Industry-Aligned Action Plan: **Digital ID to Scale Circular Systems**

EON

In partnership with

ACCELERATING® CIRCULARITY

What happens when your products leave the store?

It's a simple question, but most brands don't know the answer. Over the next decade, the introduction of Digital ID technology will see billions of retail products go online – connected with technology that increases traceability, utility, and intelligence. It's a huge step forward, but we have yet to capitalize on the true potential Digital ID holds for our industry.

This Industry-Aligned Action Plan illuminates the transformational role Digital ID can play in fashion's circular economy. It outlines the challenges and opportunities, and codifies industry best practices and solutions. It's an actionable roadmap to transition from a fragmented, linear system to a data-driven, connected and circular ecosystem. At the heart of the report is a call for shared digital infrastructure and the adoption of global standards. This is essential for brands to capture the resale market and scale textile-to-textile circular business models, unlocking viable, industry-wide systems for collection, sorting, pre-processing and recycling.

Connectivity is essential to reshape our relationship with resources and to solve for the systems and incentives preventing our transition to a circular economy. If Digital IDs are implemented according to this plan, brands can access ongoing royalties, relationships and data through products. And stakeholders across the value chain can finally collaborate to access data and identify items – creating the world's first interconnected system for asset management.

We hope this perspective offers a compelling vision for a Digital ID-enabled, circular economy. We invite you to add your voice to this conversation, and we look forward to engaging with the first movers and leaders to act on this opportunity.

Natasha Franck
CEO & Founder, EON

Acknowledgements

Accelerating Circularity is a nonprofit that creates new supply chains and business models to turn textile waste into mainstream raw materials. AC envisions a world where textiles are no longer wasted. Its approach is to research, map, model, and test circular, textile-to-textile systems from collection, sorting, preprocessing, and recycling through the conventional supply chain at standard commercial scale. The work demonstrates that textile-to-textile circular systems are feasible and worth engaging in for the entire supply chain. Because textiles are too good to waste.

EON's mission is to connect the world's products with technology to create infinite new value for business, society and the environment. EON's SaaS platform, the EON Product Cloud, is the leading product-digitization solution for retail, used by some of the world's largest global brands, including Target, Zalando and YOOX NET-A-PORTER. In 2017, EON led the development of the standardized data language for Digital ID. It was a partnership by leading brands, policymakers, academics and circular businesses. The result was the **Circular Product Data Protocol**, which launched for free, public use in 2021.

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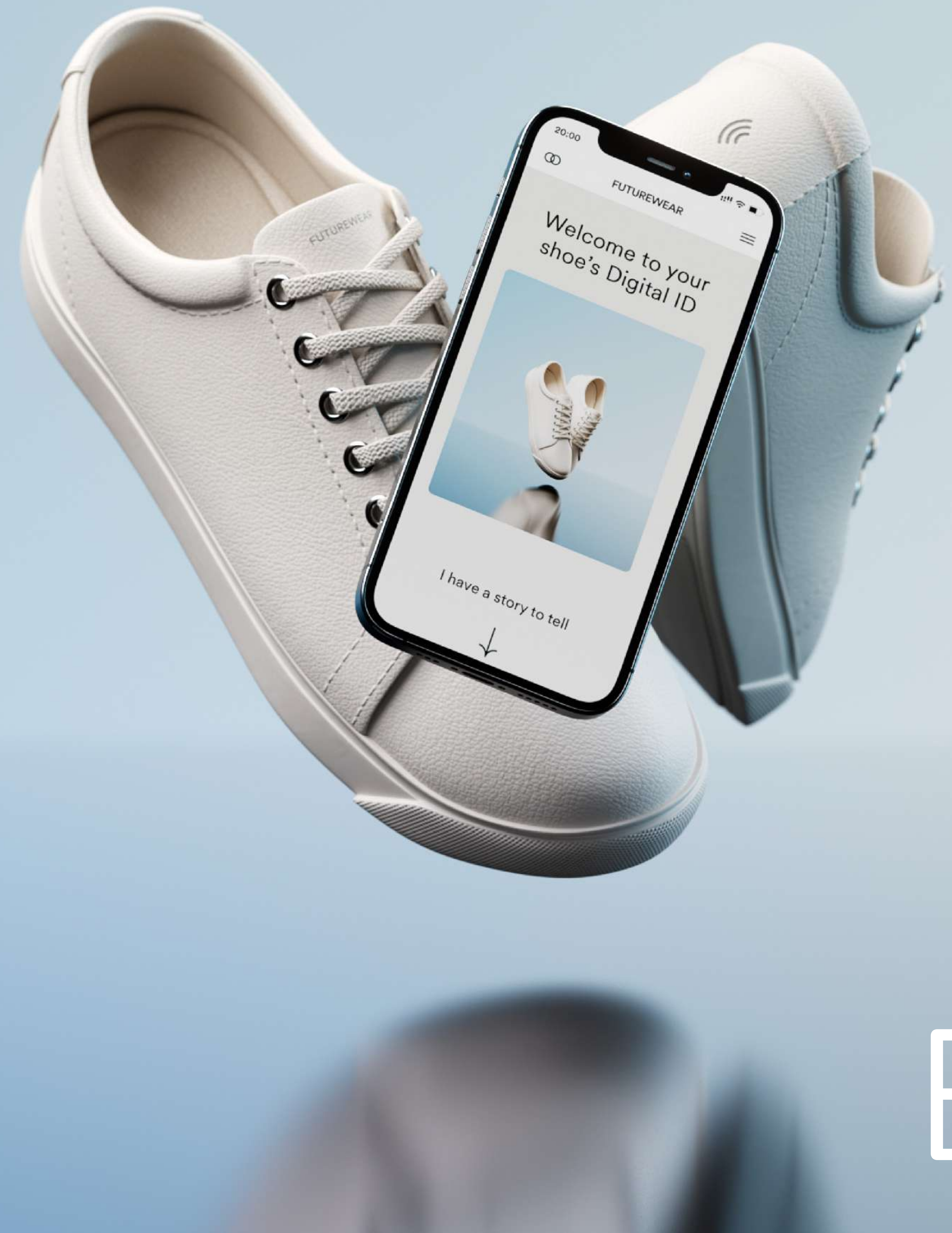
Our Vision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FUTUREWEAR
Welcome to your shoe's Digital ID
I have a story to tell

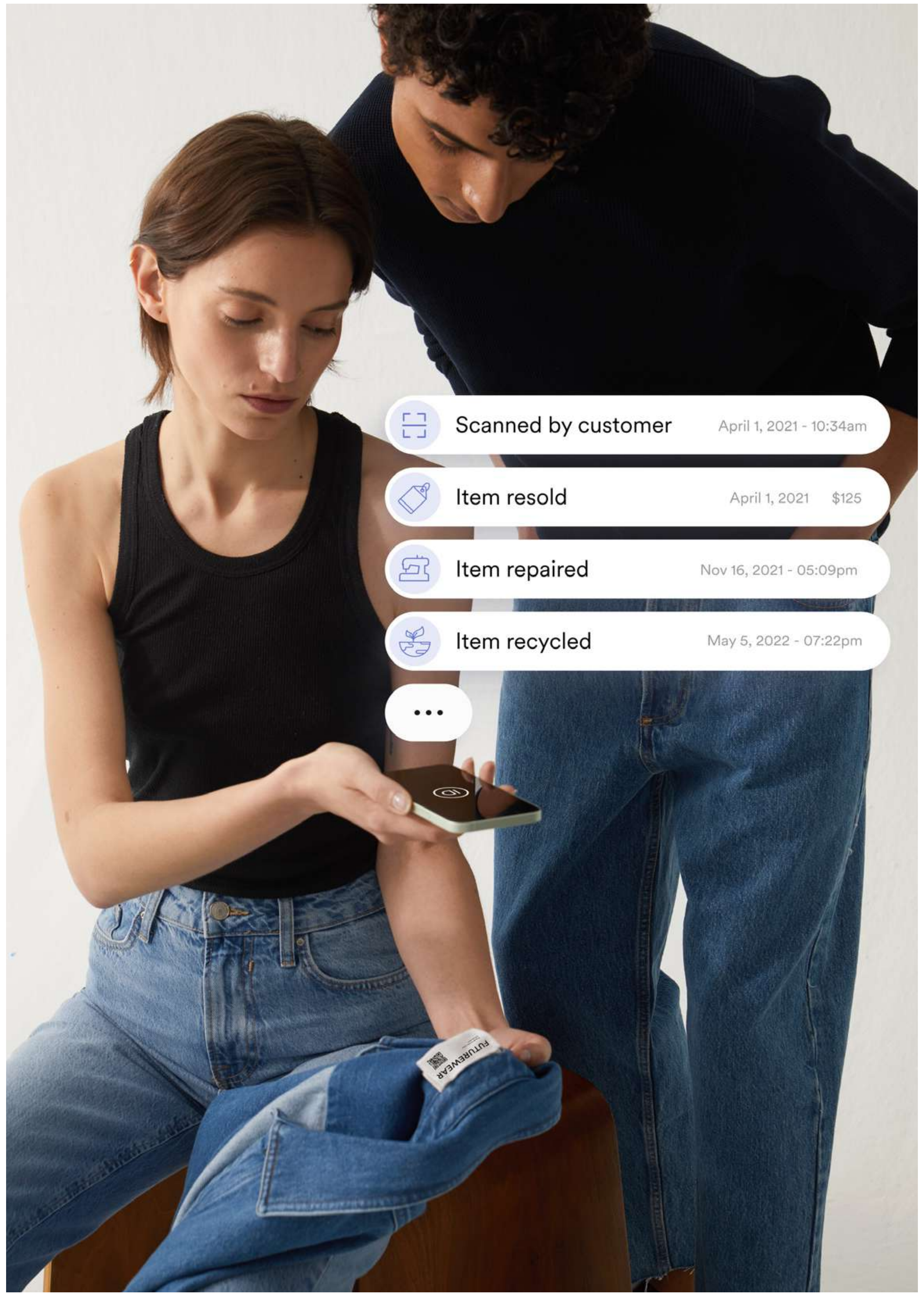
Over the last decade, textile-to-textile recycling has emerged as an essential segment of the circular textiles industry. It seeks to divert the approximately 11 million tons of textile waste lost annually to landfill in the US[1]. Brands are already investing in product design that will allow products to be recycled at end of life. Many also have ambitious climate commitments that will only be feasible if textile-to-textile recycling and the uptake of recycled fibers are widely adopted. However, textile-to-textile recycling currently lacks key elements to scale significantly. Collection and sorting are not optimized for identifying fiber composition nor detecting contaminants hostile to recycling processes. As a result, collectors, sorters, preprocessors and recyclers find it difficult to efficiently process collected goods into recyclable feedstocks that promise to consistently meet specifications at scale. Through our work, we envision a viable market capable of meeting volumes, technical specifications, and regional variations while reducing non-strategic, virgin material consumption. This aim requires detailed material information, ease of consumer engagement, an automated transfer of data to value chain stakeholders and new system infrastructure. A digital identity (Digital ID) for each and every item may provide an important means to access the data necessary to meet this growing market need.

Digital ID adoption at scale requires a forward-thinking approach. Every stakeholder demands individual consideration within the context of a circular system. Brands bear a unique responsibility and benefit. They will be responsible for capturing data and creating products with Digital IDs. These developments, along with increasing demand for more recycled content, will impact the rest of the supply chain. Voluntary brand commitments to measurable recycled product content indicate market demand is here[2]. The industry is recognizing the critical role of national mandatory recycled content targets and other policy measures, such as Extended Producer Responsibility[3] and digital product passports to meet projected demand. **Digital ID has the potential to aid the transition from a mechanical, linear system to one that is data-driven and connected.**

The benefits of a Digital ID-connected ecosystem could include:

- Improved data accuracy, verification and sharing capability
- Efficiency gains from automation
- Keeping products in circulation longer
- Dynamic and interactive customer engagement
- Monetizing product value from reuse

Through our work, we envision a viable market capable of meeting volumes, technical specifications, and regional variations while reducing non-strategic, virgin material consumption.



Introduction

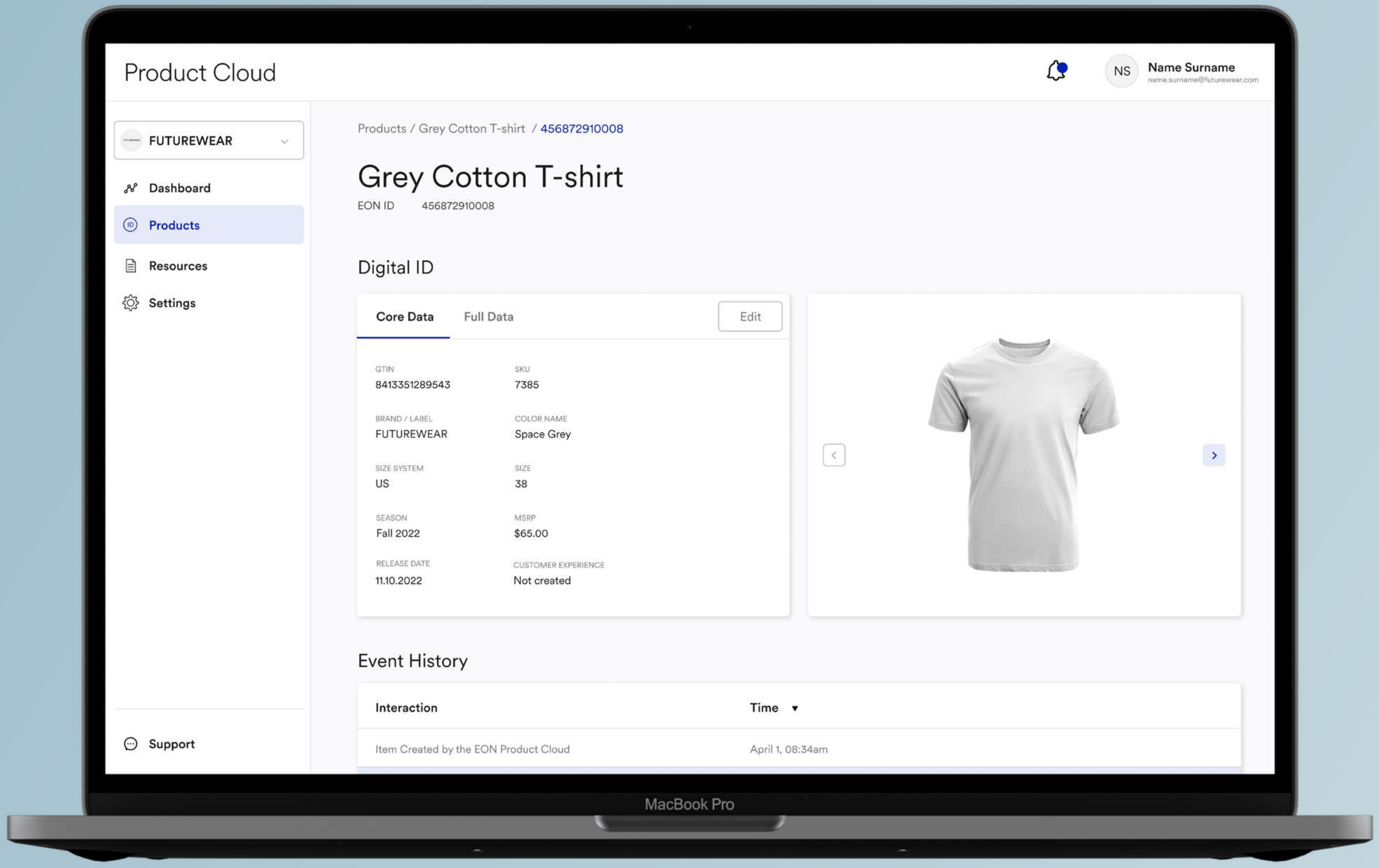
Digital IDs are digital twins of physical products that connect the physical and digital worlds. Digital IDs, also called product passports, exist at the item level. They contain all the information and events associated with a physical product from its creation through its entire lifecycle, for example, material content, country of origin, MSRP and color. Digital IDs are accessible via the internet through a technology solution partner, such as a product cloud platform. To link to their Digital IDs, physical products are associated with an on-product, interactive label, known as a data carrier. The data carrier can take many forms, including QR codes, RFID tags, and NFC or Bluetooth chips.

Until now, brands and industry lacked the technology platforms to capitalize on post-sale product connectivity. Existing item-level tracking solutions support product tracking within a brand's own organization, from point of production to the point of sale. Now products need to connect and exchange data with entities outside of a brand's own organization – third parties such as resellers, rental partners, recyclers and more. This has given rise to the demand for product cloud platforms that power the data exchange associated with each product's Digital ID between brands and third parties, enabling brands to capitalize on embedded data carriers in products and connect them across the circular value chain.

Digital IDs provide a clear benefit for brands looking to recapture product value through resale and regain direct consumer access. As indicated by the EU Waste Framework Directive[4] and mirrored in the waste hierarchy adopted by Accelerating Circularity[5], capturing resale value through reuse, repair and design is fundamental to reduce the overall footprint of the textile and fashion industries. The increased capture of resale value by brands might even generate incentives to produce higher-quality items that will retain higher resale value, disrupting the wasteful and damaging fast-fashion race to the bottom.[6, 7] Digital ID is widely discussed as a means to develop new business models around resale and reuse, driving efficiencies and opportunities for both brands and consumers.[8, 9, 10]

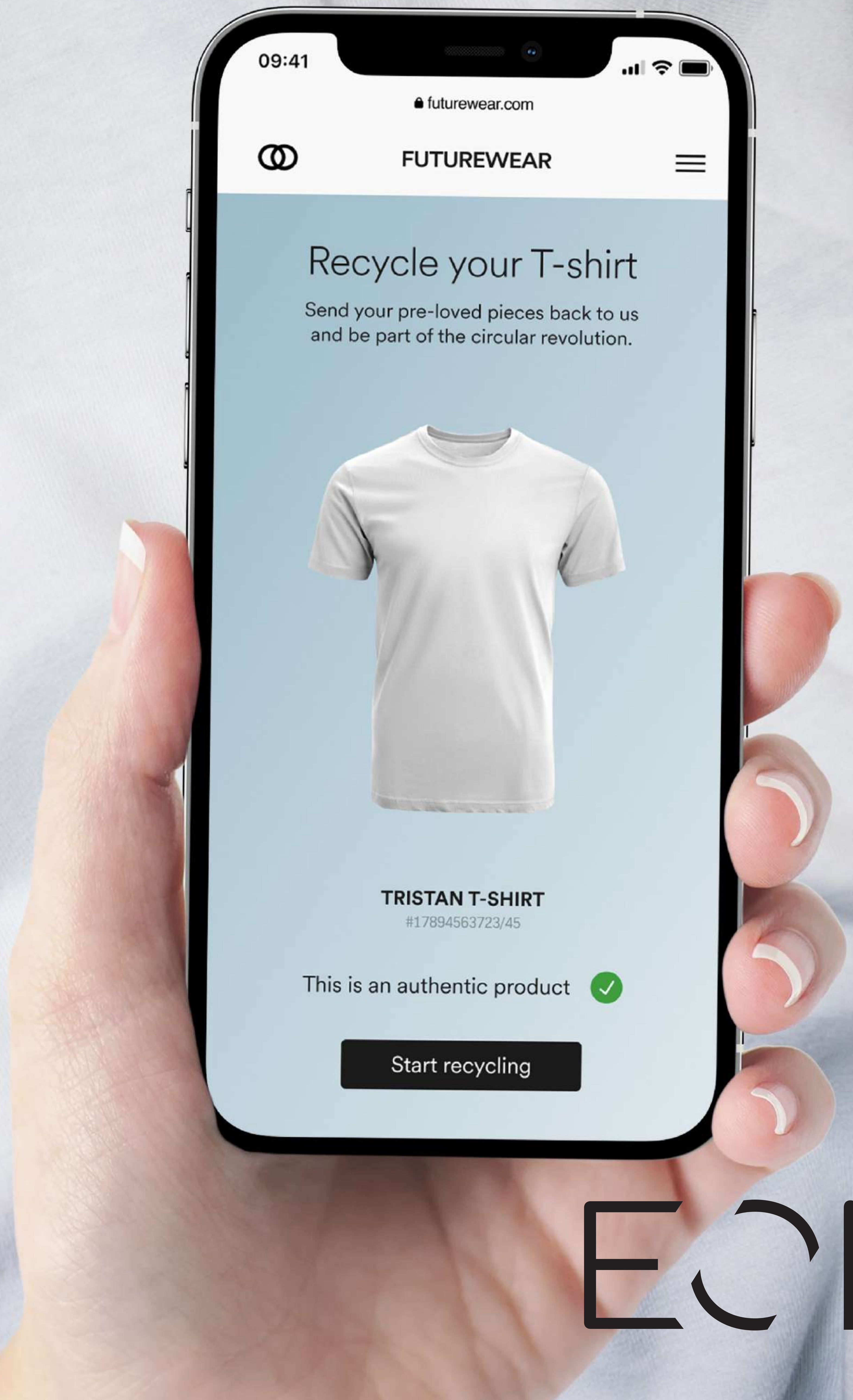
The data capture and exchange intrinsic to emerging Digital ID technology may also hold promise for the future of textile-to-textile recycling. It is important to understand the impact Digital ID will have on end-of-life recycling, and how that impact differs for brands, manufacturers, collectors, sorters, preprocessors, recyclers and consumers. This report explores this potential as well as existing implementation challenges, including: facilitating data access and exchange across the system, technical infrastructure upgrades, the material nature of data carrier hardware, the environmental impacts of the hardware and the environmental and economic liability of long-term data management. As with the development of any new solution, it's important to design the solution for future success alongside careful consideration of any unintended consequences.

Product Cloud Platform



Digital IDs are typically hosted in a cloud-based software solution known as a product cloud. Product cloud platforms create item-level Digital IDs for each product at scale, store product information and record real-time data across the product life cycle. This means events and interactions such as sales, resales, repairs, donations and recycling can be associated with the product, and accessed by any value chain stakeholder through the software.

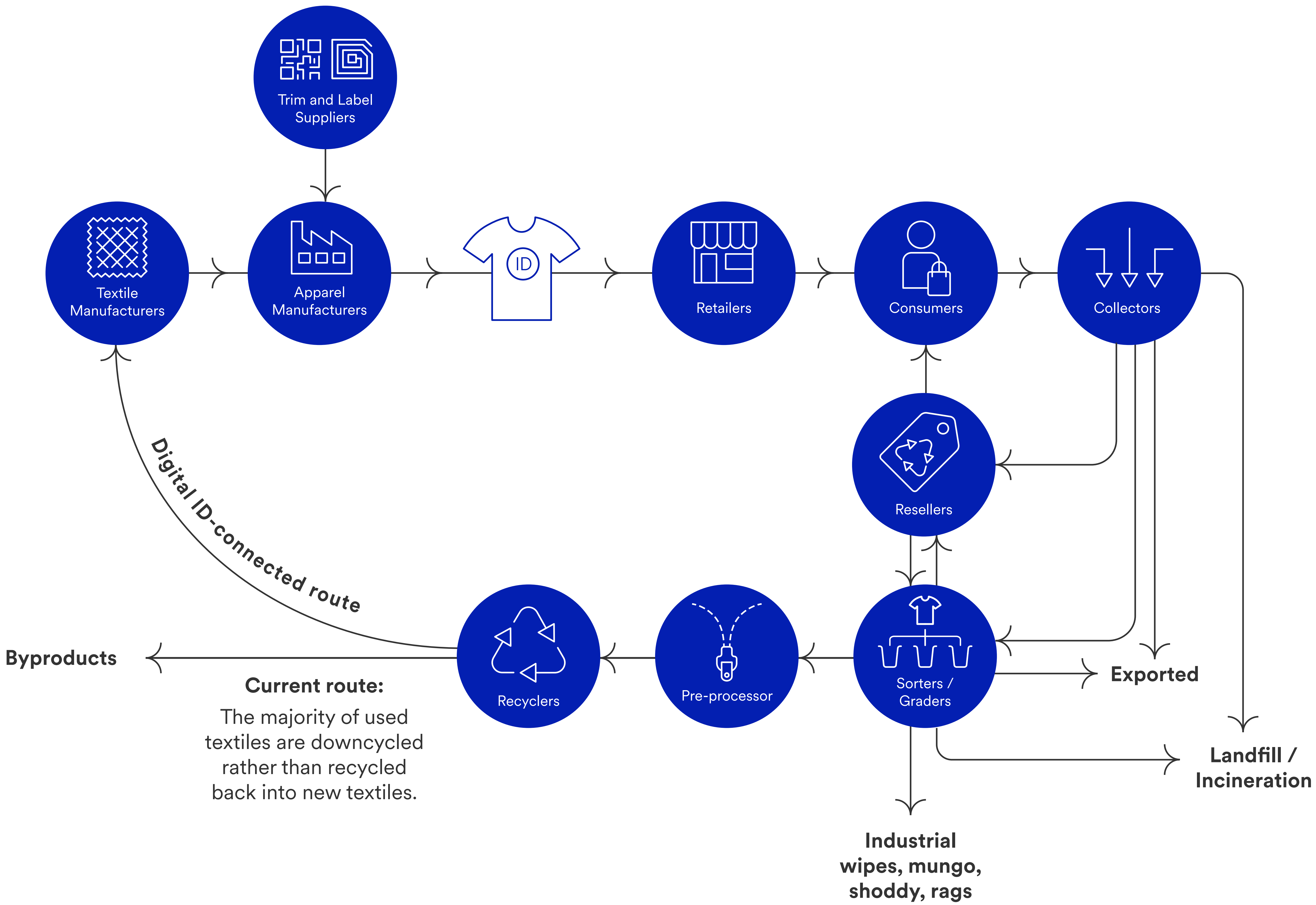
Digital ID: Textile-to-textile recycling opportunities and challenges



EON

Materials are not always channeled into their highest and best use in today's secondhand textile market. This is a lost opportunity. Increasing the quality and accessibility of product data may enable better management of a product's true end of life by allowing it to be channeled into its next highest and best use (whether resale, repair, remanufacture, recycling or downcycling). While markets exist for textile-to-textile recycling feedstocks, they're currently fed from post-industrial processes or brand-controlled take-back programs. These streams have several advantages for recycling, such as ease of traceability, identifiable fiber content and lower preprocessing demands, but the volume of supply is dwarfed by the unrealized potential of post-consumer sources. Diverting textiles from landfill at scale rests on the industry's ability to pull materials from the post-consumer landscape and into these feedstock pools. Through access to high-quality and complete data across the system, material aggregation and grading could see marked increases in scale and quality.

Textile-to-Textile Recycling Ecosystem



The data exchange intrinsic to Digital ID technology has the potential to support textile reuse and recycling by channeling products to their next highest and best use while increasing availability of feedstocks from post-consumer sources.

The widespread adoption of Digital IDs could plug textile products, producers, new service models and recycling system stakeholders into an intelligent, global, cloud-based infrastructure for asset management and product-data exchange.

The widespread adoption of Digital IDs could plug textile products, producers, new service models and recycling system stakeholders into an intelligent, global, cloud-based infrastructure for asset management and product-data exchange. The aim is to keep products in circulation longer, reduce extractive processes and minimize waste. Digital IDs have the potential to:

- Direct feedstocks to the correct collection and recycling routes
- Improve the accuracy and availability of product and material information
- Increase the speed of sorting and processing products and materials for recycling
- Support aggregation of sufficient quantities of materials suitable for textile-to-textile recycling

Brands already use several forms of Digital ID data carriers to support consumer engagement, inventory management and scale new business models. For example, warehouse workers use RFID tags to aid inventory tracking, QR codes and NFC chips support consumer engagement through mobile native technology and tracers added to fibers can validate product authenticity or other attributes. Digital IDs may have the potential to be leveraged to aid efforts to scale textile-to-textile recycling, but not without understanding the impact and limits for this part of the supply chain. All stakeholders must be able to access the data when they need to, in a way that integrates with their current operations. When implementing a Digital ID program, brands must consider the impacts on collectors, sorters and preprocessors and embed solutions within their implementation, such as:

- Special considerations for specific material needs and the uptake of recycled fibers
- Uniform data carrier hardware placement
- Data carrier hardware recycling infrastructure
- Cost considerations (e.g. cost of data storage and infrastructure)
- Complementarity, compatibility and interoperability with diverse technology solutions coming to market

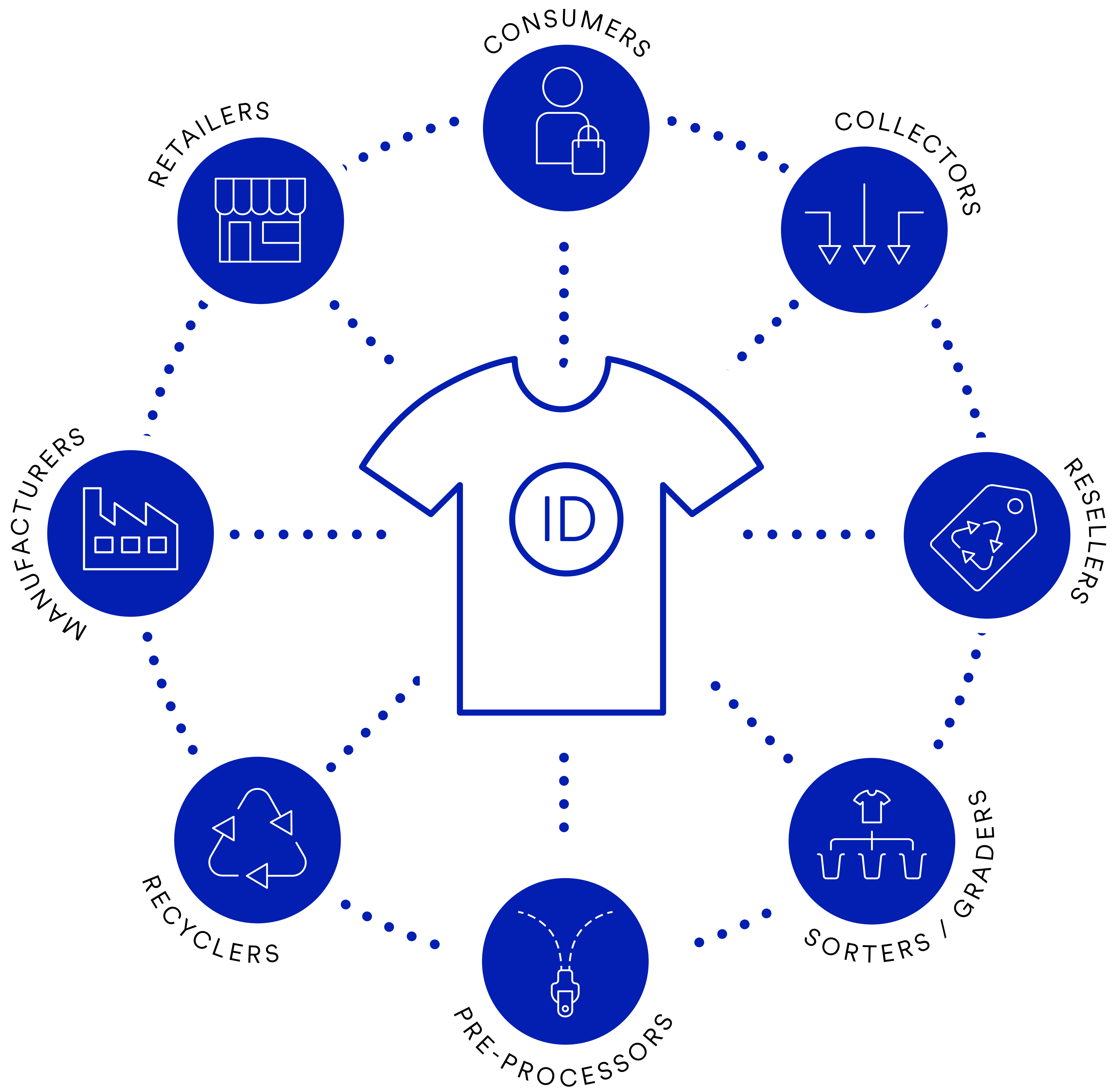
Table 1 outlines the obstacles and needs of stakeholders in the textile-to-textile recycling ecosystem, and the solutions Digital ID could provide.

Table 1: Stakeholder Obstacles and Needs and the Benefits of a Digital ID-Connected System

Stakeholder	Obstacles	Needs	Solutions of a Digital ID-Connected System
Manufacturers	• Only a small percentage of the market's new products are given Digital IDs • Insufficient knowledge and access to data carriers to support the digital identification of products	• Durable data carriers attached to physical products • A quick, scaled process for data carrier attachment and association to Digital IDs	• Facilitates the association and encoding of data carriers and integrates into the existing manufacturing process steps through software connection
Brands/Retailers	• No traceability of products past the point of sale	• Visibility of product through end of life • In-product data on material inputs and sources	• Provides a means to track products through the entire lifecycle • Provides the ability to communicate with the consumer on pathways for reuse and/or recycling • Supports optimized inventory management with data attached to the product vs hangtag
Consumers	• Insufficient knowledge on product contents, recycling potential and end-of-life return systems	• Information on product care, use and end-of-life options • Visibility into product information, traceability and transparency	• Provides access to product use and end-of-life options to support reuse, resale and recycling • Provides knowledge on garment inputs and supply chain paths
Collectors	• Collection systems in the US only manage to collect ~14% of material; the remainder is disposed of as solid waste[11].	• Demand for and access to landfill-bound textile waste	• Provides access to information that leads to demand, e.g. fiber content, chemicals, fabric construction • Can facilitate tracking the amount and types of products collected and their material composition; this can support the identification of end-markets

Stakeholder	Obstacles	Needs	Solutions of a Digital ID-Connected System
Sorters	• High level of accuracy for sorting by fiber, color, construction and other recycling-process contaminants • Sorting for recycling is currently manual and labor-intensive, creating sorting-speed limitations	• Detailed product information to support accurate sorting based on the recycler's specification • Automation of the sorting process to increase throughput	• Provides detailed product information to enable accurate sorting into a wider range of marketable grades • Facilitates high-speed, automated sorting using Digital ID to increase processing volume
Preprocessors	• Cannot efficiently identify all elements that must be removed to meet recycling specifications	• Ability to remove all necessary contaminants for a variety of recycling grades	• Presents the potential for beneficial pre-sortation and aggregation via data exchange • Provides detailed product information to identify contaminants that must be removed, including the data carrier itself, in some instances, allowing for the creation of bales that match recycler requirements
Recyclers	• The need to commercialize post-consumer textile recycling technologies at scale	• Insights on collected products/materials that fit the feedstock requirements of textile-recycling technologies	• Offers the potential of higher-quality assurance • Delivers greater quantities of accurately sorted feedstocks for recycler use, supporting post-consumer textile recycling growth • Further reduces the cost of feedstocks through accuracy, speed and volume availability

A Digital ID-Connected System for Textile-to-Textile Recycling



As shown through recycled-material commitments[12] and investments in textile-to-textile recycling technologies,[13, 14] the industry is ready to adopt textile-to-textile recycled materials. The time to scale is now. We must align with solutions and innovations that all stakeholders can leverage. Digital IDs could have a profound effect on the future of textile-to-textile recycling, but we may miss opportunities and create obstacles if we don't consider the practical limitations of a technology built for the benefit of some, whilst depending on the physical processing of others. Every technology carries a material benefit or burden for one system or another.

This report follows a roadmap for the implementation of Digital ID in terms of textile-to-textile recycling. It outlines the following key areas of relevance:

1. Hardware
2. Data
3. Software
4. Implementation
5. Limitations
6. Costs
7. Consumers

Part 1: Hardware

What is a data carrier?

Data can be connected to products in a number of different ways. A label can provide information such as material contents and care instructions. Scanning the surface of a textile with an optical scanner will identify the color of the material. RFID tags can be used to aid picking products. QR codes and NFC chips can be linked to purpose-built web pages offering product information and services. Bluetooth technologies can provide real-time inventory insights, and unique chemical markers are now being used to communicate that a textile is from a particular source, like a recycled fiber manufacturer. As technology continues to evolve, new ways to access and append information are emerging.

The landscape of current and emerging data carrier technologies

The current landscape of data carrier technologies is vast, and each solution comes with pros and cons. For example, some data carrier solutions can only be scanned at very close range, while others can be detected by a scanner meters away. Some require specialized hardware to access their information, while others can be scanned with a smartphone. The size of the data carrier is especially important to consumers, and can vary from bulky to invisible.

Today, data carrier technologies are used widely within the supply chain and typically support SKU-level identification, for example, a barcode or RFID-enabled hang tag allows for easy inventory management. They have rarely been embedded in the product to support ongoing, item-level identification beyond the point of sale. However, as the retail industry shifts towards a circular model, and new business models such as resale continue to grow, their usage is beginning to extend to the entire value chain.

Table 2 in the Appendix provides an overview of nine data carriers considered relevant for Digital ID, some of which are well established and widely used in other industries, while others are still emerging and not yet available at commercial scale.

Data carrier requirements by stakeholder

To understand the impact of a data carrier hardware recommendation for the textile-to-textile recycling industry, it's crucial to understand how different actors in the value chain will physically interact with the data carrier, and the information the data carrier will need to provide. **Table 3** in the Appendix provides a summary of the anticipated uses of each stakeholder, and their individual requirements to ensure the data carrier delivers maximum value.[15]

Data carrier criteria and assessment

To determine which data carriers would best support textiles recycling, various technologies were assessed against key criteria in two stages:

- Stage 1: A pass/fail assessment of two key requirements to facilitate textile-to-textile recycling:
    - Memory: The ability to hold and transfer sufficient product data to support sorting for recycling;
    - High-Volume Sorting: The ability to operate without a direct line of sight to the data carrier itself for processing speed.
- Stage 2: A traffic light assessment of each data carrier technology against key technical requirements and stakeholder needs, developed through stakeholder engagement with data carrier providers and actors in the textile recycling value chain.

The suitability assessment for each criterion is described in the Appendix in **Tables 4** and **5**. The assessment results are shown in **Table 6.**

Part 2: Data

As we aim for widespread textile-to-textile recycling, brands hold an incredible responsibility to ensure the digital identification of products reaches critical mass. They're also responsible for creating item-level Digital IDs at product inception.

To meet this objective, it's important for brands to work with technology partners, manufacturers and suppliers who can support the creation and association of Digital IDs to their physical counterparts. This allows key product attributes to be shared with a variety of ecosystem partners at any step of the product journey.

Key considerations are:

- Selecting an innovative product cloud platform provider who generates and manages Digital IDs
- Selecting the best fit data carrier with a supplier, often a trim or label vendor, who provides the hardware to the manufacturer (pre-associated with data, or not)
- The finished product manufacturer who affixes the data carrier to the product at production
- The sources of key product data including, but not limited to, product data systems, supply chain partners and e-commerce platforms
- Data integration, harmonization and automation that creates scalable value across the product ecosystem
- Standardization of data that promotes interoperability between brands and partners
- End-of-life management of the data carrier and the data

As the data owner, the brand is responsible for associating the correct product data with the corresponding Digital IDs. They're also responsible for stewarding the data throughout their ecosystem by assigning access permissions to stakeholders, for example, recyclers working directly with brands. Brands will often engage service providers that specialize in this and the long-term delivery of data throughout the ecosystem. Working in unison with their product cloud partners, brands must evaluate the optimal methods for collecting and verifying product data to ensure it is accurate and complete, prior to Digital ID association. This can be supported by a quality-assurance process that ensures the correct product data is associated with the correct physical product, and by leveraging a standard data language such as The Circular Product Data Protocol.

Industry-standard languages for data

It's essential we speak the same language to ensure effective communication across internal and external stakeholders. Standardization is critical for the creation of an interoperable data ecosystem and the scalability necessary for recycling and other business applications to be profitable. Product and material-level information must be communicated consistently for interoperability, or the industry will continue to be stuck in a linear, non-collaborative system where it's difficult, and often impossible, to access essential product data for recycling.

The Circular Product Data Protocol™

The Circular Product Data Protocol (Protocol) is an industry-leading protocol that coalesces existing standards to provide a standardized data language for the digital identification of apparel products. It is free and publicly available to the industry. The Protocol outlines the essential data that should be included in each product's Digital ID to enable circularity. It also calls upon existing standards where possible to set forth a consistent data format and taxonomy for each respective data field. By leveraging the Circular Product Data Protocol, a brand's item-level Digital IDs are optimized for interoperability — enabling the exchange of essential data with partners throughout the value chain. With this shared protocol, recycling-system stakeholders can identify and share product information to increase efficiencies and support recycling at scale. Learn more about the Circular Product Data Protocol at **https://circulardataprotocol.org/**.

The Protocol is governed by an Advisory Council, the decision-making body that oversees the development, management and revisions to the Circular Product Data Protocol. It includes organizations such as GS1, The United Nations Economic Commission for Europe (UNECE), Sustainable Apparel Coalition and more. The Protocol was developed in alignment with **ISEAL Standard-Setting Code of Good Practice** by EON in partnership with the members of EON's CircularID™ Initiative: H&M, PVH Corp, Target Corporation, I:Collect, Open Apparel Registry, RISE, Closed Loop Partners and more.

The Protocol describes the essential data points for collectors, sorters and preprocessors to identify material content, dye class and components (see **Table 8** in the Appendix). It also creates a language for value chain partners to adopt for the identification and management of products and materials in a circular economy, advancing the potential for consistent measurement, reporting and transparency.

Another standard, the circularity.ID® Open Data Standard, also contains immutable product data including material and chemical components and a mutable set of data that contains product information such as product images, description, sustainability consumer information and service offers.[16]

GS1 standards

The Circular Product Data Protocol calls for the use of GS1 Standards to align with industry best practices. A global leader in supply chain collaboration, GS1 creates a common foundation for business by uniquely identifying, accurately capturing and automatically sharing vital information about products, locations, companies, assets and more to power today's global supply chains.[17]

GS1 Standards support the definition of globally unique, interoperable identifiers that can associate digitally to the unique, item-level product Digital ID. Through the GS1 Digital Link, a diverse ecosystem of implementations, network services and software are supported in leveraging the GS1 identifiers, agnostic to the type of data carrier.[18]

The Protocol leverages GS1 Standards through association to the product's Serialized Global Trade Item Number (SGTIN), the leading global identifier for item-level serialization, and through EPCIS, GS1's flagship physical event data sharing standard. EPCIS helps provide traceability for the what, when, where, why and how of products and other assets. This enables the capture and sharing of interoperable information about status, location, movement and chain of custody, enabling end-to-end visibility across an entire supply chain of trading partners and other stakeholders.[19]

Data storage & security

Technology partners leveraging the Protocol must implement reasonable and appropriate measures to strengthen data transparency, assign data ownership and define data visibility to target audiences.

Different levels of security and classification will be required for different types of data. Though they center on public or semi-public product information, some Digital ID data may still be considered sensitive and some applications may require the collection of more regulated consumer data. For example, security and erasure protocols for publicly-available information will differ from what is required for commercially-sensitive information or personal data. When stored data includes personal consumer information, the requirements for security increase and data subject rights management becomes a requirement, leading to additional costs.

There is no national consumer data-privacy law at a federal level in the US at this time.[20] The toughest data-privacy law in the US is the California Consumer Privacy Act which exists at the state level. The EU has the General Data Protection Regulation (GDPR), which places strict requirements for data subject rights, data protection, accountability and security.21 This includes implementing “appropriate technical and organisational measures” which are not fully defined.

Although not required by laws such as GDPR, where consumer personal data are processed, there would be an agreement that almost certainly requires data encryption in transit and at rest. Cloud-based systems can address these encryption needs. There would likely be two general types of data to access: data that would be publicly available, for example to consumers through scanning a QR code, and data that is relevant to the textile-to-textile recycling value chain and its stakeholders. Access to this semi-publicly available data would require authorization by the person storing the data, for example, the brand or product cloud platform holding the data. This formal authorization would ensure unauthorized third parties could not access sensitive information unintentionally or without permission.

Part 3: Software

Software plays a crucial role in facilitating data exchange between stakeholders. The EON Product Cloud, for example, connects brands and products to their ecosystem partners, allowing them to exchange data. An application programming interface (API), which enables data transmission between two software systems, can speed up this exchange by providing an access point to many different stakeholders throughout the product's lifecycle, including end of life.

Software: Data capture & transfer process

Digital ID data is made available via the data carrier which can be scanned and read by various technological devices. Data carrier scanners, such as RFID readers, communicate with the product cloud via an intermediary software application layer. Application layers allow effective communication between software applications on different computer systems and networks.[22] The application layer records events and pulls data from the product cloud via an API to support material identification and other collection, sorting, preprocessing and recycling processes.

The application layer is often proprietary, and includes various forms of logic that could support sorting by:

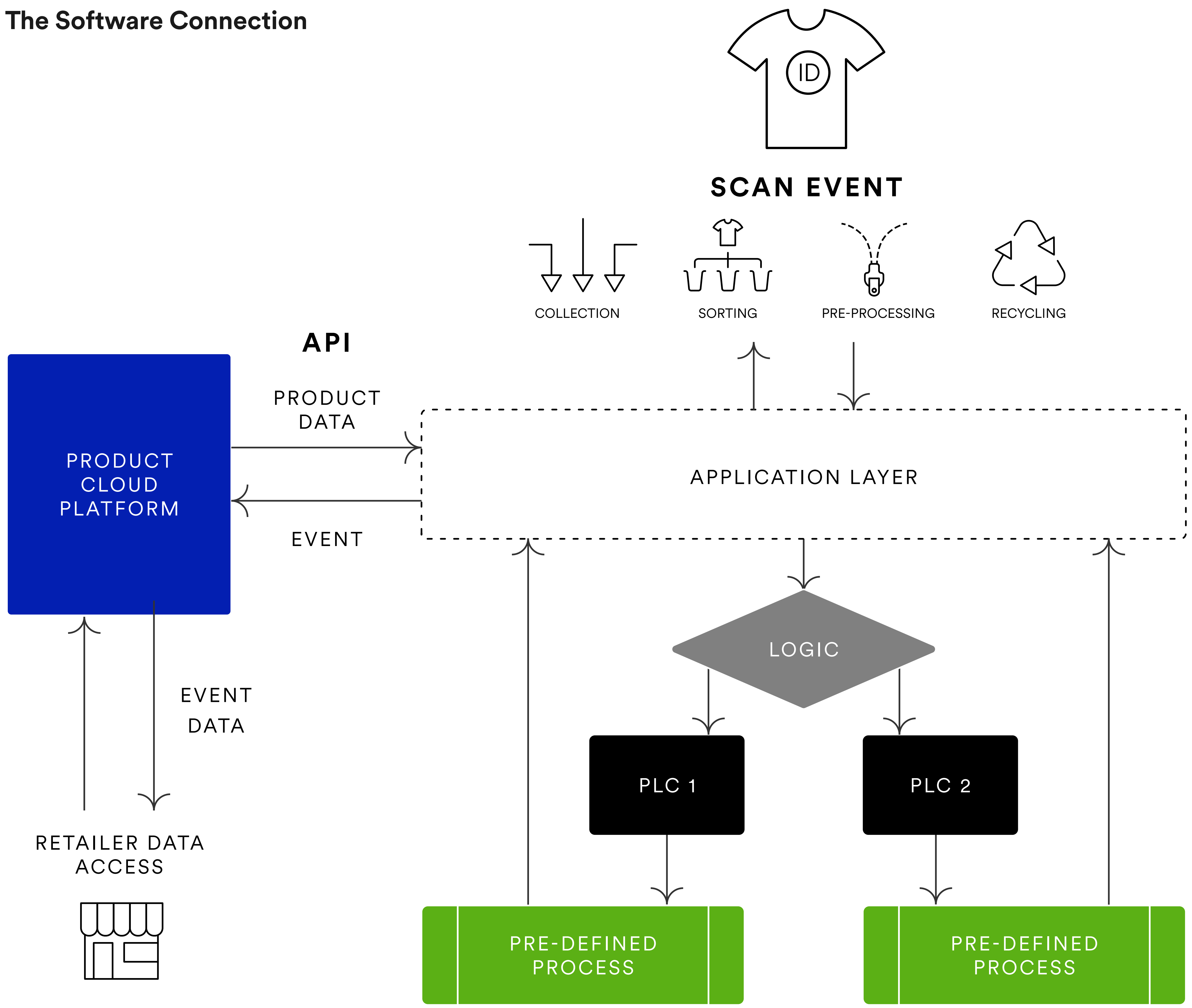
- Showing the manual sorter item-level product material and content information on their device
- Communicating product content information to a programmable logic controller (PLC), an industrial computer that aids in the automation of processes, to trigger the automated sorting of the items
- Prescribing real-world decisions and actions for sorters by using data from an item's Digital ID
- Tracking chain of custody through batch events that confirm materials have arrived/departed the various facilities in the recycling supply chain
- Augmenting near infra-red spectroscopy (NIR) scanning processes through additional verification of data

In order for the connection between the product cloud, application layer and scanners to support sorting for textile recycling feedstocks at scale, the performance of the APIs should be highly scalable, with sub-second timings. Tests conducted by SML on an RFID/QR code implementation showed the RFID could be scanned at a rate of 150ft per minute with 100% accuracy. To ensure this rapid transfer of information, the speed of connection between the following IT system elements must be evaluated:

- The software application layer, which acts as the "logic layer" that registers scan information and communicates it to the product cloud
- The API which allows the logic layer and product cloud software to communicate and relay information back and forth
- The network connection method to transfer data between systems. This could be via:
  - Wi-Fi: Requires a strong and reliable Wi-Fi signal
  - Bluetooth
  - Local Area Network: Requires an ethernet cable that allows internet connection
  - Serial/Auxiliary Ports: Require a USB cable/auxiliary cable to connect to a computer

Pre-integrated mobile applications can support manual sorting operations with various types of scanning infrastructure. Leveraging mobile native functionality, a user can scan data carriers such as QR codes and NFC chips to access product data. For example, the EON Partner App is pre-integrated to EON's Product Cloud, eliminating the need to build a custom connection or API integration.

The Software Connection



Product cloud platforms can exchange data with recycling system stakeholders through software connections facilitated by APIs. A software application layer can support the flow of information from the scanning device. An example of how this system could be designed is shown here.

Interoperability

Collected data should be compatible across systems to ensure effective communication. The Circular Product Data Protocol outlined in Part 2 of this report provides a common language for the digital identification of apparel products, which points to tools like GS1's SGTIN and GS1's Digital Link for interoperability and automation.

GS1's SGTIN is a serialized version of The Global Trade Item Number (GTIN) that allows for individual instance-level item identification and product serialization. The GTIN and SGTIN make it possible to access product data within and across various systems. The SGTIN is compatible with GS1's Digital Link, which allows information access for supply chain applications, as well as online material for consumer and business partner interactions, regardless of the data carrier.[23]

Software implementation and testing actions

The software connections in the textile-to-textile recycling value chain must be tested at scale. The key areas requiring consideration and testing are:

- Data-sharing capabilities and the speed of data transfer between software systems, for example, the application layer, product cloud platform and the sorting machinery software.
- The use of data to sort and preprocess, for example, how to make sorting decisions quicker without requiring items to be singulated at high speeds.
- Evaluating the extent of traceability required for recycled materials and how to operationally capture and validate this information.
- The cost benefit of data capture. If products are serialized individually, the number of data points will increase significantly, as will the ramifications on the server to store such information.

Part 4: Implementation

While implementation action is necessary across all processes and stakeholders within the textile-to-textile recycling value chain, the sorting stage requires the most attention. Brands are investing in recycled materials, and there are many examples of innovative recycling technology developments with the potential to boost recycling and the availability of recycled content. However, these efforts will be in vain if the industry can't identify a product or its contents, or if they can't process enough material to meet demand. The sorting and processing of recycled textiles must be more accurate and efficient than it is today to reach critical mass and scale. The industry must focus on testing technologies, such as Digital ID, that have the potential to increase sorting speed and throughput.

As Digital ID adoption grows, the industry should adapt its operations to include planning for feedstock creation, in order to reap the benefits of textile-to-textile recycling. This section explores how the system could build infrastructure capabilities to capture value from a Digital ID-connected system. **Table 9** outlines the roles and responsibilities of each recycling system stakeholder, as they support Digital ID system implementation, testing and future development.

Table 9: Stakeholder Roles and Responsibilities for Implementation

Stakeholder	Roles & Responsibilities
Product Cloud Platform	• Collect and store data in a standard, interoperable format • Support data storage, security, erasure and stewardship • Optimize platform for API and system connectivity
Brand	• Test the best ways to increase consumer engagement around recycling • Support demand through recycled content inputs • Understand the impact of material choices on end-of-life solutions, including choice of data carrier materials • Investigate the most convenient means for consumers to access textile return information to facilitate collection • Create data-rich Digital IDs across the entire product portfolio • Allow system-wide access to product data
Manufacturer	• Attach data carriers to products during production and associate them with Digital IDs • Understand the impact of material choices on end-of-life solutions, including choice of data carrier materials
Consumer	• Access recycling information: A consumer scans a mobile native data carrier (e.g. QR code or NFC chip) with a smartphone to access information on where and how to recycle an item, and what can and can't be recycled • Deposit items into the appropriate collection systems for recycling
Collector	• Collect from the consumer: Coordinate retrieval of textile products from consumer, for example, by sending a prepaid shipping bag, printable shipping label or providing drop-off points • Design and implement the intake process: This includes the electricity, internet connection, software and IT equipment required to facilitate Digital ID access at collection points • Trial the intake process for accuracy: The scan should automatically identify the data carrier and be able to read it • Scan at collection point or facility: Items are scanned individually at the collection point with the proper intake process (e.g. RFID enabled) and in batches to register receipt of the material at a collection facility • Access information: Digital IDs provide key product data such as material composition and fabric construction

Stakeholder	Roles & Responsibilities
Sorter	• Design and implement the intake process: This includes the electricity, internet connection, software and IT equipment required to facilitate Digital ID interactions, ensuring the data carrier can be read accurately, without interference and at high speeds • Evaluate facility changes/upgrades: Facility layout may need to be updated to ensure product flow and identification is optimized • Trial the intake process for accuracy: The scan should automatically identify the data carrier and be able to read it • Batch scan on arrival: Items are scanned in bulk to identify products with an associated data carrier and register receipt of the material at a sorting facility • Access information: Digital IDs provide key product data such as material composition and fabric construction • Facilitate system communication: Product data, such as material composition, fabric construction and color can be shared with automated sorting systems and other software • Sort items for reuse or recycling: When a data carrier is scanned by a sorter, the Digital ID can provide enriched product data such as the SKU, MSRP and material composition to inform reuse and recycling pathways. This information can be accessed through scanners (RFID, Bluetooth, NFC) or smartphones (QR code, NFC). Handheld scanners can be used for manual sortation, while conveyor belts, tunnels and other scanning machinery can be used for automated sortation processes • Batch scan on exit: A bale of sorted material can be scanned in bulk to register a chain of custody event on the Digital ID, confirming the materials have been sent for preprocessing/recycling
Pre-processor	• Batch scan on arrival: Items are scanned in batches to register receipt of the material at a preprocessing facility • Scan item prior to preprocessing: The data carrier is scanned prior to preprocessing to access detailed product information, ensuring all disruptive elements (e.g. components, trims, stitching, etc.) are identified and removed • Remove the data carrier: Signal the associated Digital ID that the data carrier has been removed (if necessary), and where the product will be sent for recycling. This is often the last event registered on a product's Digital ID, marking the end of its lifecycle • Develop chain of custody process: Develop a process for facilitating chain of custody and data transfer from the preprocessor to the recycler once product has been processed into recycling feedstocks
Recycler	• Batch scan on arrival: The recycler receives a bale of sorted, pre-processed material. The recycler also has access to batch scan data captured on the Digital ID during sorting and preprocessing. • Batch scan on exit: A bale of recycled material can be scanned in bulk to register a chain of custody event that may later be associated with a Digital ID if the event is linked through all the stages of manufacturing: from fiber/chip, to yarn, to fabric through to the finished product • Test the optimal method to transfer data from a sorter and/or preprocessor to the recycler to verify the bale matches input specification • Test how to ensure the Digital IDs of products received by a recycler register a "recycled" event without data carriers to scan (having been removed at preprocessing) • Identify how the authenticity of recycled fibers can be verified by fiber buyers

In order to implement a future, Digital ID-connected textile-to-textile recycling system, the infrastructure requirements listed in **Table 10** should also be considered:

Table 10: Infrastructure Considerations for Textile-to-Textile Recycling

Infrastructure Considerations for Textile-to-Textile Recycling	Description
Scanning Hardware	• **QR code:** Automated sorting is the goal. However, during the short to medium-term scaling process, sorters may access information from the product cloud platform through a QR code to improve the sorting process. Most smartphone devices can operate as mobile QR code scanners, though scanners specifically designed to scan QR codes also exist. This will require a strong Wi-Fi or cellular data connection. • **RFID/NFC/Bluetooth:** Scanners must be placed strategically, depending on how the scanning of the data carrier takes place. For example, tabletop scanning may be more appropriate for manual sorting, while scanners above a conveyor belt/in a scanning tunnel would support an automated sorting scenario. Mobile scanners provide the most flexibility but will require an adequate Wi-Fi connection.
IT Infrastructure	Associated IT Infrastructure may include: • For manual processes (e.g. existing sorting): A tablet, computer screen or even an integrated solution on the scanner itself, to communicate information to a user or receive data inputs. • For automated processes (e.g. future sorting): The PLC computer that receives product data from the API (via a logic software application layer) and communicates this to the machinery, to sort the product. • Requires a network connection such as Wi-Fi, Bluetooth or Ethernet.
Additional Scanning Infrastructure	Additional scanning equipment may include: • Connectors (HDMI/USB ports) to connect the scanner to monitors • Cameras to document items • Scan isolation equipment, such as scanning tunnels to improve scan accuracy and reduce distortion • Power infrastructure with sufficient capacity to support the necessary electrical load
Machinery & Robotics	The information gained from the data carrier can be used to support the management of products for recycling: • For manual sorting, this is typically confined to conveyor belts to support the movement of material. • For automated sorting, significant additional machinery may be used, depending on the data carrier. Robotics and AI are rapidly expanding areas to facilitate automation, which could be used in a similar fashion to packaging where materials are selectively picked off a sorting line. • For pre-processing, machinery could process a product based on the data from the data carrier.

Part 5: Limitations

Value hierarchy

If brands adopt Digital ID at scale, they will be able to leverage the technology to recapture a large share of their resale and reuse markets. In this scenario, brands will extract high-value items before they enter the existing secondary market. This will disrupt the flow of materials to this existing market. Meanwhile, many of the intuitive benefits of Digital ID proposed for the textile-to-textile sector could potentially be achieved through other, less-intensive interventions like optical fiber identification. Digital ID disruption in secondary markets may be offset by the volume and efficiency gains enabled by brands' pre-sorting activity for resale and reuse. This could take the following forms:

- **Digital ID facilitates an increase in pre-aggregated inputs:** With the knowledge that material entering the existing secondary market has little resale value, collectors and sorters could automate sorting for recycling feedstocks more readily with NIR, Digital ID and other, lower-lift technologies or activities.
- **Growth of resale market spurs manufacture of higher-quality items:** Higher-quality products increase demand for higher-quality materials and those materials benefit textile-to-textile circular systems.

Chain of custody

In the preprocessing stage, data carriers will be removed to ensure they do not contaminate recycling. Therefore, when a garment has reached the final stage of the recycling process, there will be a lifecycle-data gap between the certified recycling stage and a new product being produced. How this gap can be filled is yet to be determined, but there are some possible solutions: a mass-balance system, an intermediary materials traceability and certification software such as TrusTrace or TextileGenesis, or through data carriers like chemical tracers that can verify fiber authenticity. The final event registered against an item's Digital ID should indicate where the product was sent after the preprocessing stage. At this point, the product becomes a secondary raw material, packaged in bales or by batch. A new product identifier, for example, an RFID tag or barcode, related to this raw material batch should be generated, and the cycle starts anew.

A limitation of the product cloud software is that it does not validate or certify events data. There is a role for third-party supply chain assurance providers to fill that gap. Other solutions like NIR and manual sorting will be necessary in the market for the foreseeable future. The implementation of Digital IDs must account for existing, alternative and complementary systems that will run in parallel.

Data storage & security

The volume of data and information created, captured, copied and consumed worldwide is increasing exponentially.[24] In growing the capacity and efficiency of these systems, actual data storage is becoming easier and cheaper.[25] However, evolutions in how we access, manage and use these data (e.g. through cloud systems) mean additional costs – both commercial and environmental. Data storage costs energy, for which there is a finite amount for any given space.[26] However, it follows that if energy can continue to increase, and space is made available for data storage and processing, then this will technically be unlikely to limit storage capacity. Advances in technology will also continue, in the pursuit of greater efficiency.

There are currently several product cloud platforms in existence. The platforms that are the easiest to use and integrate into existing systems could become the most widely adopted. However, it is unlikely that all brands would utilize the same platform. To ensure interoperability of stakeholders with data from different platforms, a common language (e.g. The Circular Product Data Protocol) for how data is stored and communicated is essential. Legislation could favor a particular platform, or data schema, to increase standardization across brands.

From an implementation and optimization perspective, data security requirements will need to be considered. Example instances include during the trialing of system connections for data transfer, and following commercial scaling to support identifying efficiencies in data management.

Data carrier reuse and recycling

Data carriers should be designed to keep their electrical and mechanical integrity over time to ensure they're still functional at the end of the product's life to support textile-to-textile recycling.

NFC tags, for example, are read-write, so if the chip is recovered and returned to the manufacturer in working condition, it can be reused. RFID tags come in read-only and read-write. Read-only RFID tags cannot be reused whereas read-write RFID tags can. The RFID tag must be removed in its encapsulated form (the protective casing that stops the tag from being damaged) otherwise, the connection between the chip and antenna will likely be damaged, making it unusable.[27] Reusable RFID tags are already commercially marketed, for example, Intermec's Large Rigid RFID tag.[28] Printed data carriers, such as QR codes, could conceivably be reused if they're dynamic. That's because dynamic QR codes allow you to change the destination website link after the code has been generated.

When reusing data carriers, it can be challenging to manage the collected data. The entity looking to wipe and reuse the data carrier must ensure the data carrier's unique identifier is no longer associated with the item being tracked, and assign a new object.[29]

The recycling of data carriers is dependent on the component materials. In the case of printed data carriers such as QR codes, if the material the QR code is printed on and its ink follow the recycler's specification guidelines, the label could technically be recycled with the product. If not, the label will likely need to be removed by the preprocessor. Critical mass would be necessary to justify both the recycling and transportation of printed data carriers outside of the textile-to-textile recycling process.

Effective recycling of more complex data carriers (such as NFC and RFID) would require separating the various material components for recycling, and locating recycling facilities for these components. The recovery of metals is seen as the most feasible recovery operation for RFID tags.[30] Once RFIDs are removed from products, they could be classified as electrical or electronic in their own right. This could fall within the scope of waste electronics legislation such as EPR for WEEE in Europe, and the associated requirements for producers.[31] While some data carriers have been designed to increase the ease of the recycling process,[32,33,34] infrastructure for this process has yet to be developed at scale.

Part 6: Costs

There are several upfront and ongoing costs associated with the implementation and use of Digital IDs and data carriers:

- Data carrier production and manufacture
- Data carrier attachment
- Data capture, use and management costs
- Infrastructure to interact

When there is no legislative requirement for data carriers on products, the costs for 1-3 fall to the brand creating products with Digital IDs. The costs for 4 would be borne by the end-of-life supply chain stakeholders that wish to interact with the data carrier.

When there is a legislative requirement for data carriers on products, for example, in The EU Strategy for Sustainable and Circular Textiles which calls for Digital Product Passports (Digital IDs) to be mandatory on textiles, who ultimately bears the costs will likely come down to who "owns" the product and its data (e.g. the brand).

If the data carrier is produced separately from the textile product manufacturing line, for example in the case of an RFID tag, the cost of production and association of the data will sit with the data carrier manufacturer. Data carrier attachment costs would also sit with the manufacturer who is affixing the data carrier to the products. In both instances, these costs will be recouped when selling the data carriers to the manufacturer/brand requiring them as it is the brand who may be legally required to provide the data. At the outset, however, there may be a decision by the manufacturers and brands to co-invest in scale-up.

The initial implementation and scaling of these systems for data reporting could conceivably be supported at a government or supra-government level to facilitate compliance with legislative requirements. The costs of data management and storage for a Digital ID, if legislative, should be borne by the national government and/or supra government, as it would likely sit on a central server.

Stakeholders in the textile-to-textile recycling value chain (e.g. collectors, sorters, preprocessors and recyclers) will have CapEx costs to implement the necessary scanning, machinery and data infrastructure to interact with the data carrier and Digital ID as required for recycling.

Table 11 in the Appendix outlines additional implementation costs for consideration by the textile-to-textile recycling system stakeholders.

Part 7: Consumers

Digital ID and the consumer connection

Despite innovations in the supply chain, we simply cannot transition to a textile-to-textile recycling system without the help of consumers. We need consumers to deposit their used goods in the appropriate collection environments – in the appropriate conditions. We need their active interest and participation to keep materials in flow at their highest potential for reuse and recycling.

Thankfully, technology has shifted consumer behavior and the ways in which information is exchanged. For example, consumers have become accustomed to scanning QR codes and NFC chips with their smartphones to access information, services and enriched customer experiences.[35] These societal and technological shifts make it a great time to introduce Digital ID. Brands can use it to increase consumer awareness around what can and can't be recycled, boost collection rates, share end-of-life visibility and more.

Consumers and textile-to-textile recycling

Consumer engagement is crucial to ensure products and materials make their way into the correct recycling systems, avoiding landfill or incineration. Consumers make key decisions – they choose whether a product is resold, donated, recycled or disposed of. Without proper consumer engagement and understanding, the recycling system risks contamination from non-recyclable feedstocks and the loss of valuable post-consumer resources. Through Digital IDs, brands can engage consumers as participants in the proper care and maintenance of products to further their use and longevity.

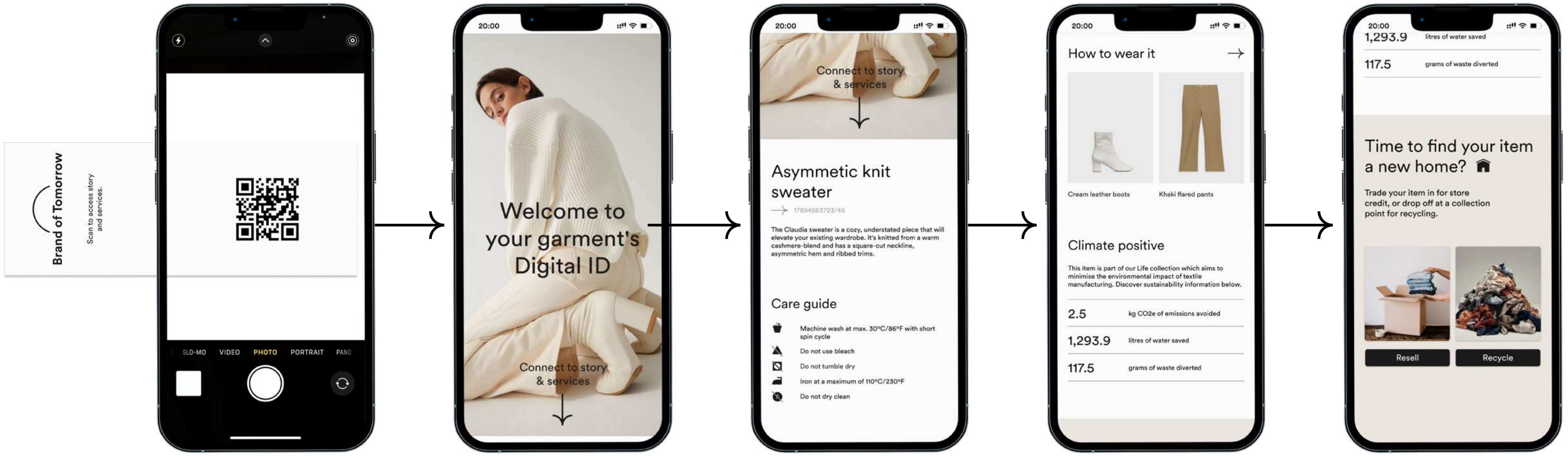
Here are some examples of useful consumer-facing information that can be shared via a garment's Digital ID:

- Provenance information on recycled material inputs
- Product design intentions such as disassembly or recyclability, so consumers know the product should be recycled at the end of its life
- Garment care instructions, including any substances and treatments that should be avoided
- Information around what is recyclable and what can be resold (based on product quality, duration of use, etc.)
- Instructions around how and where to drop off or send in products and materials for recycling
- Visibility into how and where products are recycled, and the intended circular journey of the product
- Visibility into the environmental impact of the product and its materials

How to inform and educate consumers with Digital ID

- **Give clear instructions -** Provide key product return information, such as dropoff locations, within Digital ID customer experiences.
- **Offer automation and ease -** Offer consumers the ability to request collection or shipping labels for end-of-life product return through this customer experience.
- **Support direct marketing -** As consumers demand greater transparency around environmental impact,[36] connected products offer a valuable medium to share initiatives and progress. Through Digital ID, brands can demonstrate measurable impact by communicating back to their customers in an accessible and relatable way, building awareness and trust around such topics as the importance of recycling materials. To inspire participation, brands can also share incentive-based offers through this customer experience.

Digital ID-Enabled Customer Experience



Digital ID turns products into communication channels. By scanning an on-product data carrier (e.g. a QR code or NFC chip) with their smartphones, consumers access an enriched experience that offers information to support engagement with services such as care, repair, resale and recycling.

Part 8: Next Steps

Brands must take-up recycled fibers

The ability of brands to extract maximum first and resale value through Digital IDs will disrupt the business models of the secondhand market as it is today. To offset this sector's lost resale revenue, brands must lead the way in scaling the recycling system by using recycled fibers in their products. Policy measures, such as minimum product recycled content, can support brands in this transition.

Brand Commitments

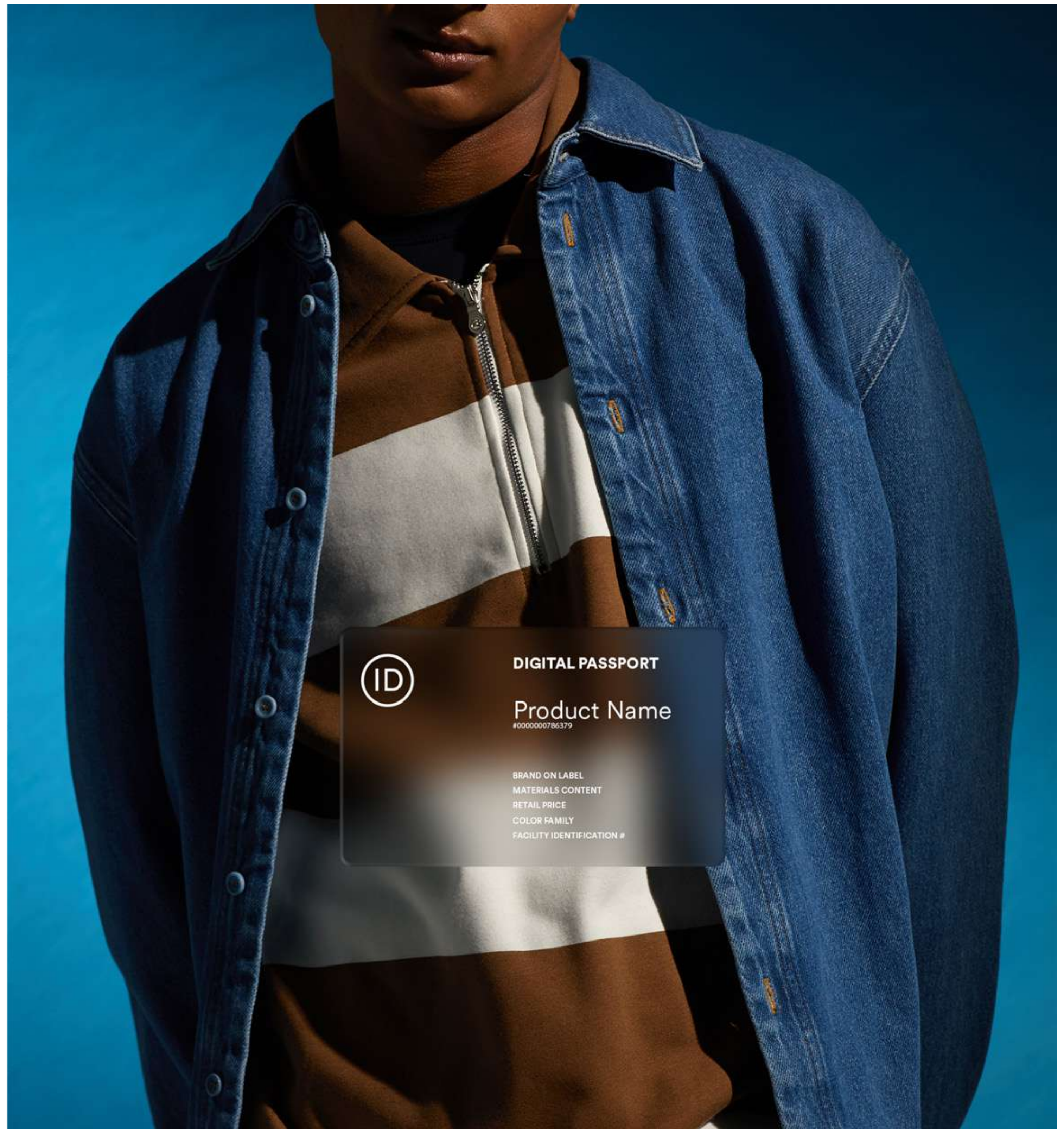
Brands are already committing to incorporate recycled material in products, as in the 141 signatories of Textile Exchange's 2025 rPET challenge,[37] and are supporting the adoption of Digital ID technology.[38]

Policy Measures

Policy measures ensure there is a framework of rules and have the potential to enable economies of scale that increase the financial viability of the new business models required for textile-to-textile circular systems. Currently, the US has little policy in place to support investments in textile-to-textile recycling. However, many measures are being explored in Europe (as described in Table 12 in the Appendix). They support Digital ID and encourage investments in recycling to increase demand for recycled fibers.

Ideally, legislative drivers would create minimum data requirements for Digital ID, supporting efficient sorting and recycling based on a standard set of information.

Further policy mandates regarding mandatory product Digital ID and product passports, such as the EU Digital Product Passport (DPP) Directive, could support scale and investment in system infrastructure.[39] Government led intervention can also support a "Green" system transition through legislative drivers such as carbon taxes, or financial incentives such as grants for green electricity upgrades.



Digital ID standardization & cross-platform compatibility

Standardization and cross-platform compatibility will increase the operational and cost efficiencies of Digital ID. Consistency and/or proper integrations between data carrier systems, equipment, software, associated machinery and the ways in which data are presented is imperative. The brands that elect to implement Digital ID must collaborate to ensure this happens. Open source access should be considered to achieve maximum adoption of universal solutions.

Systemic uptake of Digital ID

The products collected and processed by recyclers are extremely variable. They range from recently-purchased items to "legacy" clothing, over 50 years old.[40] Virtually none of the items in these mixed streams have Digital IDs today.[41] Critical mass will be needed in this stream to realize the full potential of a Digital ID-connected recycling system. While stakeholder interviews alluded to 80%, it's not possible to say what critical mass will be to enable a viable system.[42] Commitment across the sector will be crucial to increase the amount of data carriers used to leverage Digital ID at scale.

Brands are key investors to this system change. They're responsible for applying data carriers to their products, uploading product data to the Digital ID and using standards and protocols which are interoperable. It is the brand that generates and owns the product data which is stored within a product's Digital ID, and who must make this data available to the ecosystem of textile-to-textile recycling stakeholders to create scale

Backcasting the future

Products with Digital IDs flow more effectively to their highest environmental and economic value at the end of first use, supporting financial growth in the reuse and resale sector. With high resale value items extracted at an early stage of the end-of-use pathway, materials suitable for textile-to-textile recycling may be more efficiently identified in existing sorting operations and with mechanized systems coming online in the near term. This gives brands and manufacturers access to higher quantities of recycled material, which could also displace some virgin fibers. Data exchange improves understanding and the connections between the current and future phases of products and materials, incentivizing their strategic use.

In conclusion

We call on the entire textile industry to collaborate on the development and proliferation of Digital IDs. Digital ID technology is already supporting scaled systems for resale and reuse, and has the potential to support efficiency gains for textile-to-textile recycling processes as well. Following the waste hierarchy, Digital IDs can be leveraged by recycling system stakeholders to support more efficient identification of feedstocks for textile-to-textile recycling thereby delivering higher quantities of recycled material, a necessity for brands to meet recycled content commitments and deliver circular systems.

Definitions

Software Application Layer	An application layer is a software interface that the human user interacts with to run functions, such as those supported by API connections.
Application Programming Interface (API)	An application programming interface (API) is a predefined collection of functions that can be used to access data between systems. It is a software intermediary that allows two applications to talk to each other.
Circular Economy/ Circularity	A circular economy is the opposite of a linear economy, decoupling economic activity and growth from the consumption of finite resources to ensure a resilient and sustainable system for consumption. Driven in particular by design, a circular economy ensures waste and pollution is eliminated, with products and materials continuing to circulate at their highest value, while facilitating nature regeneration.
Collectors	Collectors collect textile material for recycling. This could include curbside collection companies, collections from textile banks, etc.
Data Carrier	Data carriers connect each Digital ID to its associated physical product. Examples of data carriers are QR codes, NFC chips, RFID tags and Bluetooth. Consumers and businesses can scan or tap these interactive labels with their smartphones or other devices for instant access to embedded information, content and services.
Digital ID	Digital ID, also called a digital passport or product passport, is a unique, item-level record of a physical product hosted in the cloud. It holds key product attributes from material contents to care instructions, and real-time events such as purchase, repair, resale and recycle.
Linear Economy	A linear economy traditionally follows the “take-make-dispose” step-by-step plan. This means that raw materials are collected, and then transformed into products that are used until they are finally discarded as waste. Value is created in this economic system by producing and selling as many products as possible.
Near Infra-red Spectroscopy (NIR)	Near Infra-red Spectroscopy or “NIR spectroscopy” is an optical scanning technology that uses the near-infrared region of the electromagnetic spectrum. Infra-red light is shone on a product, and the light scattered off the surface is recorded as a reflectance spectra. This can be used to identify the fiber composition.
Preprocessors	Preprocessors refers to any stakeholders that manage the preprocessing of material prior to the recycling process. This could include material cleansing, removal of material contaminants such as zippers, etc.
Product Cloud	A Product cloud is a technology platform which creates unique, item-level Digital IDs that store and record standardized product information and events in real-time. Through a product cloud, brands can access new customer insights and better understand the circulation of their products.

Recycler Specification	Recycler specification refers to the type and configuration of materials that a recycler can process with its technology. For example, 100% white cotton material, with labels removed and no polyester thread.
Recyclers	Recyclers refers to any stakeholders involved in the recycling of textiles into new textiles or new fibers for reuse within new textiles.
Recycling Contaminant/ Disruptor	A recycling contaminant is an element of a textile product, for example a fiber (i.e. elastane), an attachment (i.e. zipper), dye, or fabric coating (i.e. waterproof layer) that will stop the textile recycling process from working and has the potential to contaminate.
Resale	Resale refers to any organization involved in the resale or distribution of second-hand apparel. For the avoidance of doubt, this will include brands that have their own platforms, as well as separate entities such as stand-alone reseller sites/thrift stores and charities.
Sorters	Sorters refers to any facilities involved in the sorting and separation of textile materials once apparel has been collected, such as materials recovery facilities. This excludes resale/ donation actors such as charities or brand resale sites.
Textile-to-Textile Recycling	Textile-to-textile (T2T) recycling describes when fabrics from pre- and post-consumer textile material are processed to recover fibers for use as secondary raw materials.
Waste Hierarchy	The waste hierarchy is a tool that ranks waste management options according to what is best for the environment.[43]

Appendix


FUTUREWEAR
Welcome to your shoe's Digital ID
I have a story to tell

Table 2: List of Data Carrier Technologies

Technology	Overview
Barcode	Linear barcodes use a series of variable-width lines and spaces to encode data. The longer the barcode, the more data it can hold. When the barcode is scanned, the code will retrieve information from a computer database giving the associated product inventory.[44]
QR Code	Quick Response (QR) codes work similarly to barcodes, but instead of lines use patterns of squares to encode data. Able to store thousands of characters, a QR code can encode words and phrases such as internet addresses. There are two kinds of QR codes: static (un-editable once the code is generated) and dynamic (always editable). The more information inputted into a static QR code, the bigger and more complex it becomes, unlike dynamic codes which can remain small.[45] Some textile manufacturers are already using QR codes printed on the care label of each garment to embed information like materials used, country of origin, and recycled content.[46, 47]
Digital Watermark	Like a QR code, a digital watermark can carry information related to an item and link to a website via a mobile device. Digital watermarks can be designed to be imperceptible to the human eye, and for that reason can be repeated across an item without disrupting aesthetics. Digital watermarks specifically designed for textile applications are currently under development.
Radio Frequency Identification (RFID)	RFID uses radio waves to transmit information from a microchip to a scanner. RFID does not require a line of sight and, depending on the type of RFID, can have a scan range of between a few centimeters to over 20+ meters. Each RFID will have a unique number that is associated with data in a database, but it is also possible to store information about the object in the tag's memory itself. There are two major categories of RFID: passive (no internal power source, only activated on scanning by an RFID scanner) and active (battery-powered tags that continuously broadcast their own signal). Active tags provide a longer scan range than passive tags, but they are also larger and more expensive.[48] RFID tags also use different frequencies to communicate data: low frequency (LF), high frequency (HF) and ultra-high frequency (UHF). In general, the lower the frequency of the RFID system, the shorter the scan range and slower the data scan rate.[49]

Technology	Overview
Bluetooth	Bluetooth supports data exchange between two devices using radio waves. The system requires an antenna-equipped chip in both devices that sends and receives signals at a specific frequency. Typically, Bluetooth devices require a battery to send and receive signals, though battery-less devices are in development. Bluetooth signals typically have a range of up to 10 meters, with the maximum range depending on physical obstacles and electromagnetic environment from other devices.[50]
Near Field Communication (NFC)	NFC, developed from RFID, also uses radio waves for function. NFC tags, which can be active or passive, are tuned to respond to NFC scanners and share data. It is more refined than RFID as it can allow two-way communication but has much shorter scan distance than RFID. NFC devices like cell phones can act both as a data carrier or a scanner to share data or connect devices. NFC is widely used for contactless payments.[51, 52]
Chemical Tracers	Chemical tracers are unique chemical markers such as dyes or DNA tags that are attached to products and can be identified through spectroscopy or other testing methods. Chemical tracers have been used on textiles to verify the source of the raw material, or whether it is composed of recycled polymers.
Voice Identification	Voice identification refers to the conversion of spoken words into digital signals. This has been used in some automated textiles sorting systems to define the category of a sorted item to mechanically transfer the item into the correct collection point.[53]
Machine Vision	Machine vision is a field of artificial intelligence that uses computers and cameras to "see" and derive information from objects. Currently, machine vision can be used in textiles within manufacturing to identify structural defects within fabrics.[54]

Table 3: Data Carrier Use and Requirements by Apparel Supply Chain Stakeholder[55]

Stakeholder	Data Carrier Requirements
Manufacturer	• Highly durable and able to withstand significant washing/drying and any chemical treatments during the use phase (e.g. bleaching). • Easily attached to the product at the last stage of manufacturing. • Allows consumers to report data back to the manufacturer regarding use, such as washing frequency • Low cost.
Brand/Retailer	• Cannot be easily removed from the product. • Discreet so as not to impact the aesthetic or performance for the consumer. • Can be quickly and easily scanned to capture data and feed through to in-store software/product management systems. • Low cost.
Consumer	• May be scanned with a smartphone.
Collector	• Durable. • Can be quickly and easily scanned or accessed to capture or upload data. • Low cost.
Sorter	• Cannot be easily removed from the product. • Location of the data carrier easily identifiable to aid manual scanning. • Protected/durable. • Low cost (both the data carrier and associated scanning technologies/equipment). • Ideally, the ability to append data to the Digital ID throughout the garment's life. • Ability of data carrier and associated software to integrate with existing automation and data management systems to support sorting decisions.
Preprocessor	• Location of the data carrier easily identifiable to aid manual scanning. • Protected/durable to ensure it is still in place by the time it reaches the recycler. • When requiring removal, the data carrier should be noticeable to not interfere with recycling. • Low cost (both the data carrier and associated scanning technologies/equipment).
Recycler	• When requiring removal, the data carrier should be noticeable to not interfere with recycling (if it hasn't been removed in a separate, preprocessing stage)

Table 4: Key Technical Requirements and Stakeholder Needs to be Met by Data Carriers

Criteria	Description	Necessity for Textile-to-Textile Recycling
Wash Durability	The extent to which washing can be tolerated by the data carrier	Data carrier will still function until the end of the product's life
Size & Shape	The extent to which the data carrier will be noticed by a consumer	Data carrier will not impact consumer use of the product, reducing the likelihood of purposeful removal
Cost	How much cost will need to be borne by the brand	The cost will not be so high as to be prohibitive to implement
Compatibility with Existing Recycling Ecosystem	Can attachment, use and removal of the data carrier be integrated within existing manufacturing, collecting, sorting, preprocessing and recycling processes	Changes to manufacturing, collecting, sorting, preprocessing, and recycling processes will be reduced, minimizing costs

Criteria	Description	Necessity for Textile-to-Textile Recycling
Consumer Engagement	Can the data carrier be used to engage with a consumer	Allows consumers to locate end-of-use return options
Consumer Privacy	Are there privacy concerns	Low privacy risk to encourage brand uptake and avoid consumer risk
Scan Distance	The distance at which the data carrier can be scanned	To ensure products can be scanned individually at high throughput, without interference from other data carriers
Market Readiness	How ready the data carrier solution is for commercialization	To support textile-to-textile recycling now.

Table 5: Criteria Matrix for Data Carriers

Suitability	Memory	High Volume Sorting	Wash Durability	Size and Shape	Typical Data Carrier Cost (per unit)	Compatibility with Existing Recycling Ecosystem	Consumer Engagement	Consumer Privacy	Scan Distance	Market Readiness
Likely unsuitable	Limited memory for product data	Hardware will likely not enable increased automation for sorting. Requires line of sight.	<30 washes	Obviously noticeable	$0.30+	Unlikely to be compatible with current textile assembly, collecting, sorting, preprocessing and recycling processes.	Consumer cannot scan/get information from the data carrier.	Likely privacy risk	Max scan distance is <1m	Not yet at commercial scale
May be suitable	–	Could increase automation.	30 – 199 washes	Slightly noticeable	$0.15 – $0.30	May be compatible with current textile assembly, collecting, sorting, preprocessing and recycling processes.	–	Potential privacy risk	Max scan distance is 1m – 10m	–
Suitable	High product data capacity	Hardware will enable increased throughput for sorting. No line of sight required.	200+ washes	Unnoticeable	<$0.15	Likely compatible with current textile assembly, collecting, sorting, preprocessing and recycling processes.	Consumer can scan/get information from the tag.	Low privacy risk	Max scan distance is >10m	At commercial scale

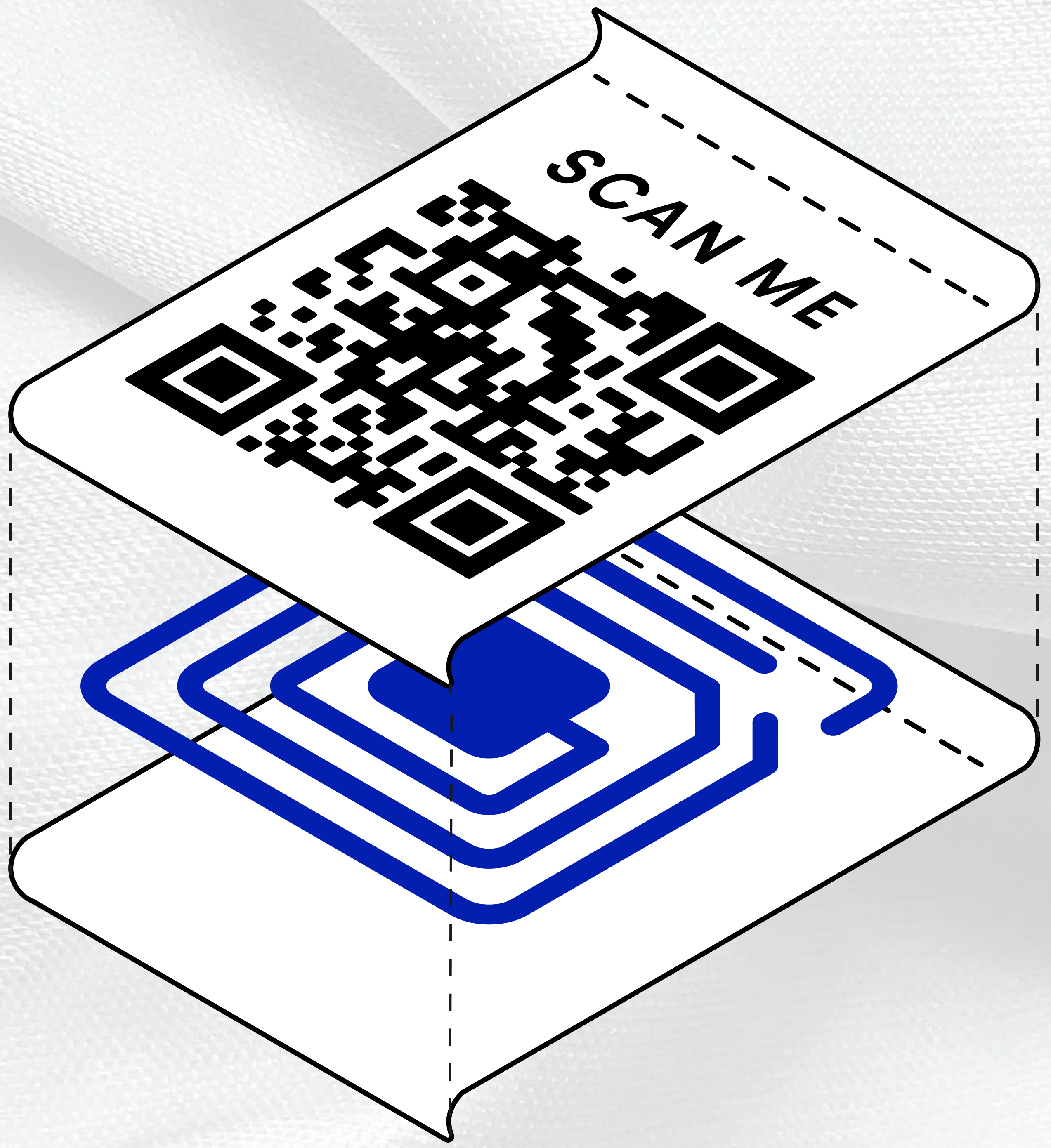
Table 6: Criteria Matrix Assessment of Data Carriers

Suitability	Memory	High Volume Sorting	Wash Durability	Size and Shape	Typical Data Carrier Cost (per unit)	Compatibility with Existing Recycling Ecosystem	Consumer Engagement	Consumer Privacy	Scan Distance	Market Readiness
Barcode	🔴	🔴	🟢	🟢	🟢	🟢	🟠	🟢	🔴	🟢
QR Code	🟢	🔴	🟢	🟢	🟢	🟢	🟢	🟢	🔴	🟢
Digital Watermark	🟢	🟠	🟠	🟢	Unknown	🔴	🟢	🟢	🔴	🔴
RFID	🟢	🟢	🟢	🟢	🟠	🟠	🔴	🟠	🟢	🟢
Bluetooth	🟢	🟢	🟠	🟢	🟠	🟠	🟢	🟠	🟢	🔴
NFC	🟢	🟠	🟢	🟢	🟠	🟠	🟢	🟠	🔴	🟢
Chemical Tracers	🔴	🔴	Unknown	🟢	Unknown	Unknown	🔴	🟢	Unknown	Unknown
Voice Identification	🔴	🔴	🟢	🟢	Unknown	Unknown	🔴	🟢	N/A	Unknown
Machine Vision	🔴	🔴	Unknown	🟢	Unknown	Unknown	🔴	🟢	Unknown	Unknown

Table 7: Suggested Data Carrier: Specifications for a Combined QR Code and RFID Label

Our research shows that a combined QR code and RFID label is an optimal data carrier solution to support a Digital ID-connected textile-to-textile recycling system at scale. Both RFID and QR codes are already utilized commercially on textile products for customer engagement (QR codes) and supply-chain tracking (RFID). Because they're already in commercial use, processes for associating these data carriers onto products are occurring at scale. Key system stakeholders are also accustomed to interacting with these data carriers to access important data and information.[56] Together, QR codes and RFID offer a cost-effective solution that can take their individual use cases further, connecting otherwise separate supply chain actors and consumers through enhanced communication, visibility and engagement.

The table to the right provides an overview of this recommended data carrier solution, developed in conjunction with digital identification solutions provider SML.



	RFID	QR Code
Material	• Coated polyester inlay. • Encapsulated within a PET layer to prevent external damage.	• Coated polyester label. • Printed at 600dpi for best scanability.
Size	• Discreet size so it is not felt by the consumer to avoid it being cut off.	• Discreet size so it is not felt by the consumer to avoid it being cut off. • At least 2x2 cm to ensure scanability.
Durability	• Ideally heat sealed or sewn in. Attachment like a care and content label possible, but this is more easily cut off. • Attached on the inside of the product. • Requires further testing.	• Ideally heat sealed. Attachment like a care and content label possible, but this is more easily cut off. • Attached on the inside of the product, but must be visible to the consume to ensure it can be scanned. • Requires further testing.
Label Style	• Dependent on the textile item the data carrier is being attached to. • Requires further testing.	• DependentW on the textile item the data carrier is being attached to. • Requires further testing.

Table 8: Circular Product Data Protocol - Attributes for Textile Recycling

Attribute Name	Definition	Standard Alignment (if applicable)	Rationale
Assigned color category	The main color family of the product and category of color.		Sorters, preprocessors and recyclers find color categorization helpful because emerging technology can sort basic colors that better align with this categorized list. It's important to capture light and dark to assist with automated sorting, particularly when sorting in the future, at scale.
Component part name	This is the name of a product component, such as the body, lining or insulation. Multiple components may need to be included and should account for the whole product.		Essential for sorters, pre-processors and recyclers to determine if component parts are a good match with their technical specifications for recycling. A standardized list is not used for Component Part Name because so many parts are possible and designers often innovate new components that wouldn't be captured in a standard list. Some companies organize Bills of Materials by components. This is intended to match that organization yet be flexible enough for those Bills of Materials that are structured differently. Some of this information will be on the product label, but including it in the Digital ID will ensure the information stays with the garment even if the label is cut off.
Materials List Used		GS1 and Higg Index	
Component Materials and Percents	The material composition of the component part listed above. There may be multiple materials per component.	GS1 and Higg Index	
Body Fabric Type	The main fabric type of the product.		Necessary for sorting, preprocessing and recycling, though this field's use will be more relevant in the future as technology use expands. This was geared toward high-volume automation.
Trim Type	Trims used on the garment. More than one entry may be necessary.	Higg Index	Sorters, preprocessors and recyclers need much more than what is on the product label to determine whether the garment can work in their recycling process. Knowing trims, type and content can either contribute to or impede the regeneration process.
Trim Materials and Percents	The material composition of the trim listed above. There may be multiple materials per trim.	GS1 and Higg Index	
Sewing Yarn Content and Percent	The material content of the yarn used in sewing this product.	GS1 and Higg Index	Sorters, preprocessors and recyclers need much more than what's on the product label to determine whether the garment can work in their recycling process. Knowing the sewing yarn content matters and can either contribute to or impede the regeneration process.
Print Ink Type	The type of ink that was used on the product.		Sorters, preprocessors and recyclers need much more than what's on the product label to determine whether the garment can work in their recycling process. Knowing print ink can either contribute to or impede the regeneration process. Though this field's use will be more relevant in the future as recycling technology use expands. This is geared toward high volume automation.
Dye Class Standard List	The standard list used to select the type of dye used.	eBIZ/Euratex and GS1	Sorters, pre-processors and recyclers need much more than what's on the product label to determine whether the garment can work in their recycling process. Knowing dyestuff can either contribute to or impede the regeneration process. Though this field's use will be more relevant in the future as recycling technology use expands. This is geared toward high volume automation.
Dye Class	The type of dye process used on the product selected from the eBIZ/Euratex or GS1 standards.	eBIZ/Euratex and GS1	

Attribute Name	Definition	Standard Alignment (if applicable)	Rationale
Fabric Finishes	The list of finishes applied to the product's composite materials	GS1	Preprocessors and recyclers often request information about finishes to determine if the item is compatible with their material regeneration processes. Knowing fabric chemical finishes can either contribute to or impede the regeneration process.
Chemical Compliance	The list of product level chemical compliance certifications or regulations with which the product complies.	Higg Index, N/A for regulatory requirements	This is useful for recyclers to determine compliance with the specifications of their process.
Product and Material Certifications	Certifications or marks of compliance that the product has received. Includes both product and material certifications.	ITC Standards Map	This may provide additional information to pre-processors and recyclers regarding the composition and compliance of the product and its materials. All certifications should be at the material or product level (not facility) and be accurate for the lifetime of the product.

Attribute Name	Definition	Standard Alignment (if applicable)	Rationale
Data CarrierType	The type of data carrier on a product that can be scanned or tapped to access data in this Protocol.		This is helpful for recycling as it provides instructions for the handler/partners to locate the digital data carrier, reuse it or recycle it as needed. Adding a data carrier/identifier to the product ensures that the Protocol can be implemented and bring value to connected services.
Data Carrier Material	The material of the data carrier on a product that can be scanned to access data in this Protocol. More than one material may be necessary.		
Data Carrier Location	The location on the garment on which the data carrier can be found.		

Table 11: Implementation Costs

Digital ID Element	Cost	Description
Data Carrier	For manufacturers and brands, the RFID element of the recommended data carrier solution would likely increase the cost of the product by at least $0.05, and as much as $0.60 depending on label(s) used. QR code element costs can range from as little as $0.001 per code (for printed labels) to up to $2.00 per code (for the most advanced labels).	The cost structure is similar to traditional label costs. Pricing is dependent on volumes, where higher volumes benefit from economies of scale. Additionally, increased adoption, technological efficiency and innovation within the industry could encourage lower prices.
Data Carrier Attachment	If the data carrier is attached in a similar manner to a label, attachment costs are unlikely to be an issue outside of training and upskilling in attachment methods.	The entire system will benefit from brands driving exploration, such as finding the best ways to attach data carriers to products. Historically, brands have been able to implement the most change in the supply chain. Supply chain implementation processes require collaboration, tests, and design.
Scanners	Stakeholder research highlighted scanner costs in the range of $1,000 for a standard static or mobile reader and up to $3,000 for readers with equipment to isolate the scan from its surrounding environment.	Prices for RFID scanners will vary depending on features such as battery life, interconnectivity and installation requirements (e.g. cabling for static scanners).

Digital ID Element	Cost	Description
IT Systems	IT equipment and software costs are variable and can increase or decrease given the proprietary nature of solutions.	The IT equipment and software application layer required to capture the scan, communicate with the product cloud platform and communicate the associated data back to the user will also be required.
Product Cloud Software License	Variable based on the product cloud software provider and subscription level.	Digital IDs will need to be hosted on a platform that provides material data access to identified value chain stakeholders. The business models for product cloud software solutions will vary depending on the platform, but generally, there will be an annual platform license fee for access to the platform, data storage and support. For pricing, please reach out to EON.
Automated Sorting Equipment & Machinery	Scanning tunnels were highlighted by one stakeholder as costing $2,500 - $3,000, but this could increase for sorting carried out on a larger scale. The cost of machinery needed for fully automated sorting is also significant.	Facilities will need to invest in additional equipment to insulate the scan from its external sorting environment to reduce interference and increase efficiency. They will also need to invest in machinery that physically sorts materials.

Table 12: Policy Measures to Support Growth in Demand for Recycled Fibers

Policy	Description	The link to Digital ID	Precedent
Textile-to-Textile Recycled Content Targets	Governments could implement recycled content mandates. These would require brands to incorporate recycled content derived from textiles into products at levels that escalate over time. This would drive demand and facilitate investment in collection, sorting, and recycling.	Digital IDs give brands access to data to verify the supply chain through which recycled content was sourced.	The EU has proposed mandatory recycled content targets as part of its Textiles Strategy.[57]
Extended Producer Responsibility	Legislation that makes producers (such as brands and retailers) responsible for the costs associated with the management of discarded textiles. Additional penalties or discounts can be applied to the fees paid by producers based on, for example, product recyclability or level of recycled content utilized. This can incentivize product design changes.	EPR relies on actors in the recycling supply chain reporting the materials processed. Through a Digital ID, actors can link products to a brand throughout the recycling value chain, to ensure costs charged back are based on the actual costs of managing products. Similarly, where producers have changed product design in order to receive a discount on fees, this can be identified and traced back through a Digital ID.	While EPR is yet to be discussed in the US for textiles, it is gaining momentum for packaging.[58,59] Textiles EPR is already in place or being developed for some European nations (e.g. France, Sweden, the Netherlands), and has been committed as part of the EU Textiles Strategy for Sustainable and Circular Textiles.[60]
Mandatory Product Passports	Many product labels report inaccurate fiber composition.[61] A policy requirement that all textile products have a digital passport, containing standardized data, such as the data set out in the Circular Product Data Protocol, will ensure all products provide verifiable data necessary for recycling.	Mandatory product passports align to the data stored in a product's Digital ID and will be contained within the Product Cloud platform. This legislation supports the systemic uptake and use of data carriers on products.	Mandatory product passports have been proposed for all products placed on the market in the EU, and this could influence their use more widely.[62] The EU has also committed to explore the potential for digital labels and data carriers as part of its Textiles Strategy.[63]
Transparency	Mandatory supply chain transparency legislation supports the development of systems to trace supply chains. This supports brands in the verification of product information to ensure the data on the Digital ID is accurate. Some organizations are already developing these systems, for example through blockchain.	This legislation could support systems that ensure the data reported through the Digital ID is accurate, and traceable. The accuracy of product data, whether on a label or product passport, will be crucial to ensure items meet recycler specifications.	New York State is debating supply chain transparency legislation.[64] In Europe, countries such as Germany and France are already progressing with legislation. This is also being considered at an EU level.[65]

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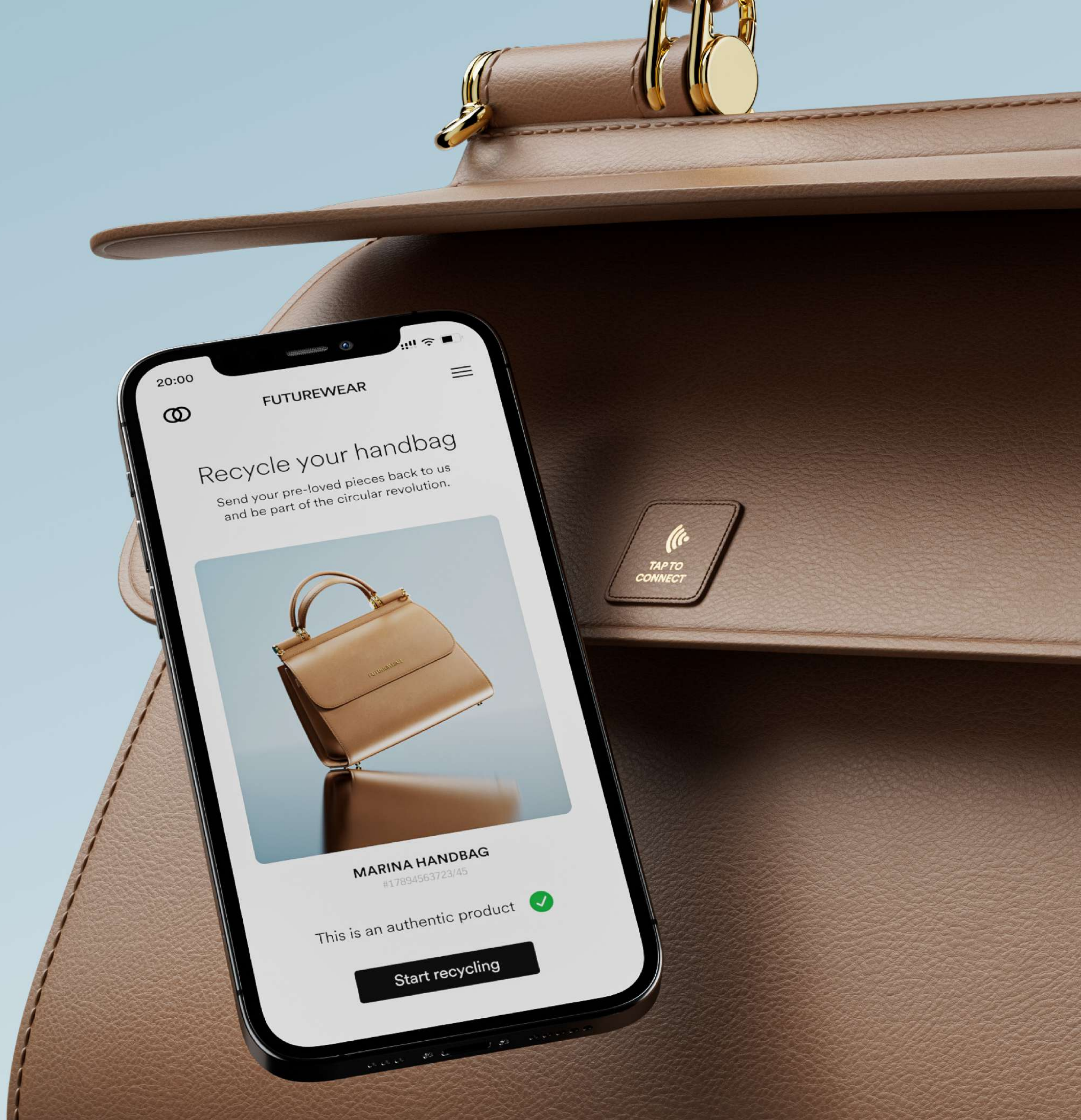

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