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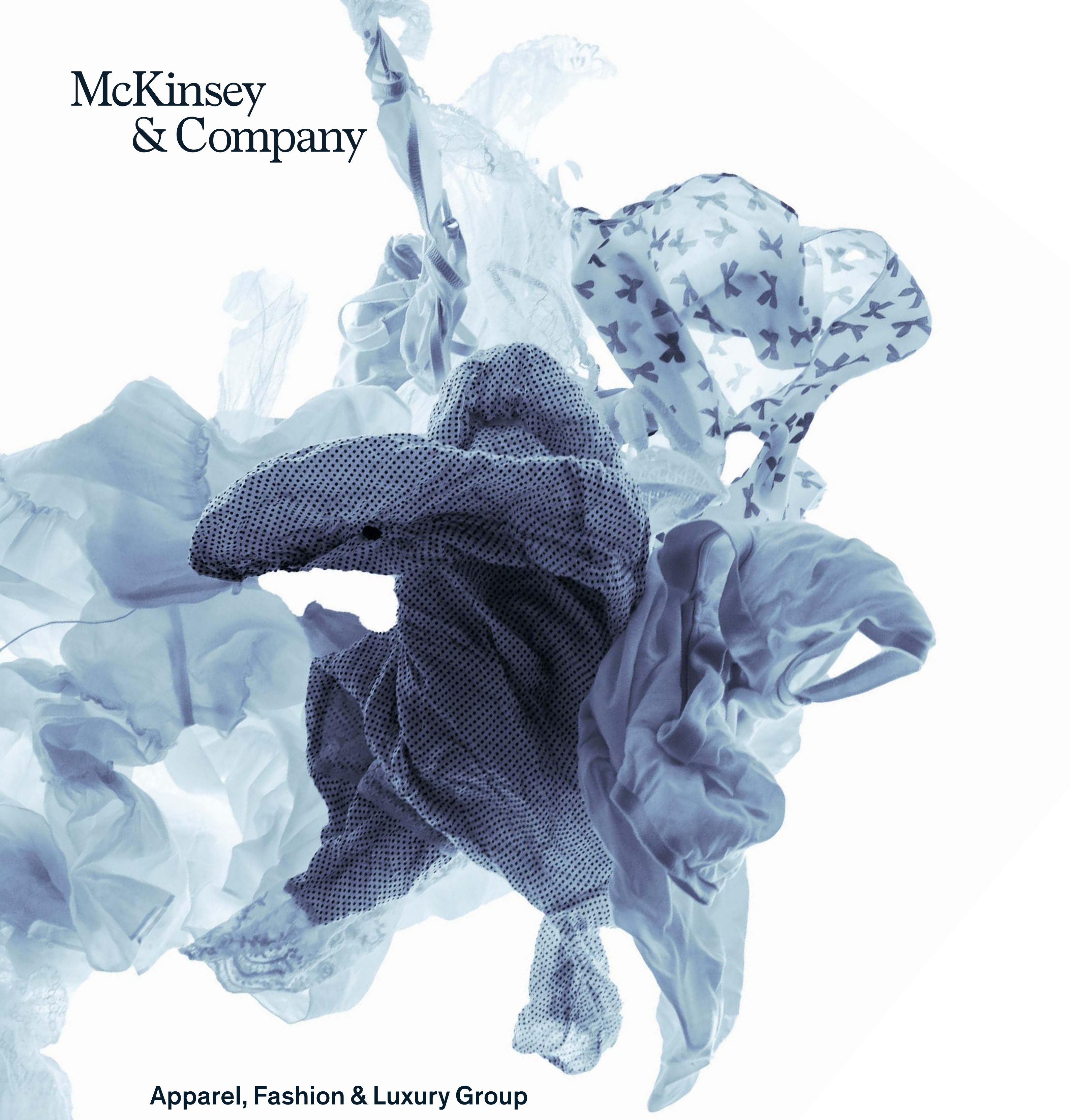

Apparel, Fashion & Luxury Group

Scaling textile recycling in Europe—turning waste into value

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Textile recycling can turn Europe's textile waste into value and build a sustainable and profitable new industry.

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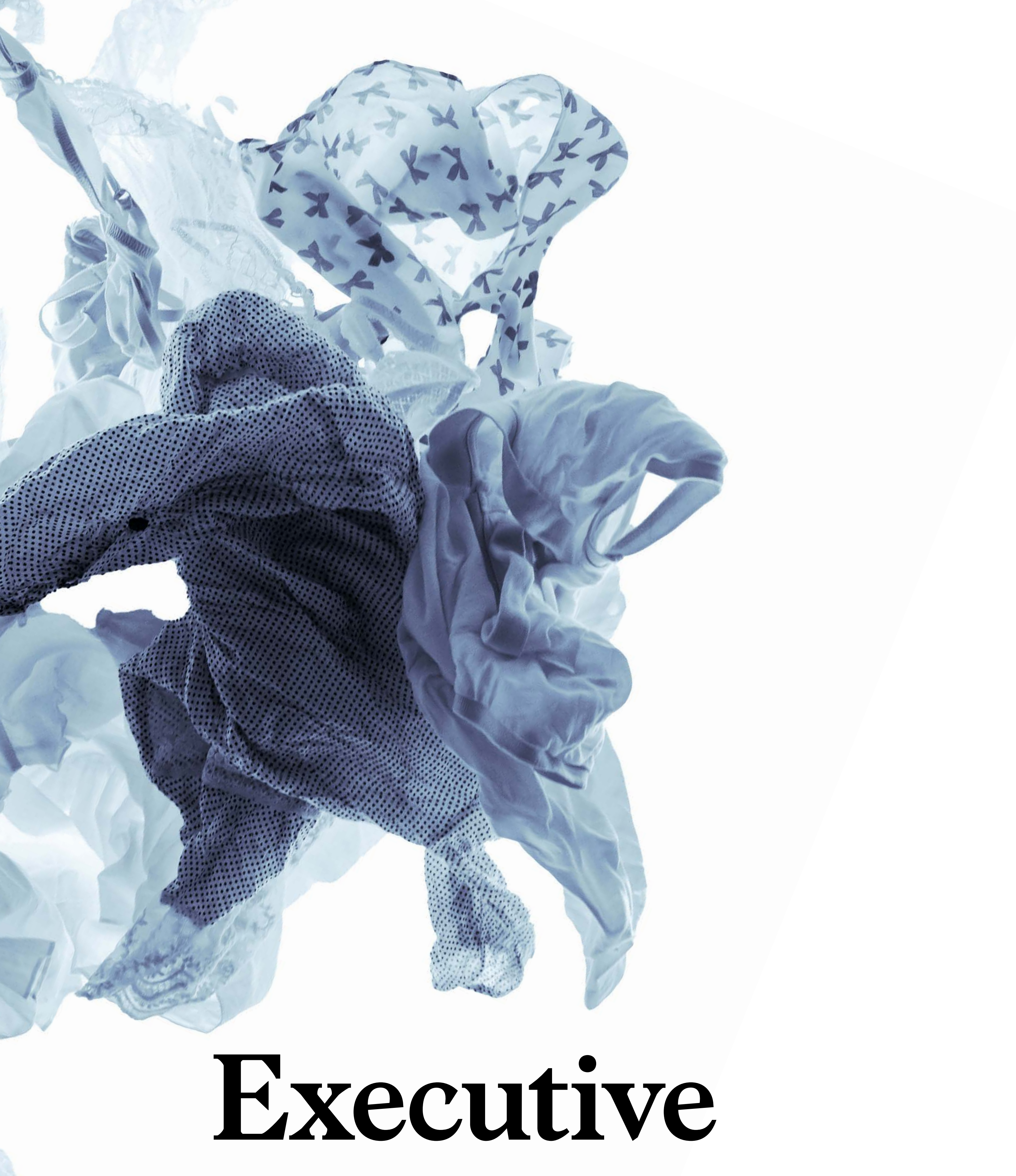


Executive summary

Textile recycling at scale could help solve Europe's waste problem—an 18 to 26 percent fiber-to-fiber recycling rate could be achieved by 2030.

Today, more than 15 kilograms of textile waste is generated per person every year in Europe. The largest source of textile waste is discarded clothes and home textiles from consumers—accounting for around 85 percent of the total waste. The generation of textile waste is problematic as incineration and landfills—both inside and outside Europe—are its primary end destinations. This has several negative consequences for people and the environment. But a significant transformation lies ahead that could create a large and sustainable new industry that turns waste into value.

There are multiple ways to address the waste problem, including the reduction of overproduction and overconsumption, the extension of product lifetime, and designing products for increased circularity. One of the most sustainable and scalable levers available is fiber-to-fiber recycling—turning textile waste into new fibers that are then used to create new clothes or other textile products. This space is characterized by fast-paced innovation and a race toward scale. Some technologies, like mechanical recycling of pure cotton, are already established. Other technologies, like chemical recycling of polyester, have been subject to intense R&D and are on the brink of commercialization. Once fully mature, our estimates indicate that 70 percent of textile waste could be fiber-to-fiber recycled. The remaining 30 percent would require open-loop recycling or other solutions like producing syngas through thermo-chemical recycling. However, today less than 1 percent of textile waste is fiber-to-fiber recycled due to several barriers to scale that need to be overcome.

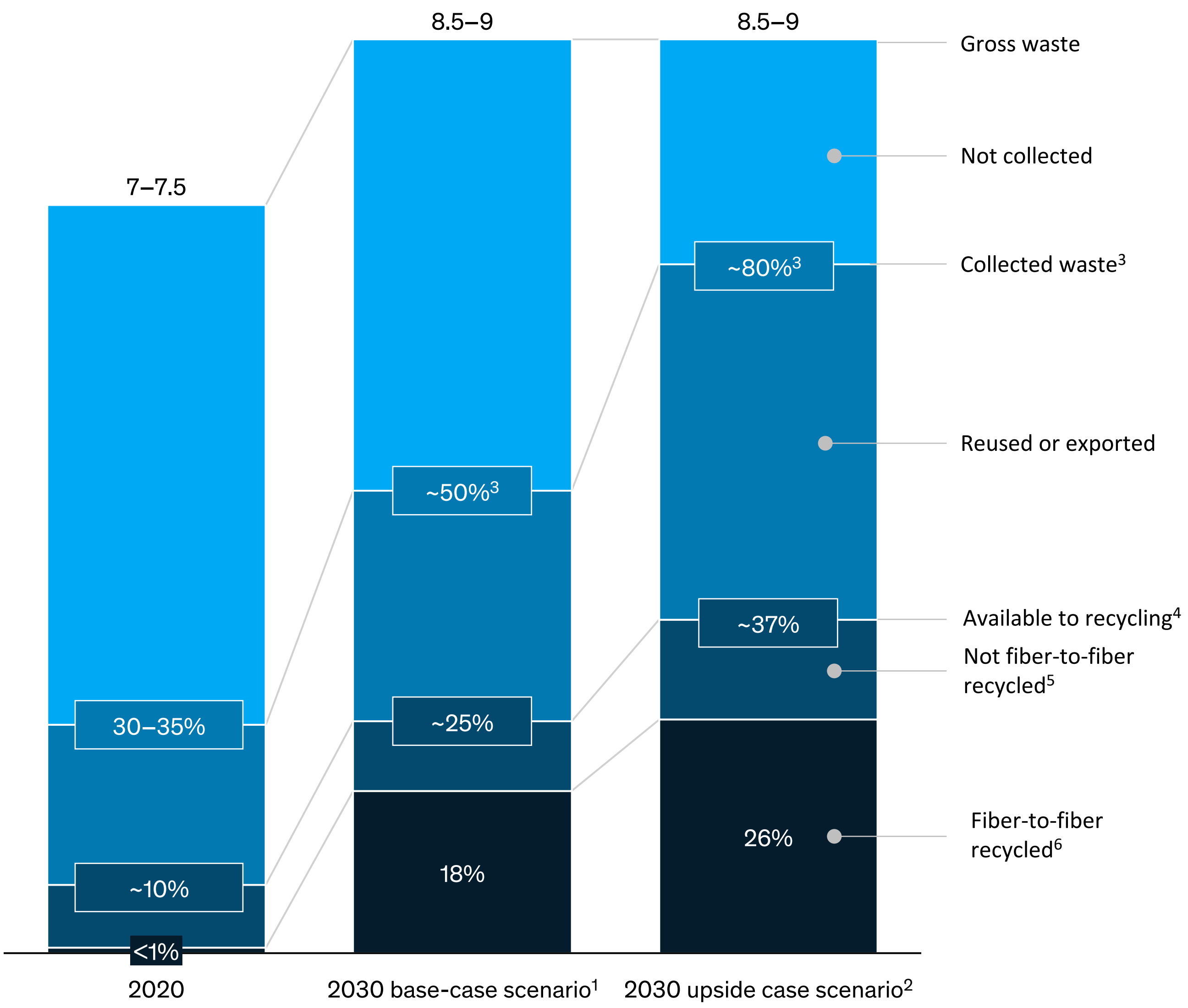
Collection, sorting, and pre-processing limit the amount of textile waste made available to fiber-to-fiber recycling. Collection rates are currently 30 to 35 percent on average, and a large share of the unsorted gross waste is exported outside Europe. Furthermore, most fiber-to-fiber recycling technologies have strict input requirements for fiber composition and purity—for example, elastane is problematic for several of these technologies. Consequently, textile waste needs to be scanned and sorted according to the relevant input requirements. As another example, jeans must have their zippers and buttons removed; a problem that needs to be solved by pre-processing. Advanced, accurate, and automated fiber sorting and pre-processing are not yet developed. Finally, to reach their full potential, the fiber-to-fiber recycling technologies must further expand their ability to handle fiber blends, lower their costs, and improve their output quality—these bottlenecks prevent the circular textile economy from scaling. Our analysis indicates that by overcoming these barriers, fiber-to-fiber recycling could reach 18 to 26 percent of gross textile waste in 2030, as illustrated in Exhibit 1.

Exhibit 1

Fiber-to-fiber recycling could reach 18–26 percent of gross textile waste in 2030.

ESTIMATE AS OF JUNE 2022

EU-27 and Switzerland textile waste volume, millions tons



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1. The base-case scenario refers to a situation where 50 percent of EU-27 and Switzerland's post-consumer household textile waste is collected, up from today's 30 to 35 percent.
2. The 2030 upside case refers to a situation where 80 percent of EU-27 and Switzerland's post-consumer household textile waste is collected.
3. Refers to the collection rate of post-consumer household waste. Total collection rate is slightly different due to other waste streams having other collection dynamics.
4. There are different ways of defining what share of textile volume is "available to recycling". This paper uses the term to describe textile waste that is collected and does not have an alternative use with a higher value that is further up in the waste hierarchy (for example, resale). Of the share that is available to recycling, there may be fiber fractions that technically are not eligible for fiber-to-fiber recycling. Our base-case scenario with allocated textile waste to the different recycling technologies assumes—based on our analysis of forward-looking feedstock purity requirements by recycling technologies—that 70 percent of what is available to recycling can technically be recycled.
5. Can either be open-loop recycled products like cleaning rags, or thermo-chemical recycling to create syngas.
6. Here defined as fiber-to-fiber recycled volume divided by total gross waste. The rate reflects the estimated full potential of fiber-to-fiber recycling of 70 percent of what is available to recycling. This number excludes open-loop recycling.

Source: Ellen MacArthur Foundation; European Commission Joint Research Centre (JRC), 2021; Eurostat Prodcom; expert interviews; Higher Institute for Environmental Protection and Research, Italy reports no. 1 and no. 2, 2021; Humana Annual Report, 2020; Intecus, Germany report, 2020; JRC Technical Report, 2021; Modare, Spain country report, 2021; Nordic Council for Ministers Baltic Countries report, 2020; Rebel, Netherlands report, 2021; ReFashion, France report, 2020; Unweltbundesmt, Austria report, 2022; Deloitte European Market Study for ETSA, 2014

To reach this scale, we estimate that capital expenditure investments in the range of €6 billion to €7 billion would be needed by 2030. The entire value chain, including textile collection, sorting, and recycling, requires investments to reach scale. Our analysis indicates that this industry could—once it has matured and scaled—become a self-standing, profitable industry with a €1.5 billion to €2.2 billion annual profit pool by 2030. The textile recycling value chain could create a new valuable raw material that enables more apparel production in Europe, which may lead to additional value creation above what is quantified in this report.

Beyond the direct economic benefits, scaling textile recycling unlocks several environmental and social benefits. For example, in our base-case scenario around 15,000 new jobs could be created and CO_2e emissions could be reduced by around four million tons—equivalent to the cumulative emissions of a country the size of Iceland.

By quantifying into monetary terms several other impact dimensions like the secondary effects to GDP from job creation, CO_2e emission reduction, and water- and land-use reduction, our analysis shows that the industry could reach €3.5 billion to €4.5 billion in total annual holistic impact by 2030—coming to an annual holistic impact return on investment of 55–70 percent (Exhibit 2).[1]

15,000

new green jobs created.

4 million tons

CO_2e emissions abatement.

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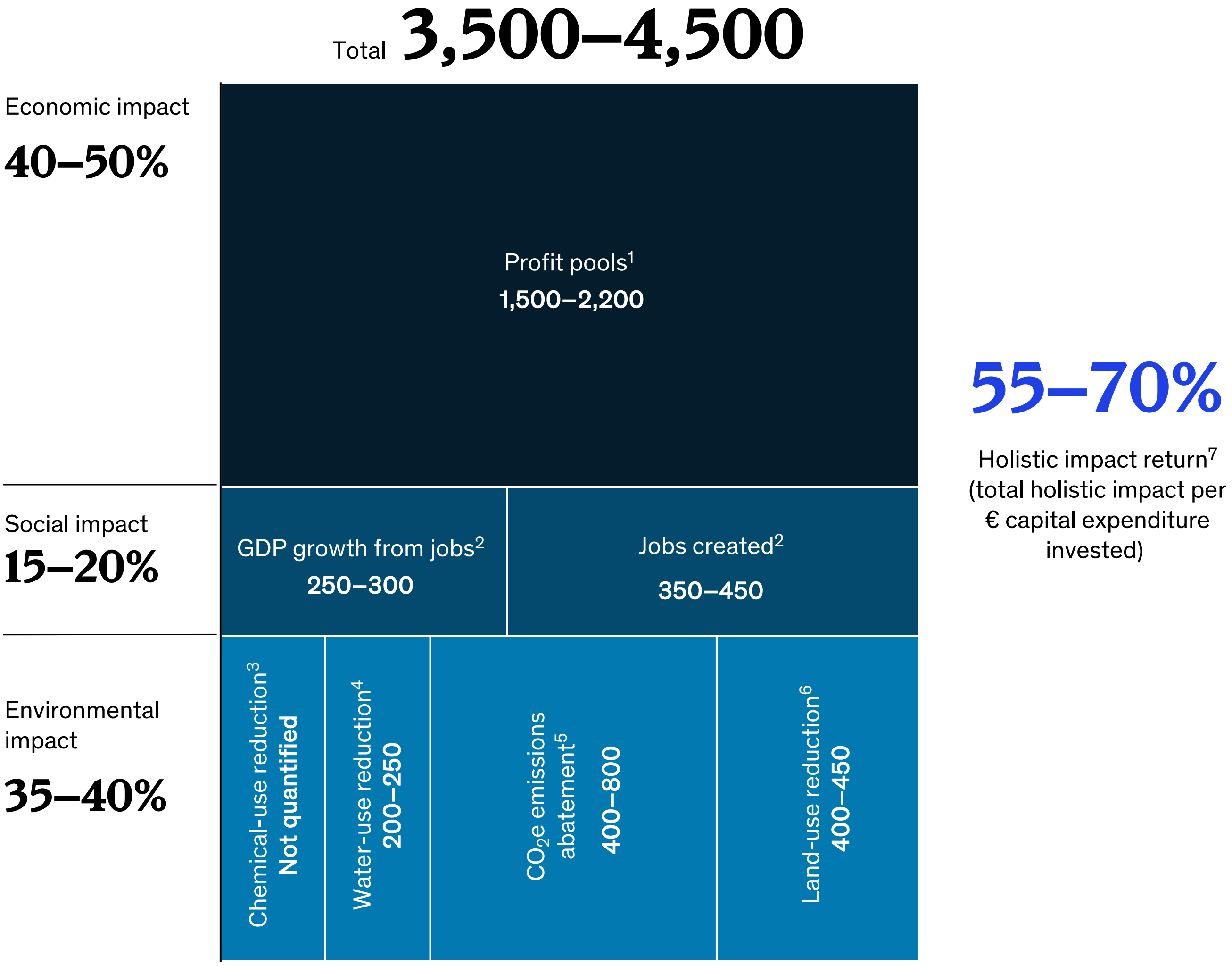
[1] This metric considers estimated industry-wide EBITDA over total capital expenditure required. Individual companies and value chain steps will have varying financial return characteristics.

Exhibit 2

Scaling textile recycling in EU-27 and Switzerland to the base-case scenario could yield an annual holistic impact of €3.5 billion to €4.5 billion in 2030.

Total potential annual holistic impact by type and source of impact for EU-27 and Switzerland, € million

ESTIMATE AS OF JUNE 2022



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1. Based on a price that is comparable to the price of the virgin equivalent whenever virgin quality is achieved, and a price with 30% discount compared to the price of the virgin equivalent when quality degradation occurs. Operating-expenditure and capital-expenditure estimates are from McKinsey analysis. The upper range of profit assumes green premium of 25%.
2. FTE-estimates from McKinsey analysis and industry experts; average annual earnings of €26,000 assumed (Source: Eurostat, 2021); fiscal multiplier of 0.67 assumed, meaning that €1 in wages increases economic growth by 67 cents (Source: European Central Bank; International Monetary Fund).
3. The impact potential of all chemical usage improvements has not been quantified separately but could be substantial.
4. Water consumption estimate of ~600m^3 water/ton fiber output, average all fibers (source: Mistra Future Fashion [summarizing various data points]); water price estimate: average of estimates in India and Bangladesh (source: "Dhaka WASA raises water price by 24.97% for households," bdnews24.com, February 2020).
5. Mistra Future Fashion (summarizing various data points); McKinsey analysis for recycling technologies; Higg MSI; carbon cost: European Union Emissions Trading System (EU ETS).
6. ~2 hectar/ton fiber output, average all fibers (source: Stockholm Environmental Institute); land rental price estimate: ~€140/hectare, representing average of EU and low-cost country land prices (source: Eurostat and banglabuysell.com)
7. The combined holistic impact—across the dimensions calculated—as a share of the total capital-expenditure investments needed across all the value chain steps.

To capture this opportunity, collaboration and innovation will be key.

The identified bottlenecks preventing scale are significant and will require several stakeholders to act boldly. Textile recycling in Europe will not reach a favorable state by 2030 unless major action is taken quickly. This report identifies five main ingredients for success.

- **Critical scale.** The textile recycling value chain cannot function at small scale. Critical scale across the value chain is required to provide sufficient feedstock[2] to the necessary fiber-to-fiber recycling technologies, and to allow for those recycling technologies to operate at scale. Therefore, the industry must set bold scaling targets and meet them.
- **Real collaboration.** Several of the main challenges ahead are best solved in a highly collaborative manner. Business leaders across the value chain, investors, and leaders of public institutions would need to come together in an unprecedented way to engage in a highly operational joint effort to overcome the barriers to scale.
- **Transition funding**. Although our analysis indicates that the textiles recycling industry could—once it has matured and scaled—become self-standing and profitable, transition funding will be needed in the near term. Examples of such funding include subsidies (potentially Extended Producer Responsibility [EPR] funding) and a green premium (potentially shared by brands and consumers). Public-private solutions may be needed.
- **Investments.** Several parts of the value chain must be built out almost from scratch, which requires significant capital expenditure. Our analysis indicates that sufficient economic value can be realized to make up for the required risk. Private investors would lead this journey by taking initiative to finance building out the value chain.
- **Public sector push.** Leaders of public sector institutions would have to help drive textile recycling. Measures include driving up collection rates, limiting the export of unsorted textile waste, engaging in demand stimulation, creating harmonized frameworks for increased circularity, as well as other initiatives.

Fiber-to-fiber recycling at scale can help address Europe's waste problem by turning waste into value. The European apparel and textile industry can start expanding the required infrastructure for collection, sorting, and closed-loop recycling today. This report establishes the opportunity at stake for textile circularity and highlights actions required to capture it. Furthermore, we hope this report can be a foundation for further research and collaboration to establish textile recycling at scale in Europe.

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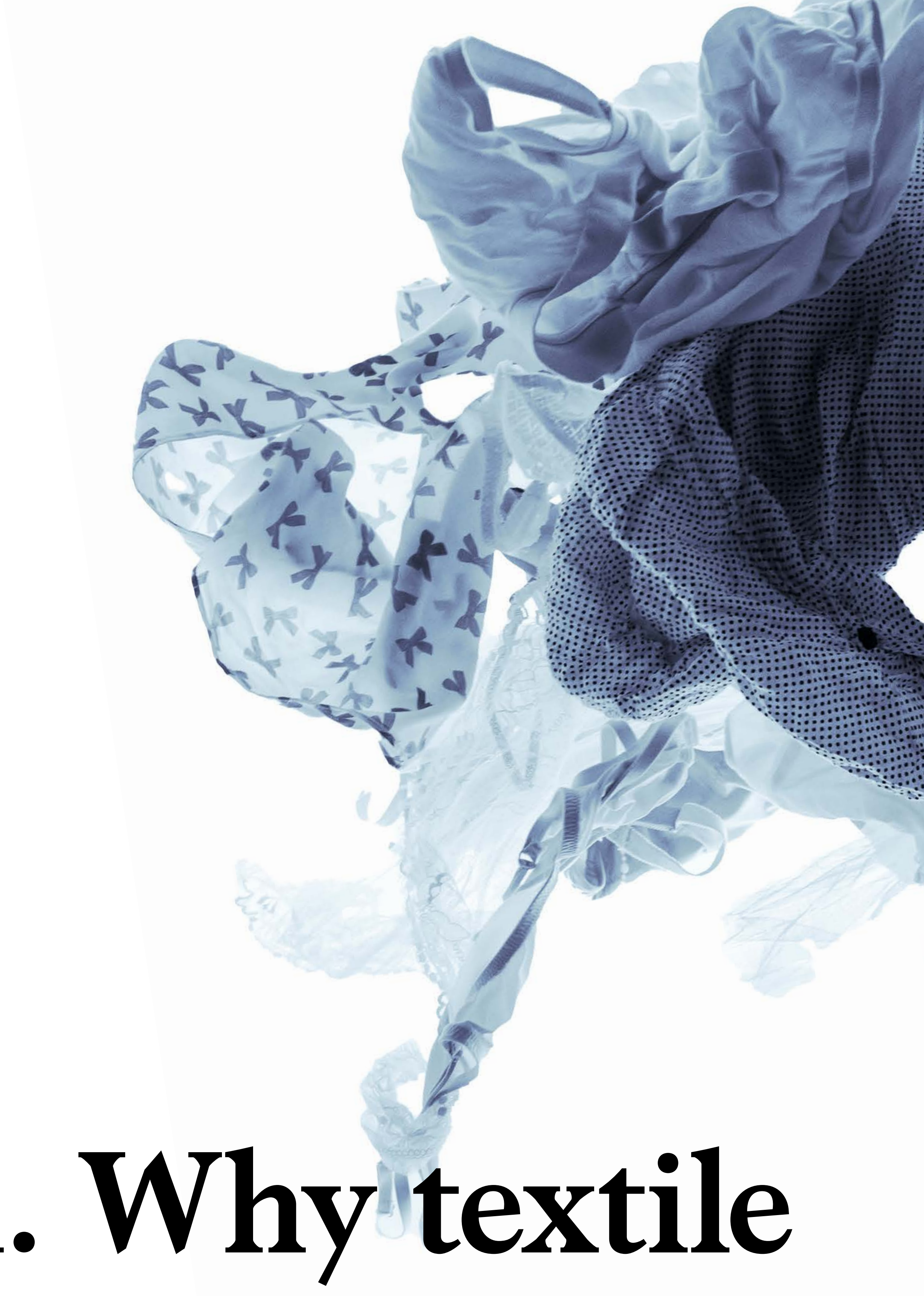
[2] Textile waste available to recycling.



1. Why textile recycling?

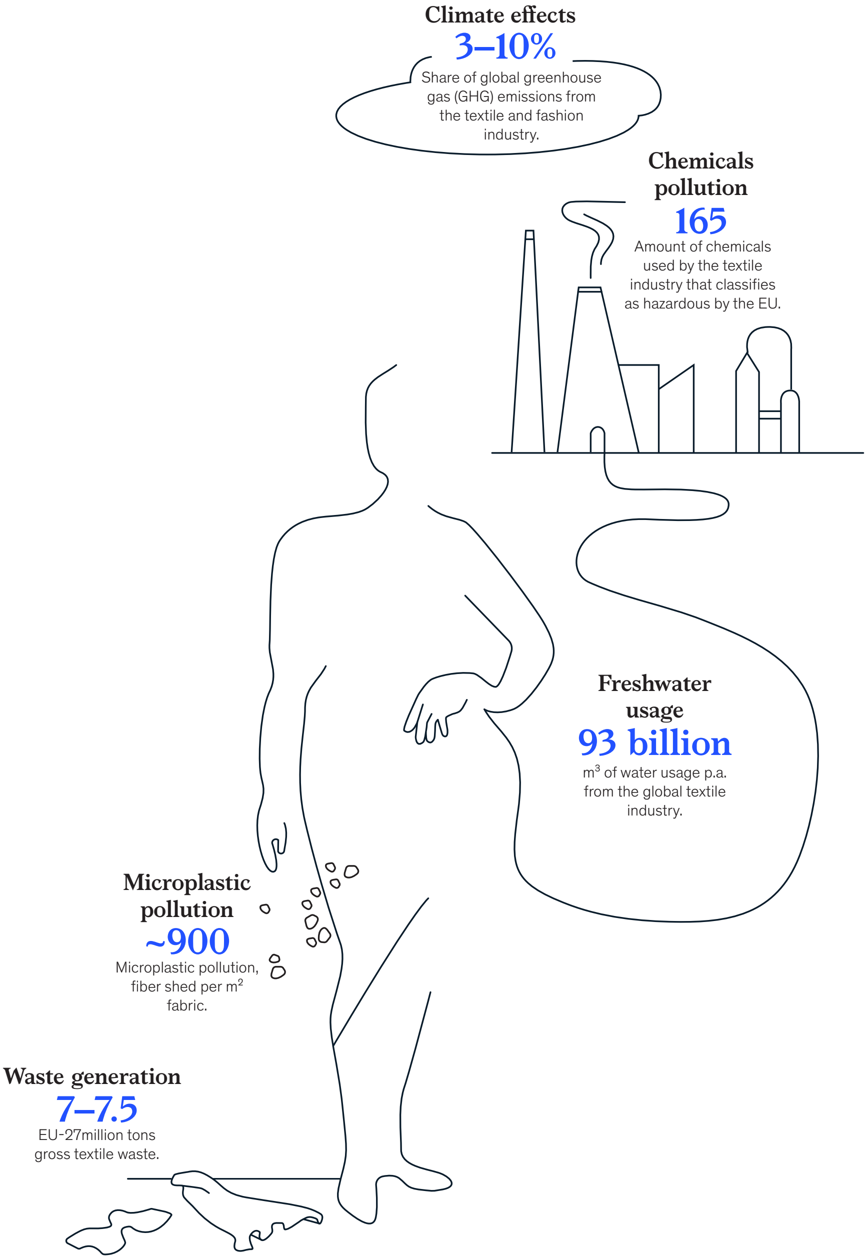
The path toward circularity includes unlocking textile recycling in Europe

The clothing and textile industry is a highly resource-intensive and waste-generating industry, accounting for 3 to 10 percent of global CO_2e emissions.[3] To achieve a transformation from linear to circular, the industry needs to pull multiple solution levers simultaneously with particular emphasis on its upstream operations. Material production represents a large share of greenhouse gas emissions (around 38 percent of total clothing and textile industry emissions), resource usage (for example, freshwater), and pollutants (for instance, chemicals). [4] One attractive lever is to embrace closed-loop, fiber-to-fiber recycling. This would aid the clothing and textile industry to take an important step in moving the industry from a linear logic toward a circular system. However, several critical bottlenecks across technology development, capacity scale-up, and cross-value-chain collaboration would need to be overcome to realize this ambition.

As climate change increasingly affects citizens and businesses worldwide, the required transformation of the current clothing and home-textiles value chain is pressing. Today, the textile value chain is principally based on a linear "take-make-waste" logic, where large amounts of resources are extracted to produce items that often are only used for a short time. [5] In addition, growing consumption and waste volumes in Europe are a global problem, as textile waste exported from Europe ends up polluting less-developed countries. [6] This linear textile system puts pressure on resources, leaves many economic opportunities untapped, and has adverse effects on the environment (Exhibit 3).

Exhibit 3

The clothing and textile industry has adverse environmental effects.



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[3] *Fashion on climate,* Global Fashion Agenda and McKinsey, 2020.
[4] *Fashion on climate,* Global Fashion Agenda and McKinsey, 2020.
[5] *A new textiles economy: Redesigning fashion's future,* Ellen MacArthur Foundation, 2017.
[6] "Poisoned Gifts," Greenpeace International, April 22, 2022.

The adverse environmental effects of the clothing and textile industry include:

- **Waste generation.** In EU-27 and Switzerland, as much as 7 million to 7.5 million tons of gross textile waste—a bit more than 15 kilograms per person—is generated each year[7]. By 2030, this annual gross textile waste figure could rise to 8.5 million to 9 million tons, corresponding to just below 20 kilograms per person.
- **Climate effects.** The global fashion industry is estimated to emit 3 to 10 percent of total global greenhouse gas emissions. [8] If the industry continues to implement decarbonization initiatives at the current pace, emissions in 2030 will remain the same as they are today—nearly double the maximum required to stay on the UN Paris Agreement's 1.5° pathway by 2050.
- **Freshwater usage.** In total, the global textile industry uses approximately 93 year; cubic meters of water per annum; enough to meet the annual consumption needs of five million people.[9] For example, around 3,800 liters of water are required to produce one pair of jeans, and dyeing a single kilogram of textiles uses up to 150 liters of water.
- **Chemical pollution.** The clothing and textile industry makes use of 1,900 chemicals, of which 165 are classified as hazardous by the European Union. In addition, global textile production is estimated to be responsible for around 20 percent of global clean water pollution, due to the dyeing and finishing of products. [10]
- **Microplastics pollution.** The increasing usage of synthetic fibers in clothing and home-textile products results in the release of microplastics into the environment during the lifetime of the product (for example, through machine washing). The long-duration plastic (PET) that is used to make synthetic fibers—like polyester—takes several hundred years to break down. The complete effects of this are not yet clear, however, it may have adverse effects on nature. Microplastic pollution is estimated to be approximately 900 fibers shed per square meter of fabric. [11]

Demand among consumers for sustainable materials is rising hand in hand with increased environmental awareness among brands, investors, and lenders. For example, among recently surveyed consumers, 54 percent anticipate buying more clothes made with recycled materials.[12] In addition, around half of surveyed European brand executives indicated that they expect more than 30 percent of their products to contain recycled fibers by 2025. [13] Industry executives have also set targets across fiber types on the share of materials that should be sustainable. However, the specificity of these targets is limited by the lack of alternative sustainable materials that are available at scale today. The most concrete targets relate to polyester replacement, where several brands have committed to using 100 percent recycled polyester. The reason is that polyester made from recycled PET bottles is available at scale.

The EU Strategy for Sustainable and Circular Textiles, published in 2022, encourages businesses to prioritize their efforts on fiber-to-fiber recycling rather than PET bottle-to-textile recycling.[14] Transforming the clothing and textile industry to circularity requires closed-loop recycling, keeping textile waste material within this industry—thereby decreasing the need for virgin materials. However, it remains true that open-loop recycling still must play a role, as closed-loop recycling is not possible in all cases and open-loop recycling is a preferable solution to incineration or landfill.

Regulators are ramping up their pressure on the clothing industry to maintain the Paris Agreement's 1.5° pathway, and recent European policy initiatives urge the industry to move towards enhanced waste collection and more circular models. For example, Article 11(1) in the Waste Framework Directive states that member states are required to set up separate collections of textiles by 2025.[15] In addition, the EU Strategy for Sustainable and Circular Textiles describes the 2030 vision for the European textiles market as such:

"By 2030, textile products placed on the EU market are long-lived and recyclable, to a great extent made of recycled fibres, free of hazardous substances, and produced in respect of social rights and the environment. Consumers benefit longer from high-quality affordable textiles, fast fashion is out of fashion, and economically profitable reuse and repair services are widely available. In a competitive, resilient, and innovative textiles sector, producers take responsibility for their products along the value chain, including when they become waste. The circular textiles ecosystem is thriving, driven by sufficient capacities for innovative fibre-to-fibre recycling, while the incineration and landfilling of textiles is reduced to the minimum."

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[7] Eurostat Prodcom database; Intecus, Germany report, 2020; ISPRA, 2021; ISPRA, 2022; Modare, Spain report, 2021; Nordic Council for Ministers Baltic countries report, 2020; Refashion, France report, 2020; Rebel, Netherlands report, 2021; Umweltbundesamt, Austria report, 2022.

[8] *Fashion on climate,* Global Fashion Agenda and McKinsey, 2020.

[9] *A new textiles economy: Redesigning fashion's future,* Ellen MacArthur Foundation, 2017.

[10] *Environmental impact of the textile and clothing industry,* European Parliamentary Research Service, European Parliament, January 2019.

[11] Bethanie M. Carney Almroth et al., *Quantifying shedding of synthetic fibers from textiles; a source of microplastics released into the environment,* PubMed, October 28, 2017.

[12] "Closing the loop: Increasing fashion circularity in California," McKinsey, March 31, 2022.

[13] Saskia Hedrich, Julian Hügl, Patricio Ibanez, and Karl-Hendrik Magnus, "Revamping fashion sourcing: Speed and flexibility to the fore," McKinsey, November 12, 2021.

[14] *EU strategy for sustainable and circular textiles,* Environment, European Commission, 2022.

[15] *Waste framework directive,* Environment, European Commission.

The transition from a linear to a circular model requires several impact levers—solving overproduction and overconsumption with a change to a "less-is-more" model is important but is still underdeveloped.[16] New circular business models, like the resale of used clothing or rental and repair services, are being explored by start-ups and scale-ups as well as by incumbent brands and retailers.[17]

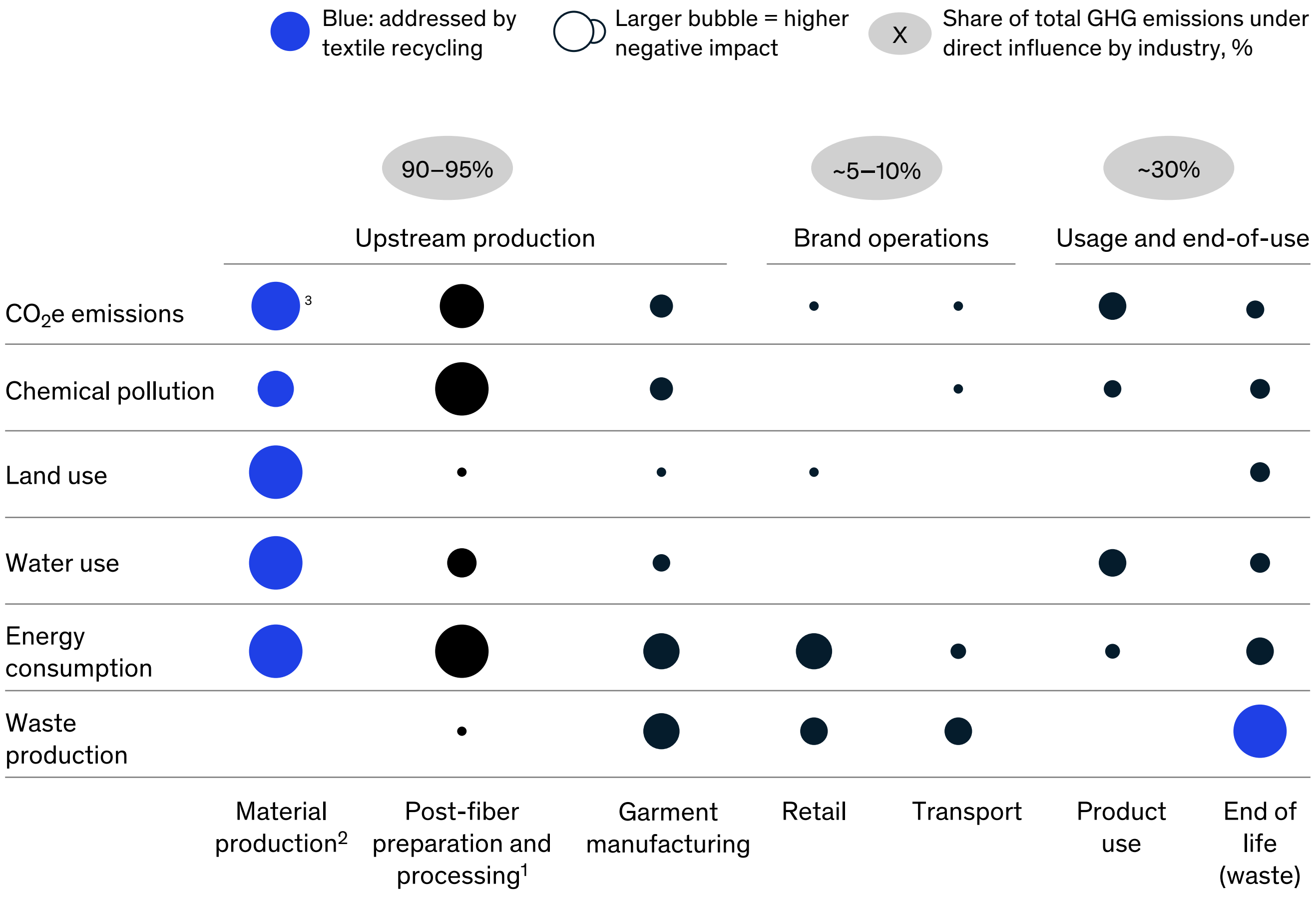
Design for circularity— with increased consideration for circularity at the design and product development stages of material consumption, as well as for the longevity and durability of the product and the recyclability of garments and home textiles—is being broadly discussed but is mostly applied only in pilot stages today.[18]

Of the available impact levers, the improvement of material production stands out as having particular environmental value as, out of the industry's total GHG emissions, around 38 percent is caused at the material production stage (Exhibit 4).[19] Furthermore, the upstream operations require many resources across land use, water use, and energy consumption, and are problematic from a chemical pollution perspective. New, innovative, and sustainable materials (such as bio-based materials) are being developed but still must be scaled.[20] In addition, waste abatement and management could be improved and expanded, and closed-loop fiber-to-fiber recycling could be ramped up.

Exhibit 4

Material production and processing are high-impact areas that represent significant resource use and most CO_2e emissions.

Estimated CO_2e emissions and other resource use across the value chain



1. Includes yarn production and fabric preparation steps due to varying degree of integration; majority will be in the wet processes.
2. Final step is fiber production.
3. Material production steps account for 38% of CO_2e emissions.

Source: *Fashion on climate*, Global Fashion Agenda and McKinsey, 2020

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[16] *The state of fashion,* Business of Fashion and McKinsey, 2021; *Fashion on climate,* Global Fashion Agenda and McKinsey, 2020.
[17] "The end of ownership for fashion products?" McKinsey, February 11, 2019.
[18] *Circular design for fashion,* Ellen MacArthur Foundation Publishing, December 2021.
[19] *Fashion on climate,* Global Fashion Agenda and McKinsey, 2020.
[20] Pauline Harmset and Harriëtte Bos, "Textiles for circular fashion: Part 1: Fiber sources and recycling option," Wageningen, 2020.

Textile recycling at scale could be a powerful impact lever because it would simultaneously address upstream production by replacing virgin materials with recycled materials, while also addressing the end-of-life waste challenge that currently exists (Exhibit 5).

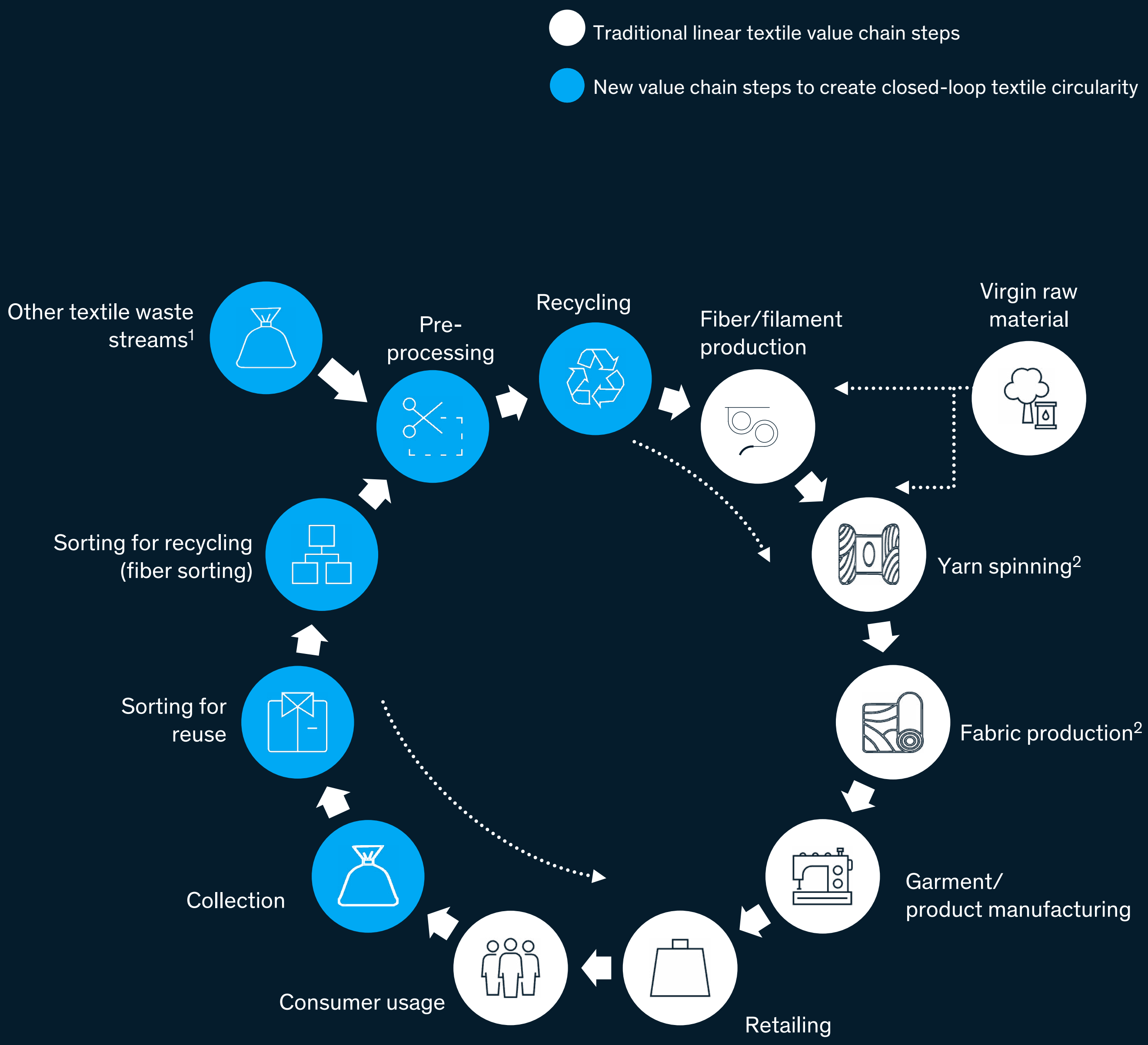
Many innovative textile-recycling technologies over the recent years have started moving from pilot stage to becoming ready for commercial scaling and, as these technologies get more advanced, they will most likely begin to offer cost-competitive alternatives to virgin fibers.

The most significant challenge, however, is the feedstock itself as all textile-recycling technologies rely on predictable sources of feedstock (that is, textile waste available to recycling). Currently, the supply of feedstock is limited due to the complexities of collection, sorting, and pre-processing of textile waste—further technological innovation and collaboration across industry stakeholders is urgently needed to fully unlock the potential of closing the loop for clothing and textiles.

Fiber-to-fiber recycling is immature. Closing the loop requires building a new circular value chain in Europe.

Exhibit 5

The closed-loop textile recycling value chain holds the potential to transform the clothing and textile industry.



[1] For example, unsellable overstock from brands or retailers, production spill from industry, or post-consumer commercial waste.
[2] Partly subject to in-house recycling.

Source: Industry experts; McKinsey analysis

2. Textile recycling technologies

Textile recycling technologies—a fast-paced race for scale and innovation

Textile recycling is one of the main solutions identified to address the textile-waste problem, along with avoiding generating waste, extending the lifetime of garments, and expanding the second-hand economy. Our analysis indicates that today's landscape for European textile recycling is characterized by fast-paced innovation and a race toward scale. There is a series of recycling technologies emerging across four main technology archetypes that have the potential to jointly recycle 70 percent of Europe's textile waste into fibers for closed-loop applications (Exhibit 6). With the possibility of reducing the carbon footprint up to 90 percent for certain fiber types, in comparison to the virgin material counterparts, as well as lower land and water usage and lower chemical pollution, the environmental incentives to pursue textile recycling are substantial.

As we assessed the recycling technology landscape, we needed to consider the various fiber types—as recycling technologies are largely applicable to specific fibers or fiber blends. Overall, polyester, cotton, man-made cellulosic fibers (MMCF), and polyamide are the dominant fibers in the clothing and home textiles value chain today and together they are estimated to represent around 90 percent of volumes.[21]

Fiber blends are, however, equally important as most recycling technologies require minimum levels of fiber purity to process textiles for closed-loop purposes.[22] An analysis based on fiber-composition data from Norna allows us to estimate the fiber composition across different brands and product categories.[23] Please see the methodology section for more detailed information. At present, the analysis suggests 50 to 60 percent of polyester or cotton respectively may have 100 percent fiber purity.[24] Pure fiber streams are relatively straightforward to use in closed-loop recycling for most technologies.

Beyond fiber composition, there are several other factors influencing a garment's or textile's recyclability (sensitivity differs across recycling technologies), including product characteristics (for example, single versus multi-layers), hard parts (for example, buttons and zippers), soft parts (for example, labels and threads), heavy coatings or finishing, prints, color (mostly relevant for mechanical recycling), fabric construction (for example, knitwear is easier for mechanical recycling than woven), and mold or oil stains.

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[21] Expert interviews; *Preferred fiber and materials market report 2021*, Textile Exchange, 2021.

[22] Fiber purity of fiber composition refers to the amount and composition of different fiber types used to create a garment. Please see the glossary for more details.

[23] Norna is an artificial intelligence company that analyzes product information based on data obtained online.

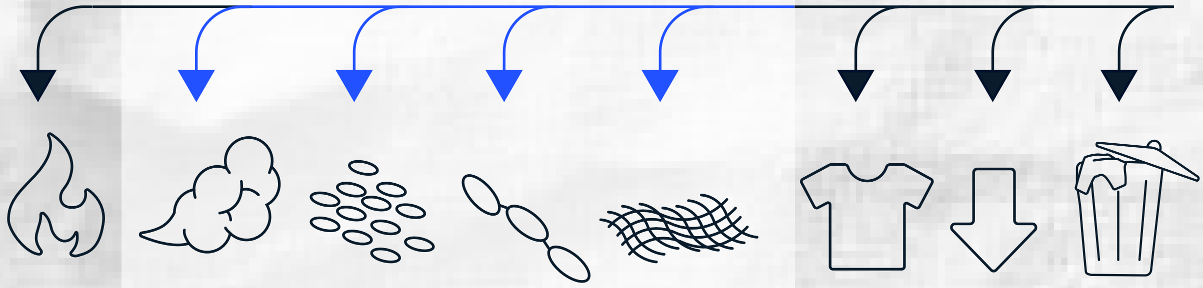
[24] Expert interviews; Norna; Textile Exchange.

The four archetypes of textile recycling

The recycling technology archetypes differ in several ways, including in their energy efficiency and their ability to return to, or keep, virgin quality. In general, however, the equally desirable traits of the ability to return to virgin quality and to be energy-efficient in the process are counter-correlated. The result is a trade-off between recycling textile waste through an energy-effective (and therefore cost-effective) process and a process that yields virgin-quality output. For that reason, the long-term solution likely includes a multitude of recycling technologies targeting different market niches. Also, the recycling technologies could realize synergies by operating in interplay. For example, the non-spinnable share of the output from mechanical recycling could be recycled through a chemical process.

Exhibit 6

4 recycling technologies archetypes are at the center of addressing textile waste in Europe.



Technology	Energy recovery	4 Thermo-chemical	3 Chemical	2 Thermo-mechanical	1 Mechanical	Refurbish/ remanufacture	Demand reduction	
Output/ recovery	Energy	Syngas	Monomers/ polymers	Polymers	Fibers	End products	Usage	Disposed products
Ability to return to virgin quality		High	High	Medium	Low			
Energy efficiency (output tons per kWh)		Low	Low	Medium	High			

1 Mechanical recycling

Mechanical recycling uses physical forces such as cutting and grinding to convert textiles into usable fibers. It is a commercially proven, low-energy, and cost-efficient recycling method. All fiber types are addressable under the “what goes in, comes out” principle, which means that the fiber composition of the textile waste will become the fiber composition of the recycled fiber. In mechanical recycling, there are both “open-loop” (mainly downcycling) and “closed-loop” applications. Currently, the open-loop applications (such as cleaning rags, shoddy fibers, and padding) are the most mature markets for mechanical recycling with a myriad different end uses. Examples include the automotive industry, furniture stuffing, wall or floor coverings, and apparel uses. [25] Our market screening shows that this technology currently faces the challenge of the quality degradation of recycled fibers with a fiber-length reduction of up to 30 to 40 percent, somewhat limiting the closed-loop applications. However, by mixing recycled, shorter fibers with virgin fibers, higher quality is obtained. This can already be found in several existing products on the market today. In addition, innovation exists to overcome this problem with the emerging “soft” mechanical recycling technology that can achieve fiber-length reduction of only 10 to 15 percent, as well as other innovations to improve mechanical recycling. [26] Companies exploring higher-quality mechanical recycling and other innovative solutions include, for example, Purfi and Recover.

2 Thermo-mechanical recycling

Thermo-mechanical recycling uses a combination of pressure and heat to melt synthetic textiles (such as polyester and polyamide) and recover polymers. The technology cannot be used for natural fibers (such as cotton or wool) or MMCF (such as viscose). It is relatively low in energy usage and has the potential to achieve less quality degradation than most mechanical recycling technologies. Thermo-mechanical recycling is a mature technology, proven at commercial scale for non-textile waste (for example, PET bottles) and at a demonstration scale for textiles. There still remain specific technical challenges to solve for textiles (e.g., viscosity issues for PET) and feedstock requirements are very strict today (more than 99% single or compatible polymers) which limit feedstock availability.

3 Chemical recycling

Chemical recycling is a broad category of multiple distinct technologies that use chemical processes to break down fibers to the polymer or monomer level. The technologies that go back to the “polymer level” include a pulping process to recycle cotton and MMCF to a pulp similar to dissolving wood pulp (DWP), which can then be used to create MMCF. They also include solvent-based and hydrothermal processes that can recycle polyester and polycotton fiber back to PET melt (and cellulosic material) which can then be respun back to PET polyester fiber. The technologies that go back to the monomer level (for example, methanolysis, glycolysis, hydrolysis, and enzymatic) focus on recycling polyester and polyamide. These recycling processes require additional processing of going from the monomer level (for example, mono-ethylene glycol [MEG] and purified terephthalic acid [PTA]) back to the polymer level, such as PET, before they can be respun back to fibers. Chemical recycling processes require more energy than mechanical recycling but have the core advantage of returning to (almost) virgin-quality fibers. On the whole, chemical recycling of textiles doesn’t yet exist at commercial scale, but many companies are building up pilot and commercial plants for both cellulosic (for example, Lenzing, Renewcell, Södra, and Infinited Fiber) and synthetic (for instance, Eastman, Erema, Worn Again, Ambercycle, Gr3n, and Circ) recycling.

4 Thermo-chemical recycling

Thermo-chemical recycling uses gasification to produce syngas through the partial oxidation reaction of polymers, and it is compatible with all forms of fibers. However, this technology is not a closed-loop application for textiles. The primary uses of the virgin-quality syngas recovered are methanol, ammonia, synthetic fuels, oxo-alcohols for plasticizer, adhesives, and construction materials. Thermo-chemical recycling as a core technology exists at commercial scale, however, this technology needs some adaptation or development for the treatment of textile waste.

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[25] Shoddy fibers can be used in many industries. While it is correct that shoddy fibers can also be used back into the textile value chain, we do not classify this as closed-loop, fiber-to-fiber recycling because it becomes a product that is different in nature from its original form. Please see descriptions in glossary for further information.

[26] Soft mechanical recycling is a process that uses a longer production line (upward ten times longer than a traditional shredding line) with maintained fiber length as a result. The longer fiber length minimizes losses from the subsequent carding and spinning processes. The soft mechanical technology is however significantly more capital intense that the traditional.

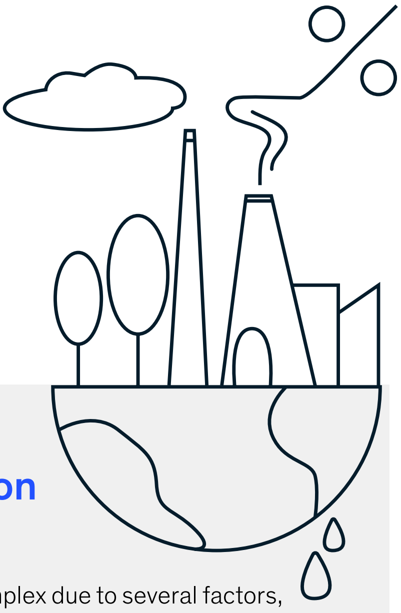
Textile recycling's contribution to emission reduction

Overall, textile recycling technologies have the potential to reduce CO_2e emissions compared to virgin-materials production by 20 to 90 percent on spun fiber levels for certain fiber types.[27] Additional benefits for reducing water and land usage, as well as chemical usage, can be achieved depending on fiber type.

As the broad range shows, a true assessment of the CO_2e emission reduction potential for the textile-recycling technologies requires a fiber-by-fiber comparison. However, there are general conclusions that can be drawn from the analysis done in this report.[28]

Mechanical recycling technologies are the most CO_2e emission-friendly, with a reduction potential of 60 to 90 percent across all fiber types on spun fiber levels. In addition, some mechanically recycled fibers avoid emission-intense, post-material processing, which saves more CO_2e emissions. Chemical pulping recycling of cotton or MMCF into MMCF has some potential to reduce CO_2e emissions compared to virgin fibers. However, the magnitude of the savings potential varies widely in different estimates and is still the subject of scientific evaluation. Conflicting estimates on impact levels exist as the virgin value chain for MMCF at times is highly optimized with biomass-run operations, while other production processes use traditional equipment and power sources, causing much higher emission levels.

Lastly, chemical recycling of synthetic fibers like polyester is expected to be CO_2e emission positive in all cases. This expectation is driven by two dimensions. First, the process emissions for recycling synthetic fibers are estimated to be lower than for virgin synthetic fibers. Second, the 2.3-kilogram CO_2e per kilogram fiber from sequestered fossil carbons in synthetic fibers cannot be double-counted—this will penalize the virgin fiber in a comparative analysis. In total, we expect a 60 to 80 percent CO_2e emission reduction for chemical and thermo-mechanical recycling of synthetic fibers compared to their virgin counterparts (Exhibit 7).



Note on process-emission estimations

Estimating process emissions is highly complex due to several factors, including:

- Variations in fiber production by region (for example, agricultural practices, water consumption, energy mix, types of equipment, and engines used).
- Complexity and lack of transparency of the value chain.
- Lack of consensus on measurements to capture emissions (for instance, including or excluding sequestered carbons, including or excluding transportation costs).
- A crowded landscape of existing emission estimations without clear consensus.

The accuracy of our estimations is hard to verify. However, there are several convincing arguments why recycled fibers likely will have a superior emission profile compared to virgin fibers.

- Recycled fibers don't add new sequestered fossil carbons or other natural carbons to the human cycle. All virgin fibers do.
- The value chain for virgin fibers exists today and is largely based on non-renewable power. If we prioritize to build a value chain largely based on renewable energy, a comparative emission advantage over the virgin value chain is created.
- The estimated process emissions for recycled fibers are in many cases far below the estimated process emissions for virgin fibers, partly because the energy bound in the molecules of the fiber is conserved.

The calculated emission reductions assume an EU-average energy mix (with some exceptions where detailed energy consumption transparency is not available). Additional emission reduction is possible if renewable energy sources are used to power the recycling process. For more details on the methodology employed, please see the appendix.

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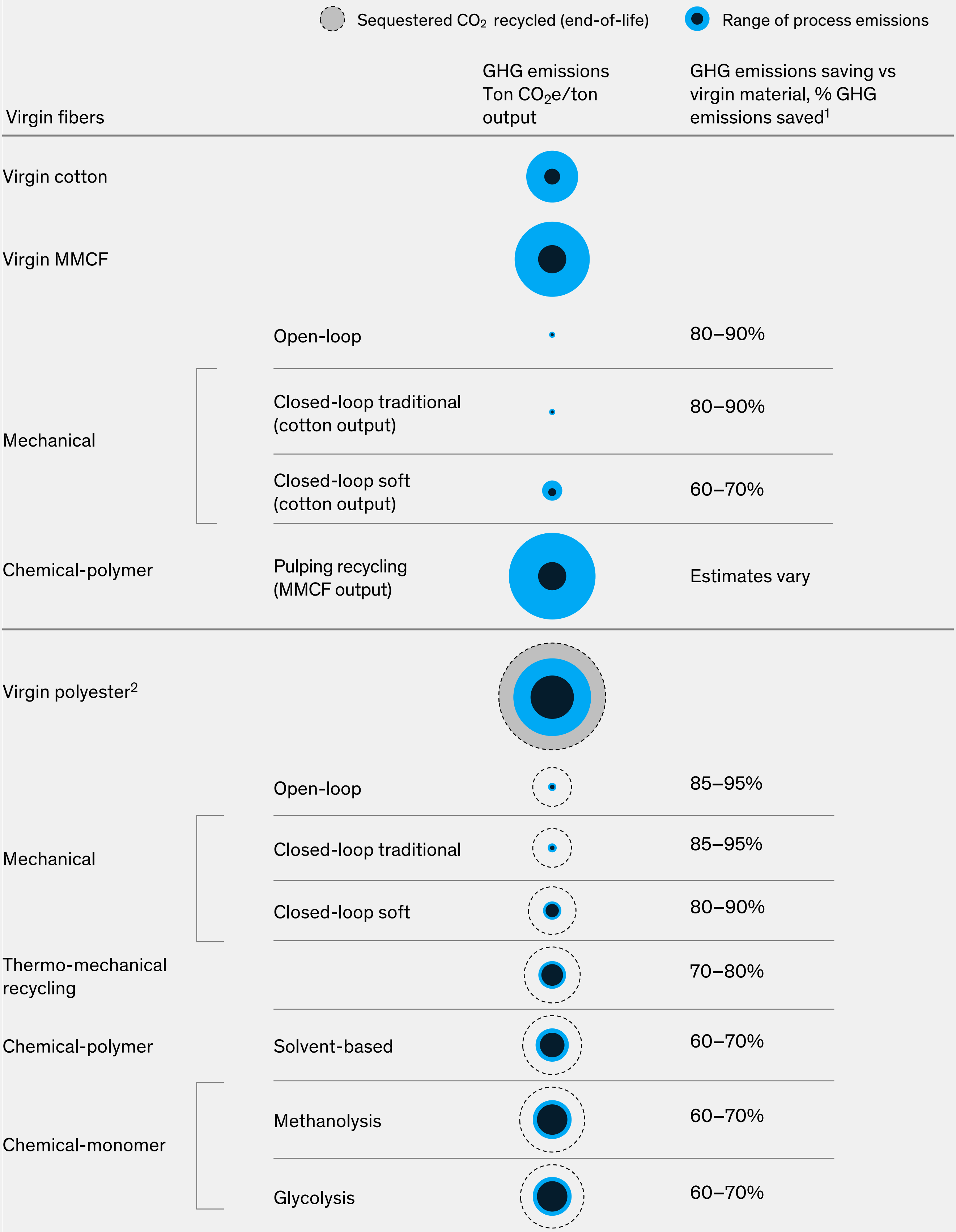
[27] Emission reduction is related to CO_2 equivalent—all greenhouse gas expressed in CO_2 equivalent.

[28] Our analysis is based on multiple reports and sources, as well as conversations with experts. Please note that is an indicative analysis. For further details, please see the appendix.

Exhibit 7

The potential for GHG emission savings of recycled fibers over virgin materials is significant.



○ Sequestered CO_2 recycled (end-of-life)   ● Range of process emissions

Virgin fibers		GHG emissions Ton CO_2e/ton output	GHG emissions saving vs virgin material, % GHG emissions saved[1]
Virgin cotton		●	
Virgin MMCF		●	
Mechanical	Open-loop	●	80–90%
	Closed-loop traditional (cotton output)	●	80–90%
	Closed-loop soft (cotton output)	●	60–70%
Chemical-polymer	Pulping recycling (MMCF output)	●	Estimates vary
Virgin polyester[2]		●	
Mechanical	Open-loop	●	85–95%
	Closed-loop traditional	●	85–95%
	Closed-loop soft	●	80–90%
Thermo-mechanical recycling		●	70–80%
Chemical-polymer	Solvent-based	●	60–70%
Chemical-monomer	Methanolysis	●	60–70%
	Glycolysis	●	60–70%

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1. Analysis accounts for the CO_2e emissions at end of life from requested fossil carbons to the virgin material and does not double count these carbons in the recycled fibers.
2. MMCF.

Source: Higg MSI; JESRT: 8(7), July 2019; JRC Technical Report, 2021; Mistra Future Fashion, 2019; recycling and industry experts; McKinsey analysis

A fundamental advantage of scaling green field recycling capacity, especially in developed markets, is the ability to ensure that only renewable energy sources are used. This could potentially reduce the process CO_2e emissions even beyond the estimations made in this paper. [29]

Chemicals, for example, are used in many recycling processes and could have potentially negative environmental impact. This creates a paradox, as the chemicals are both an enabler to create recycled fibers, which are good for the environment, but the use of some chemicals in this process can have hazardous implications for the environment. It is therefore critical that in-house recycling and strict waste-management processes are put into place to minimize the harms of chemical use in the industry. Additionally, textile waste is implicated by the chemicals used in the original production process—as the chemicals used in virgin fiber production, dyestuffs, or finishing, and others may be unfavorable to recycling. It is important that chemicals carried on from the virgin-fiber are not limiting the adoption of recycled fibers. In consequence, a very detailed consideration of chemical regulation is needed.

We encourage further investigation into and substantiation of the promise of superior environmental, social, and governance (ESG) profiles of recycled fibers.

Textile recycling technologies could tackle 70 percent of textile waste volumes

The four main technology types differ significantly in volume potential and requirements on waste input materials. However—considering the fiber mix in Europe—potentially 70 percent of textile-waste volume could be addressed by the technologies. While the share of open-loop technologies like mechanical downcycling or thermo-chemical gasification can address close to 100 percent of textile waste materials, the requirements for closed-loop, fiber-to-fiber recycling technologies limit the share of volumes suitable for recycling.

This section considers the technically addressable textile waste volumes in EU-27 and Switzerland for the respective recycling technologies. Please note that the recycling technologies will compete for overlapping textile waste, which is why the textile-waste volumes referred to are not additive.

The fiber composition data (that is, the share of cotton that is found in a 100 percent cotton product) are based on data expected to reflect the European market. However, please note that the absolute fiber data (such as the amount of cotton relative to polyester) rely on global numbers. It may be expected that the data is skewed toward polyester. A more detailed analysis is encouraged as more accurate fiber volume data for European textile waste will be collected and made available in the future. Please see the methodology section for more information on the data sources used for this analysis.

Mechanical recycling has the second-largest volume potential, as the requirements on recyclable textile waste purity for open-loop applications are low (except for downcycling into cleaning rags, which typically requires more than 50 percent cotton). Closed-loop mechanical recycling is technically capable of treating almost any fiber composition, but the market demand for and acceptance of blended fibers is a key variable in determining the volume potential of mechanical recycling. The volumes indicated can be reached if a fiber purity of minimum 65 percent is accepted in closed-loop mechanical recycling. In addition, the ability to implement innovative "soft" closed-loop techniques to compete with virgin fiber qualities will impact future volumes. Overall, mechanical recycling has, in theory, an addressable volume potential in EU-27 and Switzerland by 2030 of around 2.2 million for open-loop applications like downcycling into cleaning rags. The volume potential for closed-loop appplications is not technically limited by the recycling technologies (what goes in comes out), but rather limited by the demand for mechanically recycled blends. [30]

Thermo-mechanical recycling is limited in its volume potential as it targets high-purity fibers only. At present, 99 percent pure polyester or polyamide is needed, with a strict no-elastane requirement. As technology develops, the purity requirement could reduce to around 95 percent fiber purity. So far, the technology has mostly been proven for non-textile waste (with a more predictable and stable input), thus causing some uncertainties on the forward-looking potential.

Chemical recycling targets a broad set of fiber types including cotton, MMCF, and synthetic fibers like polyester (Exhibit 8). At this stage, the requirements for input purity create technical and economic limitations as all chemical recycling technologies are highly sensitive to elastane. Toward 2030, pulping recycling (of cotton or MMCF) could reach feedstock acceptance of 70 percent purity levels, while technologies for recycling polyester and polyamide could require more than 80 percent purity. [31]

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[29] From €280 to almost €4,000 per output ton depending on the technology.

[30] The addressable market for "soft" closed-loop mechanical recycling is expected to be slightly lower than for traditional closed-loop mechanical recycling from a technical feedstock acceptance perspective.

[31] Solvent-based recycling of synthetic fibers will have lower technical feedstock requirements compared to chemical monomer recycling, thus expanding its addressable feedstock.

Exhibit 8

Different chemical recycling technologies are capable of handling different fiber types, incl. the 3 largest by volume.

NOT EXHAUSTIVE

Chemical recycling technologies		Description	Fibers Cotton	MMCF[1]	Poly-cotton	Poly-ester	Poly-amide	Other fibers
Chemical-polymer	Pulping	Uses sulphate, sulphite, and sulphur-free to produce cellulosic pulp	●	●	●			
	Solvent-based	Uses solvent-based dissolution and filtration to extract polymers			●	●		
	Hydrothermal	Uses water containing one or more green acids to extract polymers (under pressure and high temperatures)			●	●		
Chemical-monomer	Methanolysis	Uses methanol to depolymerize (under pressure and at 200°C)				●		
	Glycolysis	Uses ethylene glycol to depolymerize (under pressure and at 200°C)				●		
	Hydrolysis	Hydrolyzes through water treatment and acid or caustic soda treatment				●	●	
	Enzymatic	Uses enzymes to depolymerize			●	●		

1. Man-made cellulosic fibers.

Source: Expert interviews; McKinsey analysis

Thermo-chemical recycling, or the gasification of materials, in principle seeks to address 100 percent of textile waste, with no limitations on fiber composition. The volume potential, therefore, is mostly determined by cost competitiveness and the competition for textile waste. Beyond textile waste, thermo-chemical recycling methods could potentially treat the residual waste of other recycling processes (such as the non-cotton share of the MMCF process), the share that is currently incinerated from the sorting steps, as well as non-textile waste.

The syngas output can replace fossil feedstocks in the several different value chains, also in the production of synthetic fibers. One advantage of the syngas recycling technology is that it deals with the long tail of waste that has no other recycling paths. For these waste volumes, gasification is superior to landfilling or incineration from an environmental standpoint, making it a vital component to fully solve the European textile-waste problem.

Note on the textile-waste volume potential beyond EU-27 and Switzerland

Addressing waste streams beyond textile waste is technically possible for several recycling technologies. For example, the chemical polyester-recycling process could also tap into PET plastic packaging waste, and chemical pulping recycling could in future potentially tap into other cellulose-rich waste materials. Furthermore, open-loop recycling processes and thermo-chemical recycling could tap into other waste streams. Finally, all fiber-to-fiber recycling technologies could tap into waste streams outside EU-27 and Switzerland (for example, production spill in Turkey). As a consequence, the overall global volume potential for the individual recycling technologies should be based on analysis extending beyond the textile-waste volumes in EU-27 and Switzerland analyzed in this paper.

The cost of textile recycling technologies

We analyzed capital investment needs, operating costs, and potential sales prices of recycled fibers to assess investment needs for scaling recycling technologies and the cost competitiveness of recycled fibers (see details on the methodology of this analysis in the appendix). As the emerging technologies mature and scale toward 2030, costs to set up textile recycling will stretch across a broad range—from €280 to almost €4,000 per output ton depending on the technology.[32] At the same time, the value of the regenerated material varies widely, for example, roughly mechanically recycled fibers for open-loop uses achieve a much lower potential sales price compared to high (virgin-like) quality regenerated fibers, which can flow directly back into garment production.

Mechanical recycling is a clear example of these dynamics. Open-loop recycling will remain the cheapest among all recycling technologies to operate—with an estimated total cost of only €280 to €560 per output ton at scale in 2030 (Exhibit 9). This recycling process is already operating profitably today. However, as the output is converted into downcycled products (such as cleaning rags and shoddy fiber), it achieves lower sales prices and has limited revenue potential.

Closed-loop, fiber-to-fiber recycling technologies, in contrast, are at a higher cost, almost twice that of open-loop. Despite this, traditional technologies for closed-loop recycling remain highly cost-competitive with other recycling technologies at a total cost of €500 to €900 per output ton. Depending on the input materials, which influence both the feedstock cost and revenue potential, traditional mechanical recycling is expected to be profitable for high- and mid-purity fibers. However, the quality of output often will be below virgin fibers due to the reduction of fiber length. Fiber length reduction is unfavorable because long fibers are associated to high quality.

The currently emerging "soft" mechanical recycling technologies, on the other hand, will be significantly more expensive with total costs of €3,000 to €3,900 per output ton at scale cost in 2030. These higher costs are offset by a superior revenue potential as the high-quality long fibers regained can be spun into yarn directly without the need for mixing virgin fibers. Both mechanical soft and traditional recycling hold potential to surpass several subsequent expensive value chain steps like washing, bleaching, and dyeing.

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[32] All cost estimates exclude feedstock and include 15 percent capital-expenditure charge.

Exhibit 9

“Soft” closed-loop is the most expensive mechanical recycling technology, but generates high-value recycled fibres.

Summary of estimated costs at maturity, € per output ton

Mechanical recycling

	Opex (excl. feedstock)	Capex (15% capex charge)	Total cost (with 15% capex charge)	Potential price per output ton
Open-loop/ downcycling	250–500	200–400 (30–60)	280–560	Low
Traditional closed-loop	450–800	300–600 (45–90)	500–900	Medium
“Soft” closed-loop	2,700–3,500	2,200–2,400 (330–360)	3,000–3,900	Very high

Source: Company press releases; industry experts; McKinsey analysis.

Thermo-mechanical recycling will likely be similarly cost-effective compared to traditional closed-loop mechanical recycling, ranging from €500 to €950 per output ton, including the required fiber-spinning step such as going from PET granulate to polyester fibers (Exhibit 10).

Chemical-recycling technologies are associated with high-scale efficiencies and high-value fiber outputs (Exhibit 10). A plant size of 50 kilotons to 200 kilotons could realize the required scale benefits to become cost-competitive with virgin material production. The cost of chemical-polymer-recycling technologies of pulping cellulose-rich fibers and solvent-based recycling of synthetic fibers is less sensitive to scale efficiencies than that of chemical-monomer recycling (of synthetic fibers).

Chemical pulping recycling of cellulose-rich fibers is a capital expenditure- and operating-expenditure-intense process, driven by the expensive fiber-spinning step. At a total cost ranging from €1,570 to €2,600, it is among the most expensive of the recycling technologies.

Solvent-based chemical recycling has an estimated cost of €950 to €1,500, making it the most cost-effective way of recycling synthetic fibers, as the polymerization step from monomers to polymers is avoided. It also, in theory, could create two output streams from poly-cotton blends: one of cellulosic powder or slush that could be processed by MMCF players, and one of recycled PET that could be spun into fibers. Currently the pursuit of dual-output streams is in early stages, yet it could be a valuable option for investors and players.

Chemical monomer recycling, like methanolysis and glycolysis, has the second-highest total cost compared to other chemical recycling technologies, driven by heavier capital investment needs, partly due to the added polymerization step. Methanolysis and glycolysis are expected to be similar in their cost structure at total cost ranging from €1,200 to €2,300 per output ton and €1,150 to €2,200, respectively (Exhibit 10).

Exhibit 10

Solvent-based chemical polymer recycling could become the most cost-efficient chemical recycling option for synthetic fibers.

Summary of estimated costs at maturity, € per output ton

		Opex (excl. feedstock)	Capex (15% capex charge)	Total cost (with 15% capex charge)	Potential price per output ton
Thermo-mechanical		400–850	650–800 (100-120)	500–950	High
Chemical-polymer	Pulping	1,000–1,900	3,800–4,700 (570–700)	1,570–2,600	High
	Solvent-based	750–1,300	1,350–1,500 (200–230)	950–1,500	High
Chemical-monomer	Methanolysis	825–1,750	2,450–3,700 (370–560)	1,200–2,300	High
	Glycolysis	825–1,700	2,150–3,400 (320–510)	1,150–2,200	High

Source: *Chemical recycling of plastics by plastic dissolution*, University of Pennsylvania; FischerSolve; IHS Markit, industry experts, McKinsey analysis

Finally, thermo-chemical recycling has broad applicability, as discussed above, but it is an open-loop technology that does not produce textile fiber outputs. Methods such as pyrolysis or gasification convert fibers to their chemical building blocks, which can then be reprocessed in upstream refining and petrochemical processes. Breaking down the materials to a molecular level is capital-intensive—the basic output materials require significant rework, likely resulting in higher processing costs and a greater carbon footprint. Close integration with refining or petrochemical assets is expected to be a prerequisite to ensure the recycled products could be monetized and used again in the production of base and intermediate chemicals.

On their path toward scale, the recycling technologies must invest, collaborate, and innovate. Investments are needed to improve unit economics and overcome technical bottlenecks. Collaboration between brand and retail designers, product developers, and their customers helps improve their output quality.[33] And finally, innovation is needed to tackle a broader variety of material blends and the ability to generate dual-output streams for poly-cotton blends.

These steps could help technologies achieve their full volume potential. If the industry succeeds in scaling, incumbents could unlock new horizons of green growth, and multiple sustainability unicorns could be born. Europe, as one of the largest textile markets globally, and with a long history in the clothing and textile industry, could turn the increasing textile-waste problem into an opportunity for environmental, social, and economic value creation. Securing well-sorted feedstock from the European textile-waste streams will be the key prerequisite for the industry to scale up.

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[33] *The state of fashion,* Business of Fashion and McKinsey, 2022.

3. Europe's textile waste

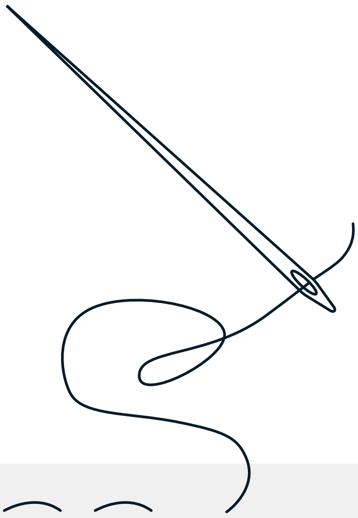
Ramping up collection, sorting, and pre-processing will help solve the European textile-waste issue

Currently, 7 million to 7.5 million tons[34] of gross textile waste are generated in EU-27 and Switzerland every year—this corresponds to slightly more than 15 kilograms per person.[35] The vast majority (around 85 percent) of this textile waste comes from clothing and home textiles discarded by households, which mostly ends up being incinerated or in (often rogue) landfills across the globe (with a negative impact on local ecosystems).[36] The remainder of the waste comes from post-consumer commercial waste, post-industrial, and pre-consumer waste (Exhibit 11).

Textile waste is inherently fragmented. While 85 percent comes from the same source (discarded clothing and home textiles from consumers), consumers as a category are fragmented. Furthermore, even the largest brands and retailers represent a small share of total volumes, and the value chain production is also fragmented and partly untransparent. Therefore, the collection of textile waste from different sources is a key strategic barrier to scale textile recycling in Europe.

Around a third (30 to 35 percent) of the post-consumer household textile waste is currently collected.[37] Approximately 40 percent of this is directly exported to second-hand markets in countries outside Europe, while the remaining share is sorted to identify more in-demand garments to be sold for reuse in Europe or other developed countries.[38] Of the waste volumes that are manually sorted in Europe, around 60 percent is currently sold for reuse to local or global second-hand markets.[39]

The remaining 0.5 million tons of post-consumer household waste, as well as the additional 0.2 million tons from other waste streams (amounting to 0.7 million tons or 10 percent of total gross textile-waste volumes in EU-27 and Switzerland), are in theory available to recycling (Exhibit 11). However, only a small fraction of this is fiber-to-fiber recycled today.[40]



Note on fibers and textiles eligible for recycling

All textiles are made of fibers, but not all fibers are used to make clothing or other home textile products, which are the primary drivers of textile waste in Europe. Fibers are used for many applications in multiple industries, including technical components, medical products, agriculture products, construction products, non-woven products, insulation, industrial textiles, and—of course—consumer textile products like clothing and home textiles. Although the textile-recycling processes discussed in this paper return to the fiber stage, not all fiber products—and not even all textile products—are relevant from a feedstock perspective for the recycling technologies considered. Many fiber or textile products are used in such a way that they require highly specialized waste treatment and recycling once they have reached the end of their life span.

The primary focus of this paper is to recycle—and close the loop—for the clothing and textile industry. There are selected fiber waste sources from production spill that could be attractive for fiber-to-fiber recycling. These have been included in our estimations. However, the end-of-life waste considered focuses only on post-consumer household waste and the relevant parts of post-commercial waste. Please see the methodology section for more details on our estimations of relevant textile waste volumes in EU-27 and Switzerland.

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[34] Country reports; Joint Research Centre, 2021 (see the list of sources at the end of the report for more details).

[35] Seven million to 7.5 million divided by 456 million (the combined population of EU-27 and Switzerland); World Bank.

[36] “Poisoned gifts,” Greenpeace International, April 2, 2022.

[37] Country reports (see the list of sources at the end of the report for details); Joint Research Centre, 2021.

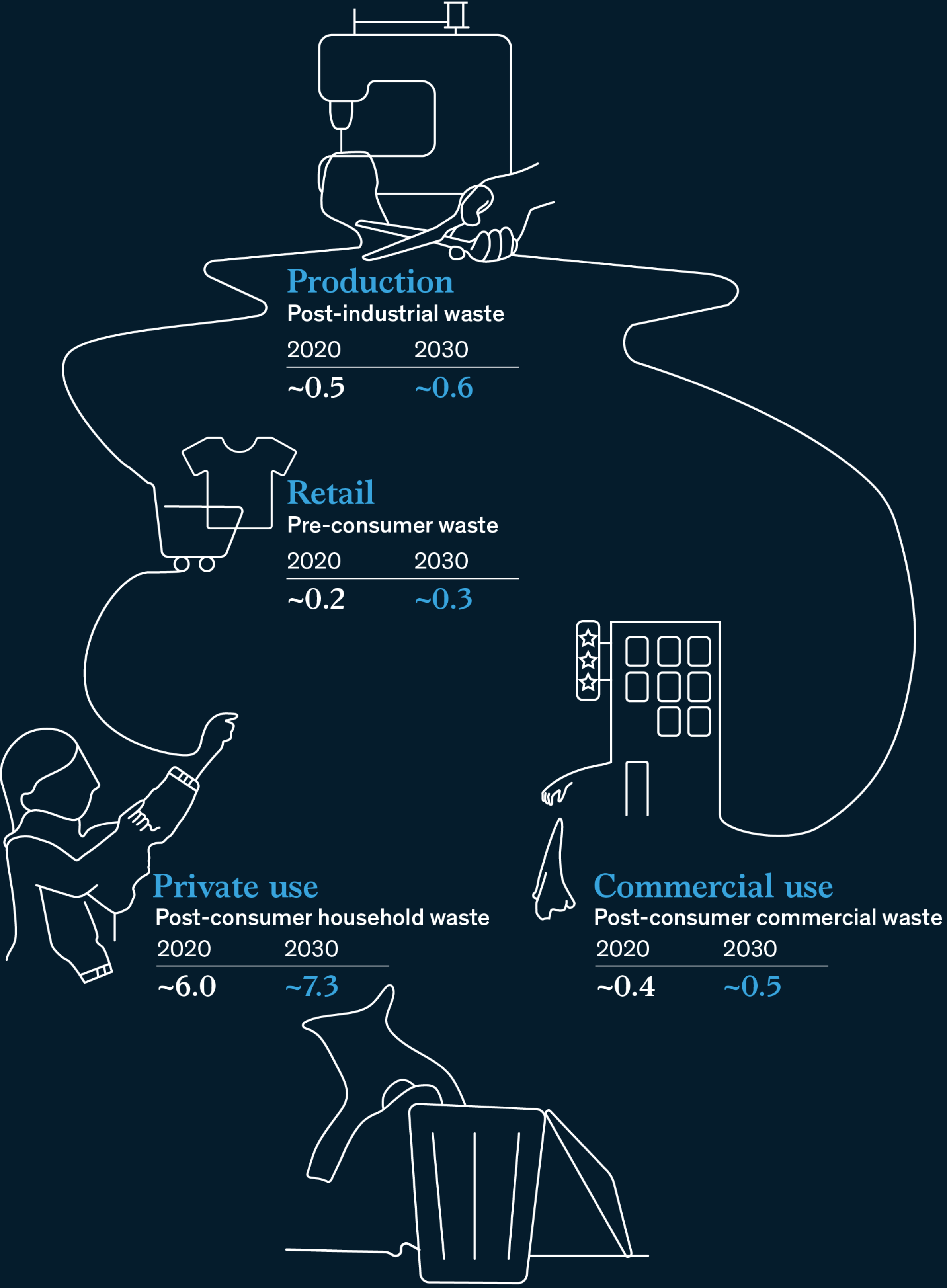
[38] Gherzi; industry experts.

[39] Industry experts.

[40] *A new textiles economy: Redesigning fashion’s future,* Ellen MacArthur Foundation, 2017.

Exhibit 11

Gross textile waste in EU-27 and Europe is expected to grow from 7.0 million to 7.5 million tons today to 8.5–9.0 million tons in 2030.



Production

Post-industrial waste

2020	2030
~0.5	~0.6

Retail

Pre-consumer waste

2020	2030
~0.2	~0.3

Private use

Post-consumer household waste

2020	2030
~6.0	~7.3

Commercial use

Post-consumer commercial waste

2020	2030
~0.4	~0.5

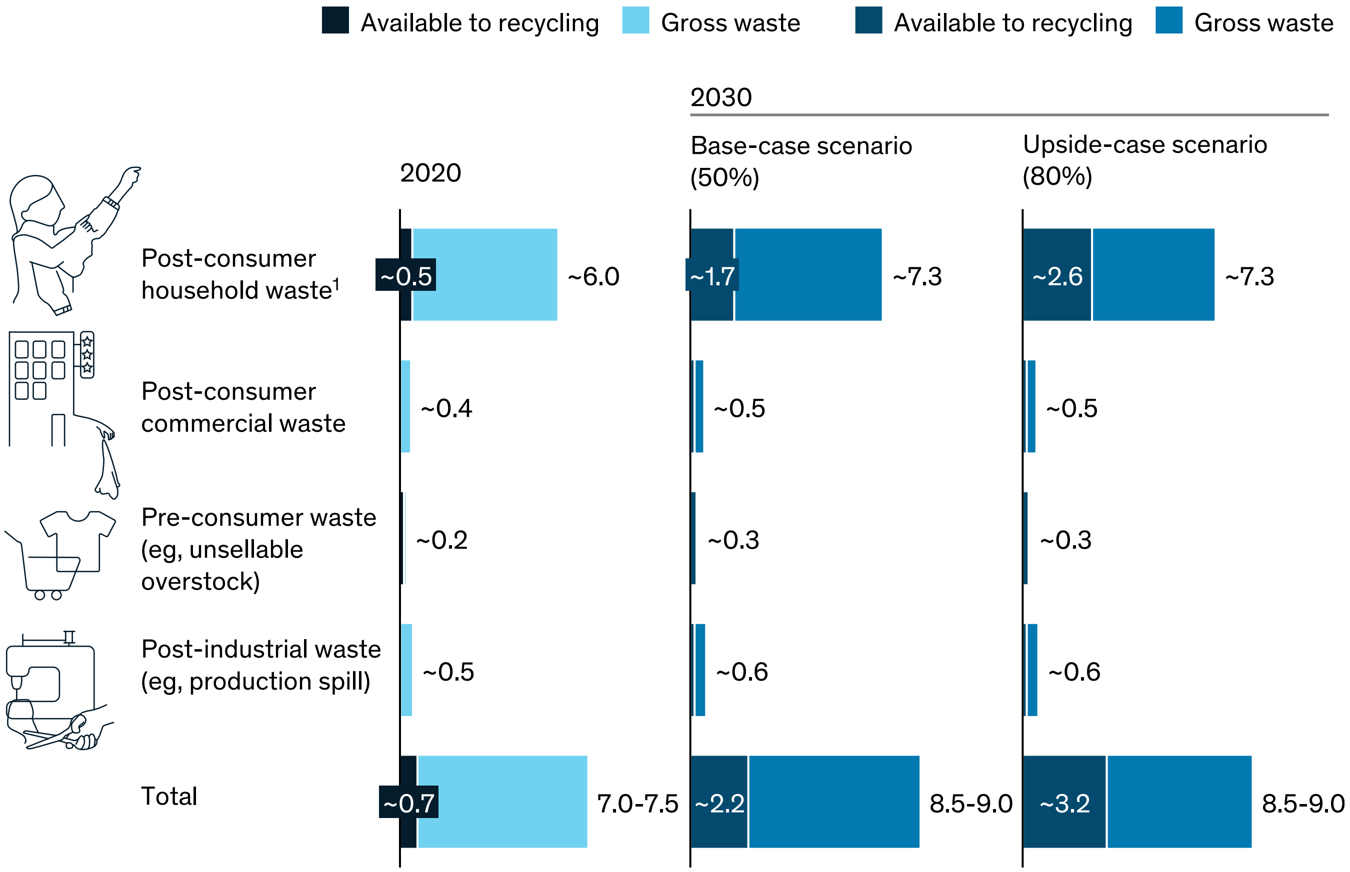
Total gross textile waste

2020	2030
7.0–7.75	8.5–9.0

Exhibit 12

The total textile waste volumes that are available to recycling could go up from around 0.7 million tons today to around 2.2 million tons in 2030.

Textile waste volume flow, million tons



1. Estimated historical values for 2020; estimated scenario for 2030.

Source: Deloitte European Market Study for ETSA, 2014; Ellen MacArthur Foundation; EUROSTAT Prodcom; expert interviews; Humana Annual Report, 2020; Intecus, Germany report, 2020; ISRPA, Italy reports no. 1 and no. 2, 2021; JRC, 2021; Modare, Spain report, 2021; Rebel, Netherlands report, 2021; ReFashion, France report, 2020; Nordic Council for Ministers Baltic countries reports, 2020; Umweltbundesamt, Austria report, 2022; McKinsey analysis

85% of textile waste comes from clothing and home textiles discarded by households.

The European waste problem will likely accelerate—by 2030, gross waste volumes are predicted to increase to 8.5 million to 9 million tons, driven by increased consumption and population growth, as well as GDP growth.[41] As recycling technologies are ready to scale, they require larger volumes of well-sorted feedstocks to be effective. Furthermore, increasing collection rates and improving the quality and efficiency of sorting and pre-processing will likely be key to scaling textile recycling in Europe.

With the implementation of EU regulation on separate textile-waste collection by 2025 and the positive effects to collection and waste management of producer responsibility organizations (PROs) established in member states, rates for the collection of post-consumer household waste could increase to 50 percent by 2030 (according to our base-case scenario). In the long term, Europe should aim to collect all textile waste, but reaching this goal will take time. We expect that the direct export of textile waste will be limited by law, and, with the shift of volumes from used clothes donations to waste disposal, a lower share of collected items will likely be suitable for resale.[42] Overall, the share of post-consumer household textile waste that becomes available to recycling is forecast to increase to around 1.7 million tons by 2030. Furthermore, additional feedstock from other sources could almost triple to reach around 0.5 million tons, bringing the total volumes available to recycling to around 2.2 million tons or approximately 25 percent of gross volumes by 2030.

Currently around 6 million tons of textile waste are generated by private households' discarded clothing and home textiles, making post-consumer household waste the largest category, accounting for around 85 percentage of total textile waste in Europe.[43] And by 2030, volumes are expected to increase to around 7.3 million tons.

> **25 percent of private households' textile waste could become available to recycling in 2030.**

Around 10 percent (0.7 million tons) of consumers' textile waste is currently available to recycling, as only about a third of post-consumer household waste is collected and a larger share is resold to local or international second-hand markets. By 2030, the textile waste available to recycling could increase by a factor of three to four (Exhibit 12). The main reason for this growth is the expected expansion of textile waste available to recycling from post-consumer household waste, reaching 1.7 million tons in the 2030 base-case scenario. This is likely driven by an increase in gross volumes from 6 million tons to around 7.3 million tons, an increased collection rate from 30 to 35 percent up to 50 percent on average in post-consumer household waste across EU-27 and Switzerland, a reduction in the share of collected textiles that are immediately exported from 40 percent down to 10 percent, and a reduction in the reuse portion of volumes in Europe from 60 percent down to 50 percent. The resulting share of gross textile waste that could become available to recycling thus goes from today's 10 percent to 25 percent in the 2030 base-case scenario. This number be even higher (estimated to be 37 percent) in the upside-case scenario where 80 percent of the post-consumer household textile waste would be collected.

The analysis of textile recycling technologies in Chapter 2 indicates that technically 70 percent of this textile waste could be recycled when the recycling technologies reach maturity. Today, however, actual recycling rates are still far lower. Recyclers currently struggle to access high-quality and well-sorted textile waste due to the high fragmentation of the collection, sorting, and pre-processing landscape, the export of unsorted waste, and a lack of high-quality fiber sorting and pre-processing at scale.

Structural and technical challenges in collection, sorting, and pre-processing need to be overcome.

Textile sorters play a critical role in the circular value chain. Once textile waste—for example, post-consumer household waste from donations or separate waste collections—has been transported to sorting facilities, textiles are categorized into what can be reused, recycled, downcycled, and what has to be incinerated.

To successfully scale Europe's textile recycling, the issues of the fragmentation of the textile-sorter landscape, and the increasing demands on sorting accuracy (to identify high-quality feedstock for the emerging recycling technologies) need to be solved. As textile waste is becoming a valuable resource for recycling, sorters will need to receive a higher mark-up compared to the currently low prices of recyclable materials.

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[41] Joint Research Centre, 2021; 2% CAGR—estimated waste growth per ton.

[42] Under the recent Commission proposal for the new EU rules on the shipment of waste, the export of textile waste to non-OECD countries would be allowed only under the condition that such countries notify the Commission of their willingness to import specific types of waste and demonstrate their ability to manage it sustainably.

[43] Country reports (see the list of sources at the end of the report for details); expert interviews; Joint Research Centre; McKinsey analysis.

Today's textile collection and sorting ecosystem is highly fragmented. The top five textile sorters in Europe handle about 80,000 to 100,000 tons of collected textiles each and share around 25 percent of the market. The middle segment handle between 25,000 and 80,000 tons of collected textiles each and share around 30 percent of the market. Finally, the long tail of textile collectors and sorters share around 40 to 50 percent of volumes, with low annual volumes of less than 25,000 tons each (Exhibit 13). Often, these small companies can at best achieve low sorting accuracy with high inconsistency. They ship what they might consider as goods for reuse to international markets, though more sophisticated sorters might classify a larger proportion as feedstock for recycling—or as waste—and manage it accordingly. This presents a problem for the receiving countries (often in the Global South), as they might lack the infrastructure to sort and handle the large waste volumes[44], resulting in excessive—and rogue—landfills and a negative impact on local ecosystems.[45]

At the same time, Europe is losing valuable feedstock that could be suitable for recycling. Regulatory action such as prohibiting export of unsorted textile waste outside EU could help address this and, consequently, could potentially drive consolidation in the textile sorting space—thus simplifying feedstock sourcing for recyclers.

18–26%

of EU-27 and Switzerland's textile waste could be fiber-to-fiber recycled by 2030.

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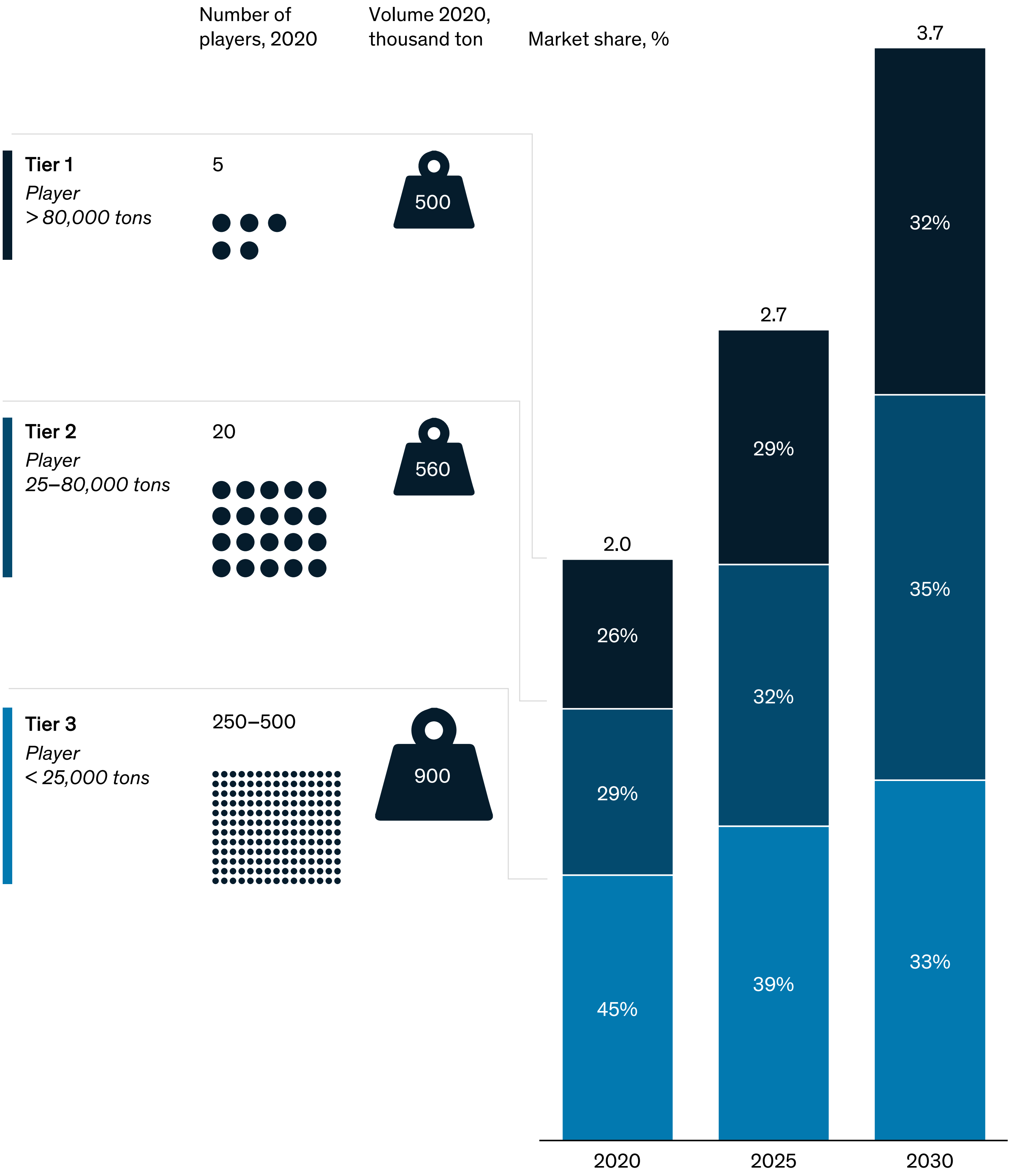
[44] Some of the volumes are reused and could in theory also be recycled outside Europe. However, there are indications that they often end up in a system without good waste management infrastructure.

[45] "Poisoned gifts," Greenpeace International, April 22, 2022.

Exhibit 13

The European textile collection and sorting market is currently fragmented, but some consolidation is expected.



Source: Expert interviews; Humana Annual Report, 2020

Manual sorting is still dominant, while demands for accurate fiber sorting are increasing. A common issue textile recyclers face is the need for well-sorted feedstock. Multiple recycling technologies have strict thresholds for fiber content—for example, solvent-based recycling of poly-cotton could in future treat up to 10 percent elastane and chemical pulping recycling could treat around 5 percent elastane; however, thermo-mechanical recycling has very strict no-elastane requirements. Therefore, the ability to sort textile waste by fiber characteristics with high accuracy and at scale is critical for the industry; clothing labels don't always give accurate information on fiber composition.[46] Currently, near-infrared scanning systems (NIRS) are among the most promising innovative technologies to overcome the bottleneck at the sorting level. Multiple technology providers are innovating to refine the technology, running several test sites across Europe to finetune real-life fiber sorting, however, the integrated system of NIRS scanning and its accurate separation of garments is not yet proven, and there are limited alternatives.

Pre-processing remains complex and costly. Pre-processing consists of cleaning, removing parts that cannot be recycled, and cutting into fabric swatches. The removal of hard parts such as buttons and zips is essential across all recycling technologies as they disrupt required material purity levels, could damage machinery, and pose a fire risk. Pre-processing remains a major bottleneck for scaling textile recycling.

Costs of pre-processing and the preferred value chain integration for pre-processing vary across recycling types. In general, mechanical recyclers could experience high pre-processing costs because they need to be careful not to cause fiber destruction, which makes automation comparably hard. In contrast, chemical recyclers could benefit from lower pre-processing costs as higher automation is achievable. Pre-processing could be integrated as part of the fiber-sorting step, thereby unlocking synergies.

Improved design for circularity could help reduce the requirements for pre-processing in the long term. However, in the foreseeable future, most textiles will be designed following traditional standards and there is an additional time lag as textile-waste collection always includes volumes produced many years earlier. Therefore, developing high-quality pre-processing at the right cost and at scale remains a bottleneck for the sorting and recycling industry to overcome.

The value of reuse exceeds the value of recycling. There is superior environmental and financial value for reusing rather than for recycling products—meaning that there are dual forces (environmental and economic) at play that will limit the access to textile feedstock for recyclers.

The task of sorting and classifying textiles for reuse involves a relatively complex method and manual fiber sorting (which is still dominant) is economically challenging. Based on the quality, category, and season of the textiles,[47] up to 300 categories for reuse exist. The main revenue and profit stream for textile sorters is selling to second-hand markets, while selling textiles to recyclers is currently of limited profitability, or sometimes even sold at a loss.

On average, prices of €4,000 to €5,000 per ton for top-quality resale items could be charged by sorters for sales in Western markets—prices could even go as high as €13,000 per ton. On international second-hand export markets, much lower prices of €1,000 to €1,200 per ton are observed and expected. The share of volumes sold on the second-hand market is expected to decrease in the future as the total collected volumes rise—this assumes that the higher-value garments are collected and resold today at higher shares than lower-value garments. Despite smaller volumes, the resell market will still account for the largest share of a sorter's revenue.

In contrast, the prices of non-reusable or resellable volumes that are open-loop recycled into shoddy fibers and cleaning rags currently range between €100 and €150 per ton on average. With increased overall collection, these volumes are expected to increase (Exhibit 14).

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[46] Hilde van Duijn and Jade Wilting, "Clothing labels: Accurate or not?" Circle Economy, 2018.

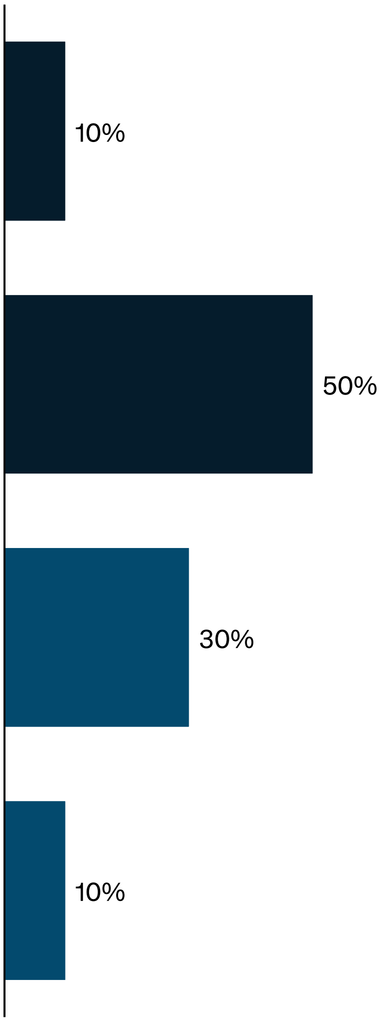
[47] For example, winter or summer season clothing.

Exhibit 14

For textile collectors and sorters, the highest value is captured by selling volumes to the second-hand markets.

Overview of current revenue dynamics for textile collectors and sorters

■ Available for recycling

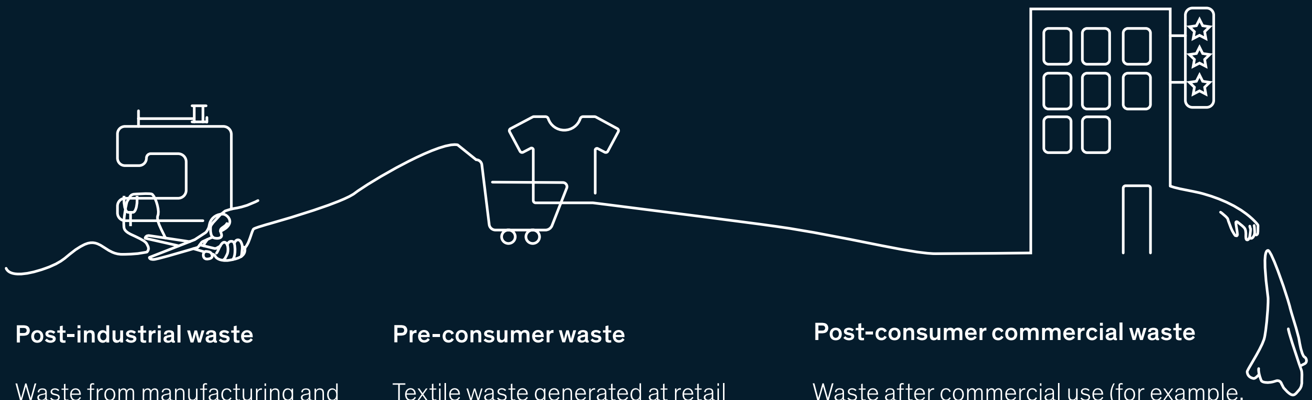


	Sorted volumes, 2020	Observed price range, €/ton	Average price for category, €/ton	Suitable for recycling
Second-hand, European market	10%	€3,500–€13,000	€4,000–€5,000	✖ No, resale in all cases
Second-hand, international markets	50%	€200–€3,500	€1,000–€1,200	✕ Resale should be prioritized when possible
Open-loop: eg, rags & shoddy fibers	30% ■	Open-loop: €0–€600 Wipes: €70–€300	Open-loop: €100–€150 Wipes: €100–€150	✔ Yes, according to feedstock requirements
Waste (incineration/ landfill)	10% ■	-€200–€0	-€100–-€150	✓ Likely parts of it that fit feedstock requirements

Source: Expert interviews; Gherzi, 2019

Non-household textile waste in Europe

Non-household textile waste (comprising post-industrial, pre-consumer commercial, and post-consumer commercial textiles) only accounts for about 15 percent of the textile waste in Europe today.[48] Each of these waste streams comes with its own challenges regarding collection, availability for recycling, and recyclability.



	Post-industrial waste	**Pre-consumer waste**	**Post-consumer commercial waste**
Characteristics	Waste from manufacturing and production processes. Includes waste from the clothing and home textile value chain and the technical application value chain.	Textile waste generated at retail level. Only unsellable overstock is available to recycling; the remainder is sold for profit to traders and other channels.	Waste after commercial use (for example, from hotels). Textiles are either owned or rented. Waste often consists of homogenous products with favorable fiber mixes that generally are not contaminated.
Volumes	0.5 million tons in 2020, with limited growth to 0.6 million tons in 2030.[49]	0.2 million tonsin 2020, with limited growth to 0.3 million tons in 2030. Only 3 to 5 percentof gross market volumes (6 million tons in 2020, 7.3 million tons in 2030) are expected to be ultimately unsellable.[50]	0.4 million tons in 2020, with limited growth to 0.5 million tons in 2030.[51]
Collection rate	Our analysis indicates a low collection rate today across the different value chain steps, due to the highly fragmented nature of production. Collection rates are expected to increase to between 30 and 50 percent by 2030. Please note that this is an average estimation, as large variations are expected for individual entities across the value chain.	“Collection” happens largely naturally as brands and retailers “collect” their overstock. Around 70 percent is expected to remain in by the original retailer or a professional counterpart in Europe, which gives it a collected status in our analysis.	Experts indicate that structured collection is low. There are no regulated collection schemes; items are generally sent for incineration or to landfills. Our assessment suggests that around 45 percent could be collected by 2030. This estimate is based on our bottom-up analysis assessing each sub-category of commercial textiles. Please note that this number is an average across different types of commercial waste. Large variations are expected in the different types of post-consumer commercial waste.
Availability for recycling	Varies by production spill category. Some in-house collection occurs.	Assumed to be high as alternative use cases are limited.	Assumed to be high as alternative use cases are limited.
Other considerations	Some of the chemicals used in processing make it harder to recycle using existing technologies. The textile value chain is highly fragmented.	The complex composition of items and fiber blends requires waste to be sorted and pre-processed, preventing it from being recycled at scale. The highly fragmentedlandscape of collectors and sorters is also a challenge.	Current low collection rates could be addressed by policy change and increased collection consolidation. Both are potentially actionable, given that textile rental companies make up 80 percent of the market.

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[48] *Circular economy perspectives in the EU textile sector,* Joint Research Centre Technical Report, 2021.

[49] European Commission, Joint Resource Centre, 2021; expert interviews; McKinsey analysis.

[50] Ellen MacArthur Foundation; expert interviews; McKinsey analysis.

[51] *Deloitte European Market Study for ETSA*, 2014; expert interviews; McKinsey analysis.

4. European business case

The European business case for a circular textile ecosystem at scale—an environmental, social, and economic value creation opportunity.

Textile recycling at scale needs to be urgently addressed to solve Europe's growing textile waste challenge. However, several questions arise regarding the development of the textile recycling value chain:

- What is the holistic impact potential for Europe?
- What are the required investments to scale up the textile recycling value chain?
- Could the textile recycling value chain reach profitability at price parity to virgin fibers?
- Will there be sufficient demand for recycled fibers?
- Should the clothing and textile industry expect green price premiums for recycled fibers?

The business case for closed-loop recycling relies on operational profitability, which is needed to attract investors and talent. Our analysis finds that by truly embracing the textile recycling challenge, backing ambition with investments, and risk taking, the industry could develop a profitable and circular value chain.

According to the base-case scenario for 2030, textile recycling in EU-27 and Switzerland could unlock a €1.5 billion to €2.2 billion profit pool and create around 15,000 new green jobs. Environmental impact could be created on several dimensions, including land-use, water-use, and chemical-use reductions, and save up to 4.0 million to 4.3 million tons of CO_2e emissions. Jointly, the environmental factors could account for 35 to 40 percent of the total holistic impact (Exhibit 15).

At maturity, our analysis finds that textile recyclers will likely be able to create recycled fibers at cost-parity with virgin fibers and therefore reach profitability without having to charge green premiums. If a green premium of 25 percent were to be applied by manufacturers, the profit pool would almost double, reaching the higher end of the estimate of €2.2 billion. If translated into monetary terms, the integrated holistic impact across company profit pools, jobs creation, environmental savings, and company profits could reach a total of €3.5 billion to €4.5 billion.

15,000

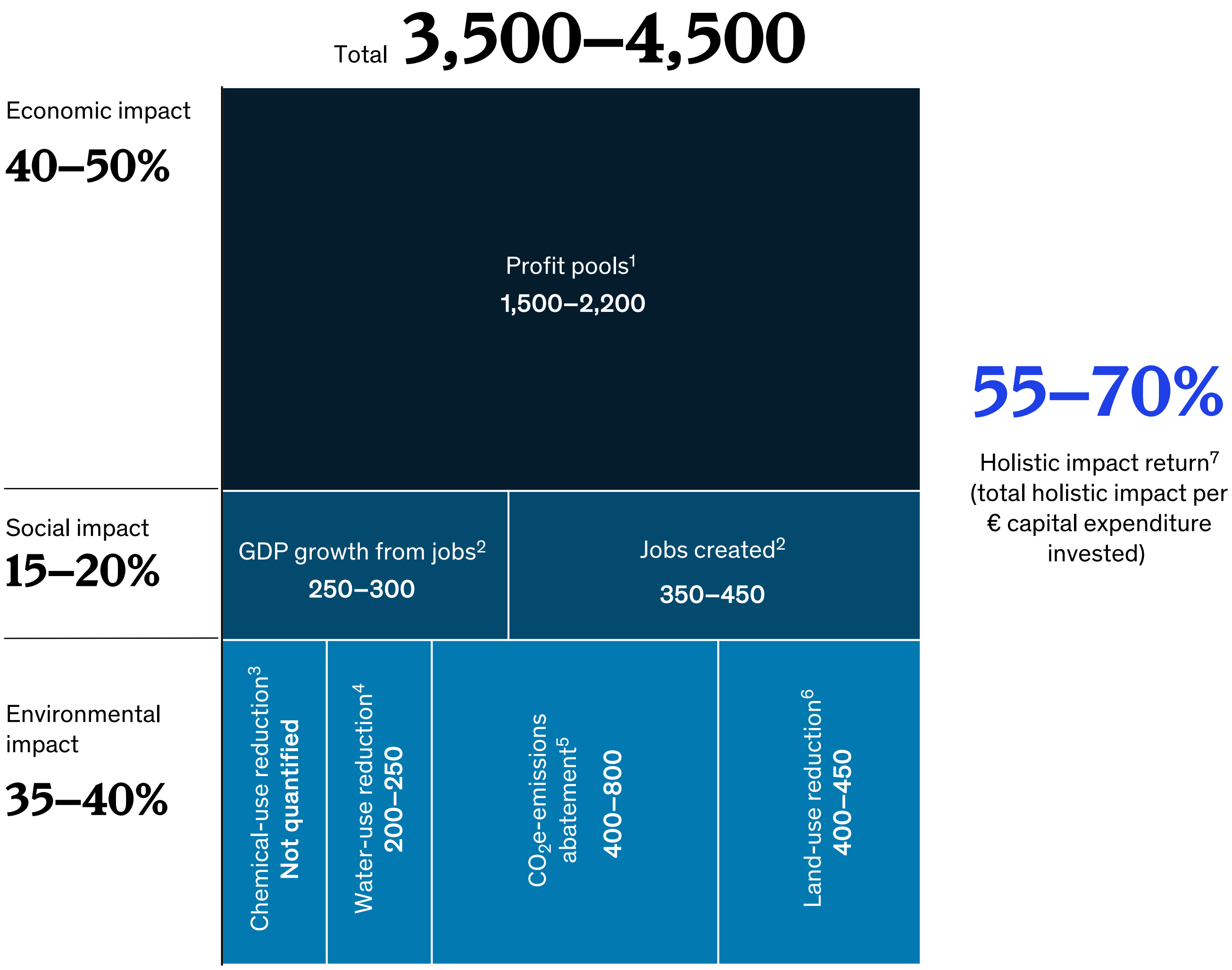
new green jobs could be created by 2030.

Exhibit 15

Scaling textile recycling in EU-27 and Switzerland to the base-case scenario could yield an annual holistic impact of €3.5 billion to €4.5 billion in 2030.

Total potential annual holistic impact by type and source of impact for EU-27 and Switzerland, € million

ESTIMATE AS OF JUNE 2022



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1. Based on a price that is comparable to the price of the virgin equivalent whenever virgin quality is achieved, and a price with 30% discount compared to the price of the virgin equivalent when quality degradation occurs. Operating-expenditure and capital-expenditure estimates are from McKinsey analysis. The upper range of profit assumes green premium of 25%.
2. FTE-estimates from McKinsey analysis and industry experts; average annual earnings of €26,000 assumed (Source: Eurostat, 2021); fiscal multiplier of 0.67 assumed, meaning that €1 in wages increases economic growth by 67 cents (Source: European Central Bank; International Monetary Fund).
3. The impact potential of all chemical usage improvements has not been quantified separately but could be substantial.
4. Water consumption estimate of ~600m^3 water/ton fiber output, average all fibers (source: Mistra Future Fashion [summarizing various data points]); water price estimate: average of estimates in India and Bangladesh (source: "Dhaka WASA raises water price by 24.97% for households," bdnews24.com, February 2020).
5. Mistra Future Fashion (summarizing various data points); McKinsey analysis for recycling technologies; Higg MSI; carbon cost: European Union Emissions Trading System (EU ETS).
6. ~2 hectar/ton fiber output, average all fibers (source: Stockholm Environmental Institute); land rental price estimate: ~€140/hectare, representing average of EU and low-cost country land prices (source: Eurostat and banglabuysell.com)
7. The combined holistic impact—across the dimensions calculated—as a share of the total capital-expenditure investments needed across all the value chain steps.

To generate this value, €6 billion to €7 billion in capital investments is likely required. A direct financial return of 25 to 35 percent could be achieved, resulting in company profit pools of €1.5 to €2.2 billion per year. Adding the social and environmental impacts to the financial benefits, the total holistic impact return on investment of 55 to 70 percent could be generated. The upside-case scenario of reaching 80 percent post-consumer household waste collection across Europe could almost double the potential across all dimensions.

Beyond potential direct value creation, the local production of recycled fibers could play a key role in strengthening the European textile value chain and unlock value creation beyond what is quantified in this report. This imbalance is reflected backward in the European textile value chain, with the yarn-spinning capacity presently at 1.5 million tons per year. If Europe generates 1.5 million tons of recycled fibers in 2030,[52] as per the base-case scenario, reshoring could become an attractive alternative to exporting recycled fibers.[53]

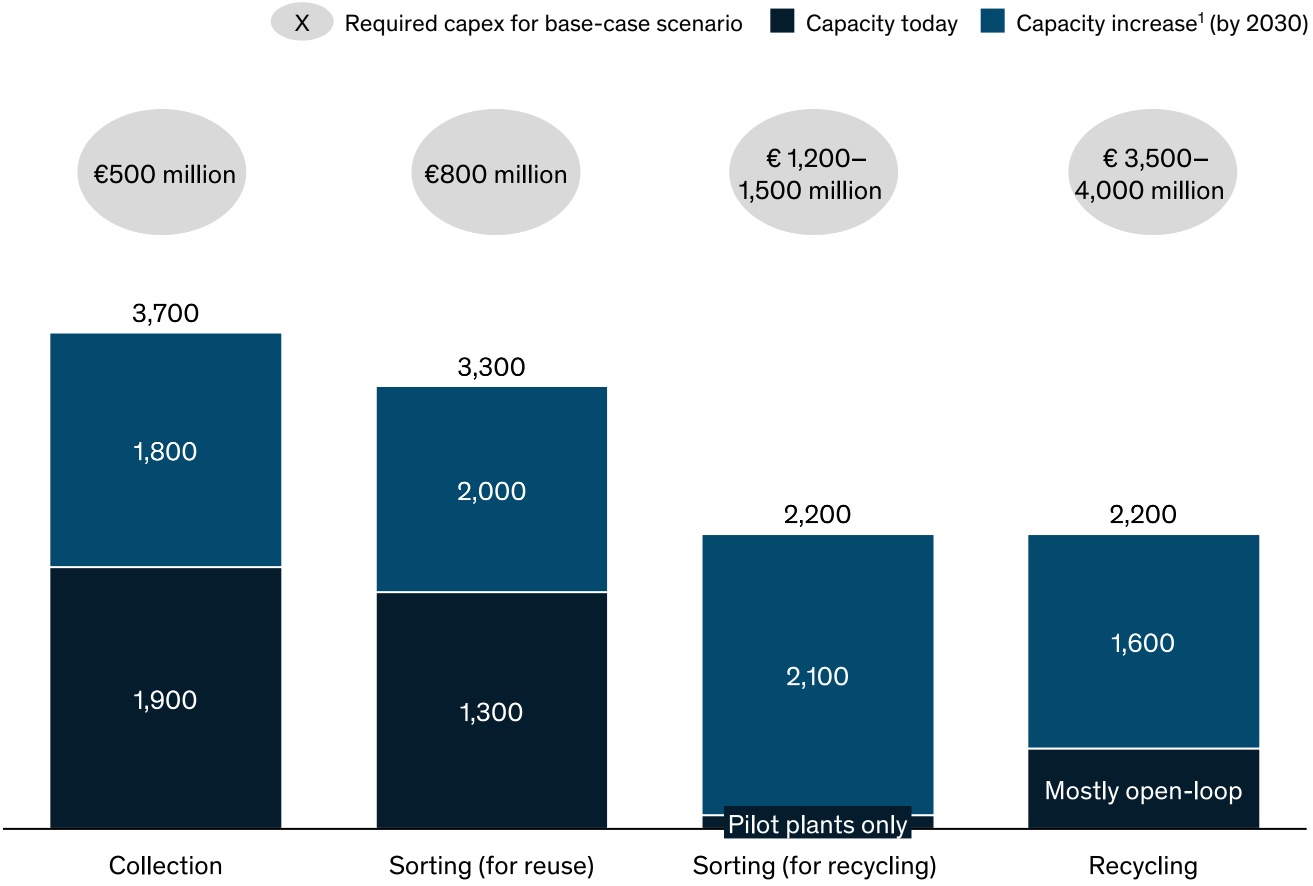
Additionally, capacity in near-shore countries—like Turkey, for example, which has more than 7 million tons in yarn-spinning capacity that could be utilized—could support the near-shoring plans of European clothing brands and retailers.[54]

As fiber production and subsequent steps are partly relocated to Europe, the potential impact on traditional virgin fiber-producing countries, textile-sourcing markets, and the farmers and workers around the globe will have to be evaluated.

Exhibit 16

Scaling the textile recycling value chain to reach the base-case scenario will require total investments of €6 billion to €7 billion.

Recycling value chain: Overview of required capacity development, thousand tons



1. Capacity needed to reach base-case scenario (weighted collection balance of 50% across EU-27 countries).

Source: Country-specific reports; EUROSTAT Prodcom; expert interviews; Humana Annual Report, 2020; JRC, 2021; JRC Technical Report, 2021

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[52] The base-case scenario where 50 percent of post-consumer household waste is collected and 70 percent of all textile waste available to recycling can be fiber-to-fiber recycled. This scenario disregards yield losses in the recycling process.

[53] "Revamping fashion sourcing: Speed and flexibility to the fore," McKinsey, November 21, 2021.

[54] There may be regulatory hurdles (at country or EU-level) that would need to be resolved before this potential could be fully realized.

Scaling the European textile recycling value chain to meet the demands of the 2030 base case requires closing multiple gaps across the value chain.

A capacity expansion would be required across the value chain. Collection operations may need to roughly double, and sorting for reuse capacity scale up two to three times, compared to today's volumes. Sorting for recycling (fiber sorting) and most textile-recycling technologies would need to be built out from the current low levels, as today's capacity is largely limited to pilot-scale plants.

Put in terms of the number of sorting or recycling plants, this capacity build-up would entail adding 150 to 200 capacity facilities across the value chain and across Europe.[55] In aggregate, this capacity scale-up could require around €6 billion to €7 billion in capital-expenditure investments toward 2030 (Exhibit 16).

The European closed-loop textile value chain could achieve end-to-end profitability at price parity with virgin fibers.

The assessment of the long-term profitability of textile recycling in Europe shows its potential attractiveness for investors. The closed-loop textile value chain could achieve end-to-end profitability at price parity to virgin fibers and, therefore, could attract the required capital to scale.[56] To reach this conclusion, we executed an end-to-end analysis of the circular value chain across several dimensions, illustrated in Exhibit 17, and further described in methodology section in the appendix.

> **Scaling the European textile recycling value chain will likely require a €6 billion to €7 billion investment.**

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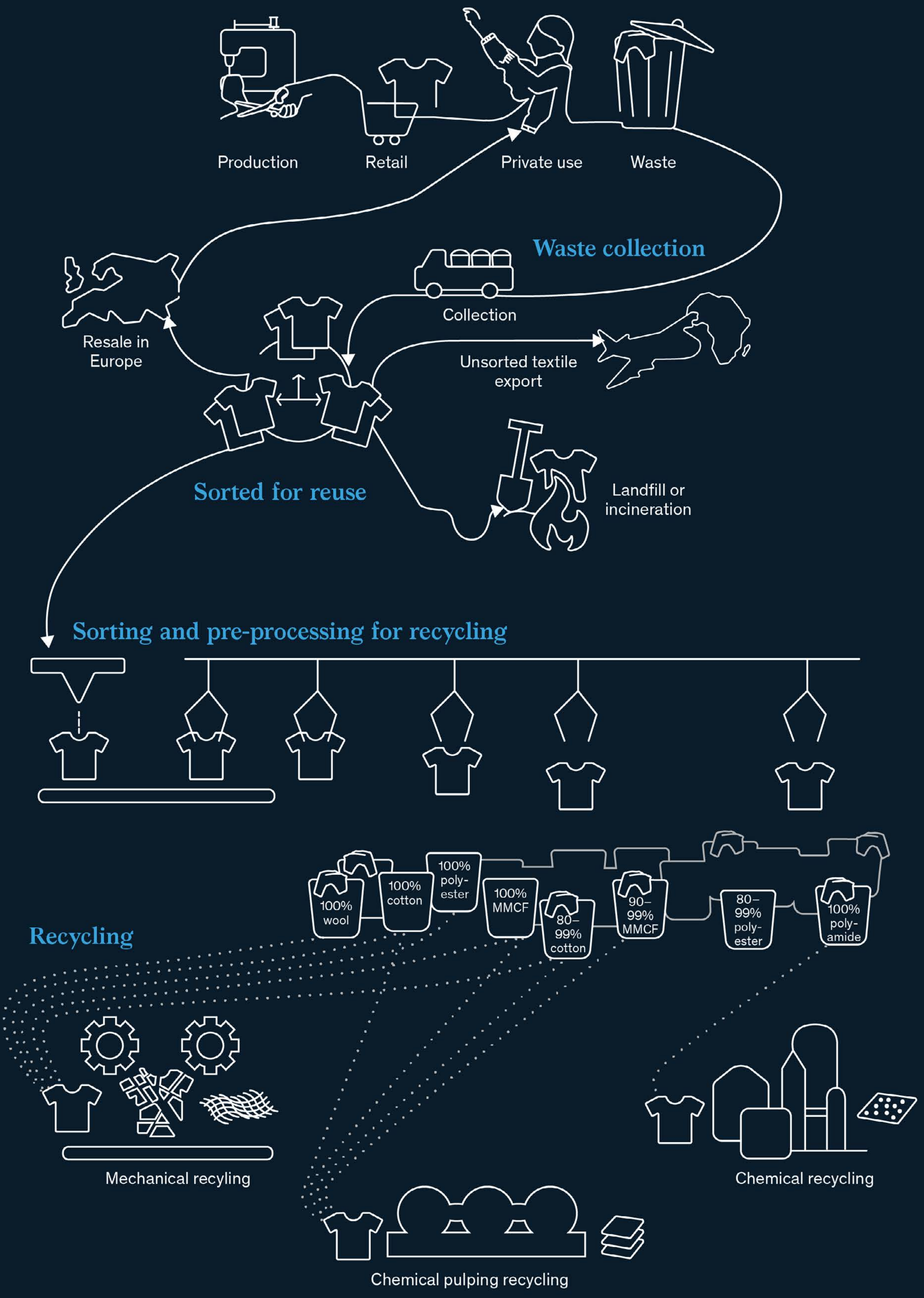
[55] Assumed annual scale of 50,000 tons for sorting plants, 25,000 for mechanical recycling, 50,000 for thermo-mechanical recycling and chemical recycling of polyamide, and 100,000 for chemical recycling of cellulosic, polyester, and thermo-chemical recycling.

[56] This is based on the outlook on waste volumes and fiber compositions, an estimate of what volumes will go to reuse rather than to recycling, a perspective on the cost of sorting (both manual sorting for reuse and automated fiber sorting) and pre-processing, and the outlook on the future potential cost of different recycling technologies.

Exhibit 17

The journey from textile waste to recycled fiber is very complex, and includes competition for feedstock between the various recycling technologies.



The analysis suggests that all value chain steps could reach acceptable profit levels, assuming that virgin prices are charged for recycled fibers that have virgin quality, and a reasonable discount applies when there is fiber-quality degeneration. The distribution of profits across the value chain is difficult to predict as it will be driven by supply and demand and competitive dynamics.

One tested scenario indicates that collection and sorting for reuse could achieve 10 percent EBITDA margin without vertical integration, and up to 15 percent EBITDA margin with integration. Sorting for recycling (fiber sorting) could reach 30 to 40 percent EBITDA margins without vertical integration. The less risky parts of this value chain—like collection—could reach breakeven at a 10 percent capital-expenditure charge, while the riskier parts of this value chain—like sorting for reuse and sorting for recycling (fiber sorting)—could reach breakeven at a 15 percent capital-expenditure charge. This scenario assumes no green price premium for recycled fibers is charged. If green premiums were to become a reality, this would substantially enhance the business case throughout the value chain.[57]

In terms of prices for feedstock at different steps in the value chain, the scenario with zero green premium implies that:

- Sorting-for-reuse players sell feedstock destined for recycling (mixed waste that must be fiber-sorted) at around €80 per ton and make the majority of revenue through the 50 percent of volume that is sold at higher prices for reuse. The €80 per ton may be higher if revenue from re-sell goes down. The €80 per ton may go down, if steps are taken to avoid incineration.
- Sorting-for-recycling players thus pay around €80 per ton for unsorted recycling feedstock and charge on average €280 to €320 per ton for sorted feedstock. There are large variations in the price of different feedstock categories. This scenario implies that pure 100 percent polyester (the largest fiber category) could be priced around €350 per ton, and pure 100 percent cotton (the second-largest fiber category) could be priced around €450 per ton.
- Recycling players will have to pay different price levels for their feedstock depending on how pure and popular the fractions of their target are. The “pickiest” recycling technologies may have to pay more than €500 per ton whereas the less “picky” (for example, those accepting blends of low purity or concentration) may end up paying €280 to €350 per ton. If open-loop and thermo-chemical recycling capture the 30 percent least-desirable feedstock, the tested scenario results in a feedstock price of around €100 per ton for these technologies.

The above outlined scenario should be read not as a forecast, but as one of several potential outcomes. The end state for the value chain, and the distribution of costs and profits across the individual steps, is extremely hard to predict. The critical takeaway of our analysis is that there could be enough economic value generated to create sufficient returns to investors in all steps.

However, to achieve this long-term vision, a transition period will likely need to be funded—several steps of the value chain remain unprofitable and unproven at the current scale and the level of technology maturity, and profitability at virgin prices may only be possible when the value chain has scaled and matured. A combination of subsidies (for example, EPR funding) and green price premiums for recycled fibers will likely be required to fund and accelerate the transition profitably.

EU-27 and Switzerland could approach a 60 to 70 percent supply deficit for recycled fibers by 2030.

Textile recycling is a key solution lever for the clothing and textile industry to transform from a linear to a circular system. The challenges related to scaling textile recycling are mainly on the supply side (for example, maturing recycling technology and scaling capacity) rather than on the demand side.

A supply gap seems to be emerging. According to our base-case scenario, 18 to 26 percent of gross textile waste could be fiber-to-fiber recycled in Europe in 2030. However, almost half of European brand executives surveyed by McKinsey say that more than 30 percent of their products in 2025 should come from recycled fibers.[58] Our analysis shows that the European demand-supply balance for recycled textile fibers could approach a 60 to 70 percent supply deficit by 2030 (Exhibit 18).[59]

This analysis compared Europe’s demand for recycled fibers to Europe’s supply of recycled fibers. This conceptually analyzed the relevant supply and demand balance. In reality, however, the textile value chain is global and complex. In consequence, European demand for recycled fibers may not exclusively be met by European recycled fibers, and European recycled fibers may be sold internationally.

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[57] Recycled fibers that achieve virgin quality are assumed to be priced at virgin prices. Recycled fibers with quality degeneration are assumed to be priced at a 30 percent discount compared to the price of the virgin fiber.

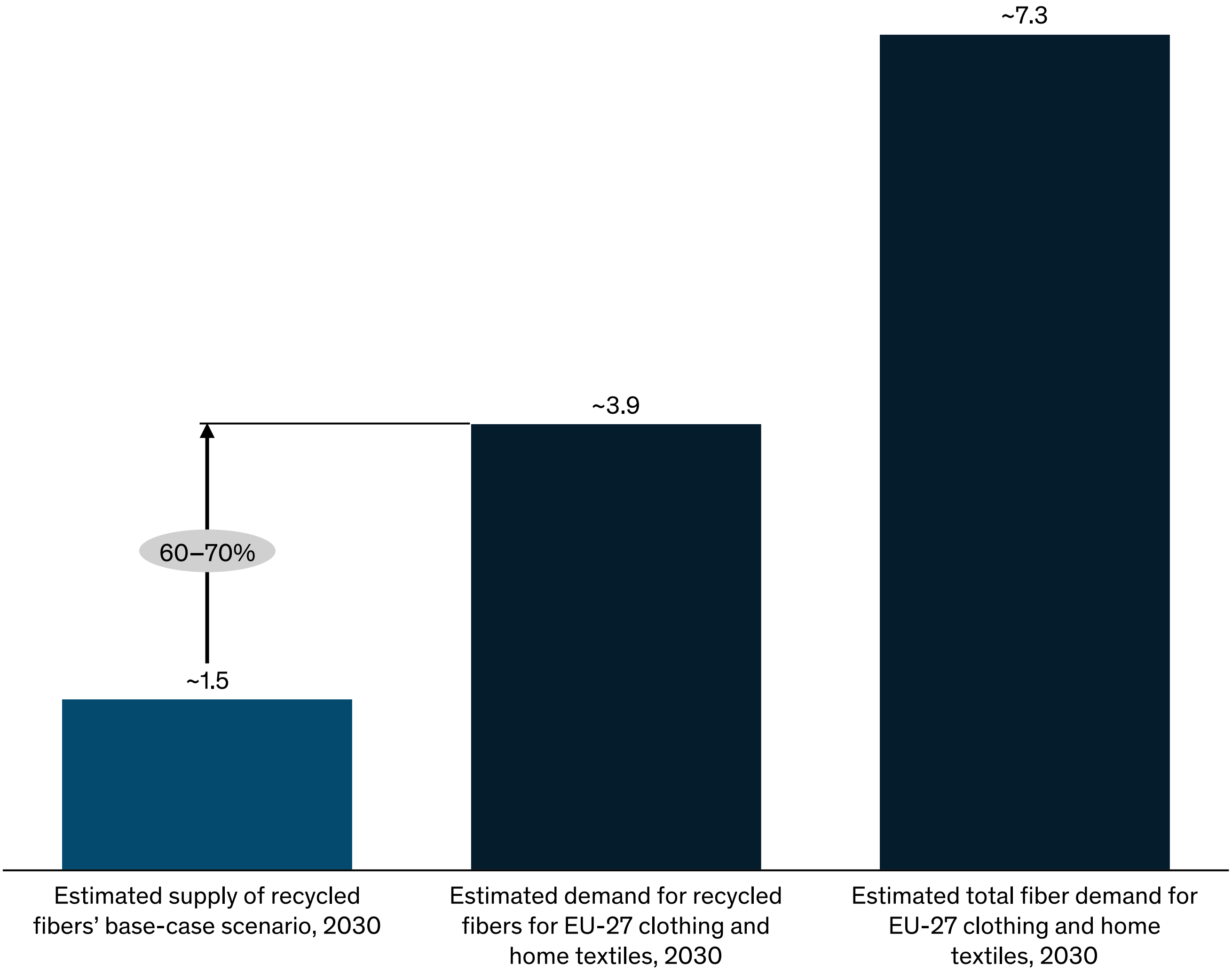
[58] “Revamping fashion sourced: Speed and flexibility to the fore,” McKinsey, November 12, 2021.

[59] This analysis considers the expected demand for fibers in EU-27 to apparel and home textiles because this is the primary source of waste and the main loop to be closed. Demand for recycled fibers to industrial and other applications are separate and could further to add the supply deficit, making this a conservative assessment.

Exhibit 18

EU-27 and Switzerland could approach a supply gap of 60 to 70 percent for recycled fibers by 2030 in the base-case scenario.

Estimated supply and demand of recycled textile material in tons[1], 2030



1. Demand calculated based on European brand survey executives' ambition for recycled fiber uptake in 2025, extrapolated to 2030. Share applied to total textile waste volumes. Supply calculated based on this report's base-case scenario in which 50 percent of post-consumer household waste is calculated and 70 percent of textile waste available to recycling is fiber-to-fiber recycled.

Source: Country-specific reports; Eurostat Prodcom; McKinsey Apparel CPO Survey, 2021; McKinsey analysis

Please note that the expectation of a supply gap does not mean that are no challenges to overcome in the value chain from the perspective of a textile recycler's offtake. For example, equipment updates and knowledge development are needed, and subsequent steps in the value chain, to effectively work with recycled fibers. Green premiums could potentially help the industry finance the transition.

Green premiums are conceivable when new industries and products seek to address environmental challenges.

For example, electric vehicles have been priced with green premiums for many years (and still they are almost 50 percent more expensive than combustion-engine cars[60]), while the technology has been developed and costs have declined.

The analysis conducted in this paper indicates that green premiums would likely not be required as a long-term solution to make the value chain for recycled profitable. However, they could play a role in the near future to help finance the transition of the textile recycling industry toward cost parity with virgin fibers. A few arguments stand out as important regarding green premiums.

First, there may be a supply shortage for recycled fibers of around 60 to 70 percent in our base-case scenario in 2030. According to economic theory, supply shortages will have the potential to lead to price premiums.

Second, the fiber cost as share of final retail price is comparably low. For certain product categories the fiber cost is 3 to 5 percent of final retail price. For these product categories, a scenario where a 25 percent premium is applied on the fiber price would result in only a 3 percent increase in retail price, taking into account that absolute margin would be increased along the full value chain (Exhibit 19).

Third, consumers value sustainable products above conventionally produced products. Several consumers surveys indicate a growing willingness to pay green premiums. For example, a group of 18- to 24-year-olds recently surveyed by McKinsey report a willingness to pay a premium of almost 15 percent for clothes made with recycled materials.[61] It is true, however, that the stated willingness to pay cannot be taken at face value—the real-life magnitude of these effects remains to be seen and the impact of the current cost of living pressures crisis needs to be considered.

3-5%

estimated fiber cost of total retail price.

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[60] "Electrify transportation," Speed & Scale, May 2022

[61] "Closing the loop: Increasing fashion circularity in California," McKinsey, March 31, 2022.

Exhibit 19

A 25 percent green premium on the fiber price could lead to about a 3 percent increase in the retail price of certain products.

Example analysis of implications of fiber green premium prices on the final retail price

SCENARIO, NOT FORECAST

Garment type	T-shirt	T-shirt	Sweatshirt	Jacket	Dress
Retail price, €	18.80	22.56	103.40	55.46	18.80
Fiber composition, %	100% organic cotton	50% organic cotton, 50% modal	50% lyocell, 50% organic cotton	71% polyester, 29% lyocell	100% polyester
Fiber cost[1] per kg	4.16	3.52	3.08	1.54	1.36
Garment weight, grams	200	200	350	275	300
Fiber cost per garment	0.83	0.70	1.08	0.42	0.41
Fiber cost[2] per garment with green premium	1.04	0.79	1.21	0.53	0.51
Retail price, € with green premium	19.34–19.43	22.79–22.82	103.75–103.81	55.74–55.78	19.07–19.11
Increase in retail price, %	2.9–3.3%	1.0–1.2%	0.3–0.4%	0.5–0.6%	1.4–1.6%

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1. Fiber prices assumed, in €/kg: 2,88 (TENCEL TM modal), 2,0 (TENCEL TM lyocell), 4,16 (cotton), 1,36 (polyester).
2. Premium of 25% added plus an additional 10% to 15% margin for each of the five value chain steps (yarn spinning, fabric manufacturing, garment production, retail, and consumer). This premium visualizes an example of fiber cost with green premium—eg, for recycled fiber regardless of which recycling technology is employed.

Source: Web search; McKinsey analysis

5. Recommendations

All stakeholders across the textile recycling value chain must act now to accelerate the industry development.

The identified bottlenecks preventing scale are significant and will require several stakeholders to act boldly. Textile recycling in Europe will not reach a favorable state by 2030 unless major action is taken quickly. This report identifies five main ingredients for success.

- **Critical scale.** The textile recycling value chain cannot function at small scale. Critical scale across the value chain is required to provide sufficient feedstock to the necessary fiber-to-fiber recycling technologies, and to allow for those recycling technologies to operate at scale. Therefore, the industry must set bold scaling targets and meet them.
- **Real collaboration.** Several of the main challenges ahead are best solved in a highly collaborative manner. Business leaders across the value chain, investors, and leaders of public institutions would need to come together in an unprecedented way to engage in a highly operational joint effort to overcome the barriers to scale.
- **Transition funding.** Although our analysis indicates that the textiles recycling industry could—once it has matured and scaled—become self-standing and profitable, transition funding will be needed in the near term. Examples of such funding include subsidies (potentially EPR) and a green premium (potentially shared by brands and consumers). Public-private solutions may be needed.
- **Investments.** Several parts of the value chain must be built out almost from scratch, which requires significant capital expenditure. Our analysis indicates that sufficient economic value can be realized to make up for the required risk. Private investors would lead this journey by taking initiative to finance building out the value chain.
- **Public sector push.** Leaders of public sector institutions would have to help drive textile recycling. Measures include driving up collection rates, limiting the export of unsorted textile waste, engaging in demand stimulation, creating harmonized frameworks for increased circularity, as well as other initiatives.

To successfully build out a well-functioning textile recycling value chain in Europe, stakeholders must act forcefully and urgently. Collaboration and innovation will be at the core of capturing this opportunity. We recommend considering multiple key initiatives led by brands and distributors, investors, and entrepreneurs in sorting, pre-processing and recycling, textile manufacturers,[62] and the public sector and NGOs. In aggregate, these actions could significantly advance textile recycling in Europe (Exhibit 20).

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[62] Several types of players in the textile manufacturing value chain are relevant, including yarn spinners, fabric manufacturers, and garment manufacturers.

Exhibit 20

Recommendations and considerations for stakeholders in textile recycling

Recommendations and considerations for …

… brands and distributors

- Set ambitious goals and clearly communicate these goals backward in the value chain to accelerate the speed of adoption of recycled fibers.
- Green premiums on recycled fibers can help to scale up most recycling technologies sooner.
- Create offtake agreements for recycled fibers to overcome the *Catch-22* effect.
- Create in-store collection points to contribute to feedstock supply, alongside education for their customer bases on the value of recycling their textile waste.
- Design for circularity by increasing designers' capabilities and understandings of what a circular model entails, such as incorporating recyclable fiber mixes into brand design and production.

… investors and entrepreneurs in sorting and recycling

- Create innovative and collaborative approaches to fund the substantial capital-expenditure requirements, for example, co-location of sorting and recycling operations to realize operational synergies and share investments.
- Invest time and resources into collaborative research projects for improved sorting and pre-processing.
- Pro-actively engage with the textile manufacturing value chain to define valuable collaboration for the end-to-end delivery of recycled fibers.
- Communicate with brands, textile manufacturers, and regulators about what is needed to bring the circular model to scale.

… the public sector and NGOs

- Build awareness on the textile waste issue, through education and agenda-setting, from the individual level to the EU level.
- Expand infrastructure for consumers and businesses to increase textile-waste collection.
- Increase incentives for sorting processes to minimize the exportation of unsorted textile waste out of the EU.
- Explore how public funds could improve economics of the value chain, including through volume-based subsidies for feedstock transactions. Extended Producer Responsibility (EPR) revenue could be a main source of this support.
- Collaborate with EPR schemes and producer responsibility organizations (PRO) across Europe to support a cross-border circular textile value chain.
- Harmonize new and existing regulation throughout the EU with the aim to enable cross-boarder collaboration and solutions.
- Explore how public procurement and buying power can be used to accelerate demand.

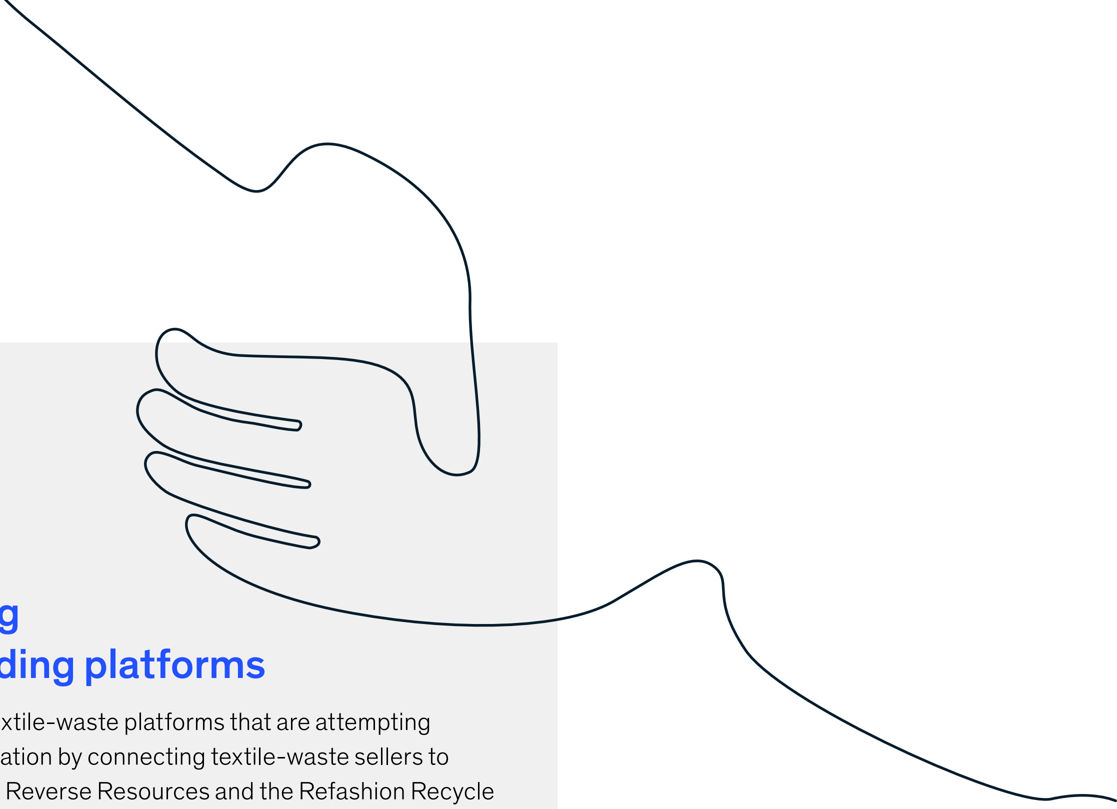
… textile manufacturers

- Adapt concrete circularity and sustainability goals on the strategic level.
- Allocate capital to fund the next-generation equipment needed to work effectively with recycled fibers.
- Engage forward and backward in the value chain to help support the adoption of mechanically recycled fibers.

To unlock the total holistic impact, the playing field might need to be levelled—such as forging public-private partnerships, enacting recycling-friendly policies, and encouraging vertical integration in the clothing industry. Collaboration is imperative, and all stakeholders are strongly encouraged to think creatively for solutions beyond normal company parameters to find collaborative approaches to develop and scale the required technology.

The required development of closed-loop recycling may potentially face a *Catch-22* situation—demand and supply are mutually dependent on each other; getting the systems in place to scale to provide supply requires demand—yet demand is dependent on the ability to provide supply. While benefits outweigh costs systemwide, and there likely is enough value to create industry-wide profitability at maturity, both benefits and costs are potentially distributed unevenly among stakeholders in the near term.

The European clothing and textile industry can start expanding the required infrastructure for collection, sorting, and closed-loop recycling today. We hope this report will establish the opportunity at stake for textile circularity in Europe, as well as the actions required to capture it. Furthermore, this report can create the foundation for further research and collaboration to establish textile recycling at scale in Europe.



Note on emerging textile-waste trading platforms

There are various emerging textile-waste platforms that are attempting to overcome market fragmentation by connecting textile-waste sellers to buyers. Two examples include Reverse Resources and the Refashion Recycle platform.

Reverse Resources is an AI-supported SaaS[63] platform for streamlining textile-to-textile recycling. The platform connects manufacturers, waste handlers, and recyclers, and focuses on textile waste from the production process. Today, the platform primarily connects the textile value chain of India to local recyclers as well as in Western Europe (about 75 percent of total activity). Around 900 to 1,000 manufacturers are connected to approximately 20 waste handlers and 50 recyclers.[64]

Refashion Recycle platform is a recently founded platform focusing on post-consumer household textile waste in Europe. It is an initiative of Refashion, a French PRO. Today, the primary function of the platform is to connect buyers to sellers, but live data of available feedstock are currently not maintained, and the transactions happen in peer-to-peer transactions between the individual parties. Currently around 250 stakeholders are associated with the platform.[65]

Both platforms are operational, though not yet mature. The expansion of either of these platforms or the creation of a new platform to cover EU-wide textile waste could be a powerful tool to mitigate feedstock fragmentation and create improved data collection and transparency for all parties.

The creation of an EU-wide feedstock platform could be led by regulators and government in partnership with industry. Such a platform would potentially consolidate the fragmented landscape of feedstock sellers, such as textile-waste sorters, manufacturers, textile-service companies, and brands, and could connect these sellers with buyers, such as fiber sorters and textile recyclers. EPR funding could also be partly allocated to industry through the platform, which would make access to feedstock more affordable and accessible to recyclers. Such an initiative could increase transparency across the value chain and therefore make it easier for all stakeholders to participate in a circular model. In addition, the industry could consider subsidies that make recycling viable in the short term, until scale is reached.

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[63] SaaS refers to software as a service.
[64] Reverse Resources.
[65] Refashion Annual Report, 2020.

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Acknowledgements

The authors wish to thank their partners at EURATEX and its ReHubs initiative for their contributions to the report, as well as the many industry experts who took the time to generously share their experience, research, and perspectives on circularity.

We are grateful to Tomas Nauclér, a senior partner at the Stockholm office, Rickard Vallöf, a partner in the Gothenburg office, Karin Östgren, a consultant at the Stockholm office, Laerke Wolf, a consultant at the Copenhagen office, Svenja Böttcher, a consultant in the Berlin office, and Baltzar Bradley, a consultant at the Stockholm office, for their contributions to this report.

We also thank Kayla Beare, Colin Douglas, and Nella Freund who helped edit the report, as well as Malin Bradshaw and Martina Grönwall who were responsible for the visual design.

The authors wish to thank the following companies for their contributions to this report through their involvement in the ReHubs initiative:

Alsico

BASF SE

Boer Group

Concordia/Purfi

DECATHLON

EREMA Group Gmbh

Gherzi Textile Organisation

Inditex

Indorama Ventures PCL

L'Atelier des Matières

Lenzing Group

Marchi & Fildi

RadiciGroup

RATTI SPA SB

Recover™

SAATI SPA

SOEX

TEXAID AG

Wolkat

Appendix

Glossary

Available to recycling

There are different ways of defining what share of textile volume is "available to recycling". This paper uses the term to describe textile waste that is collected and does not have an alternative use with higher value that is higher in the waste hierarchy (for example, resale). Of the share that is "available to recycling", there may be fiber fractions that are technically not eligible for fiber-to-fiber recycling. Our base-case scenario with allocated textile waste to the different recycling technologies assumes—based on our analysis of forward-looking feedstock purity requirements by recycling technologies—that 70 percent of what is available to recycling can technically be recycled.

Circularity

Circularity is a widely used term that generally refers to economic, technical, and environmental systems that aim to eliminate waste and maximize the reuse of resources. The concept of waste hierarchy is often used to understand circularity. For example, Reike, Vermeulen, and Witjes (2018) describe a nine-step hierarchy of solution levers to address waste.[66] According to the waste hierarchy, the reuse of items has a higher value than recycling them. Please see Exhibit 21 for further details.

Closed-loop recycling

Recycling waste from one industry into new products similar to the original products, within the same industry. For example, recycling cotton T-shirts to cotton yarn, which then can be used to create new cotton apparel products.

Collection rates and other waste collection metrics

There is a debate in the clothing and textile industry on what is the best term used to describe the share of collected textile waste. Most use the term "collection rate", some use "collection quota", and there is also reference to "collection balance". The industry mostly defines this term consistently as textile waste collected in a given year divided by the amount of new textile waste put on the market in that year. This metric deserves two comments.

First, the denominator and numerator are of different vintage, as waste collected in any year will contain products that have been put on the market at different times.

Second, the clear matching between product and waste works well for post-consumer household waste, but less so for production waste and waste from certain commercial uses (that partly require incineration by law and thus cannot be considered waste that should be collected).

In this paper, the references to "collection rates" or "waste collected" refer to the specific waste stream in question. The main metrics of 50 percent (in our base-case scenario) and 80 percent (in our upside case) refer to the post-consumer household textile waste collected, divided by the amount of new consumer household textile products put on the market.

The optimal theoretical metric would be textile waste collected divided by textile waste discarded in the same year, but it is difficult to achieve reliable data on this. For practical purposes, our definition of collection rates is a good proxy for the "real" number, as long as the volumes being put on the market are fairly stable on the product lifecycle time scale.

CO_2e emission

Carbon-dioxide equivalent. CO_2e emission is a metric measure that is used to compare emissions from various greenhouse gases on the basis of their global-warming potential by converting amounts of other gases to the equivalent amount of CO_2.

Downcycling

Downcycling refers to recycling a product to a new product of lower quality, or with different properties or characteristics to the original product. This term partly overlaps with open-loop recycling. Recycling a cotton T-shirt into a cleaning rag is an example of downcycling.

Extended producer responsibility (EPR)

In the field of waste management, extended producer responsibility is a strategy to add all of the environmental costs associated with a product throughout its lifecycle to the market price of that product.

Fiber purity or composition

Fiber purity or fiber composition refers to the number of different fibers used to create a fabric or garment. Some garments have high-fiber purity. For example, a 100 percent cotton T-shirt has high-fiber purity. Some garments have low-fiber purity or a complex fiber composition. For example, a jacket that uses a polyester-cotton blend for its main surface areas, but has down filling and polyamide pockets, would have low-fiber purity and high-fiber complexity. The concept of fiber purity and composition is relevant to textile recycling because the various recycling technologies have different requirements for the feedstock composition that they technically and economically can recycle.

Gross textile waste

Gross textile waste is approximated by considering the volumes of textile products produced and put on the market, as well as waste generated from the production of textiles or final products that become waste before they reach the consumer. The lifetime of the individual item determines the year in which it becomes waste; however, on a long-enough time

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[66] Denise Reike, Walter J.V. Vermeulen, and Sjors Witjes, *The circular economy: New or Refurbished as CE 3.0?* ScienceDirect, August 2018.

horizon, all consumption will equal waste. Therefore, gross textile waste is approximated by looking at all consumption and pre-consumption waste.

Gross waste volume

Gross waste volume describes the overall textile-waste volumes in each of the waste categories. To approximate these volumes in the post-consumer household waste category, the assumption is that waste equals volumes put onto the market each year. This is true in the long term, but it creates a time-lag difference that is unaccounted for.

MMCF

Man-made cellulosic fiber. This very often consists of natural cellulose-rich raw material like wood. Examples of MMCF include viscose, rayon, and modal.

Open-loop recycling

Recycling waste from one industry into new products for another industry. For example, recycling PET bottles into polyester, or recycling cotton T-shirts into cleanings rags.

Recycling

Recycling is a broad term that refers to different types of recycling, including closed-loop and open-loop recycling.

Reuse

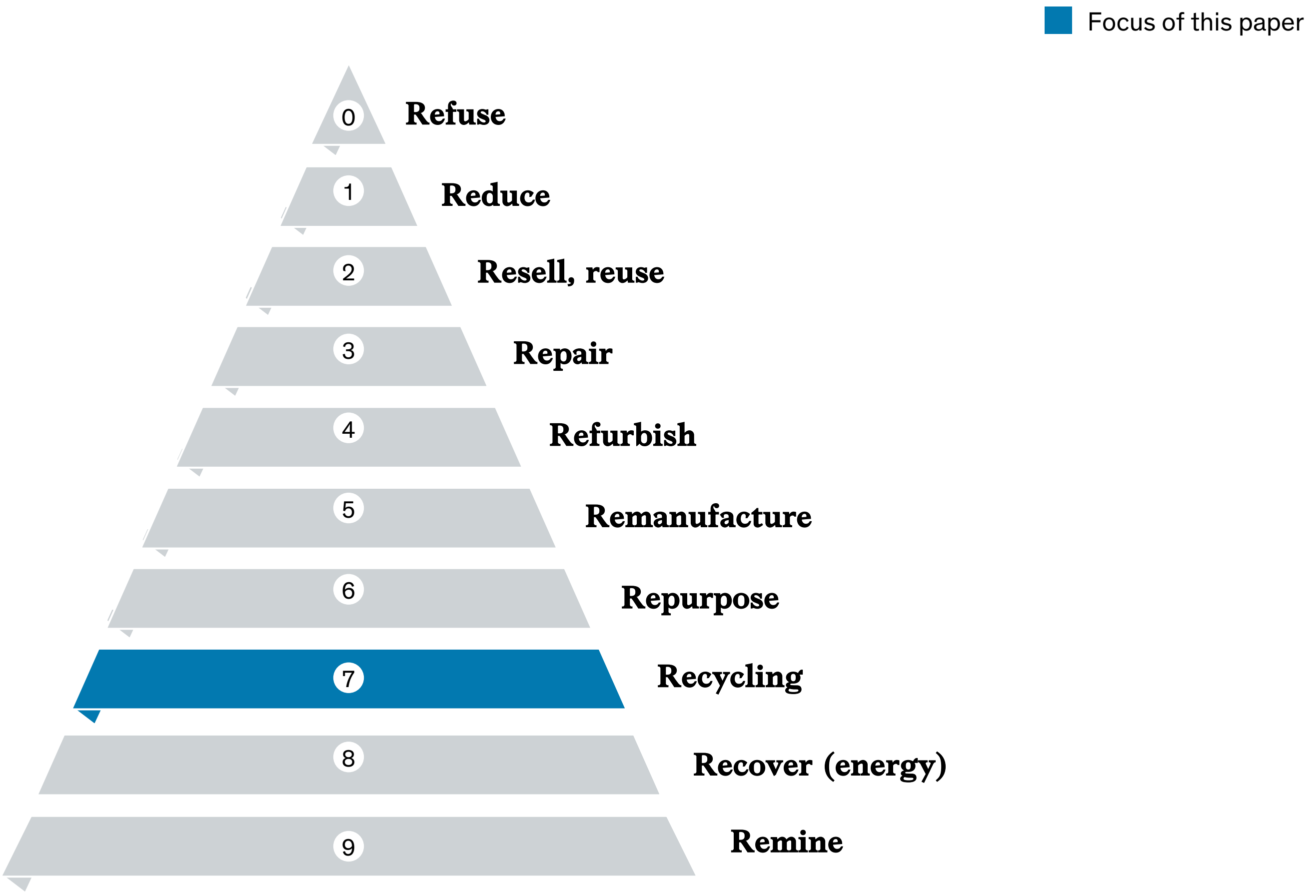
Reuse refers to taking a product at end of life from the perspective of the latest owner and giving the product an extended life by reusing it.

Refuse	Refers to consumers buying fewer products and to producers refusing to use specific materials or designs.
Reduce	Linked to producers, stressing the importance of concept and design cycle for example, using less material per unit of production (dematerialization).
Resell, reuse	Referring to the second consumer of a product that hardly needs any adaptation and is as good as new.
Repair	Bringing products back into working order by fixing minor defects; this can be done peer-to-peer or by people offering the service.
Refurbish	Referring to a large multi-component product that remains intact while components are replaced, resulting in an overall upgrade of the product.
Remanufacture	The full structure of a multi-component product is disassembled, checked, cleaned, and, when necessary, replaced or repaired in an industrial process.
Repurpose	By reusing discarded goods or components adapted for another function, the material gets a new life.
Recycling	Refers to the processing of mixed streams of post-consumer products or post-consumer waste streams, including shredding, melting, and other processes to capture (nearly) pure materials. Materials do not maintain any of their product structures and can be reapplied anywhere. Primary recycling occurs B2B, whereas secondary recycling takes place post municipal collection.
Recovery (energy)	Capturing energy embodied in waste, linking it to incineration in combination with energy production.
Remine	Landfill remining.

Exhibit 21

To fully solve the textile-waste problem, several levers could be used.

The circular economy hierarchy of levers that address waste



Source: Denise Reike, Walter J.V. Vermeulen, and Sjor Witjes, *The circular economy: New or refurbished as CE 3.0?,* ScienceDirect, August 2018

Methodology

Geographical boundaries

Unless otherwise stated, this report considers EU-27 and Switzerland as its core geography in all volume-related assessments. The emphasis on EU-27 is relevant because there is a strong link between textile waste and EU regulation (for example, the EU Waste Directive). The reason for including Switzerland is its immediate connection to EU-27 through its four main borders to Italy, France, Germany, and Austria.

Two scenarios for textile recycling in Europe

This report examines two main scenarios, itemized below. In the long run, all textile waste should be collected, in line with the textile waste regulation's ambition. However, building the necessary infrastructure for collecting, sorting, and pre-processing, changing consumer behavior, and building the recycling capacity will all take time.

Therefore, we have considered two scenarios for textile waste collection on the journey toward fulfilling the 100 percent ambition.

Scenario	Description and methodology	Main differentiating assumptions
Base-case scenario	The base-case scenario is our main assumption, where textile recycling in EU-27 and Switzerland could be in 2030. In this scenario, 50 percent of EU-27 and Switzerland's post-consumer household waste is collected—this is the primary driver of how much waste will be available to textile recycling, as it represents around 85 percent of total gross waste volumes. The total textile waste that becomes available to recycling, including from other textile waste streams, is 2.2 million tons. Of this share, 70 percent could technically be fiber-to-fiber recycled according to our assessment of purity requirements for the recycling technologies at maturity. This would generate 1.5 million tons of recycled fibers in 2030.	Collection rate of post-consumer household waste in EU-27 and Switzerland: 50 percent
Scenario	**Description and methodology**	**Main differentiating assumptions**
Upside-case scenario	The upside-case scenario is a more aggressive perspective that could be reached toward 2030, but likely will require a longer time to achieve. In this scenario, 80 percent of EU-27 and Switzerland's post-consumer household waste is collected. All other assumptions are kept equal. This would make 3.2 million tons of textile waste available to recycling. Under the same 70 percent assumption, this would create 2.2 million tons of recycled fibers. We have not assessed the expected time horizon to reach the upside case.	Collection rate of post-consumer household waste in EU-27 and Switzerland: 80 percent

The research and mapping of environmental impact is still novel and there are yet to be standardized methodologies accepted and used throughout the clothing and textiles industry, posing a challenge when quantifying the environmental performance of textile fibers. The data available are often poor in quality and limited in quantity. Several attempts at structured mapping were done—for example, the Fiber Bible—building on several reports and tools available. The gold-standard methodology of cradle-to-grave (accounting for emissions through all steps of a textile's life from production, use, and end-of-life destruction) were often difficult to perform and flawed in methodology—making them unsuitable for comparing fiber to fiber.

In this report, we instead tried to compare the direct process emission steps of recycling versus virgin-fiber production. The process emission estimates and their relative differences compared to virgin alternative can be found in the exhibits below. Exhibit 22 focuses on the technologies relevant for cotton and cellulosic fibers, whereas Exhibit 23 focuses on recycling of synthetics in general and polyester in particular.

Exhibit 22

Methodology and sources for Co_2e emission estimates (cotton and MMCF).

Level of certainty of GHG emission estimate 🟦 Low ▩ Mid ■ High ● Range of process emissions

Virgin cotton and MMCF compared to recycled alternatives		GHG emissions /ton CO_2e output	GHG emissions saving vs virgin material, % GHG emissions saved[1]	Sources used, with comments on methodology and level of uncertainty
0A Virgin cotton		●		■ Highly dependent on origin and processing methods. Estimates vary from ~1 ton CO_2e /ton output for organic cotton to ~3.3 ton CO_2e/ton output for conventionally grown cotton Source: Mistra Future Fashion
0B Virgin MMCF		●		■ Large range of emissions dependent on several factors, incl. source of feedstock (eg, causing deforestation or not), energy mix used for machinery in forest operation and processing, and chemicals Source: Mistra Future Fashion
1 Mechanical	1A Open-loop	●	**80–90%**	▩ Assumed to be the same as for closed-loop recycling
	1B Closed-loop traditional (cotton output)	●	**80–90%**	■ Range from 0.15–0.35 ton CO_2e/ton fiber output Source: JTC Technical Report, 2021; industry experts
	1C Closed-loop soft (cotton output)	●	**60–70%**	▩ Approximately 3x the energy consumption of closed-loop traditional Source: Industry experts
3A Chemical-polymer	3A.i Pulping recycling (MMCF output)	●	**Estimates vary**	🟦 Assumed pulping emissions of 0.5–1.3 kg Assumed fiber production emissions of 1–4 ton CO_2e/ton output Source: JRC Technical Report, 2021; industry experts

Exhibit 23

Methodology and sources for CO_2e emission estimates (polyester).

Level of certainty of GHG emission estimate ■ Low ■ Medium ■ High ◉ Range of process emissions

◌ Sequestered CO_2 recycled (end of life)

Virgin cotton and MMCF compared to recycled alternatives				GHG emissions, /ton CO_2e output	GHG emissions saving vs virgin material, % of GHG emissions saved[1]	Sources used, with comments on methodology and level of uncertainty
0	Virgin polyester			◉		Wide range in figures across data sources; ~3.3 ton CO_2e/ton fiber output applied as average; an additional ~2.3 would be released by end of life Source: Mistra Future Fashion; McKinsey analysis
1	Mechanical	1A	Open-loop	●	85-95%	Assumed to be same as for closed-loop recycling
		1B	Closed-loop traditional	●	85-95%	Range from 0.15–0.35 ton CO_2e/ton fiber output. Source: JRC Technical Report, 2021; Higg MSI
		1C	Closed-loop soft	●	80-90%	Approximately 3x the energy consumption of closed-loop traditional Source: Industry experts
2	Thermo-mechanical recycling			●	70-80%	Based on PET bottle recycling. Only includes energy usage of processing step: 2,600–3,900 kWh. Higher energy needed to reach melting point of PET (~250°C) Source: Mistra Future Fashion
3A	Chemical-polymer	3A.i	Solvent-based	●	60-70%	Only includes energy usage of processing step: Energy usage: ~3,500 kWh/ton. Source: Industry experts; McKinsey analysis
3B	Chemical-monomer	3B.i	Methanolysis	●	60-70%	Only includes energy usage of processing step: Methanolysis ~5,500 kWh/ton Glycolysis: ~5,000 kWh/ton Source: Industry experts; McKinsey analysis
		3B.ii	Glycolysis	●	60-70%	

Process emissions estimates do not account for emissions generated from the incineration of waste products.

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1. Analysis credits the CO_2e emissions at end of life from requested fossil carbons to the virgin material and does not double count these carbons in the recycled fibers.

Recycling technology CO_2e abatement estimation

The research and mapping of environmental impact is still novel and there are yet to be standardized methodologies accepted and used throughout the clothing and textiles industry, posing a challenge when quantifying the environmental performance of textile fibers. The data available are often poor in quality and limited in quantity. Several attempts at structured mapping were done—for example, the Fiber Bible—building on several reports and tools available. The gold-standard methodology of cradle to grave (accounting for emissions through all steps of a textile's life from production, use, and end-of-life destruction) were often difficult to perform and flawed in methodology—making them unsuitable for comparing fiber to fiber.

In this report, we instead tried to compare the direct process emission steps of recycling versus virgin-fiber production. The process emission estimates and their relative differences compared to virgin alternative can be found in the exhibits below. Exhibit 22 focuses on the technologies relevant for cotton and cellulosic fibers, whereas Exhibit 23 focuses on recycling of synthetics in general and polyester in particular.

When available, the emission estimates built on the existing databases and reports available, such as ecoinvent[67] and Higg MSI.[68] In instances where such are not available, estimates were based on expert interviews and our own analysis, which we then based on energy consumption and the European Environmental Agency's estimate of the EU-27 average energy mix.[69] In some instances, extrapolation was done from related technologies, for example, thermo-mechanical recycling of PET bottles. For this estimate, the reports by Pinsky et al[70] and van der Velden[71] were used, among others.

In all garments and textiles there is a share of carbon molecules that is "locked in" or "sequestered" in the garment. This is true for natural as well as synthetic fibers. In this report, this is referred to as the "sequestered carbon". This carbon share will be released in the end-of-life destruction of the garment. For the natural fibers, this sequestered carbon is not counted toward process emissions (as the cotton would have been broken down and released carbon, regardless of becoming a textile fiber or not). The situation is different, however, for synthetic fibers as the natural gas or hydrocarbon (for instance, crude oil) is extracted and released into the atmosphere. Therefore, synthetic fibers are "credited" with the sequestered carbon. Recycled textiles are consistently not credited with sequestered carbons because no new sequestered carbons are added as a result of the recycling process.

To be able to estimate an emission savings as compared to virgin fibers, the midpoint of the virgin-fiber emissions estimate was compared with the midpoint of the emissions from the recycling processes.

Recycling technology cost estimation

Cost estimates were largely gathered in confidence through interviews with industry experts and triangulated with publicly available reports (such as the Joint Research Centre's 2021 report, *Study on the technical, regulatory, economic and environmental effectiveness of textile-fibers recycling).*[72] For the cost estimates of the mechanical recycling technologies (open-loop, mechanical traditional, and mechanical soft), interviews with industry experts were carried out. For the capital-expenditure estimates, a feasible scale of operations was assumed, differing slightly with each technology.

To enable comparability, the cost estimates account for processing end-to-end from feedstock up to a fiber stage, but not further—for example, not including costs for yarn spinning or fabric production. However, the subsequent process steps are not identical in costs for recycled versus virgin. The process step to go from textile waste back to fiber varies for the different recycling technologies, meaning that each recycling technology requires different levels of investment. There might be investments needed in subsequent value chain steps to enable a shift towards recycled materials; these investments have however not been analyzed in this report. For example, mechanical recycling goes back to fiber directly, whereas chemical recycling requires fiber spinning to return to the fiber stage, and sometimes needs an additional intermediary step before fiber spinning.

In some cases, where the technology is immature and untested at scale, we were forced to make top-down cost assumptions by drawing parallel assumptions to similar operations. Costs were divided into operating costs and capital expenditures, and operating costs were then further split into pre-processing, processing, and fiber production when relevant:

— **Operating expenditure for pre-processing.** These pre-processing costs are either integrated with the recycling player, the sorting player, or potentially as an independent step in the future. Pre-processing today is mainly done through a manual process. Pre-processing operating costs of €200 to €500 per processed ton were assumed

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[67] Environmental data, ecoinvent.

[68] Higg materials sustainability index, Higg.

[69] "Greenhouse gas emission intensity of electricity generation in Europe," European Environmental Agency, November 18, 2021.

[70] Roxanne Z. Pinsky et al., *Energy input and process flow for plastic recycling,* International Journal of Engineering Sciences and Research Technology, July 2019.

[71] Martin Patel, Natascha van der Velden, and Joost Vogtländer, *LCA benchmarking study on textiles made of cotton, polyester, nylon, acryl or elastane*, International Journal of Life Cycle Assessment, September 2013.

[72] *Study on the technical, regulatory, economic and environmental effectiveness of textile-fibers recycling,* Joint Research Centre, 2021.

for the mechanical recyclers. For the chemical recyclers, there is potential to automatize pre-processing operating costs, partly due to chemical recycling not being sensitive to fiber-length reduction in pre-processing steps. A cost of €100 to €300 cost per processed ton is therefore assumed.

- **Operating expenditure for processing.** Costs for mechanical and thermo-mechanical recycling have been estimated through interviews with industry experts for recycling technologies. For mechanical recycling (traditional or open-loop), a cost of between €50 and €500 was assumed. We estimated operating costs of €2,400 and €2,900 for soft mechanical recycling, which requires considerably more machinery and has a higher energy consumption that other mechanical recycling methods. The methodology for chemical recycling varied. For more established technologies, a McKinsey perspective was tested and corroborated with industry experts. For the more immature technologies, information from interviews with experts on estimated costs for different steps (for instance, for depolymerization, repolymerization, and fiber production) was utilized. Processing costs for chemical recycling were assumed to be between €550 and €1,400. For chemical recycling of polyester, we took the energy usage triangulated through expert interviews and translated it to costs using the European average energy prices.[73]

- **Operating expenditure for fiber spinning.** Some recycling technologies require a separate fiber-spinning step to go back to fiber level. This will incur a separate cost for the chemical recycling technologies that, for example, go back to polymer or monomer stage, or thermo-mechanical recycling that requires a subsequent melt and extrusion step. Fiber production cost was estimated at between €100 and €150.

- **Capital expenditure.** Capital expenditure, like operating expenditure, was assessed for each separate step required for each recycling technology's journey from textile waste to fiber. The same sources were used as for operating expenditure. Total capital expenditures were estimated to include all capital expenditures needs for a fully greenfield recycling plant—that is, all investments needed for machinery, equipment, buildings, and so forth. When considering total annualized cost, we used a 15 percent capital charge as a baseline. A capital charge of 15 percent per annum corresponded to a breakeven price roughly to return of investment (internal rate of return) of 10 percent. This assessment disregarded the effects of leverage and return on equity to shareholders.

Please note that the cost estimations references in this section are the total range observed. In our estimated costs communicated earlier in this report, we assumed that the lower range was achieved. Over time, we believe that the lower range may be reached as innovation and technology development advances.

Post-consumer household waste volume estimations

Eighty-five percent of EU-27 and Switzerland's textile waste comes from post-consumer household waste. Therefore, forecasting these waste volumes was the most important driver of the total recycling potential for EU-27 and Switzerland.

As the baseline for textile-waste generation and collection in EU-27 and Switzerland is not well established, a two-stage approach was taken to determine post-consumer household waste textile volumes that could become available to textile recycling in the future.

First, we estimated the baseline of textile waste and collection, sorting, pre-processing, and availability to recycling, and then we forecasted the development of these three items. Below we outline our methodology and main assumptions for these waste volumes.

Assessing the absolute baseline. The baseline assessment required a consideration of both absolute and relative waste volumes. Two main types of sources were used to estimate the absolute baseline. First, we considered the Joint Research Centre's 2021 report, which in turn relied on Eurostat's Prodcom and Comext data. Second, we considered a series of country-specific reports for textile waste. An assessment of these sources created a baseline range of 5.4 million to 6.5 million tons. After triangulation of a consistency check of individual countries, we reached a 6.0 million tons waste baseline.

Collection rate baseline. The baseline collection rates are based on multiple sources, including expert interviews to fill data gaps. For Germany, France, the Netherlands, Austria, Italy, Spain, and the Baltic regions, we relied on country-specific reports outlining textile-waste collection. For the remaining countries, we conducted a case-by-case assessment, where each country was assigned a baseline collection rate based on the best available approach. For example, comparable neighboring countries (such as the Netherlands and Belgium) are assumed to have similar collection rates. In some cases, we needed to create a top-down assumption based on industry-expert input. In all cases, the collected volumes in absolute numbers were sense-checked with multiple triangulation

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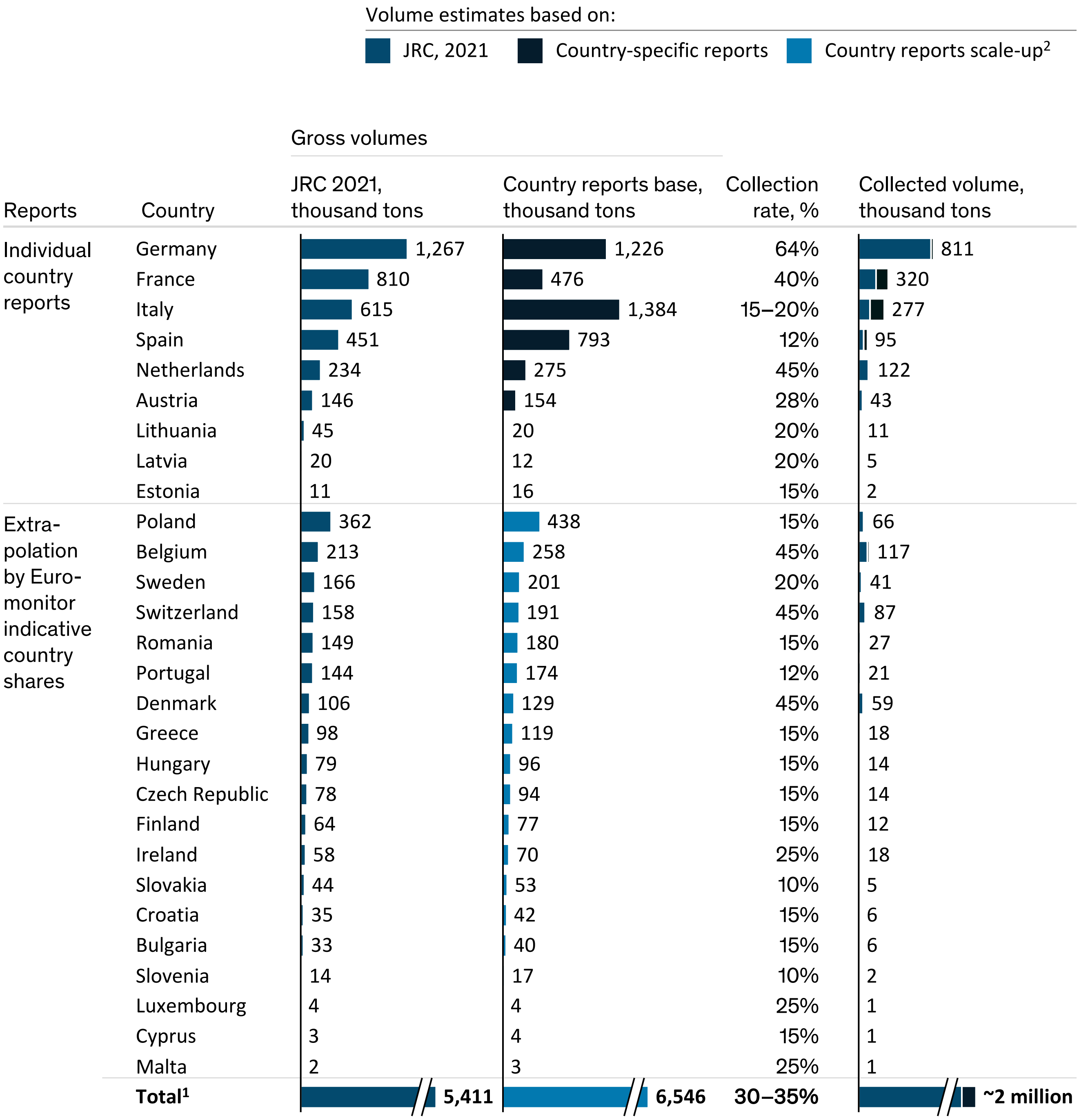
[73] "Electricity prices for non-consumer households—bi-annual data (from 2007 onwards)", Eurostat, updated April 19, 2022 (2021 H1 avg EU-27, ex VAT and other recoverable taxes).

Exhibit 24

Both approaches to gross volumes are used to refine the range of collected volumes across Europe.

Estimated waste volumes



Reports	Country	JRC 2021, thousand tons	Country reports base, thousand tons	Collection rate, %	Collected volume, thousand tons
Individual country reports	Germany	1,267	1,226	64%	811
	France	810	476	40%	320
	Italy	615	1,384	15–20%	277
	Spain	451	793	12%	95
	Netherlands	234	275	45%	122
	Austria	146	154	28%	43
	Lithuania	45	20	20%	11
	Latvia	20	12	20%	5
	Estonia	11	16	15%	2
Extra-polation by Euro-monitor indicative country shares	Poland	362	438	15%	66
	Belgium	213	258	45%	117
	Sweden	166	201	20%	41
	Switzerland	158	191	45%	87
	Romania	149	180	15%	27
	Portugal	144	174	12%	21
	Denmark	106	129	45%	59
	Greece	98	119	15%	18
	Hungary	79	96	15%	14
	Czech Republic	78	94	15%	14
	Finland	64	77	15%	12
	Ireland	58	70	25%	18
	Slovakia	44	53	10%	5
	Croatia	35	42	15%	6
	Bulgaria	33	40	15%	6
	Slovenia	14	17	10%	2
	Luxembourg	4	4	25%	1
	Cyprus	3	4	15%	1
	Malta	2	3	25%	1
	Total[1]	**5,411**	**6,546**	**30–35%**	**~2 million**

1. EU-27 and Switzerland.
2. For the estimation of gross volumes based on the country reports, we have scaled up the country report data using Euromonitor data on apparel retail volumes.

Source: Euromonitor 2022; Federmoda, 2019; Intecus, Germany report, 2021; Joint Research Council, 2021; Modare, Spain report, 2021; Refashion, 2021; Rebel, Netherlands report, 2021; Umweltbundesamt AT, 2021 points including a relative comparison to the Joint Research Centre report, the country's population and GDP, and garment consumption according to Euromonitor. The main point of triangulation was the scale-up of waste volumes from the country reports based on apparel retail volume data. Please see Exhibit 24 for details.

After the consideration of the absolute and relative baseline of textile waste collection, we moved to forecasting future textile value volumes.

— **Collection rate forecast.**The forecasted collection rates are based on the estimated baseline. Today, an average collection rate for EU-27 and Switzerland of around one-third is estimated. The base-case scenario for waste collection development was based on France as a reference case because France has the longest data record as the EPR for textiles was introduced in the country in 2009.[74] The textile collection scheme increased collection rates from 15 percent in 2007 by two to two-and-a-half percentage points per year until it reached 35 percent, and then flattened to one-and-a-half percentage points per year. Applying the French curve to the current collection rates gives different countries different growth rates based on how advanced they are. This scenario resulted in a collection rate growth of around 15 percentage points over ten years across the Europe, taking its average to 50 percent in 2030.

— **Share of waste sorted in Europe.** Currently much of Europe's collected post-consumer household textile waste is exported directly to countries outside Europe. It is difficult to estimate how much is exported as there is a long tail of small textile-waste collectors where data access is low. Experts indicate that only 60 percent is sorted in Europe. These exports are partly legitimate and aligned with the waste hierarchy as some goes to reuse, which is a desired path for textile products. However, there is simultaneously a large problem with textile-waste management, especially in some of the Global South countries to which European textiles are exported—particularly the exports of unsorted textile waste. This is problematic as many of these countries do not have the capacity to recycle this waste, and, as a consequence, much of it ends up in landfills or incineration. Going forward, the European Commission is expected to introduce new EU rules on waste shipments that will only allow the export of textile waste to non-OECD countries under certain conditions.[75] Over time, the share of unsorted textile waste to be exported is expected to decline and around 90 percent could be sorted in Europe in the future.

— **Sorted share for reuse.** Several drivers could influence the share of collected volumes that are eligible for reuse versus those available to recycling. The primary driver is that the average quality of textile waste will go down as the collection rate goes up and the tail of textile waste is collected. This dynamic could create a mix shift, where the share of textile waste not eligible for reuse will go up from 40 percent today to 50 percent in 2030, a number that has been derived through multiple conversations with experts.

— **Available to recycling and technically fiber-to-fiber recyclable.** The term "available to recycling" refers to textile waste that is collected and fiber sorted. These volumes could be purchased by textile recyclers and therefore be considered "available to recycling". The assumptions driving this rationale are outlined above within the report. Of what is available to recycling, not everything technically is possible to fiber-to-fiber recycle. This paper has estimated that 70 percent of textile waste could technically become fiber-to-fiber recyclable in the future. Currently this share is much lower, with many recycling technologies requiring up to 98 percent purity. The 70 percent assumption is based on a detailed assessment of every fiber-to-fiber recycling technology's purity requirement today and in the future.

Exhibit 25 outlines the main assumptions driving the post-consumer household waste volumes in EU-27 and Switzerland.

Estimations of post-consumer commercial waste, pre-consumer waste, and post-industrial waste

As the other three textile waste streams are significantly smaller (about 15 percent of the total gross waste), a less extensive forecast of volumes was conducted.

For pre-consumer householder waste (for example, unsellable overstock of producers, brands, distributors, or retailers) we did a top-down estimate of what share of total retail volumes will end up as unsellable. The rationale for this approach was that sellable garments are not waste, even if they are temporarily unsold, stored, and waiting to be sold in a lower-value channel. The share of retail volumes that is relevant for textile recycling is only the volumes that are truly unsellable due to defects. This share is estimated to be between 3 and 5 percent of total volumes.

For post-consumer commercial waste and post-industrial waste, we performed a bottom-up quantification based on the different sub-categories. We relied on commercial waste and production data summarized in the report, *Circular Economy Perspectives in the EU Textile sector,* by the Joint Research Centre in 2021. As no clear data sources for these collection volumes and waste streams exist, we

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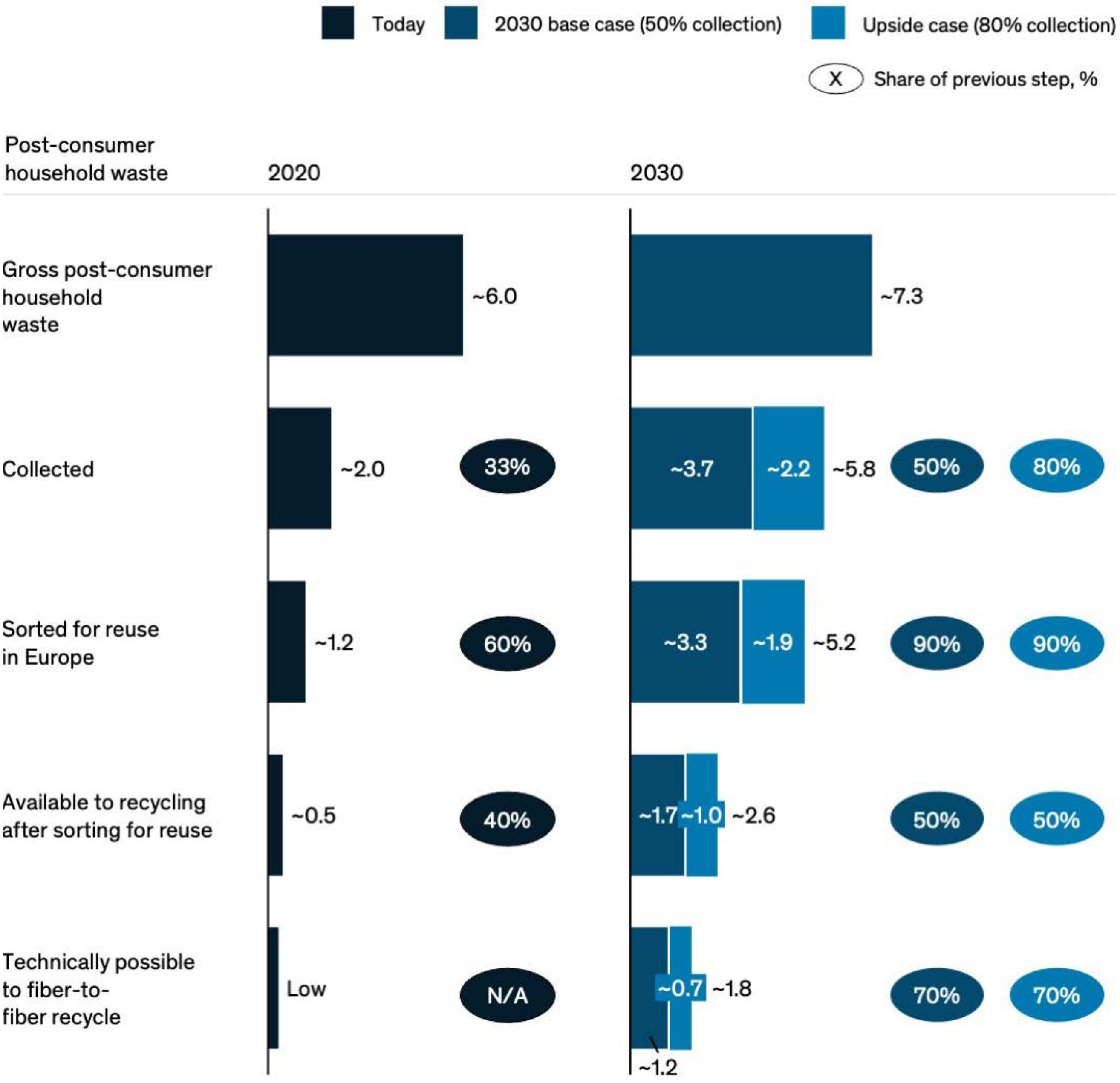
[74] Refashion.

[75] *Questions and answers on EU strategy for sustainable and circular textiles,* European Commission, March 30, 2022.

Exhibit 25

Post-consumer household textile waste availability could go up from 0.5 million tons (8 percent of total) to 1.7 million tons (23 percent of total).

Textile waste volume flow, million tons



Source: Deloitte European Market Study for ETSA, 2014; Ellen MacArthur Foundation; EUROSTAT Prodcom; expert interviews; Humana Annual Report, 2020; Intecus Germany report, 2020; ISPRA Italy country reports no. 1 and no. 2, 2021; JRC, 2021; JRC Technical Report, 2021; Le Figaro, 2019; Modare, Spain report, 2021; ReFashion, France report, 2020; Rebel report, Netherlands report, 2021; Umweltbundesamt, Austria report, 2022; Nordic Council for Ministers, Baltic Country reports, 2020; web scraping product data analysis by Norna relied on multiple industry experts to triangulate percentages applied bottom up. In total we engaged more than 20 experts from across the textile value chain for these top-down estimations.

Fiber composition analysis

There are no ideal data currently available to estimate the fiber composition of European textile waste. Notice that our data are based on global data and that we estimate the fiber composition of several waste streams (not only post-consumer apparel). Our data likely overestimate the share of polyester and underestimate the share of cotton mainly due to regional differences (global versus European data).

Fashion For Good, together with Circle Economy, are running the "Sorting for Circularity Project". They analyze post-consumer textiles waste (apparel and household textiles) and determine fiber composition across sorting facilities in Europe. They will publish their results in September 2022. The data on the composition of post-consumer household textile waste could be updated with the results from the Sorting for Circularity Project once available.

We based our analysis on three sources: Textile Exchange, IHS Markit, and Norna (an AI company that provides web scraping services). We analyzed the fiber composition across three waste streams: post-consumer household, pre-consumer waste, and industrial waste. We did not analyze the fiber composition of post-consumer commercial waste due to a lack of data. Our estimation refers to the expected fiber composition in 2030. We noticed that the share of polyester is expected to increase over time.

For simplicity, we assumed the same fiber composition in production as in waste. This is a simplifying assumption as waste equals production a given number of years ago, and (industrial) washing may change fiber composition over time (for example, cotton is "washed out" easier than polyester).

For post-consumer household and pre-consumer waste, we followed the following process:

- First, we used an estimation of the global fiber production in 2030 with a split on fiber types, for example global fiber production includes around 19 percent cotton and around 57 percent polyester (Textile Exchange). Notice that there are regional differences that we did not consider.
- Second, we used a high-level perspective on the split on applications per fiber type (Textile Exchange), for example 30 to 50 percent of cotton is used in apparel.
- Third, we adjusted the split on applications for polyamide where more detailed data was available (IHS).
- Fourth, we estimated the split on fiber composition in apparel per fiber type (Norna), for example, around 53 percent of cotton is used in 100 percent cotton products, while 7 percent is used in products with more than 65 percent cotton. Norna data are based on scraping product information for a sample of 70 brands and 424,000 products. We used Norna data to get an idea about how the different materials are used (for example how often is polyester mixed with elastane). We acknowledge that Norna data are not fully representative and are based on SKU data and do not reflect sold volumes. In addition, we noticed that CircleEconomy has made an analysis concluding that product information and labels are subject to inaccuracy.

For industrial waste, we used European production data to estimate the fiber composition. A large share of the production is technical textiles where the waste is high-purity synthetics.

Industry profitability assessment

To evaluate the potential for cross-value-chain profitability, we assessed the full flow of textile waste from collection to sorting for reuse, to sorting and pre-processing for recycling, and, finally, to recycling. In each step we considered the following dimensions:

- **Operating expenditure and capital expenditure cost assessment at maturity for all value chain steps** (collection, sorting for reuse, sorting for recycling [fiber sorting], and for several different recycling technologies).
- **Volume share and price and costs levels for different revenue sources after sorting for reuse** (that is, revenue from local resell, less-developed country resell, volumes advanced to sorting for recycling [fiber sorting], and the negative charge from incineration).
- **Volume share and price levels for the different recycling feedstock buckets produced from sorting for recycling** (for example, 100 percent cotton, 80 to 99 percent cotton, 100 percent polyester).
- **Volumes and price levels** for different recycling technologies to match the price-quality of virgin fibers.

At least 20 different permutations were tested to get a rigorous understanding of potential flow dynamics and their economics implications. The full outcome of this analysis is not communicated in this paper. Only one of the main scenarios that we believe captures one potential outcome is illustrated in the report. This scenario should be read not as a forecast, but as one of several potential outcomes. The end state for the value chain, and the distribution of costs and profits across the individual steps, are extremely hard to predict. The critical take-away of our analysis is that there could be enough economic value generated to create sufficient returns to investors in all steps

Estimation of facilities

Using the estimated waste volumes per country in the base-case scenario in 2030, we grouped the countries into six European regions: Central, Western, Southern, Eastern, Iberia, and the Nordics. We established a scenario for the feedstock volumes per region and recycling technology using the allocation scenario of feedstock volumes and a scenario of the feedstock distribution between the different recycling technologies.

A directional estimate of the number of plants per region was created by assuming an average plant size or capacity for sorting for reuse, sorting for recycling, and the nine different technologies studied. The assumed facility capacities, in tons per year, are 25,000 (for all mechanical recycling steps), 50,000 (both sorting steps, thermo-mechanical and chemical recycling of polyamide), and 100,000 (chemical recycling of cellulosics, polyester, and thermo-chemical recycling).

The assessment of the exact location of facilities has not been conducted. Transportation costs will likely be an essential aspect when considering facility location, something that has not been analyzed in this report.

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