# E-Mine2: A Blockchain Solution for Waste Electrical and Electronic Equipment

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# Disclaimers

- "The software code which is part of this report is open source and available at: "https://github.com/ETHBiots2018/e-mine2"

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## 1. Background

Any electrical and electronic equipment (EEE) that is discarded is considered as an electronic waste referred to as "e-waste" or "WEEE" (Waste Electrical and Electronic Equipment). E-waste includes almost any household or business item with circuitry or electrical components with power or battery supply [1]:

- Temperature exchange equipment: refrigerators, freezers, air conditioners, heat pumps.
- Screens, monitors: televisions, monitors, laptops, notebooks, and tablets.
- Lamps: straight lamps and LED lamps.
- Large equipment: washing machines, clothes dryers, dish washing machines, electric stoves, large printing machines, copying equipment and photovoltaic panels.
- Small equipment: vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, calculators, radio sets, video cameras, electrical and electronic toys, small electrical and electronic tools, small medical devices, small monitoring and control instruments.
- Small IT and telecommunication equipment: mobile phones, GPS, pocket calculators, routers, personal computers, printers, telephones.

The estimated total amount of e-waste produced in 2014 was 41.8 million ton [1], with an expected annual growth of 3-5% [2], which is considered to be one of the fastest growing waste streams.

The current practices adopted to deal with e-waste are ordered into four categories:

1. Local dumping or incineration: applies to the large part of the world where e-waste is locally landfilled or incinerated.
2. Export and dumping/incineration: mostly observed in developed countries where e-waste is collected mainly by individual waste dealers or companies and exported to developing countries where it is dumped or incinerated.
3. Low-level "informal" recovery: mostly seen in developing countries where self-employed, unskilled people are engaged in collection and recycling of e-waste. It uses large labor force for private door-to-door collection and junk shops, and generate low levels of income. It involves low-level technology and safety procedures. All the materials which do not have any sales value are locally landfilled or incinerated.
4. High-level recovery: mostly observed in developed countries where e-waste is collected by the official take-back system (e.g. municipalities, retailers) or individual waste dealers or companies and sent to metal and plastic recycling.

Only 15% of the global e-waste was fully recycled in 2015 [3]. There are economic, environmental and health reasons in favor of the high-level recovery of the e-waste [4]. From an economic point of view, e-waste contains more than 1000 different compounds and up to 60 different metals, among them some precious ones like iron, copper, aluminum, gold, silver, palladium in concentration higher than in the ores obtained by conventional mining operations. Taking into account the that global ore reservoirs are declining and conventional mines are forced to be exploited for more complex and fine-grained ore deposits to meet the global metal demand, the e-waste is increasingly considered as "urban mine". This urban mining industry can potentially also create additional jobs. From an environmental point of view, many of the materials contained in the e-waste are hazardous, like mercury, cadmium, lead, chromium, poly/brominated flame retardants, ozone depleting chemicals such as CFC etc. Uncontrolled landfilling and incineration of e-waste causes the release of these substances in the environment. As an example, it has been estimated that about 70% of heavy metals in US landfills comes from e-waste. Even landfilling and incineration of e-waste operated under controlled regime can lead to some release of hazardous compounds in water reservoirs and atmosphere, and it can only be a temporary solution of the problem. In the same time, recycling e-waste allows to save the energy required to extract new metals from virgin materials, which has a direct impact on the global carbon footprint. Finally, the hazardous metals and chemicals present in the e-waste can become a threat for public health through water, solid, air, dust and food causing brain damage, allergic reactions and cancer.

In 1989, an amendment of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal imposed that hazardous wastes have to be managed in an environmentally sound manner in the country of import, so that exporting e-waste from developed to industrializing countries is forbidden. In 2004, the EU legislation on Waste from Electrical and Electronic Equipment (WEEE) came into force, obliging manufacturers and distributors in EU member states to take back their products from consumers and recycle them. In spite of the legislation, nowadays a considerable amount of e-waste is still not recycled and also exported by illegal shipments to developing countries. In 2001, the Organization for Economic Co-operation and Development (OECD) has published guidelines to help the national governments to establish a policy approach, the Extended Producer Responsibility (EPR), under which producers are given a significant responsibility for the treatment or disposal of post-consumer products [5]. The EPR provides incentives to prevent wastes at the source, promoting product design for post-use recycling, and shifts the responsibility away from the municipalities according to the polluter-pays principle. Legislators are adopting EPR policies to manage e-waste and the number of Producer Responsibility Organizations (PROs) is increasing with the intention of meeting the EPR obligations as a cooperative effort of the member companies. In order to design an e-waste management system based on the EPR approach, five key parameters need to be considered [6]:

1. Legal Regulation: it can be missing, flexible or very stringent.
2. System Coverage: it can be collective (for any brand) or brand-specific (each brand is individually accountable). Another aspect would be whether to have an all-inclusive system that caters to all the items under the WEEE spectrum or have different systems for different categories.
3. System Financing: at one extreme, it can be an entirely externally financed system where the financial burden of the end-of-life treatments (collection and recycling) is on the product user or producer or municipality. On the other hand, a system with no external financing would cover the cost of collection and recycling from the e-waste itself.
4. Producer Responsibility: it can be non-existent, partial or strong. It is also important to consider when and how the responsibility is taken on in practice. Also, the responsibility can be individual or collective.
5. Ensuring Compliance: checks and balances have to be designed so that penalties for non-compliance of targets for collection or recycling can be applied.

Combinations of the above-mentioned parameters can lead to remarkably different WEEE management systems, even in the case of two countries with comparable economic indicators like Switzerland and Japan. The Swiss system establishes relatively little regulatory control via the “Ordinance on the Return, the Taking Back and the Disposal of Electrical and Electronic Equipment”

(ORDEE). The producers have full responsibility of the implementation and operation of the end-life treatments, without being brand- or product-specific. The entire system is financed through recycling fees. In comparison, the Japanese EPR-related legislation "Act for Recycling of Specified Kinds of Home Appliances" regulates in detail the end-of-life operations and is both brand- and product-specific. It gives full responsibility to the producers and introduces severe penalties for non-compliance of targets. In the expectation of having the international directives enforced soon, many other export oriented countries have started to move towards solving their domestic e-waste issues. It is happening by instituting committees, consisting of delegates of the different stakeholders, which can promote the implementation of national EPR rules and the establishment of public awareness. Although awareness and consequent readiness for implementing improvements is rapidly growing, some obstacles to manage end-of-life products safely and effectively have been identified, above all, the lack of reliable data. It represents a challenge to policy makers, wishing to design an e-waste management strategy, and to companies, wishing to make rational investment choices.

# 2. Goal

A blockchain-based system has been proposed to boost the recycling of e-waste via the introduction of incentives for the involved parties and also by providing a database to track the product throughout its lifecycle. The advantage of using a blockchain based approach is the transparency of the stored information and safety against fraud.

# 3. Approach

An e-waste management system has been envisioned based on the EPR approach. National legislations have to set the collection and recycling targets and introduce penalties for non-compliance. The regulations give also broad guidelines on the structure of the EEE management system, but producers have full responsibility of the implementation and operation of it. Each producer can be individually responsible for its products or several manufacturers can come together to form a collective WEEE management system which is not brand-or product-specific. The key stakeholders involved in the proposed EEE management system are the manufacturers, the consumers, the shops and the recycling companies.

- The manufacturers produce the EEE. They make profit from the sale of the EEE products but could also boost their reputation by increasing the percentage of recycled EEE (consumers may prefer to buy from "green companies"). The manufacturers also have to comply with the targets set by the existing e-waste legislation and needs reliable data to proof their recycling rate.
- The consumers buy and use the EEE. After usage they will return the e-waste to a shop. Upon return, the consumers receive a reward.
- The participating shops are selling EEE and are also collecting points for returned e-waste. They will then deliver the e-waste to recycling companies. As the consumer, they will receive a reward when they fulfill their task.
- The recycling companies recycle the received e-waste. The existence of the EEE management system can guarantee a stable input of e-waste which can be either free of charge or at a competitive price set by the producers.

In the proposed EEE management system, the collection is financed by the producers which will reward consumers and shops. The recycling process is self-financed by recycling companies, which will also profit on it. Additional funds can come from municipalities in terms of reduced taxation for "virtuous" producers.

## 3.1. Tokens

The solution proposed in order to provide a tracking mechanism for the EEE and incentivize the return of the used EEE to the collecting points (shops), which is the weak link in the chain, is the introduction of two tokens.

The first one is called Lifecycle-Token and is an asset token. It is created by the manufacturer when the device is fabricated. Its purpose is to track the device during its lifecycle. Therefore, the token's state is updated upon certain actions (creation, sale, return, recycling) and stored on the blockchain. By storing these data on the blockchain, information is made public and transparent and fraud is discouraged.

The second token is called Reward-Token and is a monetary token. It is created upon return of the d EEE to the shop (Token for the consumer) and upon collection and delivery of the e-waste to the recycling company (Token for shops). The Reward-Token can be traded for discounts or goods at all participating manufacturers. Once they are traded in, they will be destroyed by the manufacturer. Manufacturers receive certificates for destroying a certain number of reward tokens. These certificates can be used for marketing or proof of recycling. It is therefore a mean to check if they satisfy the recycling laws.

The temporal framework and interactions between the key stakeholders are shown in Figure 1.

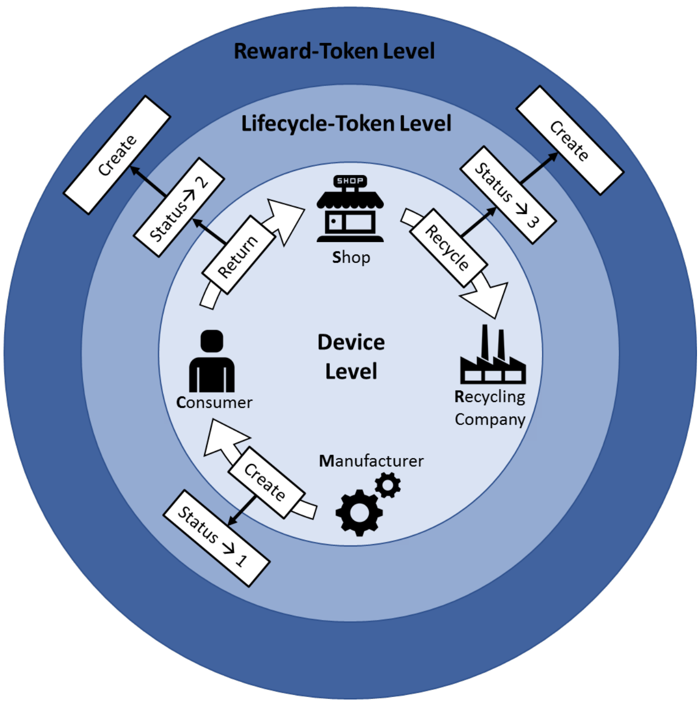


**Figure 1. Representation of EEE Lifecycle.**

The Lifecycle-Token, which is a record related to the new device, is created by the manufacturer as soon as the device leaves the factory. It is linked to the individual device by its serial number. The creation of the device sets the state of the token to “Available”. This token can keep track of the product during the usage and return of the device. It will then be updated to “Returned” as soon as the device is returned to the shop. This update is triggered as soon as the Product ID (serial number) is read by the reader of the selected sensor-based tracking technology (see “Internet of Things” section below). When the shop delivers the device to the recycling company, the state of the token is updated to “Recycled”. This action is triggered by reading the e-waste Product ID at the arrival at the recycling company.

Reward-Tokens are non-inflationary tokens that are created when consumers return e-waste to the shop and when the shops deliver e-waste to the recycling companies. These tokens are stored in an account of the consumer and shops. Reward tokens can only be used by trading them at participating manufactures for discounts or goods. They have no intrinsic value, but manufacturers have to trade them (e.g. to comply with recycling laws, or to obtain sustainability certificates). All reward tokens are immediately destroyed by the manufacturer upon reception to prevent fraud. The number of existing tokens is therefore not fixed but depends on the number of devices produced and recycled. The Reward token’s value is previously agreed on between stakeholders and specified in smart contracts.

## 3.2. Incentives

Several additional benefits for all the stakeholders, which do not yet exist in the current EEE management systems, can be created with the proposed solution.

The manufacturers will benefit in several ways. By participating in the E-mine EEE management system, they receive a tracking mechanism for their products. This can be used for internal statistical interests as well as proof of compliance with certain legislation requirements e.g. recycling quotes. Moreover, they can boost their reputation. For example, one could think about introducing recycling certificates which are a rating for the recycling efforts of different companies. This would also be beneficial for the awareness of the consumers, as it makes companies more transparent and gives information about their recycling efforts.

The consumer will also get a monetary incentive, for example in form of a discounts or goods when he or she returns the e-waste. The discounts or goods will be provided by the participating manufacturers. By participating in the E-mine EEE project the consumer can actively participate to his or her share in the reduction of potential pollution which nowadays has shown to be quite a strong incentive for many people.

The shops (collecting points) will also receive a monetary incentive from the manufacturers when they collect the e-waste and deliver it to the recycling companies.

The recycling companies profit from the E-mine EEE management project by receiving an increased inflow of e-waste since the recycling rate will be boosted. Since the shops will want to work with recyclers who join to this program, recyclers are incentivized to join this program.

## 3.3. Internet of Things

Internet of Things (IoT) provides a solution to collect data of the EEE and even their components at various stages (production, sale, return, recycling) so that it is possible to keep track and manage the physical flow of EEE during their entire lifecycle. The data integration mechanism can be supported by different technologies like the Quick response (QR) code or Radio Frequency Identification (RFID). QR code is a two-dimensional matrix barcode that can be optically read via smart phones, tablets or camera devices. The information related to the unique product ID related to the EEE item is scanned and then stored into the blockchain. QR code tags allow to store more data than traditional barcode. It is a very inexpensive solution but, on the other hand, QR codes can be scratched out or covered.

RFID are used to automatically identifying the unique EEE ID when the item is in the range of the RFID reader. The latter continuously emits radio waves of a particular frequency and the RFID tag is able to send them back to the reader. Three different kinds of RFID tags are commercially available: passive, active and semi-passive tags. The passive tags do not have any power supply and get their power from the incoming radio waves. Passive tags can cost fractions of dollars per tag and can come in a wide variety of materials, shapes and size (they can be as small as 0.15 mm by 0.15 mm). Finally, multiple RFID tags can be scanned simultaneously in a range of several meters (see Figure 2).

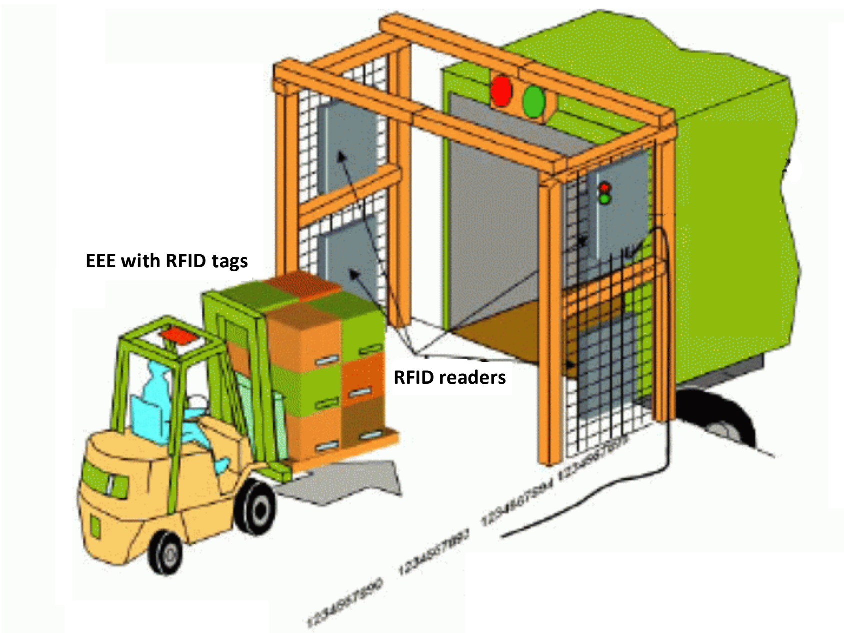


**Figure 2. EEE incorporated with RFID tags.**

## 4. E-Mine Architecture and Conceptual Model

We regard this project as a proof-of-concept which outlines the final solution which should be developed. For example, we are using QR codes for identification which should be replaced by RFID tags in the solution that we described above. For this project, we developed a solution which revolves around four smart contracts using Ethereum Blockchain. Each of these smart contracts can be observed at the contracts directory of the project as Solidity files. These contracts are going to be explained along with the technologies that are used in this project. We separated this section into 4 parts: Smart Contracts, Ethereum technologies, Web Technologies and Off-Chain Storage Technologies. We also deployed our code to https://emine2.herokuapp.com/. The site can be visited to have a feeling of how our application runs in live.

### 4.1. Smart Contracts

As mentioned at the beginning of this chapter, our WEEE system revolves around five smart contracts:

#### 4.1.1.1. EMine

This contract contains the main business logic; it assigns each of the stakeholders a role, and each address can only access certain features of the contract.

Manufacturers can mint EMineLifecycleTokens through this contract, this is the only way to create these tokens because only the owner of EMineLifecycleToken (which is EMine contract) can mint tokens. In an ideal world, manufacturers mint a lifecycle token for each electronical device that is produced and tag each device with an RFID tag that stores the ID of this device on the blockchain.

Shops receive e-waste from consumers and can change the state of EMineLifecycleToken to the Returned state, which indicates that the device is on its way to recycling. By this action, the shop directs EMine contract to reward the consumer who returns its e-waste for recycling. How much token the user should be rewarded depends on the e-waste, and the pricing mechanism should be a dynamic system. Because of this, we implemented this reward calculation as an oracle. RewardOracle is going to be discussed more in detail in its respective section.

Recyclers receive e-waste from shops and consumers; and can change the state of EMineLifecycleToken to the Recycled state. If the device is collected by a shop, the shop receives the reward (consumer already received his/her reward when he/she turned in the device), otherwise, the consumer is going to receive the reward. For the completion of product lifecycle, shops' involvement is not required, e-waste can be collected by smart recycling bins with RFID readers. However, in the real world, such bins cannot be deployed everywhere, and e-waste collection is usually done by shops. Because of that, we designed a solution which supports both ways. Recyclers are trusted to provide correct information about the recycling of the product. Because of that, we propose special RFID readers that have Ethereum addresses and access to the blockchain. We tried to mock-up this idea with QR codes and an Android app.

#### 4.1.1.2. EMineLifecycleToken

EMineLifecycle token is a non-fungible token that conforms to ERC712 token standard. It can be considered as the corresponding digital version of any electronic device. Apart from the ERC712 standard, it includes a mapping in order to store the state of the electronic device (Available, Returned, Recycled). The right to mint tokens only belongs to EMine contract address, manufacturers request tokens from EMine to take the ownership of the created token.

Instead of storing the electronic device state with a mapping in EMine smart contract, we decided to create an abstraction for the device in the blockchain. WEEE recycling can be considered as one application that uses the non-fungible token. For example, the ownership of a EMineLifecycleToken always belongs to the manufacturer that produced it. Another application might involve the sale of the product to the customer. Customer can take the ownership of the device's token and this ownership information can be used for theft detection. Another example is the protection of consumer rights; a blockchain registry for all electronical devices can be used to detect defective product lines.

In our original implementation, we planned to store the token metadata by using Storj, which is going to be discussed in Off-chain Storage Technologies. However, Storj Team decided to stop account authorization until they release the new version of Storj. Hence, we commented out the section in our code that uses Storj (index.js) and replaced it with MongoDB, hosted by mLab. We think that a decentralized application should not store ERC712 token metadata in a centralized manner, and we are going to solve this issue once our Storj account is set up; or use IPFS to store this information.

#### 4.1.1.3. EMineRewardToken

EMineRewardToken is a monetary token which conforms to the ERC20 standard. It can only be minted by EMine contract, as a result of a state change in the EMineLifecycleToken. These tokens can be used by customers and shops for discounts or goods from manufacturers. Manufacturers burn the E-Mine Reward Tokens after receiving them, incentivized by the reasons demonstrated at section 3.2.

We preferred to design one currency for all e-waste because we wanted a system that incentivizes consumers to recycle all of their electronic devices. If every brand has its own currency for recycling, we might end up with campaigns like: “Bring back your X brand phone to get a new one!”, which is not the intention behind this system.

EMineRewardToken can only be minted by EMine smart contract, the amount is determined by RewardOracle. How RewardOracle works is going to be discussed in the next section.

#### 4.1.1.4. RewardOracle

RewardOracle is an oracle contract that calculates the amount of EMineRewardTokens to be rewarded for any state change in EMineLifecycleToken. We implemented the reward system as an oracle because the pricing mechanism for rewards should be dynamic. The number of tokens to be awarded should be different for each electronic device since each device contains different amount of materials. Secondly, the price for each material is also not constant. Thirdly, to maximize the amount of recovered e-waste, the oracle can change the distribution of the reward between the shop and the customer.

We implemented our oracle by using Oraclize, as demonstrated in the BIOTS lectures. Since we do not have enough domain knowledge on how to price an e-waste, right now, the oracle just returns a random number between 1 and 100 by using WolframAlpha. RewardOracle also keeps the information of how much each user is rewarded for which action (recycling or returning e-waste) on the blockchain. In the future, domain knowledge, combined with the information included in the metadata section of ERC712 token for each device can create a proper pricing mechanism.

## 4.2. Ethereum Technologies

We used different tools to interact with the Ethereum Blockchain. Each of these tools is going to be discussed in this section. We deployed our smart contracts to Rinkeby Test Network since Oraclize service worked slower on Ropsten Testnet. To test our smart contracts, we used Ganache which is a part of Truffle Suite to create a local blockchain to work on.

To interact with real blockchains, instead of running a node and deploy it to somewhere, we used Infura, which gives secure, reliable, and scalable access to Ethereum APIs and IPFS gateways. To be able to access Infura, we used a package named truffle-hdwallet-provider and used our mnemonic to unlock our accounts. The mnemonic is deliberately exposed in the project file (truffle.js) for testers to claim a number of testing accounts. We used truffle to compile and deploy our smart contracts; as seen in the migration files in the project.

While developing our smart contracts, we used Open Zeppelin, an open framework of reusable and secure smart contracts in the Solidity language, as described in BIOTS lectures. We used the Ownable pattern for every smart contract, implemented ERC712 interface for EMineLifecycleToken and extended StandardToken to create EMineRewardToken.

## 4.3. Web and Mobile Technologies

As stated at the beginning of the section, our web application is deployed with Heroku at address https://emine2.herokuapp.com/. We used Bootstrap for a simple front-end and express.js for back-end.

To be able to use the app, user should have a proper Web3 provider; most probably Metamask Google Chrome Extension. If the Ethereum account selected by user does not have the proper user type (Recycler, Manufacturer, Shop) the user will be prompted to gain those credentials by visiting https://emine2.herokuapp.com/admin.html. The private key for the admin account is also included there for testing purposes so that it can be used to give any Ethereum address those credentials. Admin account is the owner of the EMine smart contract.

We provided each stakeholder a simple user interface to interact with smart contracts. Customers can list the EMineLifecycleTokens that they handed in to recycler or shop,and look at their EMineRewardToken balance from the wallet. Manufacturers can create EMineLifecycleTokens by also providing token metadata to the user interface as JSON. They can also list the EMineLifecycleTokens that they minted.

Shops can change the state of a lifecycle token from Available to Returned, and they can also list the e-waste that they took. There is a problematic detail there, shops can randomly generate IDs to Return the corresponding EMineLifecycleToken, and by providing another Ethereum address that they own to claim free EMineRewardTokens. This fraud can be prevented with two separate ways: the first way is to give the ownership of EMineLifecycleTokens to customers when they are sold and prevent the return of any product without the consent of its owner. This way is more elegant, but it ignores the second-hand market and the fact that the device can be collected by someone who is not the owner and returned by him/her. The second way is to track whether a device is recycled after it is returned. Since we trust recyclers because the process of changing the state of a device to Recycled is full automated, we make sure that such fraud does not happen at all.

Recycler can change the state of a lifecycle token to Recycled, and they can also list the e-waste that they recycled. In the site, it is possible to recycle an item by ID manually, however, for the reasons stated above, the process of recycling an EMineLifecycleToken should be automated. We tried to simulate this by using an Android app and QR codes. It is possible to download our Android app from the Recycler tab of e-mine website. However, in the future, we will try to do this by RFID readers and tags.

## 4.4. Off-Chain Storage Technologies

To store the metadata information of EMineLifecycleTokens, we needed an off-chain storage solution. Decentralized storage space is crowded with many interesting projects such as Filecoin, Storj, Maidsafe and Swarm. We decided to use Storj since it is compatible with Heroku, as it has its own add-on embedded in Heroku platform. Although we coded this part, we were not able to use Storj since our

Storj account is not authorized, when we contacted the support forum, we found out that Storj stopped the process of authorizing new accounts until the release of their updated platform. As a replacement, we are currently using MongoDB, hosted by mLab, but we will switch back to Storj as soon as our account is authorized.

# 5. Evaluation

In this project, we wanted to create a WEEE recycling system which would improve the state of art model that relies on cloud computing, by increasing the transparency and robustness of the model. We tried to simulate our solution by creating a demo application for proof of concept. Undoubtedly, our implementation is just a part of the actual solution we illustrate. In this chapter, we want to point out these problems and how are we planning to solve them in a real application.

## 5.1. Testing

For testing, we first created a local blockchain by using Ganache under Truffle Suite, and deployed our smart contracts on it, after we made sure that our solution works as intended, we also deployed them on Rinkeby Test Net.

In the real world, the number of stakeholders in WEEE recycling industry is larger than 3 (Manufacturers, Shops and Recyclers); we also have collectors who collect e-waste from shops and distributors who distribute electronic devices to shops from manufacturers. Any flaw in the system might cause different exploits and fraud. Since the commercial application involves a lot of real world actions and many different parties are involved, it is very hard to test whether the solution is working without a pilot project. We believe that the most effective way to test it is a pilot project after the development of a minimum viable product.

## 5.2. Known Problems

To implement RewardOracle for our application, we used Oraclize service. However, Oraclize often calls the callback function too late or totally skips it on test nets such as Ropsten or Rinkeby. Hence, our application can fail to reward parties for recycling or returning if the Oraclize service does not work well. This problem is likely to be resolved if we deploy our application to the real Ethereum blockchain.

We used QR codes and a simple Android application as a replacement for the RFID readers (Figure 2) in the solution that we propose. However, one of the biggest problems in the application is the installation of these RFID readers, and their secure connection to the blockchain. Since the proposed solution trusts recyclers' information on whether a device is recycled or not, the process should be totally safeguarded from human intervention.

# 6. Conclusion and Outlook

We see a big potential in our idea since recycling and saving energy resources has become an important issue in our society. More important, the acceptance among citizens and the will to be part of an active and carrying society is high, thus we anticipate a high number of participants. The costs and the requirements for the implementations are rather low. From the hardware side, only scanning devices in the shops and recyclers are needed. By using the blockchain to store the lifecycle information of the devices, recycling rates of different manufactures become transparent and trustworthy, as the information is public. As we expect recycling laws to become more stringent in the next years, our approach would offer manufacturers a possibility to proof and show their recycling rates by using a system in which they also profit from additional information about the lifecycle of their devices.

EMineLifecycleTokens, the digital avatar of any electronic device on the blockchain, coupled with an RFID tag for each device, can be used not just for recycling, but many other applications such as audit, theft detection, detection of illegal exports. However, for such kind of solution to be established, adoption of blockchain technology to everyday life is needed.

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