Wood v Oil: The End-Game For Fossil-Based Plastics ?

Blog Posted [September 28, 2018] Chris Rose

http://threeworlds.campaignstrategy.org/?p=2150

A burgeoning new industry, 'Ligno-Cellulosics', has the potential to be for plastics made from oil, what renewable-energy technologies have been to fossil fuels in the field of climate change. But that potential may yet get diverted or co-opted. And are campaigners and regulators paying attention?

Metsa's new Biorefinery in Finland

https://biorrefineria.blogspot.com/2017/08/metsa-next-generation-bioproduct-mill-becomes-operational-in-Finland-forest-biorefinery.html

Earlier this year I did some campaign research on plastic microfibres from textiles for Friends of the Earth in the UK. FoE have now started running a campaign about microfibres and clothing (here). What surprised me, aside from the massive potential health threat posed by microplastic fibres on land, was to discover the rapid advancement of a potential 'category killer' for oil, gas or coal-based plastic, in the shape of 'ligno-cellulosics'.

Change The Feedstock – Change The Game

In essence, this technology can replace oil, coal or gas as a chemical feedstock for plastics, with trees, grass, agri-wastes or other sources of cellulose or lignin (which can include algae, and bacteria). From a substitution point of view, cellulose ought to be environmentally benign, a bit like a leaf. After all it is the worlds commonest 'bio-polymer' and is made up of tens to thousands of units of glucose. And cellulose 'polysaccharides' (chains of sugars) and lignin (the tougher bits of plants such as bark), rot naturally, and the carbon they contain is 'neutral', being recycled by living plants, rather than transferred into the atmosphere, oceans and biosphere from stored carbon in 'fossil fuels', as happens in all conventional 'plastic'.

In my view, campaign groups and policy-makers should get to grips with this topic because it could provide the 'renewables moment' for oil-based plastics, in the same way that solar, wind and other renewable technologies did for fossil fuels over climate change (and about 8% of oil is used in making plastic).

I Declare An Interest

It's not a financial interest but being a bit of a geek I have to admit to having had some pre-existing interest in 'cellulosics' before I embarked on looking at strategies to eliminate 'oil-based' plastic. This is because they could help nature conservation. Cellulosics have long been talked about, if only in rather small circles, as 'second generation' biofuels. These create burnable liquid replacements for petrol or diesel but unlike 'first generation' biofuels which rely on oils or sugars from the seeds or fruits of food crops like maize or rape, these use non-food parts of plants. So they do not compete for land which could be growing food.

Instead they can use wood or the stringy bits of plants that are inedible to humans and which farmers and the food industry treat as waste. Consequently they can also avoid a lot of energy and chemical inputs associated with crops grown for biofuels, such as artificial fertilizers, which have their own ecological and health impacts.

By the same token they can help reduce nitrogen pollution, which causes 'eutrophication' or excessive fertility. This is a huge environmental problem in freshwaters, coastal seas ('dead zones' and algal blooms), and, as it rains back to earth in acid rain or falls out as 'dry deposition' from farm ammonia emissions and fossil fuel burning, it damages nature reserves and forests. Over-fertilization reduces the variety of life. It feeds rank growth of a few fast-responding nitrogen loving plants, leading to them out-compete most wildflowers, so robbing insects and other wildlife of their habitats. Because it's expensive and difficult to remove vegetation as 'waste' with nowhere to go, roadside verges are left to accumulate a mulch of dead plants, and sensitive environments like heaths, fens and moors gradually turn into bland expanses of low-diversity grasses. So, I thought, if this 'waste' had a value that could be realized by land-managers, maybe it would be a way to mitigate this problem.

But for many years the processes necessary to extract cellulose and lignin were difficult, sometimes toxic, and expensive. Now many of those problems seem to have been solved. New solvents and processes which include pressure, spinning, freezing, ultrasound, exposure to sulphuric acid and micro-grinding can extract cellulose 'fibrils' at nano scale, and then reunite them into new substances or 'bio-materials'. These have varying degrees of crystallinity, making them soft and flexible (long fibres), or as hard as steel (short crystals).

Not On The Radar ?

Back in spring when I asked around among NGOs working on plastic pollution, and among scientists looking at the environmental and health impacts of plastic, and even, when I could get hold of them, among UK government regulators, I was surprised that they seemed to know little if anything about 'cellulosics' (the exception perhaps being WWF).

In a way this is understandable. Many were running to catch up with the explosion of public concern over plastic, and most were focussed on marine impacts and only beginning to wrestle with the fact that 70% of plastic pollution is in fact on land. Plus few have much contact with the worlds of materials science and technology where 'cellulosics' is a booming area of R & D. This ought to change, just as climate campaigners had to engage with renewable energy.

On top of this, as previous blogs explored, the established framing of 'plastic problem' was one of waste in which the 'answer' was more 'recycling' of plastic, and if not that, reduction (less plastic) rather than substitution of feedstocks. Most NGO campaigns have so far focused on seeking an end to Single Use Plastic, and even the EU's draft 'Circular Economy' strategy on plastics released earlier this year, still promotes plastic recycling and makes little mention of substitution strategies. Which is strange as the EU has been a major funder of R & D in the cellulosics area.

'Anything You Can Make From Oil We Can Make From Trees'

The most accessible introduction to the potential of 'ligno-cellulosics' is a great little BBC radio programme presented by Tom Heap, called 'Superwood' (an episode of Costing the Earth), which is available online. Heap traveled to Finland, where at Äänekoski, the world's biggest 'Biorefinery' has been built by pulp mill specialist Metsa, and uses trees to produce an array of lignin and cellulose-based feedstocks. These in turn can be used to produce yarn for textiles and substitutes for a wide variety of plastics, even transparent screens as used in computers and phones.

That Nordic governments and companies see this as a strategic opportunity is perhaps evidenced by the fact that the two main 'PR men' for this and other 'Biorefineries' seemed to be former Swedish Prime Minister Göran Persson, and Finland's former Prime Minister Esko Aho. They didn't exactly beat about the bush. "Everything you can produce based upon oil, you can also produce based upon wood: wood is renewable, and oil is a disaster", Persson told Heap. He saw a new bio-economy: "a new era emerging". Aho declared: "I think we can save the world, we know that our way of life is not sustainable".

Blessed with a ready supply of lots of trees from forests which are by international standards well-managed (the supply for the new £1bn Biorefinery comes from forests with PEFC or FSC certification), the Nordics presumably sense a major opportunity and even their corporations are playing wood against oil. Stora Enso, another major player, says 'We believe that everything that is made from fossil-based materials today can be made from a tree tomorrow'.

The scale of investment and speed of development is remarkable. Metsä's mill at Äänekoski in Finland was constructed in just a few years and produced its first million tonnes of pulp in August this year. It is due to make 1.3mt a year, after starting up a year ago. This Bioproduct Mill is said to be the largest in the Northern Hemisphere, is zero carbon (producing twice the electricity it requires) and very clean.

Not Just The Nordics

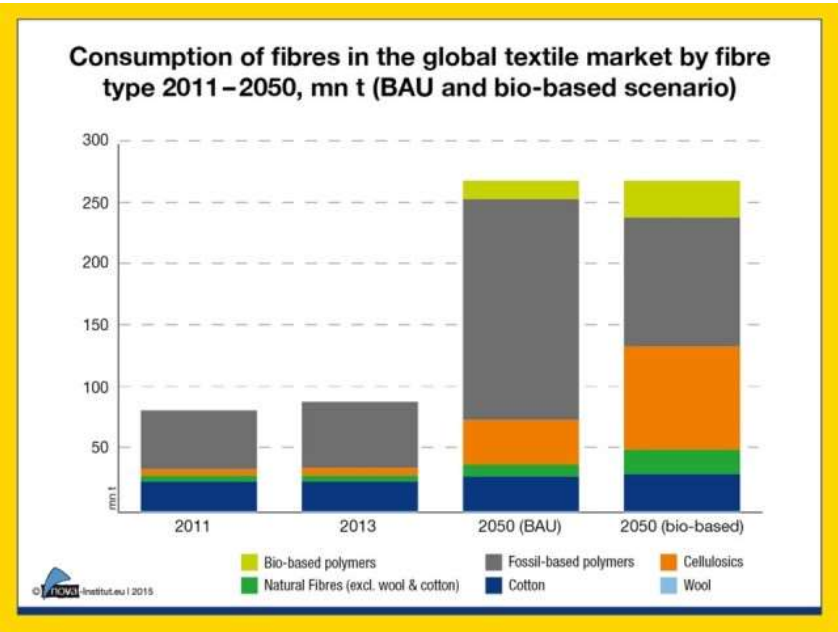
According to a recent study by Dublin-based scientists Shady Hassan, Gwilym Williams and Amit Jaiswal, there are already over 40 lignocellulosic biorefineries operating in Europe (along with 181 'first generation' biorefineries using sugars, starches and oils). They produce biofuel, electricity, heat, bio-based chemicals, and biomaterials (such as substitute feedstocks for plastics) from non-food crops or plant waste, including wood and grasses. The EU 'Horizon 2020' R+D programme is putting 80bn Euros into consolidation of lignocellulosic biorefineries and covers projects in at least eight countries. Hassan et al state that the EU aims to 'replace 30% of oil-based chemicals with bio-based chemicals and supplant non-degradable materials with degradable materials', and for 25% of transportation energy to come from second generation biorefineries by 2030. One forecast anticipates another 15 biorefineries to be running by 2024. A blog on Biorefineries around the world, created by engineer Daniel Morán Rodríguez of Universidad de Santiago de Compostela can be found here .

The 2018 *Handbook of Nanomaterials for Industrial Applications* [1] reported a wide variety of patent applications on nanocellulose including composite materials (38%), nonwoven absorbent webs (18%), paper and boards (16%), food products (13%), paper and board coatings (8%), cosmetics and toiletries (3%), and filter materials (4%) It found about 10 companies 'positioned to produce CNF [Cellulose Nano Fibres] at commercial/ precommercial scale, including Paperlogic, Forest Products Laboratory (FPL) (cooperating with the University of Maine), American Process (USA), Borregaard (Norway), Innventia (Sweden), Nippon Paper, Oji Paper (both Japan), CTP/FCBA (France), Holmen Paper (Sweden)' and that 'Celluforce is the world's largest CNC plant, capable of producing 300 tonnes per year' of CelluForce NCCt in Canada. It was built in 2011 and is in Quebec, Canada.

The EU's focus on biorefineries seems to be mainly driven by the initial impetus to get fossil fuels out of transport (and perhaps the disastrous introduction of palm oil from first generation biofuels into EU diesel). In the Netherlands, interest in cellulosics is motivated by a need to find economically attractive ways to deal with agri-waste problems and get more value out of grass. (Existing feedstocks for biorefineries include waste cotton cloth, tomato peel, rice husk, old corrugated containers, old newspapers, hibiscus leaf, soy hulls, garlic straw and oil palm biomass) [2].

Annita Westenbroek, director of the Dutch Biorefinery Cluster makes the case for cellulosics from grass and agri-waste to make farming more economically and environmentally sustainable. Grass bioferinery systems are being promoted in the Netherlands as a contribution to reducing protein and mineral inputs to cattle, and as a way to reduce ammonia pollution.

Westenbroek argues that 'the Netherlands can easily produce enough biomass to feed the entire chemical sector. But not to feed the entire energy sector'. Cellulose she says is too valuable to burn as it can be used to make chemical feed-stocks for materials. But subsidies for EU biofuels have been 'inverting the value pyramid'. Other European biorefinery R+D projects focus on seaweeds.

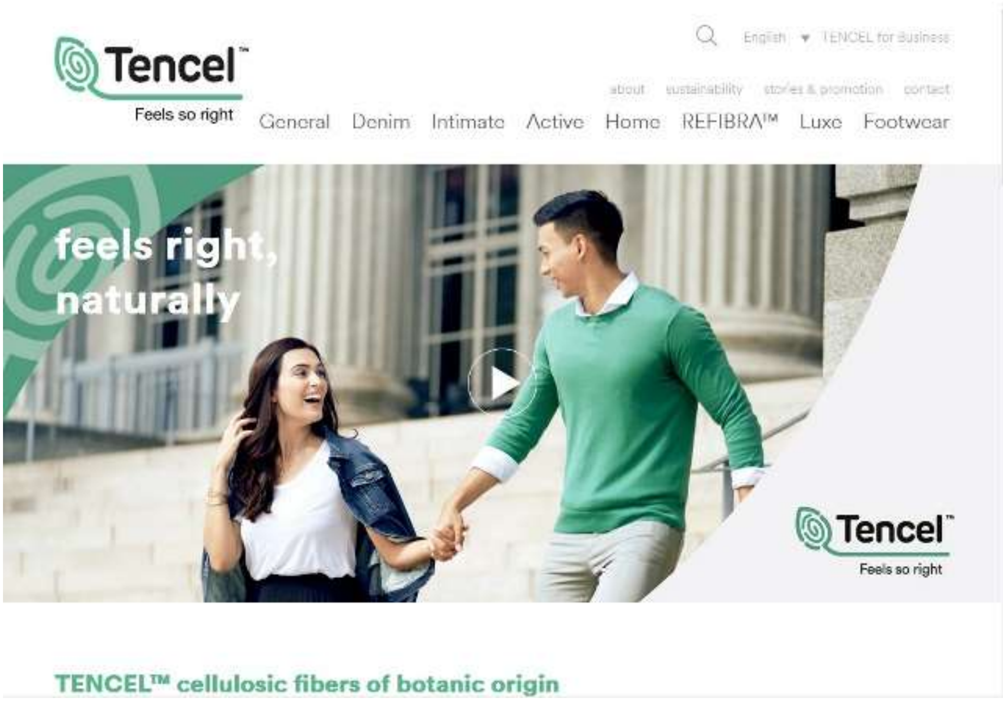


Michael Karus slide showing cellulosics potential (textiles)

Michael Karus, Director of nova-Institut GmbH presented a 'biobased' scenario for growth in textile fibres at a conference involving WWF in Berlin this May, showing potential for a very large incursion by cellulosics at the expense of fossil fuels. He has also criticized the EU's 'plastics strategy' for failing to include bio-degradable 'plastics' (not all of which are cellulosics).

So Just What Are Cellulosics ?

Actual experts will have to forgive me if I've got any of this wrong but 'cellulosic fibres' are found in woody plant material, embedded in lignin and hemicellulose. Cellulose and lignin plant fibres have long been used in strawboard, paper, cardboard and cotton, hemp and linen fabrics. It has also been known since the 1940s that pure cellulose can be extracted from plants and for example, processed to produce a yarn to make synthetic but cellulose-based cloth. This is where 'viscose' comes from but the process requires toxic chemicals and has been abandoned in many countries. Lyocell is a newer cellulose based yarn process without the main toxic chemical and in which the solvent is recycled. It's produced by Lenzing from Austria as 'Tencel', and was originally made in Hull in the UK by Courtauld.



Lenzing

Much of the drive to exploit cellulose as a feedstock rather than a source of fuel has come from wood-industry chemists. In a 2016 article in the online *Bio-based News*, Diederik van der Hoeven explained 'almost all major pulp companies now intensely research wood biorefinery: Stora Enso, Borregaard, Metsä, UPM, Mondi, Sappi'. They all 'have extensive knowledge of wood chemistry and develop many new applications starting from cellulose. The mere fact that we hear very little about this research … testifies to its promising nature: very competitive product developments'.

He added: 'The real breakthrough in wood biorefinery is that we can now dissolve cellulose in innovative liquids that are cheaper and more environmentally friendly … once dissolved, it can be spun into textile fibres or chemically reacted to produce derivatised celluloses and cellulose-based plastics … researchers have succeeded in decomposing cellulose from wood into fibrils, and binding them together again; different ways of reuniting the fibrils will determine the properties of the new product: soft as cotton, or hard as steel'.

Indeed in May 2018 [*Science Daily reported*](#) that through this recombining of nano-sized particles, a team led by Daniel Söderberg from the Royal Institute of Technology in Stockholm had created the 'world's strongest bio-material' in the form of 'artificial but biodegradable cellulose fibers … stronger than steel and even than dragline spider silk, which is usually considered the strongest bio-based material'.

It added: 'Using a novel production method, the researchers have successfully transferred the unique mechanical properties of these nanofibres to a macroscopic, lightweight material that could be used as an eco-friendly alternative for plastic in airplanes, cars, furniture and other products'. "Our new material even has potential for biomedicine since cellulose is not rejected by your body" said Söderberg.

The process took commercially available cellulose nanofibres and used jets of water to pack them into threads. This is called 'hydrodynamic focusing' and requires no additives. *Science Daily* says it mimicks 'nature's ability to accumulate cellulose nanofibres into almost perfect macroscale arrangements, like in wood', and can in principle create bio-degradable components.

Types of nanocellulose, divide into two broad groups: CNFs (fibres) and CNCs (crystals). CNFs are mainly produced by mechanical treatment like grinding or homogenization and are flexible fibers. CNCs are produced by chemical treatment with acid hydrolysis [3].

Objects 3D printed with cellulose nanofibrils.

https://www.biobasedpress.eu/2017/10/cellulose-nanofibrils-pave-the-way-for-biobased-3d-printing/

Existing applications of nano-cellulose and lignin fibres and crystals include [4] pulp and paper, plastics (eg foams), automotive, food industry, building (eg strengthening concrete), barrier/coating applications (eg food packaging), food additives, in medicine, cosmetics, and pharmaceuticals (eg, drug delivery and implants), and future applications based on their electrical and light transmitting properties, may include organic LEDs, flexible electronics, photovoltaics, 3D-printing, and recyclable electronics.

Environmental Implications

Given that these are fundamentally biodegradable feedstocks and can be used to make materials which perform like plastic, there is plainly a potential for large scale substitution of fossil-based plastics, not only in obvious places like bottles and packaging but across the range including in clothing, carpets and cosmetics, as well as car bodies and building materials. Compared to fossil-based plastic, materials made from cellulose and lignin should be far less persistent if they end up in the environment.

In addition, unlike many fossil-based plastics, these materials appear not to require toxic chemicals in order to maintain their physical properties (and which are then lost to the environment from conventional plastics as the polymers break up), and the building-block monomers are non-toxic (unlike eg styrene). Also unlike fossil-based plastic, cellulose attracts rather than repels water, so is unlikely to attract, concentrate and carry Persistent Organic Pollutants, which is a major reason why conventional microplastic is a serious health and ecological problem.

Too Good To Be True ?

So far so good but anything 'nano' can ring alarm bells, as the biological behaviour of very small fibres or particles can be quite different from 'macroscale' versions of the same substance. Moreover, the water-attracting properties of cellulosics, while good for some uses, is a problem for others. Consequently materials chemists have developed ways to manipulate the surfaces of nano-cellulose, or coat cellulose fibres with lignin, and potentially with other substances, to make it more 'waterproof'. The question then is, how safe are such modified nano-crystals or fibres for health or for nature?

Numerous 'occupational health' type studies appear to show they are fairly benign in the workplace, certainly compared to many petrochemicals and some minerals, for example as dusts. But these are mainly 'cradle to gate' Life Cycle Anlayses (LCAs). There are far fewer 'Cradle to Grave' LCAs which would take into account any impacts in the environment of nano-lignin/ cellulosic substances. Because of this, as a 2018 review article in the journal *Cellulose* noted [5], 'almost none of the studies are fully ISO-compliant'. This is an essential question for regulators to resolve, not least because the market for lignocellulosics is growing rapidly. The same paper notes that it is expected to surpass US$60bn in 2020.

So far, what studies there are don't in fact seem to flag any major problems. For example, a 2018 study [6] of cellulose nanocrystal foam conducted a so-called "block list" scan of input substances which are screened against EU REACH regulations, along with a simplified eco-toxicological test of crystal nanoncellulose, using an OECD standard Zebrafish test, and one with *Daphnia magna* (waterfleas). None of these suggested adverse effects.

Similarly, a 2017 toxicity study published in *Nano impact* [7] on the same test species along with others on algae and bacteria, found 'virtually no effects' from cellulose nano fibres and crystals, or their lignin coated versions. It found faster degradation of nanocellulose than conventional cellulose, probably due to its greater surface area. It also noted that 'at this point it is still unclear what types of surface modifications will change the toxicity of nanomaterials'. (That study appears to have been produced for regulatory purposes by a consultancy, Viero Advisors, for producers American Process Inc.)

So it would be valuable to have more environmental-fate studies of cellulosic alternatives to fossil-plastic, for example in soil, seawater and freshwater, and in urban and household contexts, and across the full range of ambient temperatures. Given the spread and potential of such materials, this needs doing urgently.

Don't Leave It To The Market

Left to its own devices, in other words led by whatever decisions make sense on purely commercial grounds, 'the market' is unlikely to eliminate fossil-fuel plastic by using ligno-cellulosics or indeed any other substance.

It seems to me there is a significant risk that investment commitments will be made that lock in these new technologies as '*part* of a solution' for companies wanting to reduce reliance on fossil-fuel-plastic, or simply because it is cheaper and performs better in some applications, rather than being part of a comprehensive phase-out of fossil plastic.

Technologists have experimented with combining polyester and nylon with nanocellulose and it is already used in composites, ie as mixed materials, and in a huge range of applications. It's is not a question of 'if' the technology is used but how.

The risk of a miss-step is magnified by the fact that many large chemical companies are, as you might expect, playing both games: keeping on producing fossil-polymers and investing in nano ligno-cellulosics. That way they can delay the day when their fossil-plastic assets finally have to be retired.

The only reliable way to avoid this prospect, which could create a whole new generation of 'non circular' materials and possibly a diversion in using nature-based feedstocks akin to the disastrous EU biofuel palm-oil experiment, is a powerful regulatory signal in favour of non-fossil plastic, with phase-out dates and some 'essential use' exceptions. If that does not happen, the promise of 'cellulosics' and other substitution options may be lost.

Without direction, materials scientists will anyway be intrigued to explore the application possibilities of new materials. Entrepreneurs, investors and companies looking for an edge will always be interested in new market advantages or opportunities. The lessons of the past tell us that to assume that this always results in products which are in the public interest, and should simply be allowed on the market because they can be invented, is wrong and naieve. Take the example of inventor Thomas Midgely, the man who brought the world both 'Freons' (eg CFCs) and lead in petrol (and himself suffered from lead poisoning).

Thomas Midgley – aka 'the man who most harmed the planet' Pic: Wikipedia

It has been said of the free-market that it is the operation of economics without the intervention of human intelligence. The same applies to the dynamics of technological development. Those gave us the plastics crisis, and they can now help us cure that problem but unguided by policy, could also land us with a new problem, and lost opportunities.

The Risks Of Not Getting Involved

Ligno-cellulosics are not sexy, at least not yet but to me they appear candidates to create the 'renewables moment' for conventional plastics. It would be a nice irony if living plants proved to be the nemesis of misused fossil-fuels, made from long dead plants. Yet to realise that, policy-makers need to guide their application with a regulatory pincer movement.

So on the one hand, if necessary, regulation must restrict applications of nano-cellulose/ lignin, for example to avoid any major problems like bioaccumulation and persistence if there are grounds for that, and to prevent them being locked-in to mixed applications which extend the use of fossil-plastic. Plus on the other hand, regulation needs to continually tighten the screw on fossil-plastic so it is rapidly phased out.

Campaigning NGOs and advocacy groups should not ignore this and sit back and wait to see what happens. It might be easier to stay focused purely on problem-driving by revealing the terrible impacts of plastic and eliminating egregious uses like plastic straws, and that surely needs doing but to deliver an end to fossil-plastic, advocates need to also engage with the solutions.

Who else but campaigners will pressure governments to put in the time and effort needed to understand these blossoming new industries and guide them to an optimal environmental solution, rather than opt for a 'light touch' easy option? The government default is to embrace policies which are easy and leave as much as possible of the technical work to business. That's exactly what happened with CFCs, HCFCs and HFCs which could have been eliminated decades earlier. What corporations say is possible and not possible is then presented as an immutable 'technical' or 'economic' truth, and this gets rationalised as a social truth, as in "we can't live without plastic".

Why We Need Substitution

One Brussels lobbyist familiar with the plastics issue said to me a few days ago: "It's not been strategic, and maybe because of that it's been all the more effective but so far, the anti-plastics campaign has won. It is amazing how rapidly user-companies are backing away from plastic".

Large companies are looking upstream for ways to avoid fossil-plastic. Unilever for example has announced a three-pronged strategy to move away from fossil-plastic. It is part of the 'Bioplastic Feedstock Alliance' and keen to avoid using anything that gets tarred as 'greenwash'. While many regulators and companies now put that label on 'oxy-biodegradables' it might soon extend to 'bio-plastics' from first generation cellulosics, to combinations of fossil and non fossil plastic, and to conventional polymers (eg polyester) created from bio-sources.

Large users are looking for drop-in solutions to plastic because they need quick and large volume results: aluminum cans instead of plastic bottles for instance. In terms of setting commitments, governments will titrate public concern against perceived feasibility and deliverability of change. This is why substitution is important, as well as achieving what can be achieved by personal behaviour change, such as re-use and consumer rejection of plastics where choices exist. It can show governments that it is possible to progressively abandon fossil-plastic 'recycling' in favour of elimination of fossil-plastic.

Economically, the cellulosic train has left the station. For instance they are the fastest growing sector of environmentally preferred textiles recorded by the cross-industry group Textile Exchange, whose 2017 conference featured 328 companies from 37 countries including Marks and Spencer, Adidas, Nike, IKEA, H&M, Timberland, Patagonia, Walmart, GAP and C&A.

Is Plastic 'The Problem' ?

Nevertheless, some environmentalists instinctively reject 'substitution'. On 5 September for instance, environment columnist George Monbiot wrote in The Guardian that the 'the problem is not plastic. It is consumerism'.

Now I am with George on many things – such as rewilding and the evils of Scottish salmon aquaculture – but not this. Yes 'consumerism', if you can actually define it in a meaningful way, is a problem but if you need to design a strategy to get rid of fossil-based plastic, the question is not what is the most perfect imaginable route to do so but which is the best available that can actually work.

George's plastic example of a non-solution was a disposable corn-starch coffee cup: first generation cellulosics. Yet even that is a solution to the narrow problem of fossil-microplastic from a conventional plastic cup, albeit not a good one seeing as a cellulosic/ cellulose cup would be better. I agree that using a re-usable cup would be better still, which is why I take my own Surfers Against Sewage bamboo cup with me when I buy a coffee when I travel, and now companies like Soho Coffee give me 25p off for doing so, which I consider a good thing. I have my own beefs with capitalism but I don't see that as a reason to try and reform the entire economic system in order to solve the particular problem of fossil fuels or fossil-plastic.

My coffee cup (right)

Environmentalists face a real-life choice. To try and go wide and campaign to change 'root causes' to huge and wicked problems such as 'global capitalism' or 'human nature' or 'values', in which case their campaigns tend to go slowly and not very far: they tend to end up as advocacy with a very limited audience. Or to be strategic, focused and make change, which should be as ambitious as possible while also being achievable. For me at least, ending fossil-fuel-based-plastic is pretty ambitious, and cellulose-based materials could help deliver that, fast and at scale.

No, it won't get rid of consumerism but neither did renewable energy. Yet that is helping tackle climate change, which seems something worth doing

Post-script

A nature conservation project to collect waste vegetation and use it in biorefineries is underway in Flanders Belgium and the Netherlands with EU Inter-Reg funding.

Chris Rose chris@campaignstrategy.co.uk September 2018

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