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# How blockchain technology boosts Operations Excellence 4.0 of chemical companies

Building trusted supply chains in the chemical industry

# Management Summary

## Mastering blockchain technology is an essential capacity for building future-proof supply chains

Trustful supplier relationships play an increasingly meaningful role in global supply chain networks today. Ever-larger transport distances, increasing sensitivity for product quality and a growing number of intermediate actors pose challenges for the performance of global supply chain networks in the chemical industry.

Blockchain technology provides a means of building trust between suppliers and customers along the chemicals supply chain. This new technology offers solutions for

- verifying the sources of raw materials,
- tracking and tracing of processed chemicals,
- assuring chemicals' product quality for customers, and
- detecting counterfeit chemicals.

Blockchain technology enables documenting supply chain data in an unforgeable and encrypted manner. This data may include various pieces of relevant information, such as a chemical's geographic location, temperature or humidity at a specific date and time. Blockchain technology allows suppliers, customers and intermediaries to create a single source of truth on supply chain information with data that is distributed across various ledgers. From the excavation of the raw materials to inbound logistics, manufacturing, and outbound logistics, to when the goods finally reach the customer – supply chain data is continuously tracked and shared. A blockchain-enabled supply chain stores data in a decentralised database that provides constant insight into the status and history of the chemicals. The automatically generated information leads to improved transparency and traceability along the supply chain, which harbours a range of advantages for the chemical industry.

There are two major methodological approaches to blockchain technology which help increase visibility along the supply chain.

The first approach combines blockchain technology with radio frequency identification tags (RFID). RFID tags are attached to goods or their containers and used to document data as the goods move along the supply chain. They enable contactless reading and writing of information. Data that is written onto an RFID tag can be encrypted and published via blockchain technology; users can determine who can read which share of the information within the network, despite the information being stored in different physical locations. The information is stored in ledgers, which are distributed across different servers, PCs, and other storage devices within the network as copies of the originally generated ledger.

The second approach is described as an incentive-driven approach. This solution uses external data feeds from so-called "oracles," which confirm events in the physical supply chain by adding the information to the encrypted blockchain. Examples of oracles are electric sensors or human beings, which provide signals or information from the physical world. The information is only added to the blockchain if multiple oracles confirm that the statement on the physical event in the supply chain is true.

One of our client use cases illustrates how blockchain technology can add value in managing present-day challenges in the chemical industry. One of these challenges is the increasing need for battery storage capacity boosted by the demand for electric vehicles. Modern battery technology is heavily dependant on rare earths such as cobalt, which are often mined in regions that are troubled by violent conflicts and poor working conditions. Both our client's company and the regulatory authorities have a significant interest in preventing the sourcing of minerals from these areas. We developed a solution that combines both blockchain approaches. By incorporating the RFID technology and incentive-driven blockchain technology using oracles, it significantly reduces the risk of accidentally sourcing cobalt from mines with poor working standards or from war zones.

# Spotlight on blockchain technology: How does it work?

Blockchain is a technology that applies cryptographic principles and operates as a distributed repository. Data is recorded in individual blocks; new data entries and transactions are validated by a consensus algorithm and added to the blockchain, so the chain of blocks grows with every transaction.

Blockchain technology is based on a distributed ledger concept, which means that data and applications are stored in decentralized nodes (repositories) of a network (see Figure 1). Decentralised systems enable reliable storage and sharing of data within a peer-to-peer network. Blockchain technology also allows data recording in an immutable and irreversible manner, as neither the users or members of the network nor hackers can change or erase data. Moreover, as a blockchain is not a central enterprise database, it is nearly immune to cyber attacks.

Blockchain technology is often mentioned in context with bitcoin. It is important to note that blockchain is only an underlying technology for the bitcoin cryptocurrency, which uses blockchain technology to securely record monetary transactions.

Data recorded with blockchain technology refers to events relating to physical objects and enables creating digital identities for physical objects, referred to as “digital twins”. A digital twin contains information on an entity or object and documents its life cycle. This feature of blockchain technology correlates with the vision of the Internet of Things: A physical object obtains a digital identity in an information system. To obtain this digital image, you need to start by creating relevant object data. The information can be provided by sensor technology linked to the object itself (e.g. a sensor node or temperature logger) or entered through human intervention (e.g. definition of a destination or expiry date). Secondly, this data must be recorded and transferred to the information system. In supply chains, a physical entity or object may be equipped with Automatic Identification and Data Capture technology (AutoID or AIDC) for this purpose. AutoID or AIDC technology supports creating the relevant data at the object level, recording of this data, and automatic communication with information systems. Radio Frequency Identification (RFID) and Near Field Communication (NFC) technologies or Wireless Sensor Networks (WSN) are frequently used examples.

The direct exchange of data between actors of a network based on blockchain technology follows a specific procedure. When a transaction executes an exchange of information between two actors, the transaction is verified and labelled with a transaction number. The validity of the transaction is checked following a set of predefined rules. These rules could be, for instance, digital signatures, predefined authorizations to remit a cryptocurrency, or smart contracts. The exchanged data is dedicated to a block in chronological order. Each block of data receives a signature consisting of a unique 256bit hash value, which is generated by an algorithm. Additionally, each block includes a reference to the previous block in the blockchain. The result of this procedure is a chronological chain of interdependent blocks with individual hash values (see Figure 2). Following successful validation through Proof of Work (PoW), each block is distributed across the whole network (nodes). This is how blockchain technology facilitates data exchange through integrity and immutability.

**Fig. 1 – Blockchain technology stores data in distributed networks instead of centralized networks.**

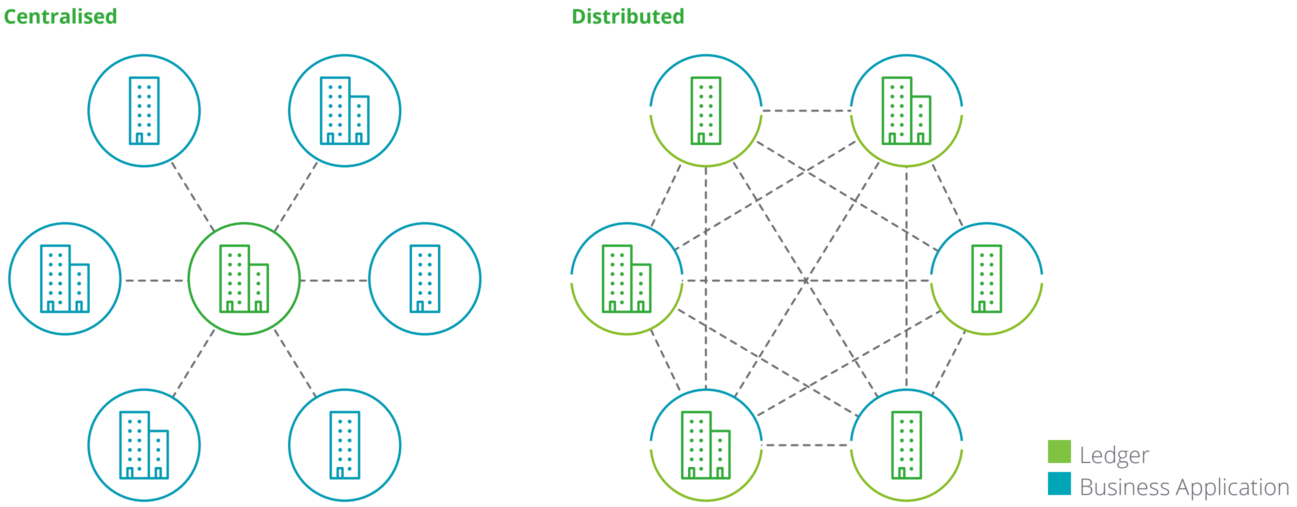
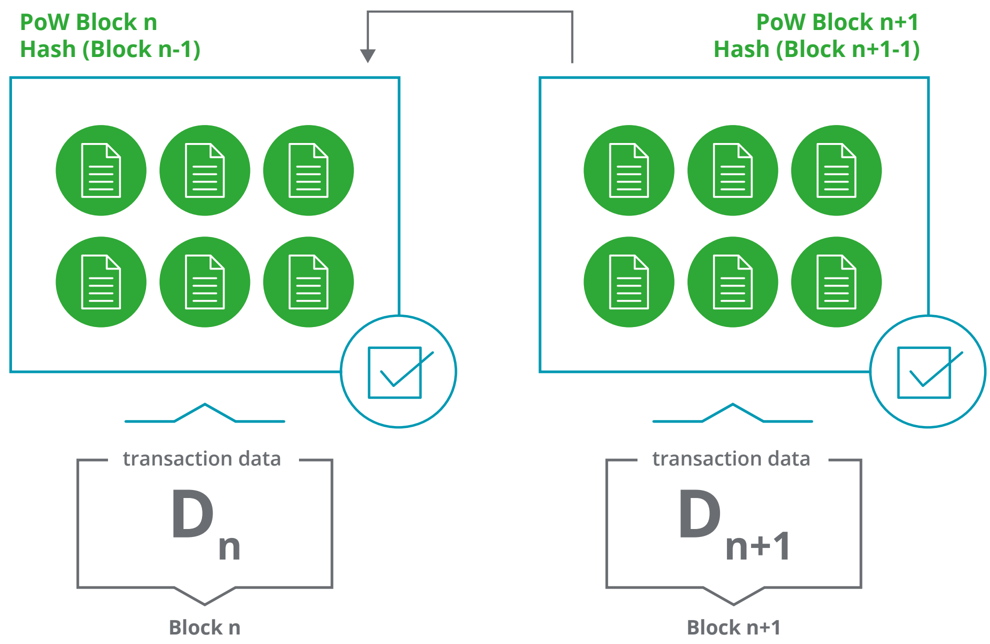



**Fig. 2 – Chronological interdependent blocks with data and hash values**




**Immutable Storage**

- The further a block lies in the past, the more complex subsequent changes to the transaction data are.
- Due to the PoW (Proof-of-Work; mathematical algorithm) and redundant storage on many nodes, the data is practically read-only.

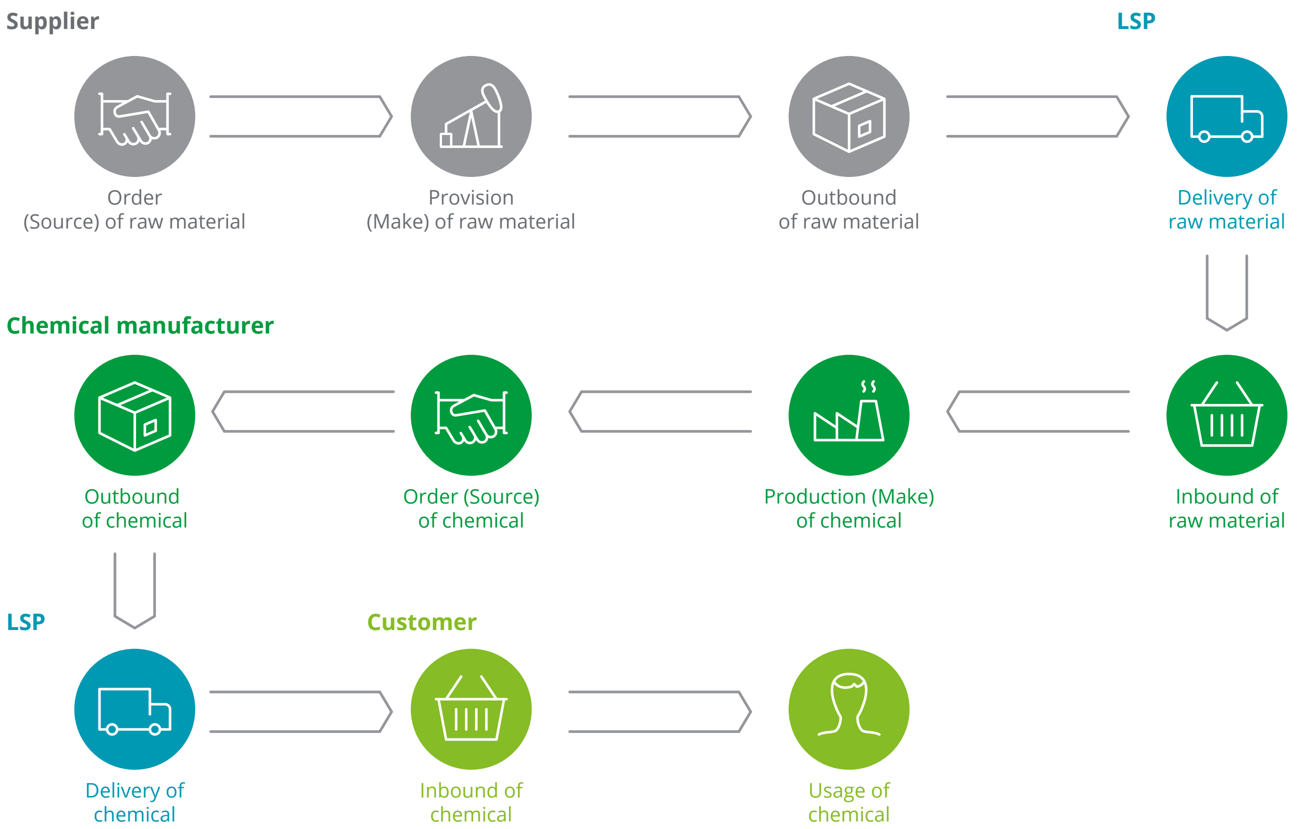
# Application of blockchain technology to achieve Supply Chain Visibility in the chemical industry

**Generic supply chain model for the chemical industry**
Figure 3 provides a generic supply chain model of the chemical industry, covering the sourcing of raw materials, production of chemicals, and distribution to customers. It also lists the relevant actors and their main supply chain activities. For the purpose of this Point of View, the authors deemed an end-to-end supply chain as one that covers the SCOR activities Source (Order), Make (Production), and Deliver.[1] In other words, our perspective on the supply chain covers supply chain visibility (SCV) issues for chemicals from the sourcing of raw materials to production and distribution.

**Approach A: Blockchain and RFID technology to ensure Supply Chain Visibility**
In order to provide a coherent and comprehensible explanation, the description of the approach will follow the steps of the supply chain as shown in Figure 3.

**Order (Sourcing) of raw material**
In the very first step, the chemical manufacturer orders raw materials (RM) from the supplier. To do so, the chemical manufacturer determines the supplier's public blockchain address (for instance, via the supplier's website). Next, the chemical manufacturer needs to conduct a transaction $T_O$, remitting a certain amount of cryptocurrency to the supplier. The blockchain's consensus algorithm approves transaction $T_O$, ensuring that the supplier is the only en-

**Fig. 3 – Generic supply chain model for the chemical industry**




[1] http://www.apics.org/apics-for-business/frameworks/scor

tity authorized to spend the cryptocurrency remitted in transaction $T_O$. Simultaneously, transaction $T_O$ defines the supplier as the authorized supplier for the raw material.

**Provision of (Making) and outbound logistics for raw material**
The supplier produces the raw material (RM) for the chemical manufacturer and packs it in an appropriate container (e.g. liquids in drums, IBC, etc.). Before outbound shipping takes place, the supplier must equip the container or other packaging containing the raw material with a serial-numbered RFID tag.

In addition, the supplier creates a digital device file for the raw material ($F_{RM}$). This digital device file contains all the relevant information on the raw material (such as unique identifier, description, time and place of production, expiry date) and represents the raw material's digital identity. Finally, the supplier adds its signature to the digital device file by means of its private blockchain key, generates the file's hash value, and stores the file, for example, in the cloud. The digital device file $F_{RM}$ is accessible via a hyperlink. Next, the supplier remits a certain amount of cryptocurrency to the chemical manufacturer via transaction $T_S$. This transaction contains information on the hyperlink, the hash value of the digital device file $F_{RM}$, and the serial number of the RFID tag. Again, the consensus algorithm validates the transaction and labels transaction $T_S$ with a transaction number $N(T_S)$. Through transaction $T_S$, the chemical manufacturer is determined as the only entity authorized to read the information on the raw material. The supplier must store the transaction number $N(T_S)$ on the tag to link the raw material to its digital identity.

**Delivery of raw material**
In the next step of our generic chemical supply chain model, a logistics service provider delivers the raw material to the chemical manufacturer.

**Inbound logistics for raw material**
When the raw material is unloaded in the inbound area, the chemical manufacturer checks the material's authenticity. To do so, the manufacturer reads the serial number and transaction number $N(T_S)$ on the RFID tag. The manufacturer can now ascertain the transaction $T_S$ in the blockchain, the hyperlink to the digital device file $F_{RM}$, its hash value, and the serial number of the RFID tag. With the link, the manufacturer can read the digital device file $F_{RM}$ and compute the respective hash value. If the two hash values and RFID serial numbers match, the manufacturer has every reason to assume that this raw material has, in fact, been supplied by the authorized supplier (original raw material).

**Production (Making) of chemical**
The manufacturer can now use the raw material to produce its chemical, which is subsequently packed into a container or other type of packaging. As before, the container or other packaging is equipped with a serial-numbered RFID tag.

The chemical manufacturer now conducts the next transaction $T_V$. With this transaction, the manufacturer refunds the unspent transaction output (UTXO) to the supplier. Bear in mind that the chemical manufacturer is the only entity entitled to spend the unspent transaction output. Again, the consensus algorithm validates the transaction for the blockchain. The chemical manufacturer will now add information to the chemical's digital device file $F_{CH}$. This device file contains data on the chemical (such as its unique identifier, date of production, production state, expiry date and quantity) as well as a reference to the raw material supplied by the supplier.[2] Like the supplier, the chemical manufacturer adds its signature to $F_{CH}$ by adding its private blockchain key, calculates the hash value for $F_{CH}$, and stores the file, for instance, in the cloud. Again, the information is accessible via hyperlink.

[2] A blockchain grows by chronologically adding interrelated blocks documenting the chemical's history.

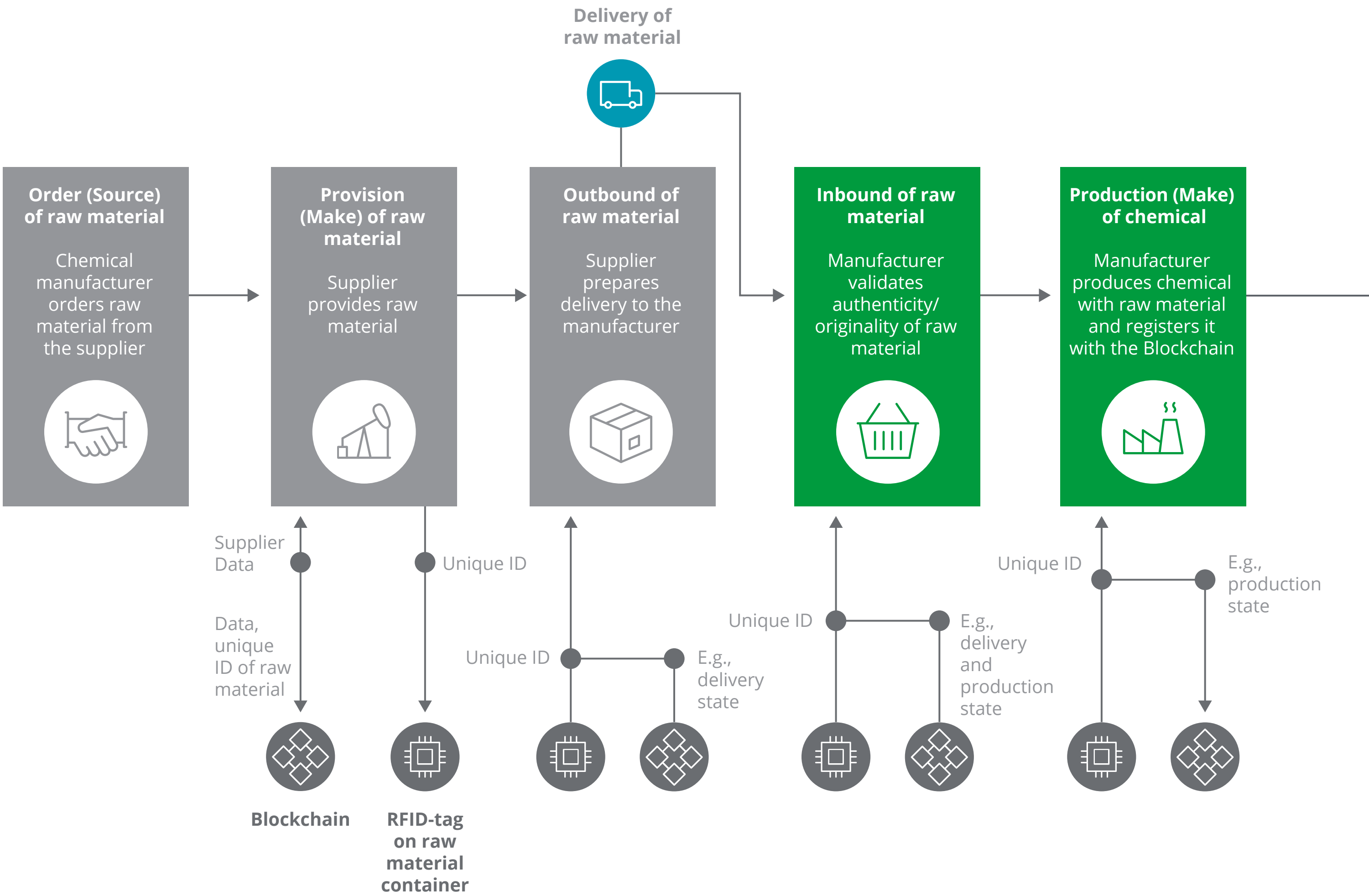
**Ordering of (Sourcing) and outbound logistics for the chemical**
Following the same steps as the manufacturer did when ordering the raw material, the manufacturer's customer can now order chemicals from the manufacturer using its public blockchain address. The customer needs to perform blockchain transaction $T_O$ by remitting a certain amount of cryptocurrency to the chemical manufacturer. As before, the consensus algorithm of the blockchain approves transaction $T_O$ and ensures that the chemical manufacturer is the only entity authorized to spend the cryptocurrency remitted in transaction $T_O$.

After completing the order, the chemical manufacturer refunds a certain amount of the cryptocurrency to the customer via transaction $T_M$. This transaction includes the hyperlink and hash value for the digital device file $F_{CH}$ and the number of the RFID tag attached to the container or other type of packaging. The consensus algorithm validates transaction $T_M$ and labels it with a transaction number $N(T_M)$. Before outbound shipping takes place, the chemical manufacturer needs to store the transaction number $N(T_M)$ and unique identifier on the RFID tag, linking the physical goods to their digital device file.

**Delivery of the chemical**
The logistics service provider delivers the chemical to the customer.

**Inbound logistics for the chemical**
Upon unloading the chemical, the customer performs the same blockchain-related activities as the chemical manufacturer did before. To check the authenticity of the chemical, the customer reads the transaction number $N(T_M)$ and serial number of the RFID tag. With this information, the customer can look up the transaction in the blockchain, the hyperlink to the digital device file $F_{CH}$, the hash value, and the number of the RFID tag. Now the customer can do both read the digital device file and calculate his hash value. If the two hash values and RFID serial numbers match, the customer can strongly assume that this chemical has been produced by the authorized manufacturer. In addition, the digital device file $F_{CH}$ provides the customer with a complete history of the chemical's life cycle throughout the supply chain so far.

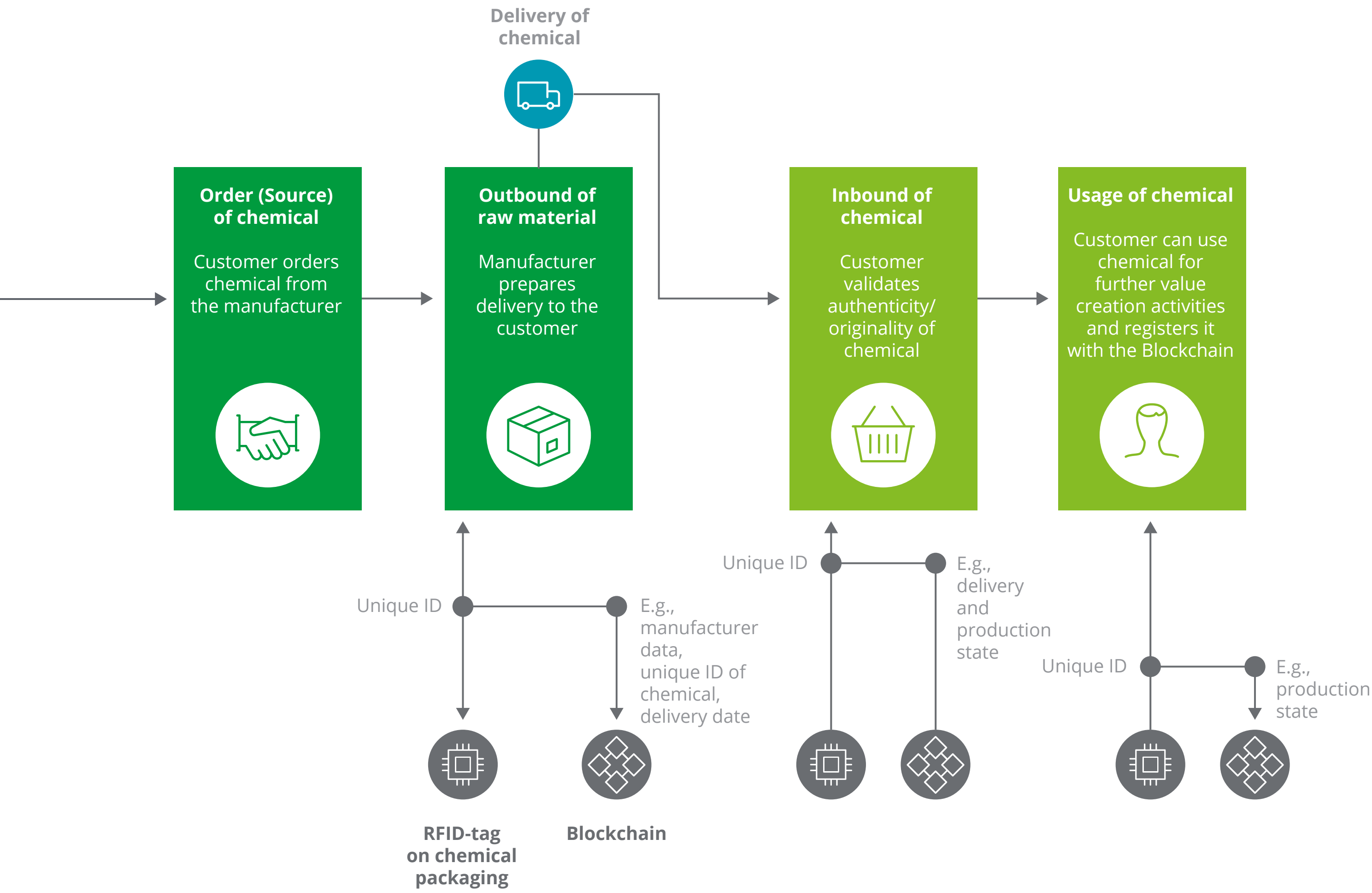
**Fig. 4 – Approach A: Blockchain technology applied with RFID-tag based procedure**



### Usage of chemical
From this point on, the customer may use the chemical for its own value-adding activities (in further B2B or B2C business relationships). However, the customer has yet to perform transaction $T_z$. With this transaction, the customer refunds the unspent transaction output (UTXO) to the chemical manufacturer. As before, the customer is the only entity entitled to spend the unspent transaction output, and transaction $T_z$ is validated by the blockchain's consensus algorithm.

Should the customer wish to add further information to the digital device file, it must add a signature in the form of its private blockchain key to the file. Upon calculating the hash value for the digital device file, the file is stored, for example, in the cloud. Again, the file is accessible via hyperlink. When the customer ships the goods, it performs the same blockchain activities for outbound logistics as the chemical manufacturer did before.

This description of blockchain-related activities shows how they are a recursive procedure based on individual cryptocurrency transactions. Figure 4 provides an overview of this blockchain solution to ensure product authenticity and SCV throughout the chemical supply chain.



## Approach B: Incentive-driven blockchain technology to ensure Supply Chain Visibility

Due to its novelty, this approach is not as well-known as a means of increasing visibility in the supply chain. It uses data feeds from human entry or machines that are referred to as "oracles". In this approach, machines gain a certain level of intelligence via machine learning. However, the concept of oracles entails that new information (events) is only added to the blockchain when several trusted identities (oracles) confirm the validity of the information. In other words, the blockchain's credibility increases with the number of oracles testifying the same event.

**Order (Sourcing) of raw material**

Again, the process begins with the chemical manufacturer placing an order for raw material (RM) with the supplier. To do so, the chemical manufacturer determines the supplier's public blockchain address (e.g. via the supplier's website). Next, the chemical manufacturer needs to conduct a transaction $T_O$ (event), remitting a certain amount of cryptocurrency to the supplier.

To confirm the authenticity of the order and transaction $T_O$ within the blockchain network, the chemical manufacturer must select a predefined number of oracles from a list of reliable oracles.[3] Basically, these oracles can add or mine transactions and blocks to the blockchain. Their trustworthiness is determined through a reputation score linked to incentives such as money, cryptocurrency or credits.[4] If the event is true, the oracles confirm the transaction for the chemical manufacturer. Transaction $T_O$ also ensures that the supplier is the only entity authorized to spend the cryptocurrency of $T_O$ and to supply the respective raw material.

**Provision of (Making) and outbound logistics for raw material**

The supplier produces the raw material (RM) for the chemical manufacturer and packs it in an appropriate container (e.g. liquids in tanktainers).

In addition, the supplier creates a digital device file for the raw material ($F_{RM}$). This digital device file contains all the relevant information on the raw material (such as unique identifier, description, time and place of production, expiry date) and represents the raw material's digital identity. Finally, the supplier adds its signature to the digital device file by means of its private blockchain key, generates the file's hash value, and stores the file, for example, in the cloud. The digital device file $F_{RM}$ is accessible via a hyperlink. Next, the supplier remits a certain amount of cryptocurrency to the chemical manufacturer via transaction $T_S$. This transaction contains information on the hyperlink, the hash value of the digital device file $F_{RM}$, and a transaction number $N(T_S)$. Like the manufacturer, the supplier must now select a predefined number of oracles required to verify the transaction if the event is true.

Through transaction $T_S$, the chemical manufacturer is determined as the only entity authorised to read the information on the raw material. It receives the transaction number $N(T_S)$ from the supplier via a secure messaging service.

**Delivery of raw material**

In the next step of our generic chemical supply chain model, a logistics service provider delivers the raw material to the chemical manufacturer.

**Inbound logistics for raw material**

When the raw material is unloaded in the inbound area, the chemical manufacturer checks the material's authenticity.
Based on the transaction number $N(T_S)$, the manufacturer can now look up transaction $T_S$ in the blockchain, the hyperlink to the digital device file $F_{RM}$, and its hash value. With the link, the manufacturer can read the digital device file $F_{RM}$ and the information on the raw material it contains, and compute its hash value. If the two hash values match, the manufacturer has every reason to assume that this raw material has, in fact, been supplied by the elected supplier (original raw material).

[3] The list of oracles can be defined by the actors of a chemical supply chain.

[4] Reputation is ranked by means of a reputation account and score for each oracle. Incentives should be defined by the actors of a chemical supply chain and allocated to reward the reputation score.

**Production (Making) of chemical**
The manufacturer can now use the raw material to produce its chemical, which is subsequently packed into a container or other type of packaging.

Next, the chemical manufacturer conducts transaction $T_V$. With this transaction, the manufacturer refunds the unspent transaction output (UTXO) to the supplier. Bear in mind that the chemical manufacturer is the only entity entitled to spend the unspent transaction output. To validate transaction $T_V$ for the blockchain, the chemical manufacturer must select a predefined number of oracles that will confirm the validity of transaction $T_V$ and the use of original raw material for the chemical.

The chemical manufacturer will now add information to the chemical's digital device file $F_{CH}$. This device file contains data on the chemical (such as its unique identifier, date of production, production state, expiry date and quantity) as well as a reference to the raw material supplied by the supplier. Like the supplier, the chemical manufacturer adds its signature to $F_{CH}$ by adding its private blockchain key, calculates the hash value for $F_{CH}$, and stores the file, for instance, in the cloud. Again, the information is accessible via hyperlink.

**Ordering of (Sourcing) and outbound logistics for chemical**
Following the same steps as the manufacturer did when ordering raw material, the manufacturer's customer can now order chemicals from the manufacturer using its public blockchain address. Now the customer needs to perform blockchain transaction $T_O$ by remitting a certain amount of cryptocurrency to the chemical manufacturer. To confirm the authenticity of the order and transaction $T_O$, the customer must select a predefined number of oracles. Again, these oracles validate transaction $T_O$ for the customer and the blockchain if the event is true.

After completing the order, the chemical manufacturer reimburses a certain amount of the cryptocurrency to the customer via transaction $T_M$. This transaction includes the hyperlink and hash value for the digital device file $F_{CH}$ and the transaction number $N(T_M)$. Again, the authenticity of the transaction requires confirmation through a number of oracles selected by the chemical manufacturer.

Transaction $T_M$ ensures that the customer is the only entity authorized to read the relevant information on the chemical. The customer receives the transaction number $N(T_M)$ from the chemical manufacturer via a secure messaging service.

**Delivery of chemical**
The logistics service provider delivers the chemical to the customer.

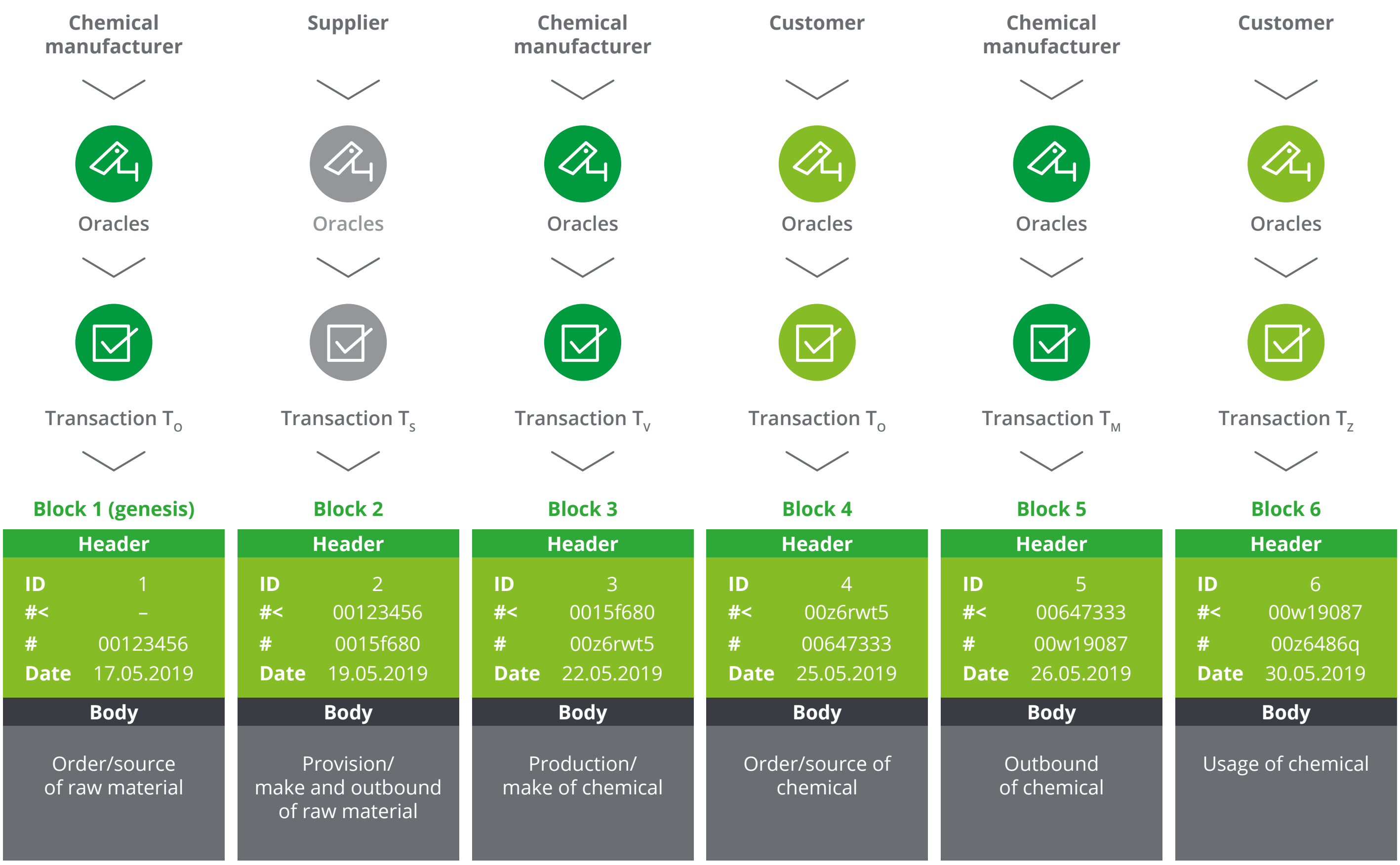
**Inbound logistics for the chemical**
Upon unloading the chemical, the customer performs the same blockchain-related activities as the chemical manufacturer did before. To check the authenticity of the chemical, the customer uses the transaction number $N(T_M)$ to locate the respective transaction in the blockchain and to find the link to the digital device file $F_{CH}$ and hash value. With the hyperlink, the customer can read the digital device file $F_{CH}$ and can calculate the related hash value. If the two hash values match, the customer can strongly assume that this chemical has been produced by this manufacturer. In addition, the digital device file $F_{CH}$ provides the customer with a complete and immutable history of the chemical's life cycle throughout the supply chain.

### Usage of chemical

From this point on, the customer may use the chemical for its own value-adding activities (in further B2B or B2C business relationships). However, the customer has yet to perform transaction $T_Z$. With this transaction, the customer refunds the unspent transaction output (UTXO) to the chemical manufacturer. As before, the customer is the only entity entitled to spend the unspent transaction output and is required to select a number of oracles that will confirm transaction $T_Z$ for the blockchain network.

Should the customer wish to add further information on its product to the digital device file, it must add a signature in the form of its private blockchain key to the file. Upon calculating the hash value for the digital device file, the file is stored, for example, in the cloud. Again, the file is accessible via hyperlink. When the customer ships the goods, it performs the same blockchain activities for outbound logistics as the chemical manufacturer did before. Figure 5 below provides a summary of our incentive-driven blockchain approach based on oracles to ensure product authenticity and SCV along the chemical supply chain.

**Fig. 5 – Approach A: Blockchain technology applied with RFID-tag based procedure**



# Application of blockchain technology: Enhancing Supply Chain Visibility in the cobalt supply chain

**As an exemplary application of the approaches introduced above, the authors present a concept that combines approaches A and B in a present-day context: Sourcing of batteries produced only with cobalt from certified mines (bulk material).**

This application is hugely important for the automotive industry in view of the changes it is undergoing as we enter the era of electronic vehicles, but equally significant for any other industry that needs to provide evidence to stakeholders that it is using cobalt from certified sources. As cobalt mines are often located in developing or emerging countries, credibility is an issue.

**The question is: How can a company trace cobalt on its journey from a certified mine and verify that this is the material used for the production of its batteries or other value-creating activities?**

We have developed a solution for the sourcing of cobalt as a bulk material in such a complex supply chain that combines approaches A and B, using both incentive-driven blockchain technology with oracles and RFID tags to enable traceability of the raw material along the entire chain. Oracles are used to monitor supply chain steps that are not suitable for RFID tagging, which, currently, constitute black boxes and are susceptible to smuggling. For instance, a camera or privileged human actor can act as an oracle to confirm the loading of a truck or waggon in a cobalt mine or the unloading of cobalt in a port. Additionally, our solution envisages tagging objects that are used to move the cobalt along the supply chain with RFID technology, such as the cases, containers and trucks. By providing a unique identification, RFID tags support the protection of the transported cobalt material as it moves along the supply chain. Our solution serves to capture every relevant event in the supply chain and record this information in the blockchain.

As tagging and tracing bulk materials such as cobalt with RFID technology along the entire supply chain can be difficult, our solution additionally uses statistic probabilities. Actors at any given point of the supply chain, such as a cobalt refiner or car manufacturer, receive a probability p that proves the authenticity of a certain amount of cobalt. This probability P is calculated based on the ratio of the verified amount of cobalt and the total amount of cobalt transported to the respective point of the supply chain. The cobalt verification process is thus supported by aggregating statistic probabilities along the supply chain. Furthermore, the authors recommend adding timestamps to every event along the chain. This way, logistics activities such as transportation or loading and unloading are captured in greater detail, which makes them easier to verify. The accurate recording of regular events in the blockchain means that smugglers face higher obstacles to introducing non-certified cobalt into the reliable supply chain.

**Fig. 6 – Exemplary cobalt raw material supply chain**

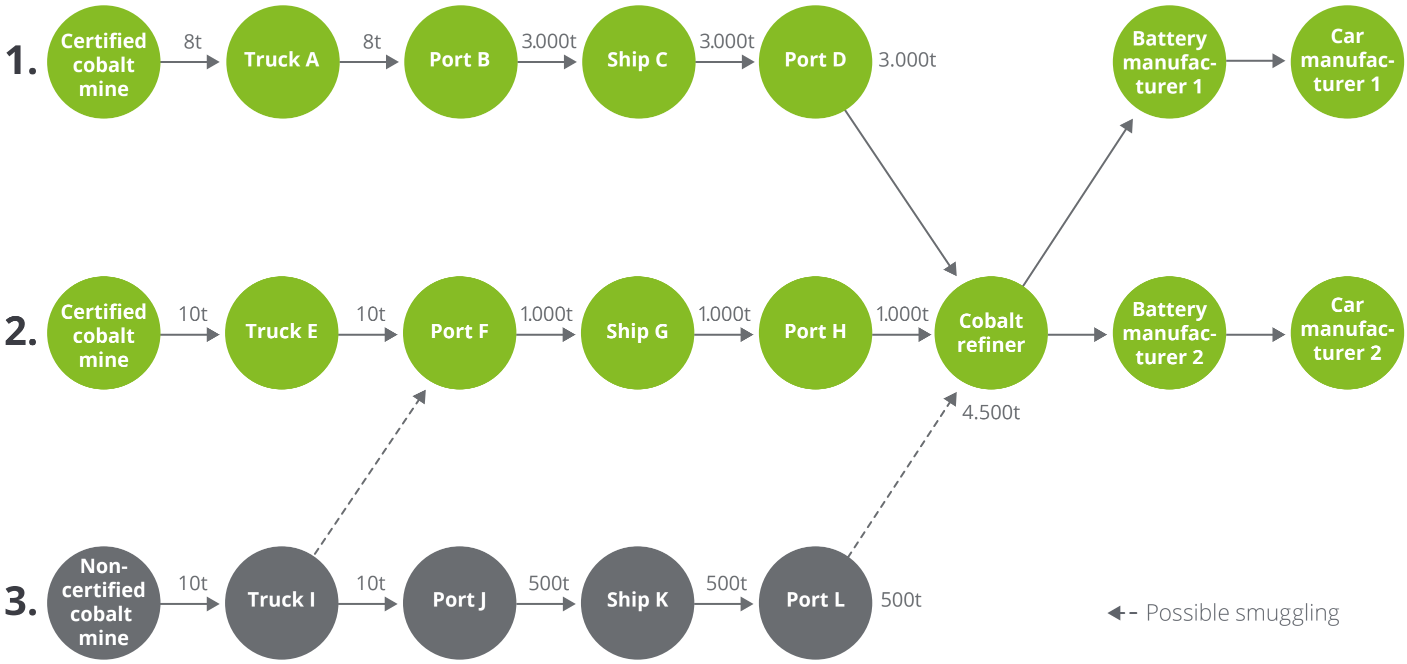



Figure 6 illustrates an exemplary supply chain network for cobalt used in the production of batteries in the automotive industry. In this basic example, there are two certified cobalt mines (Supply Chains 1 and 2) and one non-certified cobalt mine (Supply Chain 3). After its excavation, trucks and ships haul the cobalt to the main ports (D, H, L). The cobalt refiner receives cobalt from all three ports, and processes the raw material so that battery manufacturers 1 and 2 can use it for battery production. Finally, car manufacturers 1 and 2 use the batteries in their electric vehicles.

To verify the amount of cobalt received, the cobalt refiner employs our blockchain solution. It has provided him with a probability p, which proves how much cobalt originates from a certified mine. Figure 6 demonstrates that, under the assumption that cobalt was successfully smuggled from Port L to the cobalt refiner, 88.9% (4,000 of 4,500 tons) of the cobalt comes from certified mines. However, to introduce non-certified cobalt into the supply chain, smugglers would need to import the exact same quantity of cobalt as was transported via the reliable supply chain as recorded in the blockchain. For instance, Truck I in Supply Chain 3 (carrying cobalt from a non-certified mine) would have to deliver exactly 10 tons of cobalt to Port F, as Truck E (coming from Supply Chain 2) is delivering exactly 10 tons of cobalt from a certified mine to Port F. A potential smuggler would need to have precise information on the reliable supply chains and would need to cover high logistics expenditures to place its smuggled goods.

This example shows that, despite the application of blockchain technology with statistic probabilities, cobalt mines still require certification. Blockchain technology cannot fully prevent organised smuggling. However, by capturing as many events in the supply chain as possible with our solution, the reliability of verification achieved with statistic probabilities increases due to the fact that blockchains contain immutable and chronological information.

**Tab. 1 – Current limitations and potential future benefits in the chemical supply chain**

| Actor (Supply Chain stakeholder) | Current limitations | In future |
|---|---|---|
| **(Chemical) manufacturer** | • Limited ability to monitor and verify incoming raw materials from suppliers<br>• Limited ability to ensure compliance with distribution guidelines or code of conduct | • Definition of elected suppliers through blockchain transactions<br>• Reliable verification of raw material authenticity<br>• Control of incoming raw materials<br>• Tracking of production lots and batches<br>• Possibility to document chemicals' life cycle<br>• Proof of compliance with guidelines or code of conduct |
| **Supplier** | • Limited ability to sign or tag outgoing raw materials; current barcode technology only offers limited information density and is prone to damage through sullying<br>• Limited ability to ensure compliance with distribution guidelines or code of conduct<br>• Limited ability to ensure compliance with distribution guidelines or code of conduct | • Unique labelling of raw materials<br>• Provision of additional information on raw materials (for raw material life cycle)<br>• Tracking of batches |
| **Logistics Service Provider** | • Limited ability to ensure compliance with distribution guidelines or code of conduct | • The blockchain approach presented in this document provides an opportunity to include LSPs<br>• LSPs could participate in information sharing and provide information on goods delivered (e.g., batch tracing, transportation process, transport conditions) |
| **Customer** | • Limited ability to verify authenticity of chemicals and ingredients or components<br>• Limited ability to receive documentation on the chemical's life cycle | • Comprehensive information on the purchased chemical (product life cycle) |

### Benefits for the chemical supply chain

These are the benefits companies can gain with SCV obtained by applying the presented blockchain solution:

- Collaboration: Multiple actors in the chemical supply chain can add information on raw materials and chemicals and view life cycle data;
- Trust: Blockchain data (such as delivery date, expiry date, date of production) is immutable; the RFID tag only carries the unique ID/transaction number;
- Traceability: Raw materials and chemicals with a unique ID can be traced from sourcing to distribution (end-to-end supply chain visibility); and
- Auditability: Product recalls can be traced and executed more efficiently.

Applied in practice, our blockchain solution offers an efficient means of ensuring product authenticity and creates an immutable source of information on products (digital twin), allowing companies to overcome current supply chain constraints. Table 1 summarizes the constraints each supply chain actor is faced with and future benefits to be gained from our solution.

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Blockchain technology is the foundation to revolutionize trusted business transactions.

# Conclusion

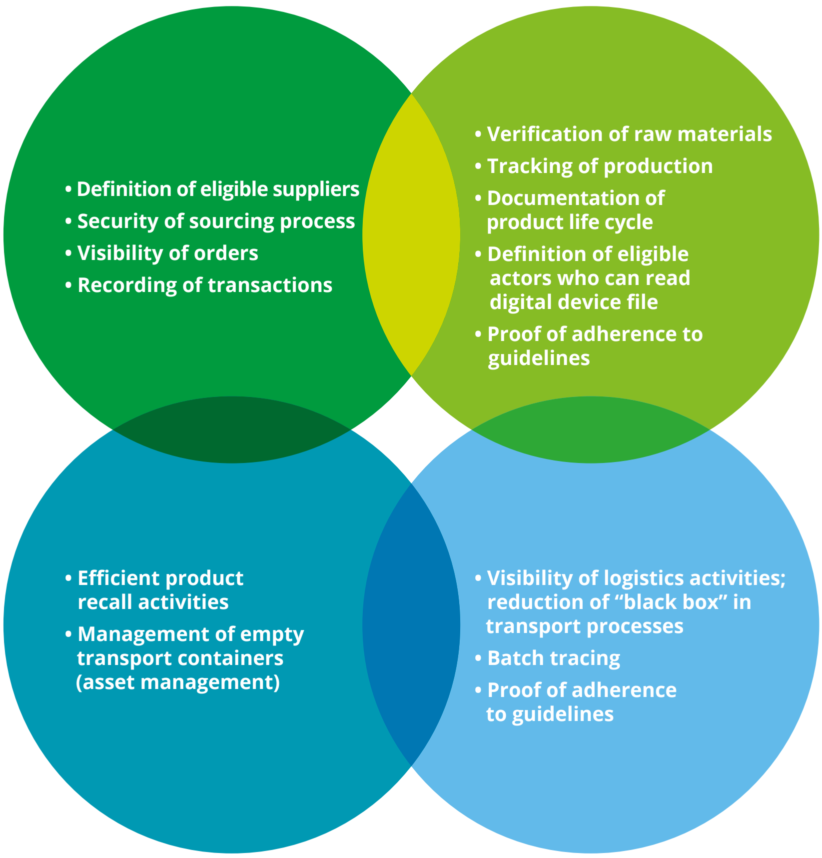
Blockchain technology offers ground-breaking opportunities for efficiency gains and new means of building trust in chemical industry supply chains. For companies in the chemical industry, the capacity to understand and successfully apply blockchain technology will become an essential prerequisite for building competitive supply chains.

Blockchain technology can be used to encrypt and record supply chain data originating from operations along the chemicals supply chain in a forgery-proof manner. Containers for liquid and solid chemicals can be traced reliably along their physical transportation routes.

Data generated in the course of the physical movement of the goods is stored across a distributed range of storage devices. The storage of data in a network allows for the unique identification of true data – which makes it virtually impossible or prohibitively expensive to fake transport data.

The application of blockchain technology offers significant benefits for supply chain managers in the chemicals industry:

**Fig. 7 – Benefits of blockchain technology for competitive supply chains**




The benefits of blockchain technology take effect along the entire supply chain and product lifecycle. Accordingly, efficiency gains are not only to be achieved in inbound or outbound logistics, but also in production, sales or events of legal recourse.

Having a trustworthy and secure database of supply chain activities is especially important in business environments characterised by low levels of trust and high sales prices. Our application to prevent the sourcing of cobalt from troubled regions showcases the huge impact that blockchain technology can have.

For this application, we used the two different approaches presented in this paper:

- Approach A: Blockchain technology in combination with RFID tags;

- Approach B: Incentive-driven blockchain approach using oracles.

Applying both approaches in a combined solution for a supply chain that is backed by blockchain technology from end to end – from cobalt mining to the electric vehicle on the road – significantly increases the trustworthiness of the processed raw materials. Apart from the financial impact, chemical companies can ensure that they source their raw materials only from mines that fulfil both regulatory and corporate environment protection and industrial safety standards.

Increasingly, chemical companies are seeking to build supply chains that add value beyond customers' basic expectations. Taking your supply chain to uncharted territory is one prerequisite for building a supply chain with a competitive edge.

Exploring the opportunities blockchain technology opens up is a must for chemical companies aiming to develop their supply chain. Deloitte is a perfect partner for this, offering a unique combination of practical supply chain management expertise through its Strategy & Operations Consulting activities as well as the leading team of experts that work at the Deloitte Blockchain Institute.

# Appendix

| Abbreviation | Description |
|---|---|
| **AIDC** | Automatic Identification and Data Capture |
| **AutoID** | Automatic Identification |
| **B2B** | Business to Business |
| **B2C** | Business to Consumer |
| $\mathbf{F_{CH}}$ | Digital device file of the chemical |
| $\mathbf{F_{RM}}$ | Digital device file of raw material |
| $\mathbf{N(T_M)}$ | Transaction number of transaction $T_M$ |
| $\mathbf{N(T_S)}$ | Transaction number of transaction $T_S$ |
| **NFC** | Near Field Communication |
| **PoW** | Proof of Work |
| **RFID** | Radio Frequency Identification |
| **RM** | Raw Material |
| **SCV** | Supply Chain Visibility |
| $\mathbf{T_M}$ | Transaction from chemical manufacturer to customer |
| $\mathbf{T_O}$ | Order Transaction |
| $\mathbf{T_S}$ | Order from supplier to chemical manufacturer |
| $\mathbf{T_V}$ | Transaction of UTXO from chemical manufacturer to supplier |
| $\mathbf{T_Z}$ | Transaction from customer to chemical manufacturer |
| **UTXO** | Unspent transaction output |
| **WSN** | Wireless Sensor Network |

# Your contact

**Andreas Flegel**
Director | Strategy & Operations
Deloitte Consulting GmbH
Tel: +49 (0)151 5800 5993
aflegel@deloitte.de

**Dr.-Ing. Markus A. Stulle**
Senior Manager | Technology Strategy & Architecture
Deloitte Consulting GmbH
Tel: +49 (0)151 5807 1139
mstulle@deloitte.de

**Alexander Brox**
Manager | Strategy & Operations
Deloitte Consulting GmbH
Tel: +49 (0)151 5807 1031
abrox@deloitte.de

**Dr. Marcel Papert**
Consultant | Strategy & Operations
Deloitte Consulting GmbH
Tel: +49 (0)151 5800 0273
mpapert@deloitte.de

Deloitte.



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