

Reinventing the wheel

A circular economy
for resource security



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Reinventing the wheel: a circular economy for resource security

by Hannah Hislop and Julie Hill

Green Alliance

Green Alliance is a charity and independent think tank focused on ambitious leadership for the environment. We have a track record of over 30 years, working with the most influential leaders from the NGO and business communities. Our work generates new thinking and dialogue, and has increased political action and support for environmental solutions in the UK.

Green Alliance
36 Buckingham Palace Road, London, SW1W 0RE
020 7233 7433
ga@green-alliance.org.uk
www.green-alliance.org.uk

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Foreword

Gev Eduljee, SITA UK



There are some strong conceptual models to underpin decision-making for sustainable development (zero waste, cradle to cradle, industrial ecology, responsible stewardship for example) but the imagery conjured by the ‘circular economy’ is perhaps the most powerful and the most amenable to policy development. Although circularity typically brings to mind the capture of material flows, relegating ‘ultimate’ waste to an ever-diminishing side-stream, the concept applies equally to the management of energy and water resources within a closed loop economy. Such instruments can help to address current market failures which occur because the environmental costs, or externalities, associated with primary production and with waste treatment are not completely reflected in market prices.

But this is only part of the story. In its broadest sense, the circular economy represents a development strategy that maximises resource efficiency and minimises waste production, within the context of sustainable economic and social development. Conservation is part and parcel of the ethos, since a resource efficient, closed loop economy protects the environment by minimising the release of potential pollutants and, by doing more with less, also reduces our draw on scarce natural capital. These resources include not just the obvious candidates (abiotic raw materials, fossil energy and water) but also extend to the carrying capacity of our terrestrial and aquatic ecosystems in the production of food and the delivery of other ecosystem services. At the same time, the management and distribution of vital resources such as energy, water and food raises profound issues of social equity relative to wealth and income.

Which policy levers are most effective in driving the circular economy? Traditionally, controls have been placed at the end of a product or resource management chain: discharge limits, disposal bans and taxes. However, by definition, there is no ‘end’ within a circular economy, but a reconnection to the top of the chain and to various activity nodes in between. Considering policy interventions in this new light radically changes the way we perceive and design the

levers for change. Being interconnected through circularity, a control lever at one point in the cycle can influence behaviours and outcomes at other, more distant points. Technical measures, such as discharge standards, recycling targets, energy efficiency benchmarks and leakage reduction targets, have been the most commonly used. But economic instruments, particularly when applied further up the resource management chain, have received less attention. Correctly designed, and in tandem with technical measures, they send a strong signal to the market and its economic actors, catalysing the transformation to a more sustainable society.

“The circular economy represents a development strategy that maximises resource efficiency and minimises waste production, within the context of sustainable economic and social development.”

Having adopted the circular economy concept to guide our strategic business development, forward planning and investment decisions, SITA UK is especially pleased to sponsor this study by Green Alliance on the efficacy of economic instruments. Expanding the study beyond the materials of immediate interest to the waste management sector, Green Alliance has also addressed some of the wider themes such as conservation and fairness in access to resources.

With resource scarcity and security rising to the top of the environmental agenda, policy initiatives targeting a more resource efficient society are expected both from the UK government and from the European Union. These findings are a valuable contribution to this debate.

Executive summary

Green Alliance aims to promote the concept of the circular economy as a new approach to the use of all resources. We examine three crucial inputs to our society: metals, phosphorus and water. The way we use them provides ample demonstration of our overwhelmingly 'linear' economy, with its current problems and future risks.

This report makes the case for the more circular use of resources, as a way of avoiding at least some of the impacts of ever more extraction of natural resources, and to avoid the worst impacts of generating waste. We concentrate on the role of economic instruments in promoting a more circular economy, a concept which has influenced economic policy in both China and Japan and which is gaining traction in many other countries.

We examine the particular conditions for, and some of the inter-relationships between, the circulation of three major inputs to our modern economy: metals, phosphorus and water. Alongside means of generating energy, these resources are crucial to our future on this planet, yet their long term future is rarely fully and frankly examined.

Metals have been in the spotlight as part of the debate about 'raw materials security', but the emphasis has been on finding new sources and improving terms of trade with those nations where the resource is found. Instead, we advocate a major political push to promote the circulation of metals within the economy, rather than continuing to allow the loss of large amounts, whether dissipated in the environment or consigned to landfill.

We recommend product standards that embody design for durability, recovery and recycling, with the addition of an economic instrument, a product levy, to help give preference to such products in the market place as well as potentially funding the development of good recycling infrastructure.

However, as no amount of good design can ensure circulation if products are not returned

for reprocessing, we also recommend some form of recovery reward to drive higher rates of return.

We also debate the need for better life cycle analysis to inform the choice of substitutes for some materials, which could then also be promoted through a product levy.

Phosphorus, in contrast to metals, has received relatively little attention as a raw material under threat. Phosphate fertiliser underpins modern agriculture, and there is no substitute. Feeding nine billion people, the least that the population is likely to be by 2050, instead of the present seven billion, will be extremely difficult without adequate phosphate supply to farmers. Agriculture currently depends on ready access to phosphate rock. While arguments rage about how long reserves might last, there is no consensus on how we might ultimately secure an orderly reduction in our extreme dependence on this non-renewable resource. Considerable losses of phosphorus, between farm and plate, are not being addressed and secondary sources of phosphate (manure, human sewage, food and crop residues) are treated as wastes rather than as valuable nutrient resources. Worse, they are also allowed to pollute water courses, putting pressure on fragile aquatic environments.

We recommend the examination of a phosphate levy, not just because this might help to ensure careful use of the product, but also to raise money for phosphate recovery and recycling.

Water resources in England and Wales have been subject to much recent debate, with a tension between the long term need to charge to reflect current and future scarcity of water, and the more short term political need to avoid the perception of high price rises for consumers. The fact is that water is too cheap to incentivise careful use, and therefore too cheap to secure long term sustainability.

We advocate universal metering, better structured tariffs for consumers, and abstraction charging that reflects scarcity.

We also propose that the issue of embedded water in the goods we buy, whether from home or abroad, is tackled by promoting water stewardship and greater transparency from companies on this crucial dimension of product sustainability. In the longer term, stewardship could become part of a product standards approach.

Stewardship is a necessary adjunct to the circular economy. The economy could achieve higher levels of recycling but still wreak havoc in the continuing extraction of primary materials.

We envisage a ‘circular economy plus’ where all extraction of all raw materials, both renewable and non-renewable, as well as water and energy production, are achieved under a flexible but powerful ethos of stewardship by the companies concerned.

Summary of recommendations	
Metals	<p>Product standards that embody design for durability, recovery and recycling, with the addition of a product levy, to help give preference to such products in the market place as well as potentially funding the development of good recycling infrastructure.</p> <p>A recovery reward to drive higher rates of return to ensure that products can be reprocessed and valuable resources reclaimed.</p> <p>Better life cycle analysis to inform the choice of substitutes for some materials, which could also be promoted through a product levy.</p>
Phosphorus	<p>A range of incentives to encourage the recovery of more secondary phosphate from sewage and the use of high quality, secondary sources of phosphate in agriculture.</p> <p>Examination of a phosphate levy, not just because this might help to ensure careful use of the product, but also to raise money for phosphate recovery and recycling.</p>
Water	<p>Universal metering, more effective tariffs for consumers, and abstraction charging that reflects scarcity.</p> <p>Increase awareness of embedded water in the goods we buy, whether from home or abroad, by promoting water stewardship and by encouraging greater transparency from companies.</p> <p>Make water stewardship part of an approach that sets environmental standards for products.</p>
Resource stewardship	<p>The development of the ‘circular economy plus’ where extraction of all raw materials, both renewable and non-renewable, as well as water and energy production, are achieved under a flexible but powerful ethos of stewardship by companies.</p>

1. Introduction

Increasing demand for raw materials from the world's emerging economies, combined with greater activity and speculation in commodities markets, has resulted in high and volatile prices for many basic resources. On top of this there is the threat of export restrictions from countries including China and Russia as they take steps to secure their resources for their own domestic industries and future use. These pressures are unlikely to ease anytime soon. While western economies dwell on their recession, growth continues apace elsewhere, and this growth needs a physical underpinning. The UNEP International Resource Panel's 'business as usual' scenario would lead to a tripling of global annual resource extraction by 2050.¹ How we achieve sustainable global patterns of resource use will be a major economic and environmental challenge of the 21st century.

The aim of this report

Green Alliance aims to promote the concept of the circular economy as a new approach to the use of all resources. We examine three crucial inputs to our economy: metals, phosphorus and water. The way we use them provides ample demonstration of our overwhelmingly 'linear' economy, with its current problems and future risks.

This report builds on previous Green Alliance work on product taxes, which argued that economic instruments could improve the environmental impact of products, as an alternative or a complement to regulation.² Here, we examine the advantages and disadvantages of using economic instruments to encourage the more circular treatment of resources, encouraged by the UK government's current intention to "increase the proportion of revenue from environmental taxes".³

At present, most regulation and policy is directed towards the 'end of life', ie when products and materials become waste. This only addresses part of a product's life cycle and does not address production and consumption impacts. It is, therefore, important to find ways to shift the focus upstream to influence product

design, material use and the whole system of consumer choice. Economic instruments could be important tools for doing this. They are unlikely to be sufficient on their own, but would work as part of a broader package, for example by ensuring that regulations or voluntary agreements are not swimming against a strong tide of price signals driving unsustainable resource use.

What we mean by a circular economy

Our global system of production and consumption is predominantly linear, enabled by a century of declining commodity prices.⁴ We extract resources, by mining or growing them; we then manufacture, transport and use products; and we dispose of them, usually as cheaply as possible. This is damaging enough with a global population of seven billion, but it is increasingly unsustainable as we head towards more than nine billion people on the planet by the middle of this century.⁵

"Our global system of production and consumption is predominantly linear, enabled by a century of declining commodity prices."

During the course of the twentieth century we became more efficient in our resource consumption, we used fewer resources to produce one unit of economic value. While global GDP rose 23-fold, total material extraction of four categories of primary raw materials: construction minerals, ores and industrial minerals, fossil fuels and biomass, grew by a factor of about eight.⁶ But thanks to population growth and increasing affluence, we are now consuming more resources than ever: between 45 and 60 billion tonnes of resources are extracted globally every year, and current growth trends suggest that this figure could increase to 140 billion tonnes by 2050.⁷

The UK economy reflects this global trend. Whilst we have also become more resource efficient in production terms, we are increasingly reliant on goods produced using resources imported from abroad. The total

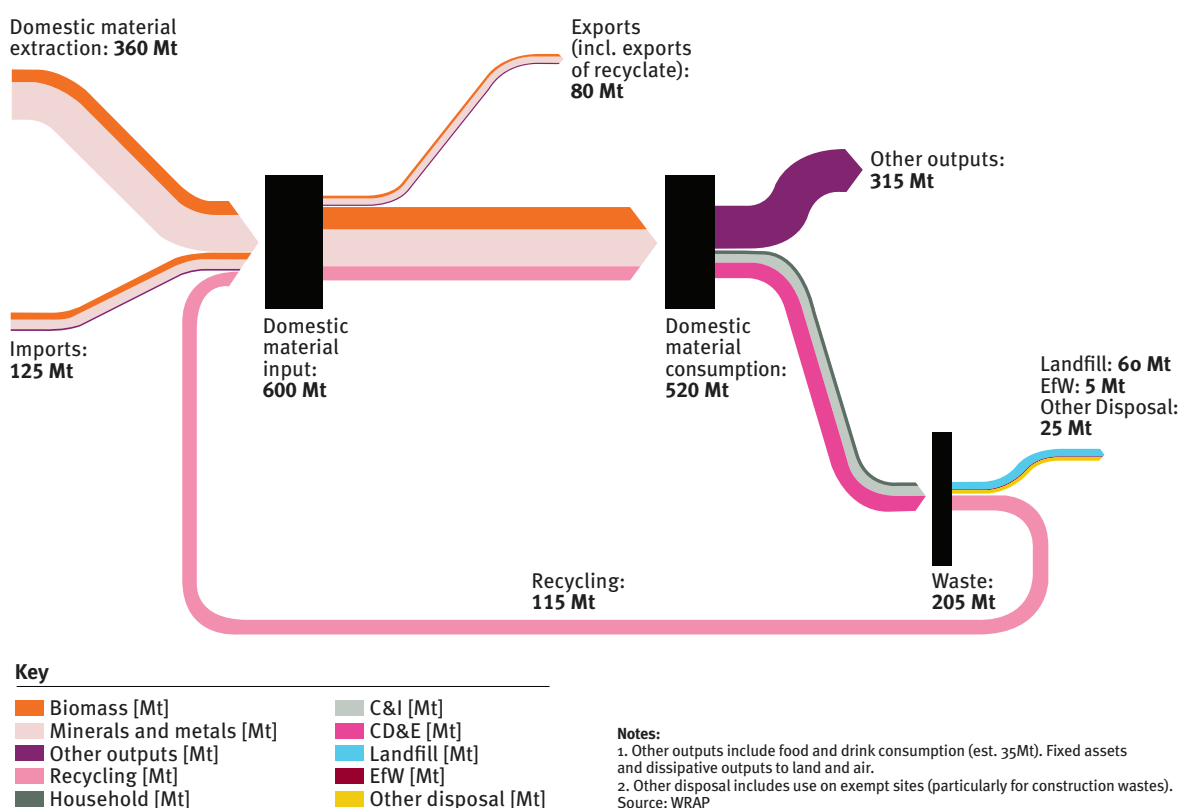
amount of resources extracted, ie grown or mined, from the UK's environment has fallen over the past forty years, but this has been offset by a 20 per cent increase in the imported resources needed to support the UK economy. The environmental and social impacts of much of this resource use are felt far from UK shores, often in countries least able to mandate or fund their prevention or remediation.

The UK is also a very linear economy, as WRAP's diagram in Figure 1 below demonstrates. While 520 million tonnes of material is consumed domestically each year, over 200 million tonnes leaves the economy as waste. This figure does not include waste from mining, which is approximately another 135 million tonnes per year. Only 20 per cent of the materials entering the economy are secondary inputs drawn from UK reprocessing, ie they are recycled here. Furthermore, this diagram does not show the 'total materials requirement' of the

UK economy, ie the additional resources consumed abroad in the course of extracting raw materials and producing goods which are then imported into the UK.

A linear economy puts huge pressure on both primary extraction and disposal activities. These pressures vary in size and nature for different resources. Food production uses large amounts of primary resource, and as a consequence is a major source of wastes, of energy, water, and fertiliser, as well methane emissions when food is landfilled. Allowing high value non-renewable resources such as metals to escape the economic cycle is also wasteful, because of the environmental and energy costs of extraction and purification, even where such resources are not yet scarce in a geological sense. The role of water in the production of goods of all kinds is rarely visible, and circularity of its use is assumed, but we displace water and use large quantities of energy to shift it around the world embedded in food and other products that we buy.

Figure 1: the linearity of the UK economy⁸



Achieving greater circularity in the economy has the potential to mitigate the impacts of both primary extraction, processing and production, as well as disposal. By using resources more efficiently and keeping those resources circulating in the economy for longer, the total throughput of resources could be reduced from UNEP's 'business as usual' scenario, taking into account the likelihood that the global economy will continue to expand.

A circular economy is one where waste is designed out, through addressing the nature of products and their supply chains. This involves improving or changing extraction and production processes. It means ensuring that consumers are able and encouraged to buy products that are more durable, as well as reducing consumption where possible. Products are able to be easily and economically repaired, upgraded or remanufactured. They are also designed for recycling and recovery through convenient and intuitive collection systems.

Closed loops for products and materials need to be established, but do not always need to be within specific countries or supply chains, so long as somewhere resources are kept in productive use. The size of the optimal closed loop for any given resource is a topic for further study and debate, and will influence the size and nature of the advantages accruing to the UK from a more circular approach. These could include cost savings for business,⁹ the creation of new intellectual capital and jobs in innovative recovery and recycling processes, as well as protecting the natural environment, both in the UK and abroad, by helping to reduce our dependence on the primary consumption of natural resources.

Why focus on economic instruments?

Market prices for resources are not necessarily reliable indicators of absolute scarcity, and are even less reliable indicators of environmental impacts. Economic instruments can create the price signals to move us towards a more circular economy, through encouraging the more efficient use of a resource, better product design

to promote reuse or recycling, or a switch to a less damaging or scarce resource. They can also raise money to develop new ways of doing things.

“Lack of information, as well as perception of higher costs than is the case, tend to hamper businesses and individuals in taking action.”

By doing so, they can address what economists call 'market failures'. These include the fact that the environmental costs (externalities) associated with primary production and with waste treatment are not completely reflected in market prices, but also the fact that lack of information, as well as perception of higher costs than is the case, tend to hamper businesses and individuals in taking action.

In this report, we use the term economic instrument to mean any fiscal measure such as a tax, charge or subsidy, or removal of any of these, used to influence demand for a resource. We include in this definition non-tax or subsidy measures such as deposit refund and trading schemes, where the price is set, either directly or indirectly, by legislation rather than the market.

Beyond the circular economy: towards stewardship

A more circular economy is a necessary but not sufficient condition for the better protection of the world's resources. Primary extraction of non-renewable resources will of course continue to take place because of growing demand, even if we start to treat those resources in a more circular way. Mining and processing primary resources have significant environmental, energetic and social costs and, as this report argues, these increase as we seek more diffuse resources in more sensitive environments. And, while we can recycle some renewable resources such as timber, the future of these resources is far more dependent on how carefully we manage their production and use.

So the concept of sustainable sourcing and stewardship of both renewable and non-renewable resources needs to gain ground at the same time as circularity. Stewardship schemes already exist for some resources such as timber and fish; but traceability and certification are even harder for resources such as metal and palm oil. This area needs more attention and to be underpinned by a system of economic incentives. At the moment we pay for the confidence offered by certification systems such as FSC timber and similar schemes if we choose to procure ethically. In future, perhaps it should be the uncertified goods that are priced more highly and eventually priced out of the market, if they cannot offer that confidence.

Our areas of focus

In the course of writing this report, we gathered academics, policy-makers and businesses together to take a broad look at the efficacy and political challenges of economic instruments implemented to date, including lessons learnt from carbon taxes. Metals, phosphorus and water were identified as three resources currently lost in large quantities from the UK economy and, therefore, as possible candidates for intervention to ensure greater circularity. These three resources are also linked.

“Perhaps it should be the uncertified goods that are priced more highly and eventually priced out of the market.”

The extraction of raw materials requires energy and water but these, and other environmental costs, are rarely factored in. This means that meeting demand by opening up new sources of materials is more likely than effort to create a more circular economy, which puts increasing pressure on energy and water resources. Secondary sources of phosphate are largely treated as waste rather than valuable nutrients, but excess phosphate leached into water courses causes environmental problems and requires cleaning up, which uses energy. This imposes costs on water companies and public authorities, which are passed on to households

and taxpayers, but are not made apparent in the price of water.

We have chosen to look at metals, phosphorus and water in this report, to broaden the resource efficiency debate, which is otherwise in danger of focusing solely on very few, specialised, strategic resources.



The problem

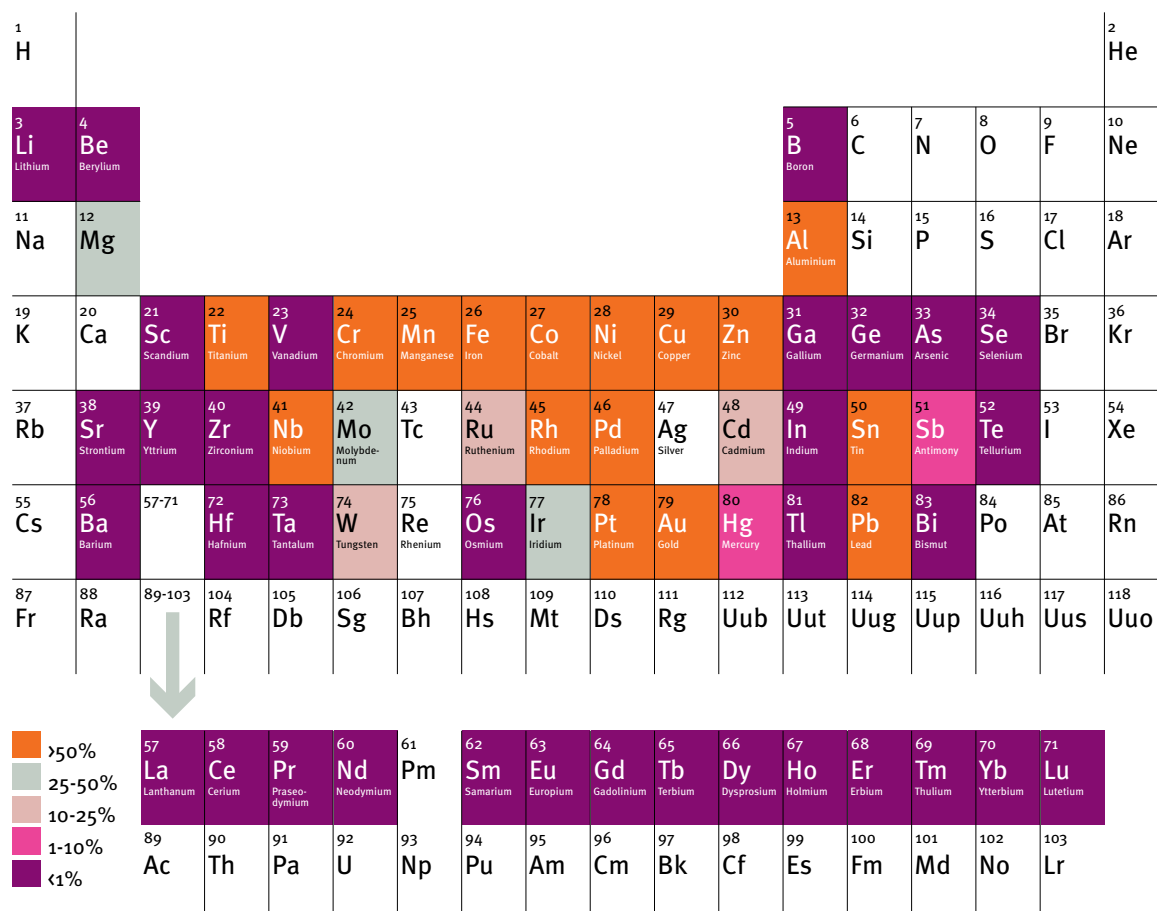
Despite the eminent recyclability of metals, in the UK and throughout most of the developed world, we treat them in a predominantly linear way. A recent report for UNEP documents the extent to which this is the case: of 60 metals analysed, only 18 had end of life recycling rates (EOL-RR) of more than 50 per cent; three were between 25 and 50 per cent; five were between one and 25 per cent; and 34 (14 of them 'rare earths') had recycling rates of less than one per cent. The metals recycled relatively well are those used in high quantities and/or with high intrinsic value, and those that can be relatively easily separated for recycling. However, as UNEP points out, this does not necessarily mean that they are being recycled very efficiently.¹⁰

This linearity matters because ultimately, metals are finite resources. No-one can say with certainty how much metal is present in the

Earth's crust. Numbers put on reserves historically under estimate what is available because they do not take into account the effects of rising price and new technology in making new sources economic. However, that also means that we are exploiting increasingly dilute ores of some important metals. Copper is the example most frequently cited to illustrate this: copper mined at the beginning of the 20th century contained about three per cent copper, but the current typical ore grade is now only about 0.3 per cent.¹² So although, in theory, metals will always be available and no-one can predict the extent of technological innovation in exploration and mining, it seems likely that, as reserves dwindle in future, these resources will come at increasing cost.

The costs are both financial and environmental. As ore quality declines, more energy and water are needed to process it, and more waste is

Figure 2: End of life recycling rates for sixty metals¹¹



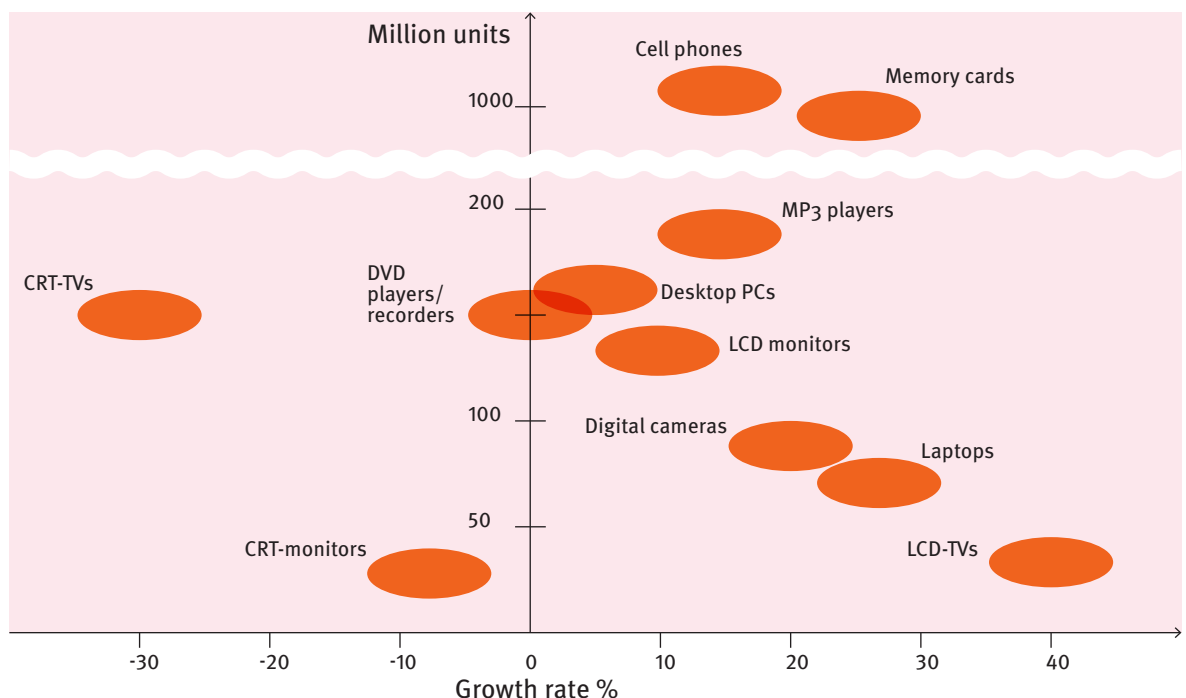
generated. A tonne of copper is currently accompanied by 300 tonnes of waste, and for Australian gold this ratio is one tonne for half to a million tonnes of waste.¹³ The energy implications of processing this amount of rock are enormous, a tenfold increase in the case of copper, as the ore quality has decreased, and that is before any smelting takes place. This means that the mining industries are a very large, and increasing, contributor to greenhouse gas emissions. On one estimate, the energy used to produce metals could approach 40 per cent of global energy supply by 2050.¹⁴ Rising water use also parallels the increase in energy use because water is needed for many ore processing techniques.¹⁵ Without enormous advances in processing efficiency, these requirements are likely to be the ultimate limiting factors on metal availability.

There is also the disruption to landscapes and pollution caused by mining activities that do not conform to good practice, including contamination of water sources.¹⁶ This is especially true where mining is taking place in countries with sensitive environments or poor governance. Half of the world's top ten pollution problems are linked to metals mining

or processing,¹⁷ and in many cases the impacts are in countries least able to fund their remediation. Unfortunately, most of the value in metal-using products such as mobile phones is added in developed countries, making it hard for the countries of extraction to generate funds to address environmental impacts.

The impacts of primary extraction are set to increase as global demand for metals expands with the growth of emerging economies. Future demand, as with future availability, is hard to predict accurately. Experts disagree on the extent to which resource needs decline as economies mature and dematerialise. Some seem to follow this pattern, others do not.¹⁸ One study predicts that consumption of metals will increase by five times the current level as a result of development in Brazil, Russia, India and China, although without taking into account future changes in prices and technology.¹⁹ Demand for some metals may wax while others wane, depending on their significance for new technologies, as figure 3 below suggests.

Figure 3: unit sales and annual growth rates of selected electrical and electronic equipment (EEE) in 2006²⁰



Whatever the precise realities of future demand and availability, there is a clear case for shifting to a more circular pattern of metal use. Remaining linear means that increased consumption also leads to increased waste, with its own associated costs. By keeping metals in the economy via recycling, at least some primary production could be displaced and its impacts avoided, even if overall increases in demand mean that primary production is still rising. This is particularly true for energy, where the use of recycled, secondary sources significantly reduces CO₂ emissions because the highly energy intensive early stages of ore processing have already been done.²¹

More metals could be recovered if either economics or regulation drove the process. But most metal loss from the economy is post-consumer, ie metals in products used by businesses and individuals. Failure to recycle metals at this stage occurs for a number of reasons.

First is because the cost of recovering and reprocessing the metals outweighs the cost of procuring new. Even aluminium, which is very widely used, has high value and is also relatively easy to recover from a number of products. It is recycled globally at a rate of only 60-70 per cent²² thanks to the costs of organising comprehensive collection systems. Copper is recycled at a rate of around 40 per cent, even though 99 per cent is potentially reusable.²³

The second reason is the fact that some metals are so dispersed in products or in the environment that they are very difficult to recover at sufficient purity. The ultra-thin metal films embedded in packaging, combinations of metal and plastic in assemblies such as circuit boards, or metal coatings that wear off, are all examples.

Third, even where recycling is technically and economically viable, materials leak from the system as exports and towards sub-standard recycling.

This means that to improve recycling rates, it is crucial to improve collection of metal-

containing products, and also to improve the design of those products, but in tandem with the development of recycling technologies tailored to specific metals.

Metals and the security debate

A number of recent studies and political statements have expressed concern about future access to raw materials. These are briefly analysed below. Although these reports employ different methodologies and consider a variety of resources, including some renewable resources, mainly they concern themselves with metals.

“There is strong concern about western economies’ high dependence on a few special metals. These are traded in relatively small amounts but are crucial to some technologies.”

These concerns have been driven primarily by price and politics, and have little to do with long term availability of metals.²⁴ Price volatility in commodities markets has increased dramatically in the last decade, with analysts attributing it to increasing demand for resources from emerging economies, overlaid by the effects of increased liquidity (investment) and financial speculation in some commodities markets.

On top of price volatility, there is strong concern about western economies’ high dependence on a few special metals. These are traded in relatively small amounts but are crucial to some technologies, such as the magnets in electric cars and wind turbines, the screens of electronic devices such as iPads or the performance of photovoltaic cells. The headlines have been dominated by the decision of the Chinese government to restrict exports of rare earth metals, but China is not the only country doing this and the rare earths are not the only substances involved (See over for a full account of the studies, their methodologies and the materials they have highlighted).

Which metals are we talking about?

Metals classification can be confusing. The term **precious metal** encompasses both relative rarity and immutability. These are unreactive metals that endure, but they are not abundant. They include gold, silver and platinum, but there are further metals in the platinum group: palladium, rhodium, ruthenium, iridium and osmium.

The term **base metal** was used historically as the opposite of precious and in chemical terms means a metal that can oxidise relatively easily, but some definitions include a wider group of metals. Generally speaking these are the workhorse metals used in relatively large quantities, and include some of the Earth's most abundant minerals. UNEP's report on metals recycling²⁵ distinguishes two groups: 'ferrous', ie iron and iron-based metals including chromium, manganese and nickel; and 'non-ferrous', which includes aluminium, cobalt, copper, zinc, tin and lead. In terms of annual tonnages, iron (steel) and aluminum dominate global metal production.

Then there are the **special metals**, used for particular properties and in smaller quantities. They include, among others: antimony, bismuth, gallium, germanium, indium, lithium, rare earth elements (REE), rhenium, selenium, tantalum, and tellurium. These are sometimes called 'minor' metals, but this misrepresents their current significance.

In terms of use and recovery, precious and special metals are sometimes termed 'technology' metals. They are often by-products from the ores of major metals, complicating the demand/supply relationship.²⁶ Although in the context of overall metal production they may be 'minor', and they are present in applications such as mobile phones and laptops in minute amounts, together they account for significant quantities of valuable material. The 1.3 billion mobile phones produced every year, for instance, account for 12,000 tonnes of copper, 325 tonnes of silver, 31 tonnes of gold, and 12 tonnes of palladium.²⁷

Table 1: summary table of materials deemed insecure or at risk by the six following reports:

EU:

Raw Materials Supply Group, chaired by the European Commission, 2010, *Critical raw materials for the EU: report of the ad-hoc working group on defining critical raw materials*

Technology Strategy Board (TSB):

Oakdene Hollins, for the Resource Efficiency Knowledge Transfer Network, 2008, *Material security; ensuring resource availability for the UK economy*

Department for Environment, Food and Rural Affairs (Defra):

AEA Technology for Defra, 2010, *Review of the future resource risks faced by UK business and an assessment of future viability*

Scottish Environment Protection Agency (SEPA):

AEA Technology for the Scotland and Northern Irish Forum for Environmental Research (SNIFFER), 2011, *Raw materials critical to the Scottish economy*

Science and Technology Committee (STC):

House of Commons Science and Technology Committee, 2011, *Inquiry into strategically important metals*

British Geological Survey (BGS):

British Geological Survey, 2011, *Risk list 2011*

US:

US Department of Energy, 2010, *Critical materials strategy*

Boldface in the table right indicates that more than two reports identified these materials as critical.

Material/report	EU ²⁸	TSB ²⁹	Defra ³⁰	SEPA ³¹	STC ³²	BGS ³³	US ³⁴
Aggregates			x	x			
Antimony	x	x			x	x	
Beryllium	x				x		
Bismuth						x	
Bromine						x	
Chromium					x		
Cobalt	x			x	x		
Copper				x			
Fish			x	x			
Fluorspar	x						
Gallium	x				x		
Germanium	x				x		
Gold		x			x		
Graphite	x						
Hafnium					x		
Indium	x		x	x	x		x
Lithium			x	x	x		x
Lead				x			
Magnesium	x				x		
Mercury		x				x	
Nickel					x		
Niobium	x				x	x	
Palm oil				x			
Phosphorus			x	x			
Platinum group metals ruthenium, rhodium, palladium, osmium, iridium and platinum	x	x			x	x	
Rare earth metals³⁵	x		x	x	x	x	x
Rhenium					x		
Silver		x					
Strontium		x				x	
Tantalum	x				x		
Tellurium					x		x
Thorium						x	
Timber				x			
Tin		x		x			
Tungsten	x					x	

Notes on the methodologies:

The EU critical raw materials methodology, which feeds into the EU Raw Materials Initiative, looks at materials with high economic importance to the EU combined with high supply risk. For an explanation of how the various factors are weighted and aggregated, see Annex 1 to the *Defining critical raw materials* report of June 2010. The report analysed 41 metals and minerals and 14 materials were defined as relatively critical, ie at greater risk than most, and these appear in the table left.

The Oakdene Hollins report for the TSB was a scoping study which aimed to provide an overview of the issues. It follows a framework developed by Tom Graedel to assess criticality. It looks at 69 materials for 'material risk' and 'supply risk'.³⁶ A crude material insecurity index was arrived at by summing the scores for eight criteria under the two headings, and the materials in the table left are the top eight of these. These eight only coincide with the EU list in two places, thanks to the inclusion of a wider set of criteria, including some environmental impact criteria, and not weighting for the degree of importance of the material to the economy. The TSB report is the only one of the six which does not identify 'rare earth' metals in its top critical materials, since it considered individual elements rather than groupings of elements.

The AEA reports for Defra and SEPA used both literature and the views of stakeholders to assess material risks to UK and Scottish businesses respectively. These reports differed from the others in including renewable materials in their scope, and generated a list of six and 12 materials respectively which were of concern. These intersect with the EU list in two places for the UK and three for the Scotland, again illustrating a different perspective on the problem.

The Science and Technology Committee report relied on evidence from witnesses as to which materials should be considered critical and acknowledged that different audiences had different perspectives on this. However, the Committee's list agrees with the EU's in 11 places.

The British Geological Survey report is the most recent (September 2011) and ranks the supply risk for 52 elements of economic value. The top ten of these are shown the table. Those ranked highest risk are primarily because of the concentration of production in a very few countries and those countries lack of political stability; there is no account taken of demand or potential for substitution. Thus some elements make it onto the BGS's top ten that are not on the other lists.

The US report concentrates on the role of rare earth metals in energy technologies, using a range of weighted factors. In the medium term, five rare earths are identified as critical, with indium, tellurium and lithium as near critical.



These different methodologies and scopes produce interesting and different views of which materials should be viewed as critical from the perspective of the organisation producing or sponsoring the report. There are several materials on which they agree, but many where they do not. However, from Green Alliance's perspective, there are seven key features to this debate:

1. **Diminishing access.** Access to these critical raw materials, many of which are special or precious metals, will become more difficult, for a mixture of geological, environmental, political and market reasons.
2. **Uncertain substitution.** Substitutes for many of these materials may be feasible, but developing substitutes is time-consuming and costly. Some important technologies, such as wind turbine blades and solar PV panels, have been subject to long research and development processes predicated on the use of specific metals. The only substitutes may be other metals, which would not improve the situation if the alternatives are subject to the same pressures.
3. **No guarantee of better environmental outcomes.** Whether talking about accessing more difficult sources or finding substitute materials, there is little to ensure that the environmental impacts of either strategy are minimised. Some extractive activities, be they mining, quarrying or forestry, are well controlled, but many are not. In design terms, there is little to ensure that substitute materials used in products or processes will have less environmental impact than their predecessors.
4. **Low priority given to better circulation and efficiency.** Greater recycling, and better resource efficiency, ie getting more value out of a given amount of resource and eliminating waste, appear low down the list of recent strategies to address resource scarcity. For example, from the point of view of the EU

“In design terms, there is little to ensure that substitute materials used in products or processes will have less environmental impact than their predecessors.”

Raw Materials Initiative, which has dominated the debate about metals, resource efficiency and recycling are given lower priority than negotiating better terms of trade and opening up new sources of material, whether in developing countries or in Europe. As well as being crucial to extending the life of metal reserves, recycling could help to address supply security by obviating at least some of primary supply, and could also help by partly decoupling supply of minor metals from primary metal production.

5. **Special metals: a particular challenge.**

The factors in the poor recycling rates of metals, such as issues relating to product design and collection systems leading to poor recovery rates, are particularly true for the special metals. They are often hard to separate from the devices containing them, particularly where there are subassemblies to get into, including circuit boards, batteries, screens and magnets; there is lack of awareness of their presence in consumer goods and the need to return them; and recycling infrastructure is often geared primarily to reclaiming more common metals such as steel, aluminium and copper.

6. **Difficulty pricing environmental impacts of materials.** Any attempt at pricing the environmental impacts of raw materials is complicated by the diverse way markets work for different resources. Some are extracted as major products, where ore is directly processed to extract the key materials, but others are co-products or by-products of other mining operations. This creates complex relationships between the availability and extraction costs of different materials.³⁷ In addition, speculation in commodities may inflate prices in unpredictable ways. This means that any price signal applied to materials, rather than the products they are made into, would have to overcome this background noise.

7. **Lack of information.** Developing a resource efficiency or recycling strategy of any kind is

hampered by the lack of information about material flows. The House of Commons Parliamentary Science and Technology Committee agreed with the Society of Chemical Industry, which argued: “we need a national review of metallic wastes in the UK, quantifying amounts and locations of each metal in the national waste inventory and then to identify routes to their recovery. Once we understand the nature of the problem, we will be in a position to address it. At present a large, but unknown quantity of metals are neither in use, nor in the recycling circuit.”³⁸

The current policy landscape

Activity in this area of policy is intensifying but the role of resource efficiency and recycling is not always given sufficient prominence. Environmental policy-makers in Europe are keen to create a better link between the resource efficiency debate and the raw materials debate. As this report went to print, the European Commission published a roadmap describing how to move towards a resource efficient Europe, making 2011-12 a pivotal time. The roadmap will set out specific resource efficiency objectives, and how to meet them, based on actions up to 2020 but looking towards 2050.

“Environmental policy-makers in Europe are keen to create a better link between the resource efficiency debate and the raw materials debate.”

In the UK, the Department for Environment, Food and Rural Affairs (Defra) is producing a resource security action plan, to be launched in early 2012. This will cover action to promote improved recovery, recycling and reuse of critical resources, actions to promote substitution of critical materials, as well as international resource diplomacy to increase access to insecure resources. It is hoped that recovery and recycling will be seen as top priority.

There is certainly potential to develop UK-based initiatives: a 2011 study by Oakdene Hollins for the European Pathway to Zero Waste

programme³⁹ looked at improving the recovery of EU-listed critical materials through the development of infrastructure based in the south east, and concluded that, of the forty applications for critical materials investigated, ten had high potential for recovery. These included the cobalt and graphite from portable batteries, the platinum group metals from catalytic converters, the rare earths from wind turbines, the indium from screens, the rare earths and ruthenium from hard disk drives and the magnesium from beverage cans, as well as a whole range of metals from aerospace applications. For some of these materials, the level of recycling could be high enough to significantly reduce demand for primary materials, although not for all.

Potential policy solutions

There are some common themes in the policy suggestions in the reports summarised in table 1, although analysis of exactly what policy instruments could be applied is thin. Five of the key common themes are described below:

Improving collection rates and incentives for recovery

This is flagged up by many commentators as crucial to ensuring better recycling rates, as no amount of recycling technology can improve secondary use if the rate of product recovery is low. The most substantial existing policy instruments that bear on collection and recycling of metals (in other words, seek to drive recycling beyond what would otherwise be achieved by the market place) are four EU directives covering: waste electrical and electronic equipment (WEEE), end of life vehicles (ELV), packaging and batteries.

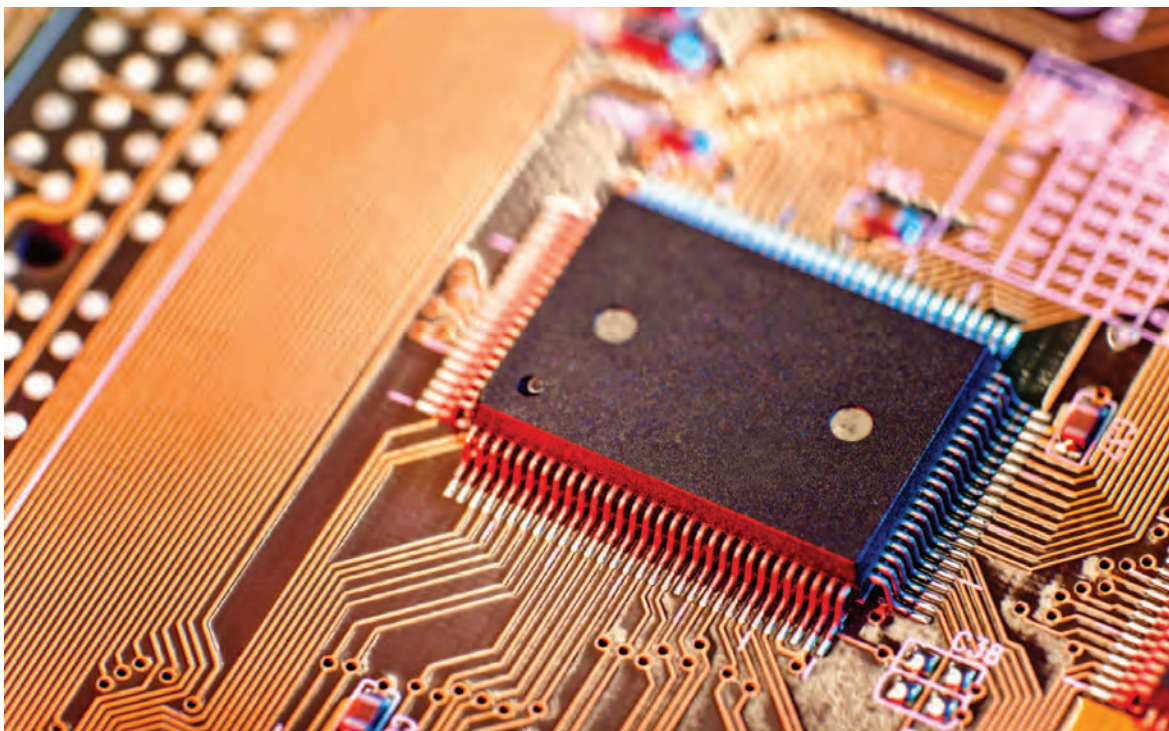
The WEEE Directive currently requires member states to collect seven kilograms of electronic waste for recycling per year per head of population, which is not a challenging target. There is a proposal from the Commission to increase this to 65 per cent, or even 85 per cent, of the amount of WEEE placed on the market, compared to a current rate in the UK of some 40 per cent. This rate does not include business

products and equipment, bearing only on consumer goods. Also, these are collection rates. There are additional targets for how much of the product is actually recovered having entered the recycling stream, because further losses occur at this stage. This may be due to poor product design, ie materials that are impossible to separate, or the fact that some collected materials are just not economic to process.

“The high ‘on-paper’ recycling rate for cars, from the point of view of those trying to reclaim technology metals, induces the wrong perception that car recycling in Europe is working very well.”

The ELV Directive has higher recycling rates of cars once collected (it requires 95 per cent by weight of collected cars to be recycled by 2015), but this is not always accompanied by high capture rates. In Germany, for example, out of 3.2 million annual deregistrations, only 420,000 cars are collected for recycling. The rest are exported, leaving a real recycling rate of 13 per cent.⁴⁰ Not all of these exports will be valid second hand cars; as with electronics, it is assumed that a certain share of these exports is illegal or of dubious legality.

Recycling of scrapped cars has, until recently, been less challenging than WEEE recycling, because of the greater homogeneity of materials with high scrap value, such as steel, used in cars. However, alongside steel, increasingly lightweight materials such as aluminium or plastics are being used. There are also increasing numbers of electronic components including small electric motors for windows and seats, technologies such as motor management and assisted brakes, and various audio and navigation systems. These turn cars into ‘computers on wheels’, stretching existing shredder-based recycling technology to its limits. The recycling rates, as defined in the ELV Directive, do not say anything about the real final fate of these materials. Unless removed before a shredder process, like car catalysts, the



technology metals contained in car electronics and in other functional components are generally lost. In this respect the high ‘on-paper’ recycling rate for cars, from the point of view of those trying to reclaim technology metals, induces the wrong perception that car recycling in Europe is working very well. This is largely the case for management of hazardous substances, but not for closing the loop for potentially scarce or critical metals (The recycling rate in the UK is close to 85 per cent⁴¹ because there is less of an export market for right-hand drive cars).

The Packaging Directive requires recycling of aluminum and steel cans, both easy metals to recycle once captured, but still the European average is only 64 per cent for aluminium⁴² and 72 per cent for steel,⁴³ thanks to the large amount of cans consumed outside the home and the lack of comprehensive collection facilities. Tellingly, the highest recycling rates for aluminium cans are achieved in countries with deposit refund schemes.⁴⁴

The Batteries Directive also has targets that lack ambition. The collection rate has to reach 25 per cent by 2012, and 45 per cent by 2016.⁴⁵ So European legislation is pointing in the right direction, but is not yet translating into high levels of capture of metals across the board.

Recycling targets that focus on specific materials and their quality, rather than simply on tonnages

This is important so as to be able to treat different materials according to their diverse properties and their diverse uses. At present the generic weight-based targets of the WEEE Directive drive recovery of the high volume metals rather than the more dispersed, specialist ones, which are often of greater economic and environmental interest.⁴⁶

Design for disassembly and recycling

None of the directives have yet substantially influenced product design to make recovery easier, although they all have some capability to do so. In evidence to the House of Commons Science and Technology Committee, David Willetts MP, Minister of State for Universities and Science agreed that the WEEE Directive’s



collective producer responsibility, with the cost of recovery, recycling and reuse absorbed collectively by all producers, means that an individual producer has no specific incentive to make their products easier to reuse or recycle. But the minister added that the government is “working with industry stakeholders to see if we could get a system of individual producer responsibility which might improve the incentives.”⁴⁷

Good design ensures the accessibility of important components, allowing them to be reused or remanufactured rather than completely reprocessed. Printer company Kyocera has for many years pioneered design for durability and disassembly, and has drastically reduced the waste associated with printer cartridges.⁴⁸ Another encouraging sign of this thinking is that metal recyclers are working with car designers on electric vehicles to ensure the ability to remove battery packs easily for recycling.

For recycling, good design also means eliminating hazardous substances that might hamper the recycling process. A recent example

is the mercury used in the backlights for some LCD monitors. Concern over the liberation of mercury during the shredding of equipment prior to recycling has led to guidance that they must be hand-dismantled, adding to costs. Good design, plus better sorting of products before processing, could also aid the recovery of the special metals which are often used in smaller quantities. Shredding may be the best way at present to liberate a number of metals from electronic equipment, but some special metals are likely to be left behind,⁴⁹ making it crucial that future product design and recycling technologies are developed in tandem to enable greatest recovery.

Some dilemmas are presented by the development of lightweight composite materials, for instance for cars, which may mean a trade-off between fuel efficiency and recyclability. Ideally, they would achieve both which is a challenge to designers and their conversations with reprocessors.

The flat screen (LCD) TV: not designed for recycling

Discarded LCD TVs is the fastest-growing stream of electronic waste in the EU, with an estimated 25,000 discarded since 2004 and a growth rate of up to 28 per cent every five years.



Among the challenges of recycling LCD TVs are:

they come in large number of different sizes, design and configurations, making automated disassembly impractical;

their screens often contain mercury, which presents a hazard during the disassembly process, but few are labelled as such;

the liquid crystals used in the screens could be recovered, but it is hard to identify which type has been used in any particular model;

a variety of adhesives are used, varying sometimes even within the same model type, so it is hard to identify the right solvent to use to separate components;

the economics are challenging: the indium used in the screens is a metal identified as critical by many commentators, but prices are low compared to precious metals, and the amount per device is low, making recovery uneconomic.

Will this change in future?

Work to develop recycling technologies is leading to identification of future design imperatives. These include 'active disassembly' fasteners that employ 'shape memory' materials. For example, when heat is applied, polymers revert from a screw thread to a smooth tube, enabling automated dismantling.⁵⁰ There is also discussion of 'smart barcodes' so that components can be easily identified and separated. But would a TV actively designed for recycling look anything like the present generation of LCD TVs? There is little reason why they should not have the same functionality. The new generation of LED screens are non-hazardous, and easier to dismantle with automated systems although, unfortunately, there is still the risk of contamination from the historic legacy of toxic LCDs that are not spotted as they go through the machinery.⁵¹

Encouraging longer product life

This is a strong emerging theme.⁵² It can be a matter of product standards, as well as extended product warranties and designing products to make repairs easier. However, a change in consumer values is also needed, to demand products with greater longevity and to be prepared to use things for longer and undertake repairs. 'Product service systems', where the consumer is provided with a good as a service, for instance computers, cars, or carpets, with the materials remaining the property of the company, are also being proposed as a possible route to greater longevity.⁵³

Avoiding leakage of valuable materials through exports

Leakage includes the perfectly legal export of electronic equipment for reuse, but also a significant amount of illegal export, where equipment supposedly for reuse is actually broken up for its valuable materials, but not always under good social and environmental conditions.⁵⁴ These losses mean that reprocessors face an unpredictable supply of recyclable materials. Overall, 60 per cent of the UK's recovered metal is exported.⁵⁵ The whole issue of exports needs to be considered in any raw materials strategy, to decide which materials should be kept in particular countries or business sectors, and in what quantities.

Solutions based on economic instruments

Economic instruments are a crucial part of tackling current market failures. It is accepted by the government that market failure occurs when environmental externalities, for instance the greenhouse gas emissions generated by primary production and by waste disposal, are not given a price in the market place, and therefore are not taken account of in market behaviour. Although the landfill tax does price the downstream externalities of waste to some extent, and drives waste to other treatment options, it does not differentiate between those alternative options in terms of recognising their relative benefits.⁵⁶ Efforts to price carbon emissions, for instance through the European Emissions Trading Scheme, are not yet working their way through

to material resource efficiency, as they bear mainly on direct energy use. This lack of a proper price, and often also lack of information or understanding about the benefits of resource efficiency, lead to lower levels of waste prevention, reuse and recycling than are considered economically optimal.

As a consequence, there is a strong argument for using economic instruments to send a long term signal to the market place to use resources more efficiently, and to prioritise or to move away from particular materials, products or processes, in a way that leaves the market time and flexibility to adapt. Regulations, and in particular, product standards, may also be a necessary part of the picture, but without price signals to back them up, these may not provide sufficient impetus.⁵⁷ Economic instruments can also raise money to invest in new solutions. At this time of credit squeeze and cuts to public spending, this function is vital.

“There is a strong argument for using economic instruments to send a long term signal to the market place to use resources more efficiently.”

There are signs that European politicians agree: language in the resource efficiency section of the European Commission’s most recent raw materials communication suggests that economic incentives are part of the package of measures needed.⁵⁸ It states that the Commission will “support research and pilot actions on resource efficiency and economic incentives for recycling or refund systems”, as well as review the coherence of the current body of waste legislation. Crucially, it will also “analyse the feasibility of developing ecodesign instruments to i) foster more efficient use of raw materials, ii) ensure the recyclability and durability of products and iii) promote the use of secondary raw materials in products, notably in the context of the Ecodesign Directive”, and “develop new initiatives to improve the competitiveness of EU recycling industries notably by introducing new market based instruments favouring secondary raw

materials”. DG Environment is working with the Institute for European Environmental Policy (IEEP) to look at the present use of economic instruments in member states, reporting at the end of 2011.

“Only three per cent of people return old mobile phones for reuse or recycling, whereas 44 per cent store them at home.”

Others are exploring the role of economic instruments in promoting recycling. The Society of Chemical Industry suggested to the Science and Technology Committee that the government should improve collection of WEEE by using “both carrot and stick” by, for example, imposing fines on people discarding old mobile phones while also providing a VAT discount on new phones when consumers trade in old ones. The UNEP Resource Panel’s report on recycling metals suggested that where the value of discarded materials is not high enough to justify the cost and effort of recycling, “incentives such as deposit fees or other cost subsidies usually based on legal requirements may make it so, at least at the consumer level”.⁵⁹ A 2010 paper on the life cycles of precious and special metals argues, “although many people are used to trading or returning old goods to collection points for reuse, some items (eg mobile phones or ‘high price’ electronics such as computers) require incentives to bring them out of ‘hibernation’ or obsolescence”.⁶⁰ A consumer survey indicated only three per cent of people return old mobile phones for reuse or recycling, whereas 44 per cent store them at home.⁶¹ The authors suggest deposits on consumer products, and also leasing of products instead of sales to “give the manufacturer a better control over his goods along the life cycle”.

Below, we make recommendations that capitalise on this interest in new economic instruments, and recommend measures that overcome current market failures in relation to producer and consumer behaviour, combined with the lack of full pricing of the environmental externalities of production of

consumption. These concentrate on 1. ensuring better capture of materials; 2. incentivising better product design, and 3. incentivising substitution of materials.

1. Ensuring better capture of materials

We advocate a ‘recovery reward’ to be applied to consumer electronic products and, where possible, business-to-business products as well.

This could follow a number of models. It could come in the form of a deposit refund system, so that a deposit is incorporated in the point-of-purchase price, and returned once the consumer takes the item for recycling. Norway has had a mandatory deposit-refund system for scrapped cars, for instance, since 1978, with the rate currently at just under £150.⁶² Sweden and Greece also have deposits aimed at reclaiming old cars and encouraging the update to newer, more efficient ones.⁶³

A variant on this idea could have a dual function, with some money going to help establish the infrastructure to extract and recycle critical raw materials, and some returned to the consumer when the product is taken for recycling. A third option would be to reward householders for the recycling they put out for collection. Although this model has proved expensive when applied to all household recyclables, the value of materials in WEEE, for instance, might justify both a separate system to ensure higher collection rates, as well as funding a householder reward to incentivise use of the service.

Having improved capture rates, it is essential to monitor the progress of metals through the recycling system, to ensure that they do not leak as inappropriate exports or go to substandard recycling facilities. One way of ensuring this would be to institute a recycling certification scheme, as recommended by the European Association of Metals.⁶⁴

2. Incentivising better product design

We recommend the introduction of a product levy with specified exemptions, to help promote products with strong ecodesign features.

We also recommend setting criteria for product design that ensure that products contribute to better resource efficiency, recycling and ultimately greater resource security. These criteria will include: product durability, to keep valuable materials in use for longer; design for disassembly and remanufacture; design for recycling; design for lower embedded energy (with priority given to carbon) and water; and avoidance of specific materials such as toxic substances, where these are damaging to people or the environment, or where they make recycling more complex.

Applying these criteria will be a matter for product standards. In our 2010 publication *A pathway to greener products*, endorsed by members of Green Alliance’s Designing Out Waste consortium, we set out an agenda for working towards such standards, conducted as a collaborative effort between government, business and other stakeholders.⁶⁵ Such standards would work in tandem with producer responsibility measures such as the WEEE, ELV and Packaging Directives, or could ultimately replace them if sufficiently successful at steering better products and raising recovery and recycling rates of key materials.

We suggest reinforcing the development and positive impact of product standards by applying economic instruments as part of the package. This could involve finding a way to place a levy on a specific product category, perhaps using a system based on VAT, and then exempting those products which meet the standards. Alternatively, there could be an exemption from the levy for products where effective end of life individual producer responsibility is in place, implemented on a voluntary basis by enlightened companies.

The advantages of this approach are that it would send a comprehensive, long term signal



about the kind of product design needed, both inside the UK and, if applied to imports, outside as well, and so reward innovation. It would also provide best in class examples that could be incentivised through public procurement. The levy exemptions could be achieved through expansion of the Ecolabel criteria, or could work alongside a requirement for full environmental product declarations. Alternatively, they could be based on processes such as a specified design process, based on guidance from a body such as the Design Council, rather than detailed product outcomes, which might simplify the process.

“Regulatory standards for products or more extensive producer responsibility could seem a more attractive option.”

There are significant obstacles to overcome. This would be seen as a new tax and could be complex to administer unless it is done through existing tax collection systems such as VAT. Detailed product criteria have to be decided, which will be complex, especially where there

are multiple criteria to be weighed up and trade-offs to be made. There is a lack of certainty in waiting for good products to be designed and then exempting them from a generalised levy. Regulatory standards for products or more extensive producer responsibility could seem a more attractive option.

A 2008 report for the European Commission rehearsed many of these pros and cons, but was sufficiently positive about the benefits of the idea for it to merit further examination. It also stated that “a majority of stakeholders consulted in the case studies tended to support reduced VAT rates for ‘green’ products, if properly designed and accompanied by supporting measures.”⁶⁶ The simpler, if less holistic route, would be to impose a levy on products where there is no clear end of life recycling route, creating an incentive for product designers to work with reprocessors to ensure that such a route is established.

3. Incentivising the substitution of specific materials

We recommend the development of more comprehensive life cycle analysis to help understand where substitutions of materials, and product levies to incentivise them, may be beneficial.

Applying an economic instrument to achieve a shift from one material to another requires confidence about the impacts of that material. Some would argue that there is no such thing as a bad material, rather there are bad applications. So use of a toxic metal may be

“We have to separate short term concerns around price volatility from longer term trends in demand and supply, and adapt our economic systems to take better care of these crucial inputs.”

acceptable in closed loop manufacturing systems, for instance, where it is recovered completely and never reaches people or the environment. However, some uses of toxic metals are clearly undesirable. Both Denmark and Sweden have introduced levies designed to shift the market away from nickel cadmium batteries to those using less toxic materials.⁶⁷ Even a renewable, natural material such as wood can take on undesirable characteristics because of the way it is processed, for instance the high chemical inputs and energy needed to make viscose fibres from wood pulp.

One very difficult area is composite materials, where materials are effectively fused together, combining metals, plastics and sometimes ceramics to produce materials with high functionality but very low recyclability. In this case, there may be justification for applying levies to discourage use of such materials unless the environmental benefits outweigh the disadvantages, such as the composites developed for wind turbine blades, or very lightweight packaging materials with low carbon impact. Similarly, nano-materials may have high utility

but low recyclability. More comprehensive life cycle analysis is needed as a means of judging the environmental trade-offs involved, and as a means of ensuring that the right incentives are put in place. The judgements based on such analysis can then work through to the product standards system described above.

Conclusions

The prominence of raw materials security on the political agenda offers an unprecedented opportunity to get to the heart of our concerns about non-renewable materials. We have to separate short term concerns around price volatility from longer term trends in demand and supply, and adapt our economic systems to take better care of these crucial inputs. This means putting greater emphasis on recovery and recycling, as well as on resource efficiency and durability of consumer products. We can only do this by adopting a multi-pronged approach: improving product design, improving capture of products at end of life, and ensuring that good substitutes are available for materials we no longer can, or want to, access in future. Economic instruments that provide incentives to adopt this ‘whole life’ approach to products and materials should be an essential part of the picture.

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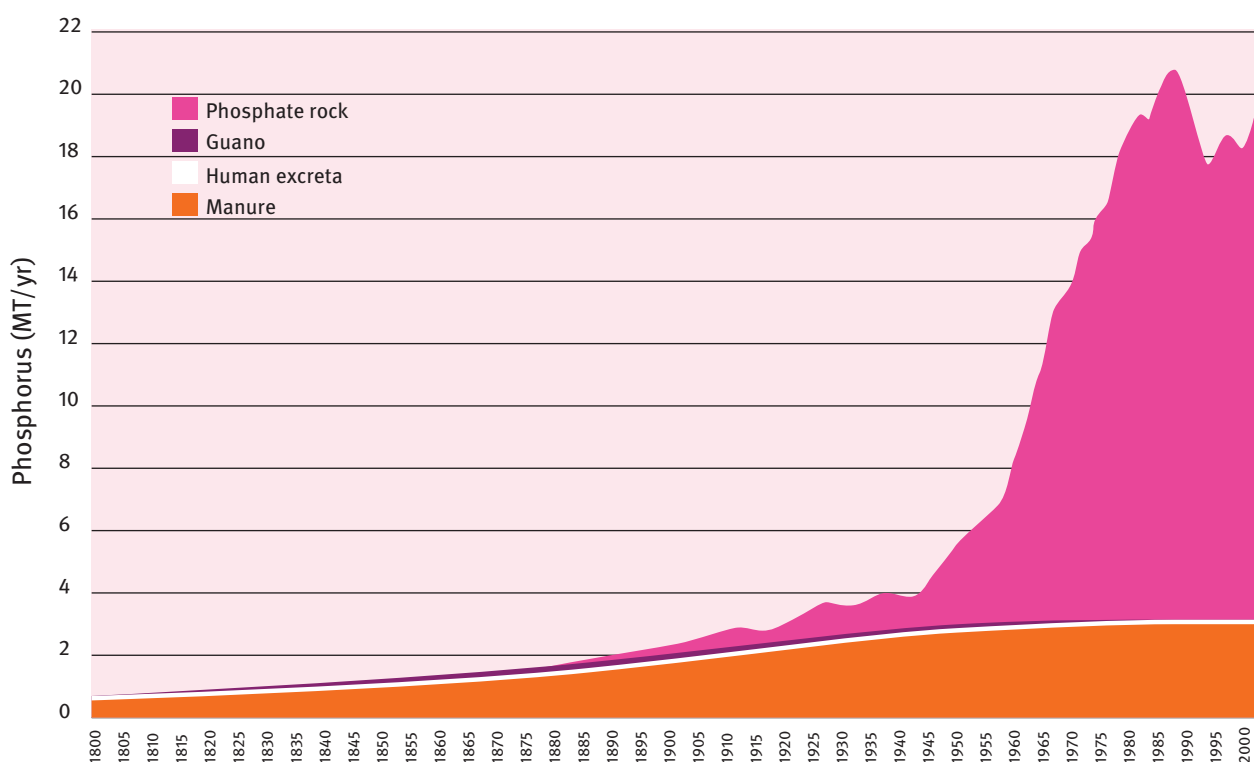
**3. Circulating
phosphorus**
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The problem

Phosphorus is one of the major nutrients needed to sustain life, and plays a crucial role in energy metabolism, membranes, structural support (teeth and bones), genetic components (DNA and RNA) and photosynthesis. It is a key limiting factor for plant growth and modern agriculture is almost completely dependent on mineral sources of phosphorus; few, if any, cultivated soils can support prolonged intensive farming without its addition or return to the soil. But there is increasing concern in scientific, if not yet political, circles about its long term availability and price, and the challenge that the end of cheap fertiliser will pose for global food security.

As the graph below illustrates, the use of phosphate rock for fertiliser production has increased 1,100 per cent since the second world war, quickly overtaking the sources of phosphorus used throughout agricultural history: crop residues and manure, human waste and guano (the excrement of seabirds, seals and some bats). It has made a crucial contribution to steadily increasing agricultural yields and, therefore,

Figure 4: global sources of phosphorus fertilisers 1800-2000⁶⁸



Some facts about phosphorus

Phosphorus is a chemical element. It has the symbol P and the atomic number 15. Due to its high reactivity, it is never found as a free element on Earth, but is almost always found in its maximally oxidised state, in minerals as the phosphate ion (PO_4^{3-}). It is also found in all life forms as an essential part of metabolism and DNA.

Phosphate rock is a sedimentary or igneous rock that contains high concentrations of phosphate-bearing minerals such as apatite.

Primary sources of phosphorus are phosphate rocks. The main application of phosphate rock is fertiliser. This brings the phosphate into the human food chain where it eventually finds its way towards dilution or waste.

Secondary sources of phosphorus are any waste where phosphorus is present at a concentration high enough for extraction to be feasible, in particular animal manure, human excreta, crop residues, food and slaughter wastes, and certain industrial waste streams. These sources mostly represent parts of the food chain where phosphate accumulates in some form after it has been used in food production in various ways.

human population growth ever since. Although phosphorus can be recovered, reused and recycled, it is both finite, as phosphate rock takes many millennia to form, and is unsubstitutable, as it cannot be synthesised.

Agriculture dominates global phosphate use: between 85 and 90 per cent of phosphate rock extracted is used for fertiliser, and a further five to ten per cent for animal feeds. The small remainder is used in detergents and other industrial uses such as pharmaceuticals, fire safety and electronics. A typical western diet includes approximately 0.6kg⁶⁹ of phosphorus per person per year, which depletes some 22.5kg⁷⁰ of phosphate rock based on current food chains and production practices.

There is considerable uncertainty and disagreement regarding both the total size of global phosphate rock reserves and, given expected increases in demand, what this means for the likelihood and timing of ‘peak phosphate’ (ie when phosphate production might reach a maximum rate or peak, after which production declines), or for pressure on resource quality, price and availability, with serious risks for food prices and global food security.

Between 2010 and 2011, the US Geological Survey increased its estimate of global phosphate rock reserves from 16 billion tonnes to 65 billion tonnes.⁷¹ This increase was attributed to new reserves estimates for Morocco and Western Sahara, whose estimated reserves increased from 5.7 billion tonnes to 50 billion tonnes based on information provided by a Moroccan producer and the International Fertiliser Development Centre (IFDC). The latter’s report, published in September 2010, argued that these new figures mean there is no indication that phosphate production will peak in the next 20–25 years,⁷² or even within the next 125 years,⁷³ as predicted by other scientists. “Assuming current rates of use”, the report states, “IFDC estimates that there are sufficient phosphate rock concentrate reserves to produce fertiliser for the next 300–400 years”.⁷⁴

Scientists at the Global Phosphorus Research Initiative, who had suggested that the peak in global phosphorus production could occur by 2033, have offered a critique of some of this report’s conclusions.⁷⁵ They argue that the data

regarding phosphate rock reserves are still shrouded in uncertainty, and that even if the new reserves estimates are accurate, the fundamental problem of phosphorus scarcity is not resolved as the peak in phosphate production would still be expected within this century.

The most convincing argument for taking more notice of this resource is that security is about more than physical scarcity. That there is such uncertainty and disagreement about the extent of reserves, and thus the timing of any peak, is concerning enough. But the following factors are recognised as playing a significant role in contributing to future problems, whether peak phosphate occurs in ten or 100 years:

- **Increasing demand.** Demand for phosphate fertiliser is strongly linked to population growth, so the expected increase in global population from seven billion in 2011 to over nine billion by 2050 will mean a corresponding increase in phosphate demand, if no additional efficiency and recycling is achieved. Further increases in crops grown for biofuels will also increase demand, as will per capita increases in phosphate demand, if diets continue to become more phosphate-intensive, ie comprise higher proportions of meat and dairy products.
- **Geopolitics.** While all farmers need phosphorus, a very small number of countries, in particular Morocco and Western Sahara and China, control the majority of the world’s phosphate rock reserves (the 2011 US Geological Survey estimates that Morocco and Western Sahara alone now control 77 per cent). Both China and the US have imposed export restrictions in recent years.
- **Declining quality and increasing environmental and energetic costs.** As we use up the best reserves of phosphate rock, those remaining contain decreasing concentrations of phosphorus and increasing concentrations of impurities and heavy metals such as cadmium, which are then transferred to



agricultural soils. Mining of more diffuse sources increases pollution, waste, water and energy consumption and overall cost.

since and the price has dropped, but there is no guarantee that similarly volatile prices will not be experienced in future.

“Further increases in phosphate prices could have devastating consequences for food security.”

- **Economic access.** Even at today’s prices, farmers in developing countries such as sub-Saharan Africa cannot afford phosphate fertilisers and so have the lowest application rates, despite the continent’s low soil fertility. Further increases in phosphate prices could have devastating consequences for food security, unless there is significant development of phosphate recycling partly to substitute the use of mineral phosphates. In 2008 the price of phosphate rock increased by 800 per cent, one of a number of factors that pushed global food prices up, causing riots in many countries. An important reason for this price increase was inadequate investment in mining and processing capacity over the past two decades. At least nine million tonnes per year of mining capacity has come on-stream
- **Water pollution.** Even if we did not face problems with the future security of phosphate supplies, we need to address the global problem of phosphorus pollution. Phosphorus discharged from inadequate sewage treatment works, livestock and poultry production, agricultural run-off and industrial processes can cause eutrophication and ‘dead zones’ that threaten water supplies and biodiversity.

Despite these challenges, in industrialised countries we view secondary sources of phosphate, such as animal and human manures, as pollutants and wastes. We dispose of them as cheaply as possible rather than making best use of the phosphorus and other nutrients (nitrogen, carbon and micronutrients) they contain. This is reflected in political discourse, where there has been little serious discussion at either a national or international level about how the challenges presented by finite supplies of mineral phosphorus can be tackled and

secondary sources can be used more fully and responsibly.

As we argued in *The nutrient cycle: closing the loop*⁷⁶, we need to stop relying on policy measures which tackle nutrients as individual substances conflicting with desired standards for soil, water and air. We need a policy framework which aims to cycle all nutrients through our economy with fewer unwanted effects and an overall gain in resource efficiency. As with the recycling of metals, there is significant market failure in that the environmental externalities of producing phosphate, and of dealing with waste nutrients, are not factored into market prices. Lack of awareness of the long term consequences of this linearity also hampers the development of solutions, amounting to another kind of market failure.

“We need a policy framework which aims to cycle all nutrients through our economy with fewer unwanted effects.”

A more circular economy for phosphorus, ie where it is used more efficiently and recovered for reuse and recycling, would help to tackle both the upstream problem of decreasing security of supply and increasing costs, and the downstream pollution problems that arise from the leakage of nutrients into surface waters.

Achieving this will require action throughout the phosphorus supply chain. We focus below on three main areas: reduction in demand, reuse of secondary sources and recovering phosphate for recycling.

Three target areas:

Reduction in demand

This means employing better agricultural and food chain management to make the best use of each kilogram of phosphate fertiliser applied. It requires the adoption of both sustainable technologies and practices, with the emphasis of the fertiliser industry shifting from selling a product to selling a service, ie soil fertility and

food security. It also means avoiding crop losses and food waste throughout the food supply chain. This is of wider importance given the embedded water and energy also wasted in the agricultural supply chain, but these related issues are not tackled here.

At the very top level, reduced phosphate consumption is just one of a number of reasons why a shift away from meat and dairy-intensive diets would also be desirable. This is, of course, controversial and in the UK the government has struggled to articulate the argument in clear terms. Defra’s 2006 report on behaviour change, *A framework for pro-environmental behaviours*, chose to avoid mention of animal protein and instead advocated that we adopt “a lower impact diet”.⁷⁷ The more recent Defra Sustainable Lifestyles Framework defines “increasing the proportion of vegetables, fruit and grains in diet (eating a balanced diet)” as a key behaviour for a sustainable lifestyle.⁷⁸

Reuse of secondary sources

Phosphate can be reused through the spreading of treated sewage sludge and animal manure on agricultural land, to ensure the recycling of nutrients. Applying sewage sludge to farmland is a long and well-established practice in most parts of the UK, with approximately 65 per cent of the annual sludge production recycled to farmland, one of the highest levels in the EU. The Soil Association recently recommended that amendments should be made to EU regulations to permit the use of sewage sludge on organic certified land, subject to certain quality criteria and appropriate restrictions.⁷⁹

However, the consideration of phosphorus recycling through sewage sludge spreading needs to take into account the real availability of the phosphorus to crops. Scientists disagree on this, but it is generally agreed that this can be very low (or even negative, where the sludge actually renders inaccessible the existing phosphorus in soil), particularly where chemical phosphorus removal is used in sewage works. There are many factors affecting the availability of phosphorus from recovered

sewage, such as soil type, and further research is needed in this area.

Reusing animal manure is more difficult because intensive livestock production tends to be concentrated in areas of the UK away from the areas of intensive cereal production, and transport between the two regions is difficult and costly because of the high moisture content and the high volume per unit of weight. This problem could be overcome with methods to 'pelletise' manures, which involve processing, eg composting then drying, to produce a granular or pellet form. Because manure has low levels of contaminants, it could also help to solve the challenges of ensuring the quality and uniformity of phosphorus sources.

Recovery of phosphate for recycling

Phosphate can be recycled from sewage and intensive animal manure and industrial waste streams for use as fertiliser or in industry. Technologies to do this exist, and are being implemented at some sites in the UK, Canada, USA, Japan and the Netherlands. For example, the Netherlands-based company Thermphos is already using a number of secondary phosphate sources in its industrial phosphorus production on a large scale, and has both the interest and capacity to also take secondary phosphates from the UK. But more widespread implementation faces economic, technological and systemic obstacles which are not currently addressed by any coherent public policies.

Solutions based on economic approaches

A classical economic analysis would argue that rising phosphate prices will lead to new technological developments, including increased efficiency, investment in mining capacity, and the opening up of less accessible or lower grade reserves. There has recently been increased investment in mining capacity so, although there is a lag between investment and production, some commentators expect there to be a surplus of phosphate rock capacity in a few years. However, in the longer term, the challenge of the increasing environmental and economic cost of mining evermore inaccessible,

diffuse and contaminated sources of phosphate rock remains, as does the fact that it is a non-substitutable resource and that millions of farmers in the developing world are highly vulnerable to even relatively small price increases.

“The challenge of the increasing environmental and economic cost of mining evermore inaccessible, diffuse and contaminated sources of phosphate rock remains.”

Such an analysis also neglects the problem that, even in the context of rising prices, more widespread and effective phosphate recovery and recycling is unlikely to develop rapidly without the use of instruments specifically designed to 'push' and/or 'pull' secondary nutrients through the system. This is due to the regulation and subsidy-driven nature of both the water and farming industries; and the complexity of the recovery cycle, which must involve the phosphate, fertiliser, water, and farming industries as well as distributors. The issue is compounded by the relatively long term horizon of the resource depletion issue but at the same time the uncertain geopolitics of supply and demand, with consequent volatility in the price of the primary resource.

1. Incentives to reduce demand for mineral phosphorus

While reducing demand through changed diets is generally seen as requiring a cultural shift, there have been calls for a livestock or meat tax to help such a shift on its way. Whilst driven predominantly by public health concerns, Denmark has already started to go down this route with the inclusion of certain meat and dairy products in its 'fat tax', which taxes food products with high fat or saturated fatty acid content. Whilst the low level of such a tax would be unlikely to change behaviour significantly on its own, it could have a broader public awareness impact.

Another possibility is a phosphate tax. In theory, a tax on primary phosphorus would create an



immediate economic incentive to reduce use of the mined resource and to make more use of secondary sources instead. But there is an argument that use of mineral phosphorus in UK agriculture has already been optimised to a large extent. Kilogrammes of phosphate per hectare per year applied to all crops and grass in Great Britain have more than halved since the early 1980s.⁸⁰ Further reductions might therefore be difficult, so unless good secondary sources are immediately available, a significant tax on mineral phosphorus would have a large economic effect on farmers, on top of the possibility of further price rises on world markets. This price would either be paid by the taxpayer, who subsidises farming, or passed on to the consumer.

An alternative approach could be to apply a small tax designed to raise enough money to fund the better recovery of secondary sources, and possibly incentivise the processing of secondary phosphorus so that it can be used industrially or directly on land. Taxing phosphorus in all its forms as it comes into the country would ensure that all uses are affected, not just agricultural, but also industrial users.

This would be complex. However, if only phosphorus in fertilisers or phosphoric acid (used in industrial applications and, in small quantities, in human foods and pharmaceuticals) was taxed, which would be easier administratively, then UK industry and farming would be put at an economic disadvantage compared to imported finished goods containing embedded phosphorus. The tax revenue collected should be used to provide credits to water companies, farmers and industries for phosphorus, either reused in useful sludge spreading or recovered for recycling, thus improving the business case for installing phosphorus recovery and recycling technology.

Perhaps the biggest challenge is whether such a tax including embedded phosphorus would infringe World Trade Organisation (WTO) rules. A WTO webpage, entitled ‘the environment – a specific concern’,⁸¹ states that “there are no definitive legal interpretations [but] trade restrictions cannot be imposed on a product purely because of the way it has been produced... one country cannot reach out beyond its own territory to impose its standards

on another country”. This suggests that, while a tax on imported embedded phosphorus in food and other products, or on certain imported sources, such as fertilisers, would not infringe WTO rules, it would infringe them if it attempted to differentiate between primary and secondary sources. A tax that did not differentiate or offer exemptions for the use of secondary sources of phosphate would be blunter than one that did, but could still reduce overall phosphate consumption and encourage the development of recovery and recycling.

2. Incentives for more direct use of good quality secondary nutrients

Here the issues are around what kind of nutrient-rich wastes are applied directly to land and how to turn what is often a waste disposal exercise into a nutrient optimisation exercise. It requires changing the dominant mind-set from one that sees sewage sludge as a disposal problem, to one that sees the value of the secondary resource, and spreads sludge to meet crop needs for a range of nutrients.

In several EU member states, agricultural spreading of sludge has been prohibited or abandoned because there are concerns, real or perceived, about its quality and compatibility with safe food production. This includes issues with medicine residues, microbiological hazards and heavy metals. To date, the UK has successfully dealt with these questions and the majority of treated sewage sludge is returned to land. But the work done by the water and food sectors to devise a safe and workable system for the use of biosolids on land still lacks statutory underpinning, which would drive investment in the right direction more effectively. Mineral phosphate fertilisers can have high cadmium levels, depending on the rock from which they are manufactured, which can raise questions about land contamination. Part of the future policy landscape could therefore be greater recognition for anaerobic digestion and composting operations producing bespoke nutrient products. In the case of anaerobic digestion, this could be incentivised through the renewable obligation certificate system already

in place to reward renewable energy generation.

Alternatively, the cross-compliance conditions attached to single farm payments to support good soil management could be strengthened, which would include using secondary nutrients in preference to mineral fertilisers derived from rock phosphate. For farmers, the considerations about nutrient sources are not just about price, but also quality and reliability, so this may point to more certification to ensure uniform quality and ease of application, as it is harder for farmers to know how much phosphorus to use in most secondary forms compared to the standardised mineral product.

“For farmers, the considerations about nutrient sources are not just about price, but also quality and reliability.”

Another approach would be recycling credits for good quality secondary nutrients, for instance products with a range of nutrients optimised for different conditions, or even to introduce recycling obligations or quotas implemented through tradable permits. In the Rhône-Mediterranean basin in France, a system is in place that incentivises the optimisation of sewage sludge treatment, through a varying level of subsidy from the water agency to the communes according to the way in which sewage sludge is disposed, with composting and digestion meeting quality standards receiving the most subsidy, and landfill and unplanned spreading receiving the least.

3. Incentives to recover more phosphorus from sewage

The two sources with greatest potentials for recovering secondary phosphorus in a transportable form are sewage works and intensive livestock units. For sewage works, a significant barrier is that recovery using currently identified technologies is compatible with biological nutrient removal (BNR) sewage works processes, which remove nutrients using specific groups of micro-organisms, but not, for any currently identified viable technology, with chemical phosphate removal processes using

iron dosing. Many sewage works in the UK currently operate chemical nutrient removal, which has much lower investment costs of installation, but which is arguably less sustainable, because it implies on-going consumption of chemicals (iron or aluminium salts) and results in considerably increased sludge production.

Whether through a phosphate tax or other means, incentives are needed to assist the changeover to biological nutrient removal, accompanied by the installation of phosphorus recovery processes, and possibly also inorganic nitrogen recovery, or to increase and further develop recovery routes via sludge digestion or incineration. Higher prices for secondary phosphorus as a result of such a tax might in any case incentivise such investment. Otherwise, some other direct incentive might be needed, such as enhanced capital allowances or other corporate tax breaks. If an obligatory phosphorus recycling objective was fixed for certain key use or handling sectors (water industry, sewage treatment plants, livestock production and certain industries), then tradable quotas could be combined with economic incentives to invest or to use secondary phosphorus sources. This could ensure that recycling objectives are defined and achieved, whilst allowing the relevant industries to choose where to invest most cost-effectively.

“Far more national and international attention is warranted on this finite, unsubstitutable resource crucial to global food supplies.”

Once investments in biological nutrient removal, manure collection, or incineration and recovery routes have been made, they will last for a significant time. But without direct funding, such investments would add to the indebtedness of water companies and therefore prices for water consumers, unless there are high-price markets for the products of recovery processes. Tradable quotas might mitigate this by optimising investment.

Conclusions

Even if those who predict imminent peak phosphorus within the next few decades are proven wrong, a perfect storm of concentrated geopolitical control, rising demand, declining quality of reserves and increasing environmental and economic costs mean that far more national and international attention is warranted on this finite, unsubstitutable resource crucial to global food supplies.

Achieving greater circularity of the phosphorus already in our economy means tackling a series of market failures. Our research suggests that, overall, ensuring the pull of secondary nutrients through the system with incentives to recover and recycle phosphates, combined with quality standards for secondary products, will be more effective than trying to push their use by pricing the primary product. So we recommend a range of different incentives to encourage more use of high quality, secondary sources of phosphate, and to encourage the recovery of more secondary phosphate from sewage. However, push and pull measures can be used in tandem, so we also recommend a relatively modest levy on mineral phosphorus, and, if possible, on embedded phosphorus, which could help to fund the development and uptake of alternatives.

4. Circulating water

instruments
scarcity
economy
standards
sources
government
incentives
future
metal

What's the problem?

There are a number of key areas where the economics of our use of water, and its effects on the environment, need to be considered. The first is that, in the UK, we have no means of charging for either water abstraction or consumption according to its scarcity, and water is a resource that can, on a seasonal and local basis, be genuinely scarce. Climate change, rising populations, and new development are all putting increasing pressure on the UK's water resources to the extent that damage is being done to the natural environment by over-abstraction. There are also no incentives to circulate water more effectively, either at a household level or within industry.

“There are also no incentives to circulate water more effectively, either at a household level or within industry.”

Our consumption patterns also have an impact on water resources in other countries, because everything we buy has a ‘water footprint’ in the same way as it has a carbon footprint. Much of this water is used in production abroad and then effectively imported into the UK. Unfortunately, unlike a carbon footprint, it is not enough to know the absolute amount of water consumed, it is also important to know how the use of water relates to its overall availability. Products with high amounts of embedded water in their production may be fine in areas of abundant water, but not in others. It seems likely that a stewardship approach to water, akin to the stewardship of resources such as timber, might be more useful approach.

Water scarcity in England and Wales

The Environment Agency's 2008 summary of current and future pressures on water resources in England and Wales showed that 15 per cent of catchments are already over-abstracted, ie the natural environment is being damaged by the amount of water taken when conditions are dry. A further 18 per cent are over-licensed, ie if abstraction rights were fully used there could be damage.⁸² And this is only going to get worse:

the UK climate impacts projections published in 2009 show that we are facing greater unpredictability in rainfall, and longer, drier summers in coming decades.

Recognising these pressures, the coalition agreement committed the government to “reform the water industry to ensure more efficient use of water, and the protection of poorer households”.⁸³ Reform is certainly needed to meet the challenging demands of the EU Water Framework Directive, which commits EU member states to achieving good ecological status of all water bodies by 2015. Currently, 95 per cent of water bodies are at risk of failing to meet the new tougher standard of good ecological status.⁸⁴ A reduction in hot water use will also contribute to meeting the UK's climate change targets. Heating water in homes accounts for five per cent of the UK's greenhouse gas emissions and a quarter of the average household energy bill, whilst water industry activities, including cleaning and pumping water and treating sewage, are responsible for a further one per cent of the UK's emissions.

The persistent perception that the UK is a rainy country and, therefore, that water is plentiful everywhere means that there is a lack of public concern and understanding about water use. Householders are responsible for over half of water use but few have incentives to reduce their usage. Business and industry are responsible for one quarter of use but, despite universal metering, few have big enough incentives to significantly reduce their consumption. Furthermore, the current regulatory framework does not reflect the value of water, and the environmental costs of taking it from the natural environment, in its management of water abstraction. There is a clear need to price water more effectively.

English and Welsh water resources are governed by a complex policy and regulatory landscape. The Department for Environment, Food and Rural Affairs (Defra) sets the overall legislative framework; Ofwat, the economic regulator, sets



limits on the prices water companies can charge customers and seeks to balance the competing demands on limited water resources; and the Environment Agency, the environmental regulator, secures the proper use of water resources through research, guidance and enforcement of legislation.

In addition, two independent reviews into the UK's water resources, both published in 2009, have recently sought to address the challenge of rising consumption and unsustainable abstraction: the Walker Review on charging for household water and sewerage services,⁸⁵ and the Cave Review on innovation and competition in the water sector.⁸⁶ The government is currently considering their recommendations and will set out its conclusions in a Water White Paper. This is intended to fulfil the commitment in the coalition agreement to reform the water industry, and to take into account David Gray's 2010 review of Ofwat for Defra. Originally planned for summer 2011, its publication has been delayed so that the results of a consultation on water affordability can be incorporated before any decisions are taken.

Global water security

There is increasing recognition that the pressure on global water resources is intense and growing. "Unless it is checked," the World Economic Forum Water Initiative argues, "worsening water security will soon tear into various parts of the global economic system... Our rapidly accelerating demand for food and fibre is meeting changing rainfall and weather patterns, overlain on land assets with increasingly depleted and polluted rivers and groundwater resources. As economies grow, more of the freshwater there is left available is demanded by energy, industrial and urban systems".⁸⁷

A recent McKinsey study found that within two decades, the collective demand of humans for water will exceed foreseen supply by about 40 per cent, with huge implications for agriculture and food prices, energy, trade, migration flows and national security, within both rich and poor countries.⁸⁸ Recent reports of 'land rush', where water scarce nations buy up, sometimes through dubious means, fertile land in more water secure countries, are one indicator of the growing challenge.⁸⁹ This is exacerbated by the fact that the countries and regions facing



looming water scarcity are often also those with the fastest growing populations and fastest shifts to industrialisation and urbanisation. These include Bangladesh, China, Egypt, India, Indonesia, Korea, Mexico, Pakistan and Turkey.

“Within two decades, the collective demand of humans for water will exceed foreseen supply by about 40 per cent.”

In the UK we are linked to the water resources of these countries, and many others, through our consumption of products grown or manufactured there. While the average person in the UK consumes 150 litres of water per day, this amount is dwarfed by the amount of virtual or embedded water consumed in the production of the goods and services we use in our daily lives. This rises to more than 4,600 litres per day when both direct and virtual uses are included.⁹⁰

Less than 40 per cent of the UK’s total water footprint (the sum of the domestic water resources it consumes through domestic,

agricultural and industrial use, plus the water used outside its boundary and imported as virtual water) is sourced within the UK, which means our consumption of many products is dependent on the water security of other countries and the effectiveness of their water management systems.⁹¹ When we waste food and other products, we also waste water: WRAP and WWF recently found that the water footprint of avoidable and potentially avoidable food waste in the UK represents nearly six per cent of our total water requirements.⁹² 75 per cent of this water had been imported.

Solutions based on economic approaches

An understanding of global water challenges should first give us impetus to use water resources in the UK more wisely. This must involve new water pricing policies and models. We need charges that reflect water scarcity, both temporally and spatially, and incentives and support for businesses and households to save and recycle water.

To reduce the pressure on water resources abroad, we also need mechanisms and incentives to tackle unsustainable embedded

water in the products we buy. The following sections explore these three economic instruments in more detail.

1. Charging that reflects water scarcity

Household water metering

The UK is unusual in Europe in having very low levels of domestic water metering. Only 37 per cent of homes currently have a meter, compared to universal or near-universal metering across Europe (with the exception of Ireland and Norway⁹³). There is widespread agreement amongst the main stakeholders, including Defra and the Consumer Council for Water, that metering is the fairest way to charge households for the water they use, and that metering should be accelerated in water scarce areas. There is less consensus that a move to universal metering is a desirable objective and, if so, the speed at which that should be achieved. As a result, water companies are largely dictating the pace of a very gradual water metering roll-out, at approximately two per cent increase in meter coverage per year. They can install meters at their discretion when there is a change of occupancy at a property, and in areas which the Environment Agency defines as seriously water stressed, subject to ministerial and Ofwat approval of their plans.

Ofwat currently supports extensive compulsory metering for Southern, South East and Veolia South East water companies due to high levels of water stress in south east England. Southern and South East water are expected to have household metering levels of at least 90 per cent by the end of 2015. In contrast, Ofwat rejected other companies' proposals for additional metering, on the basis that the benefits would not exceed the costs in areas where water resources are not under such stress. But definitions of water stress are contested. Thanks to an out-dated licensing regime, in many areas water companies have the rights to abstract far more water from a river than is sustainable. If they do not abstract the maximum volume allowed by their licence, it is judged that surplus water is available and that the costs of metering are unjustified. There are

other concerns about the cost-benefit analysis that informs these decisions, including an over emphasis on capital-intensive supply infrastructure such as reservoirs and pumping stations that deliver regulatory certainty but not long term sustainability.

The rate of water meter installation therefore remains very slow in many parts of the country. It has largely consisted of households choosing to have a meter installed where they have been persuaded that it will save them money, for example, because they are a low occupancy household so they would expect to pay less than current charges which are based on the rateable value of their property, a progressive system when it was introduced in 1974 but much less so now. The independent Walker review of charging concluded that this piecemeal system is an expensive and inefficient way to achieve a high penetration of meters. As customers switch to meters to save money, those remaining unmetered start to pay more as the cross-subsidies inherent in the rateable value system start to unravel. The review also estimates that the opt in approach of installing a meter is currently £220 per household, compared to £110-175 with a more efficient and systematic approach to installing water meters street by street.

The benefits of meters

Meters do not directly reduce water use, but they do encourage people to use less. In general, they are thought to lead to a change in behaviour that reduces water consumption by 10-15 per cent, although there are differing views as to the size of the change and the extent to which any effect wears off over time. Understanding the full impact of metering in the UK is complicated by the current roll-out, whereby people with already low water consumption relative to the rateable value of their property switch to a meter to save money.

Water companies are becoming more aware of the potential to incorporate insights from behavioural economics into their interactions with customers, and metering is a key tool.

More accurate, regular and clearer billing can help tackle water's invisibility to customers, and can harness the influence of social norms, by letting customers know whether they are using more or less water than their neighbours. This is an approach championed by US energy company Opower, which brought about a 2.75 per cent reduction in household energy use, on average across all customers, in California over a 16-month period. This was achieved after automatically sending personalised information to households on how their energy use compared to both average and more efficient households in their neighbourhood.⁹⁴

“Water companies are becoming more aware of the potential to incorporate insights from behavioural economics into their interactions with customers.”

Meter installation provides an opportunity to directly engage households with their water use, as it provides, first, a reason to visit people's homes to talk about water, and second, a reason for people to engage with the advice and products on offer.

External meters also help to detect leaks within the boundary of the house. As a result, Environment Agency research suggests that average leakage from both unmetered and internally metered properties is more than double that of externally metered properties (most water companies try to install meters externally if possible).⁹⁵

Metering and fairness

There is a strong fairness argument in favour of universal metering. Waterwise research has found that customers think it is wrong for two neighbours in identical homes to pay the same if one household uses much more water than another.⁹⁶ In many areas, the costs of ensuring security of supply are driven by peak water demand during dry summers. A significant proportion of this higher peak demand is the result of outdoor water use: for watering large gardens, filling pools and washing cars.⁹⁷ Universal water metering would help to address

some of the inherent unfairness in the current system, which can see poorer households subsidising the expensive infrastructure needed to meet the higher peak water demand created by more affluent households.

There is, however, understandable concern about the impacts of metering on low income customers, particularly those with large families. The interim results of Wessex Water trials reported that while 72 per cent of all customers paid less after a switch to metering, only 62 per cent of low income customers paid less, and one third paid more.⁹⁸ However, in our view these results argue not against metering, but for metering combined with fairer and more effective tariff structures, as we describe below.

Such tariffs will require smart water meters that can store data and be read remotely, but some water companies are still installing dumb meters that only give a snapshot of cumulative consumption at one point in time, and so cannot support more sophisticated tariffs. Government needs to give a much stronger signal to water companies that all water meters installed from now on should have the necessary functionality, and should consider legislation if necessary. There also needs to be much greater co-ordination between the roll-out of smart energy meters and smart water meters, both in terms of the technology (ensuring sufficient radio frequency for smart water meters is available, for example) and communication and engagement with households.

Despite the benefits of water meters in reducing consumption and enabling smarter tariffs, and the inefficiencies of the current approach to rolling them out, no government has yet set out a roadmap or strategy to implement near-universal metering. Although the Water White Paper has been delayed, Defra's Secretary of State Caroline Spelman signalled her reluctance at Water UK's annual City Conference in February 2011, saying that she was “not persuaded by the argument for compulsory metering dictated by central government”.⁹⁹ As well as concerns about affordability and fairness, the government

has an aversion to dictating what water companies should do from the centre, particularly when some areas such as the north east have, at least at the moment, plentiful water supplies.

“Research has found that customers think it is wrong for two neighbours in identical homes to pay the same if one household uses much more water than another.”

Ofwat has promised to work with the Environment Agency and other stakeholders to develop “a more robust framework and improved evidence base for companies to assess the costs and benefits of accelerated metering and smart metering”.¹⁰⁰ This will certainly be necessary, particularly if the Water White Paper does not lay out a clear path to universal metering, but instead concludes that it is for water companies and Ofwat to decide what approach to take.

More effective and fairer tariffs

Smart metering is a prerequisite for more effective and fairer water tariffs. These can charge users a higher unit price for water if they use more than a certain level (rising block tariffs), or different amounts at different times of year to reduce seasonal demand (seasonal tariffs). Social and transitional tariffs can also help customers on low incomes, with large families or those with medical conditions whose management requires increased water use.

Water companies have started experimenting with different tariffs but, as yet, the picture of emerging results is unclear. Veolia Water Central’s trial of a seasonal tariff, with water costing £1.42 per cubic metre in the summer months (May–August), and 61p the rest of the year, compared to a flat rate charge of 88p per cubic metre, actually seemed to increase summertime water consumption compared to its control tariff.¹⁰¹ It is thought that this could have been the result of a time lag in billing, ie customers received their lower winter bill at the beginning of summer, so were unprepared and unmotivated to change their behaviour in the summer months.

This suggests that better and more regular billing is needed (as explored below), but also confirms the results of many other studies showing that people are irrational and do not necessarily respond predictably to price signals.

For example, there is the possibility that people responded to the higher summer charge by watering their plants, washing their cars or filling their paddling pools more, because they could afford it, and the introduction of a market signal reduced the social pressure to conserve water. This suggests that metering and tariff changes must go hand-in-hand both with a deeper understanding of public notions of fairness as relates to water use, and better communication that effectively addresses these notions and ties them to the need for water conservation and efficiency measures that households can take. It is worth noting that information alone is unlikely to lead to change.

Rising block tariffs, where essential water usage is charged at a low rate, and the price for use above that rises rapidly, may equally not have the expected effects unless introduced with consideration of how people behave. Veolia Water South East trialled rising block tariffs in two areas: Lydd in Kent and Cheriton in Hampshire.¹⁰² Customers on the trial tariff were charged 75 per cent of the standard rate for the first 80 cubic metres of water they used a year, with usage above this level charged at double the standard rate. High occupancy houses with children and customers with certain medical conditions were granted up to an extra 30 cubic metres of water at the standard rate. Initial assessments of this trial suggest that there has not been a significant change in customer demand for water. This could be explained by the relatively low per capita demand in the trial areas originally. A bigger distinction between the two blocks, or a more nuanced set of tariff steps, might have had more effect.

Wessex Water has also recently trialled both seasonal and rising block tariffs, which showed additional demand reduction of six per cent on average compared to standard metered charges,



although they announced these results with a word of caution about the robustness of the statistics.¹⁰³ There is clearly a real need for a bigger evidence base: more large-scale pilot studies of different tariff structures are needed. These should be combined with programmes of engagement and communication to ensure that customers are both aware of the changes to the charging structure and enabled to make water efficiency improvements.

Tariffs should also ensure that water is affordable for all. Social tariffs protect people on low incomes, both those on benefits and those in work, and transitional tariffs help people adjust to a new charging system, particularly if metering reveals previously undetected leaks in a customer's property. But the government has rejected as unaffordable the Walker review's recommendation that low income households should receive a discount on their bill, or that low income families with children receive a free allowance of water per child. Instead, it proposes to improve the existing WaterSure scheme by capping the bills of households with three or more children eligible for the scheme at the national average metered bill, the regional

average metered bill or the actual household's metered bill, whichever is lowest.¹⁰⁴ The government expects this to improve take up and means the cost is met by the taxpayer, not the water customer, which should also spread the burden more evenly and, therefore, fairly across the population. The main problem with this approach is that capping bills removes the incentive on households to conserve water, unlike targeted aid to low income families.

As well as changes to WaterSure, the government will shortly revise its guidance to Ofwat and companies on social tariffs to reduce charges for those that have difficulty paying their bills in full.¹⁰⁵

Leakage

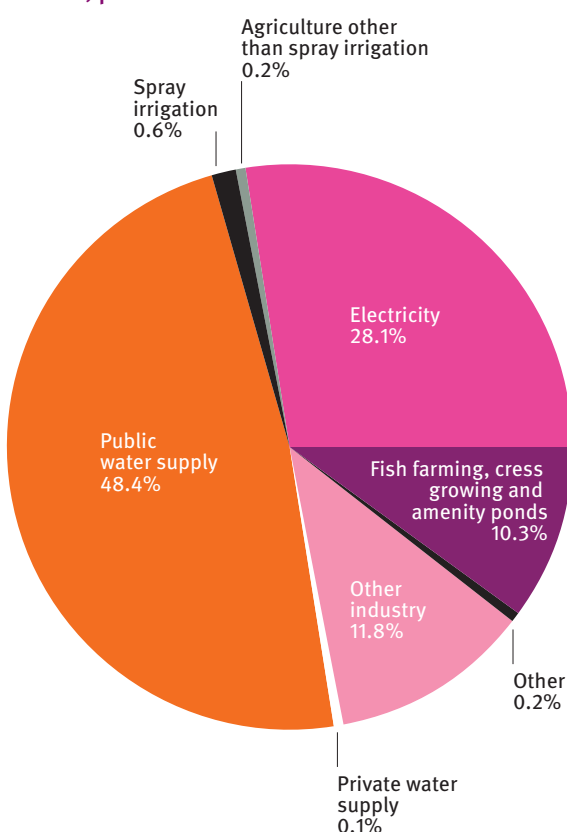
A discussion about the fairness of different ways of charging for water must also include the issue of leakage. Allowing water companies to persist with leakage rates at a level the public see as high (by 2014-15, total leakage in England and Wales will be more than 3,200 mega litres a day, 25-30 per cent of total production),¹⁰⁶ risks undermining the message that water is a scarce resource, and reducing the willingness of water customers to play their part in reducing water

use, given what we know about how much people value reciprocity. The Environment Agency states that if current best technology was applied by all companies, leakage could be 30 per cent lower by 2025 than it is now.¹⁰⁷ It supports the concept of 'sustainable economic level of leakage' which, when properly applied, requires companies to take into account the environmental benefits of reduced abstraction in water-scarce areas.

2. Abstraction pricing

Water is abstracted by two main groups of users. Water companies, who provide the public water supply, take just under half of the non-tidal water (ie freshwater from lakes, rivers and underground stores) abstracted in England and Wales. Twenty-eight per cent is used by the electricity industry for cooling power stations, but this use is described as 'non-consumptive' as the water is readily discharged back to the environment with very low environmental consequences.

Figure 6: licensed abstractions, England and Wales, per cent¹⁰⁸



All abstractors pay the Environment Agency for a licence to abstract. But the charges do not reflect the scarcity of the water or any environmental damage that might be done by taking it, now or in the future. Only 20 per cent of abstraction licences have conditions which curtail allowed abstraction when the environment is at risk, for example, from low river flows.¹⁰⁹ Furthermore, abstraction licences are tantamount to property rights. If the Environment Agency wants to stop or limit abstraction that is damaging the environment, it must change or withdraw the licence and compensate the licence holder for their loss of rights, which is typically costly. The Restoring Sustainable Abstraction (RSA) programme was set up to compensate licence holders. It is funded through the Environment Improvement Unit Charge (EIUC), a levy raised on abstraction charges, but has been criticised for being piecemeal and significantly underfunded. WWF points out that the current approach would take between 350 to 2,500 years to achieve the reductions in unsustainable abstraction indicated in the Water Framework Directive's River Basin Management Plans.¹¹⁰

Over-abstracted sites that fall under the EU's Habitats Directive, however, are funded through the five-yearly price review process, which sets water company price limits. The Water White Paper is likely to propose changes that will bring more over-abstracted sites into the price review, which could be a welcome start to a more ambitious and strategic approach to over-abstraction. But there is a clear need for a longer term roadmap for ensuring that all licences reflect the amount of water that can be taken from the environment without harm.

In the interim period, reform is needed to ensure that water companies have more effective incentives to manage abstraction in a way that reflects the value of water in a specific location, and how that value changes over time. This is recognised by Ofwat and discussions are on-going about the role of pricing, both charging and trading and regulation, to set the rules and to provide targets and backstops. WWF favour the creation of a water scarcity

mechanism that would change the merit order of different demand and supply options, thus incentivising companies to manage demand through metering, tariffs and water efficiency measures and, in terms of supply, to reflect the impact of abstracting water from sensitive areas.

Reverse auctions are one way of creating strong economic incentives for sustainable abstraction, and are overall revenue neutral to the water industry. A scarcity charge would be levied on unsustainable abstraction, which would generate revenue for a sustainability fund. The fund would then be used to buy back damaging abstraction licences through a reverse auction, where abstractors would offer to give up damaging licences in return for a payment. The payment would go to the abstractor offering the lowest bid.

3. Incentives for water circularity in households and businesses

A move to more widespread metering could also increase the incentives for households to install greywater systems and rainwater harvesting. Greywater systems involve using, and in some cases filtering and disinfecting, water from washing machines, baths and showers. This can then be used in areas where drinking water standards of purity are not needed, such as on the garden, washing cars or flushing toilets. Rainwater can also be stored and used untreated in the garden, or filtered and treated to use indoors, helping households to become more resilient in times of drought.

However, systems can have a long payback time and retrofitting them can be disruptive as well as costly, although new buildings could be fitted with greywater systems as a matter of course, enforced through building codes. More research is also needed into the carbon implications of small-scale water recycling and reuse systems. Due to the economics of mains water supply, it is thought that the carbon emissions from rainwater harvesting can be significantly higher than current centralised purification systems.¹¹¹

All businesses are metered and pay for water according to how much they use. But, unlike domestic users, large business users may not have the means of reducing their water use or recycling waste water without significant investment in new techniques or technologies. Many water saving and water efficient technologies are currently eligible for tax relief in the form of enhanced capital allowances, including efficient fittings, leakage detectors, industrial cleaning equipment and rainwater harvesting.¹¹² But take up of these tax breaks is relatively limited as most businesses do not see water as a significant contributor to their bottom line compared to other costs. It is, therefore, not worth the investment or complication of their business. The food and drink sector, in particular, seems to be wary of on-site water recycling processes, due to the nervousness of brands and retailers of anything that could be seen to compromise their brand.

“Most businesses do not see water as a significant contributor to their bottom line compared to other costs.”

Solutions based on pricing that could provide both a carrot and a stick to large water-using businesses include rising block tariffs based on sectoral benchmarks, with levies on higher users being used to fund water efficiency retrofit of business premises and factories. However, it is likely that pricing will have to go hand-in-hand with regulatory approaches such as new water efficiency standards for products and buildings, as explored later in this section.

4. The role of non-financial instruments

Perhaps more so for water than for any other resource, it is clear that sophisticated price signals should play a much bigger role in the way in which we manage water. However, they are unlikely to be enough on their own. The uptake of water efficient products, for example, could be encouraged by a price incentive, such as an environmental levy on the worst products to fund a rebate on the best, combined with a water efficiency label. But there is probably more significant progress to be made by ridding

the market of the most inefficient products through increasingly tough minimum standards, such as those agreed under the EU's Ecodesign Directive.

This argument also applies to buildings: the water efficiency measures that are starting to transform the market in new build properties, thanks to the Building Regulations and Code for Sustainable Homes, need to be more strongly applied to existing stock. Incorporating both hot and cold water efficiency measures into the Green Deal, the government's key policy for energy efficiency retrofit, is a crucial first step; compared to the cost of energy efficiency improvements, the cost of water saving measures is trivial and, therefore, a very cost effective way of reducing demand and delivering increased security of supply. A combination of regulatory and/or economic measures is likely to be necessary to drive demand, particularly in the rented sector.

The better management of urban drainage will also require the policy conditions created by an effective mix of incentives, charges and regulations. Green infrastructure in urban areas, such as green roofs and reed beds, mimics the way rainfall drains into natural systems and avoids the need to pump and treat water. Such drainage systems can prevent flooding, keep water available close to the point of use to take pressure off mains supplies and, in some cases, keep wetland ecosystems nourished. Charging developers for surface water discharged to the sewage system could encourage the use of innovative techniques and materials to enhance infiltration and discourage rapid run-off, although a regulatory approach that simply requires the establishment of sustainable drainage systems for all new developments might be simpler. The development of water cycle strategies involving water companies, local authorities and the Environment Agency in areas where water resources are expected to come under increasing stress also has potential to align new green infrastructure, including stormwater systems and flood storage, with water conservation.

5. Embedded water and water stewardship

Pricing, in combination with other measures, also has the potential to play a role in reflecting the impact of the water used in the production of the goods we buy, thus rewarding sustainable water management. Higher and/or smarter water charges for companies operating in the UK might impact on these footprints, but much of the water use will be in supply chains that stretch across the world.

“Companies are increasingly using water footprinting methods to understand the water-related risks to which they may be vulnerable.”

The water footprint of a company, product, or unit of product, can be established and companies are increasingly using water footprinting methods to understand the water-related risks to which they may be vulnerable, in the same way that many companies have worked out their carbon footprints. However, there is an important distinction to be made between the two. The location from which carbon dioxide is emitted is unconnected to the climate consequences the emissions cause. In contrast, the site of freshwater extraction is of prime importance in determining its impact, because it has direct consequences for the local water basin. Water footprints are thus only useful when interpreted in the context of the geographical location in which freshwater extraction is taking place, including local pressures on the water resource and local levels of water scarcity. This has been done by companies including the global brewer SABMiller, who can then target the hot spots in their supply chains. In SABMiller's case, this means agricultural production, as over 90 per cent of their water footprint relates to the cultivation of raw crops.¹¹³

Directly translating water footprints into either standards or consumer-facing labelling is problematic, however. The sheer amount of underlying complexity means that a standard or a label could be so reductionist as to be

misleading. An alternative approach is to develop a ‘water stewardship’ standard, which could also work as a third party certification scheme akin to the Marine and Forest Stewardship Councils (MSC and FSC).

A water stewardship certification scheme could take a more sophisticated approach to understanding the impacts of embedded water, and reveal how well companies were managing water in the round. It would allow clarity without the reductionism of a water footprint, and could demonstrate independent scrutiny of a company’s operations and products. In time, a water stewardship certification scheme could be the basis either of minimum standards, or work alongside a system of product levies. This would aim to reverse the higher costs of good water stewardship by levying products or materials where the embedded water had a high impact and was not being sustainably managed. Standards and levies would need to be consistent across industrial sectors, including textiles, food and drink, mineral extraction and energy generation.

“Water companies must be able to pass the increased abstraction costs necessary to fund the protection and restoration of vulnerable water resources on to consumers in a way that encourages lower water consumption.”

Conclusions

There is a compelling case for the better pricing of water, which reflects both the value and sensitivity of the resource in time and place, as well as the quantity used. First, we need a clear path to near-universal metering, linked to the roll-out of smart energy meters and combined with tariffs to reflect better the value of water and ensure it is affordable for all. Second, we need significant reform to the licensing and abstraction regime so that it far better recognises the value of water and gives water companies and other abstractors an effective set of signals and incentives to reduce their abstraction, particularly where and when it is damaging. These two recommendations are interlinked: water companies must be able to pass the increased abstraction costs necessary to fund the protection and restoration of vulnerable water resources on to consumers in a way that encourages lower water consumption.

Price signals will also have a role to play in the policy mix needed to encourage our buildings, towns and cities to be built and to develop and grow in a way that reflects our changing climate and increasingly precious water resources. The right incentives will be needed for water saving products and fixtures, buildings that circulate water by harvesting rainwater and recycling greywater, and sustainable urban water drainage.

Longer term, and internationally, a stewardship approach to water that builds on current efforts to establish water footprints is essential if our efforts to protect the UK’s water resources are not to be undermined by our consumption patterns.

5. Seeing the bigger picture

environment

stewardship

metering

waste

abstraction

companies

reserves

mining

recycling

management

instruments

scarcity

economy

stap

phosphorus

households

materials

demand

circular

resources

recovery

consumption

effect

The current debate about raw materials security is taking place on narrow ground. The preoccupation with high technology and the metals it comprises is obscuring the bigger picture, where availability of water and also phosphorus, the mineral on which our food supplies depend, may trip us up sooner than we think. The debate needs to be widened to address these and other resources, and to better encompass the role of a more circular economy.

“Availability of water and also phosphorus, the mineral on which our food supplies depend, may trip us up sooner than we think.”

For metals, it is access rather than absolute shortage that is the concern, but this concern is not insignificant. ‘Access’ encompasses a range of interlinked challenges, including that of declining return on energy invested. Market mechanisms may drive the opening up of new sources and the substitution of insecure alternatives. Because of the complexities of extracting and refining different metals, overlaid by the complexities of the way they are traded, the road to innovation may be bumpy, and there will be both winners and losers. But from the environmental perspective, what should concern us is not whether the market will do this, but how it will do it.

Expansion of extractive activities may not be disastrous in countries with good environmental controls, or where it is led by companies with enlightened stewardship policies. Sadly, such conditions are far from universal. As to substitutes, these may result in better environmental outcomes, or worse. Since no country has as yet set conditions on the whole-life impacts of products, there is nothing to ensure that the extraction of substitute materials will be more benign, or will improve the environmental profile of the products they comprise. So there is no trajectory based on concern over access to raw materials to take us down a more sustainable path.

What we can be sure of is that we are wasting valuable materials because of a series of market failures. These begin with product designs which make those materials hard or impossible to reclaim. They continue with the lack of incentives for consumers (whether individuals or businesses) to buy greener products, or to return them for reprocessing, which translates into reprocessors having uncertain supplies of materials. Thus investors fail to back new infrastructure and take risks on innovative recycling and reuse processes. We recommend economic incentives for better product design and promotion of greener products to consumers, coupled with direct incentives, or ‘recovery rewards’, to aid return of products. These actions would help to establish a circular economy for non-renewable resources.

We also recommend directing the course of substitution in some circumstances, by exploring how to penalise substitutes that are no less damaging to the environment. Another possibility is to attempt to internalise the environmental costs of materials by applying border taxes at national or EU borders. We have not fully analysed this possibility, fraught as it is with WTO rules prohibiting the imposition of environmental standards on other countries. It merits further examination, but given the complex layers of factors influencing prices in global commodities markets, any such price signal would have to overcome a considerable amount of background ‘noise’ to be effective.

Phosphorus is the Cinderella of the resources debate. Few of us have seen or handled this raw material without which the world population could not have reached its present levels, and on which our industrial agricultural system depends. While there are very divergent views about the likelihood of absolute shortages in the near future, as with metals, mining more diffuse and inaccessible sources will have energetic, environmental, economic and geopolitical repercussions. Unlike metals, there is no substitute for phosphorus. Secondary sources of phosphorus, the organic wastes from humans, animals and agriculture, are treated as wastes

and pollutants, rather than valuable nutrients that can displace the use of artificial fertiliser. This is, in part, due to a market failure: the cost of using these properly and safely outweighs the cost of what, until recently, has been a relatively cheap and easy mineral input. We now have to correct this failure to enable us to make better use of secondary sources. We recommend a range of incentives, including a levy on mineral phosphate fertiliser, to encourage the more circular treatment of organic sources of phosphate.

“We must also consider how to price, or otherwise protect, through a stewardship approach, the water embedded in imported products, where the impact of water scarcity is felt far outside the UK.”

With water we have an even starker market failure than with raw materials. We take water for granted, we take it wherever we need it, and we move it around the world embedded in foodstuffs and other products such as textiles. The changing climate means that scarcity problems will arise in the future, including in the UK. Here, water is not fully priced according to how much is used, and is certainly not priced according to how scarce it is, and how valuable it is to the natural environment. Metering is the fairest way to pay for water and enables tariff structures that, combined with greater understanding of peoples’ behaviours, can both encourage water conservation and ensure that those who struggle to afford water for basic needs can be helped. We also recommend developing pricing mechanisms that encourage more sustainable abstraction. By sending the right signals to abstractors, the delicate balance between water needs for households, industry and the natural environment can be better managed to the benefit of all. We must also consider how to price, or otherwise protect, through a stewardship approach, the water embedded in imported products, where the impact of water scarcity is felt far outside the UK.

We must be clear that adjusting prices and adding economic incentives is just part of the package of measures, regulatory and voluntary, that we need to achieve better resource stewardship. Which is the best mechanism to use in any given circumstance is a topic for much deeper analysis, but with this work we seek to set the agenda for that analysis. A large part of the shift to a more circular economy may need to come from our values and behaviour, which might be independent from, or else reinforced by, an economic motive.

We hope this report has put into perspective some of the current resource debates, and helped to define the circular economy concept. We thank all those who have added their thoughts and comments so far, and invite further commentary and debate.

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Green Alliance
36 Buckingham Palace Road
London SW1W 0RE
T 020 7233 7433
F 020 7233 9033
ga@green-alliance.org.uk
www.green-alliance.org.uk

Registered charity number 1045395
and company limited by guarantee
(England and Wales) registered
number 3037633
