EXCESS MATERIALS EXCHANGE

White paper: Building a Semantic Web for the Circular Economy

January 2020

Excess Materials Exchange

The Excess Materials Exchange (EME) is a digital facilitated marketplace where companies can exchange any excess materials and products. We function like a dating site: We actively match supply and demand and materials with their highest-value reuse opportunity.

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Introduction

Excess Materials Exchange (EME) aims to turn waste into wealth. EME facilitates the transition to a circular economy and the empowerment of circular business models by applying innovative technologies. By using a digital, facilitated platform, EME aims to overcome – amongst other things - transparency, scalability and privacy issues. In this white-paper we discuss the technological framework used by EME, and further explain how the suggested technologies can help overcome the aforementioned barriers.

The need for a circular economy

In 1972 the 'Limits to Growth' study first illustrated that increasing population growth paired with increasing consumption patterns would lead to both rapid resource depletion as well as increasing levels of pollution (Meadows et al., 1972). In the most likely scenario, the academics predicted a situation of 'overshoot and collapse' – life as we know it would become unsustainable.

For the past few decades we have been tempted to focus mainly on CO_2 emissions in moving towards a sustainable society, leading primarily to efforts regarding energy and mobility. Research shows, however, that 45% of the global CO_2 emissions can be attributed to producing the 'things' we use (EMF, 2019). In order to decrease these carbon emissions, it is vital that we transition from a linear take-make-waste economy to a circular economy that is restorative and regenerative by design (Braungart and McDonough, 2002).

In the circular economy we envision, there is no waste by design - rather than by accident - and resource use is regenerative and restorative. Waste is no longer incinerated or sent to a landfill, rather waste is seen as a resource for a new production process. 'Excess materials' therefore represent a value and with EME we maximise that value.
In the past decade, we have seen a rapid increase in the amount of circular initiatives. Most of these initiatives, however, tend to be fairly small scale and coincidental in nature.

Our own research and experience shows that the following main barriers limit the growth and scale of circular initiatives:

- **Lack of transparency:** What resource flows are available and where? And how can we safely exchange resource data?
- **Timing and availability:** The availability of secondary resource flows often does not coincide with demand.
- **Quality:** Quality of resource flows cannot be guaranteed.
- **Quantity:** Secondary resource flows are not available in constant quantities.
- **Traditional revenue models:** Secondary resource flows are often seen as a cost item rather than a revenue opportunity.

- **Optimising internal resource cycles:** Closing resource cycles is mostly done within organisations, occasionally within sectors, but not across sectors. This leads to suboptimal solutions.
- **Urgency:** The necessity of a transition towards a circular economy is not being recognised sufficiently.

Digital technologies for a circular economy

In a world where every household and every business is, in effect, a production site for valuable resources – we need to harness the power of technology in order to identify, trace, evaluate, and match these resources (excess materials) and overcome the barriers as mentioned earlier. EME is building a platform in which four separate modules will jointly offer a solution. These four modules are:

1. **Resource Passport (RP)**. Resources are given an identity by storing their (circular) aspects (a.o. origin, composition, quality, toxicity etc.) in the same format. This enables comparison and cross-sectoral connections. This module deals with the barriers lack of transparency and quality.
2. **Tracking & Tracing (TT)**. In order to optimally exchange materials it is important to be constantly and consistently updated on resources' locations and time of availability. This module deals with the barriers timing, availability and quantity.
3. **Valuation Module (VM)**. Insight in the value of possible applications of secondary resources is necessary to understand what application makes sense. Quantifying the financial, environmental and societal value of possible applications does this. This module deals with the barriers traditional revenue models and urgency.44
4. **Matchmaking (MM)**. Supply and demand for secondary resource streams need to be matched. Quick and large scale matchmaking is possible by automating this process. This module deals with the barrier optimising internal resource cycle.

Although digital technologies are pivotal in offering a solution for the identified barriers, applying these technologies in the transition to a circular economy also comes with challenges. In this paper we will address these challenges and discuss how we overcome them. The following challenges are elaborated on:

1. **Digitisation:** There is currently very little, consistent and comparable information, let alone digital information about the products that we use or consume. In order to scale the circular economy it is important to develop 'digital twins' of products to make this essential information accessible for matchmaking.
2. **Developing a coherent language:** The digital twin takes the form of the RP. It is important for the information in the RP to be structured in a way that enables coherent communication between sectors and languages for optimal matchmaking.
3. **Traceability:** In every step in the value chain, the composition and/or production process of a product changes. It is important this information is gathered and is

verified and accessible for those who need it, while at the same time preventing corruptive information from entering the system.

4. **Privacy and security:** When working with digital tools, privacy and security are obvious concerns. It is important to take note of issues such as Intellectual Property (IP) when accumulating data and making matches based on detailed product information.
5. **Scalability:** Many current circular initiatives are not scalable. There is no collective intelligence regarding alternative destinations for the materials or components in order to generate valuable circular matches. Moreover contextual data such as permit information, certification and logistical requirements need to be quickly incorporated for an optimal matchmaking process.

In this paper we will discuss the technologies used to address the challenges as summarised above.

Challenge 1: Digitisation

Organisations are currently exchanging resource flows, however most of these exchanges find their origins in either longstanding (contractual) relationships or in coincidental encounters. The exchange of excess materials of one company being used as input for another production process is currently uncommon. Mainly because very little, consistent and comparable information, let alone digital information exists about the products that we use or consume. We simply don't know about the availability, type, quality or quantity of resource flows that are available. Technology can help solve this problem by creating digital information on the products that we use or consume. This way we know which resource flows become available and when.

EME's platform gives resources a digital identity.
The first challenge is to create a 'digital twin' of resources, which is facilitated by the Resources Passport (RP). In the RP we gather information on resources in terms of, among other things, composition, functionality, origin and embedded energy. We capture the data about a product, component and/or material digitally, in a standardised and modular fashion, and through our cloud-based application.

The RP is the first building block of the EME platform. The other modules (TT, VM, MM) are dependent on the quantity and quality of information gathered in the RP. The success of EME is dependent on the degree of digitisation – the more RPs generated, the easier it is to make quick analyses and facilitate matchmaking. It is therefore important that the technical language of EME and the RP are widely accepted so it can be used by many different organisations and sectors.

Technical solution 1.1: JavaScript and NodeJS

In order to address the challenge of digitisation by developing a cloud based web application, we have chosen JavaScript as a programming language for our platform. JavaScript is currently one of the most popular programming languages and has become the language of the web. We use JavaScript as a front-end and a back-end language for developing our web platform.

We work with Javascript for the following reasons:

- **EME platform is a cloud based web application**
  A large part of the web development is currently done using JavaScript, and more than 95% of the web is already built using JavaScript language. The benefit for EME by using JavaScript is that we develop our web applications on a time-tested and growing ecosystem. Javascript is supported by a large community of developers who develop code open source to the world, which helps us to develop our platform faster and in a modular way. At EME we chose JavaScript because it does not only provide functionality for the front-end (client side) but also supports the back-end (server-side) programming. This gives us the speed as well as uniformity (hence reduced learning curve) in the programming of the platform.
- **EME users need to have a seamless user experience across browsers and devices**
  JavaScript is supported by multiple web browsers, such as Google Chrome, Internet Explorer, Firefox, Safari, and Opera. Hence the users can access the web applications on any web browser of their choice easily. This holds true for both computers and mobile devices using the same code.
- **JavaScript helps simplify the EME platform**
  For our EME platform, we will use JavaScript and its supported libraries to optimise web pages for mobile devices and other handheld devices. For a positive customer experience, Javascript integrates quite well with CSS3 for page design, HTML5 for behaviour, and JavaScript for business logic to make the web pages responsive. Using JavaScript and its frameworks, developers can easily, quickly, and efficiently develop highly interactive and professional web applications. JavaScript also has many libraries that can be used as per the business and web development requirements, hence easily customisable. Since we use one language across the platform, there is less context and content switching for developers and clients as they can use the same data, language structures, and modular approaches. This helps EME with faster development, easier maintainability, fewer resources required and generally a better work environment for developers.

In short: By using JavaScript, we build a highly interactive web app that helps in enhancing speed, performance, functionality, usability, and features of the platform. It also provides a strong foundation for scalability in the near future due to its vast community and modular approach. Moreover, it delivers the best and optimal user experience across various devices, browsers, and operating systems.

Technical solution 1.2: Interoperability and Standards

The growth of digital platforms in general has resulted in disparity of how data is gathered, stored and exchanged across systems, especially in the supply chain sectors. We observe similar challenges with the introduction of supply chain solutions in circular economy, each having their own way of gathering, storing and exchanging data. This does not help with interoperability and scalability, hence often the solutions are sub-optimal. Therefore, we are in need of a common ontology for capturing information about the resources passport (digital twin for the product) to be able to manage two main challenges of digitising the supply chain ecosystem:

1. **Interoperability:** System interoperability is of essence when scaling technological solutions as it enables smooth information sharing across platforms and across blockchains, automation through easier execution of smart contracts and hence increases the opportunity for collaboration.
2. **Standards:** The key to interoperability is common standards, which will require to develop common semantics (meaning of things) and an ontology (how they are related to each other).

For the semantics and ontology within our platform (to be discussed in more detail in the next chapter) we have used the guidelines provided by GS1 for developing blockchain solutions. Companies like Microsoft and IBM adapted the guidelines of the GS1 standard for enterprise blockchain solutions.

Some of GS1 standards that we (envision to) implement in the RP to achieve standardisation, easy sharing, interoperability and scalability are as below:

- Use of GS1 standards for unique identification of Resource Passports (digital twin) that are registered on the platform
- Using Electronic Product Code Information Services (EPCIS) as the standard for data format, data models and exchange format for: traceability, data aggregation, structure and analysis across the circular value chain. We use Common Business Vocabulary or CBV. CBV is a dictionary of events for e.g. recycling is an event.

Besides, some of the other standards that we will develop as a part of our solution will involve the following:

- Establishing policies around how the network participants will operate and share data by developing interoperability rules between the actors in the supply chain. For example by using Global Data Sync Network (GDSN) which is a global registry that enables companies around the globe to exchange standardised and synchronised supply chain data with their trading partners. Using this, we will develop certain rules

on how data is exchanged on the platform and after the data is submitted, it will be used by all trading partners across the ecosystem.
- Develop semantics around the data and relationships using Linked data structure for the circular economy.
- Encouraging that companies adopt an “API first approach” for the data they gather and share with our platform to increase adoption and interoperability.
- Creating a common product, materials and functionality classification scheme (Taxonomy) for the products/materials being registered and traded on the platform.

Challenge 2: Developing a coherent language

The aim of the Excess Materials Exchange is – as the name suggests – to facilitate the exchange of excess materials between organisations. In order to do so it is important that information gathered in the RP facilitates interoperability between organisations, sectors and languages. A coherent (programming) language is therefore needed to facilitate this interoperability.

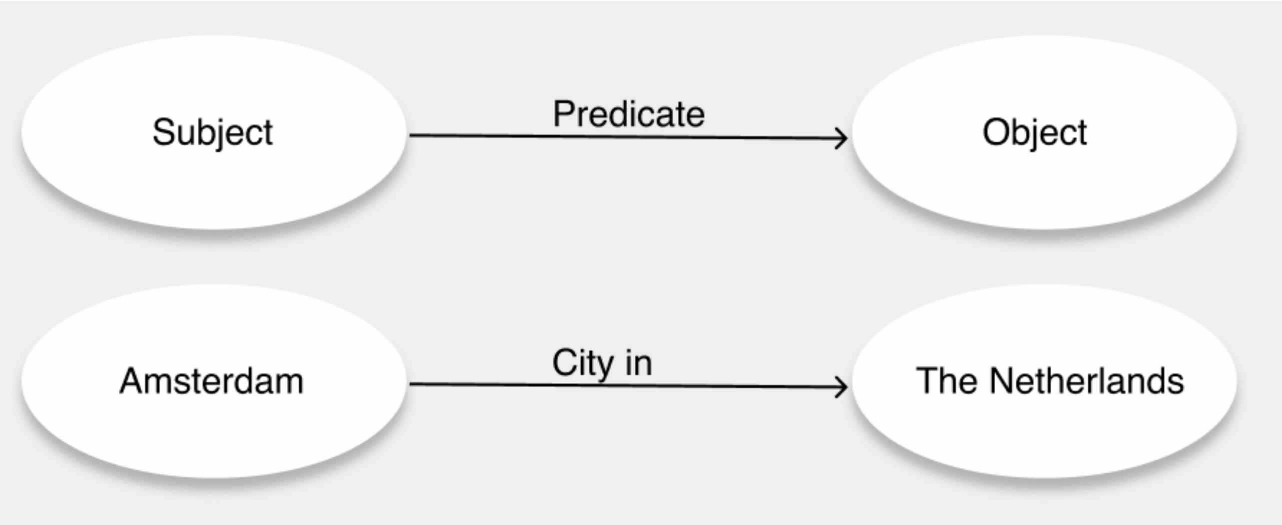
To highlight the importance of this coherent language, we use the following example: The food services sector is not accustomed to highlighting the functional properties of orange peels other than for food purposes. Yet the orange layer of an orange peel also contains phenolics, which in the form of limonene can function as a cleaning agent, a weight loss supplement, cancer medicine and bronchitis medicine, amongst other things. These different functionalities are likely unknown to professionals working in the food industry. Only when these properties are documented in the RP and communicated in a coherent language can the chemical or medical industries start to utilise the value of orange peels.

An RP for a product such as orange peels can have as many as 100 data points with the details of matches, functionality and cross sector connections. To analyse this data we need a technology that can search for possibilities across sectors. A technology that uses a scalable and systematic method to make connections between released (output) and incoming (input) resource flows. This overcomes the barrier of creating product matches based on coincidence, which is currently mostly the case.

Technical solution 2.1: Linked Data

The most suitable technology to collect, clean, organise and structure all the data fields in the RP is Linked Data technology which enables us to process data in an efficient way. We will first explain the terms and concepts of Linked Data and thereafter we will discuss how we apply them in our ontological model and semantic web.

A graph (data structure) is a series of vertices (nodes) connected by edges (relationships) sometimes having tags to each of the edges, also known as a triple. A collection of triples creates a graph data model, which can be thought of as a network of people, places, things and relationships.



An example of a triple store RDF standard (Resource Description Framework)

Linked Data is a set of best practices to publish structured data on the web. Data is connected in ‘smart links’ or triples, enabled by the RDF standard, which take the form as subject-predicate-object statements as shown in the figure above.

Linked Data technology is able to tie problems and solutions, or input and output, based on the defining parameters of a material or product. Products and materials can be matched based on colour, functionality, circular potential, composition and so forth, while not being hampered by sectoral boundaries or a lack of human problem solving capabilities.

Moreover, Linked Data provides the correct data model to handle a varying grade of information detail. Focus can be placed on either a low level of specificity, namely the product or material itself, such as jeans, or on a high level of detail, the density of the yarn used to produce the jeans. One of the strengths of Linked Data is the ability to connect cross-disciplinary data. This feature allows for maintaining the use of domain-specific terms (e.g. the textile industry uses certain naming conventions that is unique to the textile domain) to refer to one resource. At the same time Linked Data is also able to refer to the same material or product in a different discipline or domain based on their linkage.

Linked Data is deemed one of the big-data technologies, designed to handle large volumes of generated data. Linked Data can work with scaled solutions and provide systematic scalability. The range of data-connection possibilities is large and extensible as Linked Data is able to incorporate internal datasets and other external (web-based) data sources created by others.

Technical solution 2.2: Ontological model

An ontological model represents various entities, their properties relationships and sometimes even behaviour in relation to other entities; often constructed using a triple store format. Ontology can be thought of as a ‘smart dictionary’ describing concepts and their relationships within a domain and also across domains based on common “keywords”. Ontologies are used to enrich data with semantic annotations.
To achieve an optimal solution, we have used an innovative approach in which the ontologies are defined within and across domains to build EME’s own knowledge graph. In order to develop the knowledge graph (using the ontological model), we use the native graph database called neo4j.

This works as follows: As mentioned in the previous section, a graph (data structure) is a series of vertices (nodes) connected by edges (relationships between nodes), sometimes having tags to each of the edges. This structure creates our optimal ontological model. Each of the nodes and relationships also have properties which contain details such as name, description, location, relation etc. This data is stored in a graph database, a technology that facilitates a network-oriented approach. A graph database management system, is an online database management system able to translate data into network models. We use the neo4j database (used by some of the largest database companies in the world, such as Walmart and Google). In neo4j vertex (nodes) are connected so that each edge (relationship) not only goes one way but in multiple directions (one edge connected to multiple vertices). Implementation of graph architecture using neo4j will provide the scalability, performance and ability for the search engine of our platform to search and recommend products based on (metadata) keywords.

The possibility to model relationships within the data is what sets Graph databases apart from non-graph database management systems. In the latter, connections between entities have to be established by using complex or cumbersome methods. In contrast, by assembling the simple abstractions of nodes and relationships into connected structures, graph databases are able to build sophisticated models that map the problem domain. The resulting models are simpler and at the same time more expressive. Graph databases work on the concept of “joins” (creating a connection between database tables).

Moreover, querying Graph databases is much more effective compared to traditional databases where two nodes can communicate with each other directly instead of traversing through multiple tables. A Graph database can be queried based on labels, node information or the relationship between nodes. In ordinary databases query performance deteriorates, as the dataset gets bigger, since it has to traverse across multiple connected tables. With a graph database, performance tends to remain relatively constant even as the dataset grows. As a result, execution time is significantly reduced and less complex. The ability to search for a circular match on our platform with a performant and relevant search makes it very important to select an architecture involving graph databases. Moreover, the matching of products across sectors has been one of the major issues in the circular economy due to complexity and volume of data. We tackle this issue using graph architecture.

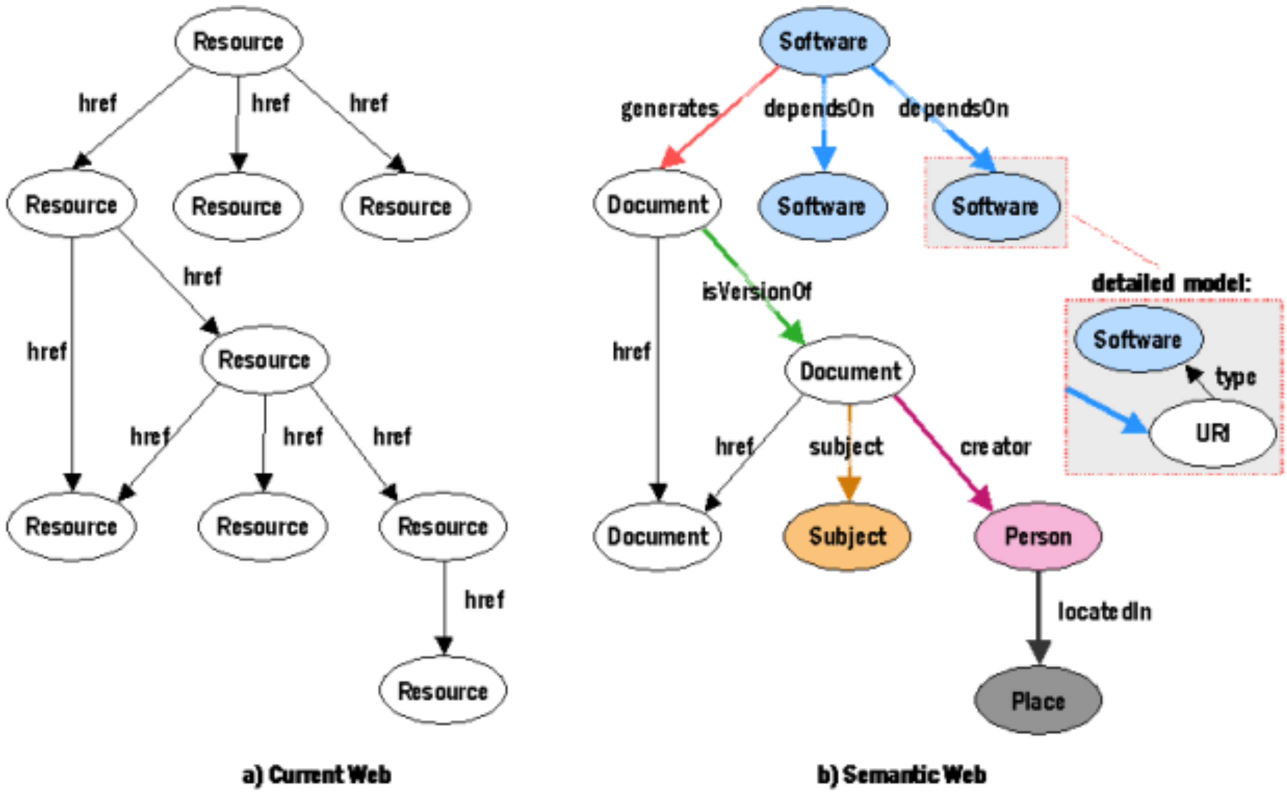
Another advantage of developing the ontological model using neo4j graph database is its flexible nature. Due to its innovative design, new nodes, relationships and properties can be added into the data sets at any given time. The flexibility of Graphs databases makes it possible to add new kinds of relationships, new nodes, new labels, and new sub-graphs to an existing structure without disturbing existing queries and application functionality. For the eventual scalability (size) and flexibility (ability to change), graph database is the most suitable technology for EME's digital platform.

Technical solution 2.3: Semantic Web

In this section, we explain how the previously described Linked Data and ontological model help us in creating a Semantic web solution for our platform.

The Semantic Web forms a web where data is connected in a structured way and where context and logical meaning can be extracted from information generated from these data sets. This enables all actors in the economy to communicate in an effective way about materials.

Semantic Web is an improvement of the World Wide Web in the sense that it doesn't store information on the internet in document format but in data format. So unlike the document format where the search results from the Internet is based on the document header name, in a Semantic Web, the search can be performed on the data within the document and the inter-links of data (meta-data) within the document and across the document (hence, a much deeper, relevant and smarter search).



An example of semantic web structure (Source [W3.org](W3.org))

With our linked data and ontological approach, we have laid the groundwork of the digital Semantic Web for a full-scale circular economy. This Semantic Web enables us to exchange secondary materials in a structural and scalable manner. All the data that is gathered from the RP for each of the products or materials is stored in linked-data format in graph databases. As mentioned earlier, all the products (called nodes) use the ontological model to define all relationships within and across the products on the platform. Once all the data is linked and a relationship is created using graph database (neo4j), the Semantic Web for the platform is ready to perform activities, such as search, recommendation and matches.

There are three ways in which the semantic web empowers the EME platform:

1. **Search engine:** EME's search engine is powered by a semantic web search. It collects, indexes, and analyses semantic web documents using Resource Description Framework (also called RDF, a framework for representing information about data and metadata on the web) format to provide search and querying mechanisms. RDF is developed by the world wide web consortium (W3C) for data standards and interchange. On our platform, the Semantic Web search engine is applied for finding ontologies where queries are usually written as natural language keywords.
2. **Recommendation engine:** Recommendation engine using semantics within our platform helps our users to provide a more personalised recommendation for their search keywords.

3. **Matching engine:** Based on the semantics of the data we have within our platform, we are able to provide our users with ranks based on the keyword and matches we find for the queries used within the key words.

Challenge 3: Traceability

In every step in the value chain, information about the composition and/or production process can continuously change. For example: the nylon from discarded fishing nets can transform into carpet tiles. For this process, however, the nylon will undergo several steps in the value chain. At every step the ‘added value’ changes, leading to a new environmental, social and financial valuation. In order to eventually make successful matches with the produced and used ‘carpet tile’, we need to accumulate information about added substances, toxicity, the composition of the tile, etc. It is important this information is accumulated in order to have accurate and up-to-date information about the product/material flow. This is instrumental in high value matchmaking and the optimisation of financial and environmental impact. At the same time every ‘transaction’ in the value chain is also vulnerable to corruption. In order to ensure the accuracy of the information and to prevent corruptive information from entering the system, we will use Blockchain to maintain the quality of the transactions.

Technology 3.1: Blockchain

Distributed blockchain networks will allow us to address the tracking trajectory of products/material flows in a cost-efficient and trusted way. Blockchain can provide unprecedented transparency into where materials are, but also traceability, showing where materials have been. Hereafter we shortly introduce blockchain technology and describe the specific blockchain configuration used to facilitate transparency.

Blockchain

Blockchain is a shared, trusted ledger for immutably storing the history of transactions from the beginning to the end of the supply chain. It provides a means to allow every participant on a supply chain network to maintain immutable records of all aspects of the production, storage and sales of a product.

The essence of chains in a blockchain is about the characteristics of its data structure. It is designed to store and organise data so that it can easily be retrieved and reviewed. Blockchain is stated to be an ordered, back-linked list of blocks, encapsulating and recording the timestamp, actions, actors in and history of the network. All actions are coded and encrypted with a hash, which is a unique encrypted identity of a transaction which incorporates the time, actor and action.

On the EME platform, authorised persons from selected companies within the consortium can among others track (raw) materials, record manufacturing telemetry, track the origin of goods, map the means of transportation, executed maintenance and repair, and review the end-of-life treatment. Graph architecture helps our users (and their companies) to retrieve information in a smooth, secure way, at the same time maintaining confidentiality with cryptography as and where needed.

With the implementation of blockchain on the EME platform, the following benefits are achieved:

Traceability & Transparency
Traceability and transparency can be defined as follows: “An indestructible record of transactions throughout the supply chain ensuring integrity of information while providing real-time information to relevant participants for faster response times.” At EME we achieve the traceability and transparency using event-based transactions logging on Hyperledger Fabric. Any transaction (event) that takes place on our platform is recorded in a decentralised distributed ledger, recording all the key activities throughout the lifecycle of the product.

Traceability is becoming an increasingly urgent requirement and a fundamental differentiator in many supply chain industries including the agri-food sector, pharmaceutical and medical products and high value goods. Luxury and high value items whose provenance might otherwise be reliant on paper certificates and receipts can easily be lost or altered. The cost involved in handling intermediaries, their reliability, and transparency further complicate managing this traceability in the supply chain, thus negatively impacting the real potential of circular economy. In addition, strategic and reputational competitive issues arise from these risks as well as lack of transparency.

Blockchain is, potentially, a disruptive technology for the design, organisation, operations, and general management of supply chains within circular economy. Blockchain’s ability to guarantee the reliability, traceability, transparency and authenticity of information, along with smart contractual relationships for a trustless environment, all portend a major rethinking of supply chains and supply chain management.

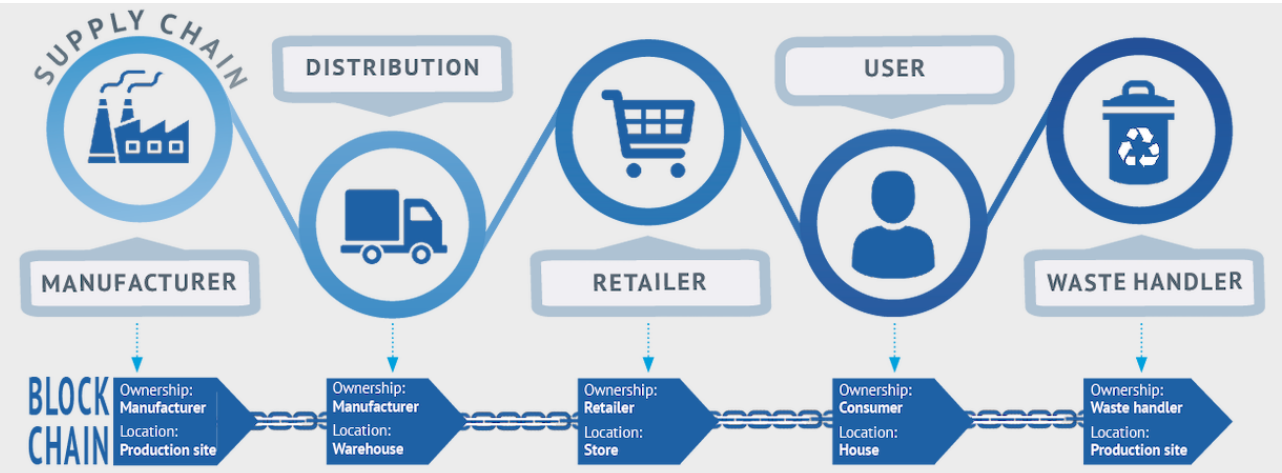
Using blockchain on our platform, we are able to effectively facilitate material and information flows through the supply chain; with automated governance requirements and tracking various stages, owners and status of products. The linked-list of blocks within blockchain provides the immutability we need on our platform to prevent fraud and create trust and transparency of events. The fact that Hyperledger Fabric (our blockchain platform of choice) is a permissioned blockchain that works with a consortium of companies, provides an added layer of quality and trust within the network. This prevents individuals and companies trading within the network to have a very high signal to noise ratio.

Auditability
Transparent records of all digital interactions facilitates easy authentication and expedited audits.

In Blockchain an agent can create a new transaction to be added to the blockchain. This new transaction is broadcast to the network for verification and auditing. Once the majority of nodes in the chain approve this transaction according to pre-specified approved rules, this new transaction is added to the chain as a new block. A record of that transaction is saved in several distributed nodes for security. Meanwhile, the smart contract, as a critical feature of blockchain technology allows for the performance of credible transactions without third parties' involvement.

A major difference between the current design of the Internet and blockchain technology is that the Internet was designed to move information (not value) and to move copies of things (not original information). In blockchains, value is represented in transactions recorded in a shared ledger and secured by providing a verifiable, time-stamped record of transactions, which provides secure and auditable information. These transactions appear through a verification process that is consistent with network consensus rules. Once the new record is verified and added to the blockchain, multiple copies are created in a decentralised manner to create a trusting chain.

EME's traceability workflow is designed to track the journey of the assets across its lifecycle. The image below represents the materials or products journey. The current material journey still ends as waste, our aim is to enable materials to turn into a new loop. In every step of the way transactions are logged and recorded on blockchain. Once transactions are validated, data is stored in an immutable block and a record is created. At the end of the tracking cycle, an auditable record of all transactions is formed; this is called record management.



Impression of how resources move across the value chain on EME platform

By adding information on our RP regarding the "owner" of the product, the physical whereabouts and the people responsible for the asset, products can be closely monitored and tracked. Furthermore, this kind of information can be stored and easily retrieved for the entire supply-chain (when a buyer on the platform is looking for the product history to evaluate the quality or when EME analysts process the “valuation” of the product before it is published on the marketplace to be sold.

Retrieving upstream product information requires over the supply chain backwards traceability, this is a cumbersome and time consuming process in traditional databases. Compared to traditional marketplace solutions, EME’s blockchain based marketplace platform stores immutable data and provides deep search ability through multiple layers within the supply chain ecosystem. This backwards search capability is the base of establishing supply chain wide transparency. Data is no longer stored in centralised databases which enables all participants to trustfully track assets throughout the supply chain. With the above mentioned benefits, we are able to bring transparency and immutability which results in trust and provides a better user experience for the users on the platform.

Technology 3.2: RFID, QR and Barcodes

An information tracking (Infotracing) system is a process to keep records revealing the trail of an input from suppliers to customers and further on. The capacity to track the complete product supply chain is possible with the implementation of automated identification systems, which establishes a link between a product and a database of the product and the processes it undergoes.

On the EME platform, depending on the type of resources, different technologies will be used for tracking and tracing. For valued yet mobile assets we will use RFID chips in order to track and trace. For less valued extremely mobile assets we will use QR-Codes or barcodes. For immobile assets and bulk items we will likely not use a new technology but rather a mass balance approach.

On the EME platform, we will explore an open source prototype system based on RFID technology using different wireless communication protocols for each phase of the infotracing flow. Through the RFID technology, the tags will be read during the various phases and, in particular in an outdoor context. For example in a large warehouse, codes can be sent through a portable reader to a smartphone with a customised application, where the code is stored and the related additional information entered by the operator. EME is working with its partners to enable optimal implementation of the RFID/ Bar Code technology for the physical tagging of products.

Challenge 4: Privacy and security

When working with digital tools, privacy and security are obvious concerns. It is important to take note of issues such as IP when accumulating data, sharing data and making matches based on detailed product information.

Most organisations are hesitant to share data, primarily for reasons relating to IP. It is therefore important to strike a balance between accumulating data in order to make circular matches, and ensuring that competitive information is not shared. For example: if transaction patterns are open for observation and interpretation, they could reveal sensitive details about business relationships. Therefore, a business ready blockchain must provide mechanisms to conceal identity, transaction patterns, and terms of confidential contracts from unauthorised third parties. Currently, there are only limited systems which can securely handle large quantities of data. Moreover, centralised databases are prone to error and fraud. System-wide supervision over these centralised databases is unattainable, which makes it difficult for customers and downstream firms to access and verify the provenance of assets and the quality of the data.

Permanent and immutable records of transactions provide a single source of data integrity. Immutability mechanisms of blockchain technology lead to improved transparency and trust. Since the contracts being executed on business networks using blockchain technologies are automated and final, businesses benefit from increased speed of execution, reduced costs, and less risk resulting in high data integrity. Within our platform, we have designed the architecture in a way that only the parties with the correct digital keys have access to product information, hence the critical information does not end up in the wrong hands, increasing integrity and trust of the platform.

The General Data Protection Regulation (GDPR) standardisation is an additional reason for the EME platform to ascertain data privacy. The GDPR is an European law on data protection and privacy for all individual citizens. It addresses the usage and transfer of personal data (GDPR) In order to comply with the regulatory framework, the usage and location of data should be transparent and retrievable at all times.

The EME platform is able to securely share and process sensitive data while securing privacy of the participant on the platform. The technologies used to provide this service are described below.

Technology 4.1: Hyperledger Fabric Blockchain

In the previous chapter we described blockchain as a shared, immutable, trusted ledger for storing the history of transactions from the beginning to the end of the supply chain. Participants in the blockchain can retrieve and execute transactions within their assigned network or consortium. Hyperledger Fabric Blockchain uses this characteristic of blockchain and extends it with several applications to facilitate the desired privacy and security.

Access Control List

Hyperledger Fabric, like other permissioned blockchains, work with consortiums (Hyperledger is mentioned by Forbes as the "Gold standard for Enterprise Blockchain Solutions" (Forbes). Only actors within the same consortium are able to interact. Access to these consortiums is securely regulated making use of Certificate Authority, which encapsulates a user's confidential data and identity. Actors with Certificate Authority are able to participate in the consortium. However, the amount and type of actions they can perform depends on the assigned Access Control List. The Access Control List is a list of permissions that are assigned to users of the system, such as being able to read, edit or create new records. As such, it is both possible to determine the actors able to enter the consortium and the actions they can perform, keeping unwanted or unclassified actors at a distance.

Private communication

Hyperledger blockchain facilitates the possibility to privately communicate (with the use of channels) with only a selection of the participants in the consortium creating security and privacy. Data can be shared and logged for only a selected number of actors through the creation of sub-networks and private channels. Hyperledger blockchain, like all blockchains, is based on a network of nodes. A node in this case is a device or a server which is used for communication with other devices within a network or across networks. Therefore, the network has a decentralised nature which is more resilient against fraud by design. As described in the previous chapter, if a node performs an action, such as deleting data, all participants of the network have to agree with that specific action. Participants based on their access right can monitor and see what the data entails and what happens to the data.

Architecture

In most of the current blockchain solutions, transactions are executed after consensus is completed and resections endorsed by the members in the consortium. This is the so-called 'order-execute architecture'. Classic blockchain frameworks are sequential in terms of architecture, limiting the scalability aspect needed in most enterprise solutions.

Hyperledger Fabric is a little different and was architectured with scalability, modularity and trust in mind, making it suitable for enterprise needs. Hyperledger Fabric's architecture operates according to the so-called ‘execute-order-validate architecture’, wherein transaction requests are executed before the blockchain nodes reaches consensus on their place in the chain. The ‘execute-order-validate’ architecture is more modular in approach by clearly separating the transaction flows and hence being able to increase scalability with the provision to create database replication. Fabric also uses a “non-deterministic algorithm” which is an algorithm that, even for the same input, can exhibit different behaviors on different runs, as opposed to a deterministic algorithm, which takes away the predictability of its outcome. This approach of Hyperledger Fabric handles the non-determinism and security issues such as resource exhaustion or performance attacks and scalability in a completely unique and innovative way.

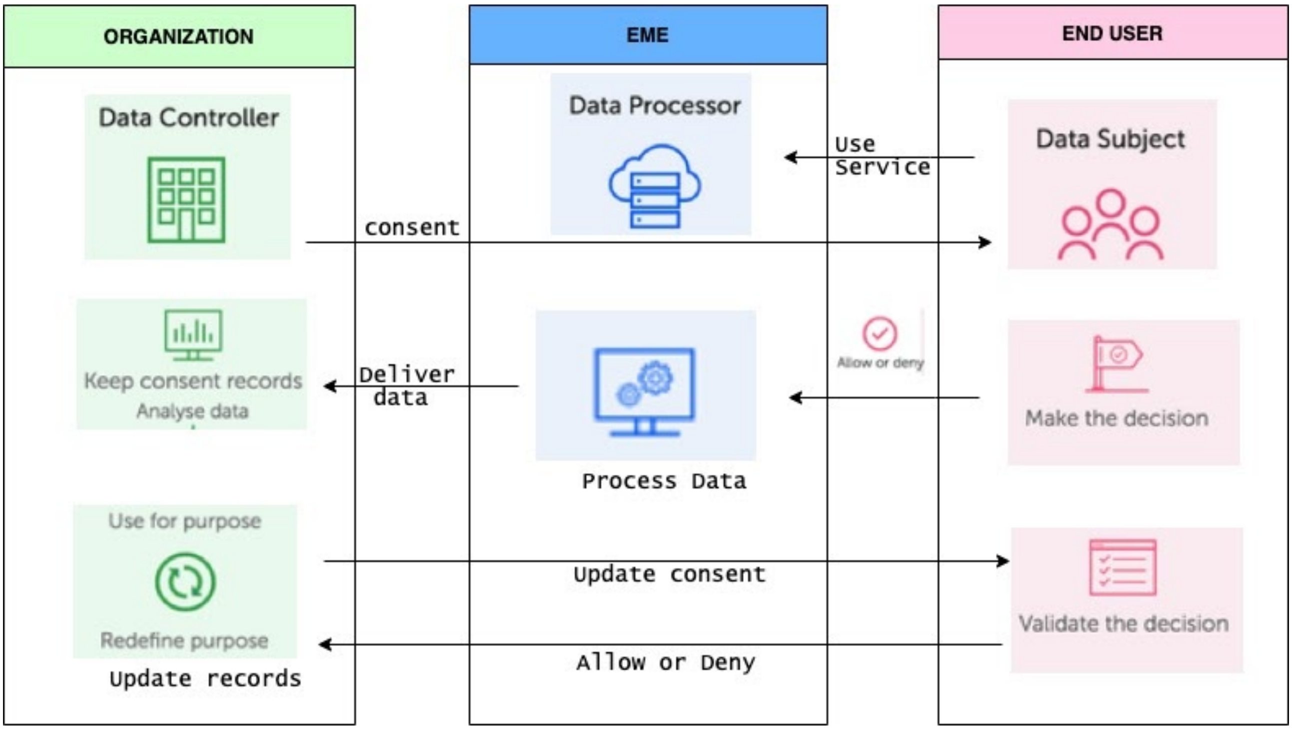
Hybrid approach

Furthermore, Hyperledger uses the Byzantine model, which provides the ability to have a hybrid replication approach by combining active and passive replication:

- Passive replication means that every transaction is executed or endorsed by a subset of peers only, which allows for parallel execution and non-deterministic algorithms.
- Active replication means that outcomes of the transactions on the ledger state are written after a consensus is reached within the consortium.

GDPR compliance

As introduced at the beginning of this chapter, GDPR is an important privacy law with which EME must comply. As per GDPR, the usage and location of data should be transparent and retrievable at all times. The EME platform therefore uses blockchain technology to provide the requested transparency. Blockchain visualises and logs the location (this does not include personal identifiable information), storage and modifications to data. In this manner, the EME platform is able to trace data through companies and across supply-chains and can show proof of compliance considering personal data flows and lineage across systems. Any personal information about the user that is recorded on the platform will be covered in mutual agreement with the companies, its users and the data generated from these companies and users on the platform. A consent layer using blockchain is to be implemented to protect company and individual data privacy.



EME's GDPR data flow between users, EME and the organisation.

Technology 4.2: Cryptography

Within blockchains, blocks can be encrypted using Cryptography. Cryptography is a technology used to read, write and share information in a code language. It uses public-private keys. For example, actors can know the location of information, but only the owner can decode the block in which the information is logged. To ensure the security and integrity of the information stored in the blockchain, a large number of modern cryptographic techniques, such as the hash function and elliptic curve, are used in the construction of EME's blockchains.

Another element of Cryptography we use is the [Zero-knowledge Protocol] (ZKP). ZKP is a cryptographic probabilistic verification method. This method lets one party, the verifier, confirm that something about another party, the prover, is true without learning anything else about the prover. Normally, the verifier must simply trust the prover to be honest. But when making use of Cryptography, the blockchain can verify the claim of the prover.

Using ZKP on our platform, companies can negotiate and collaborate without disclosing their sensitive data, such as intellectual property, price and partner/supplier information, while still being able to trade products with each other. Hence, we verify information about the customers on the platform without compromising on privacy. Also, by disclosing not all but only the relevant data/information that's needed for these businesses to transact with each other, we limit the overhead of storing private customer data, hence a positive step towards GDPR. Lastly, using ZKP we will be able to provide an easy way to share relevant information both within and across the consortiums.

Technology 4.3: Security by design

For our EME platform, we have taken a “security by design” approach, which is one of the better practices often propagated and practiced by experts within cloud infrastructure management. Our cloud infrastructure security principles are based on AWS design principles. Our focus areas for a well-managed cloud platform and how we apply them are as follows;

- **Strong identity foundation:** We implemented the principle of least privilege (The Principle of Least Privilege states that a subject should be given only those privileges needed for it to complete its task. If a subject does not need an access right, the subject should not have that right) with clear separation of duties and appropriate authorisation for each interaction with AWS resources. Our privilege and rights management are managed through an agreement of consortium members to reduce the risk of mis-handling of rights and access to the infrastructure.
- **Multi-layer security:** We applied security control at multiple layers, namely servers, edge network, VPC, subnet, load balancer, operating system, and application.
- **Data management:** Our data is classified based on sensitivity and based on its owners, processors and controllers approach. We use AWS provided encryption for this data and apply access control where appropriate.This helps to reduce the risk of loss or modification and human error when handling sensitive data.
- **Auditability & traceability:** We have a monitoring, alerting and logging mechanism for any action and changes to our environment in real time. Based on the metrics generated from the tools, we are able to effectively respond and take remediation actions.
- **Security Incident Management (SIM):** We have a formal SIM process in place, which is used for incident, tracking, logging, diagnosing, remediation, recovery and reporting of incidents related to our cloud infrastructure. We automated security best practices using templates and cloud formation, and we created a secure architecture and implementation of security protocols as code in version-controlled templates.

Operating by the Security by Design principles helps us to create forcing functions that cannot be overridden, making sure only users with proper modification rights are able to make changes to the infrastructure, establishing reliable operation of controls, enable continuous and real-time auditing, notifications and remediation of events, and technical scripting of governance policy, preventing the risk of human error.
Tenant Isolation at the Application Layer - Privacy and security through multi-tenancy
Every customer account in the AWS cloud environment is called a “tenant”. We isolate tenants at the application layer. This is a strong security architecture practice followed by

almost all cloud providers today. In the case of AWS, the application or solution deployment is shared across different tenants. This is a radical change from classic architecture patterns and a movement toward a true multi-tenant SaaS model. In order to achieve this we have architected our application from the inception to support multi tenancy.

Below is an example of our 3-tier application with shared web and application layers.

- We create a different (unique) database for every tenant to achieve maximum isolation. To enable the application layers to pick up the right database upon each tenant's request, we maintain metadata in a separate store (catalogue) where mapping of a tenant to its database is managed.
- Amazon's fine grained access controls, enables you to determine who can access individual data items and attributes in the database tables and indexes, which actions can be performed and on whom these actions can be performed.
- Each tenant has a unique domain which is easily identifiable, separated and secured with a unique resource identifier having its own independent security certificate.

Challenge 5: Scalability

As discussed earlier in this paper, many of the current circular initiatives are largely dependent on coincidental matchmaking. In order to transition to a circular economy it is necessary to create more information regarding the whereabouts of resource flows, as well as the alternative functions for the resource flows.

In the first two sections of this paper we discussed the importance of digitisation and the creation of a coherent language, which are both essential building blocks in order to scale circular thinking. Without digital information about resource flows, scalability is not possible. Similarly, in order to make matches, it is important that clear terminology is created and harmonised. The ultimate goal is to arrive in a virtuous cycle: as more information is collected and matches are made, the EME platform will start learning more about the potential of circular matches. As a result, the system becomes more intelligent, allowing more and better circular matches to be generated. In this chapter we discuss the challenges in enabling a virtuous cycle.

Technology 5.1: Artificial Intelligence combined with Collective Intelligence

Artificial Intelligence (AI) offers unprecedented abilities to quickly process vast quantities of data, which provides data-driven insights to address public needs (Ng 2015).

Collective Intelligence (CI) on the other hand offers similar potential in changing how we govern, primarily by creating a means for tapping into the "wisdom of the crowd", and by allowing groups to create better solutions than the smartest experts working in isolation could ever hope to achieve.

EME's AI tool gathers data from various sources within and outside the platform (with external API's). The collected data is used for "training" purposes enabling automated decision-making. This increases the effectiveness of AI implementations, and provides the ability to scale the platform. This would otherwise be done manually with a higher chance of creating inaccuracies. The platform is subsequently powered by the inputs of the network partners in our ecosystem and by the circular economy experts to bring the added value of CI to the platform. This approach of combining AI with CI provides a more optimal recommendation and matching solution.

EME's algorithm

To develop a knowledge graph structure that empowers our recommendation engine, we are using a statistical graphical model called Bayesian networks.
The recommendation engine uses machine learning algorithms which learns new patterns when a new product is added and also refines the information by self-learning from the new matches it creates. This makes it possible to automate and scale the solution. Linked Data (where nodes and relationships can be continuously added) is therefore an optimal background technology for the material marketplace and its matchmaking capacities.

The goal of EME's platform by using an Ontological model empowered by graph database technology is to create recommendations that are more context specific and based on meta-data as well as multi-dimensional data. Bayesian Networks are a type of probabilistic graphical model that uses the laws of probability for prediction and decision making.

A Bayesian network is a graph which is made up of Nodes and directed Links between them. This goes quite well with the Linked Data and Ontological approach and seamlessly integrates with our platform recommendation engine. When a user visits our platform and searches for a product, the recommendation engine uses the nodes and Linked-data approach (which powers our semantic web for the circular economy) to be able to find the right match for the customer.

On our platform, we use two algorithms to be able to develop a robust recommendation engine:

- **Content-based filtering:** A content-based filtering, makes recommendations based on user preferences for product features (within the product based on its own features). It recommends items to a customer based on the previously highest rated items by the same customer;

- **Collaborative filtering:** Collaborative filtering on the other hand imitates user-to-user recommendations. It predicts users' preferences as a linear, weighted combination of other user preferences. It relies on how other users responded to these same items. It doesn't rely on features of the item but the preferences from other users.

At EME, we have experienced it is difficult to achieve an optimal solution without the network of partners and experts. Most platforms and solutions end up devising a suboptimal solution to a problem, since it lacks human intelligence (from experts and the user community). With the use of CI, we are able to create a knowledge base, used to power our platform along with the data we have gathered (within our platform and from external systems). This is even more vital in the circular economy, since tapping into the wisdom of the community and allowing groups (network partners) to create better solutions yielding the highest reward.

Both AI and CI bring their own benefits and challenges. For example, AI helps in scaling our platform across industries and countries. However, we also know from experience that the effectiveness and accuracy of AI relies largely on the way the algorithm is designed and the quality of data that is used as an input to the process. Also building biases in the algorithm is a common cause for suboptimal solutions. In such scenarios, CI eliminates the risks of biases and data quality that are built into the AI algorithm, since it brings in diverse and multiple inputs from experts and the community into the equation.

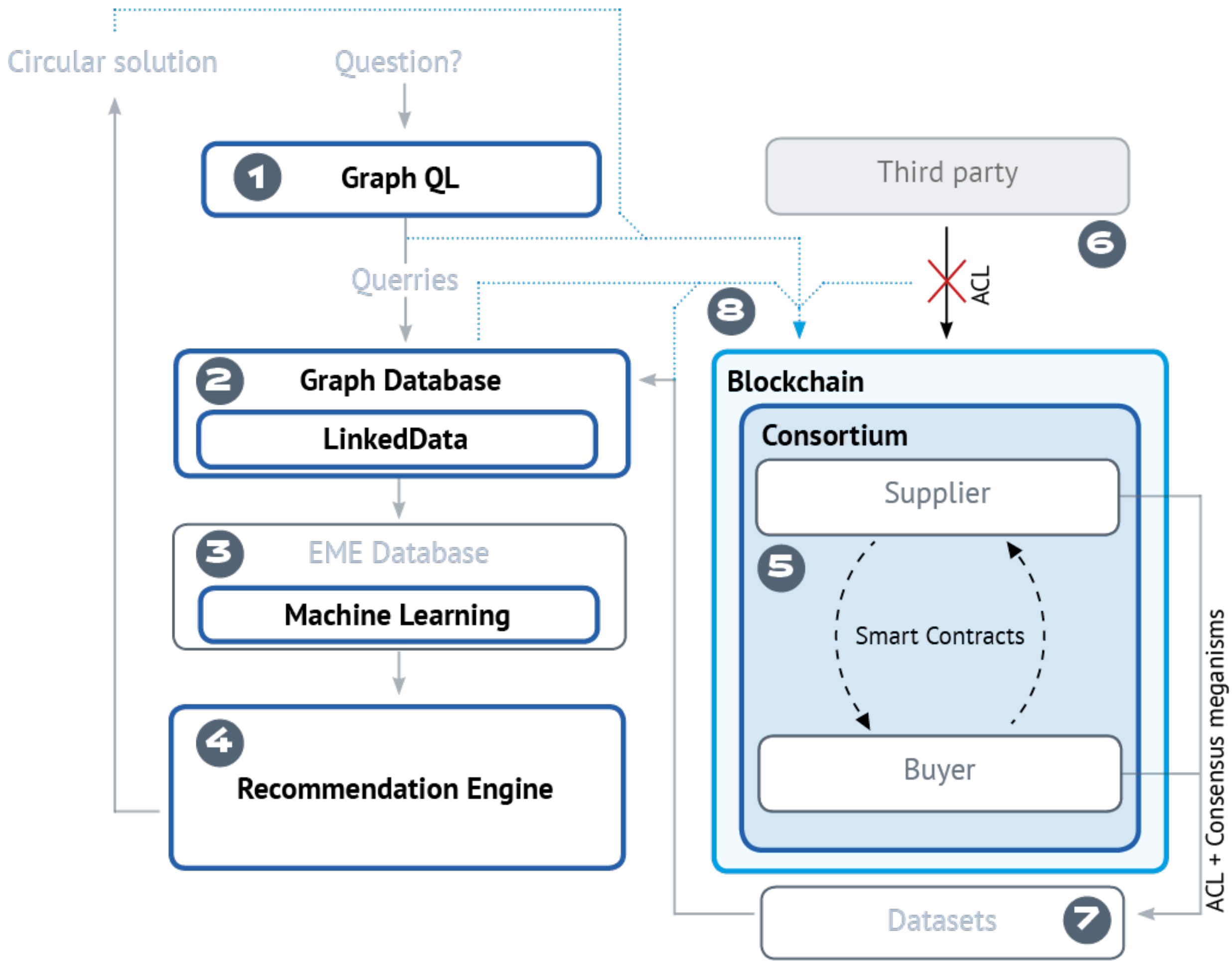
Technology 5.2: Decentralised Machine Learning

The EME platform is able to use data from decentralised databases without bundling or downloading the data on its own servers. Through the use of Decentralised Machine Learning, individual nodes, or devices, can run our artificial algorithms and provide us the scalability that we envision to have in our platform. Only the general results generated by the machine learning tools will be shared within EME's core platform. Decentralised Machine Learning can create advanced circular solutions while the data supporting these results is never extracted from the decentralised devices.

As we have architected data in a decentralised and distributed manner, EME's Machine Learning algorithms have uninterrupted data availability, which improves accuracy.

Our decentralised approach, where data is not collected at a central location (unlike centralised solutions and then algorithms are run), eliminates many issues with data collection, privacy, load and performance issues. This gives us a great opportunity to leverage the benefits of scalability within the platform, as multiple nodes based on the platforms requirements.

The below diagram shows a high level architecture of how EME's platform uses these aforementioned technologies to create an optimal solution within the circular economy.



EME's data flow architecture on the platform

Technology 5.3: Smart contracts

Business logic automation using blockchain

Smart Contracts help reduce paperwork, error rates and intermediaries through automation. Blockchains are programmable with Smart Contracts. A Smart Contract is typically a software programme that stores rules and policies for negotiating terms and actions between parties. It automatically verifies that contractual terms have been met and executes transactions. The logic of a smart contract is executed by the network of players who reach consensus on the outcome of the contract execution. Before a product is transferred (or sold) to another actor, both parties may sign a digital contract, or meet a smart contract requirement, to authenticate the exchange. Once all parties have met contractual obligations and processes, transaction details update the blockchain ledger. The records of data transactions are automatically updated by the system when a change is initiated. A smart contract between two trading partners can legally update the automated record of what goods were bought, sold, and delivered in real-time by end users across the line of business.

By combining the above described technologies, EME's platform will create an inventory of knowledge bases that consortium members and partners can use to monitor the usage of this data in a transparent manner for the benefit of the consortium. Another huge benefit that we see from this approach is the data privacy, which is protected within the platform as only the results of the algorithm will be shared on the EME platform and the private data of the companies still remains on their own servers(nodes).

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Below you can find the hyperlinks to the referenced sources.

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