Policy is driving the energy sector toward both incremental and transformational change, driven by the need to decarbonise. Four strategies have been used to foster this change, which provide useful lessons for the range of policy options that Scotland could choose to promote the circular economy.

Four strategies for change

Change strategy	Interventions
Focus on research	Fund R&D Tax externalities (eg carbon tax) Let the market do the rest
Avoid lock-in	Fund R&D Regulate away bad choices (eg no new coal without CCS, landfill bans and gCO_2/km limits for cars) Let the market do the rest
Create competition	Fund R&D Subsidise many technologies to prove commercial viability (eg the UK government's electricity market reform strategy to promote renewables, nuclear and CCS) Auction mature technologies to find the cheapest
Pick winners	Fund R&D, targeted on key sectors Analyse the viability/suitability of options early, and choose a subset of the best to focus on (eg Germany's Energiewende) Support market competition within chosen technology families

What is Scotland's existing strategy?

The strategies shown on the previous page are ideal types. Countries have chosen parts of each strategy, and Scotland has operated within the UK's overall strategy. However, Scotland has focused on the following two:

Scotland's strategies	Interventions
Avoid lock-in	Banning new nuclear and non CCS coal power stations
Pick winners	Consistently political promotion of wind and marine power, based on an assessment of Scotland's geography Support for these technologies via enterprise agencies, planning policy, and subsidy

In doing so, Scotland has been consistently much more successful at decarbonising than the rest of the UK, helped by its wealth of natural renewable resources and drawing on 28 per cent of the total UK renewables subsidy spending in 2012-13.[30]

Adapting Scotland's existing strategy

How could Scotland promote a circular economy, drawing on the strategies it has used for low carbon energy?

Scotland's strategies	Interventions
Avoid lock-in	Foster agreement (or regulate) to achieve well known 'resource efficiency' type opportunities, like separation of alloys in rig decommissioning and plastics, or extension of supermarket IT systems to food redistribution
Pick winners	Move from business-led innovation to a more directed, challenge focused innovation system to capture 'circular economy' type opportunities, like CCS and biorefining

Overall, greater resource efficiency opportunities can be achieved by improving the collaboration activities that Zero Waste Scotland and other entities, like Scottish Enterprise, already conduct. Scotland is already ahead of other parts of the UK in policy terms. As noted above, the main challenges to increasing resource efficiency opportunities for Scotland relate to its relatively small scale and consequent challenge in attracting investment for projects which require large amounts of feedstock, and enforcing regulation that is not shared with other parts of the UK or the EU.

Achieving more radical circular economy opportunities requires institutions and policy to function as an innovation system, with "interaction between companies and publicly funded research, education, public infrastructure, venture capital and regional development agencies." New innovation research shows that the state can play an important role in investing and co-ordinating research.

Developing such a system is necessarily risky: innovation happens amidst a sea of good but failed projects. The main political challenge is to invent a 'legitimising rationale' to justify investment in technologies and business models which will include failures. The main policy challenge is to build and maintain an innovation system which fosters interaction between public research, companies, venture capital and enterprise agencies.

Scotland can improve its odds of success by taking a clear political direction, backed by challenge oriented innovation bodies, mandated to concentrate on areas where Scotland is likely to have comparative advantages in the future.

A clear direction

Innovation thrives on spending. Being a relatively small country, neither Scotland's public sector nor the private sector will have deep pockets compared to international competitors like the US, China, or Germany. This means Scotland will have to choose technology families within the circular economy that are best suited to its comparative advantages, and develop a roadmap to fund and foster these. This is risky and uncertain, but the alternative, 'spray and pray' approach requires very deep pockets.

Scotland has already invested in innovation centres and has a strong university sector. Critical to success will be to remain linked to the wider UK innovation network. The precedent set by Nordic Innovation and NordForsk, where relatively small Nordic countries collaborate on R&D, shows one way to balance the specialisation demanded by a small size with access to a wider network.[31]

Creating courageous institutions

The existing focus of Scotland's innovation centres is not designed to deliver significant circular economy opportunities: the Industrial Biotechnology Innovation Centre (IBioIC) states that its "industry partners have identified five major themes for IBioIC" and the Scottish Funding Council states that "evidence of industry demand is a fundamental requirement" for innovation centres.[32]

While a connection to business experience is important for innovation to thrive, the 'led by industry for industry' model is likely to encourage shorter time horizons, more incremental innovation and a focus on lower risk near-to-market opportunities. Existing industry is quite rightly embedded in solving today's problems. New technologies and business models for a circular economy are more likely to arise from a focus on longer-term opportunities rather than existing business pressures.

Instead, if Scotland wants to capture significant circular economy opportunities, it should adopt a challenge led model. The Saltire prize provides an initial step towards this challenge led model, but Scotland could learn from examples in both the public and private sector.

For example, the US government's advanced energy innovation centre, ARPA-E, sets its objectives via a deep dive into a particularly challenging energy problem, identifying the potential technical merit of technology solutions and their potential market pull and cost effectiveness. The assessment incorporates detailed workshops, involving academics, civil servants who have specialist sector knowledge, and business experts. This problem led approach, along with a mandate to avoid incremental improvements, ensures a focus on advanced technology.

In the private sector, an excellent example of a challenge led model comes from the Confederation of European Paper Industries' (CEPI) 'two team' project.[33] This open innovation process started with a single challenge: to cut the industry's CO_2 emissions by 80 per cent while creating 50 per cent more added value. CEPI then set up two teams of scientists and business people and asked them to start building a common knowledge base, drawing on their own expertise and ideas from other sectors with carbon reduction targets, including the steel and chemicals industries. The teams were then asked to compete to develop four technology ideas each, with a view to being judged on their carbon reduction, value add, innovativeness and feasibility potentials. The intellectual property rights for the ideas were retained by CEPI, which will then license them to its members to ensure the industry as a whole benefits.

In both cases, a challenge was set externally to ensure it was stretching, and the process was characterised by the involvement of numerous actors and significant knowledge sharing. These factors should form the basis for more radical circular economy innovation institutions.

Conclusion

Achieving a circular economy in Scotland will involve a combination of diffusing established but not yet common business practices and technologies, and the development of radically new technologies and business models.

Scotland's existing policies are beginning to spread better resource management already. Therefore, we have focused our recommendations on what more can be done to exploit more radical circular economy opportunities. We see Scotland's industrial strategy for a circular economy essentially as an innovation strategy, grounded in a clear view of the country's characteristics and the global challenges that face its businesses. We stress the importance of institutions, and the connectedness needed to foster collaboration down supply chains and across sectors.

Scotland is in a strong position to benefit from first mover advantage in the development of a circular economy; the Scottish government's plan to develop a roadmap is the opportunity to make it happen.

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