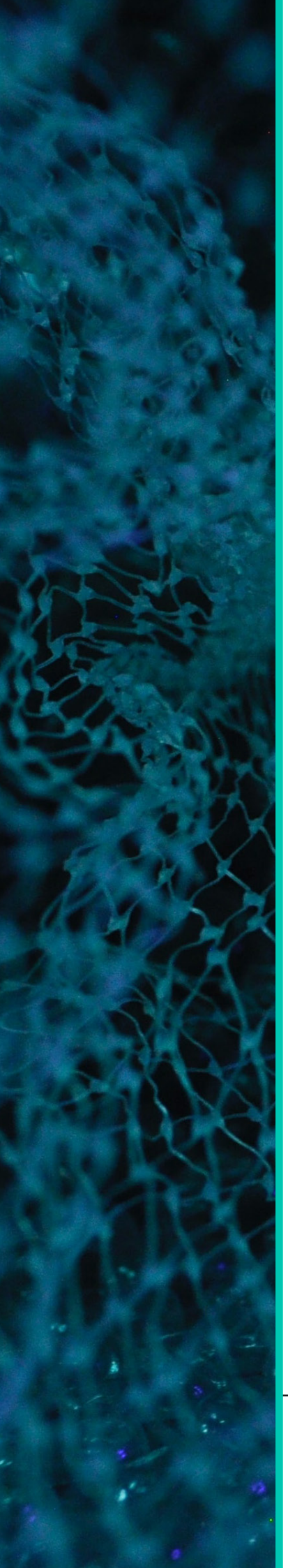

JULY 2022

Textile Exchange

FASHION FOR GOOD

THE TEXTILE TRACER ASSESSMENT

AN ANALYSIS AND USER GUIDE FOR PHYSICAL TRACER TECHNOLOGIES IN THE TEXTILE INDUSTRY

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About Us

Fashion for Good is the global platform for innovation.
At its core is the Global and Asia Innovation Programme that supports disruptive innovators on their journey to scale, providing hands-on project management, access to funding and expertise, and collaborations with brands and manufacturers to accelerate supply chain implementation.

To activate individuals and industry alike, Fashion for Good houses the world's first interactive museum dedicated to sustainable fashion and innovation to inform and empower people from across the world and creates open-source resources to action change.

Fashion for Good's programmes are supported by founding partner Laudes Foundation, co-founder William McDonough and corporate partners adidas, C&A, CHANEL, BESTSELLER, Inditex, Kering, Levi Strauss & Co., Otto Group, Patagonia, PVH Corp., Reformation, Stella McCartney, Target and Zalando, and affiliate and regional partners Arvind Limited, Birla Cellulose, Norrøna, Pangaia, Teijin Frontier, Vivobarefoot, Welspun and W. L. Gore & Associates.

To learn more about Fashion for Good, visit fashionforgood.com

Textile Exchange is a global non-profit driving positive impact on climate change across the fashion and textile industry. It guides a growing community of brands, manufacturers, and farmers towards more purposeful production from the very start of the supply chain.

Its goal is to help the industry to achieve a 45% reduction in the emissions that come from producing fibres and raw materials by 2030. To get there, it is keeping its focus holistic and interconnected, accelerating the adoption of practices that improve the state of our water, soil health, and biodiversity too.

For real change to happen, everyone needs a clear path to positive impact. That's why Textile Exchange believes that approachable, step-by-step instruction paired with collective action can change the system to make preferred materials and fibres an accessible default, mobilising leaders through attainable strategies, proven solutions and a driven community. At Textile Exchange, materials matter.

To learn more, visit textileexchange.org.

Credits

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Glossary

ACRONYMS

ERP
Enterprise Resource Planning.

NFC
Near Field Communication: is a short-range high frequency wireless communication technology that enables the exchange of data between devices over about a 10 cm distance.[1]

PCR
Polymerase Chain Reaction[2] is a laboratory technique for rapidly producing (amplifying) millions to billions of copies of a specific segment of DNA, which can then be studied in greater detail.

PLM
Product Lifecycle Management Systems.

QR Code
Quick Response Code: A type of two dimensional (2D) bar code that is used to provide easy access to online information through the digital camera on a smartphone or tablet.[3]

UVB
Ultraviolet B-ray (UVB) Technology.

VMS
Vendor Management System.

DEFINITIONS

Certification bodies
Third party organisations carrying out audits to verify criteria defined by a sustainability standard.

Chain of custody
Chain of custody refers to the chronological documentation or paper trail that records the sequence of custody, control, transfer, analysis, and disposition of physical or electronic evidence.[4]

Claims made
"Claims' or "claims made" in this report refer to the information provided by the tracer companies in regard to the enquiry topics. They do not refer to sustainable product claims of certification.

Glossary

Downstream supply chain/lower in the supply chain
This refers to the lower tiers of the supply chain e.g. Tier 1 garment producers.

Elemental meddles
Interchangeable with "trace elements". These are the biochemical elements and isotopes themselves within a fibre and/or material.

Elemental profiling
The process of building a provenance database of biochemical elements and isotopic ratios of a given fibre or material.

Enterprise Resource Planning
Enterprise Resource Planning (ERP) refers to a type of software that organisations use to manage day-to-day business activities such as accounting, procurement, project management, risk management and compliance, and supply chain operations.[5]

Fashion readiness
An indication of the level of maturity and commercial availability a tracer technology has for implementation into the fashion and textile supply chain (from a Fashion for Good perspective).

Fibres/Materials
Fibre types and textile materials are at times referred interchangeably in this report when talking of traceability verification capabilities by tracer technologies.

Fibre blending[6]
When different fibre types are merged together at spinning or fabric roll manufacturing stages e.g. cotton with polyester.

Fibre mixing
When the same fibre types with different grades are merged together at spinning or fabric roll manufacturing stages e.g. virgin cotton with recycled cotton.

Fibre quantification
Quantifying the percentage of certain fibre type present within a mix/blend (fibre quantification).

Geographic origin
Usually refers to the verification of the origin of Tier 4 for natural and animal fibres.

Infrared spectroscopy
Infrared spectroscopy (IR spectroscopy) is the spectroscopy that deals with the infrared region of the electromagnetic spectrum, that is light with a longer wavelength and lower frequency than visible light. It covers a range of techniques, mostly based on absorption spectroscopy.[7]

Glossary

Isotopic ratios
Interchangeable with "ratios of stable isotopes". These are non-radioactive atoms of the same element that contain different numbers of neutrons such as nitrogen, carbon and others.[8]

Legacy systems
Internal supply chain software systems used by manufacturers, brands, and retailers (e.g. PLM and ERP).

Micro-particle analysis
Referring to the analysis and cross-referencing of stable isotope ratios and trace meddles for a given fibre or material by a tracer company.

Off-site detection
The process of detecting the tracer (for additive tracers), or laboratory micro-particle analysis (for forensic tracers) occurring outside the operations of the supply chain.

On-site detection
The process of detecting the tracer (for additive tracers) or laboratory micro-particle analysis (for forensic tracers) occurring within the operations of the supply chain.

Physical/material verification
Authenticates the presence of certified material in a product.[9]

Product Life Management
Product lifecycle management (PLM) is the strategic process of managing the complete journey of a product from initial ideation, development, service, and disposal. Put another way, PLM means managing everything involved with a product from cradle to grave.[10]

Provenance database
A record of the biochemical elements and isotopic ratios of a given fibre and/or material. Provenance databases need to be constantly updated by the forensic tracer company to account for changing isotopic ratios and elemental meddles at the origin for the natural fibres in scope of verification.

Post-gate[11]
This refers to the section of the supply chain after the finished product is made and distributed to consumers (after Tier 0).

Site verification[12]
Verifies that the processes carried out at site conform to operational and/or sustainability criteria defined by the standard.

Substance signatures
Unique properties of tracer substances that allows for the distinction of traceability verification.

Glossary

Supply chain burden
Imposing additional operational workload on supply chain actors to implement, manage, and maintain tracer technologies.

Supply chain origin
Usually refers to the verification of origin between Tier 3 - Tier 0 of a given yarn, fabric roll, and product.

Sustainability programmes/standards (scheme owners)
They can cover a huge range of activities undertaken by organisations, and they are used by producers, companies, governments, financial institutions and consumers. Examples include Textile Exchange, Global Organic Textile Standard, and Better Cotton Initiative.

The "User"
The "User" refers to an organisation that is implementing the tracer technology in their operations. This can potentially be various fashion ecosystem stakeholders e.g. suppliers, manufacturers, brands, retailers, sustainability programmes, and certification bodies that hold motivations to explore and implement tracer technologies to supplement existing fibre traceability in the textile supply chain.

Tier 4
Raw material extraction.

Tier 3
Spinning facilities.

Tier 2
Fabric manufacturers.

Tier 1
Garment producers.

Tier 0
Brand/retailers distribution warehouses.

Tracer company
Refers to the company that owns and offers the tracer technology. Tracer companies can have many tracer technologies available.

Tracer substance
This refers to the substances that are applied by additive tracers to the fibres and/or materials, and detected later in the supply chain.

Tracer technology
Any additive or forensic technology that serves to authenticate the presence of a specific fibre and/or material in a given product.

Glossary

Transaction verification[13]
Verifies that the products and quantity exchanged along the value chain is within the certified scope of each site and reconciles to inventory.

Upperstream supply chain/higher in the supply chain
This refers towards the higher tiers of the supply chain e.g. Tier 4 raw material extraction.

Verification/validation/authentication
These three terms are used throughout this report interchangeably in reference to traceability verification.

Image courtesy of Unsplash

Executive Summary

Fashion for Good, together with Textile Exchange, have created a detailed analysis for benchmarking physical tracer technologies relevant in the textile industry. This report is the first step to creating an open-source guide where all interested parties can identify which tracer technologies are best suited for their traceability motivations, use cases, and scope. This includes understanding which tracers work well with which fibres, materials, and the challenges involved. This guide aims to accelerate the development and scaling of tracer technologies in the textile supply chain.

For the tracer technologies themselves, this enables a platform for exposure to suppliers, manufacturers, brands, retailers, sustainability programmes, and certification bodies to help drive further growth and implementation.

The assessment of tracer technologies will further support chain of custody scheme owners to explore aligning physical/material-level verification to the existing site-level and transaction-level verification. The Textile Tracer Assessment could contribute to wider supply chain risk assessment and management, as well as more strategic and streamlined auditing processes.

KEY TAKEAWAYS

An analysis of 17 tracer companies led to the following key takeaways:

Based on the innovations and scientific methodologies used, there are two main categories of physical tracer technologies:

- Forensic tracers
- Additive tracers

Forensic tracers focus on providing geographic verification of plant and animal fibres, and have less supply chain burden

Forensic tracers mainly focus on verifying the geographic origin of natural fibres, and have less supply chain burden for the user compared to their additive tracer counterparts.

Additive tracers facilitate better end-to-end traceability and have a broader use case in terms of meeting the users traceability objectives

Additive tracers have more supply chain burden, but more versatility for the user. They are capable of providing traceability verification of the middle tiers of the supply chain, and can work more proficiently with synthetic fibres than their forensic tracer counterparts.

The implementation of tracer technologies is essential to bringing physical verification alongside transactional and site verification[14]

Tracer technologies are the catalyst to strengthen chain of custody models within sustainability standards, providing physical evidence of geographic and supply chain origin to supplement transactional and site verification.

Executive Summary

Tracer technologies: one piece of a bigger puzzle

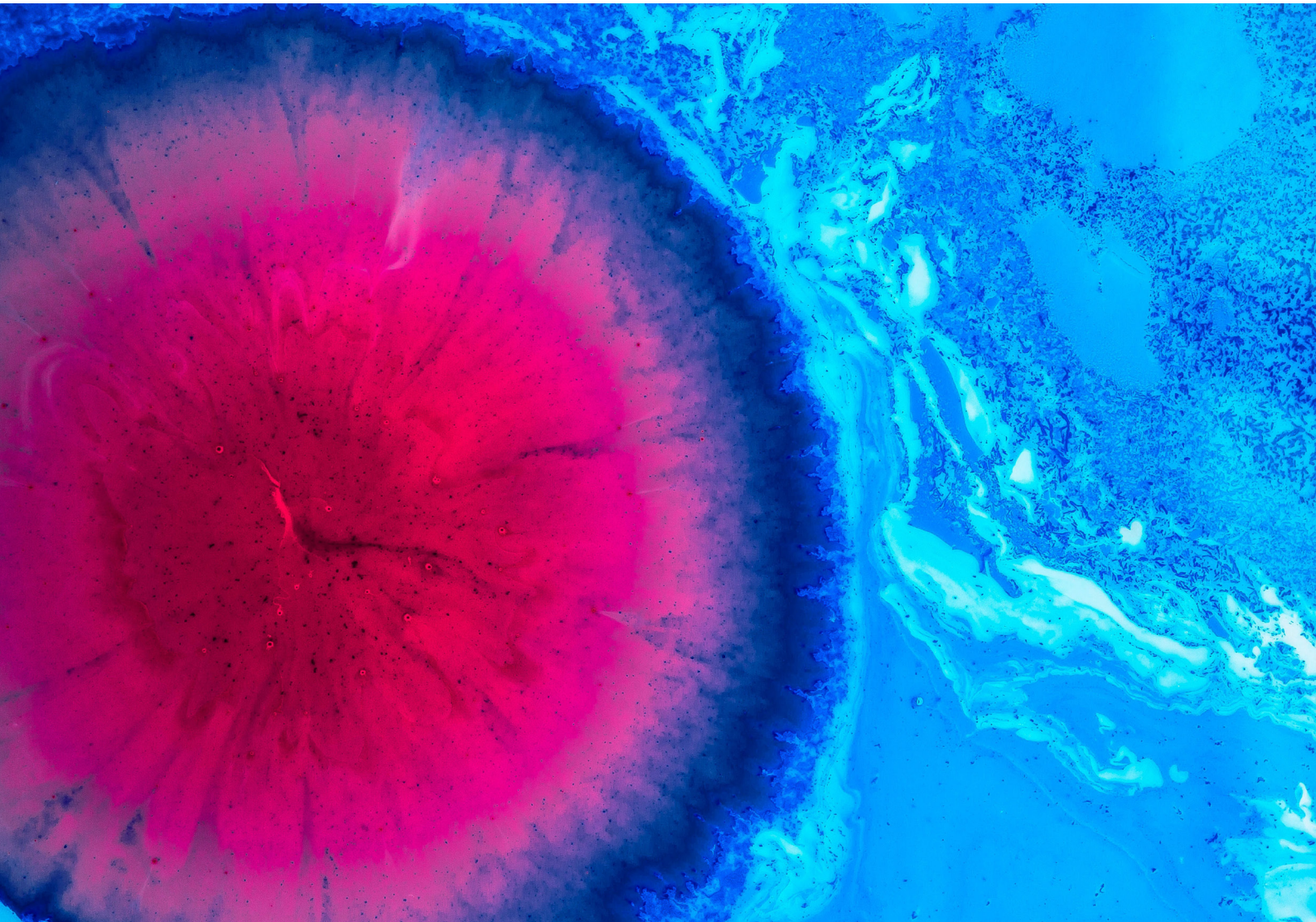
Tracer technologies are used to verify origin, create traceability of information, and flag problems in the supply chain. They do not effectively remediate environmental or social concerns, and therefore should be considered as one part within a larger sustainability strategy for the user.

Great opportunities lie ahead

Looking forward, there are various exciting opportunities to pursue increased physical traceability in the textile industry:

- Implementing tracer technologies in the post-gate circular economy to verify mechanically and chemically recycled fibres
- Scaling the use of tracer technologies to help verify sustainable product claims and sustainable fibre content
- Opportunities for further pilots and partnerships between tracer technologies and suppliers, manufacturers, brands, and retailers, to further strengthen the integrity of sustainably sourced fibres and materials

Image courtesy of Unsplash



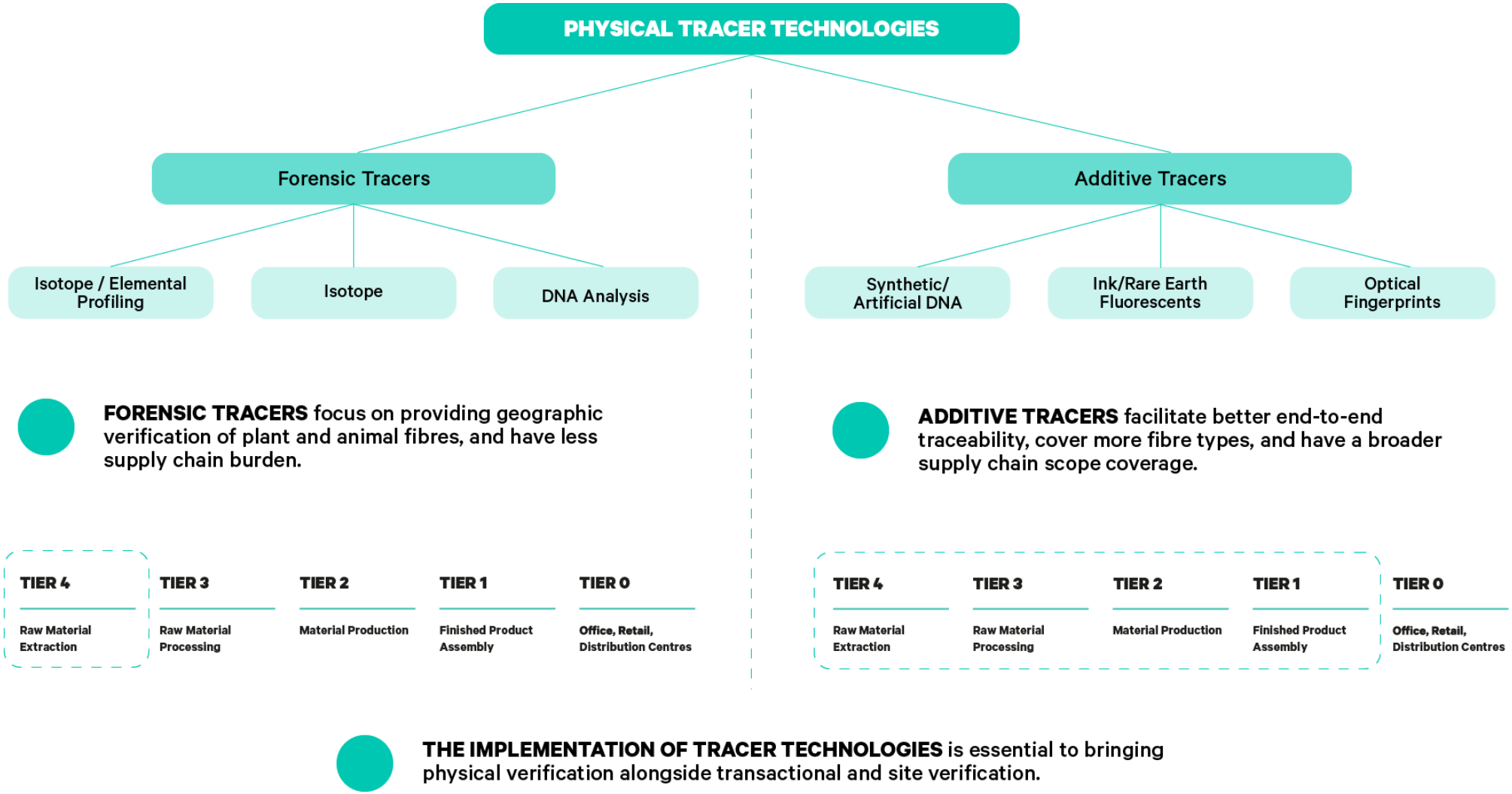


FIGURE 1: KEY TAKEAWAYS OF THE TEXTILE TRACER ASSESSMENT

Executive Summary

CALL TO ACTION

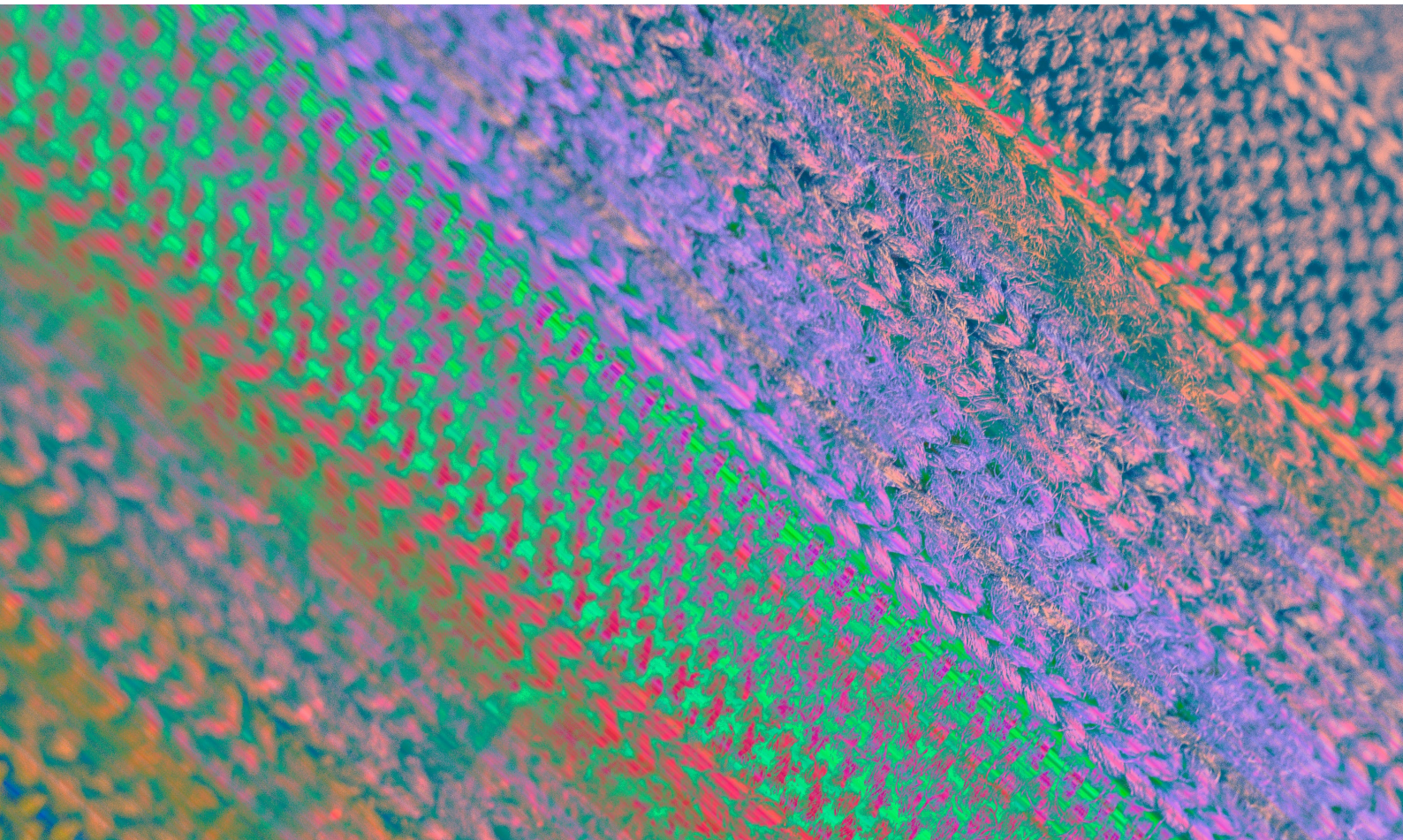
Use the Textile Tracer Assessment to accelerate the implementation of tracer technologies
Industry players should utilise the Textile Tracer Assessment to select appropriate tracer technologies for their needs, facilitating the scaling of traceability innovation in the textile industry.

Other tracer technologies, come forth!
This is just the beginning. Fashion for Good and Textile Exchange are calling all tracer technologies applicable to the textile industry to come and be a part of the Textile Tracer Assessment so that new technologies and capabilities can be showcased to the industry.

Physical traceability shouldn't be pursued in isolation
Implementing physical traceability solutions (tracer technologies) should be done in tandem with digital traceability. Alongside the push to digitise chain of custody documentation and supply chain information for suppliers, brands, and retailers alike. Digital traceability and physical traceability need to be performed in parallel to provide the user with holistic traceability validation.

In addition, for sustainability standards and certification bodies, physical/material verification (provided by tracer technologies for fibres and materials) should be seen to supplement existing transactional and site verification mechanisms, not replace them.

Image courtesy of Unsplash



Introduction

The **Textile Tracer Assessment** is a comprehensive overview and user guide designed to accelerate the understanding and implementation of tracer technologies across the textile supply chain. The intended target audience is various fashion ecosystem stakeholders e.g. suppliers, manufacturers, brands, retailers, sustainability programmes, scheme owners and certification bodies that hold motivations to explore technologies to supplement existing fibre traceability in the textile supply chain. The tracer technologies themselves are segmented into two main categories: **forensic tracers** and **additive tracers**.

The research study interviewed 17 tracer companies via questionnaires and fill out spreadsheets, obtaining claims on which fibres the tracers are effective on, which supply chain scopes the tracers are effective within, application and detection processes, amongst many other enquiry topics. The use case of this report falls into the broader business relevance of traceability in the textile industry.

WHY USE THIS REPORT

INDUSTRY CHALLENGES FOR TRACEABILITY

In the fashion and textile industry there is a lack of reliable physical traceability for fibres, materials, and finished products. Robust physical traceability and verification requires validation at site-level, transaction-level and material-level to ensure suppliers conform to specific operational and sustainability criteria, validating that the materials exchanged along the supply chain reconcile correctly with inventory, and that fibres can be authenticated in the product.

Current chain-of-custody documentation and auditing processes address site-level and transaction-level[15] assurance, but fall short in physical/material authentications which may lead to false claims and the sourcing of fibres and materials with unchecked environmental risk.

The need for robust traceability and verification is further influenced by:

- Incoming corporate due diligence legislation[16]
- Brands' commitment to international science-based climate targets
- Consumers' growing demand for better transparency and traceability understanding, to know who made the products they buy, and from where they were sourced

Introduction

Tracer technologies (categorised in this report as **forensic** and **additive** tracers) that supplement existing site-level and transaction-level verification, have the capability to provide physical/material validation in addition to chain of custody, to allow for:

- Manufacturers, brands, and retailers to more confidently verify sustainable product claims of the physical material
- More targeted audit planning and sampling by supplementing existing site-level and transaction-level verification with additional physical and material risk assessments made available through tracer technologies
- The incentivisation of suppliers and manufacturers to meet the criteria of sustainability standards and certification, ironing out upstream supply chain certificate counterfeiting and deterring material substitution
- Verified environmental, social, and human sustainability data through an additional verification layer of physical traceability for fibres and materials

Current methods of commodity and informational exchange in the textile supply chain (e.g. manual and/or digital chain-of-custody documentation) can benefit from science-based physical and forensic verification of the fibres and materials present in a final product. Tracer technologies can add this important additional layer of traceability authentication on top of site and transaction verification. Each pillar of verification plays a different but integral role in overall product verification and traceability. See below in Image 2, to see how physical/material verification can supplement existing site and transaction verification for Textile Exchange's Digital and Electronic Trackit programs.

TRACKIT™ PROGRAM - TRACEABILITY PATHWAYS

	DIGITAL TRACKIT	ELECTRONIC TRACKIT
Material verification		Forensic authentication
Transaction verification		
Traceability method	Digitised transaction certificates	Electronic tokens
Data flow	Certified organisation - Certification body - dTrackit	Certified organisation - eTrackit - Certification body
Data validation	Distributed, manual	Centralised
Transaction verification	Certification body	Certification body
Site verification	Digitised scope certificates (Certified Organisation - dTrackit - eTrackit)	

FIGURE 2: TEXTILE EXCHANGE'S DIGITAL AND ELECTRONIC TRACKIT[17] VERIFICATION AND CHAIN OF CUSTODY MECHANISMS

LANDSCAPE OF TRACEABILITY SOLUTIONS

Through desktop research, innovator outreach and existing knowledge at Fashion for Good and Textile Exchange, this report has segmented the traceability landscape in the fashion and textile industry into two overarching groups (see Image 3 below):

Tracer Technologies *focus of this report

- Forensic tracers* (5 companies assessed)
- Additive tracers* (12 companies assessed)
- Tags

(Digital) Traceability Platforms
- Supply chain
- Circularity

KEY FIGURE 3

Category focus on this report

Part of FFG's Organic Cotton Traceability Pilot (Not part of FFG Alumni)

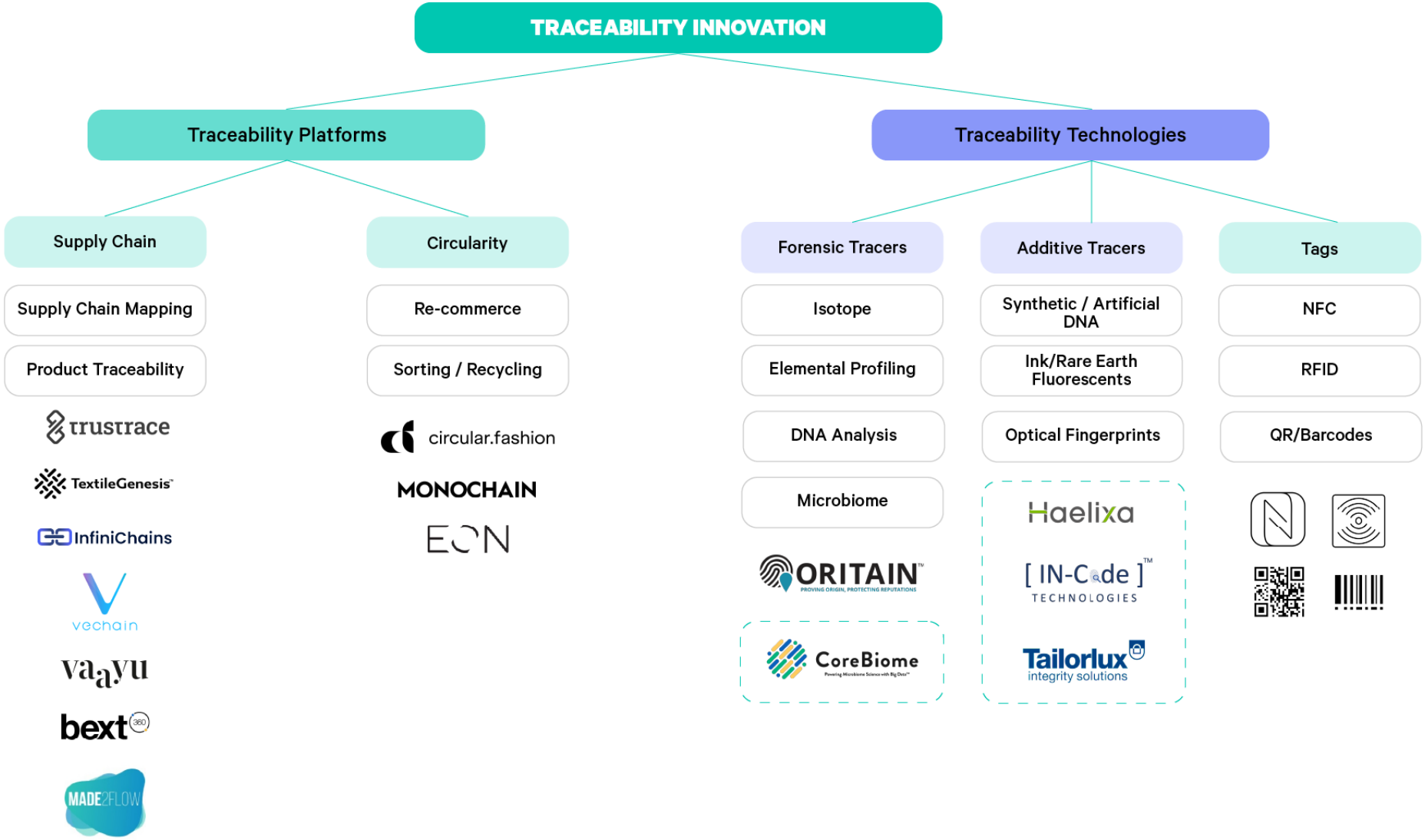


FIGURE 3: TRACEABILITY INNOVATION LANDSCAPE: CATEGORIES AND SOME EXAMPLE INNOVATORS (NOT EXHAUSTIVE)

Introduction

FORENSIC TRACERS

Forensic tracers[18] are innovations that analyse the biochemical composition of fibres, materials and/or garments through micro-particle analysis of isotopic ratios, DNA structures, and elemental meddles. The micro-particle analysis is used to validate the geographic origins via scientific methodologies. The methodologies aim to cross-reference the biochemical composition of samples pulled from the supply chain against predetermined and verified provenance databases to ensure traceability validation.

Application processes for forensic tracers are non-existent, due to the fact that detection processes consist of analysing naturally obtained elements from the environment, rather than detecting substances added by human intervention (as is the case with additive tracers - see below). Furthermore the detection processes usually occur off-site and away from the operations of the supply chain.

There are **three sub-categories** within the forensic tracer category:

- **Isotope/elemental profiling**
- **Isotope** (only)
- **DNA analysis**

ADDITIVE TRACERS

Additive tracers[19] are innovations that apply a tracer substance to fibres, materials, and/or garments on the supply chain floor, and then detect that same substance later down the supply chain to validate origin. Examples of application mechanisms range from spraying mists, applying liquid-inks and pigments, printing nano-invisible inks, and printing digital serialisation markings onto product labels and fabric rolls.

Examples of detection mechanisms range from handheld and in-line UV light detectors, portable test kits, and smartphone/tablet photographic scanning (non-exhaustive).

There are **three sub-categories** within the additive tracer category:

- **Synthetic/artificial DNA**
  Use of DNA codes and molecular identifiers that can be applied to fibre or materials
- **Optical fingerprints**
  Digital watermarks and nano-invisible prints applied to fabric rolls and garment labels
- **Ink/rare earth fluorescent**
  Safe, UV and IR legible fibre and material markings (invisible luminescent pigment inks or rare earth materials)

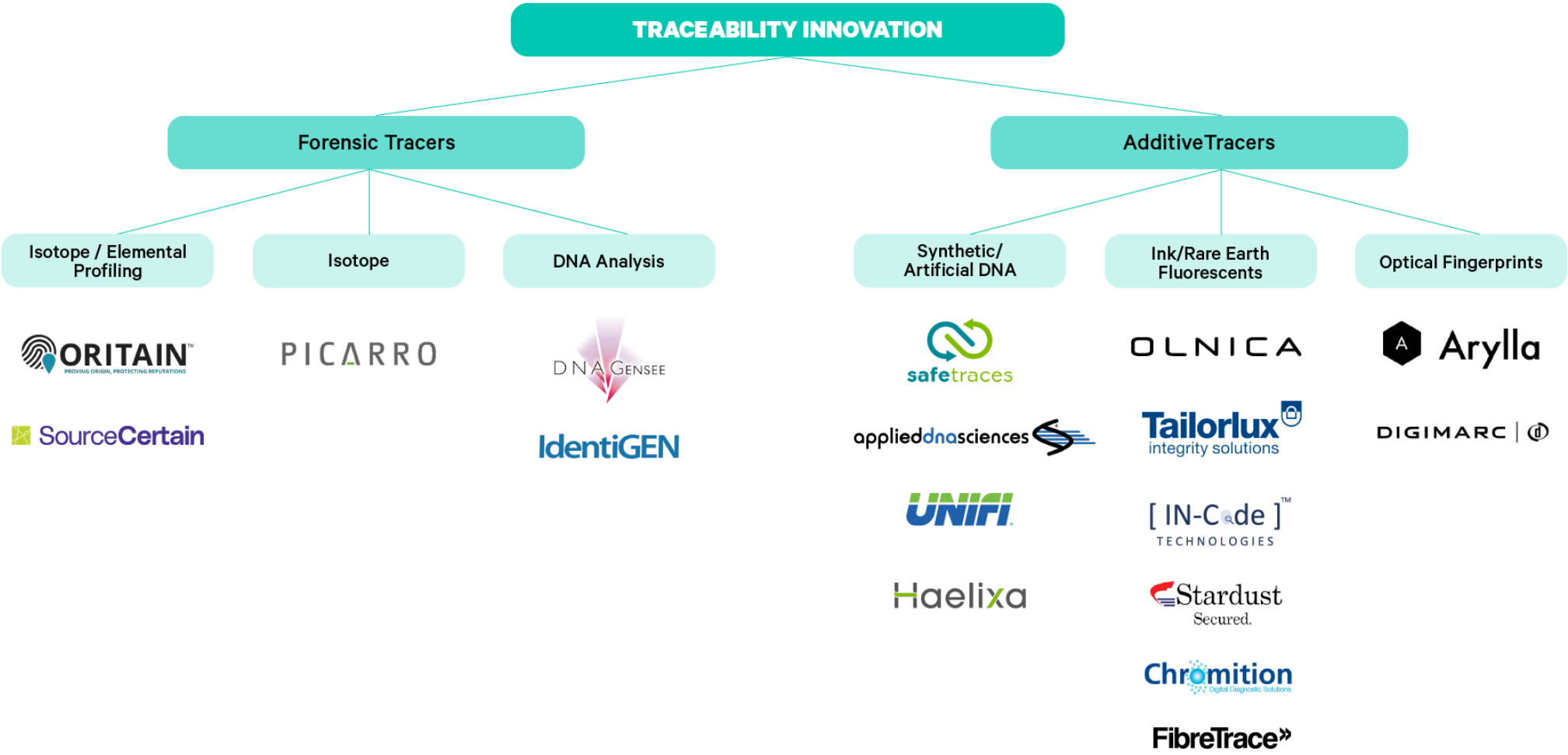


FIGURE 4: CATEGORIES OF TRACER COMPANIES[20] INCLUDED IN THE TEXTILE TRACER ASSESSMENT

Introduction

HOW TO USE THIS REPORT

WHO IS THIS REPORT FOR?

The Textile Tracer Assessment is for any fashion and textile industry players who wish to pursue fibre and/or material verification in their supply chain and increase traceability integrity of their sourcing landscape. This report benchmarks the key tracer technologies that can provide physical verification effectively, to allow users to align the correct technologies with their motivations for traceability.

The report and its findings are intended to be used by a wide variety of stakeholders as mentioned below, all of which may have different supply chain criteria to verify by using such tracer technologies:

- Suppliers
- Manufacturers
- Brands
- Retailers
- Sustainability programmes
- Certification bodies

ASSESS TRACEABILITY OBJECTIVES, THEN SELECT APPROPRIATE TRACER TECHNOLOGY

The Textile Tracer Assessment is most pragmatically useful if the users have already determined their objectives for traceability, and have concretely understood which fibres, materials, areas of their supply chain, and associated economic, environmental, and social criteria they wish to map, improve, communicate, and verify. The users of the tracer technologies have to understand the landscape of their supply chain data integrity issues, and pursue data governance and stakeholder engagement in order to create an environment fit for tracer technology implementation.

Key considerations:
Which fibres and/or materials are you focusing on?
Which part of the supply chain do you want to bring provenance and traceability verification to?

1. Read “Part 1: Fibre or Material Use Cases” and View Figure 5 to better understand the tracer technology categories and which tracers work well with the fibre types you wish to trace
2. View Figure 6/7 to understand which tracers work well with your supply chain scopes
    - Read “Part 2: Supply Chain Coverage: Application” for analysis of the application processes and capabilities of the additive tracers
    - Read “Part 3: Supply Chain Coverage: Detection” for analysis of the detection processes and capabilities of both forensic tracers and additive tracers
3. View Figure 8 to understand which tracers can detect the mixing and blending of fibres types effectively
4. Read the descriptions of the tracer companies themselves in the final section "about the Tracer Companies"

Introduction

Forensic and additive tracers are a piece of a larger puzzle of data validation, traceability, and governance that enables industry players to meet operational and sustainability targets. The effectiveness of tracer technologies are subject to how well they are integrated within broader supply chain mapping and traceability digitalisation efforts. From a Fashion for Good perspective, physical verification enabled by the implementation and performance of (additive or forensic) tracer technologies on fibres and materials, should be pursued in tandem with digital traceability and not in silo:

Digital traceability includes[21] (non-exhaustive):

- **Supply chain mapping:**
  Perform site-level verification, creating visibility and engagement with your supply chain landscape and facilities

- **Product traceability**
  Perform transactional-level verification via tracking product journeys either by fibre forward or garment backward approaches

STRUCTURE OF THE ANALYSIS

The Textile Tracer Assessment report consists of four key parts:

1. A landscape of tracer technologies in the textile industry (see page 16)
2. Results of the study: an analysis of the performance of the tracer technologies in three areas (see below for further detail):
   - Fibre and material use cases
   - Application processes of the tracer technologies within the supply chain
   - Detection processes of the tracer technologies within the supply chain
3. A conclusion with key statements regarding the tracer's capabilities
4. An appendix which provides additional information to each section of analysis (how to read figure tables)

Introduction

RESULTS OF THE STUDY

Part 1: Fibre and Material Use Cases
Part 1 analyses the claims made by both the forensic and additive tracer companies on the capabilities of tracing different fibre and material types in the fashion and textile supply chain (See Figure 5).

Part 2: Supply Chain Coverage: Application
Part 2 analyses the claims made on the application processes of the tracer technologies within the fashion supply chain, focusing on one main element and various sub-elements:

Part 3: Supply Chain Coverage: Detection
Part 3 analyses the claims made on the detection processes of the tracer technologies within the fashion supply chain, focusing on two main elements and various sub-elements.

DISCLAIMERS

Comment and analysis is built on claims and information provided by the tracer companies
It should be noted that the analysis of this report is based on information directly provided by and verified with the tracer companies. Fashion for Good did not proof-test the operational performance, efficacy, and associated claims of the tracers. This was strictly a desktop landscape analysis. Therefore qualitative and qualitative analysis, aggregations, graphs and tables of this report have relied on truthful responses by the representatives of the tracer companies themselves, and are subject to continual change, updates, and modification.

The report focuses on the technical and operational capabilities of the tracer technologies. The focus IS NOT on guiding traceability strategy and defining objectives for the user
The scope of research and analysis for the Textile Tracer Assessment focuses primarily on the technical and operational feasibility of the tracer technologies. Analysis surrounding the traceability objectives that would support the implementation of the tracers, and relevant economic, environmental, and social data points pulled from the value chain, was not the focus of this report. This alternative enquiry would be best realised with a different focus and set of interview questions: varying the interviewee list (to brands, retailers, and civil-society/public institutions) and a heightened focus on the reasons behind implementing traceability solutions.

PART 1

Fibre and Material Use Cases

Part 1 analyses the claims made by both the forensic and additive tracer companies on the capabilities tracing different fibre and material types in the fashion and textile supply chain.

Main element of analysis:

- Analysis to show the claimed use-cases per tracer, per fibre/material type (See Figure 5)

The claims from the tracer companies have been classified as follows:

- **No claimed evidence** that the tracer has worked effectively on the associated fibre/material type
- **Technical feasibility**: Claimed theoretical evidence that the tracer could work effectively on the associated fibre/material type
- **Operational feasibility**: Claimed practical evidence (e.g. pilots and/or partnerships) that the tracer has worked effectively on the associated fibre/material

KEY FIGURE 5

No claimed evidence that the tracer has worked effectively on the associated fibre type

Technical feasibility: Claimed theoretical evidence that the tracer could work effectively on the associated fibre type

Operational feasibility: Claimed practical evidence (e.g. pilots and/or partnerships) that the tracer has worked effectively on the associated fibre type

No response, or still waiting on a response

N/A Not applicable for the tracer

Part 1: Fibre and Material Use Cases

FIGURE 5: PROVIDES AN OVERVIEW OF THE CLAIMS MADE BY BOTH THE FORENSIC AND ADDITIVE TRACER COMPANIES ON THE CAPABILITIES OF TRACING DIFFERENT FIBRE TYPES IN THE TEXTILE SUPPLY CHAIN.

TRACER CATEGORY	SUB CATEGORY	TRACER TECHNOLOGY	ANIMAL FIBRES									
			Down	Recycled Down	Wool	Recycled Wool	Silk	Leather	Cashmere	Recycled Cashmere	Mohair	Recycled Mohair
FORENSIC TRACERS	Isotope / Elemental Profiling	Oritain	●	●	●	●	●	●	●	●	●	●
		Source Certain			●							
	Isotope	Picarro										
	DNA	DNA Gensee	●		●		●		●		●	
		IdentiGen	●		●		●	●	●		●	
ADDITIVE TRACERS	Synthetic/ Artificial DNA	Safetraces										
		ADNAS	●	●	●	●		●	●	●		
		UNIFI										
		Haelixa	●	●	●	●	●		●	●	●	●
	Ink/Rare Earth Fluorescents	Olnica					●	●				
		Tailorlux	●	●	●	●		●	●	●	●	●
		In-Code	●	●	●	●	●	●	●	●	●	●
		Stardust Secured	●	●	●	●	●	●	●	●	●	●
		Chromition										
		Fibretrace	●	●	●	●	●	●	●	●	●	●
	Optical Fingerprints	Digimarc					●					
		Arylla	●		●		●	●	●			

FIGURE 5: PROVIDES AN OVERVIEW OF THE CLAIMS MADE BY BOTH THE FORENSIC AND ADDITIVE TRACER COMPANIES ON THE CAPABILITIES OF TRACING DIFFERENT FIBRE TYPES IN THE TEXTILE SUPPLY CHAIN.

PART 1: CONCLUSION

Below are the key takeaways in regard to fibre and material use cases. The analysis is grouped into the following categories:

- Forensic tracers
- Additive tracer
- Fibre analysis

FORENSIC TRACERS

Where forensic tracers are useful

- FORENSIC TRACERS ARE USEFUL FOR TRACING ANIMAL AND PLANT-BASED FIBRES
  From the claimed fibre and material use cases in Figure 5, forensic tracers indicate good technical and operational feasibility for natural fibres (e.g. cotton, hemp, and wool). This means that they have good capability to verify the geographic origins of plant and animal fibres via their micro-particle detection methodologies. Elemental profiling is necessary for forensic tracers to build provenance databases to verify plant and animal fibre origins. This is to ensure the same micro-particle signatures are not prevalent in other geographic locations of sourced fibres.

- MORE USEFUL FOR VERIFYING GEOGRAPHIC ORIGIN THAN SUPPLY CHAIN ORIGIN
  Forensic tracers have been more associated with verifying geographic origin (Tier 4) of plant and natural fibres, rather than supply chain origins (Tier 3-0). This is due to the biochemical properties uptaken by plant and natural fibres at Tier 4 raw material extraction, which can then be more accurately analysed and cross-referenced against new samples taken.

Where forensic tracers are less useful

- NOT AS USEFUL FOR TRACING SYNTHETIC FIBRES
  DNA molecular structures, ratios of stable Isotopes (non-radioactive atoms of the same element that hold varying numbers of neutrons such as carbon, nitrogen and others), and trace meddles (including essential elements such as sodium, potassium, zinc, iron Na, K, Zn, Fe) are more present in naturally living (or previously living) fibres rather than synthetic fibres originating from petroleum. Therefore forensic tracers are less useful for tracing synthetic fibres, than animal or plant fibres.

- BUT FORENSIC TRACERS DO HAVE POTENTIAL TO TRACE NATURAL/SYNTHETIC BLENDS VIA ELEMENTAL PROFILING
  The process of elemental profiling has the technical capability to validate fibres and materials that have synthetic and natural blends. Elemental profiling is the process of building databases of the trace meddles and isotopic ratios obtained by the fibre, fabric, and/or product through the supply chain journey. In other words, a life-cycle forensic fingerprint that the fibre, fabric, and/or product has picked up on its supply chain journey. Usually for forensic tracers it is associated with building provenance databases of the geographic origin of natural fibres (Tier 4), but can also be applied to building provenance databases of supply chain origins (Tier 3 - 0) for fibres and materials.[22]

  Traceability validation then occurs when samples of the fibre, material, and/or product collected from the supply chain are forensically analysed[23] and cross-checked off-site with the original samples to verify similar bio-chemical elements that created the original elemental profiling database. Some forensic tracers can still identify the type of synthetic fibre if it is blended with a natural fibre, and trace the origin of the natural fibre in the blend (not to confuse the user that forensic tracers can't work with synthetics mixed and blended natural fibre types).

  In contrast to elemental profiling, for natural raw materials such as cotton, there is the technical capability to identify the type of cotton (e.g. Pima or Egyptian Giza cotton), as well as identify whether organic cotton contains GMO-markers. Genomic testing provides information that may help to confirm the cotton content and support label claims that are not possible with only elemental profiling.

ADDITIVE TRACERS

Where additive tracers are useful

- ADDITIVE TRACERS HAVE BETTER ALL-ROUND EFFECTIVENESS ON FIBRES
  Additive tracers have claimed better technical and operational feasibility for a larger scope of fibres. This is due to a greater number of tracer technologies in this space, and relates to additive tracers not having to rely on fibres containing bio-chemical elements to provide verification of provenance.

- ADDITIVE TRACERS HAVE GOOD FEASIBILITY FOR SYNTHETIC FIBRE TYPES
  A high portion of tracer technologies claim operational feasibility for both polyester and nylon synthetic fibres. This enables good visibility of tracer level verification for sustainability standards and certificates in these fibre landscapes (Global Recycled Standard (GRS) and Recycled Claim Standard (RCS)).

- ADDITIVE TRACERS OFFER VERIFICATION FOR RECYCLED FIBRES WHEN APPLIED POST-RECYCLING
  Figure 5 sees many tracer technologies effective on virgin fibre supply chains, but not yet on their recycled counterparts. Feasibility for recycled fibres gives insight into use-cases of the stakeholder engagement experience of applying additive tracers after the recycling phase. With the upscaling of recycling capabilities in the fashion and textile industry, this is a big area of opportunity between recycled fibre manufacturers, brands, and tracer technologies looking to verify recycling integrity. This potential for partnership can be applied to recycling standards (Recycled Claim Standard (RCS) and Global Recycled Standard (GRS)). If the user's focus is to provide verification of recycled content, additive tracers can meet this requirement by being applied to the fibre or material during or after the recycling process, having the same performance as when applied to virgin fibres.

- ADDITIVE TRACERS HAVE GOOD CLAIMED FEASIBILITY FOR NATURAL FIBERS INCLUDING COTTON, MAN MADE CELLULOSIC FIBRES (MMCF), AND LEATHER
  Additive tracers claim good operational feasibility and practical evidence of provenance and traceability validation for cotton, MMCF (man made cellulosic fibres), and leather.

Where additive tracers are less useful

- SUPPLIER ENGAGEMENT ESSENTIAL
  The implementation of additive tracers relies on having direct supplier engagement with suppliers and facilities. As the application (and usual detection) mechanisms are on-site, without solidified supplier relations, additive tracers cannot be applied in a managed environment.

FIBRE ANALYSIS

Which fibres are best covered by tracer capabilities

- COTTON
  Cotton holds the best coverage of claimed feasibility by both forensic and additive tracers.

- POLYESTER AND NYLON
  Polyester and nylon have great coverage of claimed feasibility by additive tracers.

- MMCF, WOOL AND LEATHER
  MMCF, wool and leather has good coverage of claimed feasibility by forensic and additive tracers.

Which fibres were less covered by tracer capabilities

- HEMP, CASHMERE AND MOHAIR
  Hemp, cashmere, and mohair have less coverage of claimed operational feasibility by tracers, but optimistic coverage for technical feasibility. This brings exciting opportunities for testing in pilots and projects for the future, and for tracer companies to pursue collaborations with associated standards (e.g. Responsible Mohair Standard (RMS)).

Part 1: Fibre and Material Use Cases

Developments on the horizon

- OPPORTUNITIES FOR FURTHER PILOTS AND PARTNERSHIPS
  There are exciting opportunities to explore collaborations and pilots for tracer technologies claiming technical feasibility for certain fibres (see Figure 5 to highlight which tracer technologies have claimed technical feasibility on certain fibres and materials). This indicates that the traceability potential is there, and partnerships can be made to pursue sustainability agendas for brands, retailers, and suppliers.

- COLLABORATIONS WITH SUSTAINABILITY STANDARDS AND CERTIFICATION BODIES
  In addition, there are exciting opportunities to explore collaborations and partnerships between tracer technologies, sustainability standards and associated certification bodies.

- TRACEABILITY VERIFICATION OF RECYCLED FIBRES WHEN APPLIED PRE-RECYCLING
  As mentioned above, there is a large potential for traceability verification of recycled fibres by additive tracers, when applied after chemical/mechanical recycling for recycled process verification. Unfortunately due to many additive tracer companies still testing their efficacy to sustain through chemical and recycling processes, at present no wider conclusions can be drawn to applying additive tracers prior to recycling, and detecting after the fibre, material, and/or product has been recycled. It is clear that mechanical recycling processes have less impact on additive tracer substances than chemical recycling. Traceability verification of recycled fibres (when applied pre-recycling) is an important space to watch as the post-gate circular economy grows within the fashion and textile industry.

PART 2

Supply Chain Coverage: Application

Part 2 analyses the claims made on the application processes of the tracer technologies within the fashion supply chain, focusing on one main element and various sub-elements:

Main element of analysis:

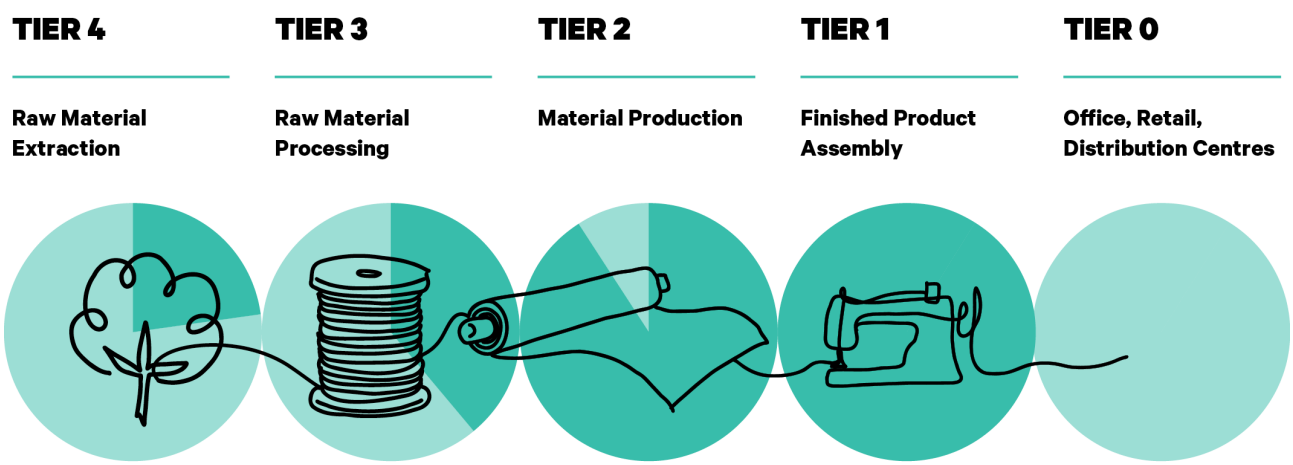
- The scope of supply chain coverage for application processes (See Figure 6)
  Analysing claims made by tracer companies of where in the fashion and textile supply chain the tracers can be detected effectively. The variables being the different tiers of the supply chain.

The claims from the tracer companies have been classified as follows:

- **Technical feasibility**: Claimed theoretical evidence that the tracer COULD be applied effectively AT and AFTER the associated supply chain Tier
- **Operational feasibility**: Claimed theoretical evidence that the tracer CAN be applied effectively AT and AFTER the associated supply chain Tier
- **Technical feasibility**: Claimed theoretical evidence that the tracer COULD be applied effectively ONLY AT the associated supply chain Tier
- **Operational feasibility**: Claimed theoretical evidence that the tracer CAN be applied effectively ONLY AT the associated supply chain Tier

Sub-elements of analysis:

- Application processes of the tracer to fibres and materials in the supply chain.
- Stakeholders in control of the application process
- How the additive tracer is transferred from the technology provider to user
  - Referring to how the tracer substance (see glossary) is transported from the tracer company to the user
- Who determines the volume of tracer substance applied, and how much is needed to be effectively detected later in the supply chain



GRAPHIC SHOWING THE TEXTILE SUPPLY CHAIN TIERS: TIER 4 TO TIER 0

KEY FIGURE 6

No claimed evidence that the tracer can be detected effectively and/or provide traceability of information at the associated supply chain tier

Technical feasibility: Claimed theoretical evidence that the tracer COULD be detected effectively and/or provide traceability of information AT the associated supply chain tier

Operational feasibility: Claimed practical evidence (e.g. pilots &/or partnerships) that the tracer CAN be detected effectively and/or provide traceability of information AT the associated supply chain tier

No response, or still waiting on a response

N/A

Not applicable for the tracer

Technical feasibility: Claimed theoretical evidence that the tracer could be applied effectively AT and AFTER the associated supply chain step

Operational feasibility: Claimed theoretical evidence that the tracer can be applied effectively AT and AFTER the associated supply chain step

Technical feasibility: Claimed theoretical evidence that the tracer could be applied effectively ONLY AT the associated supply chain step

Operational feasibility: Claimed theoretical evidence that the tracer can be applied effectively ONLY AT the associated supply chain step

Part 2: Supply Chain Coverage: Application

TRACER CATEGORY	SUB CATEGORY	TRACER TECHNOLOGY	On-site or off-site detection	TIER 4 Raw Material	TIER 3 Spinning Facility	TIER 2 Fabric Manufacturers	TIER 1 Garment Production	TIER 0 Brand/retailers Distribution Warehouse
FORENSIC TRACERS	Isotope / Elemental Profiling	Oritain	Off-site					
		Source Certain	Off-site					
	Isotope	Picarro	Off-site					
	DNA	DNA Gensee	Off-site					
		IdentiGen	Off-site					
ADDITIVE TRACERS	Synthetic/ Artificial DNA	Safetraces	On-site					
		ADNAS	Can be both					
		UNIFI	Off-site	N/A				
		Haelixa	Can be both					
	Ink/Rare Earth Fluorescents	Olnica	Can be both	N/A				
		Tailorlux	Can be both					
		In-Code	Can be both					
		Stardust Secured	Can be both					
		Chromition	On-site	N/A				
		Fibretrace	On-site					
	Optical Fingerprints	Digimarc	Can be both	N/A	N/A			
		Arylla	Can be both	N/A	N/A			

FIGURE 6: TABLE TO SHOW WHERE IN THE FASHION AND TEXTILE SUPPLY CHAIN THE TRACERS CAN BE APPLIED AND DETECTED EFFECTIVELY AND/OR PROVIDE TRACEABILITY OF INFORMATION.

PART 2: CONCLUSION

Below are the key takeaways in regard to supply chain coverage: application capabilities. The analysis is grouped into the following categories:

- Forensic tracers
- Additive tracer
  - Application capabilities
  - Application processes

FORENSIC TRACERS

- NO APPLICATION PROCESS THEREFORE LESS SUPPLY CHAIN BURDEN
  For forensic tracers nothing is added to the fibre, fabric, or garment on the supply chain floor. Therefore there is no application process. Supplier engagement may still be required if the user and forensic tracer company wish to build a provenance database in order to cross-reference samples for validation processes for geographic and supply chain origins.

ADDITIVE TRACERS

Application capabilities

In reference to Figure 6 based on the claims made, all other additive tracers can implement their tracing technologies from Tier 3 (spinning facility) to Tier 0 (Brand and Retailers), apart from the Optical Fingerprints sub-category. Some have proven technical or operational feasibility to apply their tracer technology beyond, from Tier 4 (Raw Material). For the user, this indicates there are several options in the additive tracer category to provide traceability validation from the extraction of fibers and raw materials and from spinner facilities.

A majority of tracer technologies claimed both theoretical and/or operational feasibility that their tracer can be applied “at and after” the initial supply chain step of application. This shows a large degree of flexibility to cater for the needs of the user e.g. if the user wants to use synthetic/artificial DNA tracers or ink/rare-earth material fluorescent tracers, but only has supply chain engagement up until Tier 2 or 3, it is still possible to implement as they can be applied to all fibre, yarn, and fabric material compositions.

- OPTICAL FINGERPRINTS APPLICATION CAPABILITIES FROM TIER 2
  Tracers in the optical fingerprints sub-category who apply proprietary inks and digital watermark serialisation using digital presses, laser etching systems, and industrial inkjet devices, can only be applied on fabrics or labels. Therefore they have a focused application capability from Tier 2 - 0. For the user this fits well for providing traceability integrity from Tier 2 (Manufacturers) and Tier 1 (Garment Producers).

Part 2: Supply Chain Coverage: Application

- SYNTHETIC/ARTIFICIAL DNA AND INK/RARE-EARTH MATERIAL FLUORESCENTS APPLICATION CAPABILITIES FROM TIER 4
  Synthetic/artificial DNA and ink/rare-earth material fluorescent tracers have capabilities to be applied, and therefore verify information, further up in the supply chain. This is because their tracer compounds and substances have been designed to withstand Tier 3 and 2 manufacturing processes.

- STAKEHOLDER ENGAGEMENT, ONBOARDING, AND A SECURE APPLICATION ENVIRONMENT IS ESSENTIAL
  A key takeaway of the application process for additive tracers is that training and onboarding of stakeholders is needed to implement and to create a secure application environment for effective traceability implementation. Therefore a prerequisite of application is supplier engagement, training, and logistical organisation.

Application processes

Additive tracers are applied to fibres and materials in a variety of ways depending on the tier of the supply chain in question and associated manufacturing and design process. Sprayed mists, liquid-inks, pigments, and optical fingerprints (non-exhaustive) are applied to fibres, materials, garments and / or labels to be detected further down the supply chain.

- MANUAL VS MECHANICAL (IN-LINE) APPLICATION OF ADDITIVE TRACERS
  A key distinction is between manual and in-line application processes e.g. applying additive tracers manually on the supply chain floor vs mechanically through in-line machinery. It appears the former is more common as mechanical application of additive tracers is at the early stages of integrating into supply chain manufacturing processes. Looking forward, up-scaling mechanical (in-line) application machinery within ginning, spinning, and fabric manufacturing facilities for additive tracers is an exciting space for expanding traceability integration for suppliers. It is also a collaborative opportunity for brands/retailers who are sourcing from the same facilities, and who wish to share costs on traceability implementation. Based on the claims made, many application mechanisms for additive tracers can be automated on supplier machinery for efficiency at a larger scale.

- SYNTHETIC/ARTIFICIAL DNA TRACERS APPLIED AS A SPRAY MANUALLY
  Synthetic/artificial DNA tracers are applied either through automated spray systems or, when not feasible, manually through spraying mists onto fibres and materials on the supply chain floor. This can take place from Tier 4, raw material extraction. They can also be applied together with spinning oils in Tier 3 or embedded within synthetic fibres during their manufacturing processes in Tier 4.

- INK/RARE EARTH FLUORESCENTS:
  Ink/rare earth fluorescents are embedded in or on fibres and materials through various application methods. Tracer substances can be applied within the many fibre and yarn manufacturing processes. For synthetic, natural, and animal fibres, application can occur at Tier 4 (raw material source), Tier 3 (spinning stage), or later in the supply chain. Advice is to contact tracer companies directly for more information on the potential of application mechanisms, as most tracer companies are flexible to the users demand.

Part 2: Supply Chain Coverage: Application

- OPTICAL FINGERPRINTS
  Nano invisible-ink markings printed on product labels (Arylla) are applied by the label providers using inkjet stations to print ink on companies' labels.

  Digital watermarks/serialisations (Digimarc) are applied using digital presses, laser etching systems and industrial inkjet devices. Both can only be applied effectively to finished fabrics and garments (Tier 2-0).

- THE VOLUME OF TRACER'S SUBSTANCE APPLIED IS DEPENDENT ON ITS EFFICACY AND EFFECTIVE DETECTABILITY LATER IN THE SUPPLY CHAIN
  This is highly dependent on the efficacy capabilities of the additive tracer substance itself (spray mist, liquid inks, and pigments etc). The variations are the amount of tracer applied, and the size of the fibre, materials and/or product needed for the tracer to be effectively applied and detected later in the supply chain.

  HOW MUCH TRACER SUBSTANCE OR FABRIC IS NEEDED FOR EFFECTIVE APPLICATION
  For additive/synthetic tracers and ink/rare earth fluorescent tracers, substances are applied in parts per million/billion.

  For optical fingerprint tracers, markings are printed on fabric/labels within boundaries of a few cm squared.

- SUPPLIER ENGAGEMENT, A PREREQUISITE FOR IMPLEMENTATION
  Solidifying supplier relations is an essential first step prior to the use of additive tracers.

Image courtesy of Haelixa: Haelixa marker application process on recycled cotton at a spinning mill, through an automated spraying system.

PART 3

Supply Chain Coverage: Detection

Part 3 analyses the claims made on the detection processes of the tracer technologies within the fashion supply chain, focusing on two main elements and various sub-elements:

Main elements of analysis:

1. **The scope of supply chain coverage for effective detection (additive tracers) or providing traceability of information** (see Figure 7)
   For forensic tracers: Analysing claims made of where in the fashion and textile supply chain the tracers can provide traceability of information

   For additive tracers: Analysing claims made of where in the fashion and textile supply chain the tracers can be detected effectively and therefore provide traceability of information.

   For both tracer categories the variables are on/off-site detection, and the different tiers of the supply chain.

This analysis aims to understand, per tracer technology, the technical feasibility, and/or proven operational feasibility of detecting effectively or providing traceability of information at the associated supply chain tier.

The claims from the tracer companies have been classified as follows:

- **No claimed evidence** that the tracer can be detected effectively and/or provide traceability of information at the associated supply chain tier
- **Technical feasibility**: Claimed theoretical evidence that the tracer COULD be detected effectively and/or provide traceability of information AT the associated supply chain tier
- **Operational feasibility**: Claimed practical evidence (e.g. pilots and/or partnerships) that the tracer CAN be detected effectively and/or provide traceability of information AT the associated supply chain tier

2. **Whether the tracers can effectively detect the mixing and blending of fibres** (see Figure 8)
   Quantifying fibre content: understanding how much a fibre/material has been mixed or blended with another fibre that is not from a verified source.

For this analysis, claims from the tracer companies have been classified as follows:

- **No claimed evidence** that the tracer has the capability to detect the mixing and blending of fibres
- **Technical feasibility**: Claimed theoretical evidence that the tracer has the capability to detect the mixing and blending of fibres
- **Operational feasibility**: Claimed practical evidence (e.g. pilots and/or partnerships) That the tracer has the capability to detect the mixing and blending of fibres

Part 3: Supply Chain Coverage: Detection

Sub-elements of analysis:

- The detection process
- On-site or off-site detection (see glossary)
- If off-site, does detection go through a third-party independent process?
- If your technology requires the use of a database, what is the coverage of that database?
  - For forensic tracers this is usually referring to the coverage of their provenance databases (see glossary)
  - For additive tracers this is usually referring to the database of unique tracer substance signatures (see glossary) that can be offered
- For forensic tracers, the size of the material sample is needed
  - This refers to the size of material needed to conduct micro-particle analysis on to prove provenance
- Description of the sampling methodology
  - This refers to the amount, frequency, and location of fibre, materials, and/or product samples taken within the supply chain
- Detection of fibre mixing and blending (see glossary)
- Impact of textile processing steps
- Integration with existing IT solutions
- Proprietary IT systems
- Quality control mechanisms:
  - What is the quality control mechanism?
  - How often are these quality control tests conducted?
  - Do you have any controls in place to avoid fraudulent behaviour?

Image courtesy of Tailorlux: a spectrometric triple array performing inline detection of tracer substance present in cotton

Part 3: Supply Chain Coverage: Detection

KEY FIGURE 7

No claimed evidence that the tracer can be detected effectively and/or provide traceability of information at the associated supply chain tier

Technical feasibility: Claimed theoretical evidence that the tracer COULD be detected effectively and/or provide traceability of information AT the associated supply chain tier

Operational feasibility: Claimed practical evidence (e.g. pilots &/or partnerships) that the tracer CAN be detected effectively and/or provide traceability of information AT the associated supply chain tier

No response, or still waiting on a response

N/A

Not applicable for the tracer

Technical feasibility: Claimed theoretical evidence that the tracer could be applied effectively AT and AFTER the associated supply chain step

Operational feasibility: Claimed theoretical evidence that the tracer can be applied effectively AT and AFTER the associated supply chain step

Technical feasibility: Claimed theoretical evidence that the tracer could be applied effectively ONLY AT the associated supply chain step

Operational feasibility: Claimed theoretical evidence that the tracer can be applied effectively ONLY AT the associated supply chain step

Part 3: Supply Chain Coverage: Detection

TRACER CATEGORY	SUB CATEGORY	TRACER TECHNOLOGY	On-site or off-site detection	TIER 4 Raw Material	TIER 3 Spinning Facility	TIER 2 Fabric Manufacturers	TIER 1 Garment Production	TIER 0 Brand/retailers Distribution Warehouse
FORENSIC TRACERS	Isotope / Elemental Profiling	Oritain	Off-site	■	■	■	■	■
		Source Certain	Off-site	■	■	■	■	
	Isotope	Picarro	Off-site					
	DNA	DNA Gensee	Off-site	■				
		IdentiGen	Off-site	■				
ADDITIVE TRACERS	Synthetic/ Artificial DNA	Safetraces	On-site	●	■	■	■	■
		ADNAS	Can be both	●	■	■	■	■
		UNIFI	Off-site	N/A	▲	■	■	■
		Haelixa	Can be both	●	■	■	■	■
	Ink/Rare Earth Fluorescents	Olnica	Can be both	N/A	●	■	■	■
		Tailorlux	Can be both	●	■	■	■	■
		In-Code	Can be both	●	■	■	■	■
		Stardust Secured	Can be both	●	■	■	■	■
		Chromition	On-site	N/A				
		Fibretrace	On-site	●	■	■	■	■
	Optical Fingerprints	Digimarc	Can be both	N/A	N/A	●	■	■
		Arylla	Can be both	N/A	N/A	●	■	■

FIGURE 7: THIS TABLE SHOWS WHERE IN THE FASHION AND TEXTILE SUPPLY CHAIN THE TRACERS CAN BE APPLIED AND DETECTED EFFECTIVELY AND/OR PROVIDE TRACEABILITY OF INFORMATION.

Part 3: Supply Chain Coverage: Detection

TRACER CATEGORY	SUB CATEGORY	TRACER TECHNOLOGY	On-site or off-site detection	CAPABILITY TO DETECT THE MIXING AND BLENDING OF FIBRES
FORENSIC TRACERS	Isotope / Elemental Profiling	Oritain	Off-site	
		Source Certain	Off-site	
	Isotope	Picarro	Off-site	
	DNA	DNA Gensee	Off-site	
		IdentiGen	Off-site	
ADDITIVE TRACERS	Synthetic/ Artificial DNA	Safetraces	On-site	
		ADNAS	Can be both	
		UNIFI	Off-site	
		Haelixa	Can be both	
	Ink/Rare Earth Fluorescents	Olnica	Can be both	
		Tailorlux	Can be both	
		In-Code	Can be both	
		Stardust Secured	Can be both	
		Chromition	On-site	
		Fibretrace	On-site	
	Optical Fingerprints	Digimarc	On-site	
		Arylla	Can be both	

FIGURE 8: THIS TABLE SHOWS THE CAPABILITIES OF WHETHER THE TRACERS CAN EFFECTIVELY DETECT THE MIXING AND BLENDING OF FIBRES.

PART 3: CONCLUSION

Below are the key takeaways in regard to supply chain coverage: detection capabilities. The analysis is grouped into the following categories:

- Forensic tracers
  - Detection capabilities
  - Detection processes
  - Detecting the mixing and blending of fibres
  - Integration with IT solutions
  - Sampling methodology
  - Size of sample needed for effective detection
  - Impact of textile processing steps
- Additive tracer
  - Detection capabilities
  - Detection processes
  - Detecting the mixing and blending of fibres
  - Impact of textile processing steps
  - Integration with IT solutions

FORENSIC TRACERS

Detection capabilities

In reference to Figure 7 based on the claims made, only some forensic tracers can effectively provide traceability of information for all tiers of the supply chain. A key trend is providing traceability of information at Tier 4 (Raw material production). Forensic tracers are a good way to verify the geographic origin of virgin plant and animal fibres with little supply chain burden (no application process needed).

- BUILDING A PROVENANCE DATABASE NEEDED

  To provide traceability, forensic tracers need to build provenance databases of the biochemical properties of the fibres, fabrics, and products. Samples need to be taken in order to analyse the trace meddles present in the fibres, fabrics, and products. Historically this has been more associated with providing visibility of first mile geographic origins of plant and animal fibres, building Isotopic/elemental/DNA fingerprints from raw material extraction (e.g. Tier 4 cotton farm).

  However, there are rising motivations to seek traceability verification for the middle tiers of the supply chain (e.g. Tier 3-1). But for forensic tracers, this can be more difficult. Building a provenance database of fibres and materials at these middle tiers of the supply chain is more complex. Firstly, it is more difficult to access these tiers of the supply chain in order to build a meaningful provenance database of the fibres and materials in question. And secondly, impactful manufacturing processes mean that biochemical properties of the fibres and materials can be constantly changing, creating further problems for confidently building provenance databases.

Part 3: Supply Chain Coverage: Detection

Detection processes

- OFF-SITE DETECTION
  The process of detection for forensic tracers is usually off-site, analysing the DNA/chemical/Isotopic makeup of the fibre, material, and / or product sample, rather than detecting an added tracer substance (e.g. ultraviolet (UV)-legible watermarking/luminescent pigments) as the additive tracers do. Therefore the forensic tracers needed to verify, provide transparency, and facilitate the flow of information to the user rely on taking samples from the supply chain and analysing them in off-site, sometimes third-party laboratories.

Detecting mixing and blending of fibres

- UNCERTAIN CAPABILITY
  Through the interviewing process with the forensic tracer companies the capability to detect and quantify the extent of mixing and blending (fibre quantification) was uncertain. However what had a higher degree of certainty was still being able to authenticate the presence of certified natural fibres in a mix/blend in order to provide traceability verification.

Integration with IT solutions

- FORENSIC TRACERS HAVE VARIED CAPABILITIES FOR IT INTEGRATION
  IT and digital integration capabilities were mixed in the forensic tracer category. Some rely on document send outs (e.g. PDF, CVS. spreadsheet data) and others have more advanced capabilities to integrate with existing ERP systems via API integration. However, as the detection process for forensic tracers are off-site, rather than within supply chain operations in real-time for additive tracers, API capability seems less relevant (but still of importance depending on the users requests for data integration). This is partly due to off-site detection being outside the realm of direct supply chain operations and therefore associated ERP systems. More importantly, key traceability and supply chain mapping digital platforms (e.g. TrusTrace, Textile Genesis) are providing agnostic integrative capacity with tracer technologies to incorporate forensic audit results alongside chain of custody documentation. Looking forward, this stream of collaboration is an integral one to follow in order to provide supplementary verification for fibre integrity, and the consolidation of associated digital documentation and traceability data.

Part 3: Supply Chain Coverage: Detection

Sampling methodology

- SAMPLING METHODOLOGY AND PROTOCOLS DEPENDENT ON USER REQUIREMENTS
  The sampling methodology (in this instance the protocol implemented for sampling fibre, material, and/or product from the supply chain) is mostly tailored to the users requirements and traceability objectives motivations.

  Depending on tracer detection capabilities, samples can be taken from the supply chain, raw material source, and/or at various points of the supply chain or the finished product from the market.

  It is also key to note that there are two distinct steps in sampling by forensic tracers:
  - First is building a provenance database (elemental profiling and isotopic analysis) of the desired fibre, material, and/or product to be verified.
  - Second is verifying new samples taken from the supply chain by cross-referencing them with the provenance databases built to provide verification of origin. The frequency of samples taken is totally dependent on the sampling protocol agreed between the user and tracer company.

Size of sample needed for effective detection

- ONLY A SMALL AMOUNT OF MATERIAL NEEDED FOR EFFECTIVE MICRO-PARTICLE ANALYSIS
  Only a few grams or a small piece of fibre, material, and/or product needed for forensic (isotope/DNA/elemental profiling). Sample size requirements change based on the material and where in the chain the samples are taken.

  There are two main dependencies for the size of sample needed for detection:
  - Fibre or material analysed
  - Where in the supply chain samples are taken

Impact of textile processing steps

- TEXTILE MANUFACTURING PROCESSES CAN IMPACT THE DETECTION CAPABILITIES OF FORENSIC TRACERS (The extent to which is unclear, more scientific research and R&D needed)

  For DNA analysis, heating and bleaching disrupts the chemical composition, and therefore the forensic legibility of DNA structures. For Isotopic and elemental profiling tracers, the dyeing process doesn't impact the isotopic and chemical makeup of trace meddles, and therefore doesn't impact detection capabilities.

DISCLAIMER

Responses on this topic were extremely limited and based on claims made rather than testing effectiveness of tracers first hand. Potential users of forensic tracers will gain great insight by talking one-to-one with the companies to fully understand the extent of impact of their supply chain processes on the tracer's efficacy and detective capabilities.

Part 3: Supply Chain Coverage: Detection

ADDITIVE TRACERS

Detection capabilities

In reference to Figure 7 based on the claims made, it is clear all additive tracers have claimed both theoretical and operational feasibility to be detected effectively up until Tier 0. This is subject to claims of viable application points in the supply chain, which, relative to each tracer technology, is dependent on capabilities and business focus.

- DETECTION CAPABILITIES IN THE SUPPLY CHAIN DETERMINED BY APPLICATION CAPABILITIES
  For the optical fingerprint tracers (Arylla, Digimarc) applied at Tier 2 and beyond (post fabric manufacturing stage), detection feasibility is defined alongside application feasibility. This is due to the fact that the physical composition of the nano invisible-ink markings and on fabric digital watermarking cannot sustain through Tier 4, 3 and 2 manufacturing processes.

  It should be noted that detection capabilities of the tracer technologies are not only defined by their performance to sustain and remain readable after supply chain manufacturing steps. Supplier engagement and management are essentical to secure good application environments.

- CAPABILITY TO PROVIDE TRACEABILITY RELIES ON SUPPLIER ENGAGEMENT
  For additive tracers, the capability of supply chain tier traceability corresponds directly to where in the supply chain the additive tracer can be applied and detected effectively (see Figure 7). But in order to successfully facilitate the flow of traceability information, operational change management for suppliers is required to implement the application and detection processes on the supply chain floor.

Detection processes

Detection processes of additive tracers are varied and determined by the tracer composition itself. Many detection mechanisms are “lock and key”, meaning the detection devices are only capable of detecting the substance tracer of which they are designed to read.

DETECTION PROCESSES CAN BE HANDHELD, INLINE, VIA TEST-KITS/MOLECULAR SCREENING TOOLS, OR VIA SMARTPHONE/TABLET SCANNING:

- Handheld
  For ultraviolet (UV) legible watermarking and invisible luminescent pigments (see the “ink/rare earth fluorescents” sub category for associated tracer companies), handheld portable detectors can manually scan the fibre, material and/or product to detect the tracer substance.
- Inline (mechanical)
  Inline verification detectors (automated belt detectors within fibre and material processing machines) can be integrated to the supply chain for real-time automated detection capability at a faster and larger scale.

- Test kits/molecular screening tools
  For synthetic/artificial DNA tracers the capabilities of detection can be both on-site (via test kit / molecular screening tools for in-field screening) or off-site (samples sent to a laboratory outside the supply chain operations for micro-particle analysis[24]).
- Smartphone/tablet scanning
  For optical fingerprint tracers applied at manufacturing stage (e.g. Arylla, Digimarc), the nano-particle tags can be scanned and identified by smartphones and tablets.

Detecting mixing and blending of fibres

CAPABLE, BUT TO WHAT EXTENT?

Additive Tracers have better capability for detecting the mixing and blending of fibres. However this claimed capability to detect the mixing and blending of fibres can include the following descriptions:[25]

- The additive tracer being detected after the mixing and blending with fibre types not containing the tracer substance.
- The additive tracer applying different tracer substance signatures to different fibre types, that are detected later to verify origin of different fibre types within a mix/blend.
- The additive tracer detection mechanisms (handheld, inline (mechanical), test kits/molecular screening tools) detect different strength readings of the tracer substance present in the fibre, material, and/or product analysed.
- The additive tracer quantifying the percentage of a certain fibre type present within a mix/blend (fibre quantification).

To understand the specific capabilities of detecting the mixing and blending of fibres (and/or fibre quantification), the user should explore further directly with the additive tracer technology of interest. Fibre quantification is a much desired use case for physical verification, especially to meet minimum required content for sustainable product certification (e.g. organic or recycled). But for many additive tracer technologies, the capability is still being refined and developed.

Impact of textile processing steps

- COMPOSITION OF ADDITIVE TRACERS LESS IMPACTED BY MANUFACTURING PROCESSES
  Based on the claims made, additive tracers seem less impacted by supply chain manufacturing processes than forensic tracers. Manufacturing processes seem to have more effect on the chemical makeup (DNA/Isotope composition and influence trace meddles acquired by the fibre/fabric/product) than on the ink/rare material UV legible fluorescents of additive tracers. Optical fingerprints (a type of additive tracer usually applied at fabric manufacturing stage or on product labels) are less impacted due to their focused application area later in the supply chain (Tier 2 - 0). However, it should be noted forensic tracers can rebuild their provenance and elemental profiling databases accordingly to cater for the impact on the chemical composition of fibres/fabrics/products by manufacturing processes.

DISCLAIMER

It should be noted that the responses on this topic were extremely limited and based on claims made by the tracer companies rather than testing effectiveness of tracers first hand. Potential users of additive tracers will gain insight by connecting with the companies to fully understand the extent of impact of their supply chain processes on the tracer's efficacy and detective capabilities.

Integration with that solutions:
Generally speaking, a majority of additive tracer companies claimed to have proprietary IT systems, consolidating information and providing data analytics of uploaded data through their tracer detection mechanisms. API integration from proprietary IT solutions to supply chain systems (ERP, SAP etc) was a common claim, as was blockchain compatibility. Some claims also associate API integration compatibility with brand management software (e.g. PLM), facilitating the flow of supply chain traceability data to brands' internal product management databases. Again, agnostic capabilities and roadmaps for collaboration with supply chain traceability digital platforms (e.g. Trustrace, Textile Genesis) were a key topic of discussion (and an exciting one to pursue for physical authentication to existing site-level and transaction-level chain of custody).

- OPTICAL FINGERPRINTS VARIED IT INTEGRATION FOCUS
  Arylla (nano invisible-ink marking on product labels) has a more brand/consumer facing focus holding API integration capacity also for seamless integration with third party software, including WeChat, Facebook messenger, Whatsapp etc. fitting to their consumer facing focus for product traceability.
  Digimarc (digital watermarks/serialisation on fabric rolls) has proven IT integration on fabric serialisation designs with Photoshop/Illustrator compatibility. In addition, claims made are that optical fingerprint detection can relay and synchronise with NFC, QR, RFID traceability programs, depending on the users motivations and data requirements.

- ESTABLISHED ADDITIVE TRACERS HAVE ADVANCED CLOUD BASED/BLOCKCHAIN PROPRIETARY IT PLATFORMS
  Proprietary IT systems of well established tracer technologies are based on blockchain networks or a cloudbase platforms, allowing for realtime uploading of traceability information by detection mechanisms (e.g. Manual/handheld scanning devices, inline scanning devices, test kits, smartphone/tablet scanning)

- TAILORED AND CUSTOMISED INTEGRATION CAPABILITIES
  A key trend: the integration of proprietary IT solutions of additive tracers with supply chain manufacturing systems (ERP) and brand product management databases (PLM) can be tailored and customised. This enables the flow of data associated with the additive tracer's detection to speak to other systems for the purposes of bridging physical traceability with digital traceability, and aligning associated physical-level verification of fibres/material (detecting the additive tracer) with site-level and transaction-level verification (digitised site and transaction certificates). For this to work with existing chain of custody models, tracer companies will need to align data requirements with chain of custody protocols of certification schemes and standards.

- DETECTION FREQUENCY, SAMPLING METHODOLOGY, AND AMOUNT OF FIBRE, MATERIALS AND/OR PRODUCT NEEDED TO DETECT THE TRACER EFFECTIVELY
  Detection frequency (scanning frequency for detection mechanisms) and sampling methodology (determining frequency, type of samples taken, and amount of fibre, material, and/or product sample needed for the tracer to be detected effectively, relevant for toolkits/molecular screening tools) are enquiry topics that are highly variable between the additive tracer technologies and by user motivations.

Part 3: Supply Chain Coverage: Detection

TRACING ORGANIC COTTON

Launched in 2018, The pioneering Organic Cotton Traceability Pilot successfully combines on-product markers and blockchain technology to track organic cotton from farm to consumer; a first in the apparel industry. The multi-stakeholder initiative is a collaboration between Fashion for Good, Laudes Foundation and the Organic Cotton Accelerator, with support from C&A, Kering, PVH Corp. and Zalando with Bext360 as the leading technical partner.

Read more about the project and outcomes here.

Overall Conclusion

Forensic tracers: Less supply chain burden
With off-site detection and no need for application of any tracer substance or optical fingerprint, for the user, the implementation of forensic tracers has less supply chain operational workload and burden.

Forensic tracers are useful to facilitate ad-hoc "spot checking" of the geographic origin of natural fibres. This enables the user to verify with confidence that claims of origin are true, that they meet desired sustainability criteria of the area of origin, and can help to red-flag fibres and materials sourced from questionable supply areas (e.g. forced labour concerns). If the user is a supplier and/or manufacturer, forensic tracers can maintain and communicate the authenticity of fibres and materials sold.[26]

However, forensic tracers have more difficulty providing provenance of the middle tiers of the supply chain, between Tier 3 to 1. This lesser capability of verifying supply chain origins (Tier 3 - 1) is due to the greater amount of sampling needed in order to build provenance databases[27] of the isotopic, bio-chemical, and trace meddle compositions obtained by fibres and materials during their supply chain journey (not to be confused with building provenance databases at geographic origin: Tier 4). Traceability verification mechanisms to authenticate fibres and materials within the middle supply chain tiers has more difficulties due to manufacturing process steps impacting and changing the biochemical composition of fibres and materials. Overall, forensic tracers have greater traceability effectiveness of verifying the geographic origin of natural fibres (Tier 4 Raw material production).

With less tracer technologies available in the forensic tracer category, their usability focuses on transparency of first-mile origins of natural fibres, rather than physically and digitally tracking and tracing the commodity flow throughout all tiers of the supply chain. Physical traceability verification by forensic tracers should be used in conjunction with site and transaction verification to ensure robust traceability validation for the user.

Additive tracers: Facilitate better direct "track and trace" traceability and more tailorable to the user
With more claims to on-site application and detection processes, additive tracers bear more supply chain operational burden for implementation and maintenance. However, as they have a wider supply chain coverage, they hold more flexibility for the user to provide traceability integrity for a larger scope of supply chain tiers and fibre types.

In addition, based on the claims made, most "Synthetic/artificial DNA" and ink/rare earth material additive tracers have the ability to withstand and sustain well through textile manufacturing processes. Giving confidence to the user that physical traceability of the tracer applied is sustained throughout the supply chain journey, from application in the upper supply chain to detection later down the supply chain.[28]

Overall Conclusion

In terms of confidence levels regarding detection capabilities, most additive tracers have "lock and key" mechanisms for their detection and verification processes. This means that the exact signatory composition of the tracer substance applied (e.g. artificial DNA sequence or luminous ink pigment) needs to be pre-known in order for it to be detected and authorised effectively. This makes it impossible to replicate the verification of the tracer, or for it to be used in an unauthorised way. For the user, this provides a high-degree of traceability confidence when detection processes of the tracers are successful (handheld, inline/mechanical, test kits/molecular screening tools, smartphone/tablet scanning). However, without an independent party verifying, "lock and key" detection mechanisms can be questioned.[29]

As the title suggests, additive tracers are applied onto fibres and materials. Therefore, they exist physically within the fibre or material traced. This physical traceability runs in parallel to digital traceability. Many of the additive tracer companies have their own proprietary IT system to facilitate data uploads and analysis from detection processes that "checkpoint" the fibre or material at supply chain tiers, since the point of application. This therefore creates a digital twin of the supply chain journey. For the user, this digital visibility of the flow of goods allows for analysis of real-time data points and uploads: time, geo-tagging and other relevant logistical and ESG criteria from manufacturing facilities within scope. All of which can integrate into other legacy supply chain software systems and platforms. Additive tracers therefore provide better "track and trace" traceability, following the commodity flow directly and verifying at more regular intervals within the supply chain.

With more tracer technologies available in the additive tracer category, their usability is more flexible for the user, based on wider claimed supply chain operability and coverage. They hold a focus on physical tracing of fibres and materials, and the associated digital capabilities for data uploads, real-time tracking, and analysis. This allows for an innovative synchronisation of the physical and digital traceability worlds.

Supply chain mapping and supplier engagement are prerequisites for implementation
It is clear for both tracer categories that in order to pursue supply chain traceability at tiers of the users focus, supply chain mapping and stakeholder engagement is a prerequisite to enable sample database building for forensic tracers, and pragmatic operational implementation and logistical maintenance for additive tracers.

Agnostic integration capabilities are a must have
An essential capability of tracer technologies is having agnostic capability with other digital traceability platforms, enabling forensic and additive tracer technologies to upload information onto supply chain software systems. Through the claims made, most if not all tracer technologies have experience integrating data uploads to other software systems through API integration or direct uploads.

Appendix

The appendix provides additional information for each part of the "Results of the Study" section:

- How to read the associated figure tables
- Relevance of the analysis topic (e.g. fibre and material use cases)
- What is included in the analysis topic
- What is not included in the analysis topic

PART 1: FIBRE AND MATERIAL USE CASES

How to read figure 2 "Fibre and Material Use Cases"

- On the Y axis to the left you have the "Tracer Category", "Sub Category", and "Tracer Technology"
- On the X axis above you have the fibre/material types:
  - "Plant-based natural fibres"
  - "Man-made cellulosic fibres"
  - "Animal fibres"
  - "Synthetics"
- The cells correspond to the colour code and text in the key on the right
- The focus is on the claimed use cases of the tracers per fibre/material type based on the following classifications:
  - No claimed evidence that the tracer has worked effectively on the associated fibre/material type
  - Technical feasibility: Claimed theoretical evidence that the tracer COULD work effectively on the associated fibre/material type
  - Operational feasibility: Claimed practical evidence (e.g. pilots and/or partnerships) that the tracer HAS worked effectively on the associated fibre/material type
  - "N/A" not applicable for the tracer (due to restricted scientific capabilities of application/detection, and/or outside the business model of tracer company)
  - "..." No response, or still waiting on a response

Relevance of "Fibre and Material Use Cases" analysis

- TRACEABILITY FEASIBILITY PER FIBRE/MATERIAL TYPE
  Suppliers, manufacturers, brands, retailers, and ecosystem stakeholders can understand which tracer technologies have claimed to be effective on which fibres, and the technical and operational feasibility of use with those fibres. This is useful for users focusing on specific fibres in their supply chain, helping to understand which tracers hold technical feasibility (theoretical capability), and/or operational feasibility (practical and proven experience of implementation) for the associated fibre type. From this visibility, users can then dive into the tracer technologies that are applicable to them (see Appendix also for analyses per tracer company).

Appendix

- RELEVANCE FOR CERTIFICATION OF TEXTILE EXCHANGE'S STANDARDS
  For Textile Exchange's standards and certification bodies, this analysis informs which tracer technologies are relevant for standards (i.e. organic cotton for the Organic Content Standard and recycled cotton and polyester for the Recycled Claim Standard and Global Recycled Standard).

What is included in "Fibre and Material Use Cases" analysis

- MOVING FROM TECHNICAL TO OPERATIONAL FEASIBILITY (PROVEN IMPLEMENTATION EXPERIENCE WITH STAKEHOLDERS)
  In addition to the technical efficacy of the tracer technologies, this analysis provides insight into operational feasibility, or logistical and change management experience implementing the tracers on relevant fibre/material supply chains through pilots and partnerships.

- RECYCLED FIBRE TYPES INCLUDED
  There is insight to gain an understanding as to which tracer companies have had practical experiences implementing their tracer technologies on recycled fibre supply chains, applying the additive tracers, or carrying out micro-particle analysis following a mechanical/chemical recycling process. Alternatively, to gain insight of claims made as to whether additive tracer substances can sustain effectively through chemical and mechanical processes, please stay tuned for the next update of the Textile Tracer Assessment for added tracer capabilities.

- MATRIX MAPPING OF TRACERS' TECHNICAL AND OPERATIONAL CAPABILITIES PER FIBRE/ MATERIAL TYPE
  See Figure 5 to understand which tracers claim to work well with which fibres, based on feedback forms and questionnaires to create a matrix visualisation.

- INTERIM CONCLUSIONS
  Based on the claims made by the tracer companies, aggregated conclusions and key takeaways have been scoped per tracer category (forensic tracers, additive tracers).

What is not included in "Fibre and Material Use Case" analysis

- SPECIFIC ANALYSIS PER SUPPLY CHAIN TIER
  Although the analysis brings visibility to the claimed performance of the tracer technologies per fibre/ material type, it doesn't evaluate the tracers' application and detection performance in relation to specific tiers of the supply chain (Tier 4 - 0). In other words, evaluating where in the supply chain the tracer technologies can be applied and detected effectively and bring traceability of information. For this analysis please see Part 2 and 3.

- PRIORITISING WHICH TRACERS ARE MORE EFFECTIVE
  As a desktop research assessment, this analysis does not evaluate or rate the effectiveness of tracers individually. Rather, it maps capabilities based on claims made by the tracer companies, and highlights aggregations and patterns scoped within the tracer categories (forensic tracers, additive tracers). With so many variables to consider to test the feasibility and efficacy of the tracer technologies on different supply chain journeys, "Part 1: Fibre and Material Use Cases" section holds ambiguity of results and analysis due to research methodology scope restrictions.

Appendix

PART 2: SUPPLY CHAIN COVERAGE: APPLICATION

How to read Figure 6

- On the Y axis to the left you have the "Tracer Category", "Sub Category", and "Tracer Technology"
- On the X axis above you have the variables:
  "On/Off-site detection"
  "Tier 4 - 0" of the fashion and textile supply chain
- The cells and the shapes correspond to the key to the right of the table
  To focus on the application processes, read from the "Application Key" (purple triangle and circle shapes). The decision points are split into
  - Claims made on technical and operational feasibility of application at the associated supply chain step
  - Claims made on whether the tracer can be applied "At or After" the associated supply chain step, or whether it can be applied "Only AT" the associated supply chain step
- Please be aware that the blue colour coding is focusing on the detection process of the tracers rather than the application process.

Relevance of "Supply Chain Coverage: Application" analysis

- INSIGHT INTO THE APPLICATION PROCESSES ON THE SUPPLY CHAIN FLOOR
  Readers of this report can understand in a consolidated space the application processes of the tracers technologies, and the logistical, operational and stakeholder engagement requirements needed to effectively implement additive tracers.

- UNDERSTANDING WHERE IN THE SUPPLY CHAIN THE TRACER CAN BE APPLIED (TIER 4 -0)
  Provide insight into the burden and requirements in applying additive tracers within the fibre/textile supply chain.

What is included in "Supply Chain Coverage: Application" analysis

- MATRIX MAPPING OF TRACERS' APPLICATION CAPABILITIES PER SUPPLY CHAIN TIER
  See Figure 6 for a visual benchmarking of application capabilities per additive tracer technology, per supply chain step.

- INTERIM CONCLUSIONS AND ANALYSIS AGGREGATIONS
  Based on the claims made by the tracer companies, aggregated conclusions and key takeaways have been scoped per tracer category (forensic tracers, additive tracers), and their sub-tracer categories. See aggregated analysis below.

What is not included "Supply Chain Coverage: Application" analysis

- FORENSIC TRACERS ABSENT FROM ANALYSIS AS NO APPLICATION PROCESS
  This section of analysis is more relevant for the application mechanisms of additive tracers (synthetic/artificial DNA, ink/rare-earth material fluorescents, and optical fingerprints) category. Forensic tracers are exempt from application as they don't apply any physical tracer to the fibres, textiles or product. Their forensic process usually is off-site, away from supply chain operations (See Part 3).

Appendix

PART 3: SUPPLY CHAIN COVERAGE: DETECTION

How to read figure 7

- On the Y axis to the left you have the "Tracer Category", "Sub Category", and "Tracer Technology"
- On the X axis above you have the variables:
  "On/Off-site detection"
  "Tier 4 - 0" of the fashion and textile supply chain
- The cells within the matrix table correspond to the colour coding, shapes and descriptions within the key on the right of the table
  To focus on the detection process, read from the "Detection Key" (blue colour coding cells). The decision points are split into:
  - No claimed evidence that the tracer can be detected effectively and/or provide traceability of information at the associated supply chain tier
  - Technical feasibility: Claimed theoretical evidence that the tracer could be detected effectively and/or provide traceability of information at the associated supply chain tier
  - Operational feasibility: Claimed practical evidence (e.g. pilots and/or partnerships) that the tracer can be detected effectively and/or provide traceability of information at the associated supply chain step
- Please be aware that the purple circles and triangles are focusing on the application process of the tracers rather than the detection process

Relevance of "Supply Chain Coverage: Detection" analysis

- TIER SPECIFIC DETECTION PROCESSES:
  For additive tracers (which all have on-site detection capabilities) this analysis looks at claims made on the technical and operational feasibility of detecting the tracers effectively at the various supply chain tiers. This allows ecosystem stakeholders to understand if on-site detection processes are tier specific due to the tracers capabilities. For forensic tracers, the matrix visualisation (see Figure 6) is not relevant as their detection processes are off-site. Of more interest for forensic tracers is the analysis on the sub-element queries.

- IMPLEMENTATION EXPERIENCE:
  This analysis also attempts to bring visibility to the experience of the tracer companies implementing the detection process on the supply chain floor. In order to detect a tracer effectively, accompanying detection technologies need to be implemented with supply chain partners. Therefore effective change management is needed to fully engage the supply chain in the implementation of detection processes on the production floor.

- USEFULNESS OF DETECTING MIXING AND BLENDING/FIBRE QUANTIFICATION:
  Key is also to understand the extent to which tracers can quantify different fibres when mixing and blending occurs. This allows the user to identify fabrics and products that have non-verified fibres within, and can be useful for sustainability standards and certification requirements which have a minimum percentage of organic/recycled material (e.g. GRS/RCS)

Appendix

What is included in "Supply Chain Coverage: Detection" analysis

- MATRIX TABLE OF TRACERS' DETECTION CAPABILITIES PER SUPPLY CHAIN TIER
  See Figure 7 for a visual benchmarking of detection capabilities per tracer technology, per supply chain step.

- INTERIM CONCLUSIONS AND ANALYSIS AGGREGATIONS
  Based on these claims made by the tracer companies, aggregated conclusions and key takeaways have been scoped per tracer category (forensic tracers, additive tracers), and their sub-tracer categories. See aggregated analysis below.

Shortcomings of "Supply Chain Coverage: Detection" analysis

- DOESN'T ANALYSE TRACER EFFICACY THROUGH FIBRE SPECIFIC MANUFACTURING PROCESSES
  This enquiry topic doesn't bring visibility to the efficacy of the additive tracers through the various fibre-specific Tier 4 and Tier 3 supply chains and associated manufacturing processes. The definition boundaries of Tiers within this matrix table are ambiguous to the fibres they cover. Please see Figure 5 Fibre Use Cases for better segmentation per fibre type for tracer's claimed capabilities.

Image courtesy of Unsplash

About the Tracer Companies

Below are descriptions of the tracer companies interviewed and their associated tracer technologies:

FORENSIC TRACERS

Oritain

Oritain uses forensic science to test the geochemical composition of a material, which is unique to the place it is grown. The detected isotopes and trace elements are interpreted to produce a one-of-a-kind "origin fingerprint" allowing them to detect where the fibres and materials come from. Oritain's testing mechanism does not rely on packaging, paper-based methods of traceability, tracer particles, or data integrity. Oritain tests can be carried out at various points of the supply chain.

Website: https://oritain.com/

Contact:
Isabella Sainty
info@oritain.com

Source Certain International (Company)

SW Trace® (tracer technology)

Source Certain International's SW Trace® is a scientific method for establishing the provenance of a product. Every fibre and material, whether natural or synthetic, carries a unique chemical signature. SW Trace® determines the chemical signature of the fibre and material, which reflects the geographical location in which a product was grown and/or the system by which it was produced.

Website: https://www.sourcecertain.com/

Contact:
Nathan Dubrich
info@sourcecertain.com

About the Tracer Companies

Picarro

Picarro provides solutions to measure greenhouse gas (GHG) concentrations, trace gases and stable isotopes (chemical isotopes that are not radioactive, and they do not decay spontaneously with time) across many scientific applications and industrial markets.

Website: https://www.picarro.com/

Contact:
Peter Swinkels
info@picarro.com

DNA Gensee

DNA Gensee is a biotechnology laboratory that allows the identification of plant species present in raw materials, ingredients and finished products from the plant DNA available in the samples.

Website: https://www.dnagensee.com/en/

Contact:
Nelly Dubrulle
info@dnagensee.com

IdentiGEN (Company)

DNA TraceBack® (tracer technology)
DNA TraceBack® by IdentiGEN combines DNA, and data analytics, to provide evidence-based traceability of fibres and materials back to the farm level.

Website:
https://www.identigen.com/

Contact:
Ronan Loftus
https://www.identigen.com/Home/Contact

About the Tracer Companies

ADDITIVE TRACERS

Safetraces (Company)
miniDART® (tracer technology)
Safetraces use DNA to tag and trace fibres and materials. Their miniDART® solution allows item-level traceability using edible, invisible non-GMO naturally derived DNA that is injected into the fibres and materials. Their saniTracer™ solution is a food-safe DNA-tagged particle engineered to behave like pathogens during cleaning and sanitation.

Website: https://www.safetraces.com/

Contact:
Erik Malmstrom
info@safetraces.com

ADNAS (Company)
CertainT® (tracer technology)
Applied DNA Sciences (ADNAS) is a producer of DNA sequences using polymerase chain reaction (PCR) technology. ADNAS provides supply chain authentication and intellectual property protection solutions to industries including textiles, apparel, footwear, leather, food and agricultural products, semiconductors, pharmaceuticals, fertilisers, printing, and packaging. Applied DNA's CertainT® platform provides supply chain integrity and brand protection to industry. For cotton, CertainT® has three technology pillars (SigNature® T tagging (artificial DNA tagging), genotyping (DNA analysis) and isotopes) that enable authentication of cotton at all stages of the supply chain and are tracked in a cloud database.

Website: https://adnas.com/

Contact:
MeiLin Wan
info@adnas.com

About the Tracer Companies

UNIFI

UNIFI uses a chemical tracer in their REPREVE rPET yarn that resists physical transformation until the final garment. The garment can be tested at the retail level in a laboratory to see what volume of REPREVE has been used in the final product.

Website: https://unifi.com/

Contact:
James Cooper
https://unifi.com/contact

Haelixa

Haelixa provides DNA markers that can be applied to a wide range of materials. They capture a unique DNA sequence in an inorganic matrix that protects DNA from harsh textile processing conditions and can be sprayed onto commodities. The markers can be verified at any point of the supply chain through a quick DNA test on either intermediate or finished textile products. As well as textile and apparel, they operate in diamonds, coloured stones and gold.[30]

Website: https://www.haelixa.com/

Contact:
Gediminas Mikutis
info@haelixa.com

Olnica

Developed from rare earth materials with 1.3 billion signatories, Olinica's taggant tracer is a chemical compound that is resistant to high heat and manufacturing conditions. It can either be integrated into the material itself, or integrated into an invisible marking ink onto the product. Detection mechanisms can be inline (Olinica sensor), or handheld and portable (Olinica flashlight), both using ultraviolet B-ray (UVB) technology.

Website: https://olnica.com/system/olnica-invisible-taggant/

Contact:
Julian Ansoult
https://olnica.com/contact/

About the Tracer Companies

Tailorlux (Company)
IntegriTEX® (tracer technology)
Tailourlux's IntegriTEX® tracing technology creates customised tracer substances based on inorganic materials. Proprietary sensor mechanisms can be used in-line and handheld to ensure material integrity at every stage of the supply chain. They provide tracer fibres, masterbatches, slurries and dispersions for various fibre manufacturers and traceability systems.[31]

Website: https://www.tailorlux.com/en/

Contact:
Tobias Herzog
info@tailorlux.com

In-Code Technologies
IN-Code Technologies and partners, are a supplier of on-fibre traceable solutions in the textile sector with physical tracing and digitisation of feedstock for fibres and materials.[32]

In-Code have two core technologies, both of which are capable of digital traceability also and are cost compliant:

IN-Codes: Cost efficient invisible nano-particle tracers applied at the farm or throughout as needed that are analysed by a 'rapid onsite test' and verified off-site by spectroscopy to provide unique batch IDs. They can be applied manually (sprayer), mechanically (in-line) or added to liquids pre-production for synthetic fibres and dyes. These tracers also provide invaluable at guaranteeing recycled feedstock lineage.

Li-Codes: optical tracers that are embedded within the fibres through to retail. These tracer fibres are applied to cotton in the ginner stage or at the production phase of recycled materials, and can also be added to liquids pre-production for synthetic fibres and dyes.

Website: http://in-code.uk/

Contact:
Joe Tilley
info@in-code.uk

About the Tracer Companies

Stardust Secured (Company)
StarUltraV™ (tracer technology)
Stardust Secured™ develops, manufactures, and supplies proprietary covert security solutions and supplies inorganic fluorescent tracers globally, protecting the authenticity of financial instruments, tax-stamps, textiles, leather, goose down, amongst other items.

The technology is a two-part system:
1) Covert security tracers called Stardust® which become inextricable from raw materials or physical goods.
2) Customisable Stardust® detectors for production, processing, sorting, in-line quality control, in-field authentication, and supply chain traceability.

Website: https://www.stardustus.com/

Contact:
Adam Herbenson
https://www.stardustus.com/contact-us/

Chromition (company)
Luminspheres™ (tracer technology)
Chromition uses Luminspheres™ that can be tuned into any wavelength to produce unique, identifiable barcodes of light. These Luminspheres™ fluoresce when irradiated with monochromatic light of a slide imager. This innovation can be leveraged for use in textiles with an instant reproducible test to identify fibres, dyes and chemicals throughout the supply chain.

Website: https://www.chromition.com/

Contact:
Alan Jackson
https://www.chromition.com/contact.html

About the Tracer Companies

FibreTrace®
FibreTrace® allows brands and suppliers to trace and verify textile fibres from source to store and beyond. Also providing fibre quantification and primary farm impact data, they offer a physical tracer that uses fluorescent technology to mark fibres and determine origin.

Website: https://www.fibretrace.io/

Contact:
Crispin Argento
https://www.fibretrace.io/contact

Digimarc
Digimarc offers digital watermarks and serialised optical fingerprints to increase the recyclability of plastics and improve the sustainability and functionality of packaging portfolios and commodities. Imperceptible to the eye, but readable by smart phones and tablets, the Digimarc barcodes itself the passport of the product ensuring traceability.

Website: https://www.digimarc.com/

Contact:
Gloria Adeboi
https://www.digimarc.com/contact-us

Arylla
Arylla uses a digital taggant ink to print invisible codes onto products. These codes are readable using a phone or table without the need for a special device. The decryption software is an API, which integrates with third party software to offer different types of customer experiences, fight counterfeiting, and improve traceability. Label printers and garment manufacturers use digital printers to apply Arylla's ink onto labels and products before shipping them to the factory or distribution centre. The technology is used as a secure and lower cost alternative to QR/NFC.

Website: https://www.arylla.com/

Contact:
Perry Everett
contact@arylla.com

Contact Details

Tracer companies wanting to be included in the Textile Tracer Assessment, and industry players wanting additional information, please contact:

Fashion for Good
connect@fashionforgood.com

From all at Fashion for Good and Textile Exchange, we thank you for taking the time to read the Textile Tracer Assessment and your interest in traceability and sustainability within the textile industry.

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16 Such as corporate due diligence legislation and regulations such as The Uyghur Forced Labor Prevention Act and the proposed European Union Ecodesign For Sustainable Products.
17 https://textileexchange.org/tetrackit/ These traceability programmes are work in progress
18 Not only fashion-focused: Sll forensic tracer companies interviewed also worked in other industries beyond fashion and textiles (agri-food, minerals etc).
19 Mostly fashion-focused: the majority of the additive tracer companies interviewed worked only in the fashion and textiles sector at the time of research.
20 It should be well noted that ADNAS also have the capability to provide isotopic and DNA analysis of fibres and materials, alongside their artificial DNA additive tracer.
21 See Trustrace's traceability playbook for further insight into digital traceability approaches, solutions, and innovations: https://trustrace.com/traceability-playbook?utm_source=ppc&utm_medium=linkedinads&utm_campaign=sponsoredpost
22 That said, this is a very underdeveloped capability for forensic tracers whose main focus remains for proving geographic origin of plant and animal fibres.
23 It should be well noted that forensic tracer companies can have the capability to carry out more than one type of micro-particle analysis e.g. Oritain, SourceCertain International can perform analysis on both ratios of stable isotopes and analysis of trace meddles (see glossary).
24 This form of offsite micro-particle analysis should not be confused with a similar process for forensic tracers. This refers to detection analysis of synthetic/artificial DNA additive tracers, added to fibres, materials, and/or garments and detected later in the supply chain. Not analysis of natural bio-chemical properties of the fibres, materials, and/or garments (Isotope ratios, elemental meddles, natural DNA) that is taken out by forensic tracers.
25 To understand the specific capabilities of detecting the mixing and blending of fibres (and/or

References

fibre quantification), the user should explore further directly with the additive tracer technology of interest. Fibre quantification is a much desired use case for physical verification of sustainable fibre types within a mix/blend, but still in the research and development stage for many additive tracer technologies.

26 E.g. Supima cotton: https://www.innovationintextiles.com/oritain-maps-supima-cotton-origin/, and CertainT® cotton https://sourcingjournal.com/topics/compliance/applied-dna-services-cotton-traceability-xinjiang-uyghur-forced-labor-isotech-348286/

27 It is important to note that provenance databases (records of the biochemical properties of natural fibres needed for verification cross-checking) need to be constantly updated by the forensic tracer company to account for changing isotopic ratios and elemental meddles at the origin for the natural fibres in scope of verification.

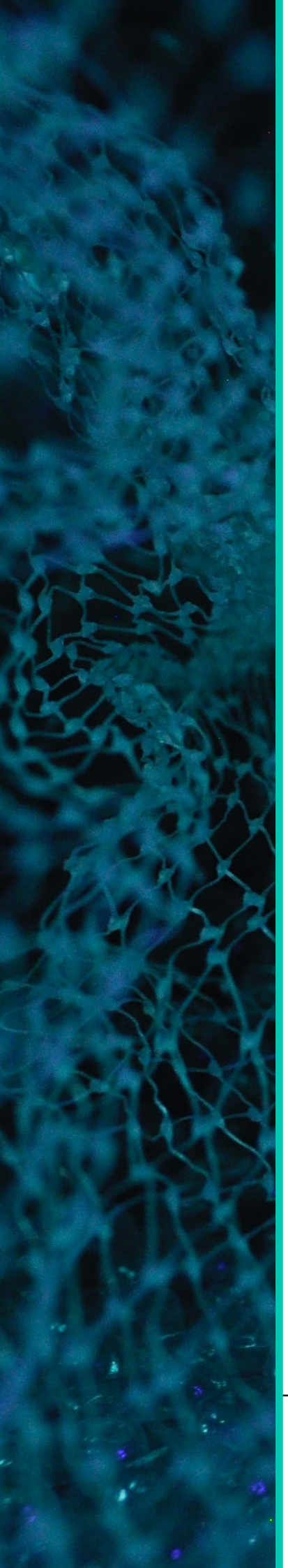
28 This tracer efficacy depends on where the additive tracer is applied, and where the user wishes to detect it. As a reminder, Fashion for Good did not test the efficacy of tracers sustaining through manufacturing processes (or any similar tests).

29 Independent party verification is still needed for cross referencing additive tracer substances and their unique composition signatories, to ensure "lock and key" detection mechanisms are verified externally. Critically speaking, relying on the tracer company itself to verify "lock and key" detection mechanism and tracer substance composition signatures can be questioned if not validated by an independent party.

30 Haelixa's tracer technology took part in Fashion for Good's Organic Cotton Traceability Pilot.

31 Tailorlux's tracer technology took part in Fashion for Good's Organic Cotton Traceability Pilot.

32 IN-Code's tracer technology took part in Fashion for Good's Organic Cotton Traceability Pilot.



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