MADITRACE

Reference architecture Model

Deliverable D3.2

Version N°1.1

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Summary

This document establishes a comprehensive framework for digital traceability in the critical raw materials (CRM) supply chain, focusing on secure, verifiable data management to ensure transparency, accountability, and sustainability. It outlines the implementation of a Digital Product Passport (DPP), leveraging blockchain, distributed ledger technologies (DLTs), and Life Cycle Assessment (LCA) to meet regulatory and industry standards. Key topics include CRM certification, environmental compliance, material fingerprinting, risk assessment using the P.A.S.T.A. methodology, and the creation of a unified Digital Materials Passport Data Model.

Keywords

Digital Product Passport, , material Fingerprint, LCA, blockchain, traceability

Abbreviations and acronyms

DID	Decentralized Identity
VC	Verifiable Credentials
EBSI	European Blockchain Service Infrastructure
NFT	Non-Fungible Token
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory

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1 Introduction

This document provides the essential basis for establishing a framework for digital traceability across the supply chain of critical raw materials (CRMs), focusing on secure and verifiable data management to ensure transparency, accountability, and sustainability. It provides a standardized and sustainable approach to CRM certification by addressing the core pillars of traceability, data integrity, and environmental compliance across the CRM supply chain.

As supply chains become increasingly global and complex, the need for advanced digital tools that promote transparency at each stage— from extraction to recycling—has become critical and requested by certain actors. This document, therefore, outlines a structured approach for implementing a "Digital Product Passport" (DPP), which leverages sophisticated data management and verification techniques to meet both regulatory and industry standards. A central focus of the document is on technological integration, particularly with blockchain and distributed ledger technologies (DLTs), which enable secure and immutable data recording across the supply chain. To provide actionable insights, the document examines various existing DPP projects, analyzing their approaches to technology selection, data security, and interoperability challenges, offering a broad perspective on current and emerging best practices.

The document also examines the integration of Life Cycle Assessment (LCA) into DPPs to assess environmental impacts, such as carbon footprints, across product lifecycles. This includes an analysis of the European Union's Battery Regulation, which underscores the regulatory depth required for DPPs to meet environmental accountability standards effectively. Moreover, the document maps the CRM supply chain, identifying key stakeholders and outlining each process stage to highlight critical points where data verification is essential. An initial architectural framework defines how the Reference Architecture Model interlinks with other project deliverables, fostering a cohesive pathway from conceptualization to implementation.

In addition, we present the key considerations for implementing Material Checkpoints (MCs) in supply chains, focusing on the importance of understanding supply chain characteristics, geographic material flows, and the role of various actors. Additionally, we discuss the necessity of a scalable material fingerprinting database for verifying material origins, highlighting its role in detecting anomalies, ensuring compliance, and supporting traceability through natural or artificial fingerprinting methods.

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Moreover, given the complexity and inherent risks of digital traceability, a dedicated section on security employs the P.A.S.T.A. (Process for Attack Simulation and Threat Analysis) methodology, providing a structured approach to risk assessment, detailing specific threats, vulnerabilities, and recommended mitigation strategies.

Finally, the document introduces the basis needed to propose a Digital Materials Passport Data Model, aimed at creating a unified, transparent CRM data repository that strengthens traceability and compliance across industries.

2 Literature Review

2.1 Detailed Battery DPP Project Profiles: Overview and Technological Exploration

2.1.1 Methodology

2.1.1.1 Projects selection

Most of the projects analyzed in this study were derived from the CIRPASS initiative[1.] From the comprehensive list provided by CIRPASS, projects explicitly citing batteries as a focal area of their activity were predominantly selected for detailed examination. Additionally, two projects, Catena-µX and Un/Cefact, were incorporated into the analysis due to their perceived significance, despite not being directly comparable to other more solution-oriented projects included in the study.

It is crucial to recognize that the project profiles in the CIRPASS report primarily consist of summaries directly supplied by the organizations spearheading the initiatives, with the CIRPASS consortium making little to no modifications to these submissions. In contrast to CIRPASS's reliance on provided content, this study has supplemented those summaries by conducting independent research, particularly focusing on the technological details of the implementations. This approach aims to enhance the depth and breadth of understanding regarding each project’s technological scope and its impact within the sector.

Disclaimer form CIRPASS Report [1]:

"*Please note that the information contained in these summary profiles was provided by the organisations responsible for the initiatives. Minimal, if at all, editing is performed by the CIRPASS consortium on the contributions received.*"

2.1.1.2 Our work vs Cirpass approach

Below is a comparative table between the two approaches:

Metric	Our Work	CIRPASS
Focus and Scope	Focuses specifically on battery-related DPP projects, detailing technological explorations and practical applications.	Presents a general classification framework for benchmarking various DPP systems across multiple sectors.
Source of Information	Conducts independent research to supplement the data provided within CIRPASS, specifically delving into the detailed technological aspects of each project's implementation	Relies on information provided by the organizations responsible for the DPP initiatives, with minimal editing by CIRPASS consortium.
Technological Details	Provides specific details on technologies like blockchain, GS1 Digital Link standard, and other interoperable solutions.	Provides a broad overview of various data carriers, IT architectures, and both centralized and decentralized data storage without focusing on specific technologies.

In summary, our work is more project-specific and detailed regarding the practical implementation of DPP technologies in the battery industry, whereas the CIRPASS approach provides a broader theoretical framework that outlines essential elements of DPP systems applicable across various sectors.

[1] https://cirpassproject.eu/wp-content/uploads/2024/03/CIRPASS-D3.1-Annex-V9_final.pdf

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2.1.1.3 Analysis metrics

We provide a “global overview” of each selected project followed by a “Technology Deep-Dive” where we explore the specific technical implementations and solutions, based on the available information. (Check Appendix A for complete results)

The main comparison metrics used across these projects can be outlined as follows:

1. Underlying Technology

The foundational technology used by each project, such as blockchain, Distributed Ledger Technology (DLT), or cloud services (e.g., AWS).

2. Data Integrity and Security

Methods ensuring the immutability, security, and authenticity of data. This includes the use of blockchain for decentralized security or compliance with standards like SOC 2.

3. Interoperability

The ability of the system to integrate and communicate with other systems, often using global standards like GS1 Digital Link or EPCIS 2.0.

4. Data Privacy Compliance

Adherence to data privacy regulations such as GDPR, and how each platform handles user data securely and compliantly.

5. User Accessibility and Interface

The usability of the platform's interface, including user-friendly applications, single sign-on (SSO), or multi-factor authentication (MFA).

6. Environmental Impact and Sustainability

How the project promotes sustainability, whether through low-carbon operations, recycling initiatives, or alignment with environmental goals like the EU Battery Directive, or adherence to due diligence practices in sourcing and operations.

7. Regulatory Compliance

Adherence to international or local regulations and standards, such as EU standards or specific technology compliance like ERC-721 for NFTs.

8. Market Adoption and Ecosystem

The extent of market adoption, demonstrated by partnerships or industry collaborations, and how well the project integrates with existing ecosystems.

9. Innovation and Adaptability

The innovation presented by the project, including its potential for scalability, adaptability to future trends, or unique technological approaches.

10. Cost-Effectiveness

Considerations of the cost-effectiveness of the solution, either through reduced lifecycle costs or specific pricing models like "pay per use."

11. Centralized/Decentralized Structure

Whether the project's governance or technology infrastructure is centralized or decentralized, impacting how control and operations are distributed.

2.1.2 Outline of Interesting Results

This section outlines the key findings from an analysis of the DPP projects considered above, highlighting interesting results and outcomes that are particularly relevant to the development of digital product passports for batteries. The analysis focuses on aspects such as underlying technology, data integrity and security, interoperability, user accessibility, blockchain use, digital identity verification, data privacy compliance, and AI and IoT integration. These findings provide a comprehensive overview of the current landscape and potential future directions for DPP implementations in the battery industry.

2.1.2.1 Centralized Solutions

Some projects prefer centralized solutions for easier data management and integration with existing systems, ensuring control and scalability.

Examples:

- **Assent Inc.** uses AWS for hosting its compliance platform.
- **Circular Passport** utilizes centralized cloud services through the 3DEXPERIENCE platform for data and lifecycle management.
- **Information for recyclers platform**: have a centralized data repository. Web-based platform with secured access, hosting detailed product data for recyclers.
- **OK Supply Chain Management platform**: centralized platform using QR codes, barcodes, and AI and centralized management and automated documentation
- **Vine**: centralized cloud services

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2.1.2.2 Use of Distributed Ledger Technology (DLT) and Blockchain:

Definitions:
DLT (Distributed Ledger Technology):
A system of digital records shared across multiple computers (nodes) in a network. Each node has a copy of the ledger, and updates are made through consensus among the nodes. It ensures transparency, security, and decentralization. Blockchain is one type of DLT.

Blockchain Technology:
A specific type of DLT where data is stored in blocks that are cryptographically linked in a linear, chronological chain. This ensures immutability and security but can have limitations in speed and scalability.

Many digital product passport projects leverage DLT and/or blockchain technologies to ensure the integrity, security, and transparency of the data. These technologies provide a decentralized method to record and verify information, which is crucial for maintaining trust and preventing fraud. While centralized systems managed by a neutral agency may seem viable, they are prone to single points of failure (SPF), making them less resilient compared to decentralized solutions.

Definitions:
IOTA[2]:
IOTA is a type of Distributed Ledger Technology (DLT) designed specifically for the ***Internet of Things (IoT)****. Unlike traditional blockchains, IOTA does not use a chain of blocks to record transactions. Instead, it relies on a unique data structure called the* ***Tangle****, which is a Directed Acyclic Graph (DAG).*

Ethereum[3]*:*
Ethereum is a ***blockchain-based platform*** *designed to support decentralized applications (dApps) and smart contracts. It extends the functionality of traditional blockchains like Bitcoin, which are primarily used for financial transactions, by allowing programmable logic to be executed directly on the blockchain.*

Hyperledger Fabric[4]:
Hyperledger Fabric is a ***permissioned blockchain framework*** *developed by the Linux Foundation as part of the Hyperledger project. It is specifically designed for enterprise applications, offering modularity and flexibility to support a variety of use cases, such as supply chain management, healthcare, and finance.*

Energy Web Chain (EWC)[5]:
The ***Energy Web Chain (EWC)*** *is a public, open-source blockchain based on Ethereum, specifically designed to accelerate the transition to a decentralized, decarbonized, and democratized energy system. It is tailored to the needs of the energy sector, enabling applications such as renewable energy certificate tracking, grid flexibility, and energy trading.*

[2] https://www.iota.org/
[3] https://ethereum.org/fr/
[4] https://www.hyperledger.org/
[5] https://www.energyweb.org/

XCEED[6]:
*The **XCEED platform** (eXtended Compliance End-to-End Distributed) is a **blockchain-based solution** developed for the **automotive industry** to enhance compliance, traceability, and transparency across the supply chain. It was developed by a consortium of automotive manufacturers and suppliers, including Renault Group, with the goal of addressing regulatory requirements and ensuring the secure exchange of compliance data.*

Blockchains Used and Their Occurrences:

1. **IOTA**
   - **Projects**: "Decentralized Blueprint for Digital Product Passports", IOTA - EBSI PCP
   - **Occurrences**: 2
1. **Ethereum**
   - **Projects**: Arianee[7], Circularise[8], Minespider AG[9]
   - **Occurrences**: 3
1. **Hyperledger Fabric**
   - **Projects**: Circulor[10]
   - **Occurrences**: 1
2. **Energy Web Chain (EWC) (Ethereum based)**
   - **Projects**: EASYBAT[11]
   - **Occurrences**: 1
3. **XCEED platform (Hyperledger Fabric based)**
   - **Projects**: Optel Group (XCEED platform)[12]
   - **Occurrences**: 1
4. **Not Available (General Blockchain Use)**
   - **Projects**: Lynx Technologies[13], whatt.io[14], FREE4LIB[15]
   - **Occurrences**: 3

[6] https://media.renaultgroup.com/xceed-the-new-blockchain-solution-for-the-certification-of-vehicle-compliance-is-moving-a-step-further-in-europe/
[7] https://www.arianee.com/
[8] https://www.circularise.com/
[9] https://www.minespider.com/about-us
[10] https://www.circulor.com/solutions
[11] https://bebat.prezly.com/bebat-et-fluvius-lancent--easybat--pour-mieux-suivre-le-cycle-de-vie-des-batteries-via-la-blockchain
[12] https://www.optelgroup.com/en/solution/digital-product-passport/
[13] https://www.lynx.swiss/
[14] https://whatt.io/
[15] https://www.freeforlib.eu/about-the-project

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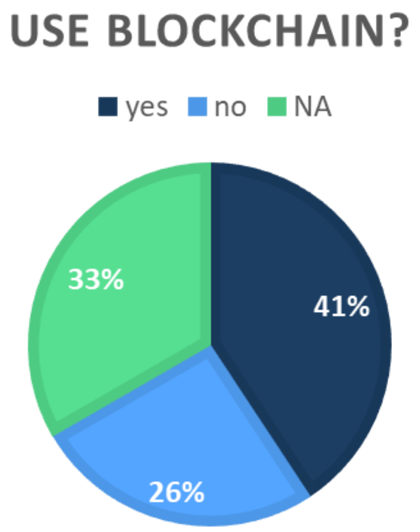

Figure 1 – The usage rate of blockchain in Battery DPP projects

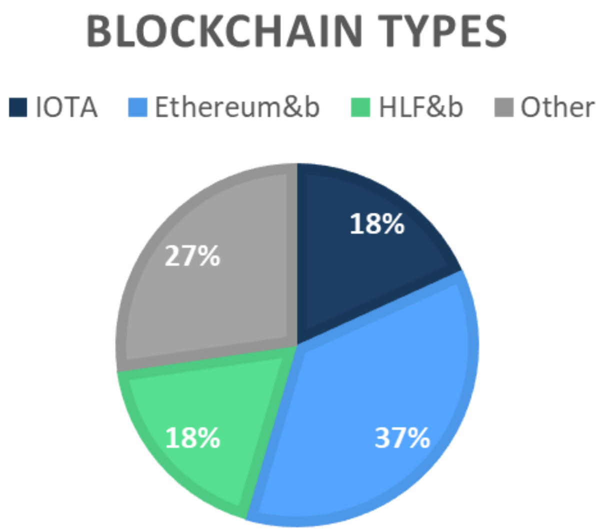

Figure 2 – The usage rate by blockchain types

Our findings depicted in Figure 1 – The usage rate of blockchain in Battery DPP projectsFigure 1 and Figure 3 reveal that 41% of the battery-focused projects utilize blockchain technology, while 26% do not, and 33% have not specified its usage (we could not find the information). Among those employing blockchain, 37% rely on Ethereum-based solutions, 27% utilize other blockchain platforms, with both IOTA and Hyperledger Fabric accounting for 18% each.

2.1.2.3 Data Integrity and Security

Ensuring data integrity and security is paramount. Projects often implement various compliance measures and technologies to protect data against unauthorized access and ensure its accuracy.

Examples:

- Solutions like IOTA and Assent Inc. implement robust security measures, including immutability and compliance with “Service Organization Control 2“(SOC 2)[16] and General Data Protection Regulation) (GDPR)[17] standards.
- Authentic Vision's MetaAnchor[18] provides a highly secure patented holographic fingerprint technology.
- Digimarc’s Illuminate Platform[19], anchor events to the blockchain for data integrity.

2.1.2.4 Interoperability

Interoperability is a key feature, allowing digital product passports to be used across different systems and industries. This is often achieved through the adoption of global standards.

Examples

- The "Decentralized Blueprint" employs GS1 Digital Link[20] and EPCIS 2.0[21] standards to ensure broad interoperability.
- Arianee[22] focuses on global open standards to facilitate compatibility with various industry platforms.

2.1.2.5 User Accessibility and Interface

User-friendly interfaces and accessibility features are critical for widespread adoption. Projects often include web and mobile applications, as well as features like single sign-on (SSO) and multi-factor authentication.

Examples

- Many solutions prioritize user-friendly interfaces, with features like single sign-on (SSO) and multi-factor authentication for enhanced security.
- Web and mobile applications are commonly provided to facilitate easy access to digital product passports.

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16 https://www.schellman.com/blog/soc-examinations/what-are-soc-reports
17 https://www.consilium.europa.eu/en/policies/data-protection/data-protection-regulation/#gdpr
18 https://www.authenticvision.com/
19 https://www.digimarc.com/blog/decentralized-blueprint-digital-product-passports
20 https://www.gs1.org/about
21 https://ref.gs1.org/standards/epcis/
22 https://www.arianee.com/

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2.1.2.6 Digital Identity Verification

Verifying the digital identity of products and users is a common feature. This often involves the use of Decentralized Identifiers (DIDs) and Verifiable Credentials.

Examples

- Implementations like IOTA's DIDs (Decentralized Identifiers) and Verifiable Credentials are highlighted for identity verification.
- Arianee employs KYC (Know Your Customer) processes for verifying digital identities.

2.1.2.7 Data Privacy Compliance

Compliance with data privacy regulations, such as GDPR applicable in the EU or equivalent regulations, is essential. Projects highlight their adherence to these standards to build trust and ensure legal compliance.

Examples

- GDPR compliance is a critical factor, with projects like Assent Inc. demonstrating strong measures for data privacy.
- However, some projects do not detail their GDPR compliance strategies, which could be a potential concern.

2.1.2.8 IoT Integration:

Integration with IoT (Internet of Things) devices enhances the functionality of digital product passports by facilitating real-time data collection and connectivity.

Examples

- The "Decentralized Blueprint" project integrates IoT to enhance connectivity and data acquisition, although this feature is not universally mentioned across all solutions.
- **Cyclance**[23]: GS1 and epics standards let enterprises adapt the system to their use case. The use of IoT devices for data capture.
- **Optel Group**[24]**:** employs IoT technologies for real-time tracking of physical assets.

2.1.2.9 AI and Data Analytics

AI and data analytics are increasingly integrated into digital product passport projects to

[23] http://european-epc-competence-center.eu/?news=132
[24] https://www.optelgroup.com/en/solution/digital-product-passport

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enhance decision-making, predictive maintenance, and data insights.

Examples

- Circulor uses Machine learning in the form of image analysis is used to detect, analyse and compare faces to verify authorized users of the platform,
- Digimarc's Illuminate Platform includes AI/data analytics features to optimize resource use and reduce waste. Actually, Artificial Intelligence (AI) has demonstrated significant potential in optimizing resource use and reducing waste across various industries. For instance, AI-powered systems have been employed to enhance waste management processes, leading to more efficient recycling and reduced environmental impact.[25] A notable application of this technology is **Digimarc Recycle**, a system that employs digital watermarks to improve the accuracy of sorting packaging waste[26].
- Lynx Technologies : Early anomaly detection, Performance indicators, Components batch overview
- Optel Group: Utilizes AI for centralized analytics and real-time data visualization, enhancing supply chain visibility
- OK Supply Chain[27] : Auto-generated quality insights and reports.

2.1.2.10 Environmental Impact and Sustainability

Some projects aim to promote eco-friendly practices, ensure compliance with environmental regulations, and support the transition to a low-carbon economy.

Solutions Helping Environmental Impact and Sustainability

1. **Promoting Sustainability and Recycling**:

Many projects emphasize promoting sustainability and recycling through transparency and lifecycle management, facilitating a circular economy and waste reduction.

Examples:

- **Circularise[28]**: Develops a platform for supply chain traceability, enabling companies to track materials and products to ensure compliance and sustainability.

[25] https://aiforgood.itu.int/revolutionizing-waste-management-the-role-of-ai-in-building-sustainable-practices/
[26] https://www.digimarc.com/press-releases/2022/03/30/digimarc-digital-watermarks-proven-achieve-more-accurate-sorting
[27] https://oktrade.org/
[28] https://www.circularise.com/

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- **CircThread**[29]: An EU-funded project aimed at creating a digital thread of information to support circular economy strategies, particularly in the management of appliances.

2. **Regulatory Compliance**:

Many projects focus on compliance with environmental, safety, and governance regulations such as PFAS, REACH, SCIP, due diligence and ESG, contributing to overall environmental sustainability.

Examples:

- **Assent Inc.**: Assent Inc. actively integrates Environmental, Social, and Governance (ESG) considerations into its operations and services. The company offers a comprehensive ESG reporting solution tailored for complex manufacturing supply chains, assisting businesses in managing and reporting on ESG metrics[30].
- **Minespider AG**: Provides a supply chain traceability solution that enables businesses to capture data for due diligence, carbon emission reduction, and ESG purposes[31]
- **Circulor**[32]: provides solutions for compliance with global regulations like ESG as well.
- **Vine**[33] is a due diligence platform that allows suppliers to measure and improve their ESG (Environmental, social, and governance) performance within battery supply chains.

3. **Traceability and Authenticity**:

Technologies for traceability and authenticity, such as anti-counterfeiting tools and verification of sustainable sourcing, help reduce environmental impact by ensuring efficient resource use.

Examples:

- **Authentic Vision MetaAnchor**[34]: Provides anti-counterfeiting technology to ensure product authenticity.
- **Battery Pass**[35]: Enhances traceability of battery components, supporting the transition to low-carbon mobility and efficient recycling of battery materials.
- TilKal[36]: Proposes traceability solutions associated to a Responsible Mica Initiative; a responsible mining initiative interested only in one mineral supply chain: micas.

29 https://circthread.com/
30 https://www.assent.com/fr/solutions/esg/
31 https://www.minespider.com/
32 https://circulor.com/fr
33 https://www.rcsglobal.com/vine-platform/
34 https://www.authenticvision.com/
35 https://sustainableindustrialmanufacturing.com/europe/news/world-first-battery-pass-project/
36 https://www.tilkal.com/

Solutions with Reduced Own Environmental Impact

Certain solutions work on their own architecture to reduce energy consumption and carbon footprint, like Arianee.

Arianee[37] operates on two Ethereum side chains utilizing both Proof-of-Stake (PoS) through Polygon and Proof-of-Authority (PoA) consensus mechanisms. These methods are highly efficient in terms of energy consumption. According to an internal audit of their carbon and energy footprint, Arianee's operations demonstrate a remarkably low environmental impact. Specifically, even if Arianee were to create 200 million NFTs within a single year, their carbon footprint would only amount to 25% of the annual emissions of an average French family. This efficiency highlights Arianee's commitment to sustainability while leveraging advanced blockchain technology to ensure product authenticity and traceability in a sustainable manner.

2.1.2.11 Innovation and Adaptability

Some projects highlight their innovative approaches and adaptability to emerging technologies and industry demands, ensuring robust and future-proof solutions.

Technological Innovations

1. Tokenization and Smart Contracts : **Arianee**: Introduces innovative approaches such as tokenization and the use of smart contracts for managing digital identities and product authenticity.
2. **Patented Technology : Authentic Vision MetaAnchor**: Showcases innovation through its patented technology for anti-counterfeiting, enhancing product security and authenticity.
3. Marketplaces: **CircThread**: Introduces an innovative 'information broker' marketplace and digital identity for products, showing high potential for scalability and adaptation to future circular economy needs.
4. Digital twin technology: **Circular Pass (Dassault)**: Uses the 3DEXPERIENCE platform, integrating virtual twin technology and a model-based approach for end-to-end battery lifecycle management.
5. Smart Questioning Technology: **Circularise**: Introduces innovative features such as Smart Questioning technology, which enables stakeholders to verify sustainability claims without disclosing sensitive information.

[37] https://www.arianee.com/digital-product-passport

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6. AI integration: **OK Supply Chain Management Platform**: Currently building AI tools to empower all organizations using the platform, respecting and understanding the value, nature, and sensitivity of the data.
7. IoT Integration: **Cyclance**: GS1 and epics standards let enterprises adapt the system to their use case. The use of IoT devices for data capture.
8. Recycling Technologies: **FREE4LIB**: Innovative in developing new recycling technologies and adaptable in process optimization.
9. Open Standards: **Spherity**[38]: Based on open standards and adaptable to various industry requirements
10. CE-RISE: an Horizon Europe project with the participation of Circularise, working in the integration of circular economy topics such as re-use, refurbishment, recycling in DPP.

2.1.3 Analysis

In the following sections, we will present the key findings based on the use of Distributed Ledger Technology (DLT) in Digital Product Passport projects.

1. **Dominance of Ethereum:**

Finding: Ethereum is one of the most frequently used blockchains across the surveyed projects, appearing in multiple forms such as public Ethereum, Ethereum-compatible blockchains, and specific implementations like the Energy Web Chain (EWC).

Implication: Ethereum's versatility and widespread acceptance make it a preferred choice for digital product passports. Its robust ecosystem, including smart contracts and NFTs, provides comprehensive solutions for digital identity, data integrity, and transaction automation. Projects such as Arianee, Circularise, and Minespider AG leverage Ethereum's capabilities, highlighting its role in facilitating transparency and trust in the management of digital product passports.

2. **Specialized Use of IOTA**

Finding: IOTA is notably used in projects focusing on distributed ledger technology (DLT) and IoT integration, such as the "Decentralized Blueprint for Digital Product Passports" and IOTA - EBSI PCP.

[38] https://www.spherity.com/digital-product-passport

Implication: IOTA's Tangle technology, designed for efficient data handling and scalability, makes it suitable for applications requiring high transaction throughput and integration with IoT devices. This is particularly beneficial for real-time tracking and lifecycle management of digital product passports, where continuous data flow and interaction with physical objects are crucial.

3. **Adoption of Hyperledger Fabric**

Finding: Hyperledger Fabric is employed by projects like Circulor for supply chain traceability and data integrity, as well as in the XCEED platform used by Optel Group.

Implication: Hyperledger Fabric's modular architecture and permissioned nature make it ideal for enterprise solutions requiring a high degree of privacy and control over the blockchain environment. Its use indicates a focus on secure and compliant data management within regulated industries, ensuring that sensitive information remains protected while maintaining transparency and traceability.

4. **Emergence of Specialized Blockchains**

Finding: The use of specialized blockchains, such as the Energy Web Chain (EWC) in EASYBAT, highlights the adoption of industry-specific solutions.

Implication: Specialized blockchains tailored to specific industry needs (e.g., energy management in batteries) provide targeted functionalities and optimizations that general-purpose blockchains may lack. This trend indicates a move towards more customized and efficient blockchain solutions, capable of addressing unique industry challenges and enhancing operational efficiency.

2.2 Integration of LCA into DPPs

Life cycle assessment (LCA) is a methodology for evaluating the environmental impacts of products and services throughout their life cycle, from raw material extraction through manufacturing, distribution, use, and end-of-life management (ISO, 2006a, 2006b). LCA is a mainstream tool used by companies and public authorities to support environmentally sound decision-making and is increasingly influential in policy development (Sala et al., 2021), including a key role in the EU Batteries Regulation (Regulation 2023/1542) and the European Critical Raw Materials Act. Given its growing importance, LCA is typically considered in DPP initiatives and concepts, with the depth of its integration primarily determined by the regulatory framework.

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The EU Battery Regulation dictates the information that shall be included in the battery passport (European Parliament, 2023), including the carbon footprint information (*Annex XIII (1)*). Table 1 shows the specific carbon footprint-related information that needs to be included. This information can be categorized into battery carbon footprint information (e.g., the carbon footprint and its breakdown by life cycle stages), technical documentation (e.g., link to the carbon footprint study), and general information (e.g., battery model and geographical location of manufacturing). Ongoing battery passport initiatives such as the Battery Pass consider these attributes (BMWK, 2023).

Table 1. Carbon footprint information to be included in the battery passport as required in the EU Battery Regulation 2023/1542 (*Article 7(1)*)

Data attribute	Data type	Description
Carbon footprint of the battery	Number	Carbon footprint of the battery over its life cycle, equivalent to the aggregation of the carbon footprint of individual life cycle stages
Carbon footprint of the battery per life cycle stage	Strings and numbers	Carbon footprint of the battery differentiated per life cycle stage, including raw material acquisition and pre-processing, manufacturing, distribution, end-of-life and recycling
Carbon footprint performance class	String	Label indicating the carbon footprint performance class that the relevant battery model per manufacturing plant corresponds to
Link to carbon footprint study	String	Web link to the public version of the study supporting the carbon footprint results
Battery model information	String	Information about the battery model for which the carbon footprint study has been performed
Manufacturing location	String	Geographical location of the battery manufacturing plant
Manufacturer information	String	Administrative information about the manufacturer
ID of EU declaration of conformity	String	Identification number of the EU declaration of conformity of the battery

LCA results (e.g., the carbon footprint of a battery) are highly sensitive to methodological choices and assumptions as well as the underlying life cycle inventory (LCI) data (e.g., energy and raw materials consumption and direct emissions to air, water, and soil). Transparent communication of methodological aspects and LCI data is also crucial to ensure that downstream users can accurately interpret and apply the LCA results. Therefore, various value chain actors as well as academic research have highlighted the importance that the DPP system should enable a consistent and transparent reporting of methodological choices and LCI data behind the impact results (Berger et al., 2023; Haupt et al., 2024). Achieving such transparency in reporting would require disclosing more detailed LCA-related information encompassing both qualitative (i.e., methodological assumptions) and quantitative (i.e., inventory) data.

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Table 2 summarizes the main LCA data categories, detailing the specific data attributes, their types, and indicating whether they may involve sensitive information that could rise confidentiality concerns. In the first phase of an LCA, the goal and scope definition, extensive definition of methodological choices and assumptions is performed, which ultimately have a significant impact on the results and conclusions (European Commission, 2010). Ensuring consistent and transparent methodological choices throughout all stages of the supply chain is critical. All methodological choices and assumptions should be thoroughly documented in the report supporting the LCA study and, ideally, reviewed and verified by an independent third party.

Inventory data in LCA is rarely based only on measured (primary) data. Instead, it typically combines primary data, secondary data (e.g., from literature), datasets from commercial LCI databases (background databases), and calculations to fill data gaps. As a result, inventory data includes not only the quantities of input and output flows (such as energy, materials, and emissions) but also comprehensive documentation of processes (e.g., process name, technology used, etc.), input/output flows (e.g., flow name, dataset used to model the supply of the flow, etc.), data sources, calculation assumptions, etc. (Scarcini et al., 2023). For example, the input of electricity might be described by attributes such as the flow name (e.g., electricity, high voltage), unit (e.g., kWh), and the process that supplies it (e.g., the Chinese market for electricity, high voltage). If the electricity supply process is modelled using a dataset from a background LCI database, it is essential to document identifying information for the dataset (e.g., the exact process name, product, and geographical location as specified in the database) along with the database version. Finally, LCA results encompass much more than just the impact results (e.g., the carbon footprint of the battery) and the breakdown of impacts by life cycle stage. They also include the aggregated life cycle inventory results as well as sensitivity and uncertainty analysis results.

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Table 2. Main LCA data categories and data types. Definitions are largely based on the ILCD Handbook (European Commission, 2010) .

LCA data category	Data attribute	Data type	Confidentiality	Definition
Methodological choices	Modelling approach	Strings	Low	Approach followed for modelling the LCI; could be attributional or consequential
	Functional unit	Strings	Low	Quantitative and qualitative description of the product system's function(s), and reference to which the impacts are referred to.
	Reference flow	Strings	Low	Flow to which inputs and outputs quantitatively relate.
	System boundaries	Strings	Low	The system boundaries define which parts of the life cycle and which processes belong to the analyzed system
	Cut-offs	String	Low	The cut-off criteria defines what parts of the product system can be excluded from the system boundaries.
	Selection of impact categories	Strings	Low	Could be, e.g., climate change, acidification, ecotoxicity, etc.
	Selection of impact assessment methods	Strings	Low	The method, and underlying characterization factors, used to translate elementary flows into potential impacts
Inventory data	LCI dataset metadata	Strings	High	This may include dataset name, geographical location, description of the dataset, details of the technology, representativeness of the dataset (e.g., geographical and temporal), etc. For a complete list of metadata descriptors of LCI datasets refer to Scarcini et al., 2023.
	Inputs and outputs flows metadata	Strings & numbers	High	This may include the flow name, unit, name of the upstream process that delivers the flow, and the quantity of the flow
	Secondary datasets metadata	Strings	Low	This refers to datasets obtained from background LCI databases (e.g., ecoinvent). Minimum metadata information to be provided include the exact dataset name, product, and geographical

				location as specified in the database. Additional information that could be included involves a description of the dataset, details of the technology, representativeness of the dataset (e.g., geographical and temporal), etc.
	Multifuntionality approach	Strings	Low	This include the description of the approach followed to solve multifunctionality issues alongside any underlying assumptions
	Data for multifunctionality (e.g., revenues)	Strings & numbers	Medium	Data used for solving multifunctionality issue. It can be, e.g., product-specific revenues used in economic allocation
	Data quality requirements	Strings & numbers	Low	It can involve quantitative, qualitative, and semi-quantitative approaches to determine the quality of the underlying LCI data
Impact results	Life cycle inventory table	Numbers	Low	The life cycle inventory table contains the aggregated elementary flows over the life cycle of the product system
	Impact results	Numbers	Low	It can be, e.g., impacts on climate change, acidification, ecotoxicity, etc.
	Breakdown of impacts	Numbers	Low	It can be the contribution of specific parts of the product system to the total impact (e.g., breakdown by life cycle stage)
	Uncertainty and sensitivity analysis results	Strings & numbers	Low	Additional analyses to test the robustness of the LCA results. It also includes the description of the analysis performed (e.g., type of sensitivity analysis or description of scenarios) as well as all the underlying assumptions

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Achieving the demand for consistency and transparency in the methodology and LCI data would require significantly expanding the LCA-related data integrated into the DPP. Additionally, this level of disclosure raises confidentiality concerns, as the LCI data (e.g., energy consumption of specific processes) is more sensitive than the final LCA results. To address this, ongoing DPP initiatives often provide specific guidelines for conducting the LCA. For example, users of the GBA Battery Passport must calculate the battery carbon footprint according to the GBA GHG Rulebook (Global Battery Alliance, 2023), while the Battery Pass refers to the GBA GHG Rulebook for modelling the cradle-to-gate carbon footprint of batteries plus the Battery Pass for modelling the use and end-of-life stages (BMWK, 2023). The requirements of these guidelines typically include a review and verification process by a third party, although further details on how this information is integrated into the DPP to reach further actors in the value chain are not provided. Certification schemes could also play a role in ensuring that the LCA results incorporated into the DPP system are calculated according to established rules (Figure 3).

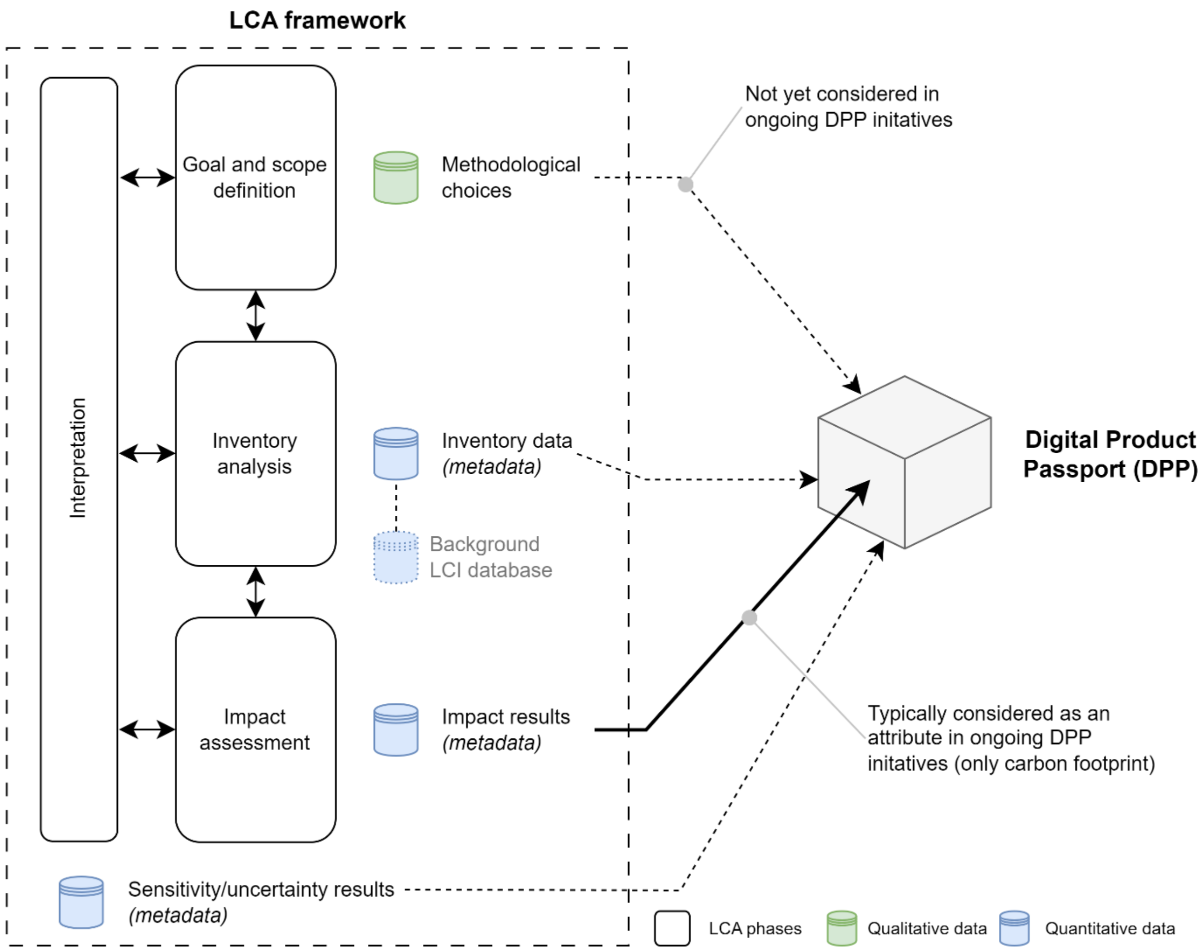

Figure 3. LCA data types and their potential integration into the DPP.

In addition to methodological harmonization, the need to integrate a broader range of environmental impact categories beyond climate change into the DPP has been acknowledged by various stakeholders (Berger et al., 2023; Jensen et al., 2023). This broader coverage aligns with the ultimate goal of LCA, i.e., to avoid potential burden shifting, especially in the context of comparative assessments—where reducing climate change impacts could result in an increase in other impacts, such as human toxicity or resource depletion. In order to identify potential trade-offs, the Product Environmental Footprint (PEF) recommends assessing 16 impact categories. While the ultimate goal must be to assess all these impact categories in a DPP, it might initially be more feasible to select a few of them. The most relevant impact categories, however, are typically product-specific (King et al., 2023). In the context of batteries, for example, the Product Environmental Footprint Category Rules (PEFCR) identifies climate change, freshwater ecotoxicity, fossil resource use, minerals and metals resource use, and particulate matter as the most relevant. Moreover, water use is often identified as a major concern in LCAs of CRMs supply chains. These categories could serve as a starting point for extending the coverage of impacts in the DPP. Other concepts proposed elsewhere include basing environmental targets on planetary boundaries (Panza et al., 2023) or the automatization of LCA calculations within the DPP system (Haupt et al., 2024).

3 Stakeholer Analysis /process flow

3.1 Classic CRM supply chain flowchart

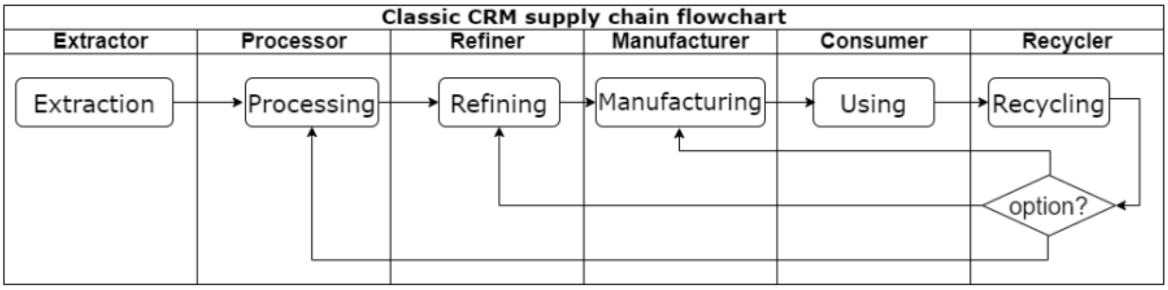

Figure 4 - Classic CRM supply chain flowchart

This diagram represents a generic supply chain for products containing metals. The inclusion of critical raw materials (CRM) is anecdotal here and serves only as a specific example.

The classical complex product containing CRMssupply chain, as depicted in Figure 4 is a structured and mainly sequential process involving various key stakeholders and stages (or steps).

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• Extraction Stage: It begins with the Extractor, responsible for the initial extraction of raw materials. This stage is fundamental to obtaining the base materials necessary for further processing and manufacturing.

• Processing Stage: After extraction, raw materials are sent to the Processor for the Processing stage, where they are prepared to meet specific requirements for the next supply chain stage.

• Refining Stage: During this stage, the materials are further purified and refined to ensure their quality and suitability for manufacturing purposes.

• Manufacturing Stage: Once refined, the materials are sent to the Manufacturer. In this stage, the materials may first undergo **intermediate manufacturing**, such as the production of components, before being utilized to create final products ready for use in various industries or consumer markets.

• Consumer Usage Stage: Following manufacturing, the products reach the Consumer. This stage involves the actual use of the manufactured products, fulfilling the end goal of the supply chain.

• Recycling Stage: Finally, the supply chain includes the Recycler stage. Here, post-consumer or production scrap materials are collected and recycled, emphasizing the sustainability aspect of the supply chain. This stage is crucial for minimizing waste and ensuring the efficient use of resources. Additionally, the recycling process can lead back into the manufacturing, processing, or refining stages, creating a loop that enhances the supply chain's sustainability and efficiency.

In complex productsupply chain, effective communication and information exchange, from extraction to recycling, encompasses specific attributes to meet regulatory obligations, adhere to standards, or fulfill specific requirements of other stakeholders in the chain. In this classical scenario, however, incorrect or misleading information can be exchanged, leading to a cascade of issues, including non-compliance with regulations, failure to meet standards, and inefficiencies in the supply chain. Therefore, it is crucial to establish robust mechanisms to verify the information exchanged at every stage of the supply chain. Ensuring the correctness of these data points not only facilitates compliance and meets specific stakeholder needs but also reinforces the integrity and efficiency of the entire supply chain process.

3.2 Generic CRM supply chain augmented with material checkpoints

To overcome the issues raised by the classical supply chain approach, we advocate the use of specific checkpoints in the chain, called Material Checkpoints (MCs). The modified flowchart is presented in figure 2. Those material checkpoints are based in the possibilities offered by material fingerprint (MFP) and artificial tagging, aspects assessed and analysed in WP2 from Maditrace project.

Geochemical traceability is based on the geochemical/geological signature naturally present in the mineralizations and is determined using a combination of analytical techniques combined with applied statistical tools. Geochemical traceability verifies the integrity and credibility of the documentation-based traceability system. The principle of geochemical traceability is to compare a sample from a given batch with the reference samples corresponding to the documented origin, stored in a database. Geochemical traceability makes it possible to assess whether or not the origin declared in the documents of the given batch is plausible.

Artificial tagging is another option in material traceability, the principle is to add materials/tracers which are not naturally in the original product. The discovery of these tracers downstream in the value chain means that the material passed through the only place where this tracer could be added to the material.

In cases where the natural composition of a materialis inadequate for definitive origin identification (lack of a reference data base, identification impossible, low confidence in MFP results), the addition of an artificial fingerprint becomes a possibility (Figure 5). The specifics of these MCs are illustrated in figure 3. During these audits, samples are tested for detect potential anomalies. An anomaly is a result from analytical/laboratory where the material controlled in the MC does not present a result coherent/acceptable compared to declared provenance. If an anomaly is detected, it may be tolerated if there is a proper justification. In cases of non-compliance, corrective actions, such as returning to the supplier, might be taken depending on the circumstances. If no anomalies are detected, the sample is accepted and eventually certified if there is a certification scheme in place. Regardless of the outcome, all details are meticulously recorded in the chosen data sharing platform, ensuring complete and reliable traceability.

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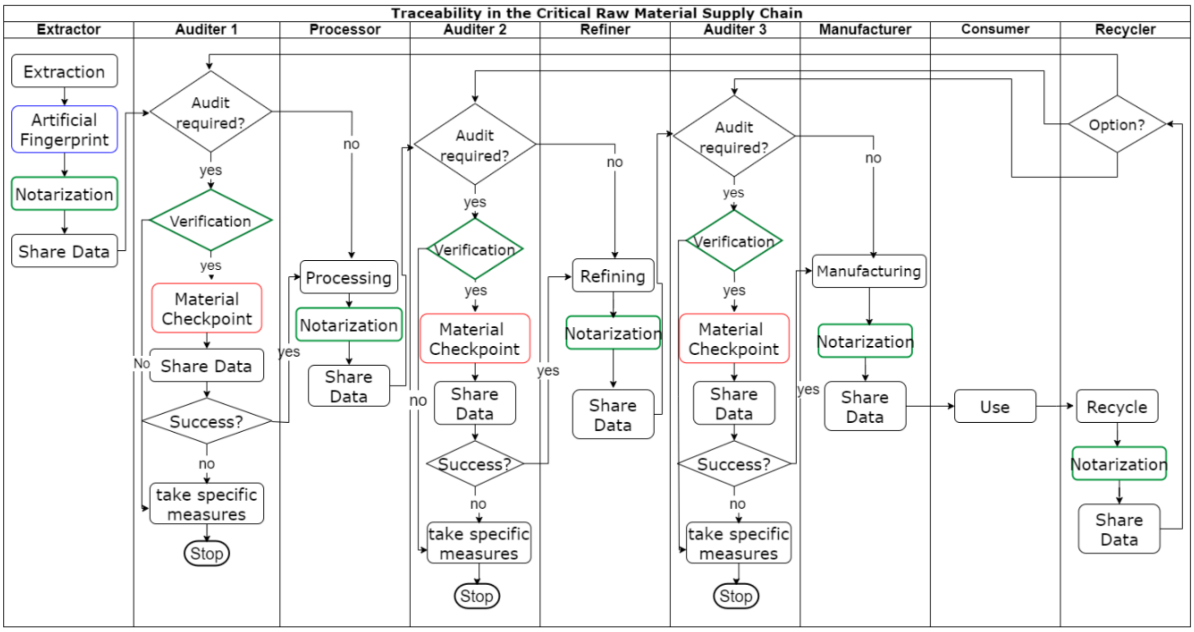

Figure 5 - Including artificial fingerprints and checkpoints in CRM supply chain flowchart

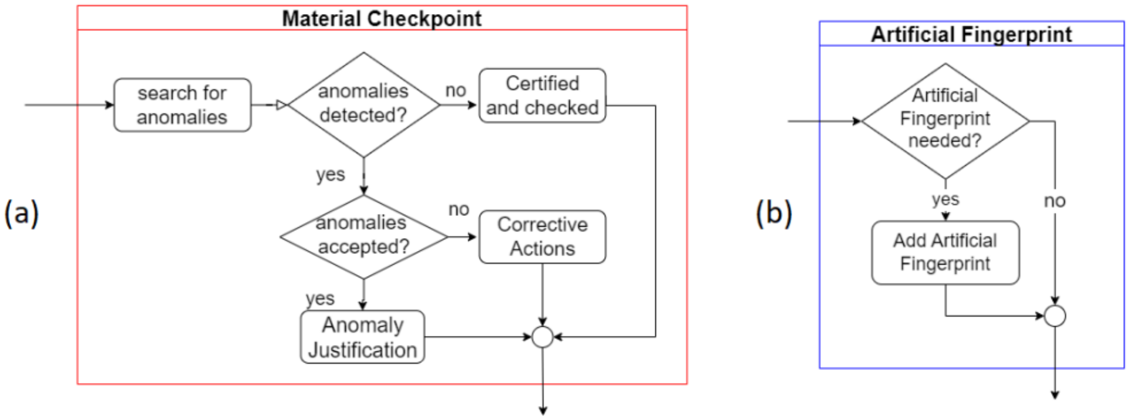

Figure 6 - (a) Zoom on the Material Checkpoint subprocess, (b) Zoom on the Artificial Fingerprint subprocess

3.3 Integrating blockchain-based Notarization into Supply Chain Flowchart

Integrating blockchain technology into the CRM supply chain is crucial for enhancing trust, transparency, and security at every stage—from extraction to recycling. Blockchain serves as a decentralized and immutable ledger, ensuring that all data recorded at various checkpoints, such as certificates of origin, compliance reports, and audit results, remain tamper-proof and verifiable. This decentralized approach mitigates the risks associated with centralized data management, such as single points of failure and unauthorized access, while ensuring that each participant in the supply chain can independently verify data integrity. As illustrated in Figure 2, the notarization process is performed by each stakeholder who needs to share data. For example:

- After Extraction Stage: The data related to the initial extraction, including certificates of origin, compliance reports, sustainable/responsible certificates or any documents confirming the source and legitimacy of the raw materials, are notarized.
- After Processing and Refining Stages: At each stage where raw materials are processed or refined, additional certificates or data confirming the quality, quantity, and compliance of the materials are notarized on the blockchain.
- After Manufacturing Stage: Final product certification, which may include detailed records of the materials used, production processes, and compliance with environmental and social standards, is notarized to ensure end-to-end traceability.

The verification of this notarized data can be done by any stakeholder, such as manufacturers, auditors, or regulators, to confirm the integrity and authenticity of the data without relying on a centralized authority. For simplicity, Figure 5 shows the verification process conducted by auditors. Auditors or other stakeholders can use the notarized hashes to independently verify documents, ensuring that no alterations or tampering have occurred from extraction to the final product.

By incorporating blockchain-based notarization, stakeholders can create a trusted, transparent, and auditable trail of all transactions and documents throughout the CRM supply chain. This approach ensures that each step, from raw material extraction to the final product, complies with environmental, ethical, and regulatory standards. It also allows for the secure sharing of sensitive information, reduces the likelihood of disputes, and enhances accountability among all actors in the supply chain.

The detailed information about Notarization will be provided in deliverable D3.5.

3.4 Additional components

Checkpoints play a crucial role in mitigating the risks associated with malevolent or inaccurate information. Simultaneously, checkpoint information must be securely stored within the infrastructure. Once entered into the system, this data must remain immutable, available, and non-revocable. In essence, the stakeholder responsible for entering the information must be held accountable for the subsequent audit. The integration of blockchain technology as the foundation for the CRM traceability infrastructure effectively meets these prerequisites. Blockchain ensures a secure and immutable record of transactions, thereby safeguarding the integrity of the audit trail and the traceability data logged at each checkpoint. Its decentralized

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nature significantly bolsters security measures against tampering or unauthorized access. Notably, blockchain facilitates the implementation of checks and authorization policies through smart contracts, which are computing programs executed within the blockchain in a highly trustworthy manner. For instance, an additional layer of security to store data can be established via data anchoring. Data anchoring refers to the process of creating a digital fingerprint of a dataset and storing this unique identifier on the blockchain. This approach ensures the verifiability of the data's integrity over time, allowing for the detection of any unauthorized alterations or tampering. To address the need of verifying confidential data, zero-knowledge proof (ZKP) (H. Wu and F. Wang ,2014) systems are an interesting solution. ZKP enables the generation of proofs of knowledge, without revealing the knowledge. This mechanism makes it possible to enable auditability and traceability while maintaining confidentiality. In our case, ZKP permits audits to authenticate CRM authenticity, verifying the existence of a valid artificial fingerprint, without revealing the specific creation characteristics or methods. The utilization of ZKPs in this context aligns with the principles of verifiable credentials featuring selective disclosure. In generating a verifiable credential, the issuer produces signed information (such as the complete audit result) using a digital signature. The credential holder, potentially the issuer, can then selectively present a subset of this information while concealing sensitive data. For instance, if a verifier requests the audit's physical scan within a frequency range, the credential holder can provide a credential that satisfies this range without disclosing the precise spectrum of the physical scan conducted.

4 Control Points Identification[39]

4.1 Determination Keys for material checkpoint locations within the supply chain

A deep understanding of the Supply Chain (SC) is necessary in order to implement Material Checkpoints (MCs). Needs and solutions for natural and/or artificial fingerprinting methods are various and likely to change over time, but one can define key parameters that drives the choice of locations of MC: (1) the commodity SC intrinsic characteristics and steps, (2) geographic material flows and (3) actors:

- (1) Commodity SC characteristics: The complexity (number of steps, materials of different nature within them, grade requirements …) of the supply chain of a given commodity often correlate with the number of actors and complex material flows, but

[39] In our project, the three terms—material checkpoints, control points, and leverage points—are used to refer to the same concept.

also determine MC suitability. Nature and form of a product at a certain step drives analytical procedures that may change the differentiation capabilities, verification time and cost. Finally, as the material get processed more and more, the geochemical signature of a deposit is degraded, making it more and more difficult to control the mine provenance but rather a process/plant signature, changing the information it is capable of providing and reinforcing the need of a global database.

- (2) Geographic material flows: the physical flows of material are what drives the possibilities of frauds (false provenance declaration, undeclared mixings …). The risk of fraud is increased when materials of different origins passes through a physical place. Risky areas are also those where coexists in a relatively small area a mining activity following certain standards with mining activities out of any ESG framework or even illegal mining. For instance, ports or important processing/manufacturing plants could be key locations to implement a MC. In addition, certain countries or regions are often responsible for a significant proportion of production, because deposits are unevenly distributed and/or the economy and local policies are favourable for the industry. This makes them important crossroads for material traceability on a grand scale.

- (3) Actors in the SC: The perception of the importance of traceability and the needs for it are different for a state, an international company or an artisanal mine, which can influence the conditions of implementing methods at the MCs, for instance the use of portable devices or a laboratory. In addition, some actors are more susceptible to fraud and this has to be taken into account: if more controls are required, it is more likely that faster traceability methods will be used. At last, material fingerprinting is by nature resilient to owner changes, but some products in the world are not likely to change ownership during multiple steps between their purchase and their sale, requiring extensive checks to ensure that an ownership throughout an important part of the SC is not a black box for traceability.

Considering these elements, the determination of the location of MC is a proper work by itself. It is different for every commodities because of the differences of processes and steps, actors, and because the SC is in constant change. There are also very specific considerations to take into account at the smallest scale, like stockpile management and storage time, which could make it difficult to carry out on-site checks. A probable approach could be to identify points for the setting up of on-site unannounced checks on remote facilities, and implement static and extensive MCs at crossroads of material flows where mixings or frauds are most likely to occur.

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The MaDiTraCe approach for the development of analytical and artificial fingerprinting methods focuses on multi-scale and multi-technic methods along the entire supply chain, which opens up a whole range of possibilities in terms of provenance declaration checking in order to make the material provenance verification enough flexible and complete to address the complexity of the MC implementation.

4.2 Material fingerprinting database dynamics and outputs behind material checkpoints

With a view to verify the declared origin of a batch of product at a given MC, material fingerprinting methods must compare its signature with a reference database. This database must contain robust data on products available on the market, requiring collection of reference samples (representative of a given provenance) from the companies that are willing to follow certification schemes along the SC. Furthermore, it must be a scalable database, as the signature of deposits can change over time and new mines and plants are susceptible to open and produce. Reference samples must be collected on a regular basis to assess these variations. The scalability of the database can be further improved by incorporating in the database the results of the provenance check of a product if it is verified. Figure _ shows an example of the dynamics of data, from the creation of the reference database to a provenance check of a material with a digital passport.

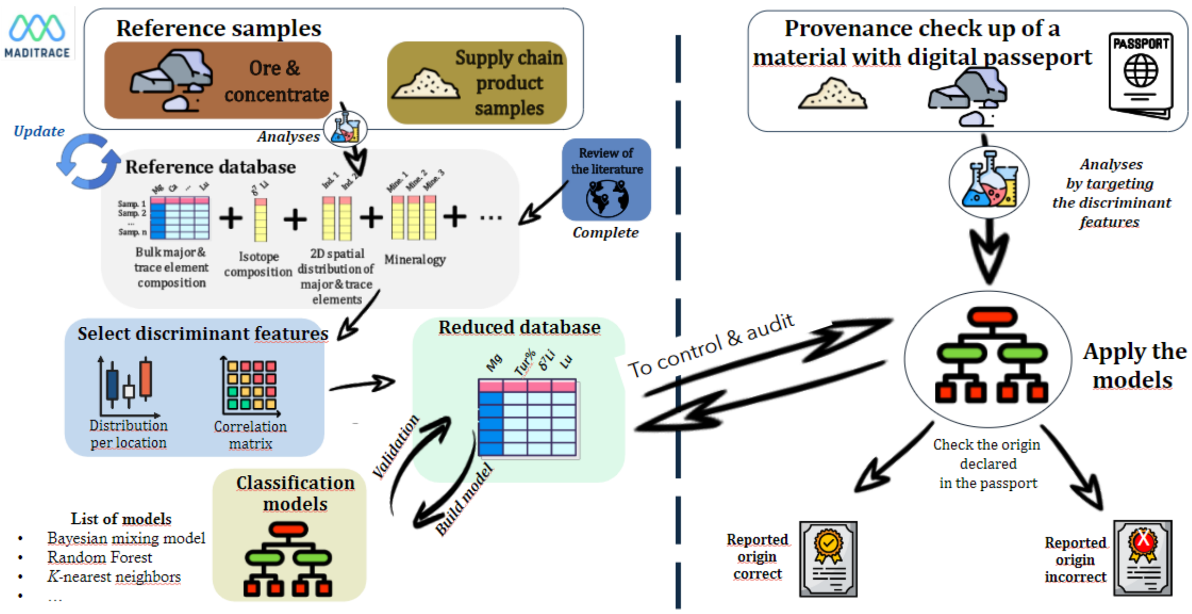

Figure _ Database dynamics between a reference sample database and a provenance verification at a material checkpoint

After the analysis and comparison of the results with the reference database, MCs could be able to validate or not the declared origin of a material, with a certain degree of confidence. If not, the signature can be compared to other certified material, giving the probability of the material to belong to the certification requirements. In case of mixing of certified materials, material fingerprinting methods could also in some cases detect it and indicate in what proportion of different origins.

5 Architectural Framework

5.1 Interconnected Project Deliverables:

The diagram in Figure 7 illustrates the relationships between different project deliverables, which are organized sequentially and interdependently.

The process begins with D3.1, a draft report on supply chain mapping, requirements elicitation, and classification, which feeds into D3.8, the final report on the same topic. From D3.1, insights are used to develop the D3.2 deliverable, which defines a Reference Architecture model.

This model serves as the foundation for D3.3, which provides Guidelines for Methodology Implementation. Based on these guidelines, D3.5 delivers Components and Smart-contract support examples.

D3.2 also supports the creation of D3.4, which offers Architecture definition for Proof of Concept (POC) Implementation in an intermediate report. This report is further refined into D3.6, the final report on the POC architecture.

Additionally, D3.7 provides Guidelines and recommendations for security, confidentiality, and privacy, which are essential details that accompany the development of the architecture outlined in D3.4 and D3.6.

In summary, the flow of deliverables demonstrates a progression from initial supply chain mapping and requirement gathering to detailed architecture and smart contract support, all of which are finalized through POC implementation and supported by guidelines for security and privacy.

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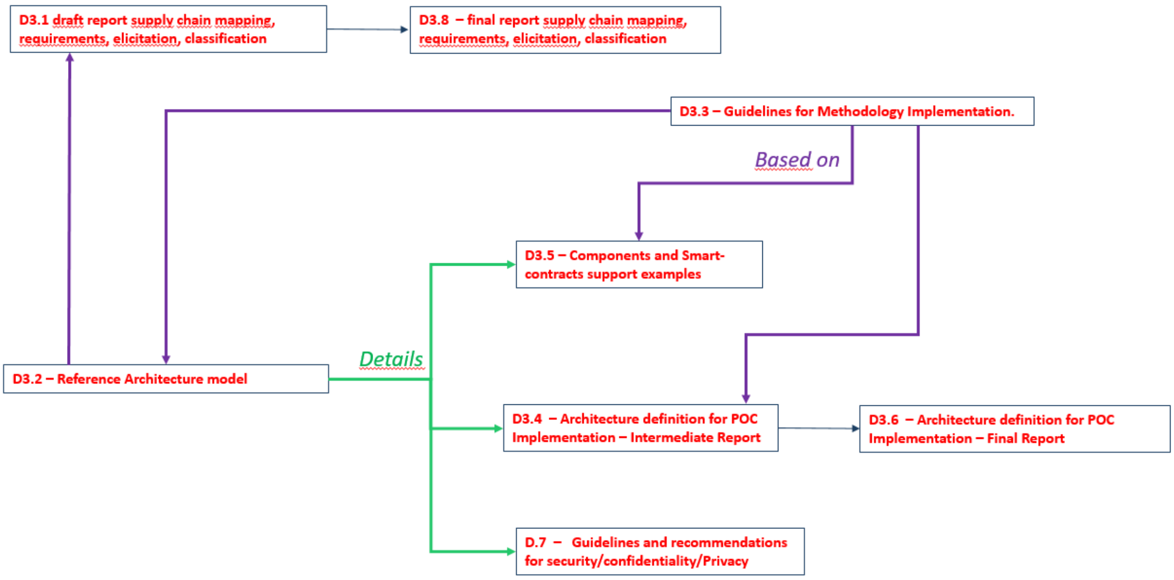

Figure 7 – interconnected project deliverables

This proposed architecture recognizes the significant advances made in the last few years in creating standards and ecosystems around all the different building blocks of the traceability and Digital Product Passport (DPP) architecture. A modular architecture structured around the following building blocks is proposed in the system architecture:

- Data Exchange Protocol: This component facilitates secure and seamless data transfers between different systems and stakeholders, consisting of a Control Plane for policy management and a Data Plane for high-speed data flow.
- Digital Twin / Data Catalogue: This serves as a digital representation and structured repository for raw material data, allowing real-time tracking and providing a complete digital record of materials throughout their lifecycle.
- Enterprise Credential (LPID): The Legal Person Identifier (LPID) is a state-issued verifiable credential[40] that uniquely identifies an organization, playing a crucial role in establishing trust and supporting secure data exchanges.
- Organization Identity Wallet: This secure digital repository stores, manages, and presents organizational credentials, such as the LPID and compliance certificates, facilitating verified participation in data exchanges.
- Semantics Layer: This component ensures that data is interoperable by defining standardized data structures and meanings, promoting effective communication among diverse systems.

[40] Verifiable Credentials (VCs) are digital attestations that represent information about an entity, such as a person or organization, and are designed to be tamper-evident and cryptographically verifiable. They enable individuals to present claims about themselves in a secure and privacy-preserving manner, without relying on centralized authorities. (reference: https://www.w3.org/TR/vc-data-model/)

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- SSI Authorization and Access Control: This component enables decentralized, credential-based authorization, allowing verified entities to access or share sensitive data while managing permissions through self-sovereign identity principles.
- Trust Chain (Root Credential): Establishes a hierarchy of trust by linking credentials back to a trusted authority, ensuring that all credentials are authentic and supporting secure interactions within the ecosystem.
- Verifiable Data: Refers to data embedded with cryptographic proofs that confirm its authenticity and integrity, ensuring that shared information can be trusted across the supply chain.

In addition to traceability architecture components, the system architecture also defines the following traceability monitoring tools and applications for the stakeholders that want to make use of the traceability data:

- Internal Database : A foundational component for storing, managing, and retrieving data related to raw materials, providing an organized record that supports traceability efforts.
- Quality Investigation Process: A structured workflow designed to analyze and address quality issues within the supply chain, utilizing data to ensure compliance with standards and regulatory requirements.
- Monitoring User Interface (UI): This user interface provides real-time visibility into raw material data and traceability information, allowing stakeholders to monitor compliance and quality metrics through an accessible dashboard.

These components work together to enhance traceability and transparency in the supply chain, facilitating secure interactions and ensuring compliance with relevant standards and regulations. For more detailed descriptions and interactions of these components, refer to deliverable *D3.4: Architecture definitions for POC implementation – Intermediate Report.*

5.2 Digital Materials Passport Data Model

A Digital Product Passport data model is designed by UN Traceability Protocol (UNTP) to meet several detailed requirements to enhance product traceability and sustainability. It encapsulates various details of a product, including its identification details, who issued it, traceability information, circularity information, emission performance, and a set of verifiable product conformity & sustainability claims. A DPP should also reference standards and regulations, provide supporting evidence for claims, and ensure that all data is digitally verifiable, fostering transparency and accountability across the supply chain. UNTP's standardized approach ensures that all stakeholders in the supply chain can effectively track

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and verify product movements and transformations with the help of a DPP.

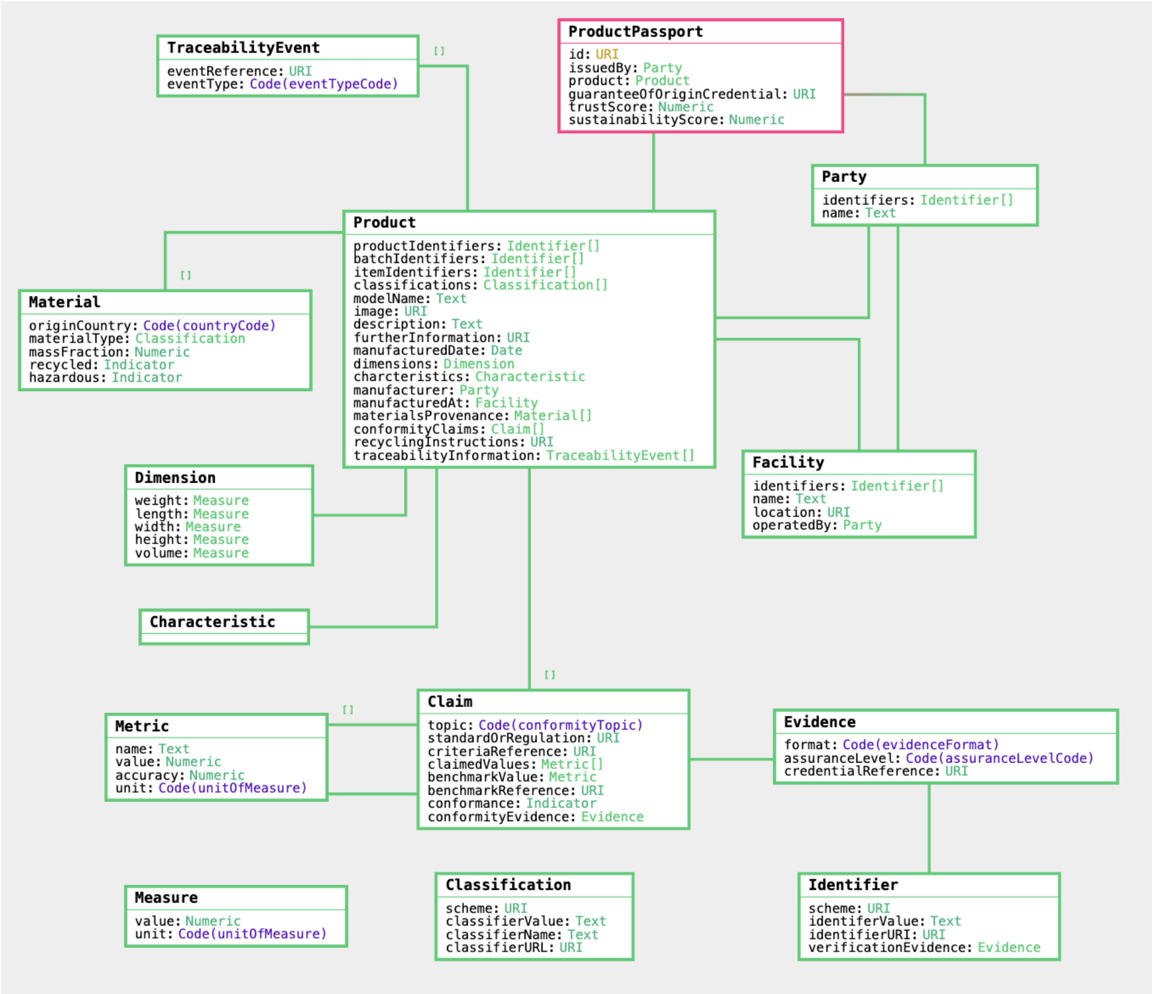

Figure 8 - Source :Digital Product Passport Data Model in UNTP Specification

Retrieved from: uncefact.github.io/spec-untp/docs/specification/DigitalProductPassport

The DPP data model of UNTP, which will also form the basis of the Maditrace DPP data model, is depicted in the Figure 8 The data definitions of the prominent DPP classes of this model are summarized below:

- DigitalProductPassport: A comprehensive data structure encapsulating various details about a product, including its identification, issuer, batch information, provenance, and sustainability claims.
- Product: Contains detailed information regarding a specific product, including its identification details, manufacturer, and other pertinent characteristics.
- Material: Represents the composition of the product, detailing its type, origin, and other relevant attributes.

- Claim: A declaration that asserts compliance with specific standards or regulations related to the product's characteristics.
- TraceabilityPerformance: An array of links to traceability events that document the product's movement through the supply chain, grouped by value chain processes.
- CircularityPerformance: A data structure that measures and reports the extent to which a product supports circular economy principles, including metrics related to recyclability, reuse, and recovery of materials.
- EmissionsPerformance: A component that quantifies the environmental impact of a product by tracking and disclosing its greenhouse gas emissions throughout its lifecycle, from production to disposal.
- CredentialIssuer: The party responsible for issuing a verifiable credential, which can be an individual or organization. It contains the W3C DID of the issuer.
- Identifier: The unique ID and name of an identified entity such as a product, facility, or organization. If the identifier is a W3C DID then the corresponding DID document should include a serviceEndpoint of type "IdentityResolver"
- IdentifierScheme: The registration scheme for identifiers used for products, facilities, or organizations, typically maintained by a recognized authority. It contains the globally unique identifier of the registration scheme.

Digital Material Passports are a subset of DPPs that are focused specifically on raw materials used in production processes. These passports document the origin, extraction, processing, and transportation of raw materials, providing a clear and traceable path from the source to the final product. As mentioned in Section 5.2, the details of the digital material passport architecture, the standards and regulations that should be referenced for critical raw materials, and the detailed identity mechanism for products are provided in deliverable D*3.4: Architecture definitions for POC implementation – Intermediate Report*.

5.3 Security Analysis and Risks associated to Blockchain Framework for supply chains

This section presents the foundational work done under Task 3.4 (Cross-Cutting Issues Analysis and Recommendations: Security, Confidentiality, Accountability at Design and Runtime Control). Following the receipt of the draft architecture from Task 3.3, we launched an initial security analysis focused on assessing vulnerabilities and defining risk mitigation strategies. This document outlines our progress in both the preparatory and current security analysis phases, with more detailed findings to be included in D3.7.

5.3.1 Preparatory Phase Summary for Task 3.4

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This preparatory phase, conducted by Funditec with contributions from Spherity and CEA, focused on building a secure foundation by addressing essential non-functional requirements such as security, confidentiality, and privacy. This groundwork ensures a smooth transition to system implementation and allows for targeted adjustments based on specific vulnerabilities identified in the early stages.

5.3.1.1 Risk Analysis Methodology and Key Developments

We adopted the P.A.S.T.A. methodology (Process for Attack Simulation and Threat Analysis) as the structured approach for risk analysis in Task 3.4. The methodology consists of seven detailed stages to capture potential risks:

- Stage 1: Defining Business Objectives – Identified critical assets within the system.
- Stage 2: Defining Technical Scope – Outlined technical components and interactions within the system.
- Stage 3: Application Decomposition and Analysis – Mapped data flows and component relationships.
- Stage 4: Threat Analysis – Identified specific threats and attack scenarios for each component.
- Stage 5: Weakness and Vulnerability Analysis – Matched threats to known vulnerabilities.
- Stage 6: Attack Modeling & Simulation – Drafted attack scenarios targeting vulnerabilities.
- Stage 7: Risk and Impact Analysis – Ranked vulnerabilities to guide resource allocation.

Each stage was documented to ensure consistent tracking of findings and to provide a basis for the more focused security analysis in the current phase.

5.3.1.2 Identification of Common Vulnerabilities in Smart Contracts

As part of our initial review, we identified common vulnerabilities in smart contracts that will inform the guidelines and recommendations in Task 3.4. The key vulnerabilities identified include:

Vulnerability	Description
Reentrancy	Repeated contract executions before initial completion, enabling exploits.
Integer Overflow	Arithmetic errors from exceeding data type limits, causing unintended behavior.

Improper Access Control	Inadequate restrictions enabling unauthorized data access.
Front-Running	Exploits transaction timing for financial gain.
Denial of Service	Exhausts contract resources, rendering it inoperable.
Weak Randomness	Predictable random numbers due to insecure methods.
Oracle Manipulation	Alters external data to influence contract outcomes.
Flashloan Attacks	Unsecured loans used to exploit market conditions or contract vulnerabilities.

5.3.1.3 Technical Tools and Initial Assessments

In the preparatory phase, we tested several tools for identifying and mitigating smart contract vulnerabilities. Below is a summary of the main tools assessed:

- Slither – Provides static analysis for Solidity, helping identify unchecked calls and reentrancy issues.
- Ziion – Used on AWS for both static and dynamic analysis, particularly effective for finding complex vulnerabilities.
- Mythrill – Analyzes Ethereum bytecode, identifying issues like integer overflows and unauthorized access.
- Echidna – Uses fuzz testing to simulate multiple scenarios, exposing potential weaknesses in smart contracts.

5.3.2 Security Analysis Phase and Preliminary Architecture Assessment

With the draft architecture in hand, we entered the security analysis phase, applying the P.A.S.T.A. methodology to selected components. This phase is currently a work in progress as we deepen our assessment and refine security measures. Below, we outline the analysis steps, exemplified by the Org Identity Wallet component.

5.3.2.1 Work done in the Analysis Phase

The initial focus has been on high-priority components central to the system's security and confidentiality. This analysis leverages the P.A.S.T.A Excel template developed during the preparatory phase, which organizes the risk assessment process and aids in tracking vulnerabilities systematically. Using this template, we conducted a structured evaluation of each component, covering threat modeling, attack simulation, and risk prioritization based on

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the component's role within the architecture. This approach has streamlined the identification of critical security gaps and guided the development of mitigation strategies.

5.3.2.2 Example: Selected Component – Org Identity Wallet

Business Objectives and Scope (STEP 1)

- **Objective**: Secure authentication and credential integrity.
- **Description**: Protects organization credentials, accessible only to authorized personnel.
- **Priority**: High.
- **Status**: In progress, requiring MFA and strong encryption.

Technical Scope (STEP 2)

- **Technologies**: DID, MFA, AES-256 encryption.
- **Components**: Org Identity Wallet, central authentication.
- **Interfaces**: Access control systems, "Access/Policy Engine."
- **Dependencies**: External authentication provider integration.

Threat Modeling (STEP 3)

- **Threats**: Identity theft (stolen credentials), credential forgery, and data interception.

Vulnerability Analysis (STEP 4)

- **Key Vulnerabilities**: Lack of MFA, missing transit encryption, insecure credential storage.

Attack Modeling (STEP 5)

- **Scenarios**:
  - Identity theft via stolen credentials (no MFA).
  - Man-in-the-middle interception in unencrypted channels.

Risk Analysis (STEP 6)

- **Likelihood**: Moderate for identity theft, high for data interception.
- **Impact**: High for both, needing prioritization.

Mitigation and Monitoring (STEP 7)

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- **Mitigation**: Implement MFA, secure transit with HTTPS/TLS, use AES-256 for storage.
- **Monitoring**: Log and alert on suspicious activity; audit encryption practices regularly.

5.3.3 Ongoing Work and Next Steps

To align on security requirements and architectural design, early collaboration with Spherity and CEA has been instrumental. Their input is supporting the refinement of security measures, especially regarding identity management and credential handling.

Preliminary guidelines and recommendations are being drafted to enhance security, confidentiality, and accountability within the system. These guidelines will evolve as Task 3.3 further defines architectural elements, enabling us to finalize recommendations based on a comprehensive security assessment.

6 Conclusions

In conclusion, this document provides the essential basis for creating a reference architecture model for establishing a transparent, secure, and standardized approach to digital traceability for critical raw materials (CRMs). By emphasizing core principles of traceability, data integrity, and environmental compliance, it aims to create a sustainable framework that supports regulatory and industry requirements. The integration of advanced technologies, such as blockchain and distributed ledger technologies, alongside robust security measures, lays the groundwork for a resilient digital product passport (DPP) system that can adapt to the complexities of global CRM supply chains.

The architecture introduced in this document serves as a foundational step within a broader series of deliverables designed to expand and detail this framework. The development process begins with D3.1, which focuses on supply chain mapping and requirements elicitation, providing insights that guide this D3.2 deliverable. Following this, D3.3 will offer Guidelines for Methodology Implementation, while D3.5 will provide specific components and smart contract examples. This D3.2 architecture also supports D3.4, an intermediate report on Proof of Concept (POC) implementation, which will be further refined in D3.6, the final report on POC architecture. To ensure security and privacy, D3.7 will provide crucial guidelines on these aspects, reinforcing the architecture's resilience and compliance.

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In summary, this sequence of deliverables charts a clear pathway from conceptual foundations to realizable implementations, culminating in a secure, efficient, and standardized system for CRM traceability, validated through some POCs and supported by comprehensive security and privacy frameworks.

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8 Appendices

Appendix A (check document « D3.2_Annex_A.pdf »)

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Reference architecture Model

Deliverable D3.2 – Annex A

Version N°1.0

Authors: Rouwaida ABDALLAH

Table of contents

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1 Detailed Battery DPP Project Profiles: Overview and Technological Exploration

1.1 Projects details

In this subsection, we will provide a "global overview" of each selected project followed by a "Technology Deep-Dive" where we explore the specific technical implementations and solutions, based on the available information.

1.1.1 A Decentralized Blueprint for Digital Product Passports

Global Overview[1] [2] [3] [4]

Digimarc[5] and IOTA[6] have collaborated to create a blueprint for Digital Product Passports (DPP) aimed at fulfilling some of the European Union's initiative requirements, such as the

[1] https://www.digimarc.com/blog/decentralized-blueprint-digital-product-passports

[2] https://www.crypto-news-flash.com/iota-to-serve-as-basic-tech-layer-for-digital-product-passport-for-european-blockchain-and-companies-report/
[3] https://thedinarian.locals.com/post/3507693/iota-partners-with-digimarc-for-decentralized-blueprint-for-digital-product-passports-to-serve-eu-bl
[4] https://www.youtube.com/watch?v=NfJ4yiyAriw
[5] https://www.digimarc.com/company/thought-leadership
[6] https://www.iota.org/

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use of open standards, decentralized architectures, and accessibility. This collaboration is part of the EU Blockchain Pre-Commercial Procurement Project for developing the European Blockchain Service Infrastructure (EBSI), which will be used to provide cross-border services to European citizens and businesses.

The blueprint focuses on meeting two primary design criteria of the EU DPP Initiative: providing open and interoperable identities and making those identities accessible to most consumers. To this end, Digimarc utilized the GS1 Digital Link standard, which they helped develop, to create unique web addresses for products that can be used in various types of carriers, such as QR codes and NFC tags, and can be read by different readers, including smartphones.

Digimarc and IOTA's roles in implementing the blueprint are clearly defined. Digimarc's Illuminate Platform is used to generate GS1 Digital Link identities at scale, and the product lifecycle data is ingested via their beta EPCIS 2.0 API. Each event is then anchored to the IOTA DLT via Digimarc's Blockchain Integration Hub, ensuring the data is secure. IOTA's implementation of Decentralized Identifiers (DID) and Verifiable Credentials (VC) allows for the identification of the author of an event to ensure they are authorized and competent to perform the specific event.

The project has successfully tested the implementation of this DPP blueprint with electric vehicle batteries, tracking several steps in the production and maintenance of the battery and its modules by a mix of stakeholders who digitally signed the events they recorded.

Overall, this project represents a significant step towards creating a decentralized, secure, and interoperable system for Digital Product Passports, with the potential to greatly enhance transparency, security, and efficiency in the product lifecycle.

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Technology Deep-Dive

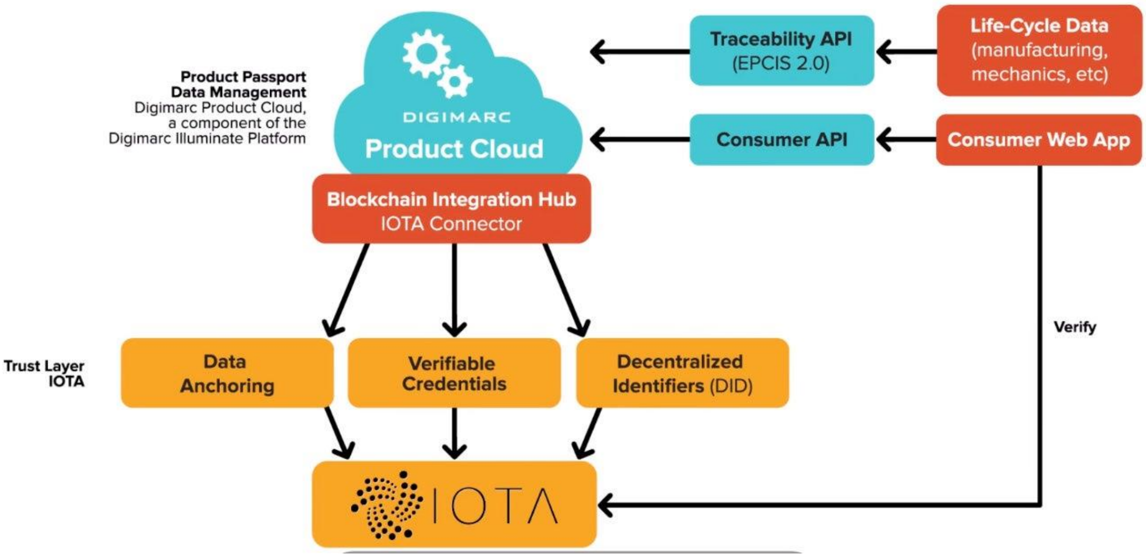

Figure 1- The Digital Product Passport blueprint as implemented by Digimarc and IOTA. Digimarc's Illuminate platform is used to build the passport data and identity, the IOTA DLT is used to provide a layer of trust.

GS1 Digital Link and EPCIS 2.0 Standards:

The GS1 Digital Link standard is utilized to create unique, web-based identifiers for products. These identifiers are versatile and can be embedded in QR codes, NFC tags, and other carriers. They are easily readable by various devices, including consumer smartphones. The product lifecycle data is managed using the EPCIS 2.0 standard[7], which acts as the lingua franca of the supply chain, enabling the capture and query of events in a standardized and web-compatible format.

Decentralized Ledger Technology (DLT) Layer by IOTA:

The DLT layer, provided by IOTA, introduces an essential trust layer in the architecture. It is used for storing crucial lifecycle events and anchoring all supply chain events formatted in EPCIS. The integration of DLT ensures that the events are immutable and secure against tampering, providing a trustable and verifiable record of the product's lifecycle.

Decentralized Identifiers (DID) and Verifiable Credentials:

IOTA's implementation of DIDs and Verifiable Credentials, based on W3C standards, plays a critical role in the ecosystem. DIDs allow the unambiguous identification of entities (e.g., manufacturers, logistics providers) involved in the product's lifecycle. Verifiable Credentials

[7] https://www.gs1.org/standards/epcis

are used to certify the authenticity and authorization of the entities performing specific events or transactions, ensuring trust and integrity in the supply chain.

Digimarc's Illuminate Platform:

Digimarc's Illuminate Platform is utilized to generate and manage the GS1 Digital Link identities at scale. The platform ingests product lifecycle data through its beta EPCIS 2.0 API. It then anchors each event securely onto the IOTA DLT using Digimarc's Blockchain Integration Hub. This ensures that the data remains secure, tamper-proof, and verifiable across the product's lifecycle.

User Interaction and Experience:

The DPP system is designed to be user-friendly, providing stakeholders with intuitive access to product lifecycle and provenance data. Consumers can check product authenticity, view the product's lifecycle, and receive specific instructions, all through a web application that automatically verifies the data against the records in the Illuminate Platform and the anchors on IOTA's DLT.

1.1.2 Arianee

Global Overview [8]

The Arianee Digital Product Passport (DPP) project represents a collaborative initiative aimed at establishing a digital identity for physical products. This initiative is particularly aligned with the European Commission's directives to provide consumers with detailed information about the origin, environmental impact, and safety of products. Arianee's approach uniquely leverages blockchain technology and NFTs (Non-Fungible Tokens) to create digital passports or certificates for products, offering an array of benefits from product transparency and traceability to customer relationship management and the potential for tokenized incentives.

The Arianee project offers a blend of commercial services and open-source elements.

Commercial services:

Arianee's platform provides a robust NFT Management Platform that allows brands to manage digital assets, particularly NFTs that act as digital product passports. This platform enables brands to create, manage, and distribute these NFTs, facilitating

[8] https://www.arianee.com/digital-product-passport

deep engagement with customers through lifecycle tracking of products, offering value-added services, and conducting data-driven marketing campaigns. Additionally, Arianee features a Dynamic Product Page, a web-based interface where users can interact with digital product passports, enhancing customer onboarding and ensuring compliance with regulatory requirements. The platform also includes Embedded Wallets, which allow for the secure storage and management of ownership data in digital wallets, seamlessly integrated into client accounts or decentralized apps. Moreover, Arianee extends its functionality through various other commercial services, including data storage, ensuring interoperability, managing user access and permissions, assisting with regulatory compliance, and providing analytical tools, all designed to support a comprehensive digital asset management ecosystem.

Open Part:

The Arianee Protocol, the cornerstone of the Arianee project, is an open-source framework designed for creating digital product passports as NFTs on a blockchain. Its codebase is transparent and open for auditing, inviting contributions from businesses, developers, and other stakeholders, fostering a collaborative development environment. The protocol's data state is openly accessible on the blockchain, upholding a commitment to transparency and trust while maintaining strict data privacy and security standards. The governance of the Arianee Association is decentralized and democratic, involving a consortium of brands, builders, and partners who jointly shape and oversee the standard, preventing any single corporate entity from asserting control. Integral to Arianee's architecture is its compatibility with global open standards, which facilitates worldwide operation and easy integration with other systems and standards, enhancing its global interoperability.

Technology Deep-Dive

Open source : Arianee SDK[9]

The Arianee SDK allows you to interact with all the features of the Arianee protocol. Because the Arianee protocol is deployed on multiple chains, Arianee designed its SDK as a multi-chain solution:

[9] https://docs.arianee.org/docs/smart-contracts

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- **Testnet**: Blockchain dedicated to testing.
- [**Deprecated] POA:** First blockchain on which the Arianee protocol has been deployed. Subchain of Ethereum, this network was economically accessible and had very few users. Since June 2023, Arianee has used a forked version of the POA network.
- **Polygon**: Blockchain on which the Arianee protocol has been deployed later on to create a larger ecosystem to connect to other environments such as OpenSea.
- **Supernet**: Side blockchain dedicated to Arianee protocol representing a separate blockchain with its unique features and functionalities which offers more flexibility.

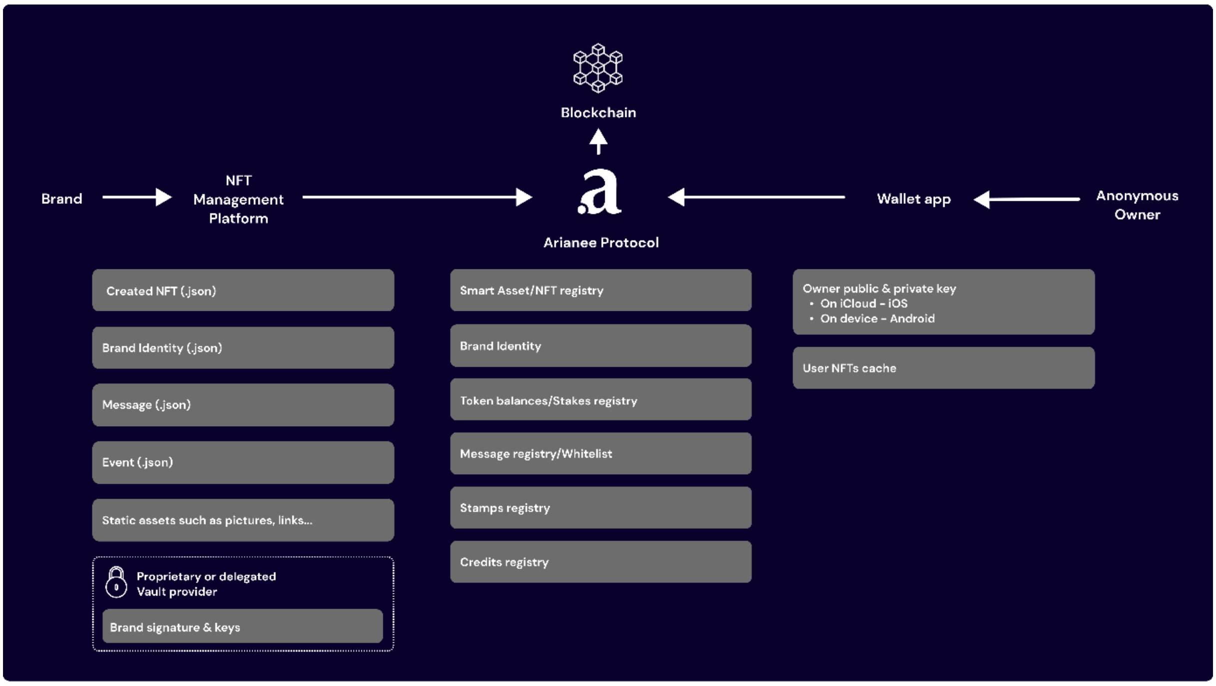

Figure 2 - Arianee Protocol

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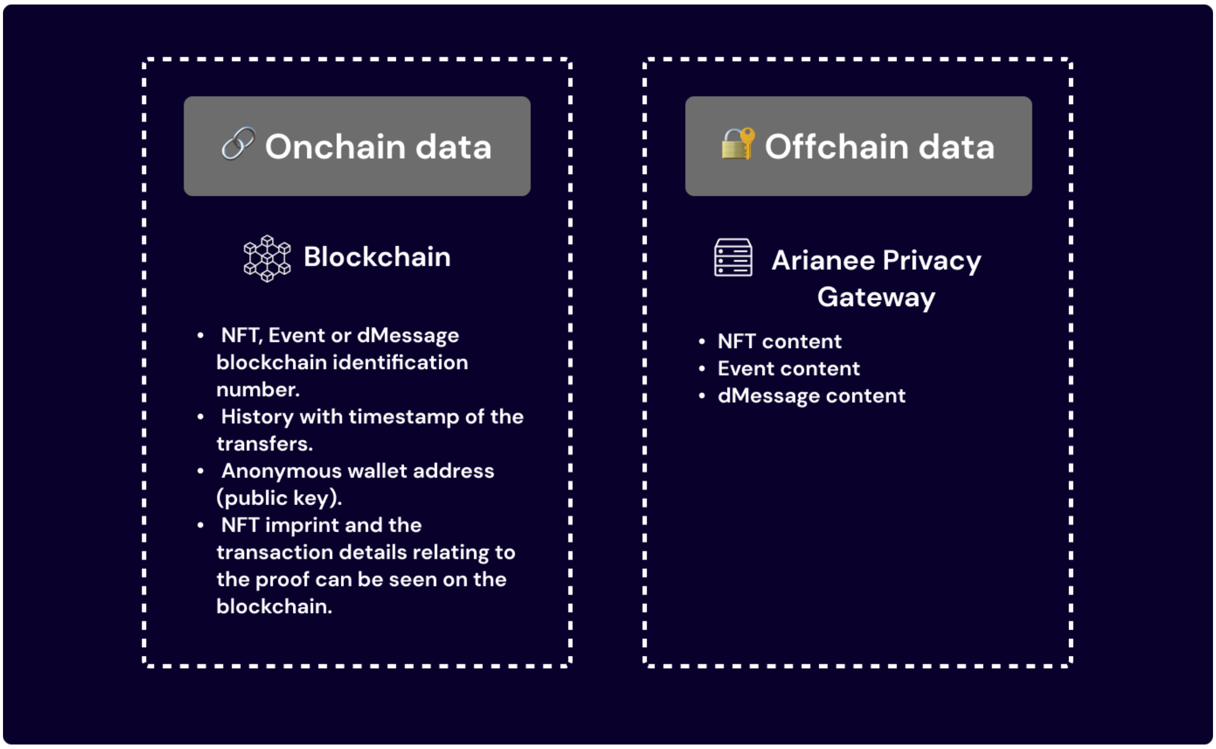

Figure 3 - Arianee data management

Smart contracts[10] : An NFT smart contract is a contract on the Ethereum blockchain that implements lines of code which then creates a list of items that someone owns, known as smart asset. The Arianee protocol is composed of that contract.

Indeed, to favor interoperability and adoption, the Arianee protocol designed NFTs – Arianee Smart Assets – compliant with the ERC-721 Token Standard and the $ARIA20 compliant with the ERC-20 Token Standard.

Other smart contracts example : (Arianee Identity Smart Contract, etc.)

1.1.3 Assent Inc

Global Overview[11] :

Assent Inc positions itself as a pivotal entity in supply chain sustainability management, offering nuanced solutions to complex manufacturers. The company's ethos revolves around enhancing supply chain transparency, compliance, and sustainability. The focal point of Assent's operation lies in navigating and addressing critical regulatory domains such as PFAS, REACH, SCIP, and ESG (check Annex). This extensive regulatory focus is

[10] https://docs.arianee.org/docs/arianee-decentralized
[11] https://www.assent.com/

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integrated with a robust commitment to sustainable and ethical manufacturing practices, making Assent a comprehensive solution for modern supply chain challenges.

We note that there was no direct reference or specific case study provided by Assent Inc that explicitly discusses the application of their solutions in the battery industry. The details provided were more general, focusing on Assent Inc's capabilities in supply chain sustainability management, compliance with environmental and safety regulations, and ESG reporting.

Techincal deep-dive :

We couldn't find a lot of information about the architecture.

Assent uses AWS to host its compliance platform and associated data.

Data encryption : The Internet communications are encrypted via HTTPS, SFTP and TLS. Customer data is secured using standard database encryption.

Assent's platform, data, and server security is provided by Amazon Web Services (AWS)[12].

Assent has three hosting locations available to its clients: (1) The North America commercial environment, hosted by AWS U.S.-East in Northern Virginia. (2) U.S. ITAR environment hosted by AWS GovCloud U.S.-East. (3) The European Union (EU) hosting environment in Frankfurt, Germany (see Figure 1). Data is housed by default in the North America commercial environment; however, clients may request a different option.

Assent provide a stron security framework.

Here's a technical deep-dive based on the available data from the Cirpass project:

- **Data Collection Method:** Assent offers multiple supply chain data collection and reporting solutions, showcasing a comprehensive approach to gathering relevant and critical data from across the supply chain.
- **Data Standardization Level:** The data standardization level is advanced, ensuring that the data collected and processed are consistent, accurate, and usable for various compliance and sustainability reporting purposes.
- **Data Transport Openness Level:** The data transport mechanism is standardized, likely ensuring secure and efficient data transfer between different entities within the supply chain.

[12] https://www.assent.com/wp-content/uploads/2022/07/OV-Assents-Data-Security-Framework.pdf

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- **Data Packaging**: Assent's platform presumably uses APIs (Application Programming Interfaces) for data packaging, facilitating integration with other systems and streamlining data exchange processes.
- **Level if Advanced**: The platform offers advanced features, including role-based access control, ensuring that data access and permissions are managed securely and appropriately based on user roles and responsibilities.
- **Evidence Convenience:** Assent employs verifiable credentials, providing a robust mechanism to authenticate and verify the integrity of the data within the platform.
- **Data Use Management:** and **Data Protection**: The platform employs anonymization techniques and potentially other Privacy Enhancing Technologies (PETs), especially in sectors like defense and medicine, where data privacy and security are paramount.

  Assent offers the highest level of security in its class, trusted by leading manufacturers around the world.

  The data is secure, with role-based access that supports your internal protocols. They can be stored in dedicated environments and you retain full ownership of them.
- **Traceability:** Assent's solution provides various traceability mechanisms, including QR tagging, NFC/RFID tagging, and possibly other digital watermarking techniques, ensuring deep visibility into the supply chain and the provenance of products.

1.1.4 Authentic Vision MetaAnchor

Global Overiew[13]

The Meta Anchor™ by Authentic Vision is an advanced mobile authentication technology designed to securely link physical products with digital experiences, services, and assets. Unlike traditional QR codes or NFC chips, which can be easily replicated or shared, Authentic Vision's patented Holographic Fingerprint technology ensures a unique, one-time production that is virtually copy-proof.

[13] https://www.authenticvision.com/

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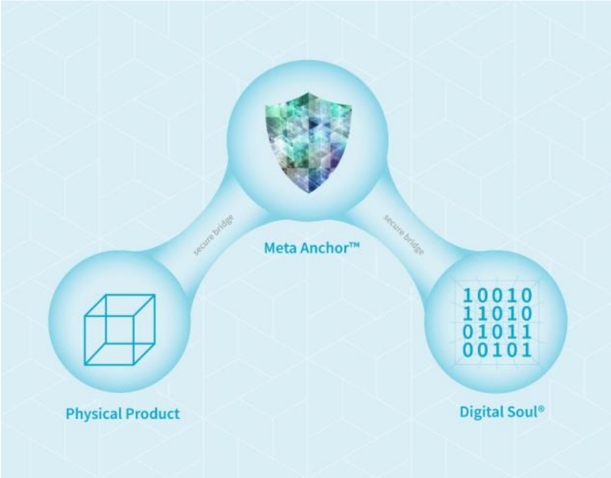

Figure 4 - Meta Anchor technology

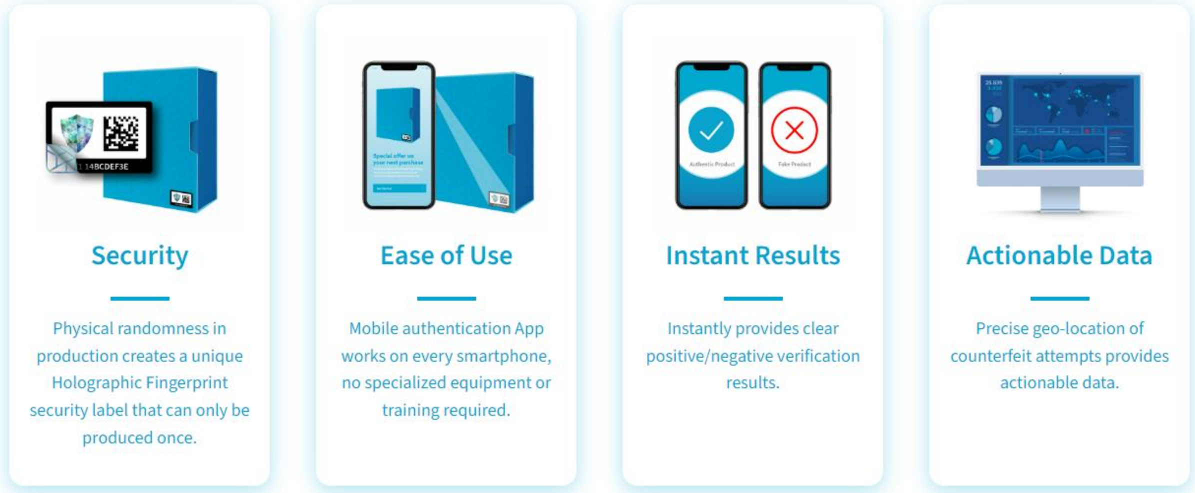

Figure 5 - Authentic Vision benefits

Meta Anchor™ technology enables various digital interactions through the scanning of a holographic fingerprint using a smartphone. This technology allows users to unlock digital actions or assets such as NFTs tied to physical collectibles, access virtual assets, redeem media content, and integrate into fintech applications like mobile banking. It significantly enhances customer experiences and promotes brand loyalty by providing each physical object with a digital twin.

Authentic Vision has successfully applied this technology for brand protection in diverse industries such as wine and spirits, pharmaceuticals, and automotive parts. The technology features self-destructive labels that prevent the tampering or reuse of holographic fingerprints, crucial for maintaining authenticity in mixed-reality applications and sectors where authenticity is vital.

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A key application of Meta Anchor™ is its use by Nexans, a leading cable systems manufacturer, to verify product authenticity and combat counterfeiting. This ensures customer safety by avoiding the distribution of substandard products and enhances customer engagement by offering additional digital content like installation guides.

While not yet reported in the battery sector, Meta Anchor™ has potential applications for battery manufacturers to combat counterfeiting and enhance consumer safety. Its unique identifiers (UIDs) for each product and the capability to track counterfeiting attempts provide a secure, easy-to-use solution that doesn't require special training or equipment, making it adaptable for various market needs. This technology not only protects brand value but also connects products to their digital lifecycle data, improving traceability and building consumer trust.

Technical deep-dive

Meta Anchor™ ensures that each product has a unique digital identity through the Holographic Fingerprint, which cannot be replicated. This provides a secure link between physical items and digital assets or experiences, such as NFTs, and enables a wide range of interactive and augmented experiences. The technology is also designed to be easy to use, requiring no specialized training or equipment, and offers immediate verification results.

Based on the Cirpass project:

The project employs a centralized approach for both ID minting and data storage, ensuring a unified and controlled environment for data management. Standardized data transport protocols are used to facilitate data transfer, indicating a reliance on established norms for data exchange that can easily integrate with existing systems. At an advanced level of development, the project adopts a role-based data use management system, which allows for granular access control and operational segregation, enhancing both security and functional adaptability. The evidence system is grounded in verifiable credentials, which assures the authenticity and integrity of data, reinforcing trust in the system. For user convenience, the project provides a versatile app that supports generic use, branded experiences, or software development kit (SDK) integration options, catering to a broad range of stakeholder needs. Data protection is handled via anonymization techniques to preserve user privacy and comply with data protection regulations. The traceability of items is secured through the use of QR codes, 2D codes, and additional machine-readable holographic fingerprints, which are both uncloneable and irreproducible, ensuring that each item has a unique and tamper-evident digital identity. This holistic approach to item identification and data management positions the project as a robust solution for secure and efficient asset tracking and verification in various sectors.

1.1.5 Battery Pass

Global Overview[14][15][16]

The Battery Pass project, spearheaded by SYSTEMIQ GmbH, is a pioneering initiative aimed at enhancing the sustainability and circularity of battery value chains, particularly for electric vehicles (EVs). The project is co-funded by the German Federal Ministry for Economic Affairs and Climate Action and involves a consortium of eleven leading organizations from various industries, research institutions, and digital service providers. Key partners include prominent entities like acatech - Deutsche Akademie der Technikwissenschaften, BASF SE, BMW AG, Circulor GmbH, and others.

Figure 6 - Battery Pass consortium

At its core, the Battery Pass project aims to develop and establish a digital battery passport. This digital passport is envisioned as a comprehensive tool for the seamless documentation of a battery's lifecycle, from production through usage, and ultimately to reuse and recycling. The passport is designed to store crucial data regarding the battery, including basic technical details and extensive information about the sustainability and ethical responsibility of the supply chain. For instance, it documents factors like the greenhouse gas footprint, working conditions during raw material extraction, battery condition (age and quality), recyclability, and repairability. The project not only focuses on drafting the content

[14] https://sustainableindustrialmanufacturing.com/europe/news/world-first-battery-pass-project/
[15] https://www.circular-economy-initiative.de/battery-pass-en
[16] https://thebatterypass.eu/news/driving-sustainability-and-circularity-in-the-battery-value-chain-through-digital-product-passports-battery-pass-and-cirpass-discuss-opportunities-for-cooperation/

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and technical standards for this digital passport but also on demonstrating its application through a pilot project.

The broader goals of the Battery Pass project include supporting the transition to low-carbon mobility and energy storage, reducing raw material extraction and dependency, and fostering increased material efficiency, lifetime extension, and the recyclability of batteries. The project is structured around specific work packages that cover various aspects such as content standard development, technical standard coordination, practical piloting, value analysis, and stakeholder coordination.

The project also emphasizes the importance of interoperability and standardization for Digital Product Passports (DPPs) across sectors, recognizing the need for a common framework to facilitate digital data collection and exchange. In this regard, the Battery Pass project collaborates with initiatives like CIRPASS, ensuring alignment with existing legislative requirements and the broader industry's reporting approaches.

The initiative is seen as a strategic step towards realizing the goals of the European Green Deal by leveraging innovation to decarbonize and dematerialize battery value chains, thus contributing significantly to a more sustainable and circular battery economy

Techincal deep-dive [17];[18]

The consortium has published various documents to guide stakeholders in the battery value chain, including a Main Content Guidance document that interprets the EU Battery Regulation and suggests ways to comply with its requirements. Additionally, they offer a Data Attribute Longlist and Carbon Footprint Rules to aid companies in calculating specific carbon footprints for different stages of the battery lifecycle. These resources are essential for achieving compliance with the EU Battery Regulation and enhancing sustainability and circularity within the industry.

The technical framework specification for the Digital Product Passport System is another critical resource provided by the consortium. It serves as a background architecture, outlining a "Standard Stack" essential for selecting, evaluating, and developing standards for the technical system. This framework addresses interoperability issues and presents the

[17] https://thebatterypass.eu/press-release/battery-pass-consortium-publishes-first-content-guidance-on-the-eu-battery-passport/

[18] https://thebatterypass.eu/resources/

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elements required for secure, reliable data exchange across different sectors, including for electric vehicle batteries.

The "Passport Technical Guidance" report addresses the challenges and standards needed for digital product passports across different sectors, emphasizing interoperability and the alignment with the European Green Deal and EU Battery Regulation. The document is designed to guide stakeholders through technical requirements, system architecture, and the interoperability necessary for deploying digital passports for batteries.

An architecture description is provided as a proposal to implement the Standard Stack into an executable system.

The system architecture is divided into three major service-oriented components: the EC Central services, the distributed DPP system services, and the third-party services. The EC Central services fall under the responsibility of the European Commission, while the distributed DPP system services are required to be established and operated by the economic operator or a designated service provider. The third-party services must be established, as mandated, by an external service provider.

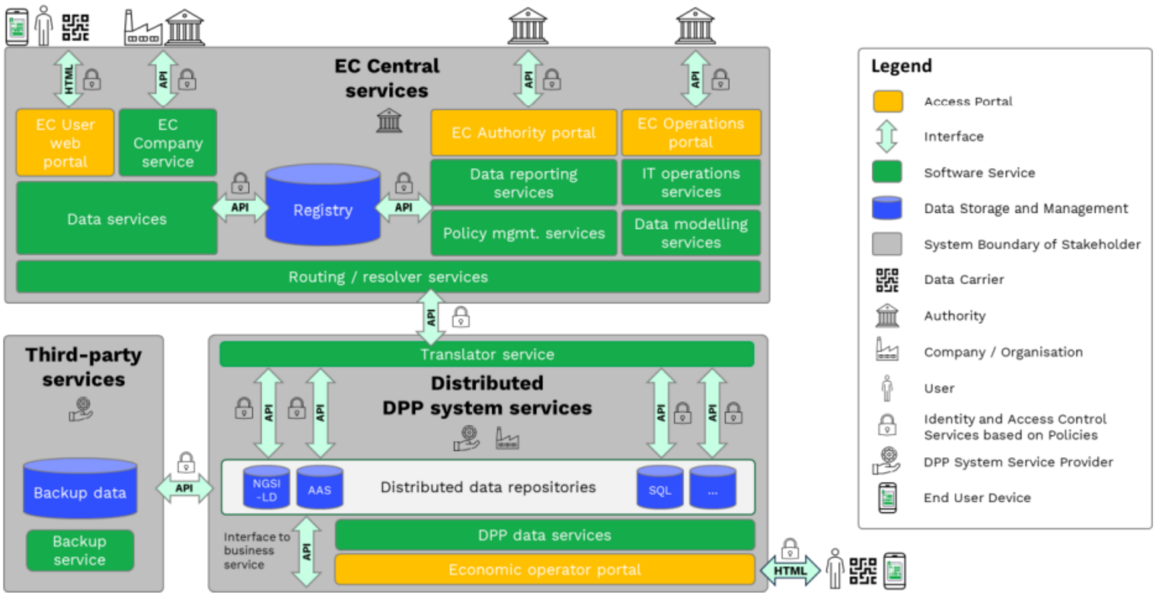

Figure 7 - Battery Pass: Principal system architecture

The report does not specify the use of particular technologies, It discusses the broader aspects of setting up a system that includes components like unique identifiers, data carriers, access rights management, and data exchange protocols.

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A software demonstrator is published alongside this report. The Battery Pass project utilizes a variety of advanced technologies to support the implementation of the EU Battery Passport, although specific technologies were not mentionned in the sources reviewed. However, the project does incorporate FIWARE's open-source software components, which are crucial for developing smart digital solutions and ensuring interoperability across different systems and platforms.

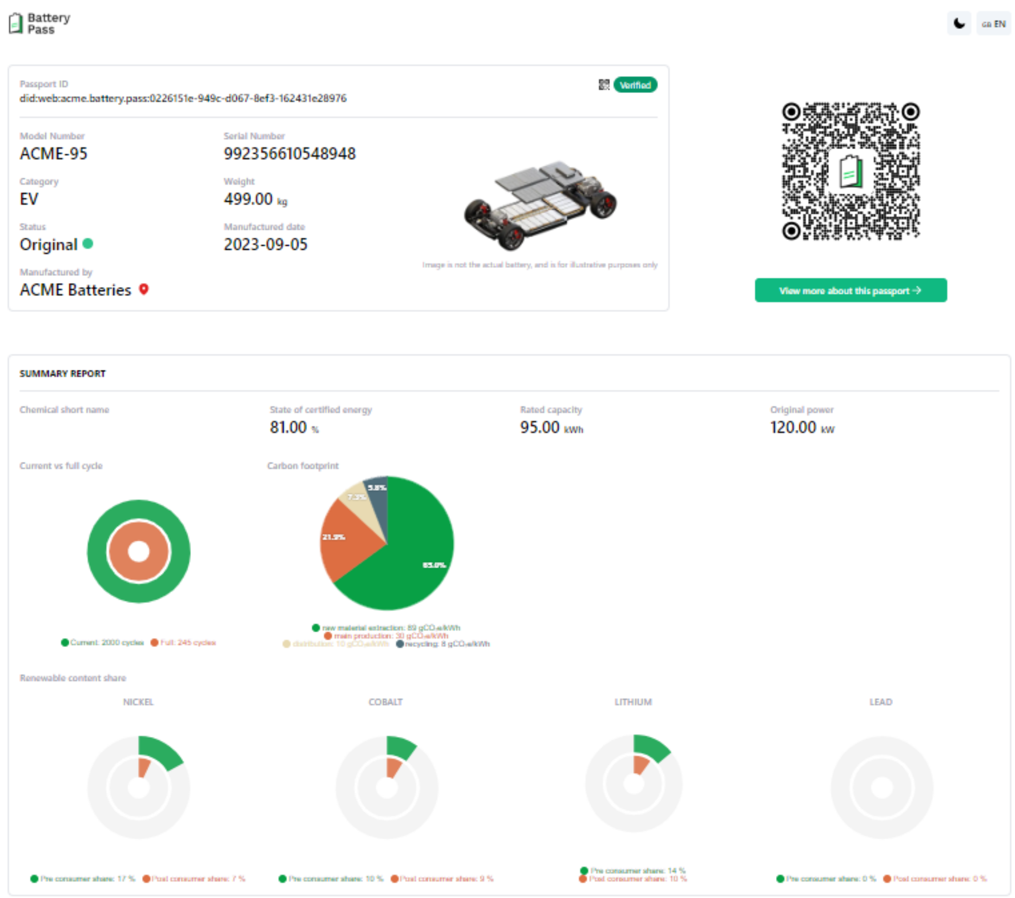

Figure 8 - Battery Pass demo

1.1.6 BatWoMan

Global Overview[19] [20]:

The Carbon Neutral European Battery Cell Production with Sustainable, Innovative Processes and 3D Electrode Design to Manufacture (BatWoMan) project is an EU Horizon initiative aimed at advancing the sustainability and cost-effectiveness of lithium-ion battery

[19] https://batwoman.eu/
[20] https://cordis.europa.eu/project/id/101069705

cell production in Europe. The project, funded with 4.85 million euros, is designed to pioneer carbon-neutral production methods that can significantly reduce both costs and energy consumption in battery manufacturing.

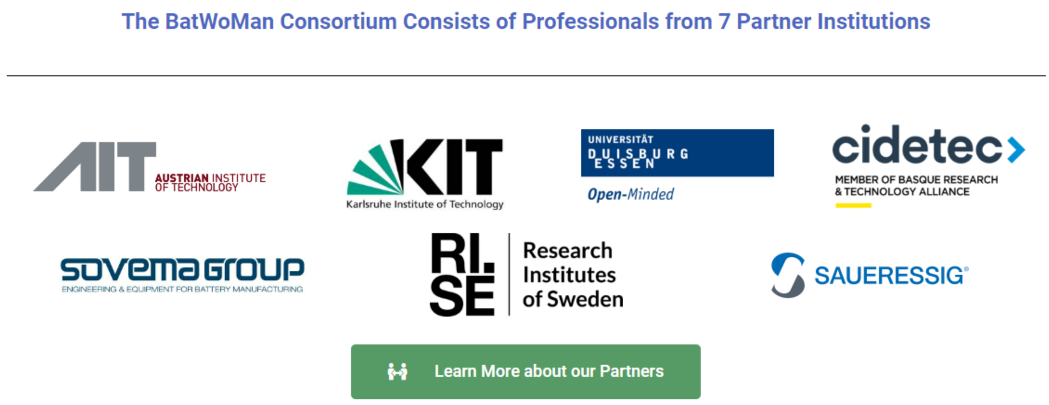

Figure 9 - BatWoMan project consortium

Key technological efforts of the BatWoMan project include the development of energy-efficient processes that do not involve volatile organic compounds (VOCs) for electrode manufacturing, using slurries with a high dry matter content. It also focuses on an innovative dry room concept that improves electrolyte filling and aims to streamline cell conditioning processes such as wetting, formation, and ageing. These efforts are supported by a platform powered by artificial intelligence, which monitors the sustainability and efficiency of the production steps.

The project's objectives are ambitious, targeting a reduction in cell production costs by more than half and a decrease in energy consumption by 52.6%. Such advancements are expected to solidify Europe's leading position in the realm of sustainable battery production. The consortium of the BatWoMan project includes several esteemed institutions and companies across Europe, each bringing specific expertise to the endeavor.

The BatWoMan project is set to run from 2022 to 2025, and its progress is likely to have a significant impact on the future of battery production in the EU, aligning with broader goals of environmental sustainability and economic efficiency in the energy sector.

Funded by the European Union

Technical deep-dive

The BatWoMan project, detailed on the EU's CORDIS portal and the project's LinkedIn page[21], is in its nascent stages, focusing on the decentralization of various aspects of battery cell production. It aims to establish a flexible data model for material information to ensure compliance with EU regulations such as REACH and RoHS. The project also plans to include extensive design-related information through manuals, disassembly maps, maintenance, and washing instructions, underscoring its commitment to transparency and consumer information.

Based on an article on ERCIM News[22] :

"The technical architecture underlying battery passports would consist of a decentralised dataspace ("electronic exchange system" in the EU Battery Regulation), potentially combined with a centralised database. The centralised part may contain static information about battery models, or simply a searchable catalogue of available data in the decentralised dataspace. The decentralised dataspace would consist of data stored at their source (material supplier, manufacturer, etc.) and shared under pre-defined conditions. For example, suppliers could exchange data with manufacturers to facilitate optimisation of the production process, or authorities might have access to information necessary to verify regulatory compliance. By making use of emerging standards for decentralised dataspaces (e.g. the European Gaia-X and IDSA initiatives), such data can also be integrated with other existing and upcoming data ecosystems."

[21] https://www.linkedin.com/company/batwoman/
[22] https://ercim-news.ercim.eu/en133/r-i/digital-battery-passports-for-a-circular-economy

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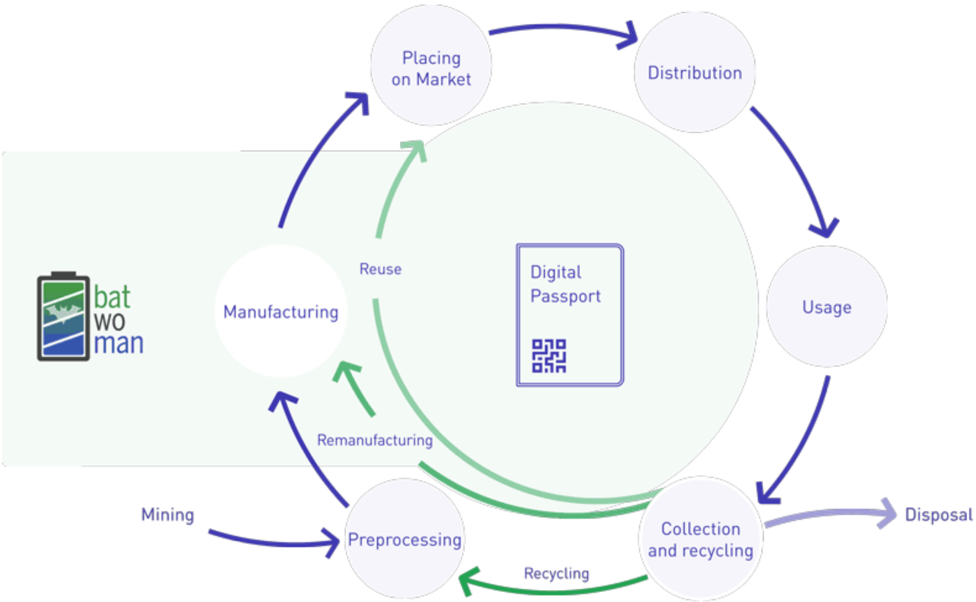

Figure 10 – BatWoman - Battery life cycle, accompanied by a digital product passport.

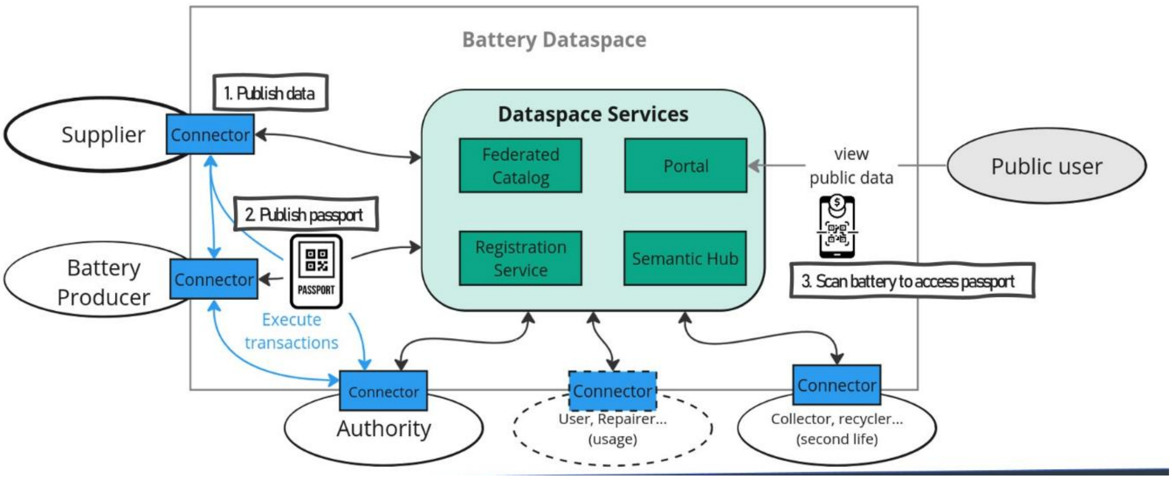

Figure 11 - BatWoMan- users and thir interactions[23]

1.1.7 CircThread

Global Overview[24 25 26]

CircThread is a pioneering project funded under the Horizon 2020 framework, initiated in June 2021, with a mission to revolutionize data utilization across product life cycles to foster circular economy practices. The project involves a consortium of 31 partners from 12 European countries and is endowed with a budget of €9M over a span of four years. Its core

[23] https://www.linkedin.com/feed/update/urn:li:activity:7137455766067720192/
[24] https://weee-forum.org/projects-campaigns/circthread/
[25] https://cordis.europa.eu/project/id/958448
[26] https://circthread.com/

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ambition lies in breaking down data silos to enhance decision-making processes for stakeholders involved in the extended lifecycle of products, from manufacturing through to end-of-use.

The initiative is particularly focused on establishing a Circular Digital Thread methodology. This innovative approach is intended to facilitate seamless information flow and exchange, encompassing a wide array of data including product components, materials, chemicals, and pertinent circularity, environmental, social, and economic information. By creating interconnected data linkages, CircThread aims to provide a robust informational infrastructure that supports a comprehensive Circular Product Chain of Custody.

Technical deep-dive[27] [28]

At the heart of CircThread's technical approach is the development of an 'information broker' marketplace software platform. This platform is designed to assign a digital identity to individual products, thereby enabling a publicly accessible catalogue of information that stakeholders can easily request and exchange. The information encompasses product status logs, materials, resources, critical raw materials, substances, lifespan data, environmental impacts, social aspects, and end-of-use options, all linked to circularity strategies like maintenance, lifespan extension, refurbishment, repair, reuse, remanufacturing, and recycling for secondary raw materials use.

The project envisages the implementation of this system across cloud platforms in three demonstration clusters located in Italy, Slovenia, and Spain. These clusters will focus on the entire extended life cycle chain of home appliances (e.g., washing machines, dishwashers) and home energy systems (e.g., boilers, solar-PV systems, batteries), to test seven circularity use cases and their associated business models. Such a setup is expected to yield tangible benefits including enhanced product life extensions, better quality assessments for end-of-life products, improved circularity routes for waste management, and more efficient materials and chemicals tracing, ultimately empowering decisions by citizens and organizations with direct access to product performance information.

The CircThread Ecosystem's design is divided into three layers: the central CircThread Platform for user and product model registration, the CircThread Data Space for secure and

[27] https://circthread.com/download/deliverable-5-1-architecture-overview-and-schematics/
[28] https://circthread.com/publication-results/project-deliverables/

sovereign data exchange based on the International Data Spaces reference model, and the integration of external Data Apps to utilize and generate new information. This architecture supports interoperability, traceability, and product data sovereignty, featuring a central product model registry, identity and user management systems, a product model meta-data catalogue, digital product passports, and user dashboards for comprehensive data interaction and management.

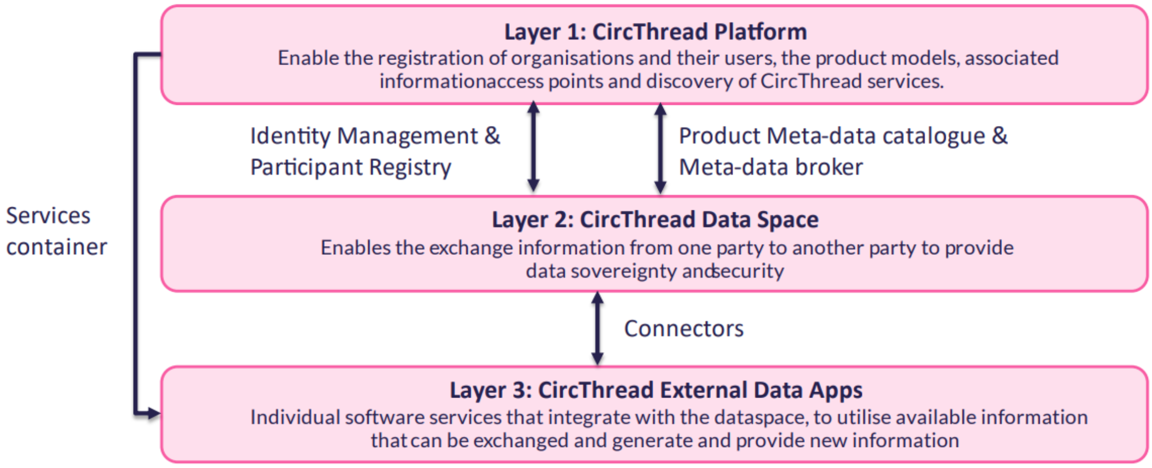

Figure 12- CircThread: Ecosystem layers and the connecting modules from the CircThread Deliverable D5.1 document[29],

Central Product Model Registry

The Central Product Model Registry serves as the foundational layer within the CircThread project, designed to create a unified and standardized repository of product models. This registry facilitates the centralization of product information, including specifications, lifecycle data, and sustainability metrics. By standardizing product data, the registry enables interoperability among different stakeholders in the circular economy, from manufacturers to recyclers. The registry's primary goal is to ensure that product information is easily accessible, accurate, and consistent, thereby supporting the traceability of products throughout their lifecycle and enhancing the efficiency of circular economy practices.

CircThread Data Space - IDSA Ecosystem

The CircThread Data Space utilizes the International Data Spaces (IDS) model to facilitate secure and controlled data exchanges within the circular economy. This approach prioritizes data sovereignty, ensuring that data owners maintain control over their data usage

[29] https://circthread.com/download/deliverable-5-1-architecture-overview-and-schematics/

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according to rigorous security and interoperability standards. The IDS architecture supports this with certification schemes and data services, enhancing trust and maintaining data ownership until it is securely exchanged with trusted parties.

Identity and User Management

The CircThread Platform needs a central registry of organisations and user entities. The IDentity Management system (IDM) to be implemented in the CircThread project will be a module that must allow the creation, modification and deletion of identities and associated accounts, as well as the authentication and authorisation necessary to access particular functions and resources.

One of the mechanisms used to authenticate a user, without using an access token, is through the so-called implicit flow of the OIDC (OpenID Connect) protocol. Different mechanisms may be involved in the authentication process depending on the scenario. One of the scenarios identified in the CircThread project is the access of an application to an API provided by the CircThread Platform to access different resources.

Product Model Meta-data Catalogue

The primary method to access product model information is via the Product Metadata Catalogue, a standardized reference catalogue designed to list documentation about products throughout their lifecycle. It organizes information either as a list or a series of cards/pages, detailing data about the product model such as model number, production dates, name, brand, photo, and manufacturer. The goal is not to store items directly in the Product Metadata Catalogue but to link them with access routes for reference. There are three envisioned types of access:

- A weblink to an external site where the document or information is directly available.
- A process to retrieve public documents from the CircThread Data Space (layer 2) upon request, which necessitates a connector linked to the Product Model Metadata Catalogue for integration with the Data Space, allowing document or information provision through that connector.
- A process for retrieving non-public documents that requires requests and permissions through the CircThread Data Space (layer 2) between two connectors (e.g., from the data provider to the data consumer). Accessing non-public items necessitates setting up permissions through a subscription from one connector to another.

Digital Product Passport (DPP)

The Digital Product Passport (DPP) manager generates and manages DPPs for individual products, detailing product identification (model, serial number, brand, production date), key indicators (lifespan, warranty, compliance), lifecycle status (location, responsible entities from manufacture to recycling), and repair logs, all accessible via standardized web URIs.

The approach for the module is to provide for a series of interfaces for entry of product information based on the role of the user across the product life cycle. Combined with a backend and datastore to enable centralised management of this data at individual product level. The generalised idea is that the information under these categories in the Digital Product Passport at individual product level is public and non-sensitive and can thus be exposed on an online web URI. On that basis a centralised secure datastore operated by the software company or organisation would be a suitable solution. One restriction that is plausibly needed is to not make the online web URI findable and not indexed by search engines, and to disallow web-scraping of the contents. This is needed to make sure that it is not possible to collect the data across individual Digital Product Passports and create a database for aggregate information for a particular brand or manufacturer. This is needed because, for example, individual product repair data is not sensitive but repair data across 1000s or higher numbers of a particular brand or manufacturer can be sensitive.

1.1.8 Circular Passport (Dassault)

Global Overview[30] [31]

Dassault Systèmes significantly contributes to the circular economy with its 3DEXPERIENCE platform, designed to aid organizations in various sectors like consumer goods, industrial infrastructure, and manufacturing, in embedding circular economic principles into their operations. The platform emphasizes three crucial pillars: sourcing sustainable materials, fostering innovative product design and manufacturing processes with circularity at their core, and nurturing the development of circular supply chains. By focusing on sustainable material use, product lifecycle design for recyclability, reusability, or dismantle-ability, and reducing carbon emissions from the early design stages, Dassault Systèmes' approach not only mitigates environmental impact but also guides businesses towards sustainable process reimagining.

[30] https://www.visiativ.com/famille-produits/3dexperience/
[31] https://www.3ds.com/

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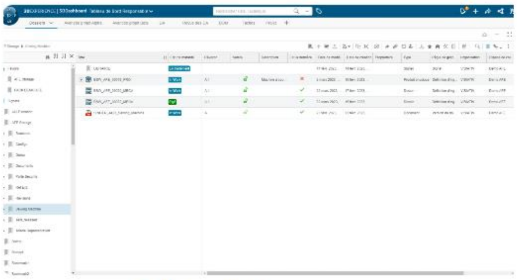
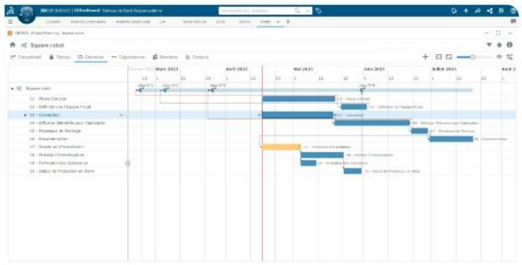


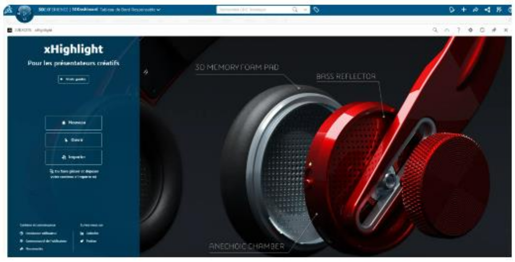
(a) Conception



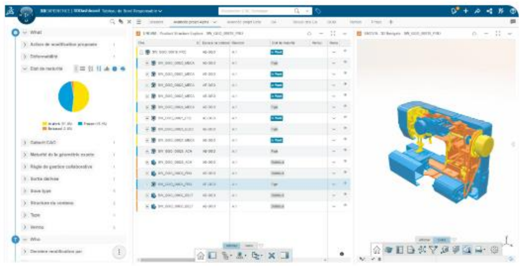
(b) project management

(c) Simulation

(d) manufacturing



(e) Marketing



(f) tool design

Figure 13 - EDEXPERIENCE platform

Technical Deep-dive

The 3DEXPERIENCE platform serves as a critical tool in the circular economy by offering end-to-end visibility of the supply chain. It allows for the strategic use of sustainable materials and components, sourced from reputable suppliers, to minimize waste and emissions from the outset. Designers and manufacturers can use the platform to ensure that products are designed with future recyclability or reusability in mind. The platform also facilitates connectivity through IoT, enabling real-time communication within the production ecosystem to optimize resources and reduce waste.

Dassault Systèmes' 3DEXPERIENCE platform empowers the Circular Passport project, particularly for battery manufacturing, we focus on the innovative use of virtual twins, model-based approaches, and comprehensive lifecycle assessment to drive sustainability and efficiency in battery production.

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Virtual Twin Technology: The 3DEXPERIENCE platform leverages virtual twin technology to simulate the entire lifecycle of batteries, from design and manufacturing to end-of-life recycling. This allows for the optimization of product designs for sustainability, predicting the performance and environmental impact of batteries before physical prototypes are made. Virtual twins enable manufacturers to experiment with different materials and designs to find the most sustainable and efficient solutions.

Model-Based Approach: Dassault Systèmes advocates for a model-based approach to battery manufacturing, which integrates design, engineering, and manufacturing processes on a single platform. This ensures seamless data flow and collaboration across different teams and stages of product development, reducing errors and inefficiencies. The approach accelerates the design-to-manufacturing process, supports the rapid scaling of production capacities, and enhances the ability to meet market demands sustainably.

Lifecycle Assessment and Traceability: The platform provides tools for lifecycle assessment, allowing manufacturers to analyze the environmental impacts of batteries across their entire lifecycle. This includes assessing raw material extraction, production emissions, energy use, and recyclability. Traceability features within the 3DEXPERIENCE platform enable tracking of materials and components throughout the supply chain, ensuring compliance with sustainability standards and regulations, such as those required for the Digital Product Passport.

Collaboration and Supply Chain Visibility: By integrating various stakeholders on the 3DEXPERIENCE platform, Dassault Systèmes facilitates collaboration across the battery value chain. This enhances visibility into the supply chain, allowing for better decision-making regarding material sourcing, supplier selection, and end-of-life management. It ensures that all participants can work towards shared sustainability goals, contributing to the circular economy.

Impact on Battery Manufacturing Innovation: Through the 3DEXPERIENCE platform, Dassault Systèmes enables battery manufacturers to achieve significant improvements in productivity and sustainability. This includes increased lab productivity, reduced need for physical prototypes, shorter manufacturing cycles, and faster product introductions. The platform's comprehensive approach helps manufacturers navigate the complexities of sustainable battery production, from material selection and design to manufacturing and recycling.

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1.1.9 Circularise

Global Overview[32] [33] [34]

Circularise is a Dutch blockchain startup that plays a pivotal role in enhancing sustainability within the plastics industry. It received €1.5 million funding through the EU's Horizon 2020 program, underlining the European Union's commitment to investing in technologies that promote the circular economy. Circularise's innovative approach focuses on tracking plastics from their initial resin stage through to the final product, encapsulating any additives used in the process. This tracking capability is vital not just for verifying the product's origin and assessing its environmental impact but also for improving the recycling process.

[32] https://www.circularise.com/
[33] https://www.ledgerinsights.com/eu-backs-blockchain-plastics-recycling-circularise/
[34] https://www.linkedin.com/pulse/start-up-story-circularise-peter-h-j-auwerx/

Funded by the European Union

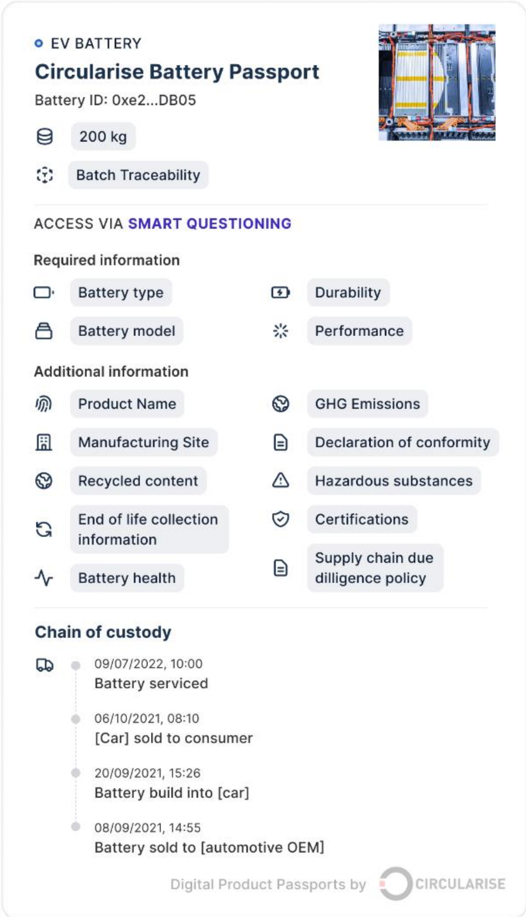

Figure 14- Circularize Battery passport (https://www.circularise.com/use-case/battery-passport)

One of Circularise's key technological advancements is its Smart Questioning technology, which allows for the tracing of a material's carbon footprint across the entire value chain. This technology was applied in a pilot project with SABIC[35] to monitor carbon emissions, demonstrating its potential to significantly reduce administrative efforts associated with data collection and providing valuable insights into upstream and downstream emissions data. The project's approach to handling Scope 1, 2, and 3 emissions (check Annex for scope definitions) data offers a comprehensive view of a product's environmental impact, from direct emissions to those associated with energy production and the broader value chain.

Circularise's mission is to bridge the gap in supply chain transparency by enabling companies to share sensitive data without risking privacy and confidentiality. This approach

[35] https://www.circularise.com/press-releases/circularise-collaborates-with-sabic-on-scope-3-blockchain-tracking

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is designed to not only improve resource use and verify the provenance of materials but also to conduct carbon footprint and impact assessments. By leveraging public blockchain technology, Circularise fosters equality and trust among all supply chain actors, emphasizing the importance of privacy, transparency, and sustainability in achieving a circular economy.

The collaboration between Circularise and SABIC, detailed on Plastics Engineering and Ledger Insights, illustrates the practical application of Circularise's technology in real-world scenarios, offering a glimpse into the future of sustainable manufacturing and supply chain management. Through such initiatives, Circularise is setting a precedent for how blockchain can be utilized to foster transparency, enhance sustainability, and support the transition to a circular economy across industries.

Technical Deep-dive[36] [37] [38]

Circularise leverages blockchain technology to enhance supply chain transparency and sustainability, focusing on the entire lifecycle of products. Their innovative approach enables stakeholders across supply chains to share sensitive data without compromising privacy or confidentiality. This is crucial for verifying the provenance of materials, assessing carbon footprints, and supporting the transition to circular economy business models. Circularise's blockchain-based system provides a robust framework for end-to-end traceability and secure data exchange for industrial supply chains, addressing key challenges in achieving transparency and sustainability in complex, global supply chains.

A key feature of Circularise's technology is selective transparency, allowing businesses to keep certain transaction details confidential while still participating in the broader public network. This balance between privacy and transparency is crucial for companies that are concerned about competitive or legal implications of sharing sensitive information. The use of zero-knowledge proofs (ZKPs) enables Circularise to scale its operations without overburdening the public blockchain network, ensuring transactions remain secure, fast, and cost-effective. This approach maintains the security and immutability inherent in public blockchains, making it an ideal solution for industries seeking to enhance supply chain insights without disclosing private data.

[36] https://www.circularise.com/traceability-with-privacy-enabling-a-circular-economy-with-blockchain
[37] https://www.circularise.com/iscc-and-circularise-pilot-blockchain-technology
[38] https://knowledge-hub.circle-economy.com/article/3997

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How does Smart Questioning work in real life?

Here are some examples of Smart Questions, disclosure type, and answers in various industries.

- Battery industry
- Smart Question [Range Proof] : **Is concentration of mercury extending 0.001%?**
- Answer: **No, concentration of mercury less than 0.001%**
- Electronics Industry
- Smart Question [Range Proof]: **Does the product contain Lead (Pb)?**
- Answer: **No Lead (Pb) content in Product**
- Electronics Industry
- Smart Question [Set Membership]: **Is tungsten sourced from the DRC region?**
- Answer: **No**
- Plastics Industry
- Smart Question [Set Membership]: **Does the product contain Bromine?**
- Answer: **No**
- Plastics Industry
- Smart Question [Range Proof]: **Is the primary fossil material content less than 25%?**
- Answer: **Yes, primary fossil material content less than 25%**
- Any Industry
- Smart Question [Range Proof]: **Is the product carbon footprint per kg over 3 kg CO2-eq?**
- Answer: **Yes**

Figure 15- Example on Smart Questionning – (https://www.circularise.com/blogs/smart-questioning-achieve-supply-chain-visibility-without-risking-data-privacy)

Circularise's blockchain solution offers numerous benefits to its users, including improved transparency, efficient and trustworthy data-sharing, and the strengthening of companies' reputations by providing verifiable evidence of their commitment to sustainability. This has significant implications for industries with large, complex supply chains such as automotive, batteries, construction, electronics, metals, plastics, and aviation. By fostering a more transparent, sustainable, and circular global economy, Circularise enables businesses to optimize their supply chains, reduce environmental impact, and enhance their market reputation.

The Circularise protocol utilizes unique identifiers, or CIRLABELS, attached to materials, parts, and products via QR codes, RFID, NFC, or any IoT-enabled device, facilitating the monitoring and data gathering at every stage of the value chain—from miner to recycler. This comprehensive tracking system, combined with Circularise's software solutions for mass balance bookkeeping and digital product passports, provides an end-to-end batch traceability that is essential for companies aiming to improve resource use, verify provenance, and conduct carbon footprint and impact assessments.

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Circularise's collaboration with ISCC Plus certification highlights its potential to make auditing more efficient and enhance the integrity of certified data. By using a public blockchain, Circularise ensures that sustainability claims are verifiable and cannot be misrepresented, laying a foundation of trust in data integrity. This approach is especially beneficial for the chemical sector's sustainability transformation efforts, enabling more sustainable feedstock sourcing and supporting the use of existing infrastructure for a more sustainable future.

« They are developing an open source, free access BC platform based on the Ethereum protocol in order to smoothen the flows of information between different stakeholders within the value chain [39]»

« 09:43 M: Yes, exactly. And that's why you use Ethereum?

09:46 J: Ethereum, in this case, is so far the most developed, it's not ideal but currently the best option. The reason is that you can have tokens on Ethereum, so you have a means of payment to ensure you can pay other people who compute a computation for you and you have smart contracts, those are the only two requirements we need from a blockchain. Yes, it must of course be secure, etc., but in principle, if another chain were to emerge that, for example, has a higher transaction speed and still has smart contracts and tokens, we could switch. So, we are not dependent. »

« Our solution uses Pedersen commitments, which are cryptographic algorithms that are very similar in function to hashes. It allows the prover to prove a committed value or certain properties thereof, but without revealing or being able to change it. [40]»

1.1.10 Circulor[41]

Global Overview:

Circulor offers a blockchain-based platform that enhances supply chain traceability and sustainability for materials critical to industries like automotive and electronics. They focus on ensuring responsible sourcing, reducing environmental impacts, and aiding companies in regulatory compliance.

[39] https://repository.tudelft.nl/islandora/object/uuid:d6736f9b-f870-4736-a5e7-2ef292cf69aa/datastream/OBJ3/www.bamb2020.eu/topics/overview/state-of-the-art/
[40] https://www.circularise.com/blogs/smart-questioning-achieve-supply-chain-visibility-without-risking-data-privacy
[41] https://www.circulor.com/solutions

Technical Deep-dive[42] [43]

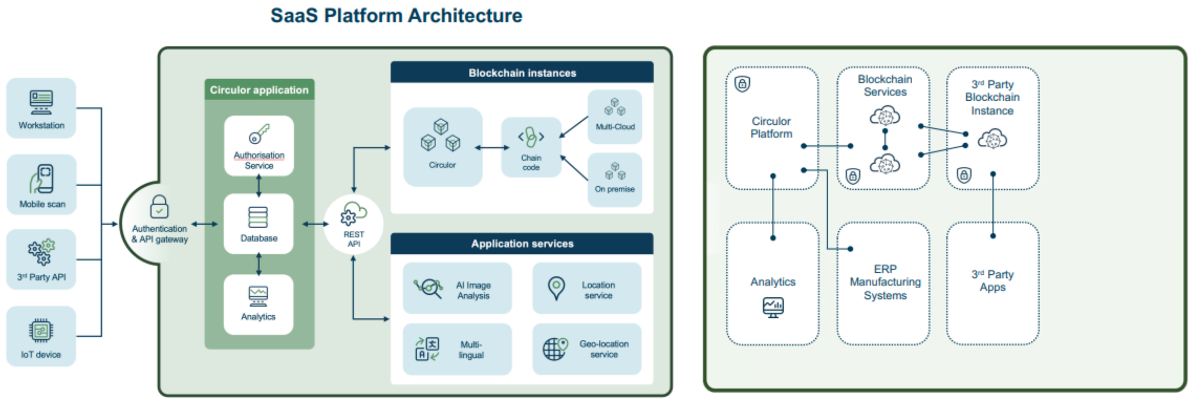

Figure 16 - Circulor : SaaS Platform architecture

Circulor leverages Hyperledger Fabric to enhance the traceability of supply chains, particularly for electric vehicle batteries. Their platform integrates digital twin technology and a robust ESG database to create and manage digital product passports. This setup tracks the provenance and carbon emissions of materials from their point of origin through the manufacturing process and beyond. By utilizing blockchain, Circulor offers a secure and transparent record-keeping mechanism that is pivotal in meeting regulatory requirements such as the EU Battery Regulation. Their system ensures that all battery materials are sourced responsibly and sustainably, contributing significantly to environmental sustainability goals.

Key elements:

- A hybrid solution using Oracle Database and Hyperledger Fabric creates a private permissioned blockchain network
- Only approved organisations can join the network only accessing data directly related to them
- No personally identifiable information is written to the blockchain, these are kept off-chain and can be removed when no longer required
- Business rules and data analysis identify anomalies and detect trends and patterns
- Custom analytics dashboards provide both deep and wide views of the data as it flow through the system

[42] https://osseu2023.sched.com/event/1Qqz7
[43] https://static.sched.com/hosted_files/osseu2023/b3/Circulor%20-%20OSS-EU%20-%20Sept%202023.pdf

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- Machine learning in the form of image analysis is used to detect, analyse and compare faces to verify authorized users of the platform

2. Transaction

A transaction involves at least two profiles as the ownership and/or possession of the mineral, metal, scrap or product is transmitted from one entity with a unique single identifier to another.

Each transaction recorded shall be linked, at any point in time, to a single unique identifier for ownership and a single unique identifier for possession.

The transaction may be linked to two single unique identifiers where the entity that owns the mineral, metal or product is not the same as the entity that possesses the mineral, metal or product. The transaction may be linked to one single unique identifier where the ownership and possession of the mineral, metal or product overlap. For example:

- Material ownership may be transferred with the possession of the mineral, metal or product;
- Material ownership may be transferred without a change in the possession of the mineral, metal or product (e.g., where minerals are already in the custody of a refiner after assaying/appraisal); or
- Possession of the mineral, metal or product may be transferred without a change in material ownership (e.g., in tolling agreements, transportation or storing).

At a minimum, each transaction should include the following attributes:

- A hash unique to the transaction
- The single unique identifier at the beginning of the transaction
- The single unique identifier at the end of the transaction
- Primary metal name

In addition, each transaction should include the following attributes for:

Upstream supply chains:

- Grade (based on assay or estimates)
- Mine location
- Ore/concentrate weight (wet or dry)
- Calculated metal weight
- Export documentation complete (if required)

Downstream supply chains:

- Product information

Figure 17 - Extract from rmi guidelines[44]

Besides , Circulor advocates interoperability; we supported the establishment of the RMI [45] Blockchain guidelines and contribute to leading-edge research in this space.

1.1.11 CYCLANCE

Global Overview[46] [47]

CYCLANCE-World, launched by EECC, is a platform showcasing sustainable business models through the use of a digital twin. The project utilizes advanced EPCIS 2.0 technology, IoT, and Digital Link to demonstrate future capabilities today, especially highlighting the forthcoming EU Digital Product Passport. CYCLANCE-World emphasizes

44 https://www.responsiblemineralsinitiative.org/media/docs/RMI%20Blockchain%20Guidelines%20-%20Second%20Edition%20-%20March%202020%20FINAL.pdf
45 https://www.responsiblemineralsinitiative.org/
46 http://european-epc-competence-center.eu/?news=132
47 https://www.eecc.info/

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sustainable circular economy practices, enabling the unique identification and recycling of plastic packaging through the R-Cycle[48] service. It aims to foster best practices across various sectors including textiles, food, batteries, and electro/industry, utilizing GS1 standards to enhance supply chain operations and product lifecycle management.

Figure 18 - cyclance initiative in EECC innovationLabs

Technical deep-dive

Create a connected event dataflow using GS1 EPICS standard. Then, the information is stored decentralized (not specified how) and items are registered using RFID or QR codes. Data packaging is done via an API. [49]

1.1.12 EasyBat

Global Overview

The Fluvius, Bebat, and Energy Web collaboration focuses on an innovative project to advance battery lifecycle management through decentralized technologies. This project is part of Energy Web's broader initiative to use blockchain and decentralized tech to enhance energy systems.

[48] https://eecc.de/?news=124
[49]https://cirpassproject.eu/wp-content/uploads/2023/06/CIRPASS-D3.1-Annex-V2_June-1st.pdf

Funded by the European Union

The project focused on building an open-source solution for decentralized lifecycle battery asset management in light of EU's Battery Directive (and the new) that requires member countries to institute schemes to ensure environmentally responsible recycling and/or disposal of post-consumer batteries. The current conditions in Belgium, such as the registration of customer-owned assets, requires a lot of information and burdensome paperwork collection. Under this project, decentralized digital passports or identities were created and assigned to batteries to digitally track their lifecycle.[50]

Focused on the EV Battery sector in Belgium. This is a pilot project that is still being developed and tested. There is no commercial release and no defined business model.

Technical deep dive

The initiative involves developing and implementing a decentralized solution called EasyBat, which is designed to manage the lifecycle of battery assets. This system leverages Energy Web's Decentralized Operating System (EW-DOS), focusing on the entire battery lifecycle. It aims to connect various stakeholders, including original equipment manufacturers (OEMs), distributors, installers, and certified inspection organizations, facilitating seamless and secure transactions across the battery's lifecycle.

The project utilizes the Energy Web Decentralized Operating System(EW-DOS Technology), a sophisticated open-source technology stack designed for the energy sector. This system supports various functionalities essential for decentralized data exchange and digital identity verification (ew-did-registry), enhancing the security and efficiency of battery lifecycle management.

At its core, the project leverages blockchain technology to ensure that all transactions are secure and verifiable. EasyBat is designed to integrate smoothly with existing industry systems.

The project has used blockchain standards like ERC 1056 and 1155, but also DIDs and VCs. They propose a decentralized approach.[51] [52] [53]

[50]https://bebat.prezly.com/bebat-et-fluvius-lancent--easybat--pour-mieux-suivre-le-cycle-de-vie-des-batteries-via-la-blockchain
[51]https://www.bebat.be/en/about-bebat
[52]https://www.energyweb.org/
[53] https://github.com/energywebfoundation

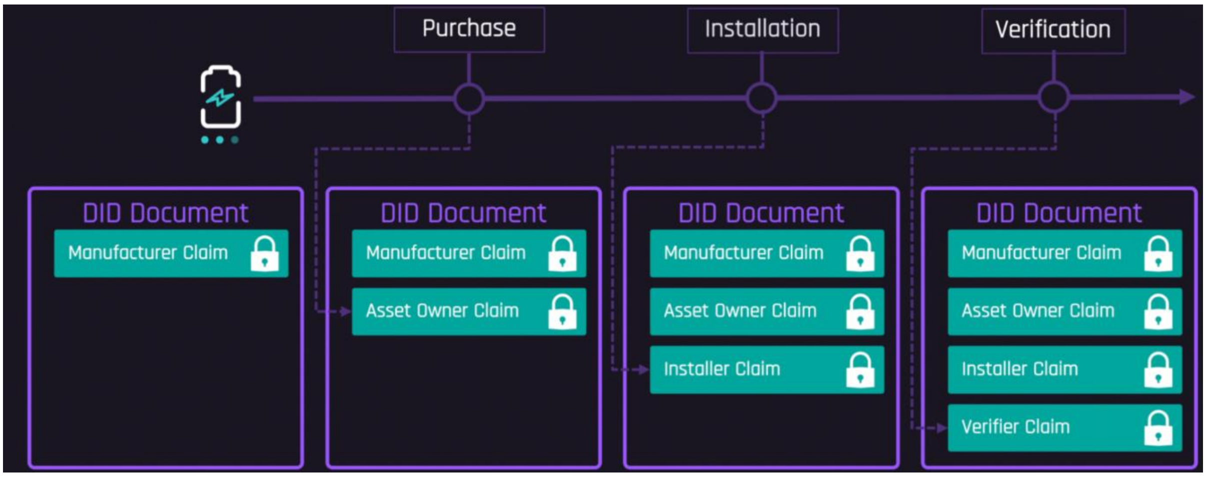

Figure 19 – EasyBat : Claims at each phase of the battery's lifecycle are stored on the DID Document[54]

1.1.13 Free4Lib [55]

Global Overview

Feasible recovery of critical raw materials through a new circular ecosystem for a li-ion battery cross-value chain in Europe (Free4Lib) project objective is to facilitate Lithium –Ion batteries (LIB) recycling. To do this, they approach the whole recycling process from the correct identification and labelling (introducing a battery passport) to the industrial process of recycling this batteries. Part of the EU Horizon project. They are focused on EV batteries for the EU market. The project started in 2022 and is in progress.

FREE4LIB is a EU-funded research project on 21 technologies covering the entire Li-Ion battery value-chain. It aims to develop new technologies (5-6 TRL) to achieve sustainable and efficient processes to recycle EOL LIBs: dismantling, pre-treatment and 4 materials recovery processes). The new processes will deliver recycling solutions to reach efficient materials recovery in high amounts and thus improving the supply of secondary resources at EU level.[56]

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[54] https://energy-web-foundation.gitbook.io/energy-web/foundational-concepts/scaling-access-to-grid-flexibility
[55] https://www.freeforlib.eu/
[56] https://www.freeforlib.eu/about-the-project

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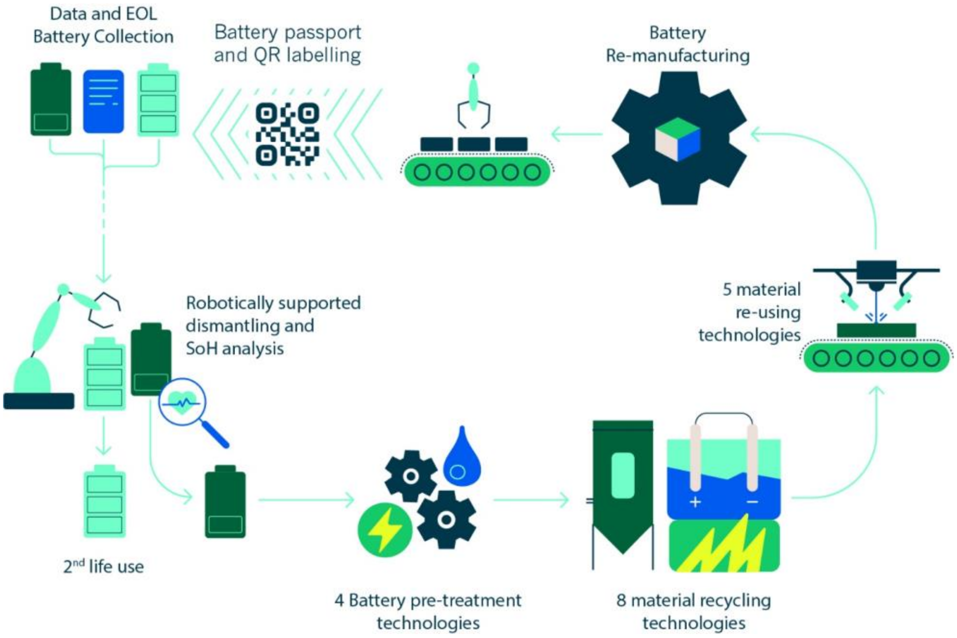

Figure 20 – FREE4LIB technologies[57]

FREE4LIB also will deliver 3 processes aiming at metals and polymers re-using and electrode synthesis: this will allow the re-manufacturing of new LIBs with a Design for Recycling. The team will also study options to harness non-reusable elements.

FREE4LIB will also optimise processes and traceability thanks to new Battery Passport (BP) methodology, and Open Platforms for the BP and Data-driven models.

Technical deep-dive

They propose a centralized approach to handle battery passports. Yet the technological prospective of the project go beyond tracing and digital passports but the complete overhaul of the battery manufacturing process. They aim to propose new materials and recycling technologies for batteries systems, aiming at the 2nd life use of batteries and boosting circular economy.

1.1.14 Global Battery Alliance[58]

[57] https://www.rhinoceros-project.eu/wp-content/uploads/2024/01/FREE4LIB_DBP_workshop_results.pdf

[58] https://www.globalbattery.org/about/

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Global Overview

The GBA 2030 Vision is to foster a circular, responsible and just battery value chain. *They present* challenges related to battery raw material extraction, production and lifecycle management. It also outlined a vision for how multi-stakeholder collaboration across the battery value chain could address and mitigate each of the ESG risks and establish a pathway for the achievement of a sustainable and responsible battery value chain by 2030.[59]

Establish a circular battery value chain as a major driver to achieve the Paris Agreement

1. Maximizing the productivity of batteries in their first life
2. Enabling a productive and safe second life use
3. Ensuring the circular recovery of battery materials

Establish a low carbon economy in the value chain, create new jobs and additional economic value

4. Disclosing and progressively decreasing greenhouse gas emissions
5. Prioritizing energy efficiency measures and substantially increase the use of renewable energy as a source of power and heat when available
6. Fostering battery-enabled renewable energy integration and access with a focus on developing countries
7. Supporting high quality job creation and skills development

Safeguard human rights and economic development consistent with the UN Sustainable Development Goals

8. Immediately and urgently eliminating child and forced labour, strengthening communities and respecting the human rights of those employed by the value chain
9. Fostering protection of public health and the environment, minimizing and remediating the impact from pollution in the value chain
10. Supporting responsible trade and anti corruption practices, local value creation and economic diversification

Figure 21 – Global Battery Alliance : Guiding principles[60]

Technical deep dive[61]

The project is technology agnostic and is open to IT solution providers for their propositions.

1.1.15 Information for Recyclers platform[62]

[59]https://www.globalbattery.org/battery-passport/
[60] https://www.globalbattery.org/about/
[61]https://www.globalbattery.org/action-platforms-menu/pilot-test/
[62]https://i4r-platform.eu/about/

Funded by the European Union

Global Overview

To better respond to recyclers' needs, APPLiA and DIGITALEUROPE have created this single central online platform – the Information for Recyclers Platform (I4R) – where recyclers can access recycling information at product category level. The WEEE[63] Forum, an international association of producer responsibility organisations and a centre of competence, will host and maintain the platform. To meet the requirements of Directive 2012/19/EU, the recycling information will be linked to the presence and location of materials and components in electronic waste that require separate treatment.

The I4R platform provides treatment and recycling facilities and preparation for re-use operators with access to WEEE recycling information in line with the requirements of Directive 2012/19/EU.[64]

Technical deep dive

They propose a centralized repository with information for recyclers.

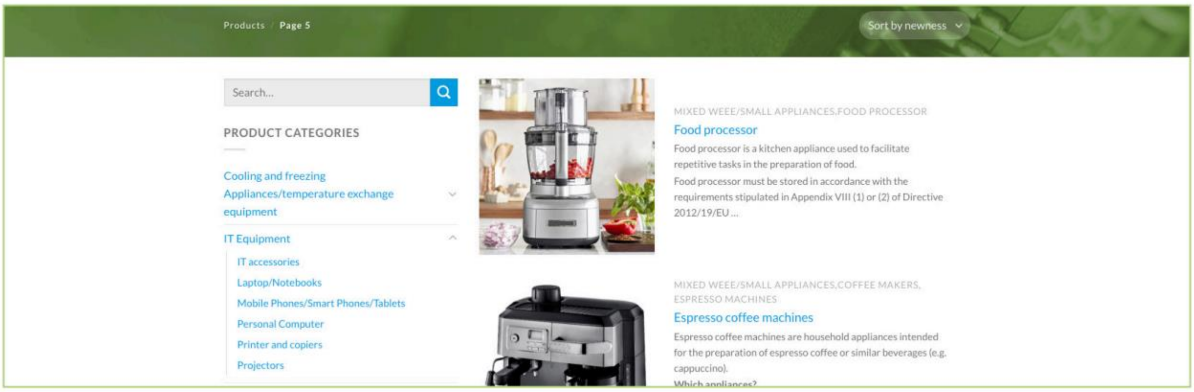

Figure 22 – I4R platform

1.1.16 IOTA - EBSI PCP[65]

Global Overview

The European Blockchain Services Infrastructure (EBSI) was born in 2018 when 29 countries (all EU members states, Norway and Liechtenstein) and the EU Commission have joined forces to create the European Blockchain Partnership (EBP).

[63] https://www.weeeireland.ie/close-the-loop-initiatives/i4r-weee-recycling-information-platform/
[64] https://i4r-platform.eu/wp-content/uploads/2020/09/Triptic_I4R_Platform_DIGITAL.pdf
[65] https://www.iota.org/solutions/ebsi

EBP's vision is to leverage blockchain to create cross-border services for public administrations, businesses, citizens and their ecosystems to verify information and make services trustworthy.

EBSI wants to improve the efficiency and trust of EU-wide transactions, enhance the mobility of citizens, enterprises and goods, and reduce Europe's environmental impact.

The European Commission is looking for novel blockchain solutions for the European Blockchain Services Infrastructure. The first solution design phase of the EU blockchain PCP was completed by 7 contractors. Phase 2A 'prototype development and lab testing' was completed by 5 contractors. Phase 2B 'final solution development and field testing' is now ongoing.[66]

The IOTA Foundation is participating in EBSI's pre-commercial procurement (PCP), which pilots new distributed ledger technology (DLT) solutions to underpin the evolution of EBSI.

After being selected for Phase 1 of the PCP with six other projects from 35 applicants, and also successfully completing rigorous testing in Phase 2A of the EU blockchain Pre-Commercial Procurement the IOTA Foundation has been selected along with two other projects for the last phase to develop and test at a larger scale a distributed ledger solution for delivering improved European-wide blockchain services.

IOTA is offering our core technology that can be integrated into the EBSI infrastructure, making IOTA's functionalities available for institutions and actors from across Europe.

Technical deep dive.[67] [68]

DPPs built using W3C, GS1 standards and the EBSI as a trust anchor.

DPP will build on frameworks such as IOTA Streams for protecting data confidentiality and IOTA Identity for guaranteeing data integrity and access control. In addition, IOTA's new Digital Assets framework will be leveraged to create Non-Fungible Tokens (NFTs) to track ownership of original intellectual work.

The IOTA Foundation is offering its advanced core technology, packaging it with additional solutions required for integration into the EBSI infrastructure and supporting a wide range of crossborder use cases foreseen for EBSI. The proposed modular approach combines

[66]https://digital-strategy.ec.europa.eu/en/news/european-blockchain-pre-commercial-procurement
[67]https://files.iota.org/comms/IOTA-EBSI-leaflet.pdf
[68] https://fr.beincrypto.com/marches/40785/iota-sapprete-a-activer-ebsi/

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existing and new components from the core IOTA protocol and runs IOTA frameworks such as IOTA Identity or IOTA Streams on top of it. This way, the broad set of functionalities of the IOTA protocol are made available for institutions and actors across Europe, enabling them to develop novel use cases.

Core Technology - IOTA Tangle: Unlike traditional blockchains, IOTA's Tangle uses a directed acyclic graph (DAG) structure that allows transactions to be processed in parallel, increasing throughput and scalability. This structure is particularly suited to the EBSI's needs for high transaction volumes and interoperability among EU institutions.

Modular Approach: IOTA's proposal includes modular solutions that integrate seamlessly with existing EBSI components. This modular architecture allows for flexible implementation and scalability, adapting to specific needs of the EBSI framework.

Data Sharding: IOTA introduces data sharding capabilities to enhance scalability and performance. Sharding allows the network to partition data according to geographic or institutional parameters, aligning with EBSI's requirements for localized data handling and compliance

1.1.17 Lynx Technologies [69]

Global Overview

Traceability enabling trust and supporting a circular economy. It means more than maintaining visibility over products and ensure they meet regulatory standards. Transparency builds trust by providing consumers with accurate and up-to-date information about their products. Continuous support to the latest global traceability standards. A Digital Product Passport (DPP) is a way of collecting information about a product in a structured way.

Lynx Technologies is an IT company that provides DPP solutions.

Lynx integrates with existing traceability and manufacturing systems, consolidating data on a single platform and reducing collection, validation and reporting complexity.

[69] https://www.lynx.swiss/

Whenever a new partner becomes part of the supply chain, its data becomes available to brand owners for a fraction of the cost.

Lynx enables continued monitoring and an automated alert system to communicate efficiently with all involved partners and internal teams whenever an issue is observed.

Technical deep dive [70] [71]

Integration with Existing Systems: Lynx Technologies' platform integrates with current traceability and manufacturing systems, providing a centralized data hub that enhances the management of product lifecycle information. This integration facilitates real-time insights into the activities of supply chain partners, ensuring that brand owners maintain up-to-date knowledge of their products' journey from creation to consumer

Data Handling and Security: The platform prioritizes security and efficient data management, focusing on the protection and integrity of the information processed and stored. This is crucial for ensuring that all stakeholders in the supply chain can rely on the accuracy and timeliness of the data provided

1.1.18 Minespider AG

Global Overview

Minespider provides digital traceability for raw materials and products, including digital Product and Battery Passports, enabling companies to communicate their compliance and sustainability efforts. By leveraging their blockchain-based platform, Minespider offers immutable and secure records, offering transparency and helping businesses contribute to the circular economy by optimizing their supply chains and reducing waste and inefficiencies. With Minespider, companies can track their products' journey from raw materials to finished goods, empowering them to make data-driven decisions that benefit both their bottom line and the planet.[72]

Minespider is a member of the European Battery Alliance (EBA) and Batteryline. Minespider is also part of the BATRAW project, which is an European Commission-funded project consisting of a 18 member consortium, with companies across the whole battery value

[70] https://trustvalley.swiss/startups/lynx-technologies/
[71] https://www.startup.ch/lynx-technologies
[72]https://www.minespider.com/about-us

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chain. The project is about developing new technological processes for the recovery of critical raw materials contained in electric vehicle batteries, and establishing a fully traceable Battery Passport, starting with end-of-life batteries - to track, collect, assess, and share relevant data along battery supply chains and recycling loops efficiently - in a way that facilitates the collaboration of participants along the supply chain.[73]

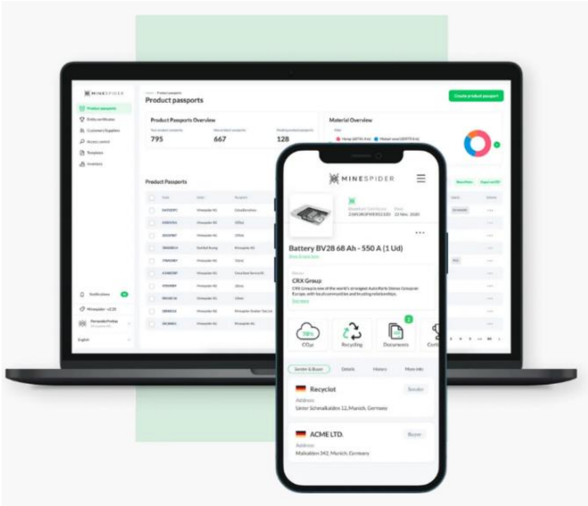


Figure 23 – Minespider Platform

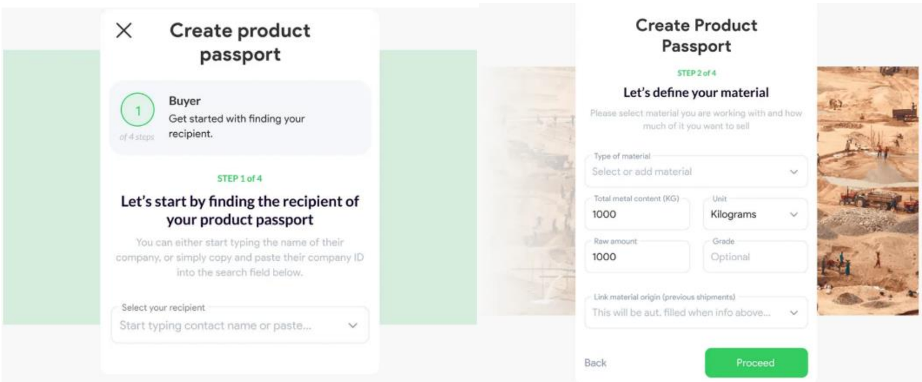


Figure 24 – Minespider Platform (steps 1 & 2)

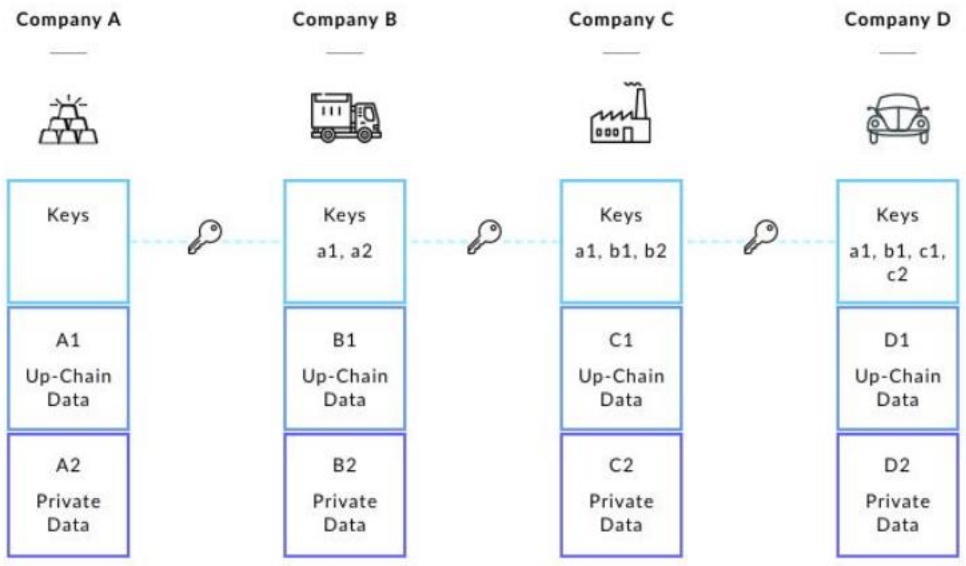
Technical deep dive [74]

Minespider utilizes blockchain technology to create secure and transparent digital product passports for materials like minerals. These passports contain critical lifecycle data, which

[73]https://cordis.europa.eu/project/id/946437

[74] https://uploads-ssl.webflow.com/5bb20121ca2e96ee01db29bc/5c0fa81d4a4585e37ea764b7_Minespider_Whitepaper.pdf

can be crucial for compliance and sustainability reporting. Minespider's platform also integrates with IoT devices to facilitate real-time data collection from the beginning of the supply chain. Their system is designed to be blockchain agnostic, providing flexibility in adapting to various blockchain frameworks.



the Minespider Protocol employs a "russian doll" data structure where keys to access supply chain history stored in the certificate are passed as a nested, encoded data packet. To accomplish this we propose data be stored in 3 segments.

Key Packet contains keys for the segments of the doll to which the company has access. **Segment 1** contains data which should be visible to every member of the supply chain. **Segment 2** contains data which should be stored but visible only to the current and successive member of the supply chain. A company will create one of these for each sale.

The Minespider Protocol is comprised of three key elements:

1. The Blockchain Layer: Decentralized, so that no single entity controls supply chain data.
2. The Application Layer: Enterprise software that grants access to the protocol.
3. The SILQ utility token: Allows the system to function without centralized control.

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Minespider's responsible sourcing solution employs a proprietary blockchain system built on top of the public Ethereum blockchain. The choice of a public blockchain was taken to give more flexibility and scalability to the system if demand grew.[75]

The system employs an energy-efficient proof-of-authority consensus mechanism in so that, "The power equivalent of only a couple of light bulbs is necessary to run the Minespider blockchain" [respondent 5]. A senior manager at Minespider confirmed the low costs of operating the system, stating that the total cost of developing and operating the system, including data entry and storage, and conducting transactions, amounts to "pennies per container" (respondent 2). At the mid-November 2023 spot price of roughly $24,500/ton, a container holding 25 tonnes of tin is valued at $600,000. Therefore, the system makes for extremely efficient tracing at a tiny fraction of the cost of each container. Minsur mines 12% of the world's tin annually, and in this context, the initial investment in the blockchain traceability system is comparatively small. [75]

1.1.19 Optel Group [76]

Global Overview

The Optchain platform acts as a supply chain control tower, capturing and connecting granular data along the supply chain to provide greater visibility and transparency. Optchain's traceability capabilities allow you to optimize the performance and sustainability of your supply chain while complying with local regulations and international standards.[77]

The Optchain™ platform provides a solution to trace a product from its source to manufacturing sites, ensuring it comes from approved suppliers that meet the sustainability requirements of the brand. This responsible sourcing solution provides raw-material traceability and visibility to limit the negative impact of the supply chain.

[75] https://openresearch.surrey.ac.uk/esploro/outputs/99862366502346?institution=44SUR_INST&skipUsageReporting=true&recordUsage=false
[76] https://www.optelgroup.com/en/solution/track-and-trace/
[77] https://www.optelgroup.com/en/solution/digital-product-passport/

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Figure 25 – Optel group platform

Figure 26 – Opchain :track and trace

Technical deep dive

Optchain, developed by OPTEL Group, utilizes blockchain technology as part of its capabilities. This technology integration is highlighted in the collaborative work between OPTEL and IBM's XCEED platform, which is a blockchain-based system designed to enhance traceability and compliance across various industries, including automotive and aeronautics.

Artificial intelligence is utilized within Optchain for dynamic supply chain mapping, real-time inventory geolocation, and to improve operational intelligence by providing predictive analytics that enhance decision-making processesProject Evaluation.

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Internet of Things technology is employed to facilitate real-time tracking of physical assets and environmental conditions across the supply chain, which greatly aids in inventory control and ensures more accurate, up-to-date information

Metric	Description
Underlying Technology	Optchain collaborates with IBM's XCEED blockchain-based platform. Integrates AI and iot.and seems to have cloud solution for their track and trace solution.
Data Integrity and Security	supported by blockchain's inherent security features.
Interoperability	Easy interoperability by using GS1 standards.
Data Privacy Compliance	Complies with international data protection regulations,
User Accessibility and Interface	Offers an intuitive, user-friendly web interface
Environmental Impact and Sustainability	Supports sustainable practices through carbon footprint tracking and ESG goal achievement
Regulatory Compliance	Compliance readiness and connection with external partners (audit data, gov).
Market Adoption and Ecosystem	Continuously evolves to incorporate the latest technologies and meet changing industry demands.
Innovation and Adaptability	N/A.
Cost-Effectiveness	N/A.
Centralized/Decentralized	Probably hybrid, with blockchain-based solution, and cloud based data management(track and trace).

1.1.20 ProSUM[78]

[78]https://www.prosumproject.eu/

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Global Overview

Information about SRM arising from waste streams in the future in Europe.

The ProSUM project will deliver the First Urban Mine Knowledge Data Platform, a centralised database of all available data and information on arisings, stocks, flows and treatment of waste electrical and electronic equipment (WEEE), end-of-life vehicles (ELVs), batteries and mining wastes. The availability of primary and secondary raw materials data, easily accessible in one platform, will provide the foundation for improving Europe's position on raw material supply, with the ability to accommodate more wastes and resources in future. ProSUM will provide data for improving the management of these wastes and enhancing the resource efficiency of collection, treatment and recycling.

To deliver the first **Urban Mine Knowledge Data Platform**

- A centralised database of all available data and information on arisings, stocks, flows and treatment of waste electrical and electronic equipment (WEEE), end-of-life vehicles (ELVs), batteries and mining wastes.
- Primary and secondary raw materials data, easily accessible in one platform.
- Provides the foundation for improving Europe's position on raw material supply, with the ability to accommodate more wastes and resources in future.
- Will provide user friendly, seamless access to data and intelligence on mineral resources from extraction to end of life products with the ability to reference all spatial and non-spatial data.

To provide **harmonised data** to allow stakeholders to improve the management of these wastes and enhance the resource efficiency of collection, treatment and recycling

- Providing screened interoperable data on products and mining waste in stock, waste flows, the nature of the waste and the materials and elements which they contain.
- Providing protocols and methodologies to update the EU-UMKDP and to make future data comparable and interoperable.

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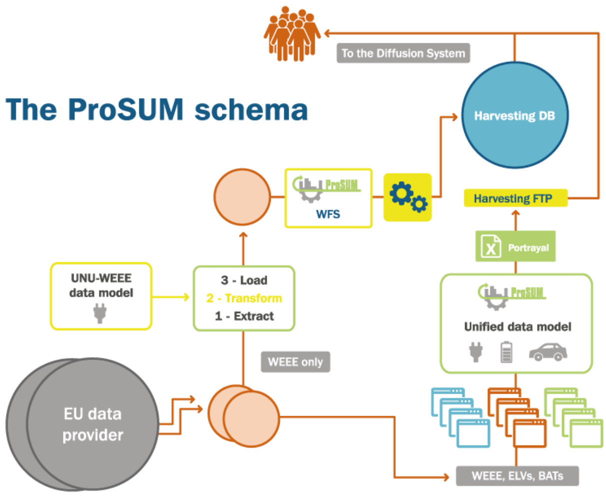

Figure 27 – ProSUM schema

ProSUM, Latin for 'I am useful', has created an **Information Network**

- Allowing partners in the network to provide and use data by the creation of an inventory of waste streams with a high potential to serve as a source of CRMs.
- The project will be addressed to a wide range of end-users, including the recycling industry, producers and producer compliance schemes, and policy makers.
- The Network will identify how data should be presented and organised for this wide range of stakeholders to ensure it meets their needs.

Technical deep dive

The ProSUM project's core was the development of the Urban Mine Platform, a centralized database that provides detailed information about the stocks and flows of critical raw materials (CRMs) derived from WEEE, ELVs, and batteries. This platform aimed to support better management and recycling practices by providing accessible, consolidated data on secondary raw materials that could be worth billions of euros

1.1.21 RCS BP [79]

Global Overview

The Battery Passport is a pivotal tool that enables the development of a sustainable, circular, and just battery value chain. RCS Global is proud to have presented the first Battery Passport Pilot in collaboration with the Global Battery Alliance at the World Economic Forum in

[79]https://www.rcsglobal.com/batterypassport/

January 2023. Based on lessons learned and counting on validated supply chain data from industry leaders, we introduce the Claritas Battery Passport Solution.

Claritas is a comprehensive real-world and a digital solution working in tandem, specifically designed for Battery Raw Materials (BRM), enabling traceability and the collection of validated responsible sourcing and Carbon Footprint data. This innovative solution covers the entire battery supply chain, seamlessly integrating different approaches such as tracing and tracking. It ensures interoperability while providing accurate and verified information on responsible sourcing practices and carbon footprint throughout the entire lifecycle of Battery Raw Materials, from mine to market.[80]

Technical deep dive

Responding to the outlined regulatory requirements, Claritas operates simultaneously as a database and a data exchange system including both centralised and decentralised governance. To facilitate this, the solution utilises Spherity's digital wallet and Self-Sovereign Identity technology, which is applied to the battery raw m*aterials supplier ecosystem.* The platform's high level of customization ensures adaptation to future legislative, market or company requirements. Claritas users will have the capability to issue Battery Passports with consistent data sets, meeting both EU and US regulatory demands for EV batteries.

Decentralized Aspects:[81]

- **Digital Wallet and Self-Sovereign Identity (SSI) Technology**: The system uses Spherity's digital wallet and SSI technology, which are typically associated with decentralized architectures. These technologies enable secure, individual control over identity and data, allowing stakeholders within the battery supply chain to manage their information securely and autonomously.
- **Data Sovereignty and Decentralized Data Storage**: Claritas allows supply chain partners to retain control and sovereignty over their data. This decentralized approach to data management helps ensure that each participant in the supply chain can manage their data independently while still participating in a larger integrated system

Centralized Aspects:

[80] https://www.rcsglobal.com/eu-battery-regulation-battery-passport/
[81] https://www.rcsglobal.com/batterypassport/

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- **Central Database and Data Exchange System**: Claritas functions as both a database and a data exchange system with centralized governance. This aspect of the solution helps manage and synchronize multiple, complex data points across the entire battery supply chain, ensuring consistency and reliability of data.
- **Centralized Management of Compliance and Standards**: The solution is designed to meet EU and US regulatory requirements comprehensively. Centralized management ensures that all data meets these stringent standards uniformly across all users of the system.

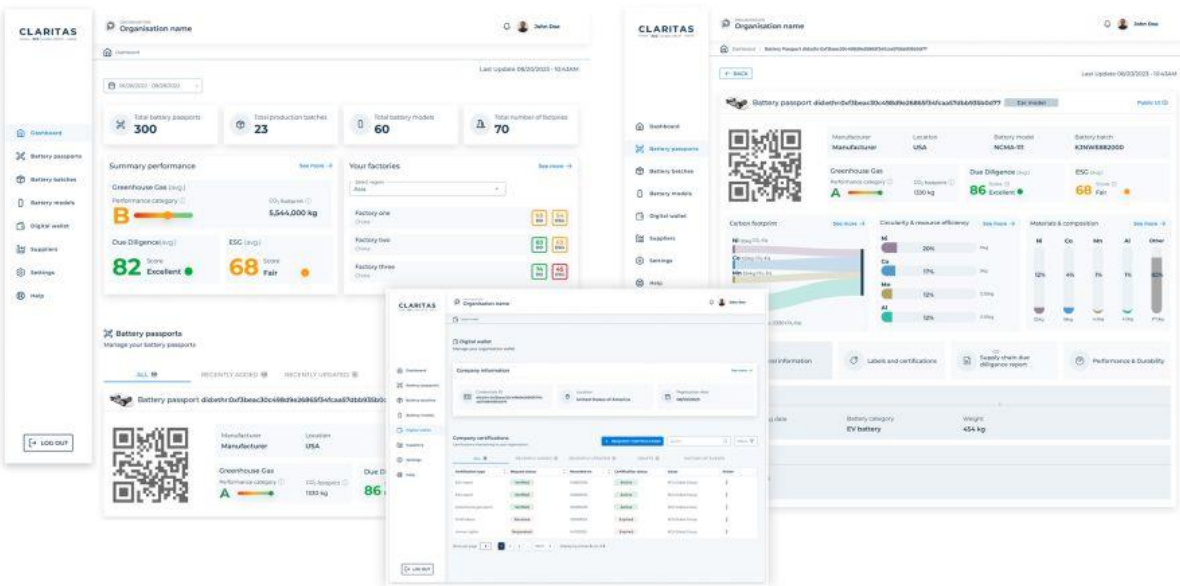

Figure 28 – Claritas platform

1.1.22 Spherity GmbH [82]

Global overview :

The Spherity Digital Product Passport solution, known as VERA, is designed to revolutionize supply chain management, particularly in the battery sector, by facilitating product traceability and compliance with regulatory requirements. This solution is a collaboration between Spherity and RCS Global's Claritas, aiming to provide car and battery manufacturers with the capability to issue digital passports for batteries. These digital

[82] https://www.spherity.com/digital-product-passport

passports are crucial for tracking a product's journey throughout its entire lifecycle, including use, reuse, and recycling, thereby enhancing traceability and sustainability within the supply chain.

Spherity's Digital Product Passport is not limited to the battery industry; it also offers solutions for other regulated product categories, aiming to automate processes by digitizing certificates and sensitive data exchange, thereby enhancing digital trust within ecosystems

Technical Deep-dive

The technical aspects of Spherity's Digital Product Passport solution, VERA, highlight its emphasis on ease of integration, interoperability, and adherence to open standards, which collectively aim to facilitate a seamless and secure digital transformation within supply chains. Below, we delve into these technical components to understand their significance and impact:

Easy Integration through Web Applications and REST APIs

VERA's design for easy integration is critical for its adoption across diverse supply chain ecosystems. The use of REST (Representational State Transfer) APIs (Application Programming Interfaces) is a cornerstone of modern web services, offering simplicity, scalability, and flexibility. These APIs allow for straightforward communication between different software systems, enabling VERA to be integrated into existing IT landscapes without significant overhauls. This means that companies can adopt VERA without needing to replace their current systems, significantly lowering barriers to entry.

SAP Certification

SAP Certification is a mark of reliability and compatibility with one of the world's leading enterprise resource planning (ERP) software providers. This certification indicates that VERA meets rigorous technical and functional standards, ensuring it can seamlessly interact with SAP's vast array of business applications. This not only enhances performance but also assures businesses of the reliability and stability of integrating VERA into their existing SAP infrastructure.

Interoperability and Open Standards

Interoperability is a critical feature for digital solutions in today's interconnected world, where supply chains span multiple jurisdictions and involve various stakeholders using

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different systems. VERA's interoperability ensures that it can work across these diverse systems, facilitating seamless data exchange and collaboration.

Adhering to open standards, particularly those specified by the World Wide Web Consortium (W3C), such as Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs), VERA positions itself at the forefront of digital identity and security. DIDs offer a new form of identifier that is fully under the control of the subject, independent from centralized registries, and VCs provide a way to securely attest to the truth of certain claims, such as the origin or authenticity of a product. These standards are critical for creating a trustworthy digital ecosystem that is secure, privacy-respecting, and resistant to vendor lock-in, ensuring that businesses are not dependent on a single provider for their digital identity needs.

1.1.23 The OK Supply Chain Management platform

Global Overview

The OK trade platform helps organisations in any industry manage and share documentation, work, and relationships for products, sites, workers, and the organisation itself. The main unique selling points is a strong focus on intuitive user interfaces over depth, allowing small-to-medium enterprises to unify and share basic information across the value chain (including with end consumers) more easily and with a low barrier of entry. Their goal is to help companies start their sustainability journey and build brand trust through transparency over time, by sharing lab reports, quality control logs, automated visual supply chain maps of individual items and the like with ease.

At OK, they view it as their responsibility to their members to track the development of Digital Product Passports, Digital Ports etc. and build simple interfaces to synchronise data to such systems systems, even if you are a smaller or growing actor without the engineering or financial means to implement enterprise level software.[83]

[83]https://oktrade.org/

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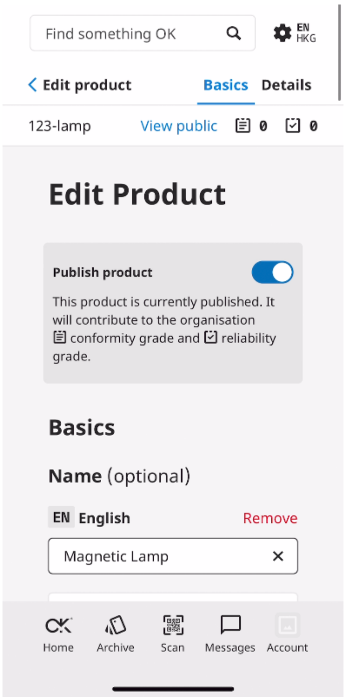

Figure 29 – OK platform

Technical deep dive[84]

The OK platform allows organisations to centralise basic product, site, user, and organisation data in one unified Archive. The platform focuses on the type of data that would be useful to synchronise to multiple industry- or material specific solutions, such as Data Ports, and Digital Product Passports.

1.1.24 Twintag[85]

Global Overview

Twintag's Digital Product Passport (DPP) is designed to provide a comprehensive digital record of a product's lifecycle, enhancing transparency and facilitating circular economy practices. This platform integrates seamlessly with existing systems to offer real-time access to detailed product information, such as repairability, durability, and the environmental impacts of the products. Twintag utilizes QR codes as data carriers connected to unique digital identifiers, which are scanned to access and share product data.

[84] https://www.getapp.com/operations-management-software/a/ok-platform/
[85]https://twintag.com/

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Figure 30 – Twintag – dpp solution

Twintag seamlessly integrates into your existing management systems, working hand in hand with the tools you already rely on. Whether you use CRM, ERP, or other systems, through custom connectors, Twintag enables you to access and manage data from multiple sources in one place.[86]

Technical deep dive

Context-aware digital experiences: Dynamic digital experiences driven by location, persona and time provide the correct information at the right time on the right device. You define access levels and user behaviour patterns and our platform makes sure each interaction feels uniquely relevant.

Twintag Designer: This is our engine for creating dynamic web apps, offering pre-designed templates and customization options to build your branded digital interface and unlock seamless product experiences.

Twintag Admin Portal: Product data, workflows and teams: with Twintag Admin Portal, they all move in sync. So everyone in your enterprise has info and tools needed to multiply their impact.

We support GS1 EPCIS for standards-based integrations, or customized integrations based on RESTful API and JSON data interchange.

[86] https://twintag.com/the-eu-digital-product-passport-i-twintag-solution

1.1.25 VINE[87]

Global Overview

Vine is a due diligence platform that allows suppliers to measure and improve their ESG (Environmental, social, and governance) performance within battery supply chains.

With over 2300 verified suppliers in the EV battery and battery storage supply chains already in the platform's database and more being added every month, Vine is rapidly scaling and becoming the most comprehensive database for supplier ESG performance in the battery raw materials sector.

Vine enables users to map and connect suppliers to better understand complex raw material supply chains. As a visualisation tool, Vine builds full transparency in new or unique supply chains.

Vine is built from high-quality datasets based on RCS Global's expert audits and confirmed supplier disclosures. The Vine Supplier Map is created on the basis of confirmed material flows and links between entities. Get insights that can be utilised for analysis, decision making and reporting to internal and external stakeholders based on reliable data. Demonstrate positive supply chain impact through continuous improvement that can be reported.

Rely on validated ESG performance data based on audits pegged against internationally recognised standards. Vine will also allow you to connect to Better Mining assured data from upstream certified artisanal mine sites in 3TG, copper and cobalt.

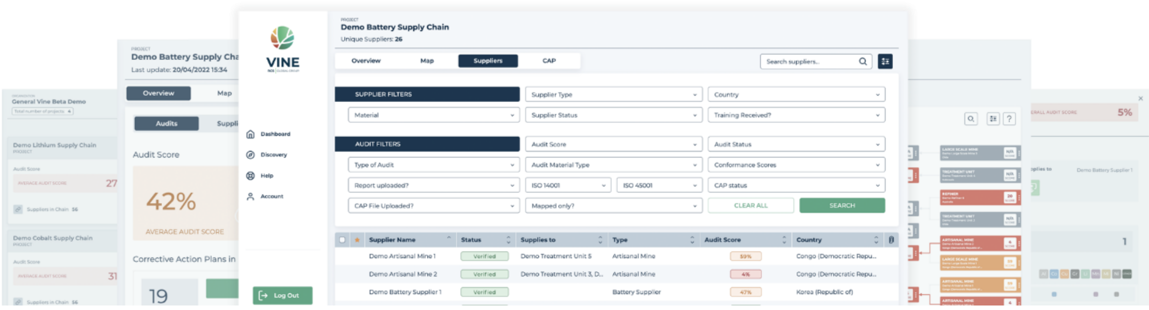

Figure 31 – VINE platform

[87] https://www.rcsglobal.com/vine-platform/

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Technical deep dive

The projects aim to build a supply chain exchange platform, curated by expert auditors from RCS Global.

1.1.26 whatt.io [88]

Global Overview

At whatt.io, we revolutionize the way physical products interact with their digital counterparts through a secure, instantaneous, and accessible connection. Our innovative solution merges a cloud-based product information platform, advanced programming tools, and cutting-edge manufacturing techniques to seamlessly integrate RFID tags (NFC) and QR codes within products.

This integration ensures perpetual access to the product's distinct digital data, facilitating traceability, recycling information, spare parts management, ownership transitions, communication endeavors, and much more.[89]

We're a comprehensive solution featuring a Content Management System, apps, tools for QR code management, NFC tag programming, and most importantly, the bridge that connects your physical products to their digital counterparts.

At whatt.io, we're not just another Digital Product Passport (DPP) initiative. We bring a distinct edge to the table - the unparalleled fusion of expert knowledge in 3D printing and additive manufacturing. This unique feature sets us apart from the rest and opens up a new dimension in the world of DPPs.

Technical deep dive

Security is paramount, and we've embraced blockchain technology to ensure the highest level of authorization and protection. Our platform utilizes blockchain to secure both physical assets, guaranteeing tamper-proof authenticity and transparency throughout a product's lifecycle.

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[88] https://whatt.io/
[89] https://discover.whatt.io/about

Funded by the European Union

With blockchain, you can trust that your products and their data are safeguarded against unauthorized access and counterfeiting.

whatt.io have been developed during the last 4 years with industry leaders in the Digital Product field and cloud technology to create a platform for traceability and support of the circular economy with 7R. The system uses NFC tags ISO 14443A and QR codes and can be integrated already in the manufacturing process to connect metadata live to unique individual items. Spare parts are connected to each Product to enable repairs and it also supports local 3D printing opportunity. Certificates, EPREL connection etc is standard in this solution. Tapping a product with a mobile phone without any registration or App download.

An extension of 3MF that adds additonal meta data to enable better protection for IP, Patent and copyright. It also adds a token, generated by the checksum of the file so it is not possible to modify the geometry or the meta data.

While QR codes have their limitations, they remain a potent tool for bridging the gap between the digital and physical worlds. These codes provide a quick and accessible way to access product information, empowering users to make informed decisions. At whatt.io, we harness QR codes' potential to ensure easy and instant data exchange, enhancing the overall user experience.

1.1.27 Catena-X[90]

Global Overview

Catena-X is a decentralized data space for the automotive industry with common standards for sovereign data exchange between companies along the entire value chain. Use cases include demand and capacity management, traceability of production parts, and increasing sustainability, for example by reducing CO2 emissions – typically business processes involving multiple supply stages. In this context, Catena-X standards ensure that apps from different providers are interoperable, allowing each business partner to select the app that suits them best for a particular business process. Take the deep dive here.[91]

The Catena-X funding project has brought together 28 companies, including several automakers, large and small suppliers, software and platform providers that normally

[90] https://catena-x.net/en/about-us
[91] https://catena-x.net/en/about-us/development-environment

Funded by the European Union

compete with each other, and research institutions. The companies are united by the conviction that successful digitization of the end-to-end supply chain can only be achieved together in an open network with fair rules of the game. SupplyOn is one of these companies actively participating in the initiative.

Technical deep dive [92] [93]

The Catena-X architecture is structured to support a collaborative and interoperable data ecosystem specifically for the automotive industry. Here are the key components:

1. Core Services: These enable basic functions of the Catena-X ecosystem, such as identity verification and data discovery. These services are crucial for the overall functioning of the ecosystem and are operated centrally but aim for future decentralization.
2. Enablement Services: These services can be either self-managed by each participant or managed by an Enablement Service provider. They provide or consume data within the Catena-X data space and are built on the Eclipse Data Space Connector (EDC). The EDC ensures data sovereignty and secure data exchange by separating metadata and actual data transfer channels.
3. Business Applications: These applications solve specific business problems, such as demand and capacity management, circular economy initiatives, and more. They are designed to be scalable and can range from large enterprise solutions to specialized applications for small and medium-sized enterprises (SMEs).

The Catena-X data space architecture ensures that data is exchanged in a secure, interoperable, and decentralized manner. It uses the Gaia-X cloud infrastructure to support its decentralized approach, aiming to replace initially centralized services with decentralized and federated operations over time.

1.1.28 Un/Cefact[94]

[92] https://github.com/catenax-ng

[93] https://catena-x.net/fileadmin/user_upload/04_Einfuehren_und_umsetzen/App_and_Service_Provider/Application_and_Service_Provider_Guide.pdf

[94] https://unece.org/trade/uncefact

Global Overview

UN/CEFACT is the United Nations Centre for Trade Facilitation and Electronic Business. It was established as an intergovernmental body of the United Nations Economic Commission for Europe (UNECE) in 1996 and evolved from UNECE's long tradition of work in trade facilitation which began in 1957.[95]

UN/CEFACT's goal is "Simple, Transparent and Effective Processes for Global Commerce." It aims to help business, trade and administrative organizations from developed, developing and transition economies to exchange products and services effectively. To this end, it focuses on simplifying national and international transactions by harmonizing processes, procedures and information flows related to these transactions, rendering these more efficient and streamlined, with the ultimate goal of contributing to the growth of global commerce.

Technical deep dive

Un/Cefact defines standards and policies and is technology-agnostic.

[95] https://fr.wikipedia.org/wiki/UN/CEFACT

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the European Union