UNIVERSITY OF BIRMINGHAM | BIRMINGHAM ENERGY INSTITUTE

ERA ENERGY RESEARCH ACCELERATOR

At the forefront of energy transformation

ENERGY FROM WASTE AND THE CIRCULAR ECONOMY

NET-ZERO AND RESOURCE EFFICIENT BY 2050

THE BIRMINGHAM POLICY COMMISSION

FOREWORD

Waste, not least in terms of plastics, has had a high profile over this last year. There's been the government's Resources and Waste strategy, and a government manifesto commitment to levies on plastics and deposit return schemes. On the international front, Asia has rejected its former role as the West's destination for low-grade recyclate. That lazy route of exporting the leftovers of our consumer society has closed. Few of us regret that change. It's a move on from polluter pays to polluter sorts out its own mess.

At the same time, on a broader scale, industry and policy-makers have become more familiar with the term 'circular economy', and the wastefulness of its linear cousin. Waste hierarchies might have to wait a little longer for full public recognition.

When it comes to energy, the last 12 months have seen the further rise of renewables, the falling away of their costs, and ever increasing periods of coal-free generation.

But a fully circular economy is still some way into the future. As we have seen, we can no longer export our problems away. Nor will landfill remain an acceptable – or affordable – solution. Yet at the same time, we urgently demand ways to deliver low-carbon heat and power.

Energy from waste will remain an important part of this complex jigsaw. Yet on the face of it, energy from waste, low-carbon energy, and the circular economy are not obvious bedfellows. That's why this report is of its time, and why I was pleased to chair its Commission.

Energy from waste is an essential intermediate technology, but it has to improve its act. The full utilisation of waste heat must be mandatory. Bringing together commercial and industrial enterprises around EfW plants in Resource Recovery Clusters has to be the solution.

Even that goal is a limited one. We should also use waste carbon emissions to produce new products – on site. The report uses the term 'moving molecules' rather than just electrons.

Then there is a further generation of energy from waste technologies – anaerobic digestion and pyrolysis. These too can increase our carbon efficiency and get us further up the waste hierarchy. But we also need research and an ever better pathway to the future. So I welcome the report's call for a national Centre for the Circular Economy.

I greatly thank the many witnesses we met during the Commission's work, and the Commissioners who gave freely of their time.

Lord Robin Teverson, Policy Commission Chair

ABOUT BIRMINGHAM ENERGY INSTITUTE

The Birmingham Energy Institute is the focal point for the University of Birmingham and its national and international partners, to create change in the way we deliver, consume and think about energy. Bringing together interdisciplinary research from across the University of Birmingham and working with government, industry and international partners, the BEI is developing and applying the technological innovation and original thinking required to create sustainable energy solutions.

Our global community is consuming more energy than ever. As we run out of time to contain climate change the BEI is upscaling their innovative technology solutions for applications across the globe and influencing and shaping policy on critical issues such as waste management, materials supply and decarbonisation of heat to shape the energy solutions of tomorrow.

The UK government is committed to bringing all greenhouse gas emissions to net-zero by 2050. The Midlands region is renowned for its ability to drive technology revolution and its nationally leading manufacturing and engineering base. The Birmingham Energy Institute is working with business, industry and policy stakeholders across the region to realise the transition to net-zero.

ABOUT ENERGY RESEARCH ACCELERATOR

The Energy Research Accelerator (ERA) draws on the expertise and world-class facilities of the Midlands Innovation group of universities – Aston, Birmingham, Cranfield, Keele, Leicester, Loughborough, Nottingham and Warwick, plus the British Geological Survey.

ERA is funded by Innovate UK, which has invested £60 million in 23 state-of-the-art facilities with an additional almost £120 million of co-investment provided by a range of industrial partners who are working with ERA on a range of projects across the Midlands.

The purpose of the Energy Research Accelerator (ERA) is to work with UK government, industry and the higher education sector to undertake innovative research, develop the next generation of energy leaders, and demonstrate low-carbon technologies that help shape the future of the UK's energy landscape.

CONTENTS

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LIST OF FIGURES

LIST OF TABLES

LIST OF BOXES

LIST OF CASE STUDIES

A note on terminology

In the waste industry, the term energy-from-waste (EfW) is often used as a synonym – or perhaps euphemism – for incinerators. This is because incinerators are the predominant technology and generally unpopular with the public. There are, however, other energy-from-waste technologies, such as AD, pyrolysis and gasification. In this report, we use 'EfW' only as an umbrella term. No inherent criticism is meant in our use of the word incinerator.

1. EXECUTIVE SUMMARY

Disposing of waste is a vital public service that protects society from infection and infestation. The waste industry, though hardly popular, has performed this role well over the years. And for many of us, after we throw our rubbish in the bin, it's out of sight and out of mind.

But now we and the industry face a major challenge. The main methods of waste disposal in Britain today, landfill and incineration, emit large amounts of greenhouse gases and squander valuable resources – both energetic and material. It is widely agreed this cannot continue, but there is less consensus about what to do. We believe the Midlands could lead the way.

The problem is getting more complicated. We no longer have only CO_2 to worry about, but also our resource efficiency – or inefficiency – which, in a finite world, is clearly unsustainable. On average, each kilogramme of products consumed in the UK takes 10kg of material to produce, of which 9kg is discarded as waste. In other words, measured by weight, our resource economy is just 10% efficient.[1] Then there is rising public concern about plastic waste, reinforced by appalling TV images of marine litter.

Time is getting tighter, too. Britain lacks the capacity to deal with all the waste it produces and exports millions of tonnes. But now countries in the Far East have rightly banned unwanted shipments of waste from developed countries. Britain still exports 3.5 million tonnes of waste to Europe, but the Netherlands has recently imposed tariffs, and a no-deal Brexit could cause a waste crisis at the end of this year. The difficulty of managing these challenges is compounded by datasets that are incomplete and incompatible.

For some, the answer is clear: we need a 'circular economy' with much higher levels of recycling, which both conserves resources and cuts CO_2 emissions. If we achieve that, they argue, we won't need energy-from-waste (EfW) plants, which are mostly incinerators that generate only electricity, because we won't have any rubbish left to burn. Worse, they claim, the very existence of incinerators discourages recycling, so we must get rid of them.

We entirely agree that everything must be done to raise recycling rates. But the choice is not binary. Changing large infrastructure systems takes time, and there are newer EfW technologies like anaerobic digestion (AD), and pyrolysis and gasification plants, which could play an integral part in the circular economy. And however high we manage to raise recycling rates – currently stuck at about 45% – there will always be some residual waste. In some ways, this may not be a problem but an opportunity.

We believe some EfW will always be necessary but that it must be made more circular and lower-emitting. And we are convinced that with the right changes in policy the industry can plot a path to become zero-emission and resource-efficient by 2050. With far higher recycling rates, it will be a smaller industry than today but potentially more valuable. It will certainly be more integrated with recycling systems and local economies.

WE CAN ACHIEVE THIS IN THREE STEPS

1. Exploit the waste heat of existing and new EfW plants. Britain's incinerators are the most carbon-intensive generation on the UK grid after coal, largely because only one-in-five plants makes any use of its waste heat. Scandinavian plants, where incinerators are used for district heating, emit scarcely a quarter as much per unit of energy.

2. Develop and roll out second-generation EfW technologies including AD, pyrolysis and gasification, which turn waste into molecules and products as well as energy.

3. Roll-out proven small-scale carbon capture technologies that turn CO_2 into (for example) building products and fertiliser, and greatly boost R&D in this field.

National policy reforms must include a more Scandinavian approach to heat, major public investment in infrastructure and strengthened support for R&D and VC-stage technologies. Together, this would greatly improve resource efficiency; start to decarbonise heat, one of our toughest challenges; and set EfW on course to reach net-zero by 2050.

We recommend many detailed reforms in this report but believe that meeting this challenge depends critically on three major innovations: building a network of local and regional **Resource Recovery Clusters**; creating a national **Centre for the Circular Economy**, and launching an **R&D Grand Challenge** to develop small-scale circular carbon capture technologies.

The Resource Recovery Cluster

Waste and energy from waste are inherently local issues, and we believe they demand a local and regional approach. We propose a network of new Resource Recovery Clusters (RRC), developed on post-industrial sites, which could produce significant environmental and economic benefits. The RRCs would combine a spread of EfW and recycling technologies with businesses that can consume their cheap electricity, heat, fuels, CO_2 and material outputs – so greatly reducing carbon intensity and improving circularity (see Figure 1).

This idea chimes with existing work by BEIS and the Department for International Trade, known as the Load Creation Model, designed to lure inward investment by providing secure, economic and low-carbon energy supplies.

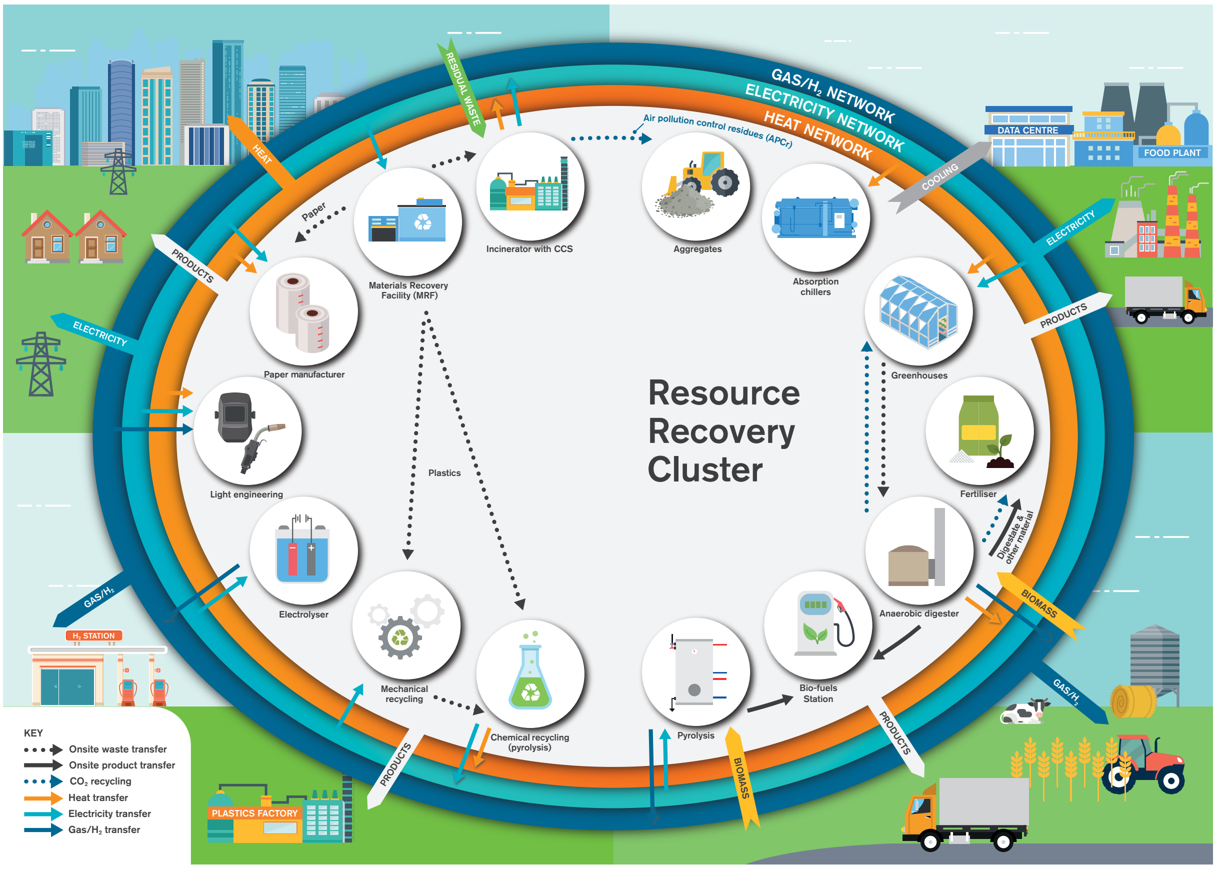
The clusters would reduce CO_2 emissions and improve circularity in the short-term but would also support the innovation needed to reach net-zero and far more circular economy by 2050. The Midlands has plenty of suitable post-industrial sites, including recently de-commissioned coal-fired power stations (see Figure 2), redundant surface mines and former manufacturing plants.

The Centre for the Circular Economy

At a national level, we urge the government to set up a new national Centre for the Circular Economy (CCE). Despite a plethora of recent reports, our understanding of resources and waste still lags our understanding of greenhouse gas emissions. The CCE would analyse material flows throughout the economy down to regional and local levels; develop deep expertise in recycling and EfW technologies; develop strategy; and make policy recommendations. The CCE would draw on national materials-flow databases developed in Far Eastern countries such as Taiwan and consider how to replicate them here. Crucially, it would provide expert guidance and support for local authorities as they develop local or regional strategies and planning frameworks. Another important role would be to set 'accounting' standards for life cycle assessment (LCA).

On climate, the government has long recognised the need for the robust, independent advice and scrutiny provided by the Committee on Climate Change (CCC). The CCE could perform a similar role. The two bodies would be jointly tasked with resolving any conflicts between climate and resource priorities.

FIGURE 1: THE RESOURCE RECOVERY CLUSTER



R&D grand challenge

Achieving net-zero in the waste system will depend on making big advances in small-scale carbon capture. Technologies to turn CO_2 from EfW into useful products already exist and are economic, but so far capture only a small proportion of the CO_2 emitted. We urge the government to launch an R&D grand challenge for small-scale carbon capture so that 100% of CO_2 from an EfW plant can be economically captured and turned into useful products. Encouraging ways to use CO_2 rather than sequester it is particularly important for areas such as the Midlands that are remote from depleted oil and gas reservoirs. The government has promised to raise its R&D spending to £22 billion by 2024–25, including £800 million for a new ARPA-style blue skies funding agency. This is exactly the kind of challenge it should tackle.

The Midlands

The Midlands is not a unified political entity, but its size, diversity and resources make it an ideal region in which to pilot our ideas. The region covers a major urban conurbation in the west and less densely populated rural areas in the east; a variety of political structures including regional, unitary and two-tier authorities; and many post-industrial sites that could become Resource Recovery Clusters. It also boasts deep and widespread academic expertise in energy. These characteristics mean it could be an excellent test bed to demonstrate the potential of the RRCs for the country as a whole.

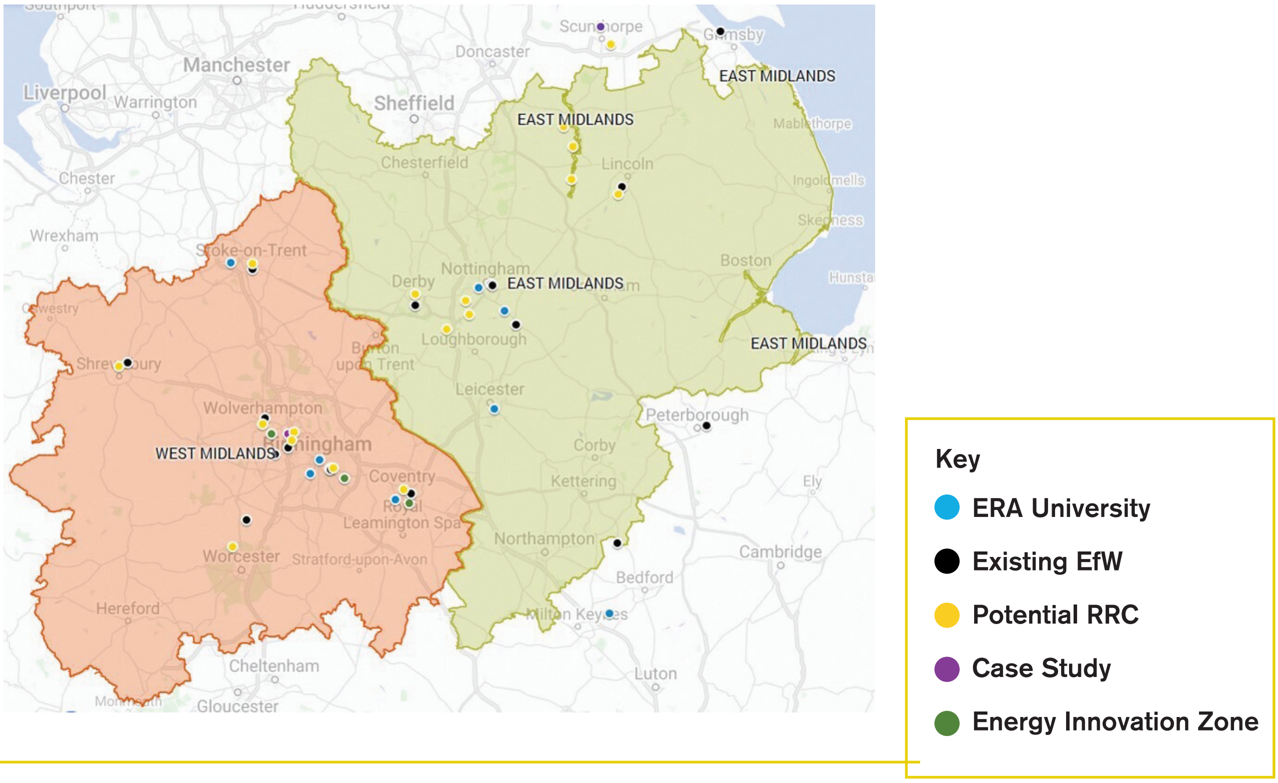
The economic benefits to the Midlands could be large. An analysis by Advantage West Midlands (AWM) in 2010 found that in the West Midlands the wholesale cost of energy, compost and fertiliser totalled £3.9 billion, while the wholesale value of the carbon contained in the region's waste was almost £500 million.[2]

Our proposals are evidently urgent, and not simply because of the rising climate chaos. The UK has recently legislated the world's first net-zero target for 2050[3], and the West Midlands Combined Authority has set 2041 as its regional target.

Developments in waste export markets imply deadlines that are even more pressing. So we have a narrow window in which to make the right choices to avoid carbon lock-in or stranded assets, and make sure we can still benefit from future innovation in waste, energy and green chemistry.

If Britain develops compelling answers to this challenge, it could unlock a massive global export opportunity. Almost 1,000 EfW plants exist worldwide, with a total capacity of 13.7GW, of which incinerators account for 11.6GW, and there is huge unmet demand for waste processing in China, the Middle East and Africa.[4] It is also a great opportunity to demonstrate UK leadership at COP26.

FIGURE 2: ENERGY-FROM WASTE PLANTS, CENTRES OF ACADEMIC EXPERTISE, AND SAMPLE POST-INDUSTRIAL SITES IN THE MIDLANDS. SEE APPENDIX 1 FOR FULL LIST OF SITES.



RECOMMENDATIONS

We urge the government to:

Heat

- Ban the building of new incinerators except those which make full use of their waste heat, IBA and APCr residues, and a rising proportion of their CO_2. Even now, incinerators continue to gain planning permission without such obligations, potentially locking us into high-CO_2 electricity-only plants for decades to come. This must stop.
- Consider introducing an efficiency ratchet, which would oblige operators of future and existing plants to meet rising efficiency standards by target dates. This would force operators to find users – probably industrial – for their waste heat and would support the development of Resource Recovery Clusters.
- Introduce 'green gas obligation' – like the Renewable Transport Fuel Obligation (RTFO) scheme – so that suppliers have to ensure a rising proportion of their gas comes from low-carbon sources such as biomethane or sustainably produced hydrogen.
- Increase support for district heating networks tenfold. Current funding for the HNDU/HNIP programme is £320 million – plus a further £270 million announced in the budget of March 2020.[5] The IPPR calculates that if government raised this to £3 billion, it would lever in private investment of £22 billion, enough to supply 10% of UK heat by 2030, the target set by the Committee on Climate Change (CCC). We believe the government should commit to raise HNIP funding to the level needed to achieve the CCC target – raising it tenfold to £3 billion if necessary.
- Offer the HNIP funding approach to any Resource Recovery Clusters established around existing electricity-only incinerators.
- End the uncertainty about the RHI and renew or replace it.

Circularity

- Standardise and level-up the separation of waste streams at source and make good on the waste strategy's promise to fund local authorities to provide separate collections.
- Introduce fiscal measures to shift the balance from virgin to recycled materials, and to move waste streams up the waste hierarchy. The proposed tax on any plastics containing less than 30% recycled material would be a good start, but the same approach should be extended to a much wider range of materials.
- Introduce business rate (or other tax) relief for companies relocating to new Resource Recovery Clusters provided they demonstrate both circularity and carbon reduction.
- Introduce 'renewable fertiliser obligation' – modelled on the RTFO – which would oblige suppliers to incorporate a rising proportion of non-fossil fertiliser in their sales. This would stimulate more investment into – for example –

upgrading AD digestate into properly formulated fertiliser.

Support for local authorities

- Task upper-tier and strategic regional authorities to lead infrastructure assessment and planning for Resource Recovery Centres.
- Revise the National Planning Policy Framework to ensure local authorities have powers to impose conditions around circularity and greenhouse gas emissions on developers of waste and recycling facilities. The government has an early opportunity to do this in its forthcoming planning white paper.
- Support local authorities in developing Resource Recovery Clusters. After a decade of austerity, most local authorities lack the resources and capacity to tackle waste and energy challenges, and this is one of the biggest barriers to progress. The new Centre for the Circular Economy will have little impact if local authorities lack the capacity to act upon its advice and adapt it to local circumstances. The government must rebuild local authorities' financial and human resources so they are able to develop strategy and let and manage commercial contracts.
- Fund councils to map the area around each UK incinerator, particularly those remote from sources of heat and cooling demand, for land that might be available and suitable for new Resource Recovery Clusters.
- Where mapping shows potential, provide financial support to help develop the first few Resource Recovery Clusters – as in Scotland (see case study, page 54).
- Support councils to solve the problem of contract cliff-edges, where towards the end of a heat network operator's contract it becomes uneconomic to take on new connections (see page 33). Fixing this should be possible with some kind of 'transfer of undertakings' from one operator to the next, but the problem is widespread and illustrates the lack of capacity among councils to deal with these contractual issues.

Technology

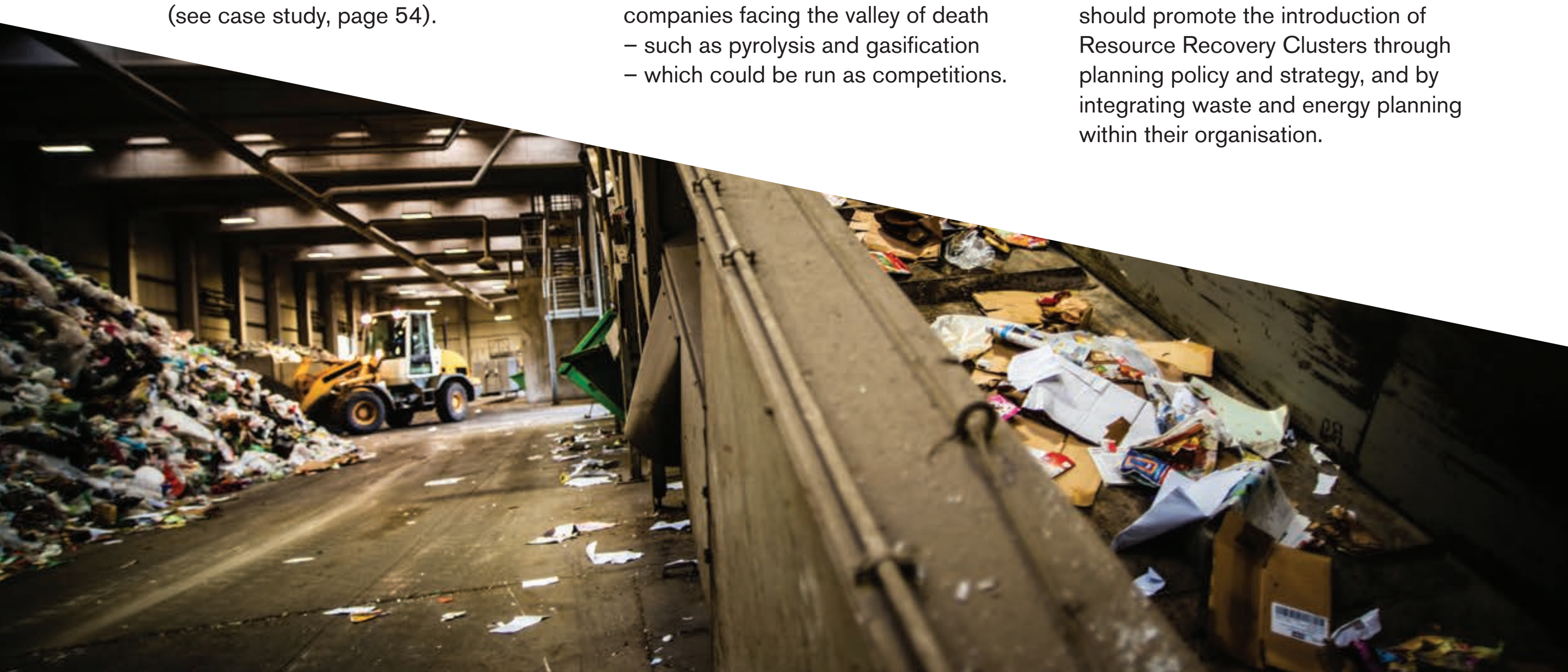
- Launch an R&D grand challenge for small-scale carbon capture and reuse so that 100% of CO_2 from an EfW plant can be economically captured and turned into useful products. Encouraging ways to use CO_2 rather than sequester it is particularly important for areas such as the Midlands that are remote from depleted oil and gas reservoirs. The government has committed to raise UK R&D spending to £22 billion per year, and both EfW and the circular economy deserve significant support.
- Fund R&D in high-priority areas. In biogas, this should include research into yield improvement, digestate upgrading and centralised gas injection. In pyrolysis and gasification, the main priority is to mount full-scale demonstrators. Developing small-scale, economic technologies that capture all the CO_2 emissions of EfW plants is exactly the sort of challenge the government's new ARPA-style 'blue skies' funding agency is intended to tackle.
- Reinstate ETI-style venture capital support for waste technology companies facing the valley of death – such as pyrolysis and gasification – which could be run as competitions. The ETI was highly successful, for example, in bringing down the price of offshore wind, but its public-private funding model meant that the resulting IP was kept in private hands. We favour a model that produces communal knowledge, which may imply a higher proportion of public funding or a different approach to tax relief.

Industry

- Oblige industries that manufacture hard-to-recycle products to produce roadmaps showing how they will reach 'net-zero and resource-efficient' by 2050. Sectors would include mattresses, tyres, paint, nappies and electrical and electronic. This should form part of a broader strategy to impose Extended Producer Responsibility (EPR) across the economy.
- Oblige all companies making LCA claims in marketing or other communications to publish at a minimum the 'goal and scope note' of their analysis. This sets out the objectives, boundaries, methodology and assumptions of the analysis, and identifies the datasets used. This would allow others to understand and challenge the claims made, while keeping proprietary data confidential.

Local and regional authorities

- Local authorities may be weakened and need central government to restore their financial and human resources (see above). But until then they can still play a significant role. Even with existing powers, councils and regional authorities could and should promote the introduction of Resource Recovery Clusters through planning policy and strategy, and by integrating waste and energy planning within their organisation.



2. SQUARING THE CIRCULAR ECONOMY AND ENERGY-FROM-WASTE

The circular economy

The basic ideas of the circular economy are hardly new, but they are increasingly urgent. Hand-me-downs the milkman collecting his empties, and the local electrical repair shop were all commonplace within living memory. Now we live in a world of plastic cutlery and 'fast fashion', where for many it seems impossible to walk down the high street without the latest hard-to-recycle smartphone in one hand and an un-recyclable coffee cup in the other. Our ever-accelerating consumption demands that we consider not only the CO_2 we pour into the atmosphere, but also the finite resources we hack from the earth.

Yet the public mood is turning. People are increasingly alarmed about spiralling climate disasters – from bush fires to floods – and some are turning politically militant: witness Extinction Rebellion. That awareness is now spreading to the issue of waste, particularly plastic, reinforced by appalling images of marine litter in the BBC's *Blue Planet* series.

Whereas climate change is about keeping CO_2 out of the atmosphere, the circular economy is about keeping materials – glass, plastic, wood, metals, chemicals, plant fibres – circulating in the economy for as long as possible. The idea is to replace the current 'linear' economy – in which we extract resources, turn them into products, use them once and then throw them away – with a more circular system, in which products are repaired and re-used, and materials recycled, to extract the maximum use from the primary resources. The benefits should include slower resource depletion, less damage to the natural world and, because recycling typically consumes less energy than primary production, savings in cost and CO_2.

The idea of the circular economy has developed over the last 50 years or so in the academic literature, and is now being taken up by governments. Since 2006, China has included circular economy ideas in its five-year plans. In 2015, the EU adopted a Circular Economy Action Plan with recycling targets for municipal waste, packaging waste and individual materials, and in 2018 introduced another plan for plastics[6]. That same year, the UK government launched its resources and waste strategy for England (waste is a devolved responsibility for Scotland, Wales and Northern Ireland), which also committed to move towards a circular economy.[7]

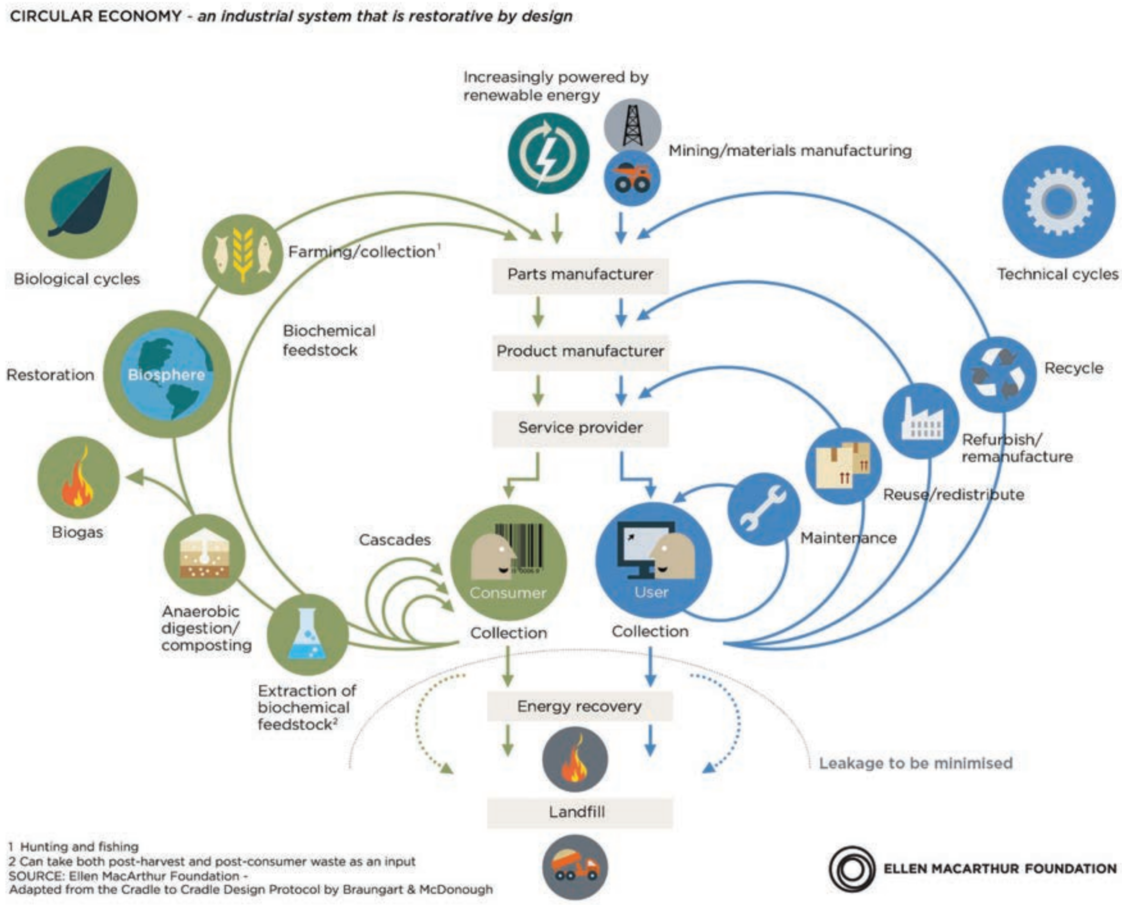
Big business has also embraced the concept almost across the board, perhaps because it offers financial as well as resource savings. Supporters range from investors such as Black Rock, tech giants Google and Dell, and engineering companies like Schneider Electric. The biggest concentration of support is among consumer-goods companies and retailers, however, whose customers are appalled by TV images of marine pollution. In Britain, 120 companies representing two-thirds of consumer plastic packaging have joined the UK Plastics Pact, with a series of targets for 2025 against which significant progress has been made.[8]

While plastic waste is clearly a huge problem, there are signs that the focus on plastic is producing unintended consequences. Unilever has promised to halve its use of virgin plastic by 2025[9], but its boss insists that a 'hysterical move to glass may be trendy but it would have a dreadful impact on the carbon footprint of packaging'.[10] Recycling old plastic bottles as fleeces might seem a good, circular idea at first sight[11], but now it emerges that fleeces shed microfibres[12] that cause all sorts of environmental damage such as stunting the growth of earthworms.[13]

In Britain, the most active promoter of the idea is the Ellen MacArthur Foundation, which since 2013 has explored its resource, environmental and economic potential in a series of reports.[14] The circular economy is based on three principles: design waste out of products and production processes; keep products and materials in use; and regenerate natural systems.

As shown in Figure 3, the idea distinguishes between biological and technical cycles. In the biological cycles, food, sewage and other biological materials such as cotton or wood, are processed to recover useful materials and energy, and then returned to the soil to restore its structure and nutrients. In technical cycles, products are kept in use for as long as possible through sharing and repairing, and then broken for parts, or the materials are recycled so that finite resources are kept in play for as long as possible.

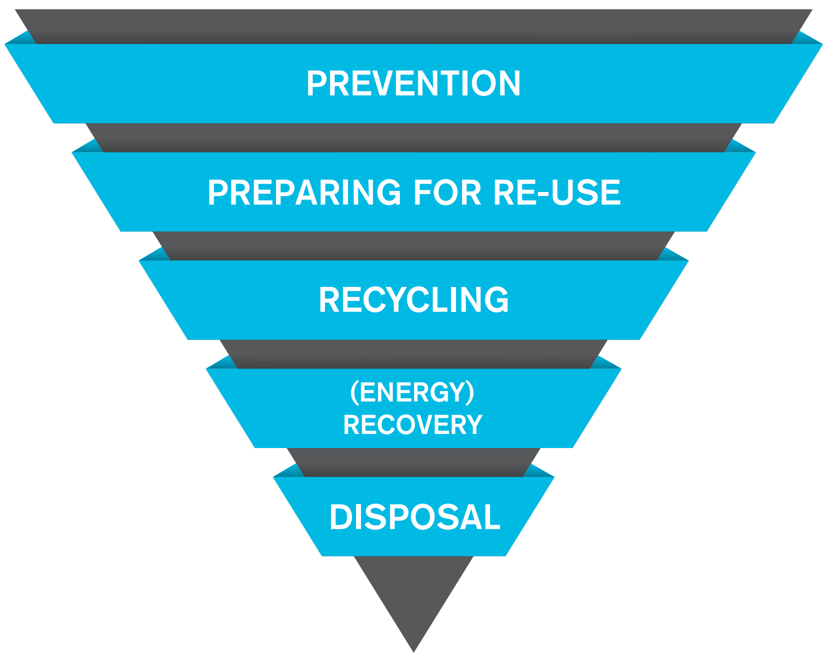
FIGURE 3: THE CIRCULAR ECONOMY. SOURCE: ELLEN MACARTHUR FOUNDATION.[15]



As the Figure 3 graphic makes clear, the whole idea is to minimise the amount of material that goes to energy-from-waste (EfW) or to landfill. More generally, the priorities of the circular economy are expressed in the Waste Hierarchy (Figure 4). Only after prevention of waste, re-use and recycling should EfW be considered, and disposal in landfill is the last resort.

There is no doubt that our current, linear economy creates mountains of waste, mostly invisible to the consumer. According to a major study co-ordinated by Biffa ten years ago, in the UK, each kilogramme of products takes on average ten kilos to produce, or 100 if water is included.[16] So although we are used to thinking of capitalist economies as efficient, in resource terms they are anything but. For every supermarket delivery van idling in your street, the resources required to produce its contents would fill another nine, and those resources have been – literally or metaphorically – dumped into a skip.

FIGURE 4: THE WASTE HIERARCHY



The Biffa study also found that Britons collectively consumed around 30 million tonnes of food and 30 million tonnes of other products, a total of around one tonne per person per year.

For the world as a whole, the 10% efficiency ratio remains broadly true (see Figure 5). But for many modern gadgets, the ratio is even worse: producing a 200g smartphone consumes raw materials weighing 86kg.[17]

There is also no doubt that this 'waste' is in fact a huge resource. Analysis by the Green Alliance in 2018 found that the UK imports 3.3 million tonnes of plastics each year, of which only 0.6 million tonnes is recycled (mostly abroad), and 2.3 million tonnes ends up in landfill or incinerators. If government measures could stimulate a proper recycling market, therefore, the UK's plastic waste could provide around 70% of its demand. Likewise, the UK could halve its cobalt imports by recycling the 9,000 tonnes currently exported as scrap in end-of-life products. It could also triple its domestic steel recycling to 6 million tonnes, which would reduce iron ore imports by 40% and the CO_2 emissions of steelmaking by 30%.[18]

The losses imposed by the linear economy are not just material but also financial. Separate research by the Green Alliance has found that '£1.7 billion worth of just three materials – plastics, food and electronics – are lost to the UK economy each year because our collection systems do not enable domestic reuse or recycling'.[19] The government estimates businesses could save £3 billion a year through resource efficiency measures that would cost little or nothing to implement.[20] The Ellen Macarthur Foundation calculates the circular economy could save European businesses $630 billion per year.[21]

The main aim of the circular economy is to improve resource productivity rather than cut carbon emissions, but recycling usually achieves that too, according to a recent paper from scientists at the University of Southampton. That's because recycling materials typically consumes less energy than producing new ones, especially for mined materials such as aluminium and steel (see Figure 6). The paper's authors stress, however, that some of the data is poor and the results highly sensitive to underlying assumptions.[22]

FIGURE 5: EMISSIONS SAVINGS PER TONNE OF SOURCE-SEGREGATED WASTE. SOURCE: UNIVERSITY OF SOUTHAMPTON.[23]

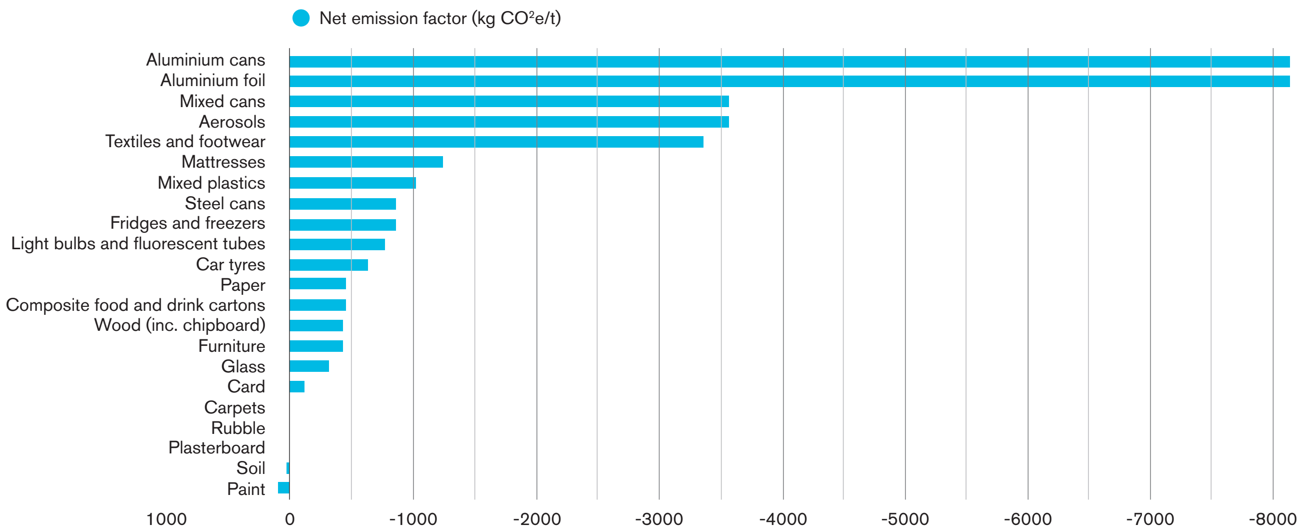
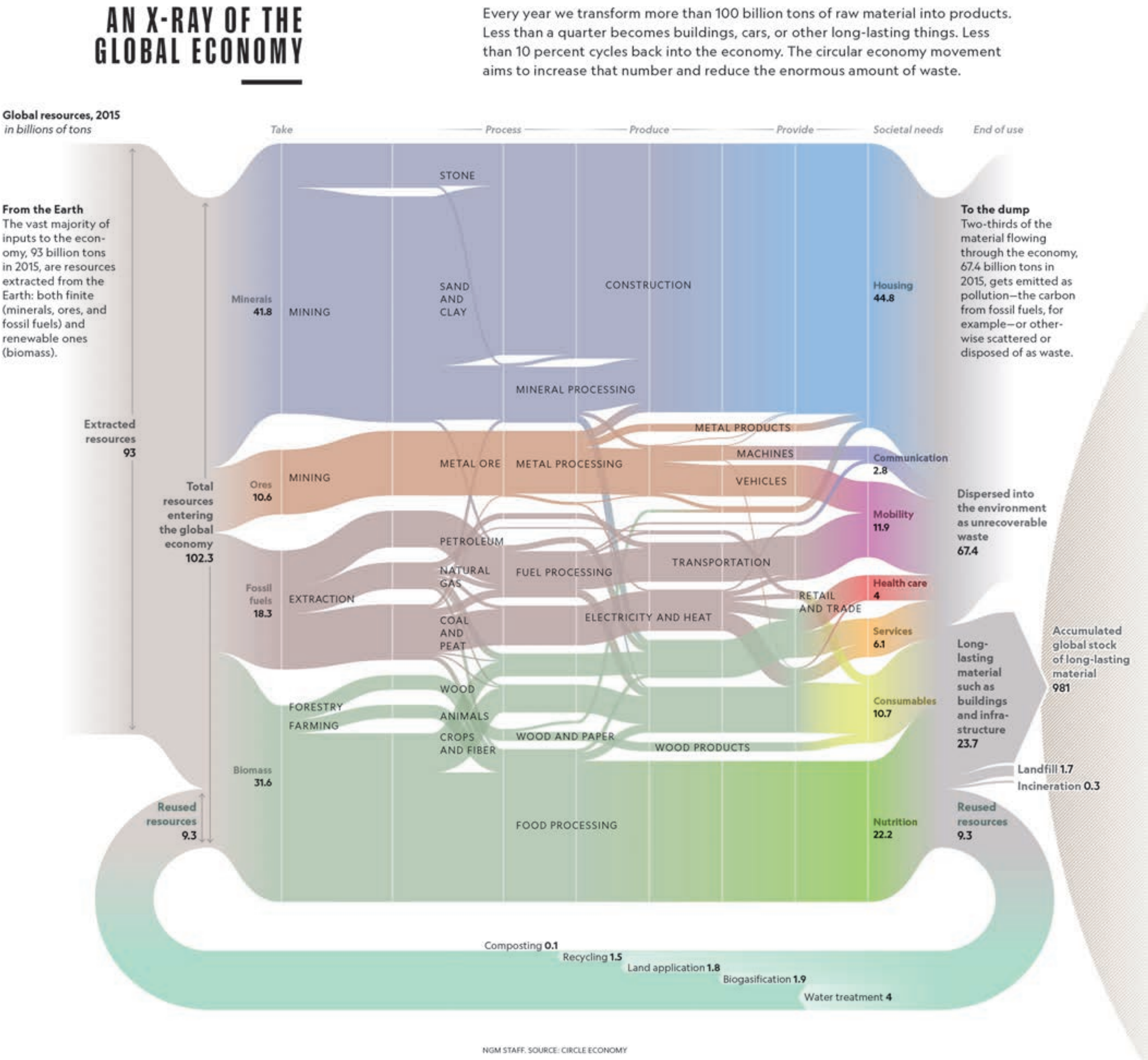


FIGURE 6: GLOBAL RESOURCE FLOWS
SOURCE: NATIONAL GEOGRAPHIC/CIRCLE ECONOMY



Recycling and its limits

The ideal is 'closed loop' recycling, in which the material is recycled in a form pure enough to produce an identical product to that from which it came, but the norm is 'open loop' recycling, or 'downcycling', which produces progressively cruder material each time.

When paper is re-pulped, for example, the fibres break and shorten, meaning the paper that can be produced from them will be a coarser grade. As a result, paper fibres are usually recycled only around four to six times before they end up in an incinerator. Toilet paper clearly ends up at a sewage works, where it may be fed along with the rest of the waste into an anaerobic digester to produce energy. In plastics, there are two types of recycling: mechanical and chemical. In mechanical recycling, the difficulty is separating the different types of plastic (such as PET or HDPE) so that when it is melted and reformed, the new pellets will have the same chemical properties as virgin material. Since cross-contamination is inevitable, this means plastics will typically recycle a handful of times, downcycling each time from (say) drinks bottles, to car fittings to garden furniture, and will finally end up in an incinerator. Chemical recycling can cope with mixed plastics by reducing it through pyrolysis to near-virgin quality oil, from which a range of new products can be made. Pyrolysis typically consumes around a fifth of the plastic for energy, although in principle this energy could be provided from renewable sources.

Since recycling consumes energy – some electricity and a lot of heat – there may be circumstances in which it is mistaken to recycle. A recent unpublished analysis by scientists at the University of Birmingham compared the pyrolysis technology marketed by Waste2Tricity, which converts plastic into hydrogen to displace oil in transport, with an alternative scenario in which the plastic was recycled three times and then incinerated. It found the hydrogen route would produce lower emissions. If so, it suggests the waste hierarchy can sometimes be misleading.

TABLE 1: PRICES AND QUANTITIES OF VARIOUS RECYCLED MATERIALS. SOURCE: WRAP.[24]

RECYCLATE	PRICE £ PER TONNE 2019 WRAP	TOTAL RECOVERED/RECYCLED – KTONNES 2017 UK STATISTICS ON WASTE
GLASS		
Clear	20	**1,623**
Amber	17	
Green	15	
Mixed	10	
METALS		
Aluminium cans	765	**924 of which aluminium: 94 of which steel: 431**
Steel cans	100	
Mixed cans	130	
PLASTICS		
Clear PET bottles	222.5	**1,044**
Coloured PET bottles	50	
Natural HDPE bottles	490	
Mixed HDPE	385	
Mixed polymer		
PAPER		
News and PAM	87.5	**3,754**
OCC (Old corrugated containers)	25	
Mixed paper and board	22	
TEXTILES AND FOOTWEAR		
Bank	195	
Charity	333	
WOOD		
High-grade wood	8	**411**
Low-grade wood	36	

BOX 1: Life cycle assessment

Judging which of several alternatives is the better environmental course of action depends on life cycle assessment (LCA), which has developed since the 1970s as a way of comparing products, technologies or energy processes in the round. LCA can be used to compare not only CO_2 emissions, but also other kinds of environmental impact such as ozone, acidification, eutrophication or land-use changes. It can also be used to assess economic and social costs and benefits.

LCA could be used to compare disposable and washable nappies, for example: one uses lots of plastic, the other lots of water, but which is better for the environment overall? Done properly, the calculation must take into account every stage of each life cycle, from producing the oil to make the plastic, on the one hand, or planting the cotton seed on the other, all the way through to recycling or disposal in landfill or an incinerator. It must account for all the energy and resources consumed and waste streams produced, and the analysis must also be geographically specific; agricultural and industrial practices differ between countries.

Done rigorously and transparently, LCA can provide invaluable insights to policy-makers. But unfortunately, much of it falls far short of the standards set out in ISO14040-44. One academic survey by Felix Mayer and colleagues assessed 315 LCA studies of EfW technologies found that 'a majority' were marked by shortcomings and 'poor compliance' with the ISO standards.[25] More than 45% of the papers failed to publish a life cycle inventory – listing the datasets used – and the survey concluded that 'many authors refrain from this step, potentially to reduce the vulnerability of their work'.

Worse, we have found that companies making environmental – that is, marketing – claims about the performance of their technology often refuse to share the underlying LCA, claiming it is 'confidential'. This could be because the company needs to protect proprietary processes, but it is clearly also susceptible to commercial interests. LCA is particularly vulnerable to such pressure since its conclusions depend critically on where the analyst draws the system boundaries, and what he or she chooses as the 'counterfactual' or benchmark comparison. This perhaps explains why several witnesses to the commission used the phrase 'Lies, damned lies, and life cycle assessment'.

It is for these reasons we think government should make it obligatory for all companies making LCA-type claims about their products and services to publish from their life cycle analyses, at a minimum, the 'goal and scope definition' note.[26] This would open them to scrutiny and challenge but allow their intellectual property to remain protected.

Energy from waste

Energy-from-waste is an umbrella term covering a range of technologies, but as things stand, it is effectively a euphemism for incinerators, since these currently dominate the waste industry. Incinerators burn residual waste to drive a steam turbine to generate electricity, and only one-in-five plants makes any use of its waste heat. Even today, incinerators continue to gain planning permission with no obligation to secure users for their waste heat.

Since half the fuel it incinerates is organic, the waste industry likes to stress the 'renewable' aspect of the electricity it produces.[27] But since incinerators also burn a lot of plastic, and since steam turbines are inefficient, that is misleading. Once coal is banished from the grid in 2024, incinerators will be the highest CO_2-emitting form of baseload electricity generation.[28] We estimate Britain's incinerators emit 0.440tCO_2/MWh, more than double the 2018 grid average of 0.208tCO_2/MWh (see chapter 4 for calculation). This is hardly the industry's fault, since it doesn't control the composition of society's waste, but nor is it sustainable – even in the short term.

Incinerators are already circular, however, to the extent that they recycle incinerator bottom ash (IBA) and air pollution control residues (APCr). Almost all IBA is recycled as aggregates for roadbuilding, and about a fifth of air APCr is also recycled.

Squaring the circle

So, if EfW today is carbon-intensive and not very circular, whereas recycling saves CO_2 and conserves resources, in an ideal world we would recycle everything and burn nothing. In principle, we agree this should be the goal, but unfortunately, it's not that simple.

To start with, the household recycling rate in the UK is just 45%. It rose steeply in the early part of the century but more recently has hit a plateau. Recovering the upward trajectory depends on major reform of waste collection services, to improve the separation and quality of waste streams, and of recycling markets, to sharpen the economic incentives to industry. The government is due to issue a second consultation on its proposals this year (see chapter 3).

Britain, like the EU, has targeted a 65% recycling rate by 2035. This looks stretching, if Europe is anything to go by. But even if the target were achieved, we would still need more EfW capacity because of the large amounts of waste being diverted from landfill.

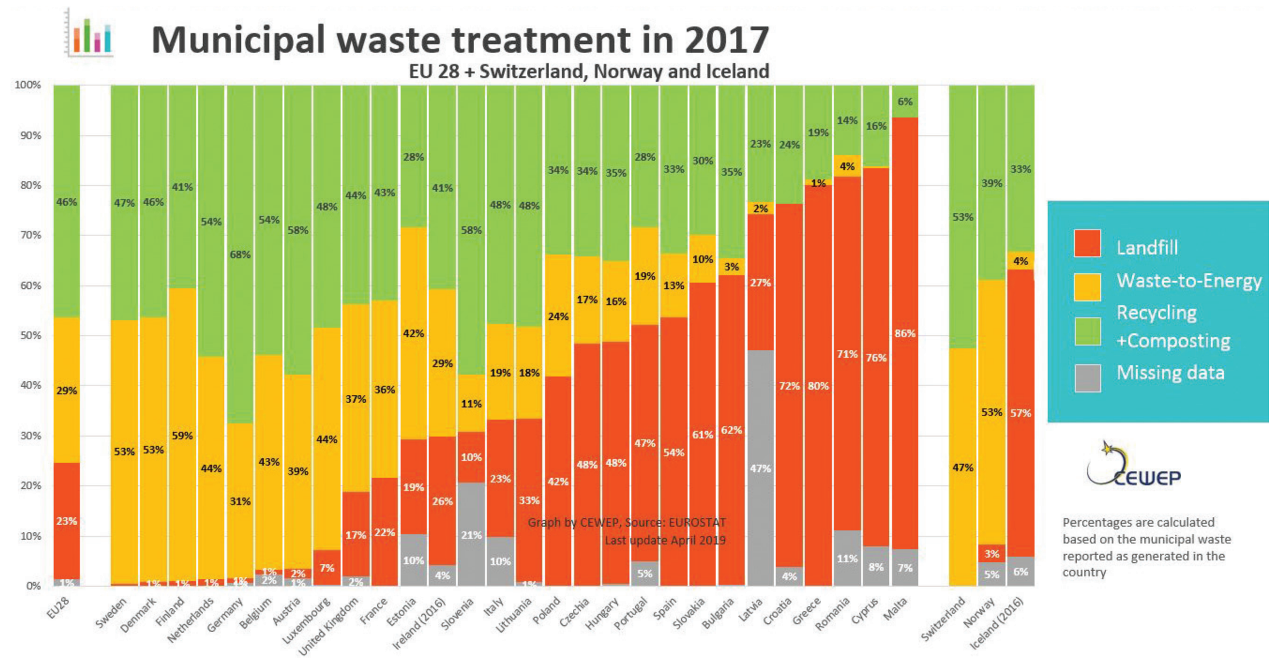
The Confederation of European Energy-from-Waste Plants (CEWEP) calculates that if the EU achieves its 65% recycling target, and assuming landfill is reduced to 7%, then it would still need 142 million tonnes of EfW capacity, 49 million tonnes more than now.[29] Using the same approach, the UK would need 18 million tonnes of capacity, an increase of 6.4 million tonnes.[30] 3.4 million tonnes of capacity is currently under construction.[31]

Nor will existing EfW assets disappear quickly: incinerators have 30-year lives, and many have been built in the last decade since the landfill tax started to bite; the average age is 11.4 years.[32] Even so, we may still have too little capacity to deal with all our waste if exports to the EU are cut off in the event of a no-deal Brexit.

Supporters of the circular economy often argue that the very existence of incinerators suppresses recycling because financing the plants depends on long-term contracts for waste. There is some truth to this, but the evidence from northern European countries shows high incinerator capacity can and does co-exist with high levels of recycling, and the near elimination of landfill (Figure 7). In the Netherlands, Germany and Scandinavia, it is illegal to send mixed municipal waste to landfill, which is reserved for soils or hazardous waste. The recycling and incineration rates in these countries are not wildly dissimilar from those of the UK, but the amount of energy extracted from residual waste certainly is.

It is also true that EfW plants can be far less carbon-intensive than they are in Britain today. We estimate incinerators in the UK emit an average of 0.44tCO_2/MWh (see chapter 4 for calculation). In Scandinavian countries, almost all EfW plants are integrated into district heating networks and their emissions per unit of energy are much lower. In Copenhagen, for example, the Amager Bakke plant emits 0.12tCO_2/MWh in normal operation (electricity and heat), and just 0.086tCO_2/MWh when producing heat only (see case study, Amager Bakke, page 32).[34]

FIGURE 7: MUNICIPAL WASTE TREATMENT IN 2017 (EU28 + ICELAND, NORWAY AND SWITZERLAND). BASED ON EUROSTAT FIGURES, 2019. SOURCE: CEWEP.[33]



There are significant barriers to exploiting the waste heat of EfW in the UK, but they are entirely surmountable, as we explore in chapter 4.

Britain's failure so far to exploit fully the waste heat of EfW is one reason it has not decarbonised heat anything like as much as electricity. Compared to electricity (and even transport, where the elements of a strategy are becoming clearer) decarbonising heat remains the outstanding challenge, and is at least as important as raising recycling rates. Increasing the proportion of incinerators' waste heat that is put to good use should be a higher priority than shrinking their capacity.

Incinerators are only the current generation of EfW technologies. Second-generation technologies can be more circular and potentially far lower-emitting (chapter 5). AD, for example, produces both biomethane (energy) and digestate for use as fertiliser (circular product), and its CO_2 emissions can be negative in some circumstances. Pyrolysis and gasification plants can reduce plastics, wood and other organic matter to oil or gas, which can then be used to make chemical feedstocks, fuels or electricity. In other words, these EfW plants can work equally well as energy or recycling technologies. All three produce useful waste heat, and are smaller than incinerators, so can be more easily integrated into district heating. AD is well established but pyrolysis and gasification are earlier stage technologies that need further R&D and VC support.

The third generation of technologies, some of which have already been proved (chapter 5), can absorb the CO_2 and waste outputs of EfW plants to make building products and fertiliser, and some also produce significant usable heat. In Europe, EfW CO_2 is already being used to displace CO_2 from fossil fuels in horticulture.[35]

BOX 2: Second-generation EfW technologies

Anaerobic digestion (AD) processes food and crop wastes through the action of bacteria in the absence of oxygen. In other words, it replicates the workings of an animal's stomach to produce biogas, comprising methane and CO_2, and digestate, a nutrient-laden liquid. The biogas can be burned in a gas engine to produce electricity and heat, or upgraded into biomethane and used for transport fuel or injected into the gas grid. Since the CO_2 comes from recently grown organic sources it is generally discounted as a greenhouse gas emission, but if captured and re-used (see chapter 4), can result in negative CO_2 emissions.

Pyrolysis processes organic and plastic wastes by heating them to around 500°C in the absence of oxygen. This decomposes the materials without burning them, producing oil, which can be used as a chemical feedstock or transport fuel, gas and 'char', a carbon-rich dust. If the wastes processed are purely organic, the resulting 'biochar' can be spread on fields to improve soil structure. Char can also be used to sequester carbon permanently, meaning the energy or fuel produced can even be CO_2-negative.

Gasification is similar to pyrolysis but heats the material to around 800°C with limited oxygen. This produces a 'dirty syngas' comprising hydrogen, carbon monoxide, methane and other compounds. This can either be burned to raised steam to generate electricity and heat, although this is inefficient, or further processed to produce a clean syngas of hydrogen and carbon monoxide. This can then be used to supply hydrogen or converted through the Fischer-Tropsch process into chemical feedstocks or transport fuels.

Both pyrolysis and gasification consume a portion of the waste to generate the heat needed to process the rest.

For more detail on these technologies, see chapter 4.

Ultimately, there will always be residual waste: however well separated, waste streams will always suffer contamination; materials like paper and plastic can be recycled only a handful of times before they degrade too much for further use. The challenge is to plot a transition from the current situation to one in which EfW capacity is held to the minimum necessary, and where it is provided by efficient, circular technologies that re-use or sequester any residual CO_2.

We believe these three stages – waste heat, second-generation and-third generation technologies – provide a roadmap to a waste processing system that is both resource-efficient and zero-carbon by 2050. That 30-year journey coincides with the lifespan of the last few large incinerators that will ever be built in Britain.

3. WASTE DISPOSAL

2020

In 2016, the last year for which complete figures are available, the UK produced 223 million tonnes of waste. By far the biggest fraction (Figure 8) comes from Construction, Demolition and Excavation (CD&E), followed by Commercial and Industrial (C&I) and Household. Because CD&E already achieves more than 90% recycling and recovery rate (Table 2), this report – like the debate more generally – focuses on Household and C&I.

The **waste produced by households** seems to have peaked in 2004 at just under 30 million tonnes, and fell to around 25 million tonnes in 2012, but has now started to rise again to 27.3 million tonnes in 2016, which partly reflects the rise and rise of online shopping. The most recent UK-wide figures for C&I waste show rising from around 42 million tonnes in 2010 to just over 44 million tonnes in 2012 and back down to 42 million tonnes in 2014.

FIGURE 8: UK WASTE ARISINGS BREAKDOWN 2016. SOURCE: DEFRA.[36]

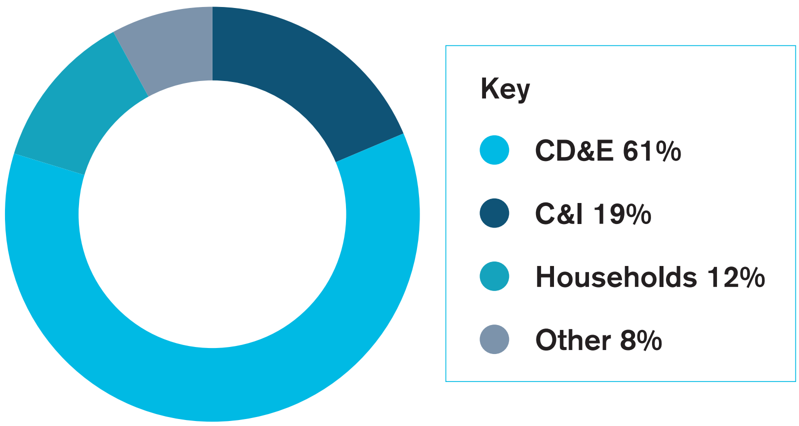


TABLE 2: UK WASTE ARISINGS, RECYCLING AND RECOVERY 2016. SOURCES: ALL FIGURES ARE FROM DEFRA[37] EXCEPT THE ESTIMATES (E), WHICH ARE BASED ON WRAP'S ESTIMATE OF COMMERCIAL RECYCLING RATE OF 35%.[38] THERE IS A HIGH DEGREE OF UNCERTAINTY IN THIS FIGURE.

UK, 2016	WASTE ARISINGS (M TONNES)	RECYCLED, RECOVERED (M TONNES)	% RECYCLED, RECOVERED	RESIDUAL WASTE (M TONNES)
Household	27.3	12.3	45.2%	15
Commercial and Industrial	41.1	Out of scope		
Of which commercial	27.5	9.6(e)	35%(e)	17.9%(e)
Of which industrial	13.6			
Construction, Demolition and Excavation (includes dredging)	136.2	Out of scope		
Of which non-hazardous	66.2	60.2	91%	6
Other	17.7	Out of scope		
Total	**222.9**	**104**	**48.5%**	**118.9**

The main ways of dealing with waste are **landfill, recycling, composting, EfW and exports**. Over the past decade, the Landfill Tax has driven a sharp fall in waste going to landfill and a boom in EfW – as shown in Figure 9.

Household recycling has risen sharply from 11% in 2001 but more recently appears to have hit a plateau at around 45%.[40] Household recycling in the UK looks set to miss the 2020 target of 50%, as it does in all constituent countries except Wales (Figure 10). While recycling rates have risen, more than 7 million tonnes of biodegradable waste is still sent to landfill.[41]

The tonnage of **residual waste** – that left over after recycling – going to incinerators has risen sharply, from 3.3 million tonnes in 2006 to 11.5 million tonnes in 2018. In that year, Britain had 47 incinerators in operation or being commissioned with a total capacity of 11.5 million tonnes. A further 15 plants with a total capacity of just under 3.4 million tonnes per year are under construction.[43]

In 2018, UK incinerators produced almost 2.3 million tonnes of bottom ash (19.9% of the waste processed), almost all of which was scoured for recoverable metals and then recycled as aggregates for road building. They also produced around 378,000 tonnes of air pollution control residues (APCr). In 2017, around 20% of the APCr was recycled.[44] All incinerator CO_2 is dumped to the atmosphere.

The amount of biomass going to landfill, and the recent inertia in household recycling rates, are compounded if not caused by the **waste collection services of around 350 local authorities in England**. Scarcely 40% of England's household waste is segregated at source as recyclables, much lower than in the best performing European countries.[45]

One major problem is that in two-tier authorities, waste is collected by district councils and disposed of by the county council. Collecting recycling in a single bin is cheaper for the district council but means the disposing authority must separate the glass, tins, plastic and paper in a Materials Recycling Facility (MRF), which results in cross-contamination and makes the process more expensive overall. Only half of the local authorities in England provide separate collection for food waste. Only in the unitary authorities of larger metropolitan areas are the economics of collection and disposal properly integrated and balanced.

After ten years of austerity, councils' capacity to improve collection is severely constrained. In its waste and resources strategy, the government has promised separate collections will be funded.[46] This cannot come soon enough.

In **packaging waste**, which is covered by the Producer Responsibility scheme (see overleaf), recycling rates for materials that are easier to recycle and valuable to industry are already relatively high: glass (67%), metal (68%) and paper (82%), as shown in Table 3. But plastics (45%), which has repeatedly fallen short of its targets, and wood (30%) represent major opportunities for improvement.

FIGURE 9: LOCAL AUTHORITY COLLECTED WASTE MANAGEMENT 2001–2017. SOURCE: DEFRA.[39]

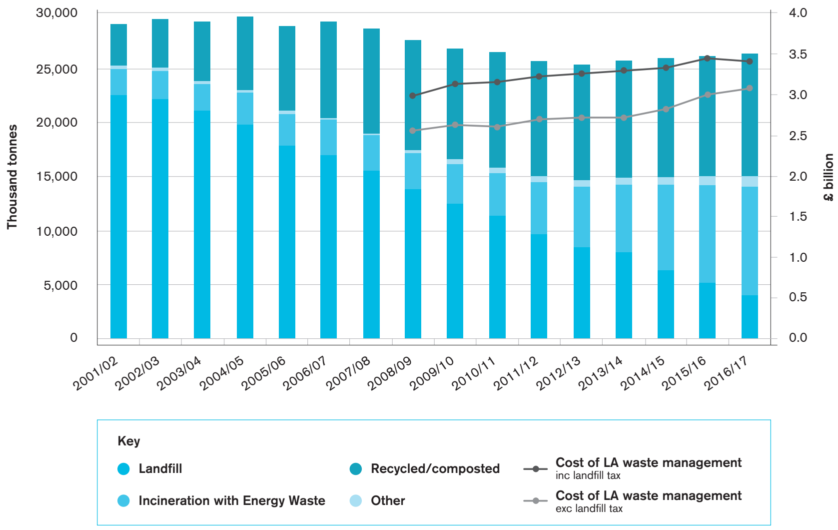


FIGURE 10: HOUSEHOLD RECYCLING. SOURCE: DEFRA.[42]

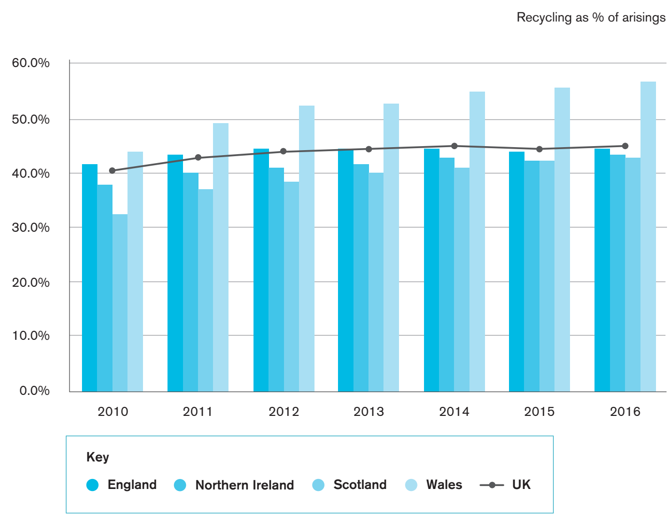


TABLE 3: UK PACKAGING WASTE RECYCLING RATES 2015 AND 2016. SOURCE: DEFRA.[47]

	2015			2016 (PROVISIONAL)			
	TOTAL PACKAGING WASTE ARISING (thousand tonnes)	TOTAL RECOVERED/ RECYCLED (thousand tonnes)	RECOVERY/ RECYCLING RATE %	TOTAL PACKAGING WASTE ARISING (thousand tonnes)	TOTAL RECOVERED/ RECYCLED (thousand tonnes)	RECOVERY/ RECYCLING RATE %	2013–14 EU TARGET %
Aluminium	177	76	42.9	177	90	50.8	n/a
Steel	559	364	65.1	559	416	74.4	n/a
Total metal	**736**	**440**	**59.8**	**736**	**506**	**68.7**	**50.0**
Paper	4,749	3,667	77.2	4,749	3,892	81.9	60.0
Glass	2,399	1,577	65.7	2,399	1,609	67.1	60.0
Plastic	2,260	891	39.4	2,260	1,015	44.9	22.5
Wood	1,310	375	28.6	1,310	405	30.9	15.0
Other	23			23	0	0.0	n/a
Total recycling	**11,476**	**6,950**	**60.6**	**11,476**	**7,427**	**64.7**	**55.0**
Energy from waste		476	4.1		767	6.7	n/a
Total	**11,476**	**7,427**	**64.7**	**11,476**	**8,194**	**71.4**	**60.0**

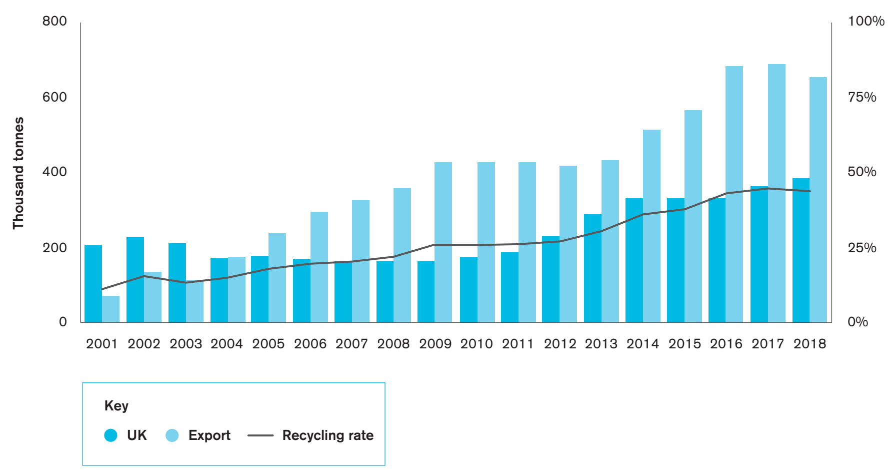
Britain also relies heavily on **exports** of both 'recyclates' – recyclable material that has been sorted into separate streams such as plastics or paper – and residual or 'black bag' waste that would normally end up in an incinerator.

The **export of plastics for recycling** has grown strongly this century, and until recently most was sent to Asian countries. Figure 11 shows the growth of exports of plastic packaging, which continue to outstrip the rise in UK recycling: in 2018, Britain recycled 384,000 tonnes of plastic packaging waste and exported around 650,000 tonnes.[48] Packaging represents about half the total plastics 'placed on the market' (2.4 million tonnes of a total 4.9 million tonnes in 2017).

Exports predominate partly because Britain still has too little recycling capacity – estimated at 450,000 tonnes in 2018. Since early 2019, the industry has announced plans to build a further 250,000 tonnes of capacity, but this is too little to absorb current exports. Exports may also persist because the Producer Responsibility scheme inadvertently rewards exports more highly than UK recycling. The plastics industry has called on the government to reform the scheme (see Box 3: Economics of the waste business).[49]

In 2018, Asian countries began to restrict imports of foreign plastics and other waste streams. China, which had taken two-thirds of UK plastics waste exports in 2015, issued the first ban. This shifted the exports to countries like Malaysia, Indonesia, Vietnam and others, which then imposed their own restrictions. There has been little if any effect on the level of UK exports, and the biggest importer of UK plastics waste is now Turkey (see Figure 12 on page 26). As export markets tighten, however, it should drive up the price of recycling in the UK and incentivise investment in new capacity.

FIGURE 11: PLASTIC PACKAGING: UK RECYCLING AND EXPORTS. SOURCE: WRAP/ENVIRONMENT AGENCY.[50]



Britain also exports residual waste as 'refuse-derived fuel' (RDF), which is black bag waste that has been compressed and wrapped in (of course) plastic for incineration in EU countries. This requires an export licence, and it is illegal to export waste, as opposed to recyclates, further afield.

Exports of RDF from England and Wales ballooned from just 9,000 tonnes in 2010 to 3.6 million tonnes in 2017, or around 10% of our residual waste (Figure 13). But exports appear to have peaked and fell to 2.7 million tonnes in 2019.[52] The decline looks set to continue since the Netherlands, the biggest importer of British RDF, has just announced an RDF import tax of €32 per tonne. The second largest importer, Sweden, has announced an import duty starting at £6 per tonne, but rising each year.[53] These moves are expected to raise the cost of incineration in the UK. Although exports are shrinking, UK RDF exporters fear that their trade could be disrupted in the event of a no-deal Brexit.[54] The same could also be true for much of our plastic packaging waste exports (Figure 11). These exports have – ironically – helped to lower fuel costs for energy and cement producers in mainland Europe.

FIGURE 12: UK RECOVERED PLASTIC EXPORT DESTINATIONS (JAN–JUN 2019). SOURCE: WRAP/HMRC.[51]

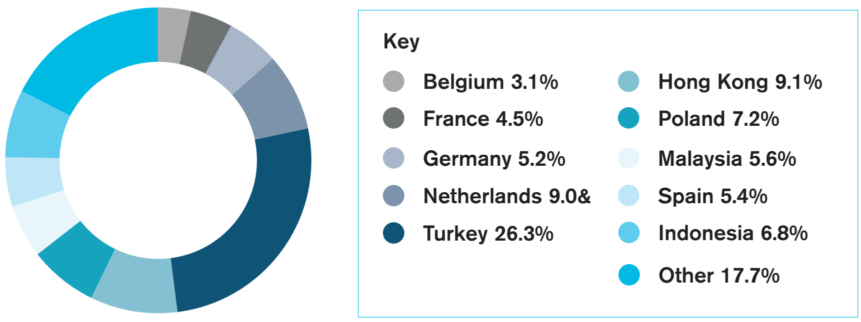
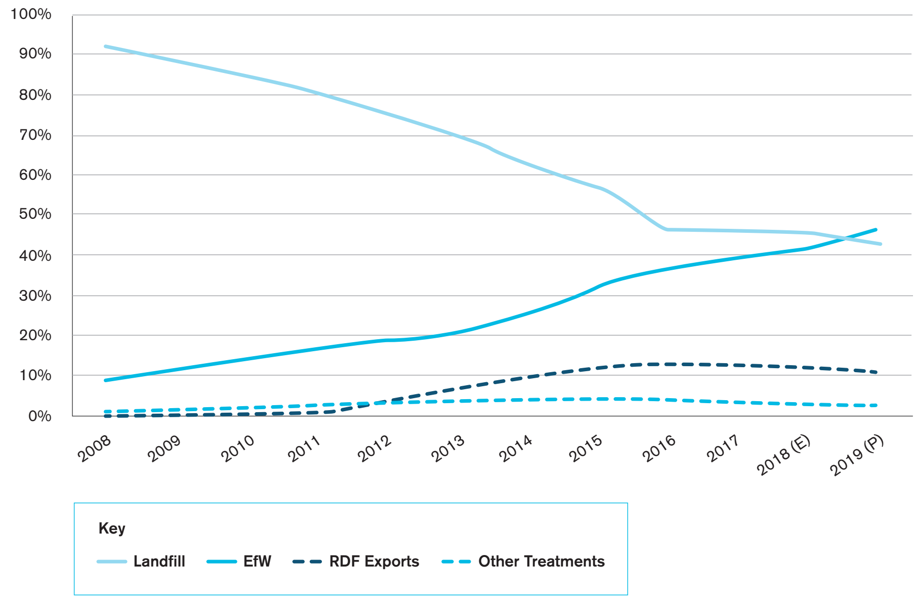


FIGURE 13: UK RESIDUAL WASTE MARKET BY TREATMENT METHOD. SOURCE: TOLVIK CONSULTING.[55]



Box 3: The economics of the waste business

Britain's waste sector has been transformed over the past decade by two pieces of legislation: the **Landfill Tax** and the **Producer Responsibility Regulations**.

The landfill tax was introduced in 1997 at £7 per tonne and rose gently but ineffectually for 13 years[56]. Then in 2010, the government announced an annual escalator of £8 per tonne, rising to a minimum level of £80 per tonne between 2016 and 2020. The rate from April 2020 is £94.15 per tonne.[57]

The landfill tax, collected by the landfill operator on top of its own 'gate fees' (commercial charges) and passed to the government, now created a major incentive to find alternative means of disposal, and made it economic for companies to invest in new plants to provide them.

A Material Recycling Facility (MRF), for example, could now turn a profit by charging a lower gate fee than the landfill tax and selling separated streams of glass, plastics and paper on to recyclers. Incinerators that cost hundreds of millions of pounds to build were now economic and operated on broadly the same business model – but sold electricity rather than recyclates. AD plants, which could claim the Renewable Heat Incentive, also sprouted.

Altogether the tax incentivised investment of around £1,212 billion in new incinerators, with £55 billion in the pipeline[58], and the tonnage of waste going to landfill has plunged.

Investment in recycling capacity has also been driven by the Producer Responsibility Obligations (Packaging Waste) Regulations 2007, Britain's translation of the EU Packaging and Waste Directive. These oblige manufacturers and retailers to meet progressively tighter annual recycling targets for packaging materials.

To prove their compliance, companies must buy Packaging Recovery Notes (PRN), or Packaging Export Recovery Notes (PERN), for each tonne they place on the market. The Notes are issued by recyclers, such as glass or paper manufacturers, for each tonne they recycle, or by exporters for each tonne they export for recycling abroad. The system, therefore, directs money from waste producers to recyclers, helping them to invest in more capacity. If recycling targets are missed, the price of the Notes, which are tradable, should rise and encourage further investment in recycling capacity. Across aluminium, paper, glass, plastic and steel, the PRN system drove investment of more than £130 million in 2018.[59]

The PRN/PERN system has two problems, however. First, although it drives money towards recyclers, it provides no funding for local authorities to introduce separate collections for various the recyclates, and therefore improve the quality of recycling streams.

Second, the plastics industry complains that the system rewards exporters more highly than domestic recyclers, because PRNs are issued for plastics that have been washed and shredded, whereas PERNs are issued on plastics that have not been. Because the Notes are issued for each tonne of waste, exporters are effectively rewarded for exporting dirt and other contaminants – although developing countries are now beginning to reject these exports (see page 25).

Although these two laws have changed the waste industry dramatically over the past decade, household recycling rates are stuck at around 45%, and our resource economy is still hopelessly inefficient at 10% (see page 26). The government's upcoming reforms will need to be truly radical to move the dial on either number.

Recycling faces particular problems for some specialist waste streams such as waste electrical and electronic equipment (WEEE, or e-waste). According to the waste company Suez, Britain sends more than a million items of e-waste to landfill or incineration every week – 60 million a year.[60] This represents a huge waste of gold, silver, cobalt, platinum, titanium and rare earth metals.

E-waste is one of four waste streams – along with packaging, vehicles and batteries – covered by producer responsibility schemes in the UK. Manufacturers of electrical and electronic equipment (EEE) have to pay into a WEEE Fund that finances centralised collection points, mostly at council depots.[61]

Yet Britain keeps missing its EU e-waste recycling targets. In 2018, Britain should have recycled 45%, or 537,000 tonnes, but managed only 493,000 tonnes. When the data is in, it looks likely the target will be missed yet again in 2019.[62]

The problem is partly that we buy and later discard an ever-growing stream of gadgets. The average Briton produces almost 25kg of e-waste each year, compared to less than 18kg for the average EU citizen. But it is also because councils do not collect e-waste separately, and small items are easy to throw into the general rubbish. The government accepts the system is not performing well enough and has announced that from 2021 big retailers will no longer be allowed to contribute to the WEEE Fund and will have to accept end-of-life returns in store.[63]

There are similar difficulties with bulky items such as mattresses – of which we discarded 7 million in 2017 but recycled only 20%[64] – and tyres, along with textiles, furniture, carpets. The government has said it will introduce extended producer responsibility (EPR) schemes for these products, forcing manufacturers and retailers to cover the full costs of recycling, recovery and disposal (see next section). These EPR schemes will clearly need to be more effective than the WEEE Fund scheme has been so far, and that probably means the sticks will need to be bigger. EEE manufacturers paid in just £3.5 million to the WEEE Fund in 2018, which is tiny compared to the £ billions their products would have generated in revenue.

Government policy
Waste policy is devolved to Scotland, Wales and Northern Ireland, but the government's main policies for England include:

- The Landfill Tax, introduced in 1997. This is a tax on each tonne of waste sent to landfill, which rises each year and currently stands at £94 (April 2020). Over the past decade, it has driven waste from landfill to EfW (see above).
- The Packaging Waste/Producer Responsibility Regulations of 2007, which introduced a trading scheme intended to raise the proportion of packaging recycled. Under the scheme producers of raw materials, manufacturers and retailers must buy Packaging Recovery Notes (PRN), or Packaging Export Recovery Notes (PERN), equal to a rising percentage of the packaging they produce. See Box 3 for more detail. The government is consulting on reforms to the scheme and has promised councils will be funded to collect recyclates in separate streams.
- The waste and resources strategy for England published in 2018[65], in which the government committed to:

    - Strengthen producer responsibility to the full costs of disposal including collection
    - Fund local authorities to collect separate recycling streams rather than co-mingled in a single bin: 'we must, and will, ensure that local authorities are resourced to meet new net costs arising from the policies in this Strategy'
    - Standardise a core set of materials for councils to collect
    - Legislate for weekly separate food waste collections for all by 2023
    - Introduce a plastics tax
    - Consider introducing an incineration tax
    - Consider extending the existing 2030 ban on food waste going to landfill to all biodegradable material by the same date
    - Develop a National Materials Datahub
    - Roll out resource efficiency clusters for small businesses (the government's proposal, not to be confused with our Resource Recovery Clusters, see page 48) from 2020

The government is due to issue a second consultation this year on its favoured proposals.

- The Industrial and Clean Growth Strategies, which commit Britain to doubling resource productivity and eliminating 'avoidable' waste by 2050.

The government plans to introduce **EPR** to five new areas including textiles; bulky waste, including mattresses, furniture and carpets; some materials in construction and demolition; vehicle tyres; and fishing gear. The waste and resource strategy commits to make producers bear the 'full net cost of managing their products at the end of their life', and to use variable fees to encourage manufacturers to make products that are easier to reuse, repair or recycle, and to penalise those that do not.

The government is considering a **plastics tax** because recycled plastics can be more expensive than new ones. The tax would be imposed on all packaging containing less than 30% recycled plastic, to encourage manufacturers to produce more sustainable packaging and, in turn, create greater demand for recycled material. We welcome this idea and believe it could be extended to a much wider range of materials.

The idea of a **National Materials Datahub** is intended to provide 'comprehensive data on the availability of raw and secondary materials, including chemicals, across the economy to industry and the public sector, and by modelling scenarios around material availability'. We strongly support this idea, and we urge the government to ensure the Datahub gathers data and analyses material and waste flows not only at a national level, but down to the regional and local levels too. This would make it extremely useful for local and regional authorities as they plan waste infrastructure. The Datahub would also be a central resource for our proposed **Centre for the Circular Economy** (see Recommendations).

Work on the UK National Materials Datahub is at an early stage, but such a system has already been introduced in Taiwan. There it is available to companies to link up buyers and sellers of glass, plastic, metals, fibre and biomass, so they can replace virgin materials with recycled wastes of a defined specification.

Defra estimates that businesses could save £3 billion a year through resource efficiency measures that cost little or nothing to implement[66], and has begun to pilot resource efficiency clusters through LEPs to promote this. The clusters offer free resource efficiency audits and financial support for subsequent investments. We support this idea but believe that resource efficiency could be greatly accelerated by creating physical clusters of waste and recycling infrastructure, as we propose with our **Resource Recovery Clusters** (see Recommendations).

Heat policy is also relevant:

- **Renewable Heat Incentive (RHI)**, which subsidises investment in renewable heat technologies, but which is due to close in March 2021. This uncertainty about future government support for renewable heat has depressed investment in anaerobic digestion and other technologies. The government should end this uncertainty quickly by renewing or replacing the RHI. The government introduced a Low Carbon Heat Support Scheme in its March 2020 budget to support the installation of heat pumps and biomass boilers, although its details are not yet clear. On the face of it, this supports consumers of renewable heat but not producers, such as AD, pyrolysis or gasification plants. In other words, the uncertainty over RHI remains, and must be resolved.
- **Heat Network Investment Project (HNIP)**, under which the government has committed £320 million to 'gap fund' heat network projects that would not otherwise be economic. The scheme was announced in 2016 and has supported 13 projects with a total of £41 million so far, reducing both CO_2 emissions and energy bills. The government estimates the full programme will lever in private investment worth £2 billion.[67] So far, however, only 14% of applications have concerned EfW heat.[68] EfW suffers specific barriers on top of those faced by heat networks. In the March 2020 budget, the government provided a further £270 million in funding to encourage new and existing heat networks to switch to low-carbon heat sources.[69] Giving evidence, one EfW heat network developer described this scheme as a 'good start'.

The Industrial Cluster Decarbonisation Mission (£170 million) which is being used by the Black Country LEP to demonstrate many of the recommendations in this report. In particular supporting a 'Repowering the Black Country' programme to plan and develop a portfolio of mini-resource recovery clusters and net zero energy hubs across four local authorities, using planning powers and business engagement programmes to encourage the development of circular economy eco-systems around each hub.[70]

In transport policy, the Renewable Transport Fuels Obligation introduced in 2008 obliges suppliers of road transport fuels to incorporate a steadily rising fraction of renewable fuel. The rate stands at 9.75% in 2020 and will rise to 12.4% by 2032.

4. WASTED OPPORTUNITIES
THE HEAT IMPERATIVE

In 2018, 47 incinerators generated just over 6,000 GWh of electricity, or 1.9% of the UK total.[71] The industry likes to call EfW electricity 'renewable', but this is misleading. Its emissions may be lower than those of landfill, which produces methane, but they are also among the highest on the grid. Once coal phase-out is completed in 2024[72], EfW will be the most carbon-intensive form of baseload generation. Incinerator CO_2 emissions are high because they are generated by inefficient steam turbines; the fuel contains a lot of plastic (made of oil); and because very few of the incinerators – eight of the 47 in 2018 – make any use of their waste heat.

We have found no authoritative figures for the carbon intensity of incinerator-generated electricity and heat in the UK. But we have found enough credible data to calculate the emissions ourselves:

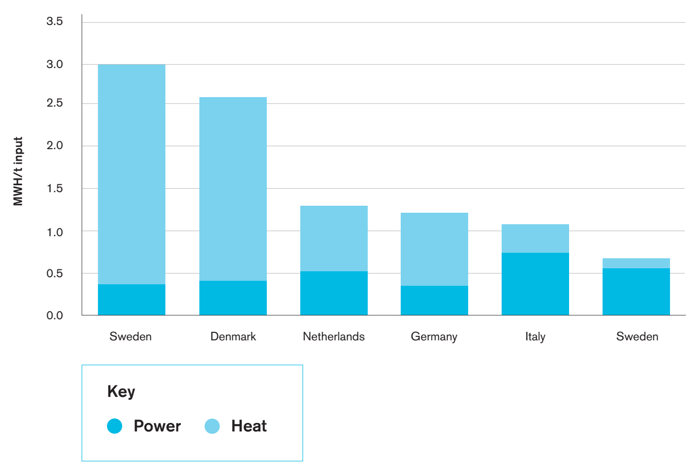
- In a report for the Scottish government, the Eunomia consultancy provides estimates for carbon dioxide emissions per tonne of waste for UK and European 'thermal treatment' plants.[73] UK plants emit 0.28tCO_2e per tonne of waste while those in Denmark, Netherlands and Sweden emit 0.13tCO_2e. The difference is accounted for by the fact that European plants typically use their waste heat to supply district heating whereas most UK plants do not. In other words, operating as a combined heat and power plant (CHP) roughly halves carbon intensity of processing each tonne of waste.
- The Tolvik Consultancy produces industry-wide figures for the electricity and heat produced by UK incinerators, and the amount of waste processed, which give an industry average waste-to-energy production ratio of 1.56 tonnes per MWh (implied in Figure 14 below.)[74]

Multiplying the Eunomia and Tolvik figures together shows that the average UK incinerator emits 0.44tCO_2/MWh.[75] That's almost four times higher than the most efficient European plants. The Amager Bakke plant in Copenhagen emits just under 0.120tCO_2/MW, when producing both electricity and heat (see case study on page 32).

UK incinerator emissions of 0.44tCO_2/MWh are more than double the 2018 UK grid average of 0.208tCO_2/MWh and a quarter higher than combined cycle natural gas plant emissions of 0.349 tCO_2/MWh. Since we already have low-cost ways to produce low-carbon electricity (UK offshore wind now undercuts natural gas), but few options for low-cost, low-carbon heat, it makes no sense to run incinerators for electricity only. This argument strengthens every year, as rising renewable capacity pushes UK grid carbon intensity ever lower.

Indeed, there is a strong argument for using incinerators, where physically possible, to produce only heat and no electricity. Heat loss from well-insulated pipes is likely to be far less than that from a steam turbine, meaning overall energy production can be far higher and emissions much lower. This is how many plants operate in Scandinavia, which is why Sweden extracts almost six times more energy per tonne of waste than the UK (Figure 14 below). The Amager Bakke plant emits just 0.086t$CO_2$3/MWh when producing heat only, one-fifth of the average for UK incinerators. In Denmark, EfW supplies 25% of the district heating and 5% of the electricity.[76]

FIGURE 14: EFW ENERGY PER TONNE OF WASTE BY COUNTRY. SOURCE: TOLVIK CONSULTING



COUNTRY	ELECTRICITY (MWh/t)	HEAT (MWh/t)	TOTAL (MWh/t)
Sweden	0.36	2.62	2.98
Denmark	0.40	2.19	2.59
Netherlands	0.48	0.81	1.30
Germany	0.34	0.86	1.20
Italy	0.73	0.33	1/07
UK	0.54	0.10	0.64

CASE STUDY: Amager Bakke, Copenhagen

The Amager Bakke incinerator in Copenhagen is an extraordinary example of what can be achieved with a modern incinerator. Commissioned in 2018, it burns around 540,000 tonnes of waste per year – representing over half a million people and almost 50,000 businesses – to supply two district heating networks and generate electricity for the grid.

The plant has an energy efficiency of 107% – meaning it produces more energy than contained in its fuel. This apparent magic-trick was largely achieved by installing heat pumps in the chimney to condense the flue gases and extract the maximum heat. The average incinerator in Denmark is around 85% efficient, and this measure adds another 20% on top. The plant also scavenges waste heat from ancillary equipment like air compressors to feed the heat networks.

ARC (Amager Resource Centre), which runs the plant, can extract heat at five different points along the turbine, meaning it can operate in several modes with a different balance between electricity and heat output. In normal CHP mode it produces around 190MW heat and 50MW electricity, and emits just 0.119tCO_2/MWh – scarcely a quarter of the emissions of the average UK incinerator. In heat-only mode it emits still less – just 0.086tCO_2/MWh. The plant is controlled by the seasonal requirements of the heat networks; they tell the ARC how much heat they need, and must compensate the waste suppliers for any resulting loss in electricity production.

All EfW and districting heating in Denmark is not-for-profit, and Amager Bakke is owned by five municipalities. Any heat network that wants to expand can secure low-cost, government-backed loans. ARC is currently developing a business plan to capture its CO_2 and convert it into transport fuels.

The plant is not only energy-efficient but also architecturally striking. Its long, slanting roof doubles as a ski slope and running track, and its sides provide the world's tallest climbing wall.

FIGURE 15: AMAGER BAKKE INCINERATOR IN COPHENHAGEN. SOURCE: ARC

Since only 2% of British buildings are connected to a district heating network[77], it is not hard to see where the opportunity lies. But if we want to reach Scandinavian levels of heat from EfW, we perhaps wouldn't start from here. Compared to Sweden and Denmark, where combined heat and power (CHP) and district heating are long-established, much of it sourced from incinerators, the UK suffers several disadvantages. Now Britain must overcome not only the barriers to developing heat networks, but also specific barriers to exploiting the heat of EfW in those networks.

Historically, Britain had no great incentive to develop CHP district heating networks because of its extensive gas network and natural gas supplies from the North Sea. Now that emissions reduction and resource efficiency are higher priorities, heat from natural gas is arguably too cheap.

Retrofitting district heat – digging up the streets – is expensive, and raises the question of who funds the infrastructure, and how. Local authorities, which in theory have the power to compel housebuilders to integrate district heat in new projects through Section 106 planning notices, in practice struggle to impose their will on this powerful lobby. Local authorities' planning powers clearly need to be reinforced.

The government's Heat Network Delivery Unit (HNDU) and £320 million Heat Network Investment Project (HNIP) are starting to drive the development of heat networks. But take-up has been slower than expected and most applications so far have relied on gas-fired CHP (51%) or heat pumps (29%), and only 14% EfW.[78]

Evidence presented to the commission in hearings and interviews suggests that heat network developers in the UK face a series of extra barriers to using EfW heat:

- Incinerators were typically built near landfill sites, and, therefore, remote from sources of heat demand. Electricity generation was the easier way to export some energy.
- Incinerator operators are, by contract or business model, tied into electricity generation; they see heat as outside their core business.
- There is widespread public opposition to incinerators. Operators know this, and do not want to attract further attention.
- The low price of gas and heat compared to electricity, which makes it hard for heat network developers to get incinerator operators interested.
- Incinerator operators wrongly believe they will have to guarantee 100% security of supply, when in fact all district heating networks have back-up built in – it's just a question of who supplies it.
- Mismatch of volumes of supply and demand: incinerators tend to be large and can generate far more heat than needed by a start-up heat network, whose initial demand is too small to interest the incinerator operator commercially.
- Mismatch of contract and plant end-dates: if the heat network operator's contract is due to end within a few years, or the incinerator operator's waste contract with the local authority, or the incinerator is due to close, it can be difficult to agree a deal without some kind of external guarantee of continuing supply and/or demand. Nobody provides this at the moment.
- Local authorities, after ten years of austerity, mostly lack capacity to broker and manage such arrangements.

These and other commercial difficulties can prevent the use of waste heat from EfW even where sources of supply and demand are within touching distance. For example, Birmingham has built Britain's biggest heat network over the past 20 years, and the city's incinerator at Tyseley is close by, yet still its waste heat goes untapped (see case study on page 34). As a result of these kinds of issues, Britain has fewer than ten district heating schemes powered by EfW. In the March 2020 budget, the government increased funding by £270 million to 'to enable new and existing heat networks to adopt low-carbon heat sources'.[79] It is not yet clear to what extent this will solve the barriers to uptake of heat from EfW.

CASE STUDY: Birmingham heat network

Since 2007, Birmingham has built the country's largest heat network with three interlinked schemes at Broad Street, Aston University and the Children's Hospital. Each year, the Birmingham District Energy Scheme's gas-fired CHP plants supply 56GWh heat, 51GWh of electricity and 8GWh of chilled water, saving more than 15,000tCO_2.[80]

The scheme, whose assets are owned and operated by Engie, has been highly successful so far, and, given the massive redevelopment going on in Birmingham, has the potential to more than double in size. For example, three impending developments on the east side of the city – HS2, Smithfield and Rea Valley – will need at least 75GWh of heat. But now the scheme faces a series of challenges that could stop any further expansion.

One is simply that time is running out on Engie's 25-year contract, signed in 2007. Under its business model, Engie charges customers 10% less for energy than would a conventional supplier, funded by the system's higher efficiency, but this means the investment needed to connect each new customer takes a long time to pay off. Engie's 25-year contract ends in 2032, meaning that any connections made now have to make a return in 12 years rather than the original 25, which makes them either loss-making or uncompetitive.

As a result, unless another body such as the city council can provide an external guarantee that the energy will keep being provided after the end of Engie's contract, and thus extending the payback period, the scheme will take on no new customers. But as things stand, the city council has neither the resources nor the in-house expertise to make such commitments.

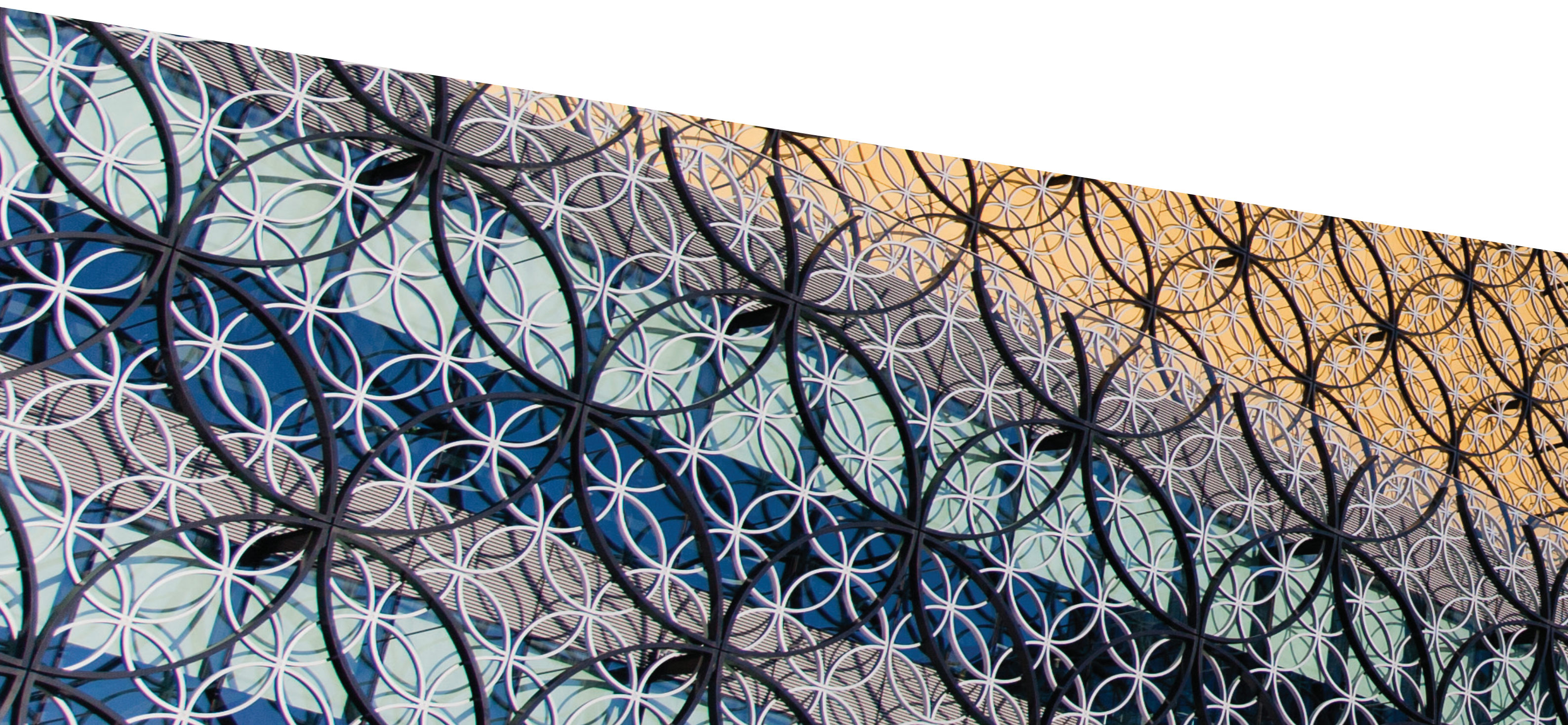
The same factors also affect greenhouse gas reductions. Digging up streets and running gas-fired CHP plants emits carbon, so it takes some years for the district energy scheme's greater efficiency to pay back these emissions before it starts to make savings. Again, that means that after a certain point, even if the scheme could attract more customers, in climate terms it would be counterproductive, unless from a heat source with lower carbon intensity than gas CHP.

If the scheme is to expand, therefore, it not only needs to solve the contract termination issue, but also find a big new source of low-carbon heat.

As luck would have it, there is one: Birmingham's 350,000-tonne, 25MW waste incinerator at Tyseley, is less than five miles from the new developments on the east of the city.

The Veolia operated plant was built in 1996 and is nearing the end of its original contract, which the council recently extended until 2024. The council has put out to tender the plant's operation for a further 15 years and the plant could well be replaced in four years' time.

This uncertainty complicates any decision about whether to integrate its heat into the district energy scheme. But this is a decision the city council will have to confront soon. If the council decides to replace the plant, it will need to tender almost immediately. In this compressed timeframe, the replacement is very likely to be another incinerator in the same location. A modern plant at Tyseley, like Amager Bakke in Copenhagen (see case study on the previous page), could provide huge amounts of heat to the city's heat network and future developments.



CASE STUDY: Nottingham heat network

Nottingham's district heating network was founded in the 1960s and now serves 5,000 houses and 100 commercial buildings. With 85km of pipework, it is one of the largest in the country and saves 27,000tCO_2 per year.[81]

Originally managed by British Coal, the network switched heat sources after the Eastcroft incinerator was built in the 1970s. Eastcroft provides steam to a heat station managed by Enviroenergy, which is wholly owned by Nottingham City Council. The incinerator has been fully refurbished in recent years but the heat station now needs to be replaced. Eastcroft incinerator plant is owned and operated by FCC, whose contract runs out in 2030. The company's lease on the land lasts until 2070, however, which puts it in a powerful position during the contract negotiations. The council does have one other site, Blenheim Allotments, that could host an alternative supplier, but it seems most likely that it will renew with FCC.

The government does already support the development of heat networks through its Heat Network Investment Programme (HNIP) with funding of £320 million available until 2022. But only 14% of applications so far have involved incinerator waste heat, perhaps reflecting the specific barriers listed above. It also suggests HNDU may need to adjust the conditions attached to future HNIP rounds. In evidence to the Commission, one district heat network developer described the HNIP programme as a 'good start'. In its March 2020 budget, the government increased funding by £270 million, but we believe it should go much further; this policy needs rocket boosters.

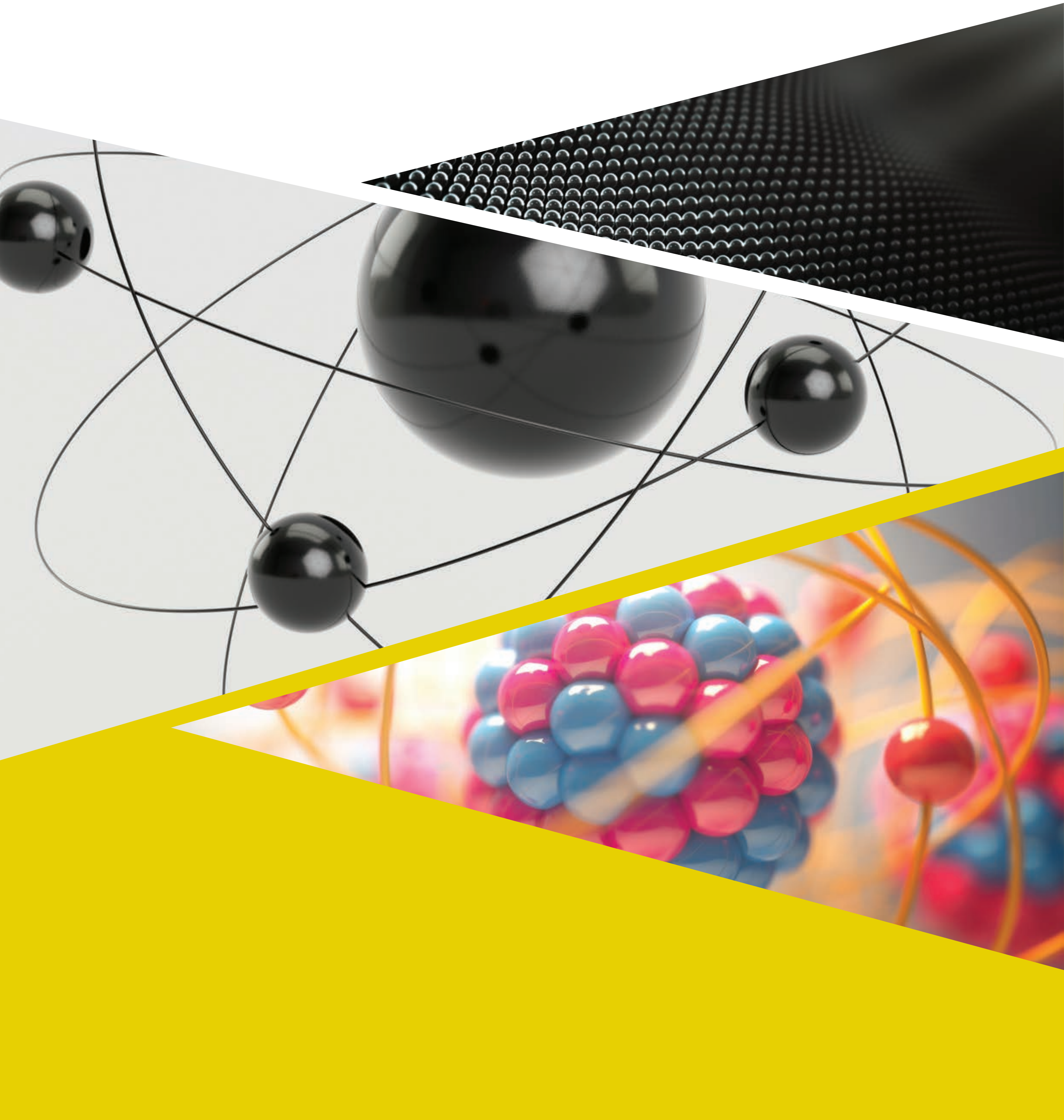
The IPPR has argued that the government needs to extend the HNIP beyond its current closure date of 2022 and increase its funding between six and tenfold. The think tank's starting point is that the Committee on Climate Change (CCC) estimates that cost-effective heat networks could provide 10% of Britain's heat by 2030, representing 33TWh to 54TWh under various scenarios. Based on previous HNIP deals and some assumed cost reduction towards Scandinavian levels, the IPPR calculates this would require investment of between £13 billion and £22 billion, and that this could be catalysed by HNIP funding of between £1.8 billion and £3 billion.[82]

We believe the government should commit to raise HNIP funding to the level needed to achieve the CCC target – raising it to £3 billion if necessary.

In the UK context, it may be easier to exploit EfW waste heat for industrial rather than domestic purposes – at least initially. If EfW plants were co-located on a single site with industrial consumers of heat and cold, the infrastructure would be cheaper and the energy demand constant year-round, so the waste heat might be more fully exploited. The Suez incinerator at Wilton, which both generates 49MW of electricity for the grid and supplies up to 73MW of high-grade heat to the neighbouring industrial estate, is an excellent example. Another is the AD plant built in Scunthorpe to process local farm waste and provide heat to the paper manufacturer CorrBoard (see case study, chapter 5).

For this reason, we believe the best way to start to exploit EfW waste heat is to develop commercial clusters on post-industrial sites of which the Midlands has plenty. These would combine a spread of EfW technologies, along with recycling facilities and other businesses that can consume their cheap electricity, heat, fuels, CO_2 and material outputs – so greatly reducing carbon intensity and improving circularity (for detail, see chapter 6). The government should extend its HNIP programme to these new industrial clusters.

5. ELECTRONS TO MOLECULES: CIRCULAR EFW AND RECYCLED CO_2



Second-generation technologies

Even after the most rigorous separation and recycling of waste streams, and after exploiting all the waste heat from incinerators, incinerating waste to generate electricity does not make best use of valuable material. There are cleaner and cheaper ways to generate electricity – offshore wind now undercuts gas-fired power – and grid average carbon intensity improves every year. So waste could be better used to decarbonise 'hard to reach' sectors by producing transport fuels and chemical feedstocks. Even the industry accepts it must transition from generating electrons to producing molecules. It could be argued that some of the emerging EfW technologies are as much about recycling as energy.

Anaerobic digestion (AD)
One technology that is already established, far lower-emitting, and far more circular than incinerators, is anaerobic digestion. AD takes organic matter and digests it to produce biogas (methane and carbon dioxide) and a nutrient-rich digestate that displaces slurry and fossil fertiliser. The biogas can be burned directly to generate electricity; upgraded to biomethane and injected into the gas grid; or converted into transport fuel. The process also gives off useful waste heat.

The greenhouse gas emissions savings from AD are large because it reduces methane emissions to the atmosphere from landfill; generates electricity or fuels; converts the methane into much less damaging CO_2; displaces carbon-intensive fossil fertiliser; and produces valuable waste heat. At scale, the methane it produces can be injected into the gas grid. AD is also properly circular in that it turns agricultural and food waste into digestate that restores nutrients to the land.

According to the Anaerobic Digestion and Bioresources Association (ADBA), replacing one tonne of artificial fertiliser with digestate saves roughly one tonne of oil, 108,000 litres of water, and seven tonnes of CO_2. In total, almost 4 million tonnes of food waste is processed through AD, generating approximately 3 million tonnes of digestate, which saves 100,000 tonnes of CO_2e.[83]

There are problems with AD digestate, however. Like slurry, digestate is governed by rules on Nitrate Vulnerable Zones, which apply across most of England and which limit the amounts of nitrate fertiliser that can be applied and at which times of year. It's also true that most AD plants currently pay to have their digestate taken away, because, being in liquid form, it is more expensive to spread than the synthetic fertilisers to which farmers are more accustomed.

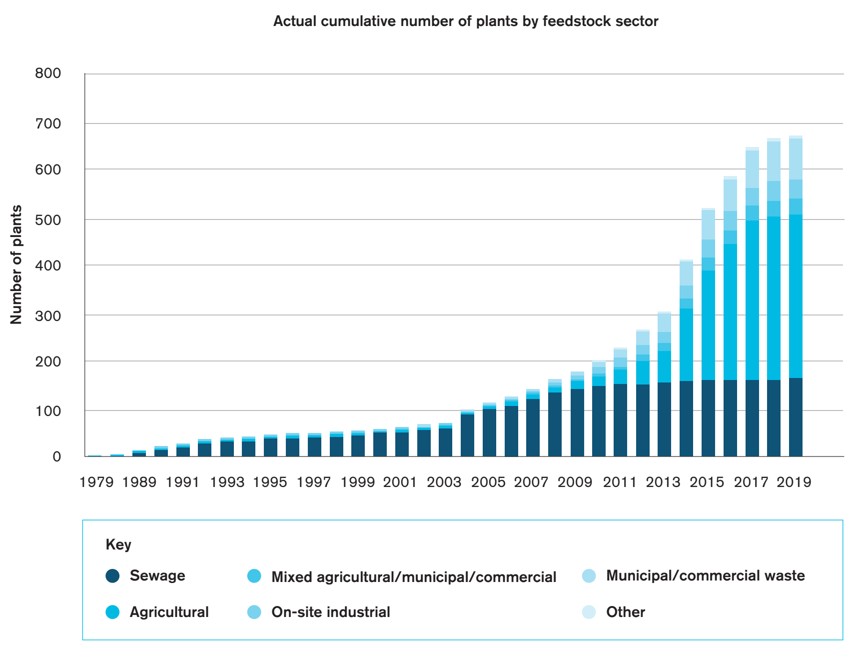
There are, however, various technologies that upgrade digestate by, for example, dewatering, mixing with compost to increase the organic content and stripping out excess nitrates. At least two companies, SGTech[84] and CCm (see Third-generation technologies, on page 43), have proved technologies that upgrade digestate into precisely formulated solid fertilisers. Sewage sludge can also be converted into transport fuels through pyrolysis (see case study, page 44).

The number of AD plants in Britain has risen sharply this century, driven largely by agriculture and the water sector (Figure 16). There are now just over 670 AD plants, of which 108 inject biomethane into the national grid, as at the Minworth sewage plant.[85] Growth was driven by government incentives, but has tailed off now that the Feed-in-Tariff (FiT) has been scrapped and the Renewable Heat Incentive (RHI) is due to end in March 2021.

Yet AD is still hugely under-exploited in the UK, where 90 million tonnes of manure is still spread directly onto the land rather than processed through AD, and 4 million tonnes of food waste still ends up in landfill or incinerators.

In the March 2020 budget, the government announced a new support scheme for biomethane, paid for by a 'Green Gas Levy', though it provided no details. We welcome the announcement, but believe the government should also remove the uncertainty around the future of the RHI by renewing or replacing it; create market mechanisms to stimulate demand for biomethane such as a 'biogas obligation' on gas suppliers, similar to the Renewable Transport Fuel Obligation (RTFO); and support further R&D.

FIGURE 16: UK AD PLANTS BY FEEDSTOCK. SOURCE: ADBA



CASE STUDY: Scunthorpe AD plant and cardboard manufacturing

Most of Britain's AD plants are owned by farmers or water companies, but industry is also beginning to invest. In Scunthorpe, North Lincolnshire, CorrBoard UK has become the world's first corrugated cardboard manufacturer to build a digestor, allowing it to cut emissions and start a local circular economy in food waste and packaging.

The CorrBoard AD plant, commissioned in 2019, has capacity to digest 25,000 tonnes of mostly vegetable waste from local food processors to generate 6.4GWh of electricity per year.[86] Farmers take the digestate to spread on their fields.

CorrBoard's off-cuts could also be processed through the digestor, but it makes more sense to recycle them separately; corrugated cardboard can be recycled up to nine times before ending up as low-grade tissue paper.

The plant's biogas engines generate 800kW of electricity and the same again in heat. CorrBoard consumes 400kW in electricity, exporting the rest to the grid, and all of the heat. The company's gas consumption has fallen 70%, and since the CO_2 emissions from the remainder are offset by the grid exports, the manufacturing operation is now carbon neutral. As a result, the food processors that provide the waste are now beginning to buy their packaging from CorrBoard.

CorrBoard is owned by a consortium of nine companies, two of which invested £5.5 million to build the plant. The investment is supported for 20 years by Renewable Obligation Certificates (ROCs) and the Renewable Heat Incentive (RHI).

Pyrolysis and gasification
AD is well-suited to processing organic waste, but it cannot deal with plastics or municipal solid waste (MSW, or 'black bag'). For this, the most promising technologies are pyrolysis and gasification. These produce either liquid fuels, in which case CO_2 is released to the atmosphere but fossil fuels are displaced (meaning CO_2 may still be reduced overall), or feedstocks for plastics and other chemicals, in which case the process is more circular and keeps some carbon out of the atmosphere.

Pyrolysis and gasification have had a torrid history of technical and corporate failures, but the technical problems are now being overcome, and the remaining policy issues are more about supporting venture capital (VC)-stage companies to commercialise. Both types of plant are typically far smaller than incinerators and therefore easier to integrate with district heating. With the right support they could form the basis of local, low-carbon, circular economies.

Pyrolysis is important because it could solve a major problem of plastics recycling. Under conventional mechanical recycling, plastics are separated into their different types (such as PET or HDPE) and each is melted down to produce new pellets of the same material. The problem is that every waste stream is bound to be contaminated, and so plastics downcycle to a lower quality every time – for instance, from food packaging, to car plastics, to materials for a park bench. This is why plastics tend to recycle only three or four times before ending up in an incinerator.

By contrast, pyrolysis heats plastics to around 500°C in the absence of oxygen, which breaks down the various polymer molecules, meaning a mixed collection of plastics can be reduced to a 'virgin' feedstock oil, which can then be used to produce different types of plastics again. This chemical recycling solves the problem of downcycling and is energy self-sufficient. But the process consumes a portion of the plastic to provide that energy, so in principle there is still a limit to the number of times an initial quantity of plastics can be recycled. One major challenge of chemical recycling of plastic waste is to ensure the oil produced is consistently high quality.

Several British companies are developing chemical recycling through pyrolysis including Recycling Technologies, based in Swindon (see case study opposite). Its process emits less CO_2 than incineration and mechanical recycling, but is able to deal with soft plastics and films that cannot be recycled mechanically. The company plans to combine the two technologies on a single site to greatly increase the total proportion of plastics recycled.

Pyrolysis and gasification can also be used to process organic wastes such as wood, sewage sludge and manure to produce bio-oil and biochar. This, in turn, can be used to produce carbon-negative chemical feedstocks and transport fuels (see case studies opposite and overleaf).

CASE STUDY: Chemical recycling of plastics

Chemical recycling is not new, and the term covers a range of different technologies. But only now is it developing as a commercial means of processing mixed plastic waste. Recycling Technologies, originally a spin-out from the University of Warwick, is one of several companies working on new local-scale technologies.[87]

The company has developed a 'fluidised bed' pyrolysis plant to recycle mixed plastic waste – including soft items like films, pouches, toothpaste tubes and crisp packets – that cannot be recycled using conventional mechanical recycling. The plastics are fed into a bubbling bed of sand-like material at around 450°C in the absence of oxygen, which causes the polymer chains to break and produces a mixture of hydrocarbon gases. Most of the gases are then condensed to produce a feedstock for making new virgin quality, food-grade plastics.

The company has run a 700 tonnes-per-year prototype at Swindon Borough Council's waste processing site for three years, and has secured funding to install its first commercial unit, the RT7000, at the Binn EcoPark in Scotland (see case study, page 54).[88] The unit is factory-built, designed to be transported by lorry and intended to co-locate with mechanical recycling. This would mean that all plastics could be collected in a single bin (Figure 17), which could dramatically increase the recycling rate.

The company carried out a study with the Ellen MacArthur Foundation to analyse the potential impact of this technology. A conventional plastics recycling facility can recycle only the 52% of plastics amenable to mechanical recycling. Of the rest, the non-recyclable soft plastics, which make up 43% of the total, are usually incinerated, and the remaining 5%, mostly PVC, is sent to landfill. If the 43% were instead processed through an RT7000, three-quarters of it (or 32% of the total plastics) would be turned into new materials and a quarter (11% of the total plastics) burned to provide heat for the process (see Figure 18 below). The company claims its process emits less CO_2 than incineration, and that combining mechanical and chemical recycling in this way would emit 21% less than mechanical recycling and incineration.[89]

The RT7000 can process 7,000 tonnes of waste per year, about the amount of residual mixed waste plastics produced by a city of 300,000 people. The company favours local-scale plants because factory production cuts engineering costs, and because local recycling will reduce rubbish truck journeys and emissions. The company intends to build a fleet of 12 plants at first, to gain operational experience, and then move to mass production. By one estimate, the addressable market in the US alone is worth $120 billion per year.[90]

FIGURE 17: COMBINED MECHANICAL AND CHEMICAL RECYCLING OF PLASTICS. SOURCE: RECYCLING TECHNOLOGIES.[91]

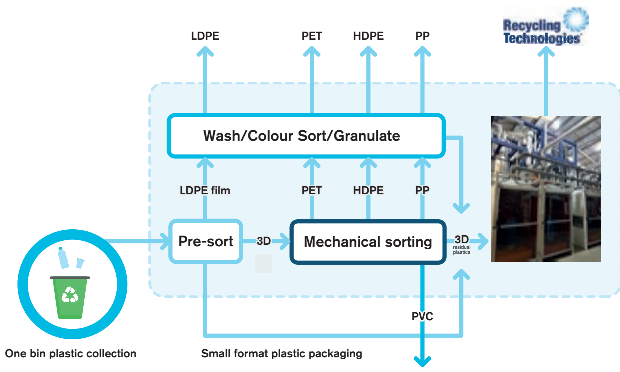
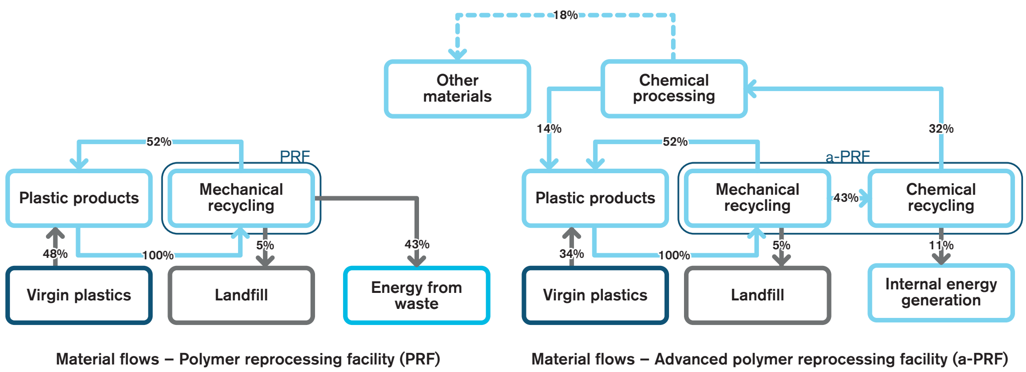


FIGURE 18: COMBINED MECHANICAL AND CHEMICAL RECYCLING COULD RAISE RECYCLING RATE FROM 52% TO 84% OF PLASTICS RECEIVED. SOURCE: RECYCLING TECHNOLOGIES.[92]



CASE STUDY: Biomass pyrolysis for carbon-negative fuels and feedstock

Pyrolysis can be used to process biomass as well as plastics. This means outputs such as synthetic transport fuels, chemical feedstocks, hydrogen, heat and electricity are low-carbon, or even – if the biochar is permanently sequestered – carbon negative.

One challenge has been to produce high-quality bio-oil reliably from variable feedstocks such as sewage sludge. But now the ToSynFuel project[93], with 12 partners across five countries funded through Horizon 2020, has developed a proprietary combination of technologies that solves this problem.

Dried sewage sludge is first heated without oxygen to around 500°C in a reactor that is controlled to prevent the production of tars and other contaminants. In a second stage, the material is heated to around 700°C to produce more gas and improve its quality. This produces bio-oil, a hydrogen-rich synthetic gas ('syngas') and biochar, a dust consisting largely of carbon. In two further steps, hydrogen is separated from the vapour through pressure swing adsorption (PSA), and then re-combined with the bio-oil through hydro de-oxygenation (HDO). This produces stable hydrocarbon oil regardless of the exact composition of the sewage sludge feedstock, which can then be refined into petrol or diesel. The bio-char can be spread on fields to enhance soil structure, where it will last for decades.

This Thermo-Catalytic-Reforming (TCR®) technology was developed by Fraunhofer UMSICHT in Germany, and has been licensed to a spin-off company, Susteen Technologies. A pilot plant at the University of Birmingham demonstrated the process at a rate of 80kg of sewage sludge and 10 litres of bio-oil per hour. Now ToSynFuel is building a pre-commercial plant at Hohenburg in Germany to process seven tonnes per day or around 10,000 tonnes per year.

If successful, this demonstration plant will pave the way for a commercial-scale plant capable of processing around 70 tonnes per day. With such plants installed around Europe, this technology could produce thousands of tonnes of green fuel per year from organic waste, which ToSynFuel estimates would reduce greenhouse gas emissions compared to fossil fuels by more than 80%.

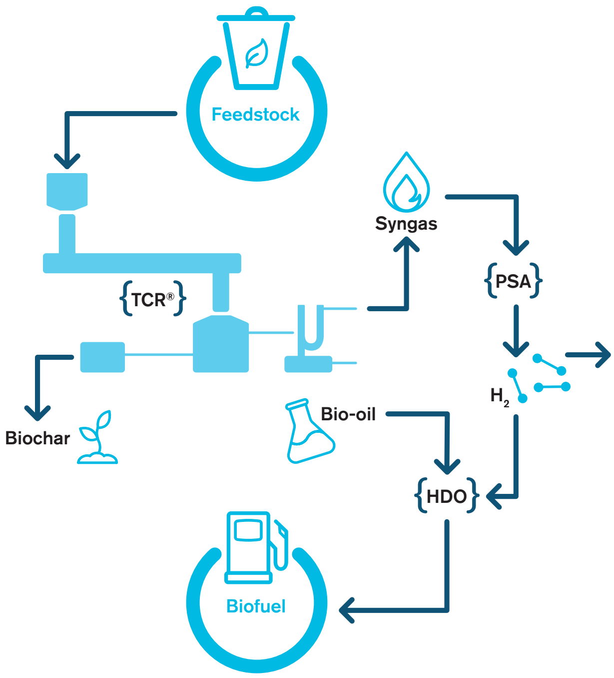


FIGURE 19: THERMO-CATALYTIC REFORMING OF BIOMASS TO PRODUCE SYNTHETIC TRANSPORT FUELS. SOURCE: FRAUENHOFER UMSICHT.

Gasification is similar to pyrolysis but goes a step further, by heating waste to around 800°C to reduce the material to a synthetic gas ('syngas') made largely of hydrogen and carbon monoxide, which can be further processed into chemical feedstocks, diesel or hydrogen. Again, the process is energy self-sufficient and produces waste heat.

Gasification has long been used to turn coal into oil, for example, but dealing with variable waste feedstocks has been challenging. Many gasification projects have failed and many developers gone bust. Now a British company, Kew Technology, has developed and demonstrated a pressurised – and therefore compact – process that turns MSW into a consistent syngas, regardless of the composition of the waste (see case study on page 42). Another firm, LSF, has developed a different gasification process to turn waste oil into diesel and plastics into naphtha. Yet another British gasification company, Waste-2-Tricity, has developed a technology to turn plastics waste into hydrogen for road transport, and plans to build a 35-tonne per day plant near Ellesmere Port.[94]

Gasification plants may not be markedly more efficient than incinerators, but they do have significant advantages. The first is that while they can be used to produce electricity, most produce chemical feedstocks, which is circular, or transport fuels such as diesel or hydrogen, to help decarbonise 'hard to reach' applications such as long-distance, heavy-duty transport, for which there are so far no other viable options.

The second is that the technology favours much smaller plants of 5–10MW, meaning they can integrate more easily into local heat networks. Crucially, they are the right size for a start-up heat network, where initial demand would be too low to interest the operator of a large incinerator.

The big problem for gasification developers is getting across the 'valley of death' between demonstrating and commercialising a technology. Publicly backed support for VC-stage energy companies ended with closure of the ETI and needs to be reinstated.

CASE STUDY: Community-scale waste gasification

Gasification is a well-established technology for materials like coal and wood, but applying it to waste is challenging because the feedstock varies by season. This has led to a string of technical and corporate failures that makes the technology difficult to finance.

Kew Technology has developed a plant it believes can overcome these problems. Like all gasifiers, it heats its fuel or feedstock to around 800°C produce a 'dirty syngas', made up of hydrogen, carbon monoxide and tars. The Kew plant adds a second, high-temperature cracking stage that eliminates the tars, and produces a clean syngas whose proportions of hydrogen and carbon monoxide are consistent regardless of any variation in the feedstock. The hydrogen can be burned to generate electricity, consumed directly as transport fuel or used to produce synthetic diesel or chemical feedstock.

The other key feature is that the plant is pressurised to around seven times atmospheric pressure, which makes it compact. This, in turn, means it can be built in the factory as a modular unit and then transported, rather than being built from scratch on site every time. Factory construction should reduce costs in future, and the plant's small capacity means it can integrate with local heat networks more easily than a large incinerator.

Kew has built a demonstration plant at Wednesbury in the Black Country capable of processing 15,000 tonnes per year to produce 2MW of electricity and 3MW of heat (Figure 20 below). The company has proved the technology works by running the plant for two weeks, but now needs to prove its reliability by running it for a full year, which would then allow insurers to back a product warranty.

Kew has received funding of £16 million so far, around half from the Energy Technologies Institute (ETI) and the rest from various grants and investors. The company estimates it needs a further £15 million to bridge the 'valley of death' and reach commercial lift-off. The history of gasification makes this hard to secure, especially since the ETI, funded by government and industry, closed in 2019. That means there is no longer any public support for VC-stage clean energy companies in Britain. We believe government should revive the ETI's VC investment role.

The ETI also conducted research that supports the business case for establishing a network of roughly 1,000 town-scale gasifiers across the country, rather than a few large centralised plants. In Birmingham, this would mean nine plants distributed across the city and integrated into local heat networks (see Figure 20 and ETI case study opposite). This would produce roughly twice as much energy as centralised incinerators of equivalent capacity.

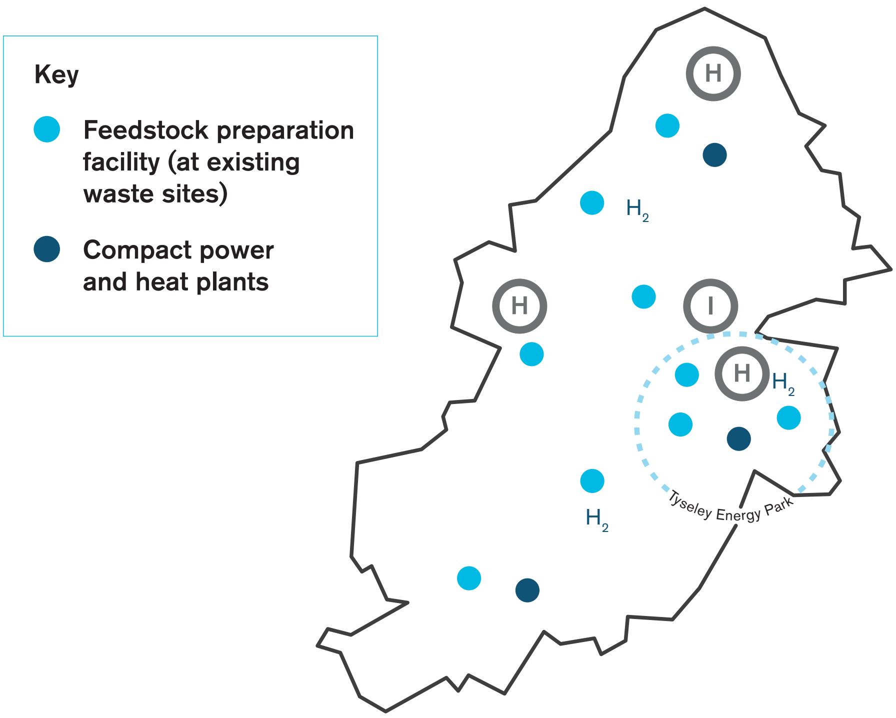


FIGURE 20: KEW TECHNOLOGY'S PLAN FOR DECENTRALISED, COMMUNITY-SCALE GASIFICATION PLANTS. SOURCE: KEW TECHNOLOGY.

CASE STUDY: ETI decentralised gasification of waste and biomass

The Energy Technologies Institute (ETI), which ran from 2007 to 2019, was a partnership between the government and six engineering companies to accelerate the development of low-carbon technologies. It ran 11 major programmes, made targeted investments and had notable success in helping to bring down the cost of offshore wind.

As part of its bioenergy programme, the ETI analysed potential options for dealing with residual waste through gasification plants. It compared competing scenarios in which the country's residual waste was gasified either through 50 large, city-scale plants, each serving about 1 million people; or 1,000 town-scale plants serving around 50,000 people; or 4,500 village-scale plants serving around 5,000 people.[95]

The analysis showed the village-scale plants were uneconomic because of the disproportionate impact of labour costs, and the-city scale plants caused higher emissions – because the rubbish had to be transported longer distances – and were harder to integrate into heat networks. The optimum choice was the town-sized gasifier with a capacity of 5-20MWe. In the future energy network, this scenario could save £1.25 billion and 5 million tonnes of CO_2 each year.

On this basis, the ETI decided to invest in a gasification project, first to demonstrate the technology's reliability and efficiency by generating electricity, but also to support research into future options, including the production of hydrogen, chemicals and fuels.

The ETI favoured gasification over AD because AD was already beginning to grow strongly under existing government incentives, and because AD supported the wet waste streams. Gasification could process a wider range of feedstocks, and the technology needed support to overcome known technical hurdles – such as the cleaning of syngas. The ETI ran a competition among several companies from which Kew Technology emerged the winner (see previous case study). The company has proved its technology but needs further funding to become commercial. But following the closure of the ETI, Britain has no publicly backed VC-type investor to provide evidence-based selective support. We believe the government should revive this role.

One further reason the ETI backed a network of town-sized gasifiers was that, should Britain increase its recycling so successfully that it runs out of residual waste, or the remaining waste becomes incompatible, the plants could run equally well on biomass; there would be no stranded assets. Separate research by the ETI shows that Britain has enough land to grow enough miscanthus or willow sustainably, from which the gasifiers would produce biofuels or bio-chemical feedstocks. Miscanthus and willow are particularly good for increasing the carbon retained in the soil around their roots.

Third-generation technologies

Even second-generation EfW technologies that make full use of their waste heat will continue to emit CO_2. To reach net-zero by 2050 we will need to find ways to store or re-use this carbon, and some promising technologies are beginning to emerge.

Over the past decade, the progress of Carbon Capture and Storage (CCS) in the UK, and the policy intended to support it, has been tortuous. This is perhaps because of the inherent barriers to CCS as originally conceived. As a large-scale technology applied to fossil-fueled power stations and industrial emitters, CCS would need huge investments and was therefore high risk. And because it requires access to depleted oil and gas fields, in the UK it is therefore limited to coastal sites or would otherwise require a huge new pipeline network. Even now the HyNet project is under way, no infrastructure is likely to get built for another decade.

EfW offers an entirely different way to think about CCS that may make it quicker to develop, cheaper, more practical for inland areas like the Midlands – and more circular. Small-scale carbon capture technologies are already being used with EfW to displace fossil CO_2 used in commercial greenhouses, to produce aggregates and other building products, and to produce fully formulated fertiliser (see case studies overleaf).

CASE STUDY: Carbon capture fertiliser

Whereas conventional carbon capture seeks to bury CO_2 in depleted oil or gas reservoirs, several young companies have developed processes to turn CO_2 into commercial products. Instead of viewing CO_2 as waste in need of disposal, they treat it as a resource to be returned to the circular economy.

One such is CCm Technologies, which takes the products of anaerobic digestion (AD) to capture CO_2 and incorporate it into fully formulated fertiliser, solving some of the problems of using raw AD digestate on the land. CCm has demonstrated its process at a Walpole Viridor site in Somerset where food waste is processed through an AD plant to produce biogas, which is burned in an engine to generate electricity.

AD digestate is 95% liquid and 5% solid, meaning its nutrients are dilute, the liquid is difficult and expensive to spread, and its ammonia is unstable and can evaporate as a powerful greenhouse gas. The CCm process takes AD digestate cake (the solid fibrous material) and coats it in ammonia from the liquid, and then runs the exhaust from a biogas engine through the mixture (see Figure 21 opposite). The nitrogen in the ammonia reacts with and captures the CO_2, which in turn stabilises the ammonia.

The mixture is topped up with extra recycled nutrients – such as nitrogen and potassium from AD digestate and phosphate from slaughterhouse waste – to produce solid fertiliser pellets. Unlike conventional carbon capture processes, this reaction produces lots of heat, which can be used to dry out AD digestate to produce the solid.

Field testing over five years has shown the product works: yields are identical or sometimes fractionally better than those of fossil-based fertilisers, but with scarcely a tenth of the LCA carbon emissions; and early results suggest major improvements in soil health and retained carbon.

The company says that because of the energy intensity of conventional fertiliser production the CO_2 savings are enormous. Whereas each tonne of fertiliser produced in Europe (the EEA) emits between 3.6 and 4.5 tonnes of CO_2, CCm Technologies says its fertiliser emits less than 0.4 tonnes of CO_2. (In the US, producing a tonne of conventional fertiliser can emit up to 6.5 tonnes of CO_2 and in Russia and China as much as 8 tonnes of CO_2).

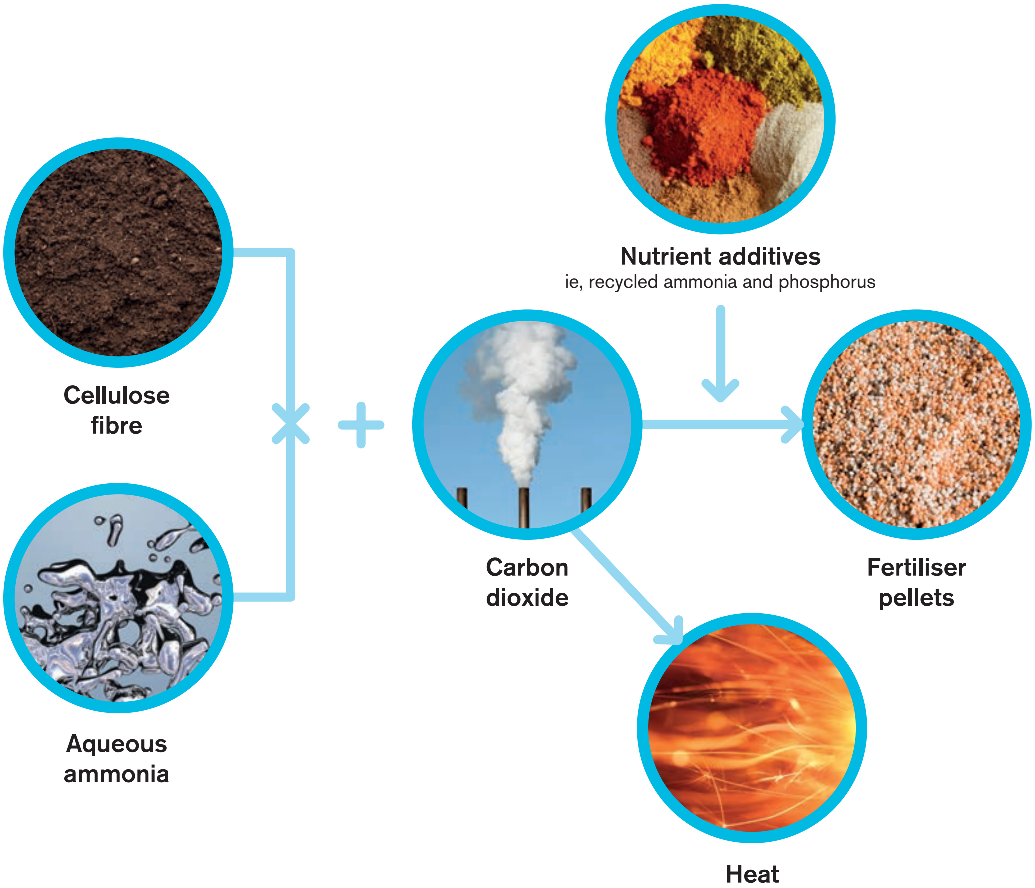
In some circumstances, the process can even be carbon negative. CCm Technologies is working with one European food manufacturer to process vegetable waste and produce a fertiliser tailored to the needs of its suppliers.

Here, because the whole process happens on one site, and the fertiliser is back-hauled to the farmers in the same trucks that deliver the crop waste, the process is slightly carbon negative.

The company says the process is already economic and makes a project return of 15–18% without subsidy, in part because it saves water companies the need to transport sewage sludge between sites in lorries. The company is in talks with three British water companies and one food waste company about scaling up. CCm Technologies estimates that if its process was to supply half of Britain's fertiliser demand, it would save 1.3TWh of energy at 4.4 million tonnes of CO_2 per year. If it achieved 50% penetration worldwide, the annual savings would be almost 100TWh and more than 350 million tonnes CO_2.

The same technology can also be used to produce low-carbon fibres for strengthening fibreglass and plastics, which could displace 10% of the oil content, and as a means of electricity and heat storage.

FIGURE 21: CARBON CAPTURE FERTILISER PRODUCTION PROCESS.
SOURCE: CCM



CASE STUDY: Netherlands incinerator carbon capture for greenhouses

The Netherlands may be tiny but it is an enormous exporter of agricultural products – second only to the US. Most of its fruit and vegetables are produced in vast greenhouse complexes, some of which cover 175 acres each. The total area of land under glass is 1.5 times the size of Manhattan.[96]

Dutch greenhouses are so productive partly because the growers burn natural gas to provide electricity, heat, and extra CO_2 to make the plants grow faster – 'even when it's warm outside and the vents are open'.[97] But this is hardly sustainable, and the industry is beginning to turn to EfW to help reduce its emissions.[98]

In 2019, the energy-from-waste operator AVR added carbon capture to its incinerator in Duiven, near Arnhem, to supply 60,000 tonnes of CO_2 per year to greenhouses nearby. It is the latest and largest of several such projects. Each tonne of external CO_2 saves the greenhouses 0.95 tonnes of CO_2 in their own emissions.

AGR's pilot plant captures only 15% of the incinerator's total emissions, but the same amine-cycle technology could capture up to 90% if market incentives existed to justify the extra investment. In total, the Netherlands' greenhouses consume 2 million tonnes of CO_2 per year, while its incinerators emit just under 8 million tonnes per year.[99] So, in principle, Dutch horticulture could source all its CO_2 from incinerators – with three times more left over for other applications.

One problem is that the greenhouses need the CO_2 only between March and October, which hurts the business case; to make carbon capture commercial requires year-round operation. One possibility is that in winter incinerators could send their CO_2 to the Porthos CCS project being developed in the port of Rotterdam, intended to sequester industrial CO_2 in a depleted gas field offshore.[100] This project would be viable at an EU ETS carbon price of €30/tonne[101], only €5/tonne higher than the price in February 2020[102], and awaits a decision on further Dutch and EU support.

If Dutch incinerators were to supply greenhouses in the summer and Porthos CCS in the winter, because two-thirds of the carbon burned by Dutch incinerators is biogenic and only one-third fossil, the overall impact would be negative fossil CO_2 emissions.

CASE STUDY: Carbon capture building materials

When waste is burned in incinerators about 20% of the original weight ends up as incinerator bottom ash (IBA), which is usually recycled as aggregates for roadbuilding. A further 3–5% ends up trapped in the chimney's filters as air pollution control residues (APCr). These contain a range of contaminants and must be disposed of in specialist landfill. But now Carbon8 Systems, originally a spin-out from the University of Greenwich, has developed a way to use APCr to capture CO_2 to produce more aggregates to manufacture concrete blocks.

The company's plant, housed in a shipping container, employs simple chemistry to speed up the natural process of carbonation. Chemicals in the APCr react with and trap CO_2 direct from the incinerator's flue gas to produce calcium carbonate within 20 minutes rather than the decades or millennia it takes in nature. In the UK, the resulting aggregates have received 'end of life' approval from the Environment Agency, meaning they are safe to use in concrete blocks. The company estimates the life cycle CO_2 saving for each tonne of APCr they process is 44kgCO_2.

In Britain, three full-scale plants operate under licence at concrete block manufacturers in Leeds, Avonmouth and Brandon (where APCr and CO_2 are trucked in). Carbon8 Systems says the process is already economic, and that the cost of carbon capture is more than covered by avoided landfill tax. One advantage of this technology is that the CO_2 is permanently sequestered, but the amount captured is limited by the availability of APCr and other reactive residues. We estimate that if all of Britain's APCr were treated through a Carbon8 Systems plant, it would capture around 20,000tCO_2 and produce almost 402,000 tonnes of aggregates for use in concrete blocks, representing about 1% of the UK market.[103]

Carbon8's technology can be applied to other industrial wastes, however, including cement kiln dust, which absorbs almost ten times as much CO_2 per tonne of material as APCr (the company proved its technology can capture carbon dioxide direct from flue gases at a Canadian cement plant in 2018). The company is in talks with major incinerator companies and cement producers in the UK and abroad. It says the introduction of a CO_2 price, or other measures to encourage demand for low-carbon aggregates, could transform the markets it sells into.

Both Carbon8 and CCm are commercial already, but small-scale CCS clearly needs policy support including R&D, VC and market support mechanisms. Since these technologies capture only a small percentage of EfW CO_2, we urge the government to launch an R&D grand challenge to develop technologies that can singly or jointly capture and reuse all of the CO_2 emitted by EfW and turn it into useful products rather than energy or fuels. This is precisely the kind of problem the government's new US ARPA-style research agency, with funding of £800 million, is intended to solve.

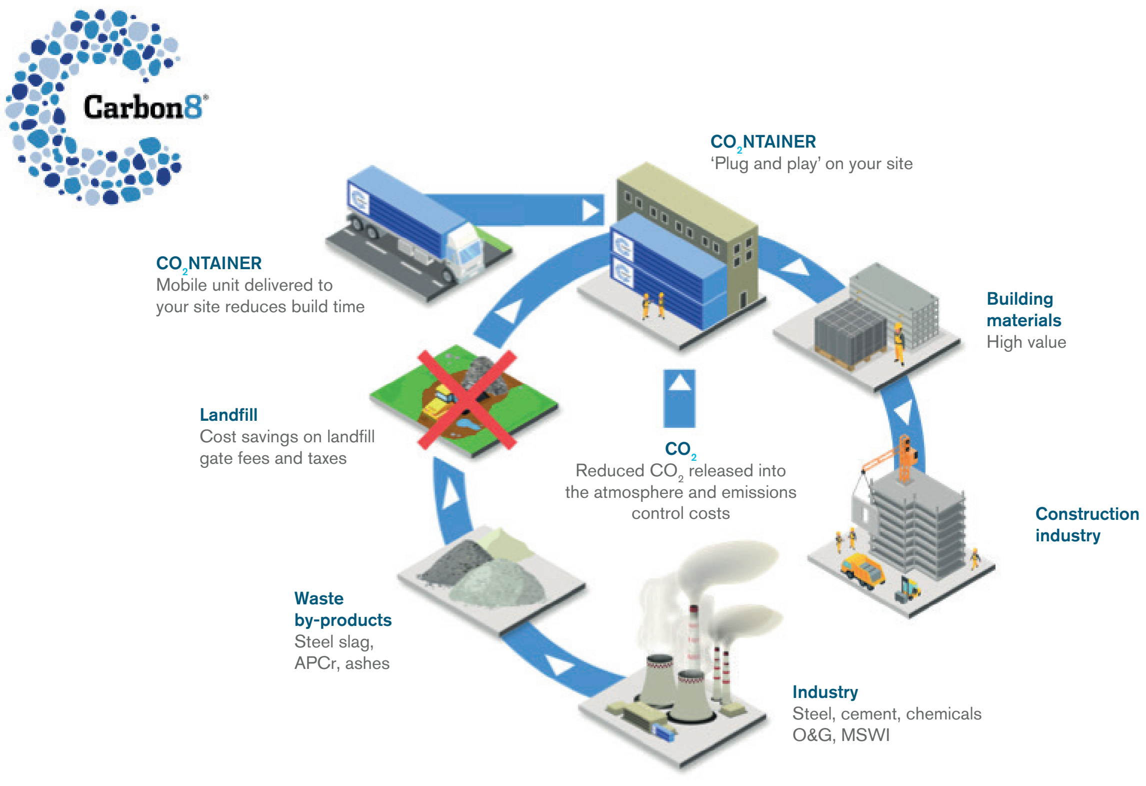


FIGURE 22: AGGREGATES MADE FROM INCINERATOR AIR POLLUTION CONTROL RESIDUES (APCR). SOURCE: CARBON8

6. THE RESOURCE RECOVERY CLUSTER: A MIDLANDS CASE STUDY

We believe the best way to improve the sustainability of energy-from-waste could be to organise it into local Resource Recovery Clusters, initially in the Midlands. Each cluster would co-locate waste processing technologies and sources of demand for their energy and physical outputs to maximise recycling and minimise CO_2 emissions. The clusters would also provide a testbed for innovative and increasingly circular EfW and carbon capture technologies that could then be rolled out more widely in decentralised community-scale energy and resource centres. These would greatly reduce CO_2 emissions from 'waste miles'.

The clusters could be created either around an existing incinerator where there is land available, such as the Tyseley Energy Park in Birmingham, or created from scratch on post-industrial land, such as decommissioned coal-fired power stations and redundant manufacturing sites, of which the Midlands has plenty. These sites typically already have large grid connections, making them ideal for electricity generation and/or injecting AD biomethane into the gas grid. The first AD injection plant was built at Didcot in 2011, and there are now more than 100 in the UK.

The energy produced by the clusters would be not only lower carbon, but also lower cost – provided through short-distance heat networks and private wire power grids – which could attract businesses to relocate there, even from abroad. This chimes with existing work by BEIS (the Department for Business, Energy & Industrial Strategy) and the Department for International Trade, known as the Load Creation Model, designed to lure inward investment by providing secure, economic and low-carbon energy supplies.

The clusters would improve CO_2 emissions and circularity in the short term but would also support the innovation needed to reach net-zero and a far more circular economy by 2050.

How would it work?
Each cluster would reflect its local conditions and so each would be different. But in principle, all would include a range of recycling, EfW, manufacturing, horticultural and other businesses to maximise recycling and minimise emissions. All the businesses could be connected to the cluster's heat, electricity, gas and CO_2 networks, and each could consume another's physical outputs (see Figure 23).

On the **EfW** side, the cluster could be built around an existing incinerator and/or include any combination of new gasification, pyrolysis and AD plants.

The **incinerator** would probably process the bulk of the residual waste received to feed heat and electricity into the cluster's networks. The **gasifier** could also run on black bag waste or biomass, to produce either electricity, chemical feedstocks, transport fuels or hydrogen, and would also contribute heat to the network. The **pyrolysis** – or chemical recycling – plant could run on mixed plastics or biomass, to produce chemical feedstocks and heat for the network. An **AD** plant would receive food and agricultural waste from local farms and businesses or those on site, to produce biomethane for transport, digestate or upgraded fertiliser, and heat for the network. In some locations (rural but with adequate gas infrastructure), a large AD plant could service many farms on a 'hub and spoke' model and inject biomethane into the grid.

On the **recycling** side, an MRF (Materials Recycling Facility), powered by the private wire network, would receive recycling waste and sort into the various streams, to be recycled either on site or at other facilities nearby.

A co-located **mechanical plastics recycling** plant would process the PET and HDPE (bottles, etc,) amenable to this treatment, and the PP and PE (films, bags, laminates such as crisp packets and sweet wrappers and composites), which cannot be recycled mechanically, would be processed by **chemical recycling** (pyrolysis plant) into virgin-quality oil. Chemical recycling is closed-loop, meaning it can be used to produce identical products to those discarded.

The combination of mechanical and chemical technologies could raise the recycling rate to around 90% of the plastics received (see Binn EcoPark case study on page 54). PVC would go to the incinerator or gasifier.

Other **specialist recycling facilities** – batteries, mattresses, tyres – could also be located in the cluster, and powered by heat and electricity from the cluster's networks.

On the **demand** side, any business needing heat, cooling, cheaper electricity and any of the cluster's physical outputs would make sense.

Large-scale **horticulture** or **vertical farming** would benefit in several ways. The greenhouse operator could feed its green waste into the AD plant, which in turn could supply digestate or upgraded fertiliser (potentially tailored to the greenhouse's specific nutrient requirements). The greenhouse could also take heat from the heat network, and CO_2, to make its plants more productive, sourced from any of the EfW plants.

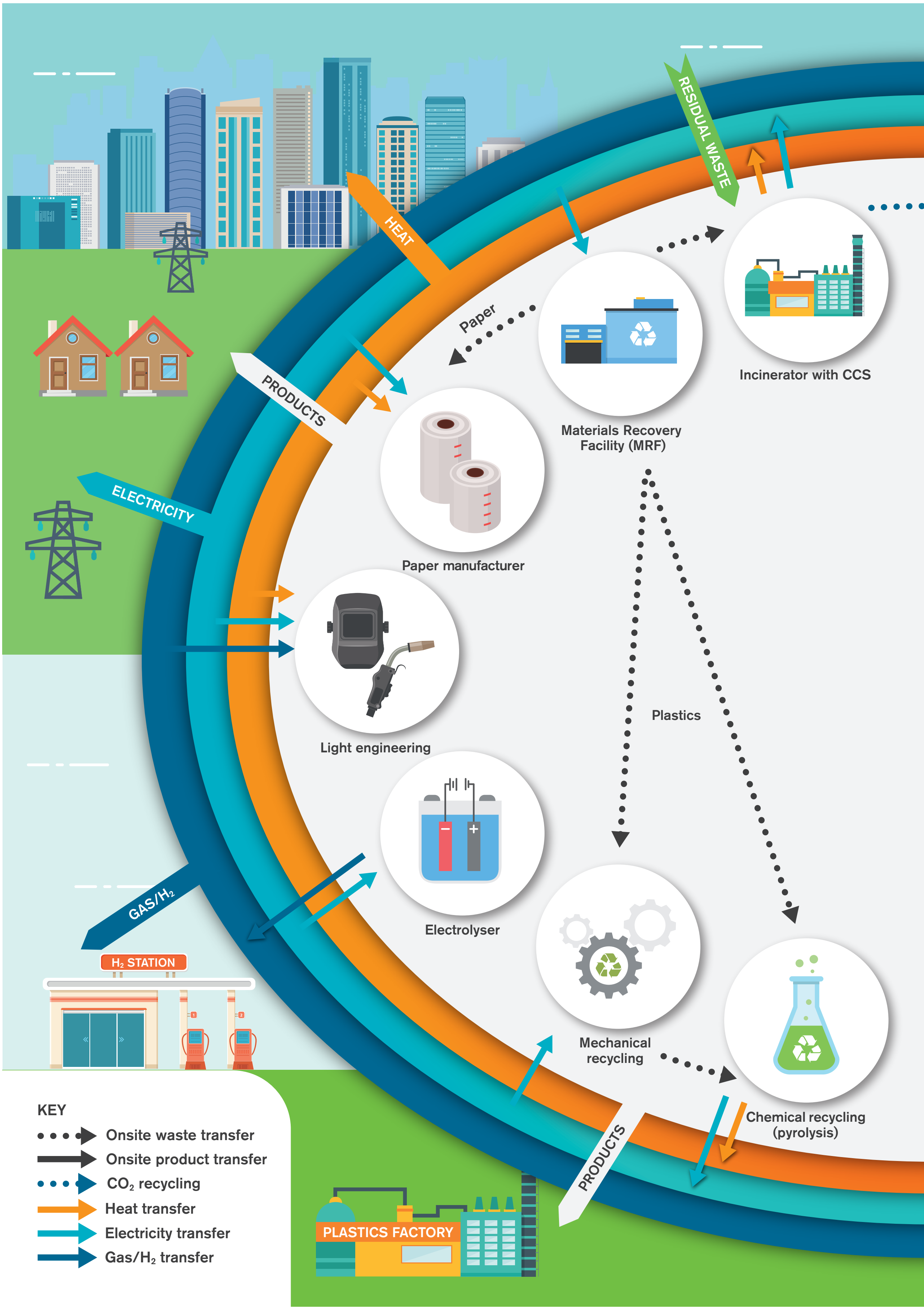
Paper plants would also be a natural fit, needing both heat and power, and producing offcuts that could be treated by AD. **Plastics manufacturing** and **food processing** could also benefit from the low-carbon, low-cost heat and power.

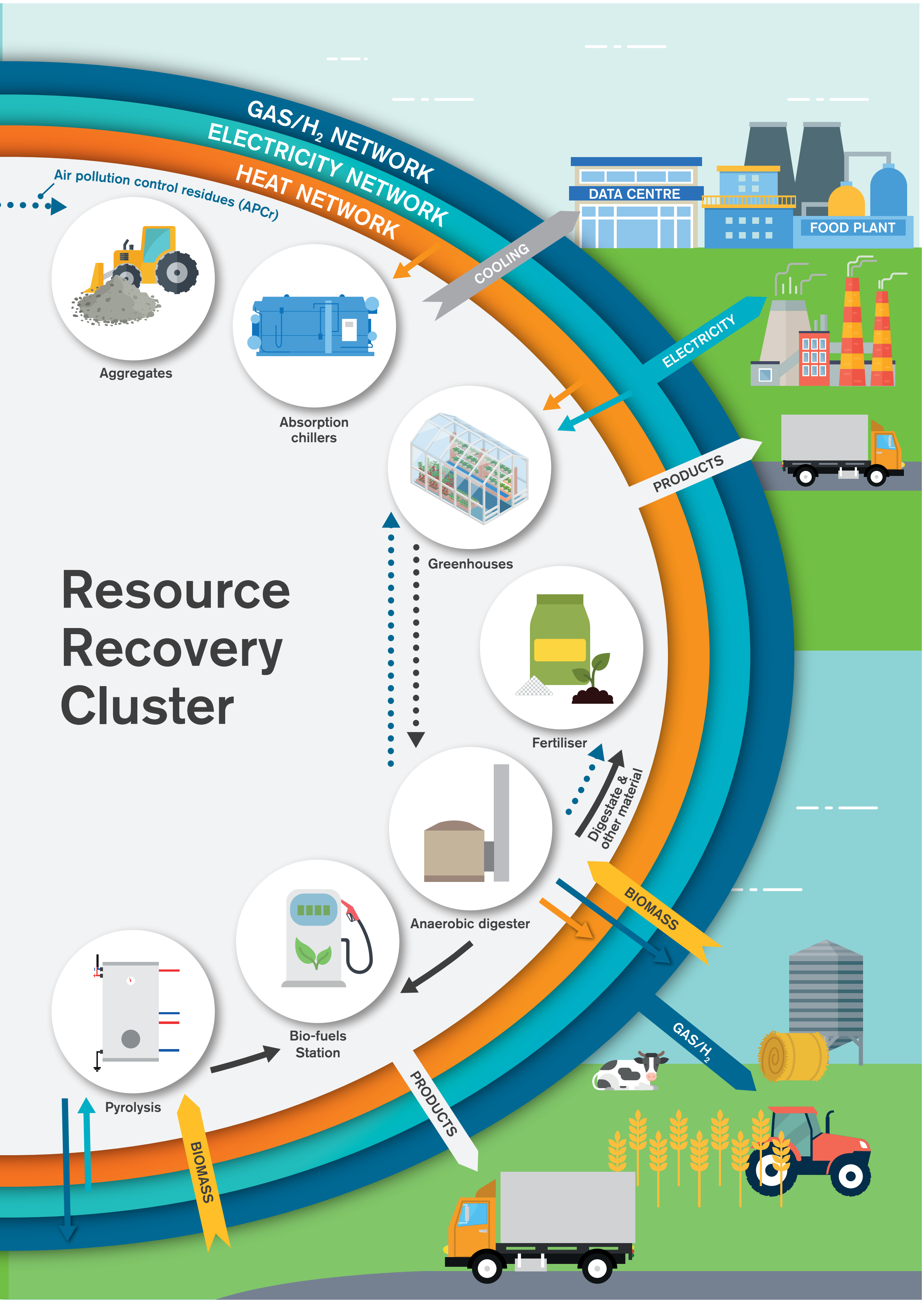
Waste heat can be converted into **cooling** using absorption or adsorption chillers. Users could include **food processers** and **data storage companies**.

Third-generation **carbon capture** technologies could be integrated into the EfW plants to turn exhaust CO_2 into products such as **aggregates** and **fertiliser** (see Carbon8 Systems and CCm Technologies case studies, pages 44 and 46) and to supply the greenhouses.

The clusters would produce immediate CO_2 emissions reductions and increase circularity in the short term. But no less valuable would be the innovation they would stimulate, demonstrating and advancing the technologies needed to achieve net-zero and thorough-going circularity by 2050.

FIGURE 23: THE RESOURCE RECOVERY CLUSTER




GAS/H2 NETWORK
ELECTRICITY NETWORK
HEAT NETWORK
Air pollution control residues (APCr)
DATA CENTRE
FOOD PLANT
COOLING
ELECTRICITY
PRODUCTS
Aggregates
Absorption chillers
Greenhouses
Resource Recovery Cluster
Fertiliser
Digestate & other material
Anaerobic digester
BIOMASS
GAS/H2
Bio-fuels Station
Pyrolysis
BIOMASS
PRODUCTS

Rationale

Huge improvement in waste resource efficiency
Resource Recovery Clusters would greatly improve CO_2 emissions and resource efficiency in both energy and materials. Waste heat is critical: making use of incinerators' waste heat could reduce CO_2 emissions per unit energy by half or even more. Clusters could make better use of this waste heat more quickly than the alternative, district heating. The waste heat could also be used to drive absorption chillers for food, data processing, and perhaps to supply high-energy-consuming sites nearby such as airports.

Combining conventional and novel waste processing and recycling plants on one site would give them access to low-carbon, low-cost energy, reduce transport emissions and maximise the proportion of material recovered: combining an MRF, mechanical plastics recycling and chemical plastics recycling could raise the plastics recycling rate to 90%.

Many levels of circularity could be developed. For instance, if an AD plant and greenhouses were co-located, the greenhouse could feed horticultural waste to the AD plant, and in return take digestate or upgraded fertiliser, heat and CO_2 to make the tomatoes grow faster. The AD plant could also inject biomethane to the gas grid, and the heat and CO_2 could be also provided by other EfW technologies.

Innovation
Clustering would not only reduce waste-miles but has also been shown to encourage innovation.[104] The waste and consuming businesses in the cluster would be umbilically connected by heat, electricity and gas networks, and collaborating to innovate would be natural. Innovative technologies could be demonstrated here in order to prove their reliability, allowing them then to be integrated into distributed, community-scale schemes. In particular, small-scale carbon capture technologies that produce fertiliser and building products from CO_2 could be demonstrated and further developed on EfW plants in the clusters.

Economies of scale
While the broad thrust of EfW technologies is towards smaller plants (gasification, pyrolysis, and AD), for some difficult-to-recycle products such as tyres or mattresses, it could make sense to build one plant with a larger catchment area to gain economies of scale.

City-regions could achieve big economies of scale if they each appointed one contractor to deal with hard-to-recycle products like tyres or mattresses. This is better done at the city-regional level than national. First, it keeps logistics distances shorter; second, it suits the scale of technologies; and third, a national approach would be winner-takes-all and would not optimise local solutions. One idea could be to offer incentives to industry (producers and waste processors) to create specialist centres for these types of products.

Why the Midlands?
The Midlands is well-endowed with potential sites, either land available around existing incinerators, such as the Tyseley Energy Park, decommissioned coal-fired power stations, of which there are many and will soon be more, and redundant manufacturing sites (see map and case studies on page 56) study. These sites offer plenty of space, pre-existing electricity and gas grid connections and perhaps staff with transferable skills. Planning permission may be easier here than in more populous areas.

Research by the Commission has uncovered a long – though certainly not comprehensive – list of other sites to consider (see map opposite).

Of these we highlight:
- Tyseley Energy Park
- Phoenix 10 Enterprise Zone
- Coal-fired power stations in Nottinghamshire:
  – Cottam, Nottinghamshire (recently closed[105])
  – West Burton (closing by 2024)
  – High Marnham (closing by 2024)
  – Ratcliffe-on-Soar (owned by Uniper, closing 2024)
  – Rugeley (closed 2016, being redeveloped for housing)

The Midlands' fleet of incinerators is ageing, and in any case the predicted capacity gap is 2.5 million tonnes per year[106], which makes the region ideal to pilot this approach.

The Resource Recovery Clusters chime with existing initiatives, such as the Energy Innovation Zones and the East Midlands Development Corporation, which is developing plans for Ratcliffe, East Midlands Airport and the HS2 station at Toton. If our ideas are welcomed, they should be integrated with these initiatives before any opportunities are closed off.

The economic benefits to the Midlands could be large. An analysis by Advantage West Midlands (AWM) in 2010 found that in the West Midlands the wholesale cost of energy, compost and fertiliser totalled £3.9 billion, while the wholesale value of the carbon contained in the region's waste was almost £500 million.[107]

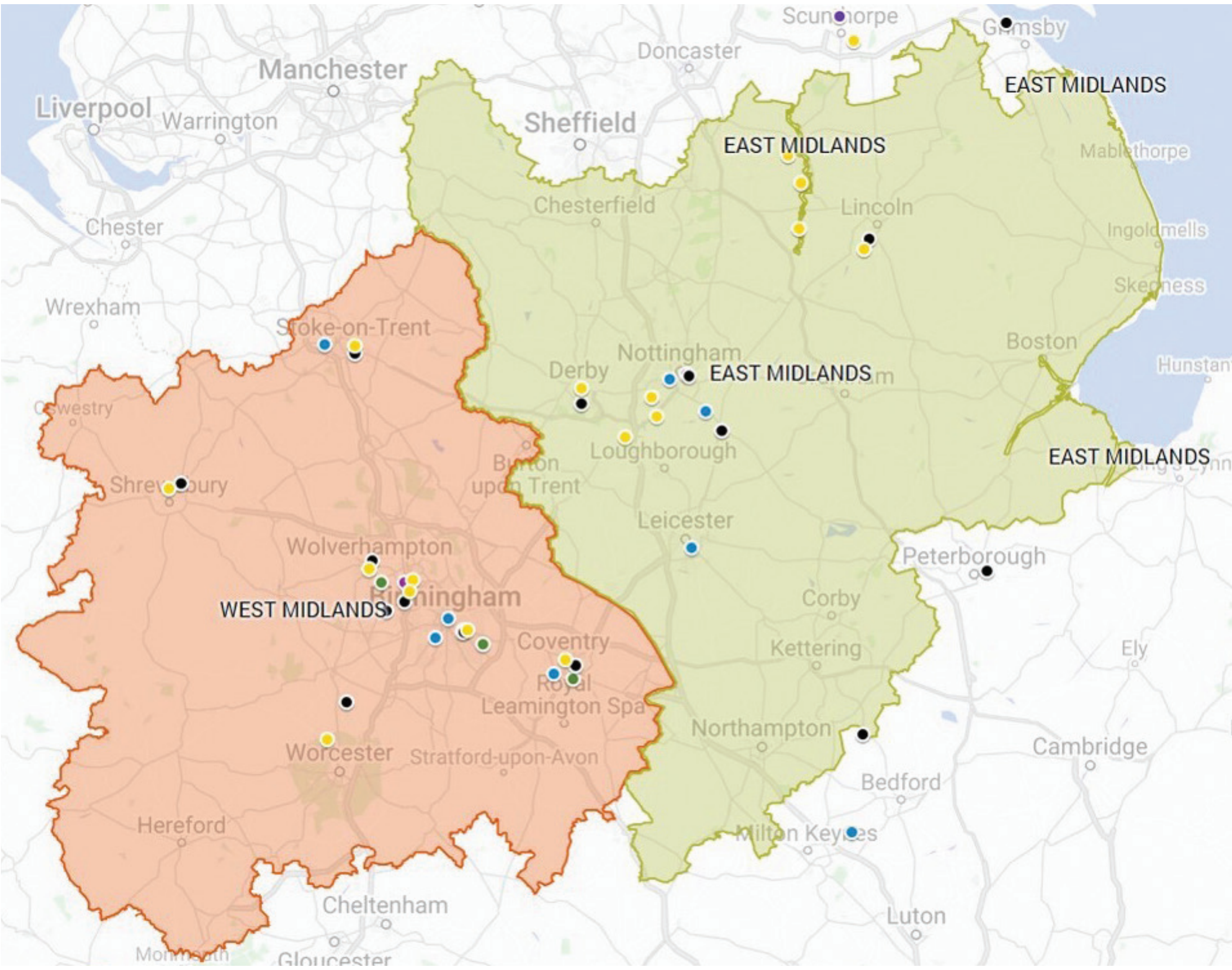
There may be an opportunity for local authorities in the Midlands to take a lead in the transition by securing the waste streams and necessary processing capacity, so generating regional expertise that can then be exported.

Governance and funding
Local authorities should be central to establishing and governing Resource Recovery Clusters:

- Each area will have different assets and needs, meaning the local or regional authority is the natural governing body
- Councils let the contracts for collection and disposal of waste, and often collect the waste themselves, and waste collection can be a sensitive political issue in some areas
- Councils control the planning consent process and have some powers to steer development in their areas
- Coordination between various different areas of planning responsibility – waste, physical infrastructure, economic and energy – will be vital to the success of these schemes.

After a decade of austerity, however, many councils have neither the resources nor the capacity to take the strategic decisions and make the commercial arrangements required. Many will need help with both from central government. The government has granted £2 million in seed funding to the East Midlands Development Corporation, which may provide one model. Others could include regional authorities – which might be the natural choice, where they exist – such as WMCA, Local Enterprise Partnerships and Energy Innovation Zones.

FIGURE 24: ENERGY-FROM WASTE PLANTS, CENTRES OF ACADEMIC EXPERTISE, AND SAMPLE POST-INDUSTRIAL SITES IN THE MIDLANDS. SEE APPENDIX 1 FOR FULL LIST OF SITES.



Key

- ERA university
- Potential RRC area
- Energy innovation zone
- Existing EfW
- Case study

Box 4: What is the right size for a Resource Recovery Cluster?

The short answer is – it depends. And contrary to the normal expectation in technology development, it seems likely that the first RRCs may be large and later ones smaller.

The optimum size of any plant will depend on many factors: the inherent characteristics and economics of the technology, policy incentives, and existing infrastructure and systems. But several factors favour smaller plants in the future: easier integration into start-up heat networks; reduced waste miles; local circular economies. Analysis by the ETI found optimum scale for gasifiers (see case studies, pages 42 and 43) was 'town scale', each serving a population of around 50,000, meaning the UK would need around 1,000 plants. Further research is needed, but the optimum scale and distribution of RRCs may turn out to be similar.

We are where we are, however. Most existing incinerators are large, with catchment areas and logistics to match, and with an average age of just over 11 years, many will be operating for decades to come. But that is no excuse not to exploit their waste heat and other outputs to make them as low-emission and circular as possible.

So it may be that early RRCs centre on a large existing incinerator such as Tyseley, and potentially Ratcliffe (see case studies on page 58), and a wide collection of recycling and other assets are built around them to make the best use of all their outputs.

As new recycling and EfW technologies are demonstrated, new RCCs would become smaller and more closely integrated with local economies. The ultimate goal would be to make the incinerator redundant or truly residual, as at Binn EcoPark (see case study below), where the planned incinerator is just 8.5MW.

Whether or not this is the optimum size for RRCs would need further research. It may well turn out that 'right' size for an RRC will always differ by location and circumstances.

CASE STUDY: Beacon Project, Binn EcoPark

Some of the ideas of the Resource Recovery Cluster are already being put into practice at the Binn EcoPark, near Glenfarg in Perthshire. The 200-hectare site already hosts two material reclamation facilities for commercial and industrial waste; a 30,000-tonne per year anaerobic digester; composting; wood and aggregates recycling; and production of solid recovered fuel (SRF). But soon these will be joined by an Advanced Plastics Sorting and Upcycling Facility (APSuF), which could help create a local circular economy in plastics.

The APSuF will combine a state-of-the-art plastics sorting plant with both mechanical and chemical recycling plants. This means all types of plastic can be collected in a single bin, which should increase recycling rates.

The PlasSort 3000, developed by Pi Polymer Recycling, uses advanced optical technology to separate plastics into separate fractions to feed co-located mechanical and chemical recycling plants. It is the world's first plant to optically sort large rigid plastics such as crates, pipes and broken toys.

The chemical recycling will be provided by Recycling Technologies' RT7000 unit (see case study, page 39), which turns previously unrecyclable plastics – including crisp packets, chocolate bar wrappers, food pouches and films – into a hydrocarbon feedstock to produce fresh plastics.

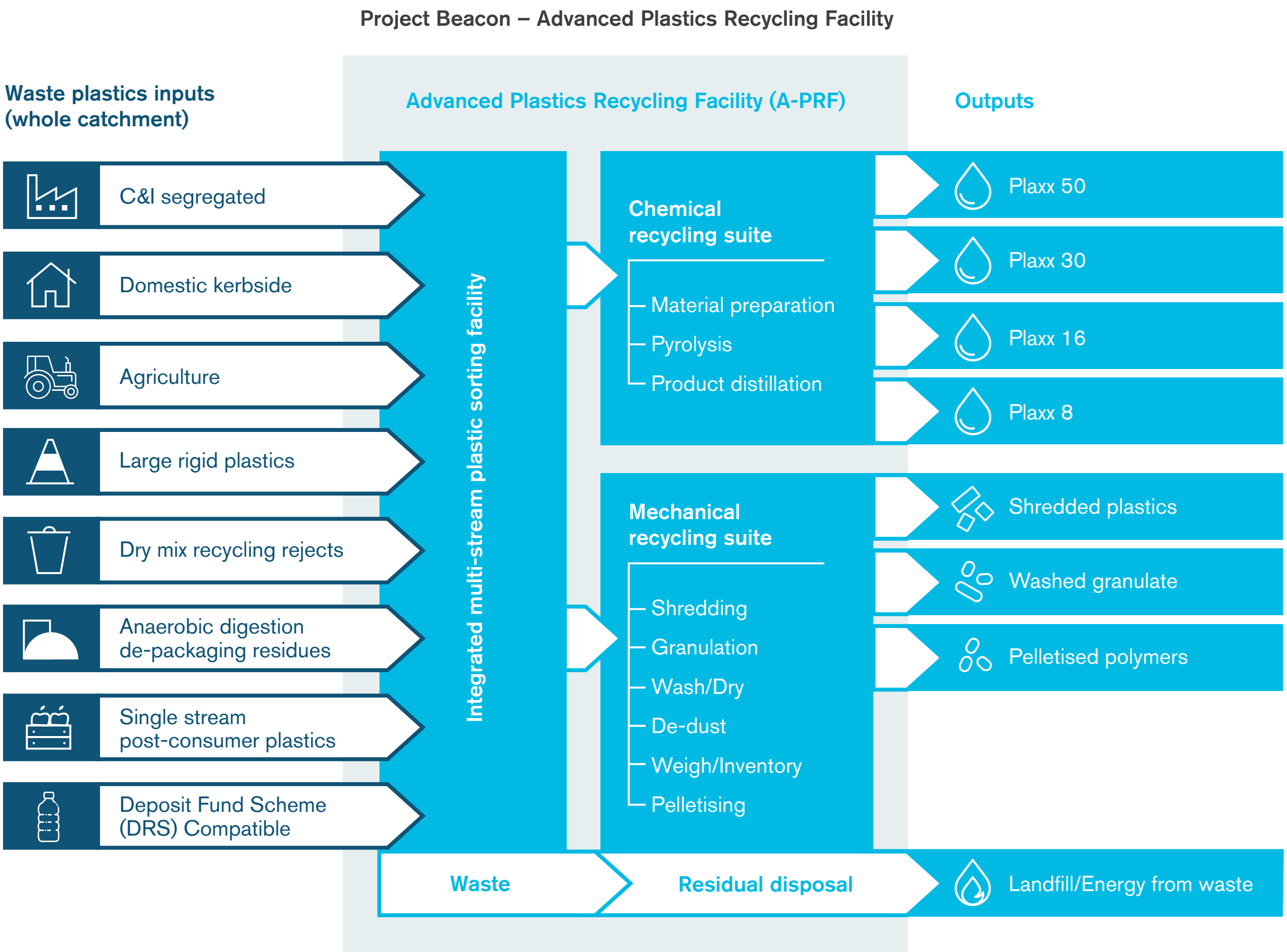
This combination of smart sorting and mechanical and chemical recycling should raise the recycling rate from around 20% to around 90% of all plastics received[108] – even if householders and businesses continue to put all types of plastic into a single bin.

The project is part of the Beacon Project and has received £5.2 million in funding under the Tay Cities Deal, and £570,000 from the Zero Waste Scotland Circular Economy Investment Fund, a partnership between local, Scottish and UK governments and the private, academic and voluntary sectors. The project is currently seeking a further £10–15 million in funding.

Binn EcoPark also hosts a private wire electricity grid and a 10MW wind farm. It also has plans to build a small-scale (8.5MW) incinerator for residual waste.

FIGURE 25: THE BEACON PROJECT AT BINN FARM, GLENFARG, PERTHSHIRE.
SOURCE: ECOIDEAM

FIGURE 26: THE BEACON PROJECT ADVANCED PLASTICS RECYCLING FACILITY
SOURCE: ECOIDEAM



CASE STUDY: Tyseley Energy Park

Tyseley Energy Park (TEP) is an ideal site for a Resource Recovery Cluster. In fact, it is already beginning to look like one. The site covers 16 acres of post-industrial land vacated by Webster and Horsfall, which makes wire and wire rope, as its manufacturing footprint shrank. The company is developing the site as an energy park to power its own operations and to supply low-carbon electricity, heat and transport fuels to its business tenants and customers in the city. Its partners include the University of Birmingham, the City Council, the Local Enterprise Partnership and several private sector organisations.

In the first stage of the project, Birmingham Biopower invested £47 million to build a 10MW waste wood biomass power plant, which has diverted 72,000 tonnes of waste wood from landfill. The power is used on site to reduce Webster and Horsfall's energy costs and emissions. Surplus power is also sold by the private wire network to tenants on the site – one of which is the depot for a fleet of rent-by-the-hour electric taxis – or exported to the grid.

The next step was to build Britain's first low- and zero-carbon refuelling station for commercial fleets including rubbish trucks, buses and other commercial and private vehicles. The fuels include hydrogen produced by an electrolyser installed by ITM Power; compressed natural gas supplied by CNG Fuels; and synthetic fuels with lower tailpipe emissions such as the Shell GTL diesel provided by Certas Energy. The station also has commercial-scale electric charging points. TEP also hosts a pilot pyrolysis plant for producing synthetic fuels from sewage sludge (see case study, page 40).

Future phases will include the University of Birmingham's Innovation Hub, with extensive facilities for research into energy, energy storage and critical materials. The University also plans to build a rare earth magnet recycling facility here.

TEP already produces some energy from waste through its wood gasification plant, but it is ideally sized and situated to expand into a full-scale Resource Recovery Cluster. The site sits between the city centre and Birmingham Airport, and next door to the main incinerator, operated by Veolia, meaning the city's rubbish is already brought right to its doorstep.

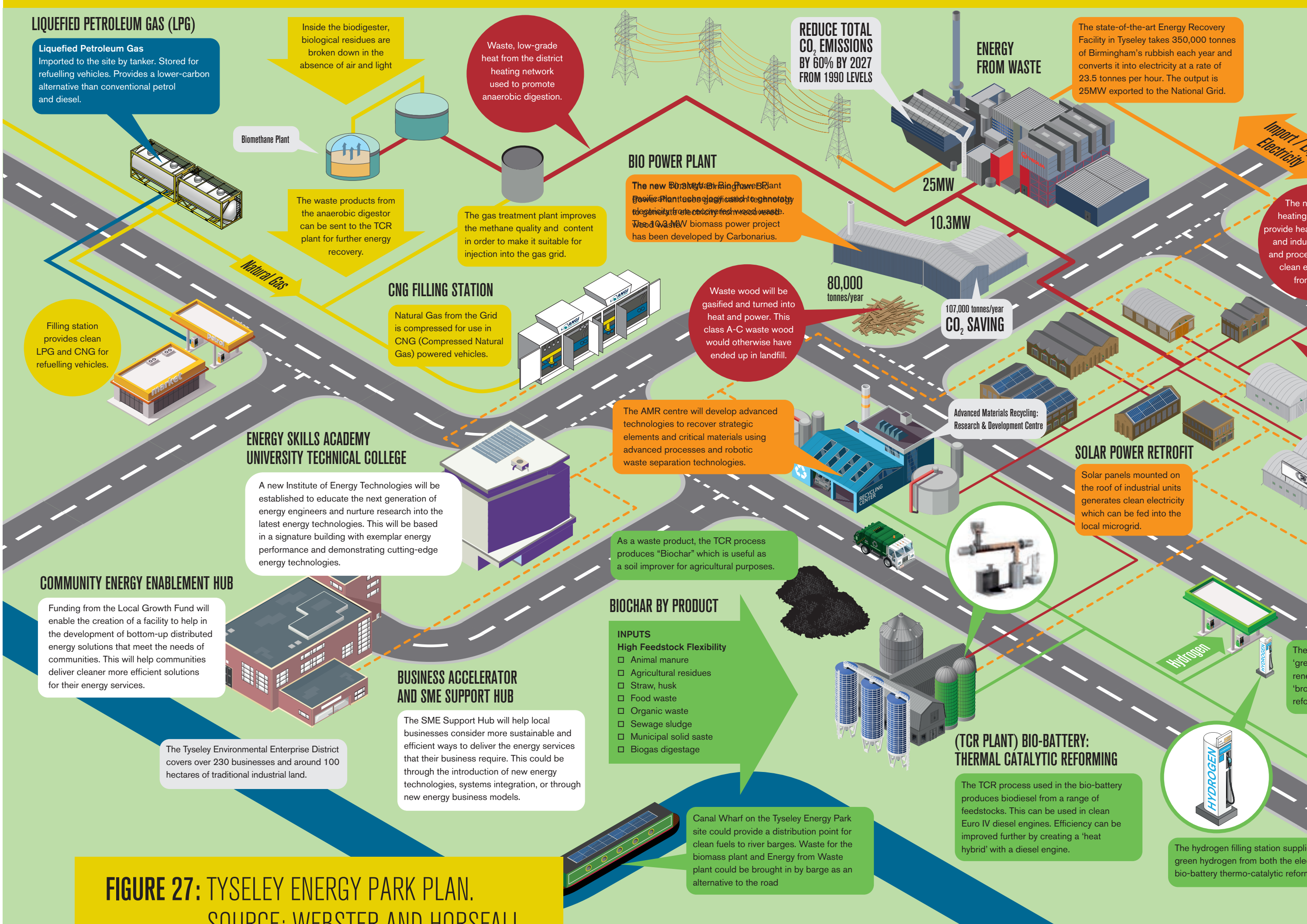


FIGURE 27: TYSELEY ENERGY PARK PLAN. SOURCE: WEBSTER AND HORSFALL

The Veolia incinerator generates 25MW of electricity but makes no use of its waste heat – despite being within five miles of the city's district heating network (see Case study: Birmingham heat network, page 34). The plant was built in 1996 and may soon be replaced. If so, it would make sense to replace it with an efficient and possibly smaller plant as the heart of a Resource Recovery Cluster. The incinerator, and other second-generation EfW plants, could provide low-carbon energy for electricity and heat-hungry recycling processes such as MRF plants, plastics, paper and glass (see main text), and heat-and-cooling-intensive businesses such as food processing and data storage.

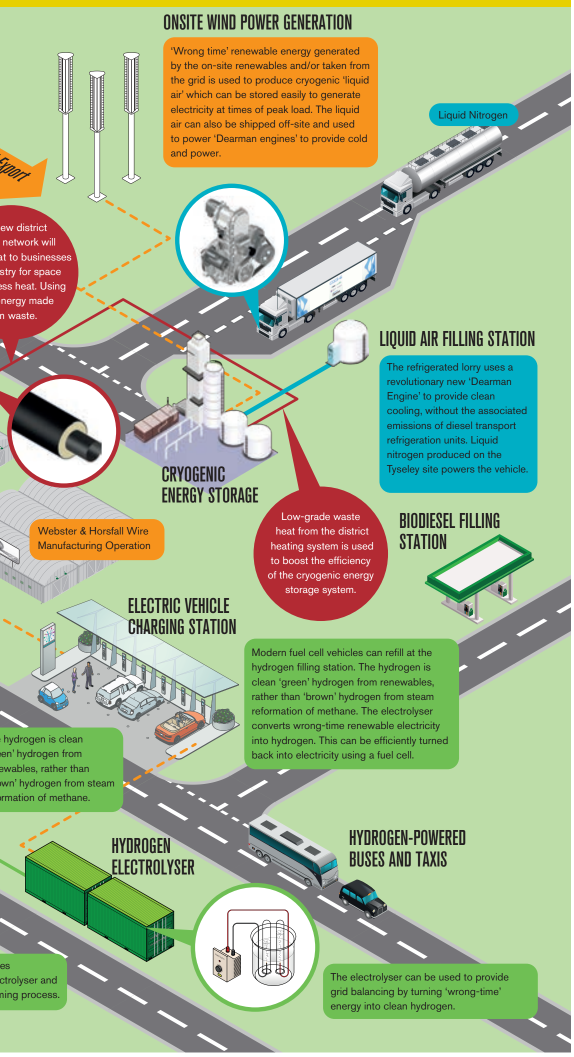


FIGURE 28: TYSELEY ENERGY PARK WOOD GASIFIER (ABOVE) AND LOW-CARBON FUEL STATION (BELOW). SOURCE: WEBSTER AND HORSFALL

CASE STUDY: East Midlands post-industrial sites

The East Midlands also has several sites that could make ideal Resource Recovery Clusters.

The recently formed East Midlands Development Corporation (EMDC) has an ambitious development for three sites, East Midlands Airport, the HS2 station at Toton and the Ratcliffe-on-Soar power station, which together cover more than 1,200 acres. Of these sites, it is the last location that looks most prospective as an RRC.

Ratcliffe-on-Soar is currently a coal-fired power station, which under government policy will close by 2024. The owner, Uniper, a German energy company, has recently announced plans to build a 500,000-tonnes per year, 49.9MW incinerator, and hopes to attract businesses to re-locate to make use of the plant's waste heat.[109] A total of 675 acres are available once the coal-fired station has been dismantled, and the company says a significant area is already available. Uniper says the plant will start to operate in 2025 and will be called the EMERGE (East Midlands Energy Re-Generation) Centre. Uniper has committed to making its European power generation climate neutral by 2035.[110]

The EMDC's plans for the Ratcliffe-on-Soar site include a new Centre for Integrated Zero Carbon Futures, bringing together regional expertise, to demonstrate clean energy and building technologies at scale. Together, EMERGE and CIZCF could form the basis of a large RRC.

Ratcliffe-on-Soar is only one of several coal-fired power station sites in the East Midlands that could serve the same purpose. Others include High Marnham, Cottam and West Burton A, owned by EDF Energy.

These sites are not as well connected to the road network as Ratcliffe-on-Soar but have large grid connections that could be exploited. Their relative remoteness could make them good sites for services such as data storage. Cottam is close to a large gas grid connection, and EDF has plans to build a new gas-fired plant at West Burton, so both could be potential sites for large-scale AD and biogas injection.

FIGURE 29: COMPUTER-GENERATED IMAGE SHOWING PROPOSED DESIGN OF EMERGE CENTRE BUILDING. SOURCE: UNIPER

CASE STUDY: Black Country smelting revival

Another site that could be re-purposed as a Resource Recovery Centre is the former IMI James Bridge Copper Smelting works near the M6 in Walsall. The plant closed in 1999, ending 400 years of copper smelting in Walsall. It was the last copper smelting facility in the UK, a local landmark and anchor employer.

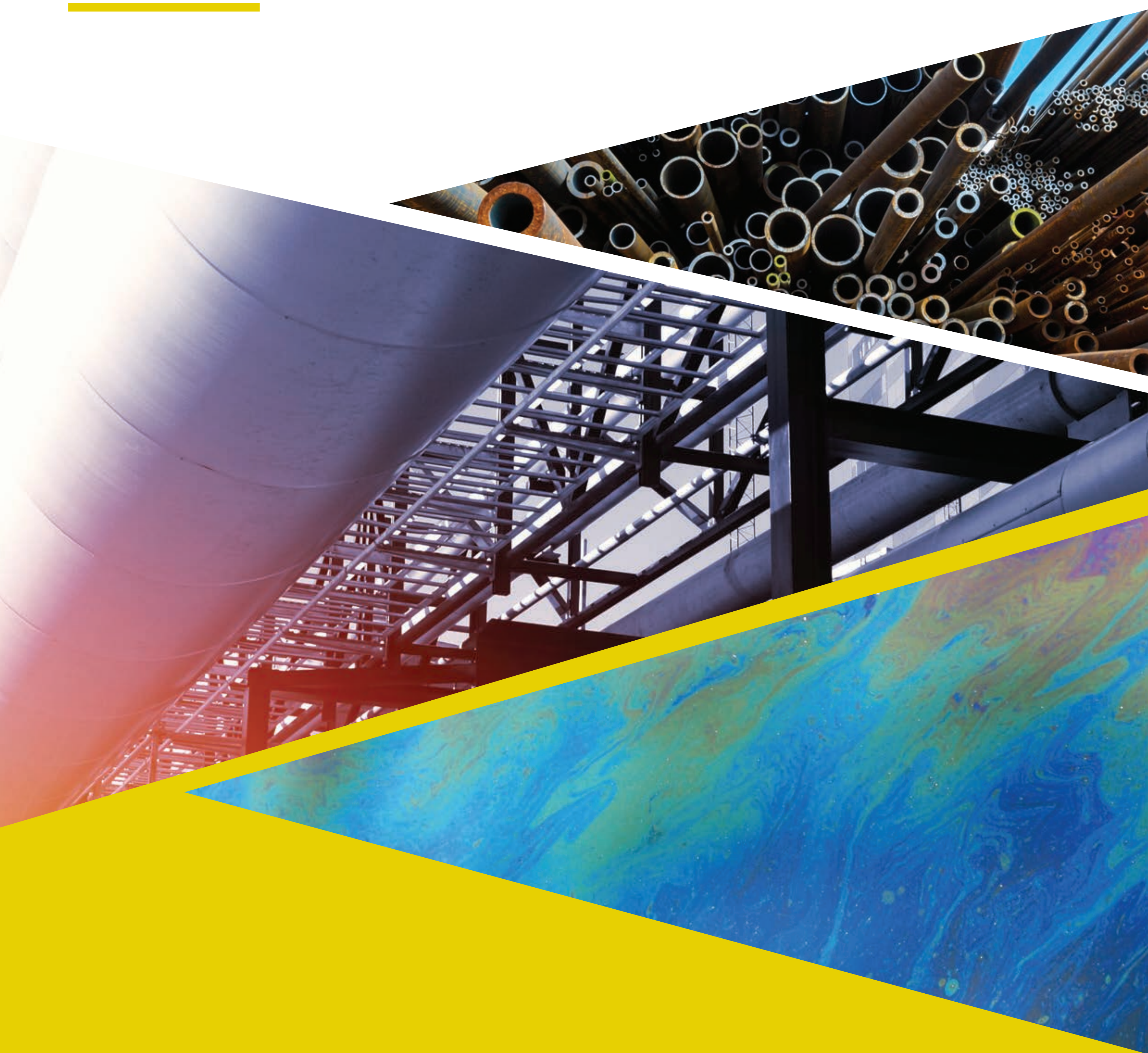
The Black Country LEP is currently exploring the potential to revive the site as a hub for aluminium recovery, smelting and manufacturing, to make components for the automotive and aerospace industries. The location, which is close to the centre of the national motorway network, is ideal for the logistics of collecting recycled aluminium; the co-location of smelting and manufacturing means the aluminium would be melted only once, not twice, saving energy and cost; and the use of district heating to distribute low-grade waste heat to the surrounding housing and industrial areas would increase energy efficiency. There is also a strong cultural fit with the history and skills base of the local people.

APPENDIX 1. KEY TO MAP, LISTING EFW AND ERA ASSETS, AND A NON-EXCLUSIVE LIST OF SAMPLE SITES FOR RESOURCE RECOVERY CLUSTERS.

NAME	TYPE OF FACILITY/INSTITUTION
University of Birmingham	ERA University
University of Nottingham	ERA University
Keele University	ERA University
University of Leicester	ERA University
Aston University	ERA University
British Geological Survey	ERA University
University of Warwick	ERA University
Cranfield University	ERA University
Tyseley Energy Park EIZ	Energy Innovation Zone and case study
Coventry and Warwickshire EIZ	Energy Innovation Zone
UK Central Hub EIZ	Energy Innovation Zone
Black Country EIZ	Energy Innovation Zone
Sustainable Energy Centre	Case study
Nottingham Heat Network	Case study
Scunthorpe Papermaker/AD Plant Case Study	Case study
Ratcliffe Power Station	Case study
Veolia Household Recycling Centre Tyseley and Energy Recovery Facility	Existing EfW
The Coventry and Solihull Waste Disposal Company Ltd	Existing EfW
North Hykeham Energy from Waste Tata Steel	Existing EfW
Eastcroft EfW Plant	Existing EfW
Peterborough Energy from Waste Facility	Existing EfW
Dudley Energy from Waste Facility	Existing EfW
EMR Oldbury	Existing EfW

NAME	TYPE OF FACILITY/INSTITUTION
MES Environmental Ltd, Waste to Energy Plant, Stoke on Trent	Existing EfW
Battlefield Energy Recovery Facility	Existing EfW
Mercia Waste Management	Existing EfW
Birmingham Bio Power Biomass Gasification Plant	Existing EfW
MES Environmental Limited Waste to Energy Plant, Wolverhampton	Existing EfW
CEG UK Ltd	Existing EfW
Equitix ESI CHP (Nottingham) Limited	Existing EfW
Ancillary Components Limited EfW	Existing EfW
Newlincs Development Ltd, EfW	Existing EfW
HS2 Station Toton Industrial	Potential RRC Area
East Midlands Airport	Potential RRC Area
High Marnham Power Station	Potential RRC Area
Cottam Power Station	Potential RRC Area
East Birmingham Urban/ Industrial	Potential RRC Area
Staffordshire Potteries Urban/Industrial	Potential RRC Area
Black Country Industrial	Potential RRC Area
Sandwell District Heating	Potential RRC Area
Lincolnshire Rural	Potential RRC Area
Derby Urban/Industrial	Potential RRC Area
Shrewsbury Rural	Potential RRC Area
Wednesbury Rural	Potential RRC Area
Worcestershire Rural/ Industrial	Potential RRC Area
Coventry Urban	Potential RRC Area
Scunthorpe Urban/ Industrial	Potential RRC Area

APPENDIX 2. COMMISSIONERS' BIOGRAPHIES



CHAIR

1. Lord Robin Teverson

Lord Teverson was Member of the European Parliament for Cornwall and West Plymouth between 1994 and 1999, becoming one of the first two Liberal Democrats elected to the European Parliament.

He was Chief Whip of the European Liberal Democrat Group from 1997 to 1999. In Europe, he spoke on marine, transport and regional policy issues, and was previously spokesperson in the Lords for Environment, Food and Rural affairs.

He joined the Liberal Democrat group in the House of Lords in 2006, speaking on climate change and energy issues. He is a trustee of the Green Purposes Company, which holds the 'green share' in the Green Investment Bank, and a trustee of the North Devon Biosphere Foundation.

Before entering parliament, Robin had a 20-year career in the freight industry.

On 1 June 2006, he was created a life peer as Baron Teverson of Tregony in the County of Cornwall.

ACADEMIC LEAD

2. Martin Freer

Professor Freer is Director of both the Birmingham Energy Institute (BEI) and the Energy Research Accelerator (ERA). He is former Director of the Birmingham Centre for Nuclear Education and Research, which he established in 2010. His background is in Nuclear Physics for which he was awarded the Rutherford Medal for his contributions to the subject. He has overseen the development of the BEI, helped establish Energy Capital and has co-led the establishment of the joint University of Birmingham–Fraunhofer Germany research platform.

To date, Professor Freer has supported three policy commissions for the University of Birmingham, the first on the 'Future of Nuclear Energy in the UK,' the second on 'Doing Cold Smarter', an examination of the global demand for clean cooling technologies and the potential for UK leadership and the third on 'Powering West Midlands Growth: A Regional Approach to Clean Energy Innovation.'

COMMISSIONERS

3. David Boardman

Dr David Boardman is a Fellow of the Institute for Knowledge Transfer, Head of Strategic Projects for the College of Engineering and Physical Sciences and Deputy Director of the Birmingham Energy Institute (BEI).

Whilst developing his career at Birmingham he led the Birmingham team that helped to deliver the national Mini-Waste Faraday Partnership, the national Waste Minimisation Knowledge Transfer Network and the national Environmental Sustainability Knowledge Transfer Network. Over the last six years he has supported the development of the BEI and its strategic innovation translation ambitions including the Midlands Energy Consortium, the Energy Research Accelerator, Energy Capital and Sustainable Clean Cold. David's current mission is to support BEI to deliver a new Energy Innovation Hub within the city's Energy Innovation Zone.

4. Adam Chase

Adam Chase has overall responsibility for E4tech's work on low-carbon transport and on energy innovation and policy. He has been a director of E4tech since joining in 2001 and he plays a role in many of the firm's projects where strategy, policy or stakeholder engagement – in combination with technology – are key. Adam's project work often relates to corporate or national strategy and involves an understanding of how energy systems operate, rather than technologies in isolation. Adam's particular interest is low-carbon innovation in the energy and automotive sectors. He also has operational responsibility for the London office.

Adam was previously a manager with the global management consulting firm A.T. Kearney, where he took part in and led teams engaged in a wide range of strategic and operational projects across the international energy and chemicals sectors. Prior to this, Adam worked for seven years in the upstream and downstream oil and gas industry and also spent time as a journalist with the Financial Times organisation, focusing on energy, environment and automotive issues. He has degrees in Economics, Engineering (University of Birmingham), and Energy and Environmental Technology (Imperial College). He speaks English, French and conversational Italian.

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COMMISSIONERS

5. Matthias Franke

Dr Matthias Franke is the Head of the Department of Recycling Management, Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Germany.

Matthias Franke graduated from the Agricultural Engineering and Environmental Protection Engineering Program at the University of Rostock. He is a member of the Board of Directors of the German Society for Waste Management (DGAW) and a member of the scientific advisory board of the Circular Economy Coalition for Europe (CEC4Europe) and the European Biomass Conference and Exhibition (EUBCE). Since 2009, he has been teaching at the Technical University of Munich, where he teaches waste management in the international study program Sustainable Resource Management.

6. Andreas Hornung

Professor Andreas Hornung (CEng FIChemE FRSC) studied at the TU Darmstadt in Germany, where he graduated as Engineer in Chemistry in 1991, before doing his PhD at the TU Kaiserslautern in Germany. From 2000 to 2002, Andreas worked for companies in Austria and Italy developing first prototypes. Such units have been used from 2002 at the Karlsruhe Institute of Technology, where he worked until 2007 as head of the pyrolysis and gas treatment division. In 2007, he took over the chair in Chemical Engineering and Applied Chemistry at Aston University in Birmingham. In 2008, he founded the European Bioenergy Research Institute EBRI, of which he was leading as Director until the end of 2013. In the beginning of 2013, he became the director of the Institute branch Sulzbach-Rosenberg of Fraunhofer UMSICHT. Andreas is a member of the board of the International Biochar Initiative IBI and holds a Contract Professorship at the University of Bologna.

Andreas holds 19 patents and has published over 150 scientific publications to date. In 2014, his institute employed an estimated 120 staff members who are doing applied research in various sustainable topics.

The main strategic topic of Andreas's work today is the development of decentralized power-providing units combined with pyrolysis, gasification and digestion units – called the Biobattery.

7. Peter Jones

Peter Jones has 30 years' experience in the UK waste material sector, 20 as Director of Biffa where he was responsible for logistics, sales and marketing and business development strategy. He expounded and delivered the concept of the circular economy via the £10 million Biffaward Mass Balance Programme from 1997 to 2008. His career has covered industrial gases, 'just in time' parcels logistics, pallet hiring and welding products distribution with a focus on innovation in handling systems, marketing and information technology. Now retired, he operates in support roles for advanced thermal conversion technology companies as well as pro bono work for environmental NGOs, chartered bodies and a social co-operative not for profit.

Peter qualified as an Industrial Economist from Nottingham University in 1969, holds an Honorary Degree from the University of Southampton and is a Fellow of CIM, CIWEM, CIWM , CILT. He was awarded an OBE for services to the environment in 2007.

Peter chaired a WRAP-sponsored Gas to Grid study Group and the groundbreaking West Midlands study into co-location of renewable energy and recovery processes in 2009. He has also Chaired a Multi Academy Trust.

8. Daniel Mee

Daniel Mee joined the Energy Systems Catapult in August 2016 as their Energy Systems Architect initially to explore whole system approaches to the challenge of decarbonising domestic heat and also to bring a systems of systems engineering approach to energy system design. Prior to that, he was the Chief Engineer on a number of Electrical Power Systems in the aviation industry responsible for both 'clean sheet' system development and multi-party integration, leading multi-disciplinary teams of engineers to deliver smart electrical distribution system solutions for some of the world's most successful aircraft manufacturers. Daniel holds an MEng from the University of Birmingham.

9. Matthew Rhodes

Matthew Rhodes is a Board member of the Greater Birmingham and Solihull Local Enterprise Partnership and Chair of Energy Capital in the West Midlands. He's worked in the energy industry for over 20 years, initially with international companies including RWE and BP. Prior to this, he worked in manufacturing and management consultancy. From 2003 to 2017, he founded and ran an independent engineering and building physics consultancy specialising in low-carbon innovation, developing and delivering collaborative projects at the leading edge of the energy system transition.

10. Adrian Smith

Adrian joined Nottinghamshire County Council in 2016 as Corporate Director of Place and became the County Council's Deputy Chief Executive in January 2019.

Adrian leads many of the Council's most visible frontline services used by their 800,000 residents and 31,000 businesses including highways, transport, waste and recycling as well as the catering, cleaning and landscaping services that the Council provides to many local schools. The Department also provides important place-based services such as planning and economic development and community services such as trading standards, community safety and support for the voluntary and community sector.

A strong Place Department will help sustain what local residents value about Nottinghamshire, whilst ensuring the County Council achieves its ambition for inclusive growth and prosperity. There are many significant opportunities for growth in the county, not least their important role in the Midlands Engine. Adrian has a key role for Nottinghamshire in the Midlands Engine Development Corporation bringing forward the plans for HS2 and the ambitious developments at Toton, East Midlands Airport and the Ratcliffe-on-Soar Power Station. These opportunities will bring new jobs, better housing, more connectivity and more prosperity to the county's residents and businesses, but only if there is a Place Department with the right capacity and resources, aligned to the county's vision.

11. Patricia Thornley

Professor Patricia Thornley is director of the Energy and Bioproducts Research Institute at Aston University. She is a chartered physicist with over 25 years' experience working on bioenergy energy projects in industry and academia. She has been director of the UK's Supergen Bioenergy Hub since 2012, which is funded by EPSRC and BBSRC to bring together academia, industry and other stakeholders to focus on sustainable bioenergy development. Her main research interests are in whole systems analysis of bioenergy, greenhouse gas balances and feedstock sustainability.

She has particular interests in combustion, gasification and synthesis of alternative fuel vectors from renewable resources and in evaluating the sustainability of such low-carbon alternatives and has worked on several commercial biomass and waste plants.

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COMMISSIONERS

12. Helen Turner

In 2015, Dr Helen Turner was appointed Director of the Midlands Innovation group, which includes the universities of Aston, Birmingham, Cranfield, Keele, Leicester, Loughborough, Nottingham and Warwick.

She has significant experience of managing strategic collaborations having spent the last seven years as Director of the Midlands Energy Consortium, where most recently, Dr Turner played a key role in the successful £60 million bid to establish the Midlands Energy Research Accelerator.

Prior to working in the Midlands, Dr Turner spent time working at the University of Sheffield managing a major research collaboration and their portfolio of Knowledge Transfer Partnerships. Dr Turner also spent time working for the Royal Society of Chemistry in academic publishing. A materials scientist by background, Dr Turner has a degree and PhD in Materials Science from the University of Leeds.

13. Stuart Wagland

Dr Wagland is a Senior Lecturer in Energy and Environmental Chemistry and the Deputy Director of Research in the School of Water, Energy and Environment at Cranfield University. He has expertise in the properties of solid waste materials, the recovery of resources, the energy potential of UK waste streams and enhanced landfill mining. His expertise spans waste and fuel characterisation techniques, waste treatment technologies and energy recovery processes (including anaerobic digestion, incineration, gasification and pyrolysis). Dr Wagland's work on UK-wide assessment of waste contributed to substantial government investment in a demonstrator advanced thermal treatment facility aimed at accelerating the development of the UK capability in advanced thermal conversion.

He has over ten years' experience in the waste sector. Current projects include those funded by EU Horizon 2020, Innovate UK, the Engineering and Physical Sciences Research Council (EPSRC) and private waste companies. Dr Wagland's research applies the concept of waste characterisation to develop town-scale advanced thermal treatment of wastes. This work extends to developing countries and is included in a recent Innovate UK project to derive liquid fuels from the pyrolysis of wastes. Dr Wagland is currently working to develop real-time image analysis techniques to be applied to mixed wastes to assess fuel properties and to optimise energy from waste processes. Combining expertise in waste chemistry, characterisation techniques and conversion processes, Dr Wagland is also working on critical resource recovery from enhanced landfill mining.

POLICY COMMISSION MANAGER

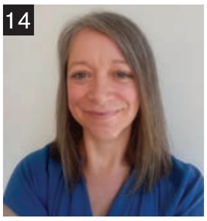
14. Emily Prestwood

Dr Emily Prestwood is responsible for developing Birmingham Energy Institute, working with academics, researchers, students and external stakeholders to build the profile of energy research at the University and develop partnerships to support and shape the regional transition to a zero-carbon energy system. Emily has nearly ten years' experience in multi-stakeholder, collaborative UK and European energy research and project management. She has previously worked at the University of the West of England (UWE), Loughborough University and the University of Manchester on research projects on energy, carbon and air quality management in cities, low- and zero-carbon energy scenarios, civic engagement and policy development. For her PhD, she modelled historical changes in energy-related CO_2 emissions of the UK residential sector to examine the relationship with policy, technology, socio-economic and structural change. Before moving into energy research, Emily worked as a Forensic Examiner for eight years.

EDITOR

15. David Strahan

David Strahan has been a professional writer for over 30 years. He learned his trade through the exacting discipline of writing for television, first as a reporter for Thames TV, and then as a business correspondent and producer-director at the BBC. For ten years he made investigative documentaries for *The Money Programme* and *Horizon* until leaving to write *The Last Oil Shock* (John Murray Ltd, 2007). Since then he has worked as a writer and editor specialising in clean energy, including journalism for *Bloomberg New Energy Finance* and *New Scientist*, and commercial reports for clients such as Ricardo, the Energy Systems Catapult and the University of Birmingham Energy Institute. He also teaches clear writing for science, business and journalism, and provides a REF consultancy service for universities. **www.writefirstdraft.co.uk**



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