CLOSING THE LOOP

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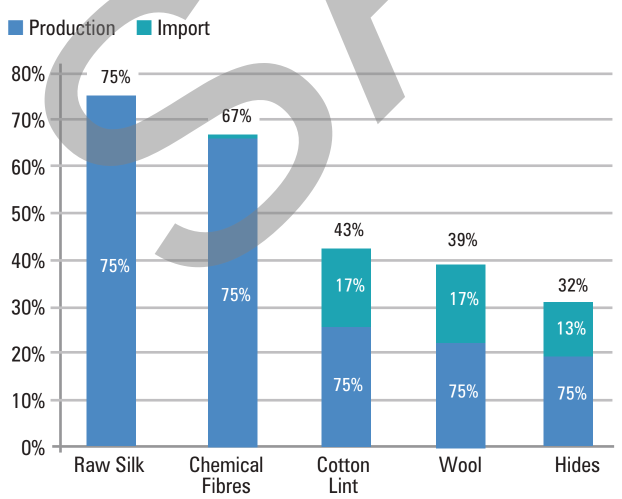
The materials shown in the chart here are commodities – at these levels *any* domestic movements caused by regulatory or physical (water scarcity) shifts by China as alluded to by the recent HSBC report with China Water Risk, "*No Water, More Trade-offs: Managing China's growth with limited water*" will affect the prices of these globally. Whether one is making anything in China becomes irrelevant – the entire apparel and footwear sector is exposed to water risks (be they regulatory, physical, pollution or reputational).

Cotton vs synthetics – China exposure appears to be still rising

The drought in 2010/2011 caused fashion to shift to a year of viscose and synthetics when cotton prices soared as the crop suffered. Synthetic prices also rose as a result, and brands saw a significant downside to their real P&L. HSBC in its recent report warns that managing water in China may result in shifts in cotton output. The alternative is synthetics but at 66 per cent of global chemical fibre production, swapping out of cotton is not going to help reduce exposure to China. The question here is: has the trend of sourcing cotton and chemical fibres been falling? Has China lost market share in recent years?

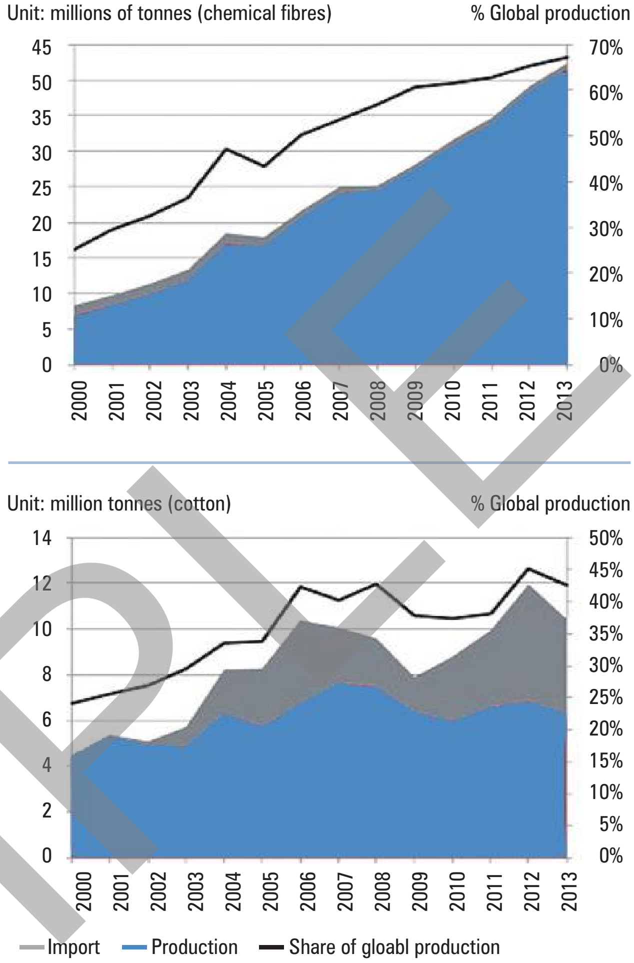
A closer look at these substitutes' historical trends in China revealed the contrary – China exposure has been rising for both cotton and synthetics. Synthetics, unaffected by weather and fluctuating farming subsidies, enjoyed a smoother rise than cotton.

FASHION APPAREL - RAW MATERIALS EXPOSURE TO CHINA (2013)



Source: China Water Risks estimates based on NBSC, FAO, CIRFS, UN Comtrade

2000-2003 GLOBAL INDUSTRY EXPOSURE TO CHINA



Source: China Water Risks based on NBSC, CIRFS, UN Comtrade, FAO

The 'Water Pollution Prevention & Control Action Plan' ("Water Ten") released by the Chinese Government in May 2015 adds another layer of complexity to navigating China exposure. The Water Ten Plan wants businesses/factories to comply with the new industrial standards or shut down within the next three years. In the Yangtze River Delta, factories face a tighter deadline.

China Water Risk highlighted that textiles was the most targeted sector in our review of the plan, but a glance at the map on this page shows just how dire this is – 77 per cent of chemical fibres are produced in the Yangtze River Delta. That is a shockingly high level of chemical fibres production facing "comply or else" by 2016/2017.

fibres – to achieve a longer fibre length and stronger yarn) and carding (the combing of fibres in the same orientation to prepare for spinning).

• **Polyester:** the mechanical recycling of polyester involves shredding, melting, melt-spinning/melt-extrusion (the melted solution is placed in a metal container called a spinneret and forced through its tiny holes). The precise steps following melt-spinning are dependent on the type of fibre produced, whether it's filament yarn or staple fibre.

• **Chemical Recycling:** chemical recycling technologies differ greatly depending on the fibre that is recycled. However the main principle is that fibres are broken down into their basic chemical components (monomers, cellulose), impurities are removed and components are subsequently built up to form virgin quality, regenerated fibres.

Several closed loop projects exist that have successfully realised fibre recovery or the recycling of used textiles (post-consumer textiles) and processed these fibres into new yarns, fabrics or even products. While these projects are, to date, relatively small in scale, they do offer a glimpse into a potentially more sustainable textile industry in the future.

Most projects involve mechanical recycling (with the main exception being Teijin's garment recycling collaboration with Patagonia).

Many projects use denim as a feedstock as this is easily sorted manually, is uniform in colour and traditionally contains a high percentage of cotton. Other initiatives use work-wear as a feedstock since it's collected, is uniform in colour and the material composition is known.

Can the existing business model for apparel continue as it is if more circular ways of working are to be introduced?

Circle Economy argues that the business model for a closed loop production system may still be a 'traditional' product-sales model provided that all of the above-mentioned aspects are addressed and that longer use, return, re-use and recycling is ensured or stimulated via, for instance, an incentivised return system or sale-buy back. ○

	MECHANICAL RECYCLING	CHEMICAL RECYCLING
FEEDSTOCK	• 100% cotton (PCT) <70% cotton (PIT) • 100% denim • 100% polyester • 100% blends into chunky, lower quality yarn	• Chief value cotton/cellulosics • Polycotton blends • Chief-value polyester • Other belnds still in R&D stages
OPPORTUNITIES	• Lower environmental impact • Short-term option • Less investments needed (existing assets can be used) • Good results (quality) with pre-consumer textile recycling & work wear	• No fibre degradation; virgin quality • Separates contaminations; colour, chemicals and other fibres • High potential for scaling • Less labour needed
CHALLENGES	• Lower environmental impact • Fibre degradation (cotton more than polyester) • Stretch fibres • Processing blended materials • Limited up-scaling potential	• High energy & costs (improvements expected with new technology) • Still in R&D phases

Pilot projects: mechanical recycling of PCT – workwear

- **KLM uniforms – unclear which products were made exactly: scarfs & non-woven products.**
- **Wefashion – knitted sweater with 50 per cent PCT based on uniforms.**
- **Recent initiatives are 'circular by design' and involve controlled sub-loops that incorporate circular design, circular business models and use of recyclable fabrics to create 'circular workwear' (EcoProFabrics with Returnity; Dutch Spirit with Inspire; Van Puijenbroek Textiel with Rework). However, none of these include fabrics with recycled content yet that we know of.**

Something old, something new

The separation of post-consumer textile fibres via a chemical process has become a huge area of interest in recent years. But how does such a process actually work, can it be carried out on an industrial scale, and does it offer a financially viable way forward for apparel manufacturers? Nick Morley, associate director with Oakene Hollins, looks at some of the key issues at play.

What do we mean by chemical recycling in textiles?

The scope of chemical recycling includes taking back the polymer that makes up the fibre to the original chemical building block (the monomer) or to a short chain of monomers linked together (an oligomer). Another route includes dissolving the fibre polymer in a solvent and then re-precipitating the polymer in the same or in a modified form while recycling the solvent. For cellulosic fibres this can also include a pulping or wet processing stage, when the fibre is pulped in water with additional chemicals prior to any further treatment in or by other chemicals.

So the fibre can be chemically transformed, or it can simply be dissolved and then re-extruded. In this case the fibre's physical properties have been changed but its basic chemical composition has remained unaltered.

What are the general approaches to chemical recycling for different fibre blends?

If we consider a blend of two fibre types, for example polyester and cotton, almost all approaches try to dissolve out one of the fibre types while leaving the other one as a solid that can then be removed and purified. The dissolved polymer can be spun from solution back into a fibre, or recycled in some other way, while the solvent in which it is dissolved is recycled back into the process to dissolve more of the fibre.

If the polymer chosen to be dissolved is polyester, then research over the past 30 years has included using solvents such as sulphones, or mixtures of aggressive solvents such as chlorinated hydrocarbons (which are clearly no longer acceptable). The polyester can also be depolymerised *in situ* back to its monomer or to an oligomer, using a catalyst rather than being dissolved. However some of the existing polyester chemical recycling processes, such as that operated by Teijin, have a tolerance of impurities up to around 20 per cent – so if the mix is high in polyester, separation may not actually be necessary.

In fact, tolerance, it should be noted, does vary by fibre; to provide another example, the tolerance level for spandex is zero.

Where have research efforts in this area focused so far?

Most recent research has focused on dissolving the cellulosic (cotton) fraction. Ionic liquids, which are organic materials possessing positively and negatively charged ions (as opposed to the neutral, covalently bound atoms of most organic materials) have received much attention from green chemistry researchers over the past 20 or 30 years. Many different types of ionic liquid can be produced, each with subtly different abilities to dissolve solids, and they have been put to use to 'tailor' reactions that otherwise would be wasteful of energy or material. Chemical

Chemical separation of fibre blends: our analysis

Our research has identified a number of projects and papers which claim to have established – at lab scale – a way to chemically separate textile fibre blends such as cotton/polyester into their individual components.

Our understanding is that Worn Again's work is closest to commercialising this kind of work, although to this point two caveats need adding. Firstly, if our analysis is correct, the challenges facing Worn Again and its partners are huge and there is no guarantee that they will be overcome; put another way, demonstrating this process in the laboratory was the easy part.

Secondly, we don't know for sure what is happening in China, although several research papers have been put out by Chinese authors. To offer one example, see the Elsevier Science paper: *Isolation and recovery of cellulose from waste nylon/cotton blended fabrics by 1-allyl-3-methylimidazolium chloride* (*bit.ly/1Gd2e7f*). A major development from China in this area in the next two years would come as no great surprise.

Below we have set out what we believe are the main issues and challenges regarding the commercialisation of this technology; these could be applied to the work of Worn Again or, indeed, any other organisations attempting to re-spin new fibres from old (even if only cellulosic).

- Who will fund the commercialisation of this technology, whether on a full scale or even pilot scale? Will it be brands? Or venture capitalists? And will brands collaborate or ultimately seek to establish their own supply arrangements?
- What about permits to operate and environmental health and safety aspects, which could be high with chemicals and solvents involved – what will total investment and operating costs be?
- Such a facility would require an assured supply of waste material to the required input specification. Our research suggests a 10,000 tonnes per annum capacity would equate to 50 million garments needed, all at the required sorting specification. How will this supply be met? Scaling up provides better investment economics for those involved – but bigger facilities make establishing a reliable flow of segregated waste more challenging.
- Is there the risk that the introduction of new technologies – particularly from Asia where we have little idea about what is going on in this area – might obsolete any investment? Has any due diligence been carried out in this area and would investors be willing to take the (potentially huge) investment risks involved.
- What are the on-going costs of solvent use and other input materials?
- Will there be hazardous waste from the process, whether this be the chemicals and treatment on the garment waste or the residues/other fibres left in the bottom of a vessel.
- How versatile is the process? For example, if the technology takes 5 – 10 years to establish is there the risk that the materials used in clothing will not be the same and in the same percentages in 2025?
- Will the recovered materials meet raw material and chemical compliance standards?
- Will the newly spun fibres be price-competitive with current fibres? This is a critical issue – if the recycled yarns (as expected) have a premium over virgin materials, will brands pay that premium? The evidence so far is not too promising: several brands we are aware of have shifted away from recycled programs due simply to pricing issues.

polymers shorter which decreases the strength of the textile fibres. Weaker fibres result in textiles of poor quality, and such textiles would not contribute to a circular flow, but rather to an open loop system instantly requiring inflow by virgin materials of high quality. Hence, the fibre quality of textile waste must be restored to create a closed loop recycling. This is possible using different chemical methods and a chemical recycling process would for that reason be the better solution.

The report also says "cotton could be recycled through integration into the existing production of man-made cellulosic fibres". Could you elaborate on this?

When designing a recycling process for cotton, it may be [said] that cotton is made out of pure cellulose. Cellulose is also the main constituent in so called man-made cellulosic fibres, where the two most well-known fibres are viscose and Tencel (Lyocell). This implies that cotton could be recycled through integration into the existing production of man-made cellulosic fibres.
Today man-made cellulose fibres are mainly produced from wood, which is processed into a special grade of pulp called dissolving pulp. To integrate cotton into the viscose industry, it is key to understand differences in how cotton and dissolving pulp react to chemical treatments. Our research showed that acid treatment of dissolving pulp and used cotton gave similar results, giving positive indication for the possibility to mix cotton waste with dissolving pulp. Mixing will not lead to a completely circular flow, but according to us, it is an important first step to achieve recycling.

To [look at] the whole chain from fibre to fibre we launched a project called the "Post-Consumer-Cotton project". In this project Chalmers University of Technology, Swerea IVF and SP Technical Research Institute of Sweden collaborated to perform the whole recycling process. Cotton sheets, used at hospitals and provided by the Swedish company Textilia were dissolved, and spun into new fibres using a dissolution process developed in Sweden adaptable for the pulp industry. All steps of the process will now be further optimised, together with industrial partners within the Mistra Future Fashion programme, which is necessary for the process to be considered industrially. However, our results show that is it possible to recycle cotton using this method.

Could you tell us about your work in the area of polyester recycling research. Based on your work, what would you say is the most sustainable way forward for the textile industry in terms of polyester recycling?

The easiest way to recycle polyester waste would be to add it to a melt-spinning process. The waste would then be melted and spun to new polyester fibres. Another way to recycle polyester is to de-polymerise it into its primary building molecules, and re-synthesise brand new polyester. The second approach requires more energy, and is also more costly than the first.

However, our research showed that polyester is degraded during use and laundering, losing its quality. As a result the melting approach is not feasible for used polyester textiles (in comparison to creating textiles from recycled PET-bottles having an inherent higher quality). Re-melting the polyester will not restore its quality but create polyester of poor strength, leading to an open loop system instantly requiring inflow by virgin materials of high quality. Instead, we are exploring the de-polymerisation/re-synthesis approach. Our results show the importance of understanding the waste before choosing a recycling method.

In Mistra Future Fashion, the de-polymerisation of polyester was achieved using two different methods. One involved using a new technique utilising an eco-friendly nano-catalyst, more suitable for pure polyester, and one was developed for the separation of cotton and polyester.

In the second method, the programme involved a masters student, Anna Peterson, located at Chalmers University of Technology. In this project a process to de-polymerise polyester without affecting the cotton fibres was investigated, with the aim to integrate the process into an existing