From waste to resource plants:
The need for a paradigm shift in principles and policies

If we are serious about creating a sustainable society, we need to start using the raw materials we already have, over and over again.

Since the industrial revolution in the 18th and 19th century, we have been using natural resources in the belief that they will never run out. This attitude governs our mining for raw materials, how we manage our freshwater, how we use our land, how we source energy, and so on. Today, we see the results: Climate change, depleted resource deposits, and most of the planetary boundaries defined by science already behind us.

Returning to the time before the industrial revolution is not an option. But we should use the technology we have developed to support the transition to a sustainable society. This requires new guiding principles, new regulation and new incentives—and we need to act now.

In a world where we strive to minimise what we have chosen to call waste, which in fact is simply resources that have not been properly sorted yet, we are continually losing resources. A future way to manage resources also need detoxification functions, the kidneys and liver of society, whereas today's waste minimising paradigm works in the opposite direction and pushes toxic substances into the ecosystem.

Circular economy has been recognised by science as a crucial tool to reduce the risk of overshooting planetary boundaries. Such a system is so much more than recycling. It is a complete shift in how we design, use and manage our resources and it requires a detoxification step.

The United Nations Environment Programme describes our current predicament as a triple planetary crisis: Climate, nature, and pollution, all brought on, UNEP reminds us, by "unsustainable production and consumption". Transitioning to a more circular society and building detoxification capacity would be a very effective, and frankly the only, way to answer their call for swift action. UNEP does not mince words about the root cause of the triple crisis: "Our relentless and unlimited extraction of resources from the Earth is having a devastating impact on the natural world, propelling climate change, destroying nature, and raising pollution levels."

In the following material, we have deep dived into several of the linear processes which, at best, serve to "do bad thing less bad" instead of serving our planet and our future generations, and offered alternatives. It shows that if we change direction, implement new principles and new policies we will be able to produce more renewable energy, circulate more resources and detoxify urban flows without risking economic growth.

The following chapters focus on technology that can convert today's wastewater treatment plants into resource plants and the possibility to increase food production on land and in water, while producing energy and nutrients and reducing the risk of eutrophication. We will also see how waste-to-energy plants can provide detoxification, produce resources and reduce landfilling, as well as how carbon dioxide can be used as a resource in producing new materials.

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A new view on waste is needed:
Turning wastewater from a problem into a resource

The primary objective for today's wastewater treatment plants is, simply put, to do bad things less bad. We need a complete shift, elevating the production of resources needed in society as the number one task for these facilities.

As the resource plants of the future, today's wastewater treatment plants can produce clean water for industrial and agricultural use. The amounts of water that growing industries need cannot be provided by traditional freshwater reserves, whose capacity is already stretched. Water scarcity in agriculture also needs to be addressed, particularly in areas where the majority of the world's population lives, and which are increasingly affected by droughts and flooding caused by global warming. The resource plants can also be stable and reliable producers of renewable energy, and there is a huge potential to have them provide key agricultural nutrients like phosphorus and nitrogen.

As Earth's population is expected to keep growing rapidly, and ever more people leave the countryside for our expanding cities, several challenges present themselves. More city dwellers mean higher demand for food, with less farmers to produce it. It also turns up the pressure on the planet even further, as we turn to ever more depleted and poisoned deposits of phosphate rock to supply expanding agriculture.

But we can turn these challenges into nearly unimaginable opportunities. With more people concentrated in megacities, it will be easier to design these cities in ways that enable better flows of goods, food, and waste. We will be able to close some of the most fundamental loops of humanity, letting our bodies turn food into sewage, taking the nutrients from the sewage and returning them to the fields and farms where the next crop grows and the next chicken is reared, and so on in a practically endless cycle.

If we turn today's wastewater treatment plants into tomorrow's resource plants, they will be factories where valuable raw materials are produced from carefully designed waste streams and sent for another spin around the loop. This new role must become the norm. But this is impossible unless we fundamentally change our view on waste.

Old hierarchies intended to minimise the problems traditionally associated with waste have turned into shackles, impeding our transition to the circular society we all realise must come. Many innovative ways to produce the raw materials we need from waste, including some of the really low-hanging fruit such as recycling phosphorus and nitrogen from sewage, are still practically impossible, financially unviable, or simply illegal. Even as farmers clamour for affordable fertiliser, most of the phosphorus flowing through sewers literally under our feet is still discarded.

In less than a century, every phosphate reserve known to man bar one will be gone. There is no way around circulating phosphorus; it is just a matter of when. If we are willing to look at what we call waste with different eyes, we can start today.

Why the world needs circularity

Every year, more than 100 billion tonnes of raw materials are used globally. Since the turn of the millennium, this extraction has increased by 70 percent, and since 1970 it has tripled. Within the next 35 years, it is projected to grow by an additional 60 percent.

At the same time, only 7.2 percent of the global economy is circular, meaning that it consists of materials that have already been used, replacing virgin materials. In 2018, this number was 9.1 percent. Despite a slight increase in recycling, the world has rapidly become less circular since the extraction of virgin materials has increased so much faster.

This development has devastating consequences. According to the UN, the extraction and processing of natural resources account for about 50 percent of climate change, 90 percent of biodiversity loss, and 90 percent of the threat to access to water. As traditional sources for raw materials become increasingly depleted, it takes more and more energy to extract the same amount. Similarly, many other forms of pressure on the planet also increase, such as the use of land and the amount of pollution.

Consequently, the transition to a circular economy is crucial. If the world fails to do this, it will be impossible to fight climate change and several other imminent threats to the planet.

The problem is that today’s outdated view on waste effectively stops the transition to circular models by placing legislative or economic penalties on the use of raw materials produced from sources classified as waste. Changing this harmful paradigm and removing unnecessary obstacles to a circular society would be one of the most important efforts enabling the transition to a sustainable future.

In fact, relatively small changes to our sourcing of raw materials could have a profound impact. The pledges already made under the Paris Agreement are not enough to rein in global warming. But just over doubling the circular share of the global economy from today’s small numbers, in combination with countries delivering on their promises, would limit global warming to well under two degrees Celsius, according to the UN-backed Circularity Gap Reporting Initiative.

The harmful waste hierarchy

Since the 1970s, regulation of waste in most wealthy nations is governed by some form of the so-called waste hierarchy. In the EU, this hierarchy is the foundation for laws, taxes, permits, and practically all policies that concern waste in any way.

The waste hierarchy lays down an order of preference for waste management, where the most favoured option is to prevent that waste is produced at all. This rung on the ladder is followed by the reuse of materials that have served their purpose; recycling of materials; energy recovery; and as the least favoured option, landfill.

The waste hierarchy represents an outdated view on waste. It can be seen as an attempt to mitigate negative consequences of a linear economy. As long as the linear economy has easy access to raw materials and is not forced to bear the full costs of effects like climate impact, the long-term and indirect effects of the extraction of raw materials were not seen as a consequential problem. It has had effect in terms of reducing the visible negative effects of the linear economy, but today serves to block the development of circular systems.

As the access to pure and highly concentrated raw materials decreases, we have resorted to sources of increasingly poor quality: more diluted, more polluted, and more distant. Extracting these raw materials now requires more and more energy, as well as additional resources—water, land, machinery, and input chemicals.

Today, therefore, the problems caused by our increasing extraction of raw materials from poor quality virgin sources—the climate crisis, the threat to biodiversity, the lack of water—have a much greater impact. Hence, the conditions that made the waste hierarchy logical no longer apply.

This development also means that the actual difference in quality and concentration between virgin materials and waste as sources of raw materials is shrinking. In some cases, it no longer exists. For example, the concentration of copper in bottom ash from incineration—a waste—is higher than that in the copper ore in existing mines. Similarly, the ashes from incinerated sewage sludge, also classified as waste, contains higher concentrations of phosphorus than mined phosphate rock. Despite this, the market and legislative conditions for these raw material sources are radically different, all because of the waste hierarchy.

In an increasingly circular economy, raw materials are increasingly produced from sources currently classified as waste. This shows why reducing the amount of waste in general should not be a goal in itself. In fact, in the long run, waste will be our only source of raw materials. The true goal is to minimise the extraction and processing of virgin resources.

The greatest undesirable effect of the waste hierarchy is that the economic incentives and policies of many economies aim to reduce waste rather than the virgin extraction of materials. Hence, the model actively works against the transition to a circular economy.

One of those who have come to realise the harmful effects of the waste hierarchy on the transition to increased circularity is the man who developed it in the 1970s: Dutch lawmaker Ad Lansink. (In fact, the hierarchy is often referred to as *the ladder of Lansink*). Mr. Lansink, who recently turned 90, now discusses changes to his model in order to adapt it to the drastically changed needs of society.

In fact, it has never been beneficial for society to minimise all waste streams—quite the opposite. Several waste flows are created as a consequence of reducing direct emissions harmful to people and the environment. Water treatment is a good example: In order to reduce the amount of sludge waste, wastewater treatment facilities would have to do a worse job of purifying wastewater, which of course no one advocates.

The important thing should be what we do with the resources and pollutants concentrated in the sludge. Instead, regulations and economic mechanisms based on the waste hierarchy incentivises treatment plants to get rid of the sludge. Phosphorus, despite being pinpointed as critical to the EU economy and stability, gets thrown out with it.

To make a circular economy possible, we must replace the waste hierarchy with a new governing principle. If such a principle, focused on resources instead of actual waste, would be the basis of all regulation, taxation and other policies, society can secure a sustainable supply of raw materials over time. It would allow for the raw materials we already have extracted to be used efficiently, over and over again, without posing a threat to our health, our economy, our environment, or our climate.

Feeding the megacities: The case for circular nutrients

In just 30 years, the world's population is expected to increase by 2 billion people. By the next turn of the century, we will have peaked at around 10.4 billion.

This brings enormous challenges for the global capacity to produce enough nutritious food, while not overtaxing the planet's resources and resilience. Agriculture is already responsible for a third of global climate emissions. This is compounded by the accelerating urbanisation. Already more than half the world's population live in cities; by 2050, that number is projected to be around 7 in 10. This leaves significantly fewer people in the countryside to farm the crops and animals feeding the expanding cities.

There are many challenges associated with expanding agricultural capacity at the pace required. One of the most salient is the corresponding demand for fertiliser nutrients, chiefly phosphorus, nitrogen, and potassium. Looking at phosphorus, global sourcing is already deeply problematic, not least from a European point of view.

Phosphorus comes from phosphate rock, which is mined. This practise has a substantial climate impact and several negative effects on the local environment, producing vast amounts of harmful spoils. As we are forced to mine less attractive, more depleted sources, all these adverse effects will continue to worsen.

The discussion about exactly when we will run out of phosphate reserves is not settled, but it is well established that at least two-thirds of the deposits are located in Morocco; a source sure to outlast all others by a significant margin. However, these reserves are contaminated with heavy metals such as cadmium and uranium, known for their harmful effects on humans and nature. According to a study by the Swedish Chemical Agency, one in seven bone fractures in women is linked to cadmium-induced osteoporosis, costing society some 400 million euros annually in Sweden alone in addition to the human suffering.

There is also the issue of supply risk. With production of phosphorus concentrated to a few key nations, disturbances in the supply chain can create ripple effects which cause prices to spike. This vulnerability became evident during the COVID-19 pandemic as global shipping was ruptured. The problem was exacerbated when Russia, a major supplier of fertiliser to the global market, invaded Ukraine.

According to the UN-backed project Our Phosphorus Future, one in seven farmers globally are unable to afford sufficient fertilisers to maintain fertile soils. By 2050, this development will lead to crops dropping by 30 percent in many parts of Africa if nothing changes, bringing food insecurity and possible starvation.

From a European perspective, supply risk is a major challenge. The EU has only one active phosphate mine, Siilinjärvi in central Finland, whose production covers only a fraction of European demand. Subsequently, the bloc is almost entirely dependent on imports. Almost 10 percent of the entire world production of phosphate fertiliser ends up in Europe, according to the European Commission, which notes that “the EU, other than is usually assumed, is not at all self-sufficient in food production due to this phosphate dependency”.

In 2023, 3,350,000 tonnes of phosphate was imported into the EU, in addition to 400,000 tonnes of phosphatic fertiliser. More than 500,000 tonnes came directly from Russia, in spite of the EU’s efforts to slow down the Russian aggression against Ukraine by imposing economic sanctions (agricultural commodities such as fertiliser is exempt from sanctions).

The war has also driven fertiliser prices even higher, leading the Commission to talk about a “global mineral fertiliser crisis, of a severity unseen since the 1970s” and calling for “a concerted effort is needed to address the global fertiliser crunch”. Phosphorus and phosphate rock have long been listed by the EU as critical raw materials, on account of their vast importance in combination with supply risk and the fact that no substitute exists.

These price hikes and fluctuations contribute to economic difficulties for European farmers, more expensive food for European consumers, and ultimately to social unrest and political challenges in Europe. The root cause of this is dependency on other countries, some of them hostile, giving them strategic leverage.

As for nitrogen, the challenges are quite different but no less severe. Our supply of nitrogen in the atmosphere is practically infinite. However, atmospheric nitrogen needs to be fixated in a form which allows plants to absorb it and enjoy its fertilising effect. This is done industrially through a method known as Haber-Bosch, invented over 100 years ago by two German chemists who were awarded the 1918 Nobel Prize for their contribution to humanity. However, this production comes with huge negative consequences, primarily because it requires the burning of fossil gas.

Recent research has shown that nitrogen fertiliser is responsible for emissions equivalent to more than 1 gigaton (1 billion tonnes) of carbon dioxide every year. This makes up 2,1 percent of total global emissions; for reference, more than air travel. Almost half of this enormous impact comes from Haber-Bosch production alone. In summary, keeping agriculture supplied with nitrogen fertiliser today undermines all efforts to fight climate change and helps maintain a problematic dependence on fossil gas, a lot of which traditionally is imported to Europe from Russia.

At the same time, one of the most important tasks of wastewater treatment plants is to remove nitrogen from sewage to keep it from causing eutrophication. However, this task is carried out using bacterial treatment, a method which leads to the nitrogen being released back into the atmosphere. This means that we miss the chance of harvesting the valuable nutrient when we have amassed it in treatment plants, just to capture it from the air again to produce new fertiliser using an extremely emission-intensive method.

The price of fossil gas has also risen considerably following the Russian invasion of Ukraine. This is reflected in the price of nitrogen fertiliser and significantly exacerbates the pressure on agriculture. “Farmers have been paying a ‘gas price penalty’ on fertilisers, and bad news is that seems set to continue into 2024”, Tom Lancaster, a land analyst with the UK’s Energy and Climate Intelligence Unit (ECIU) said in February of 2024. The ECIU estimates that British farmers have spent more than 2.5 times more on fertiliser since the invasion than they would have given normal cost development. As a result, many European countries have seen farmer protests and other unrest connected to higher food prices.

The need to improve nitrogen management is urgent. According to a horrific report from the World Bank, poor water quality associated with nitrogen overload severely affects the growth and brain development in children in many countries. In heavily afflicted areas of Africa, GDP growth is reduced by as much as one-third, the study shows. In one of the most developed countries in the world, the Netherlands, construction output recently took a multi-billion-euro hit when nitrogen levels were found to breach EU regulations, stopping many projects in their tracks.

The bacteria-based nitrogen removal methods common today are also connected to emissions of nitrous oxide, or laughing gas. Nitrous oxide is an extremely potent greenhouse gas whose impact on global warming is more than 250 times that of carbon dioxide. This adds to the urgency in looking for alternative solutions which can both capture the nitrogen for recirculation as commercial fertiliser and do away with laughing gas emissions.

Circulating key nutrients like phosphorus and nitrogen would reduce dependency, stabilise prices and significantly reduce Europe’s climate and environmental impact.

From wastewater treatment plants to resource plants

With a fundamentally changed view on waste, where our need to secure raw materials in a sustainable way is the core principle, entirely new dimensions open up around wastewater treatment plants.

Treating wastewater is key to any sustainable society. However, many countries are far off the mark: Around 80 percent of wastewater globally is released back into nature without treatment. This is a major challenge, connected to several environmental and health problems.

Among the planetary boundaries defined by scientists, nutrient overload is the one where we are already the deepest into red territory, meaning a very high risk of irreversible damage to the planet. Same thing when they take into account how human lives are affected: Ill-advised use and production of phosphorus and nitrogen cause more grief today than climate change or diminishing access to water. Some 3 million tonnes of phosphorus is discharged in wastewater into the environment every year. Still, proper treatment could reduce the concentration of phosphorus and nitrogen in this wastewater by 80 percent or more.

Even if the problems are more severe in lower-income countries, there is no question that wastewater treatment in Europe needs to develop in order to protect the environment. But a far more interesting development would be to completely transform the role of every wastewater treatment plant, turning them into factories producing marketable raw materials which can replace the same commodities from traditional production.

Many of the substances which treatment plants remove from municipal and industrial wastewater are actually desirable in various ways. Phosphorus is an obvious example: It needs to be stopped from reaching surrounding waterways and causing eutrophication, but it is also traded at high prices in the global market.

Modern technology is now available to recover phosphorus from treatment plant systems. For example, the Ash2Phos method, developed by Swedish-founded environmental company Ragn-Sells’s innovation subsidiary EasyMining, recovers more than 90 percent of the phosphorus from the ashes of incinerated sewage sludge. At the same time, other market-grade commodities such as iron and aluminium are produced, while heavy metals such as cadmium present in the sludge are separated out for safe disposal. Research into using the silica sand byproducts as a substitute for cement is ongoing.

Ragn-Sells has secured all environmental permits for the construction of its first Ash2Phos plant in Helsingborg, Sweden, and are in the final stages of the permit process for a plant in Schkopau, Germany. The phosphorus output from the Helsingborg facility alone will generate savings of 20,000 tonnes of carbon dioxide annually when it replaces traditionally produced fertiliser. The phosphorus product is cleaner and of higher quality than comparable goods from phosphate mined outside the EU.

There are several techniques being tested, but incinerating sewage sludge has several advantages: most notably detoxification of the nutrient loops. When sludge is actually put to use as fertiliser today, it is generally disseminated straight onto the fields. However, the majority of the sludge produced in Europe is not of sufficient quality for direct distribution, generally due to contaminating substances. Incineration destroys organic pollutants and concentrates other potentially harmful substances, enabling their separation. This way, even the vast amounts of low-quality sludge can yield its valuable raw materials back into circulation, while unwanted substances can be phased out.

Ragn-Sells and EasyMining also offer a solution for harvesting nitrogen at the treatment facility. Unlike today's bacteriological methods for nitrogen removal, the Aqua2™N technology uses chemistry to capture the nitrogen in a form which can be used in fertiliser production. This circular approach does away with the harmful and backward practise of releasing nitrogen which has already been fixated using climate-intensive methods and having to catch it from the atmosphere again to make new fertiliser. It also removes the problem of bacteria-based methods causing large emissions of nitrous oxide. The process is based on commonly available chemicals, which are then collected at the end of the production and used again.

If all nitrogen fertiliser in the world were produced in this manner, it would mean reducing global climate emissions by almost one-half gigaton of carbon dioxide equivalents every year.
In recent scientific studies presented in both India and Switzerland, the nitrous oxide emissions from current wastewater treatment plants are shown to be very high. If updated technology is not implemented, the laughing gas emissions from wastewater will in end up surpassing those from agriculture. The Aqua2™N technology removes ammonia in the reject water phase, which eliminates the risk of nitrous oxide emissions. Taking out the ammonia will also enable significantly more efficient biogas production from the sludge and enable up to 30 percent of the nitrogen to be converted into nitrogen fertiliser.

For the EU, turning wastewater treatment plants into resource plants in this manner would represent a seismic change. For the first time, Europe would have reliable, large-scale domestic production of clean, safe, high-quality phosphorus to fertilise its fields and a stable production of renewable energy. Correctly handled, this would effectively mean the creation of a circular mine that never runs out, and which does not harm climate, the environment, or local communities the way traditional phosphate mining or Haber-Bosch production of nitrogen fertiliser does.

This would go a long way towards building a more resilient, stable, and sustainable Europe. Domestic production of phosphorus would contribute to breaking the strategic stranglehold that nations outside the EU currently have due to European dependency on importing a commodity it cannot do without. It would lead to a stability in fertiliser pricing which would ease the pressure on farmers and help mitigate the effect on food prices from the next inevitable supply shock, regardless of the reason behind it. On an even higher level, it would help establish food security and social stability by ensuring European agricultural production in times of turmoil. At the same time, it would assist in reaching crucial climate emission reduction targets.

According to the European Environment Agency, up to 6 percent of the European agricultural consumption of phosphorus could potentially be recovered from EU treatment plant sewage sludge. This is a conservative estimate: EasyMining calculates a potential of up to a quarter of total demand.

This transformation is possible. However, there is a number of critical obstacles that need to be removed through policy, legislation and regulation. All of them stem in some way from an outdated view on waste.

The most obvious example is EU legislation that prohibits the use of recycled phosphorus in several branches of agriculture. The ban on phosphorus fertiliser in organic farming within the bloc may possibly be slated for reform, as the permanent expert group for technical advice on organic production (EGTOP) has recently recommended that it be lifted. However, using phosphorus produced from wastewater as feed phosphate is still illegal, despite high demand, high prices, and the stated ambitions of the EU to transition to a more circular economy. The calcium phosphate produced through the Ash2Phos process has been subjected to trials by the Swedish University of Agricultural Services (SLU), and found to yield excellent uptake results in pigs and poultry.

In short, the EU has outdated laws on the books which stand in the way of its own strategies for circularity, raw material sourcing, and resilience. As a result, contracts for the production of recycled phosphorus are agreed with partners in other nations, such as Canada, which allow high-quality phosphorus from waste to be used as feed in animal farming. This is a very illustrative example of how the fruits of European green-tech development benefit other countries due to unnecessary market impediments in the domestic markets.

In order for the transformation from mere wastewater treatment plants of today to the resource plants of tomorrow to be successful, several actions are needed.

- Governments need to explicitly redefine the assignments given to treatment plants—most large-scale facilities are owned by the public—ordering them to produce raw materials, including treated water.
- Legislation prohibiting the use of recycled raw materials have to be revised. This is also the view of the European Environment Agency (EEA), which has repeatedly called for such measures with the stated purpose of turning treatment plants into resource production centres.
- Market conditions in general have to be adjusted to compensate for the disadvantages imposed on recycled materials competing with virgin production. Again, this action is suggested by the EEA.
- All regulation concerning placing raw materials on the market must be based on the quality of the product and not, as it is today, on their origin. It is unreasonable to allow lower-grade products while banning or imposing hindrances of higher-grade competitors simply because the latter are produced from sources classified as waste.
- Strict quality demands should be placed on fertilizer nutrients. Low bars favour cheaper but more harmful virgin alternatives with which recycled phosphorus cannot compete.
- Governments need to introduce ambitious upstream measures to ensure sufficient quality of the inflowing wastewater, as pollutants contaminating what is essentially the source of raw material production at the plant is a major threat to its updated role.

- Targets for the use of recycled raw materials should be considered. For example, the Our Phosphorus Future project, with UN support, proposes a target of 20 percent recycled phosphorus in fertilizer by 2030.

Several reports and studies have demonstrated the potential in converting wastewater treatment plants to resource plants. Here are a few examples.

United Nations Environment Programme, UNEP (2023) - Wastewater and nutrient management for #ClimateAction

European Environment Agency, EEA (2022): Beyond water quality: Sewage treatment in a circular economy

World bank (2018): Wastewater? From Waste to Resource

Waste-to-energy facilities and other sources of circular raw materials

In a more circular society, waste-to-energy facilities, much like wastewater treatment plants, can act as resource hubs, producing large quantities of valuable raw materials while detoxifying the flows of society.

Incinerating waste to produce energy is a very old practise, originally conceived to get rid of unwanted or useless materials in a way that contributes something. This view also led Dr. Lansink to place energy recovery near the very bottom of his ladder, or waste hierarchy, when it was introduced in the 1970s. According to this model, striving to avoid incineration should lead to more valuable raw materials being recycled higher up on the ladder.

Unfortunately, we know today that this does not hold. The world economy is a lot less circular after being run according to the waste hierarchy for 50 years. The model also leads to fundamental misconceptions about the role of waste-to-energy plants in the modern world.

In a circular society, waste can simply be regarded as a jumble of raw materials, not ready for use as they have not been sorted and prepared yet. Products are designed for maximum potential recovery of their raw materials at the end of their life span. Today, however, this is still exceedingly rare. Hence, it is often extremely difficult and costly to fully recycle materials from disused products.

Most of the time, products are made from different materials which are impossible to separate. Toxic or otherwise harmful substances are also commonly used, leading to the need for special treatment of the waste in order to remove these substances from circulation. This is where incineration comes in.

In contrast to simply being a method for getting rid of things society does not want, incineration is a treatment step. It concentrates valuable raw materials in the ashes and allows us to successfully extract them in a way which is not economically or technically feasible with the original waste stream. Concentration also enables us to separate out harmful substances for safe handling and disposal. This dual purpose—making raw materials available for safe circulation back into the market and removing toxins from society, completely redefines the role of waste-to-energy plants and defies their misinformed place in the waste hierarchy as something which should be avoided at all costs.

For example, Swedish environmental company Ragn-Sells opened the world's first recycling facility for fly ash in 2023. Inaugurated by the country's minister for the environment, the plant has the capacity to treat 150,000 tonnes of fly ash each year, recovering commercial salts from the ash. As fly ash is formed when flue gasses from waste incineration is cleaned and filtered in the chimney, it is a good example of a waste which derives from efforts to keep the environment free from pollution; full of desirable raw materials as well as harmful substances in a concentrated form. When the salts reach the market, they come with a 90 percent reduction in climate footprint compared to the same products from traditional industry.

Still, this technological breakthrough has not come without challenges. Most notably, the potassium chloride produced at the plant is banned from use as fertiliser within the EU. Despite its high quality and purity, the facts that it is sourced from a hazardous waste stops European farmers from using it on their arable land, allowing instead the Belarusian dictator Aleksandr Lukashenko to maintain his lucrative export of mined potassium. Again, the outdated view on waste which governs legislation stands in the way of increased circularity and European independence.

Similarly, the ash residues forming at the bottom of the incinerator also contain large amounts of valuable raw materials and toxins calling for removal from society. Some of these are recovered, but in many cases, regulations and tax codes designed to implement the waste hierarchy lead to materials like copper being left behind and the ash used as cheap construction material.

Naturally, it is important to limit the climate impact of using waste to create energy, although it can be argued that this impact arises at the moment the product is designed in a way that renders material recycling impossible and not at incineration. All modern incinerators today are looking at various forms of carbon capture to minimise the amount of carbon dioxide and other greenhouse gasses that reach the atmosphere. Global cleantech company Hitachi Zosen INOVA, for example, has adapted a "waste-to-X" vision that encompasses carbon capture, increased resource production such as metal, aggregate, and salt recovery, and baseload energy production from materials which still go to landfill in most of the world; a practise which we know leads to the release of greenhouse gasses as well as a waste of resources. This means that the HZI facilities can deliver raw materials while detoxifying society, performing the kidney or liver role, through better utilisation of the potential of waste streams.

However, EU regulation and incentives need to be broadened to enable large-scale use of captured carbon dioxide instead of storage under the ocean floor being the only viable alternative. For example, Ragn-Sells, together with scientists from Tallinn

University of Technology (TalTech) and the University of Tartu in Estonia, have developed a method for using oil shale ash combined with carbon dioxide to create a calcium compound (PCC) commonly used in flooring and other industrial applications.

After decades of getting energy from burning oil shale, a rock with a high content of hydrocarbons, Estonia has enormous deposits of this ash. Using it as a raw material effectively means working off an environmental debt, while putting captured carbon dioxide to use means that the PCC has a negative climate footprint, binding carbon. Traditionally, PCC is produced by mining and burning limestone, a process with extreme climate impact.

In addition to the PCC, the ash can also yield an array of other valuable elements, such as magnesium, aluminium, iron, zinc, and materials with a high silicate content. In the case of magnesium, full-scale success could make Europe self-sufficient in this strategic raw material.

The project has had early, smaller-scale commercial success and attracted the interest of international industry, but scaling up is slowed by the difficulty in sourcing captured carbon dioxide due to EU systems being aimed squarely at burying it.

Another example of a global industry with huge untapped potential for turning waste into resources, but which also suffers from hampering and outdated legislation, is aquaculture. Fish farming is one of the keys to providing an expanding global population with high-quality protein, provided that it is done sustainably. Until now, however, the waste streams associated with aquaculture have been a challenge rather than an opportunity.

Generally, sludge formed primarily from fish faeces and feed residue, sinks continually through the net pens and washes out into the surrounding ocean. This can lead to eutrophication and has led many nations to impose strict limits on the number of fish raised in a given coastal area. But regarding the sludge from a resource perspective yields the opportunity to capture its valuable compounds as well as energy contents and go from a problem slowing down expansion to an opportunity for replacing virgin extraction of resources.

In the Havbruk project currently operated in Norway, the sludge is collected by a cap at the bottom of the netting instead of washing through it. The sludge is transported to shore and used to produce energy-rich biogas by anaerobic digestion, a process commonly used for biological waste from businesses and households. After incineration, more than 90 percent of the phosphorus in the sludge ashes can then be extracted using the technology around which Ragn-Sells is planning its phosphorus recycling plants in Sweden and Germany.

According to a report by international consulting firm PwC, the sludge potentially collected from Norwegian fish farms alone could produce biogas containing 300 million cubic meters of methane each year. The energy value is approximately 3 TWh, equivalent to the electricity use of 600,000 households. The report also shows that 11,000 tonnes of phosphorus could be extracted from the sludge, more than the annual consumption of many EU member states. Adding a step for also capturing the nitrogen in the sludge is in the works.

Bearing in mind that Norway is only the world’s 11th largest aquaculture nation, far behind giants like China, Indonesia, and India, the potential for harvesting energy and fertilizer nutrients while protecting coastal environment is very large. However, the impediments raised by outdated legislation remain. Chief among these is the ban on using recycled phosphorus in animal feed—in a circular system, the phosphorus taken from the sludge could be used as feed for the fish—but other obstacles, such as regulation governing the cross-border transport of matter classified as waste, also make it difficult to sufficiently scale up the project.

According to the Food and Agriculture Organization of the United Nations, global food production from aquaculture should triple. This, however, must be done while protecting the increasingly threatened coastal areas and contribute to the overall minimising of total resource use. It is vital, therefore, that the systems employed to expand fish farming are designed to prevent eutrophication, harvest the potential energy of the sites and circulate key nutrients.

Conclusion

With the waste hierarchy still in place, representing an outdated view on waste from the linear economy, transitioning to the circular society will be impossible or exceedingly slow. In the meantime, we risk losing the race against climate change and resource depletion.

Imposing a new view on waste, and letting it saturate all policies, legislation, regulation and incentive structures, is inevitable in order to transition quickly enough to a sustainable future. This paradigm shift not only tackles the most pressing problems facing nations, but offers great opportunities for prosperity, development, and security.

Waste as a resource: Necessary policy changes

The way the EU considers waste needs to be redefined through a broader revision of the Waste Framework Directive, as well as by the introduction of a new resource legislation which is based on the assumption that waste is a resource, and urban flows are considered society's new mines. This change would lay the foundation for a new concept: Resource plants, a completely redefined role for today's waste-to-energy plants and wastewater treatment plants. Today's detoxifiers will be tomorrow's producers of raw materials and energy, while still working to take harmful substances out of circulation.

Nutrients from Wastewater

The waste hierarchy drives businesses to a waste logic. For the resource plant concept to be a reality, the EU needs to move from this waste logic to a resource logic. The Commission needs to remove all references to the waste hierarchy and apply resource logic in its development and revision of EU legislation.

This is crucial in the Commission's upcoming implementing act to **the Urban Wastewater Treatment Directive**, focusing on minimum reuse and recycling rates for phosphorus and nitrogen. The Commission should consider to

- **Set** a recovery rate of at least 80 percent for phosphorus from ash, **and** at least 15 percent for nitrogen before the incineration process.
- **Promote** clean recovery technology that does not lead to the accumulation of pollutants in soils, and **set** scientific-based levels for what is allowed.
- **Ensure** that recovered materials are marketable.

Critical Raw Materials

The same goes for the upcoming revision of **the Critical Raw Materials Act**. The Act's focus on recycling is positive, but it does not sufficiently problematise how linear material flows should be replaced by circular flows. In its revision of the Act, the Commission should consider the following two points:

- **An extended focus on recycling of raw materials.** Many of the critical and strategic raw materials in the Commission's proposal exist in our waste. Today's outdated view of waste does, however, prevent the extraction of critical raw materials from the waste and thereby securing Europe's self-sufficiency. Only with a new approach to waste, where it is fully treated as a source of sustainable raw materials, can we tackle both problems at the same time. Europe and the rest of the world have to close the cycles of critical raw materials needed for the green and digital transitions, as well as the agri-food sectors.

- **Look beyond technology.** The scope of the current Act, focusing on technologies important for the green and digital transitions needed to produce modern batteries, is limited. The exclusion of other sectors, such as the EU's food sector and materials such as phosphorus, is a missed opportunity to strengthen the EU's independence and resilience. Phosphorus is today listed as a critical, but not strategic, raw material for the food value chain, meaning it is not covered by the fast-track permitting process or any other benefits that come with being listed as a strategic material. Adding phosphorus to the list of strategic raw materials could help facilitate the Union's production and supply of this key nutrient.

Recovered Phosphorus in Feed Phosphate

Animal feed and feed additives have an important role to play and have great potential to be part of the transition to a circular economy. However, according to the **EU's feed regulation (Regulation (EC) 767/2009 – the Feed Legislation)**, restrictions are placed on the use of recovered nutrients from wastes "obtained from the various phases of the urban, domestic and industrial wastewater" and "solid urban waste" in animal feed (**Annex III, Chapter 1, point 5 1 and 6, page 19**).

It is important that the EU has strong safety requirements to prevent risks of pathogens and contaminations in animal feed and feed additives. However, today´s legislation is not open for feed additives/feed raw materials derived from manure, from municipal or industrial wastewater, even after incineration at high temperatures, intensive chemical processing, and purification, which can guarantee safety. Irrespective of quality and safety, such nutrients are currently excluded from use in feed according to Regulation 767/2009, which constitutes an unnecessary obstacle to the nutrient circular economy. **The Feed Legislation, therefore, needs to be revised, to take the quality of materials rather than their origin into consideration.**

Recovered Phosphorus in Organic Farming

Recovered phosphorus from incinerated sewage sludge is approved in the legislation covering conventional farming, but not **included in the list of authorised fertilisers, soil conditioners and nutrients (Annex II of the Organic Farming Regulation's (EU 2021/1165))**.

The EU's Expert Group for Technical Advice on Organic Framing (EGTOP) has recently recommended the Commission to authorize the use of Ragn-Sells and EasyMining's calcium phosphate from sewage sludge ash in EU Organic Farming. This is a step in the right direction that will support the ambition to increase food production within the EU and the world. **Due to the high potential of Ragn-Sells technology, it is important for the EU that the Commission swiftly propose an amendment to the Organic Framing Regulation (Annex II), to have the Ash2Phos calcium phosphate added to the list of approved materials in Regulation 889/2008 on organic production and labelling of organic products with regards to organic production, labelling and control (Annex I).**

Carbon dioxide as an important raw material

With the right legal conditions, Europe has great potential to extract key raw materials, such as silica, aluminum and magnesium—all classified as strategic raw materials in the Critical Raw Materials Act—from waste. As mentioned, new technology using stockpiled oil-shale ashes and carbon dioxide (CO2) as input exists in Estonia and could make the EU self-sufficient in magnesium. A guaranteed supply of carbon dioxide is, however, required for the partners behind the project to be able to invest. **Today, existing legislation, as well as the lack of common carbon management**

rules and standards, hinder the develop circular innovations using carbon dioxide as a raw material.

The EU needs to start considering carbon dioxide as a resource, not waste. Below are listed three main challenges, which are partly identified by the Commission in its **Industrial Carbon Management Strategy**, and solutions for the development of technology putting oil shale ash to new use.

1. **Undeveloped carbon dioxide transportation infrastructure**. The lack of a sufficient carbon dioxide transport network in Europe prevents a functioning single market for carbon dioxide. **The Commission should put forward a legislative package that ensures an open, non-discriminatory multimodal cross-border CO2 transport and storage network.**

2. **The origin of carbon dioxide.** The EU supports carbon capture and storage and has shown increased interest in understanding the potential of carbon capture and usage (CCU), as well as expressing the need for these technologies. Due to the Commission's strong commitment to reducing fossil fuel activities in the EU, the use of captured fossil carbon dioxide is, however, often met with scepticism. Efforts to move away from fossil fuels are necessary, but in this case, the reluctance to support the use of fossil carbon dioxide impedes innovations that could reduce the amount of carbon dioxide released into the atmosphere. One way to deal with this challenge would be to initially allow the use of all types of CO2 for use in CCU projects, and plan for the gradual phasing out of the fossil sources. Such a transition period is necessary to create the incentives for investment in, and the development of, CCU technologies.

3. **The definition of carbon storage**. Uncertainty around the future labelling of carbon removals affects the business case for CCU projects. The mentioned Estonian technology of storing carbon dioxide in PCC carbonate could be considered a permanent storage method (provided the continuous use and recycling of the product can be proved) since the carbon dioxide is chemically bound in the PCC (for the carbon dioxide to be released, acid treatment or incinerate is required). **With the implementation of proper monitoring rules and frameworks, carbon dioxide stored in products, such as PCC, should be considered as permanently stored.**

Below are three scenarios which would facilitate the development of CCU projects.

1. The Commission puts forward a legislative package that ensures an open, non-discriminatory multimodal cross-border carbon dioxide transport and storage network. During a transition period, all types of carbon dioxide are allowed to be used in CCU projects. Storage of fossil and biogenic carbon dioxide in products is considered permanent, as long as the producer can guarantee the storage, for example by the use of a circular certification system/framework.

2. If storage of carbon dioxide in products such as floorings or paint is not considered a permanent way of storing carbon dioxide, a certification framework for temporarily stored carbon dioxide should also, during a transition period, allow the storage of fossil carbon dioxide.
3. If fossil carbon dioxide usage is not allowed by a permanent or temporary certification framework, even higher demands are placed on the fast establishment of a functioning transport network for biogenic carbon dioxide.