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Blockchain-based Carbon Market

by

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Abstract

Emissions trading schemes (ETS) are a policy tool at the forefront of the fight against climate change. In this thesis, I will present a blockchain-based approach for creating a carbon market driven by hydrogen certificates. By using carbon tokens, an effective price can be placed on the use of carbon removing a market failure existing in the production of natural resources. I will use a high-throughput permissioned blockchain to motivate how trust can be placed in a market made volatile by inconsistent government policy and scepticism on the behalf of participants.

Abbreviations

BTC Bitcoin

USD United States Dollar

EU European Union

ETS Emissions Trading Scheme

TPS Transactions Per Second

OSN Ordering Service Nodes

HTTP Hypertext Transfer Protocol

Contents

List of Figures

List of Tables

Chapter 1

Introduction

A blockchain can be defined as an immutable ledger maintained by a network of mutually untrusting peers [ABB+18]. Since the creation of Bitcoin (BTC) in January 2009 by the maverick Satoshi Nakamoto there has been an explosion of interest in the underlying technology behind blockchains. Specifically, the immutability and openness of the distributed ledger makes blockchain an attractive option for markets with untrusting participants exposed to information asymmetry. The market for carbon is particularly well suited to the blockchain due to inconsistent government policy - for example the ill-fated outcome of the Carbon Pollution Reduction Scheme in Australia [ea13].

Recent attempts to create blockchain-based carbon markets have been met with some success - but have been held back by technicalities or innovations that disrupt the fundamental goal of using the blockchain as a 'trust machine' [The15]. I will outline how hydrogen certificates on the blockchain can be used to automatically spend carbon tokens and add extra validation before being sold on the commodity market. Hydrogen is particularly well-suited as an example for certificate-based carbon markets due to hydrogen producers attaching a carbon footprint to certificates.

I shall summarise how permissioned blockchains are principally useful for carbon markets due to support for high-throughput transactions. A carbon market would have to scale to a large number of distributed producers with scalability matching hydrogen energy production - an industry expected to be worth USD155 billion by 2022 [ea18]. I will propose Hyperledger Fabric as a blockchain framework - chiefly due to its support for up to 3500 transactions per second (TPS) and a plugable consensus algorithm [ABB+18]. Moreover, my proposed solution will accommodate an optional carbon 'reputation' as part of the price for exchanging carbon tokens between producers.

In Chapter 1 an overview of the thesis and its novel approach to certificate-based carbon markets is presented. In Chapter 2 I outline the background to the project and important literature for markets on a blockchain. In Chapter 3 I provide methodology for the blockchain architecture. In Chapter 4 I outline some preliminary results with creating smart contracts (programs on the blockchain) for auctions on a public blockchain. In Chapter 5 I conclude with some remarks on the future potential for the thesis topic.

Chapter 2

Literature Review

2.1 Brief Background

The pricing of carbon emissions is a policy tool where emitters must pay for carbon usage - thereby disincentivising reliance of unclean source of energy. The conventional wisdom held by economists is a price on carbon will provide an incentive for emitters to be 'priced' out of using unclean energy and choose to invest in clean renewable energy like solar and wind. The economic theory behind carbon pricing is simple - according to neoclassical economics markets are prone to failure due to free riding. In the case of carbon, emitters free ride by releasing carbon without considering the cost of carbon to the planet and society. To remove the deadweight loss due to free riders, economists propose placing a price on carbon to properly adjust emitting markets to a socially optimal equilibrium price.

Presently, the great majority of humankind's emissions are not placed under a price, with only 20% of global emissions under a pricing scheme [The20]. Globally, the largest emissions trading schemes (ETS) are run by the European Union (EU) and China. The EU ETS has recently been expanded to cover around half of all emissions produced inside the EU (see Figure 2.1). Notable economists suggest that for a carbon price to be effective in fulfilling the Paris pledge then prices must stay between the range of

$40-80 per tonne [The20]. As of 2020, the existing median price per tonne of carbon emissions is only $15 [The20].

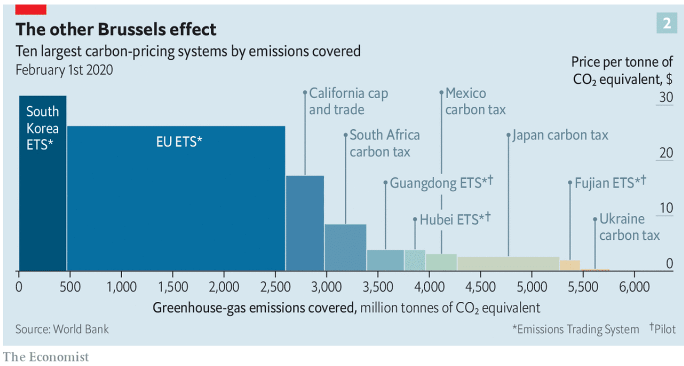

Figure 2.1: Largest Emissions Trading Schemes

Carbon prices are open to government manipulation from centralised authorities and are often the subject of heated debates. An example was the 'axe the tax' campaign resulted in the abolishment of the Australian ETS in 2014 [The20]. Moreoever, there is often debate over where the money associated with carbon prices will go - particularly in the case where an auction for carbon credits occurs. If money raised from an ETS is used to lower taxes elsewhere then opponents on the left of politics accuse the policy of not actively fighting climate change. Generally, opponents on the right accuse carbon prices of stifling economic growth - an example of an unecessary government overreach.

The blockchain, which acts as an immutable ledger, has the potential to deliver 'trust' into the market for carbon. As opposed to being run by a centralised authority like the government, it can instead be run openly on the blockchain visible to all participants in the market for carbon. Therefore, the openness of a blockchain ETS can be used to combat its most fierce criticsm - which is its usage as a political tool. A blockchain ETS can be designed so a 'fee-and-dividend' is used, meaning the distribution of payments can go straight back to the people thereby incentivising long-term adoption [The20].

I will use the rapidly growing Hydrogen energy market - with its novel Hydrogen certification process - to show how producers can pay for accrued negative externalities. Hydrogen certificates can be automatically submitted with a level of recorded emissions, whereby tokens are deducted from a producer's carbon account upon submission. Smart contracts (programs on the blockchain) will be used to represent the logic of an ETS targetting hydrogen energy producers.

2.2 Hydrogen Certificates

The hydrogen market is a growing form of energy production created from resources such as natural gas, coal, solar and wind. Hydrogen is deemed a 'clean fuel' because when it is consumed in a fuel cell only water is produced. The hydrogen market is particularly important for Australia since the industry is expected to create up to 7,600 jobs and contribute $11 billion a year to GDP [COA19]. As part of an effort to reduce cumbersome regulation associated with Hydrogen markets internationl standards have been developed. Moreoever, standards embedded into a *hydrogen certificate* can assist to manage the lifecycle of hydrodgen and ensure carbon is not being emitted. As of 2020, there are eight international hydrogen standards (see Table 2.1) defining features such as safety and quality [Sta20].

Standard	**Description**
AS 16110.1:2020	Safety
AS ISO 16110.2:2020	Performance
AS ISO 14687:2020	Fuel Quality
AS 22734:2020	Industrial, commercial, and residential applications
SA TS 19883:2020	Safety of pressure swing adsorption systems
AS ISO 16111:2020	Transportation
AS ISO 19881:2020	Gaseous hydrogen
AS 19880.3:2020	Gaseous hydrogen – Fuelling stations

Table 2.1: International Hydrogen Standards

To help develop standards, centralised certification authorities are being developed to act as certification schemes for hydrogen. One of the most popular such schemes is CertifHy - a European scheme for hydrogen certification [cer21]. Centralised certification schemes provide services such as the issuance of hydrogen certificates along with the ability for users to create an account to track the registry of owned certificates. Generally, hydrogen certificates have the ability to detail technical information along with crucial greenhouse gas information.

A key problem with the centralisation of certification authorities is the lack of openness involved. Customers become reliant on a key provider to conduct certification, fostering less 'trust' in the market for hydrogen. Due to a lack of trust, a blockchain-based approach to hydrogen certification would allow for greater extensibility in the different certificates available. Crucially, an ETS with on-chain energy certification can enforce carbon prices in a market. For example, if a hydrogen certificate has not paid for its carbon usage using the on-chain ETS - then due to the immutability and openness of the blockchain such a certificate could be marked as not valid for trading inside a commodity-market. This thesis will make the assumption that such a rigorous certification scheme exists, and will outline how an ETS can be constructed to make use of certificates created by producers thereby pricing carbon.

2.3 Academic Blockchain Emission Trading Schemes

2.3.1 Bitcoin-based ETS

An early adoption of blockchain carbon pricing was the creation of a bitcoin-based emissions trading infrastructure model in 2015 [KAS15]. The model proposed a blockchain called Decentralised Carbon Emissions Trading Infrastructure (D-CETI) inheriting a significant amount of the innovations created with Bitcoin by Satoshi Nakamoto in 2009. The authors proposed that the significant barriers limiting the effectiveness of the major ETS schemes (EU ETS) was the lack of security and privacy participants face in cardbon trading [KAS15]. As a solution, Bitcoin's at the time novel approach to security using hashed transactions and computationally difficult hash puzzles was deemed by the authors as an appropriate solution to the shortcomings of the large ETS schemes.

In principal, the bitcoin-based ETS proposed functionality for users to generate carbon tokens, register, sell, and bid for credits. As a result, the system for a carbon market was almost identical to the cryptocurrency Bitcoin with the primary difference being the use of an ETS focused coin. To deal with the throughput demands for an active

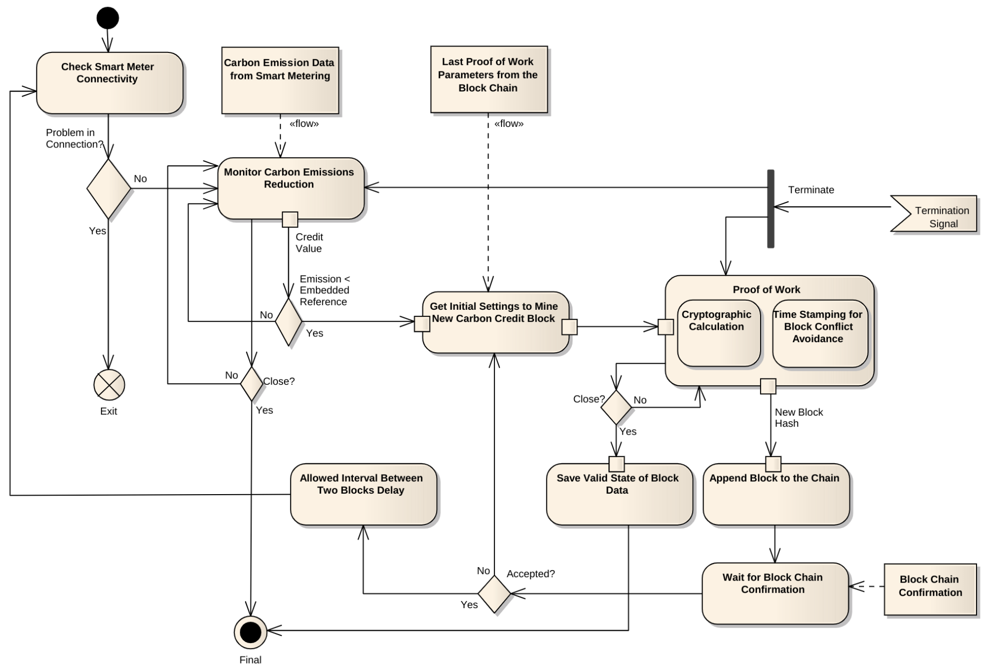

Figure 2.2: Bitcoin-based ETS

ETS market, the block generation rate on the chain became one block every 150 seconds in contrast to Bitcoin's one block every 600 seconds [KAS15]. Moreoever, participants in the bitcoin ETS market would have to generate new blocks through miners solving cryptographic hash puzzles (see Figure 2.2).

The downsides to the bitcoin-based ETS are significant - the throughput of the system is too low to ever be usable in an active ETS market. Although increasing the throughput from 7 transactions per second (TPS) for Bitcoin to roughly 28 TPS, such a solution still relies on computationally expensive mining to achieve system consensus [KAS15]. Moreoever, Bitcoin's reliance on hash puzzles requires the continuous consumption of carbon emitting energy - potentially worsening the market failure which the ETS is aiming to remedy.

The bictoin-based ETS relies on a primitive form of smart contracts inherited from *Bitcoin Script* - meaning the smart contracts are not turing complete. Therefore, it would not be possible to express detailed business logic such as the auctioning of tokens or custom carbon prices into such an architecture. Simply stated - a Bitcoin-based ETS is insufficient for a carbon market.

2.3.2 Blockchain-based Smart Grid

A more innovative public blockchain, such as Ethereum, has been proposed as a system to host local energy markets [ea17]. The benefit of using Ehtereum primarily comes from the use of a turing-complete Ethereum Virtual Machine allowing for the creation of complex smart contracts. Hence, the creation of an intricate local energy market becomes possible through a distributed programs written in a high level language (such as Solidity) which is then compiled into Etherum bytecode. The researchers found the use of Ethereum as a local energy market allowed for electricy cost reductions across a model scenario [ea17].

Despite the technical feasibility of developing an ETS on Ethereum, the platform is not suitable due to technical limitations. The researchers acknowledged that further analysis into the suitability of public blockchains for energy markets is required [ea17]. Specifically, Ethereum supports a 25 TPS for system throughput [Rac21]. For an active ETS in an emerging industry such as hydrogen production, such a low system throughput would do damage to the usability and customer satisfaction involved in carbon trading. Moreover, Ethereum is being actively developed and has planned forks due to a move towards a proof of stake consensus algorithm [Ozo21] - making it unstable for a certificate-based ETS requiring customer trust.

2.3.3 Reputation-based ETS Blockhain

Researchers in 2017 proposed the use of a reputation-based ETS with a blockchain infrastructure, employing a permissioned blockchain to overcome the throughput issues asscoiated with public blockchain networks [KSHK18]. The researchers concluded that the environment *Multichain* would be a good candidate for a blockchain ETS due to its support for a system throughput with up to 1000 theoretical TPS [KSHK18]. Similar to previous blockchain carbon markets, the researchers made smart meters and the trading of tokens central components to the functioning of the system - as observed in Figure 2.3.

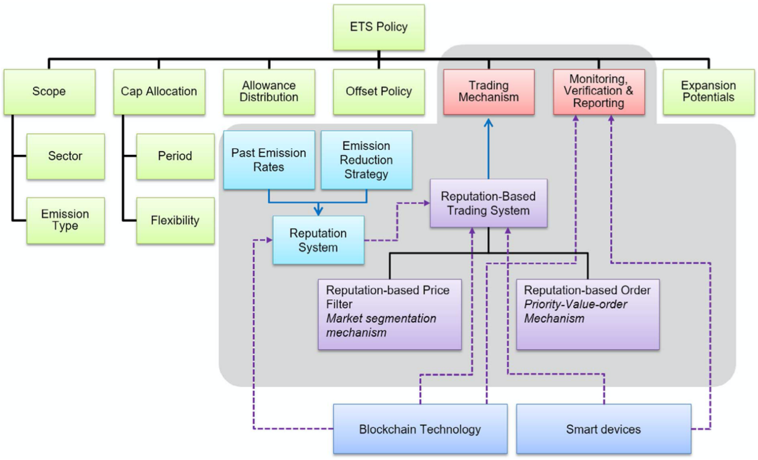

Figure 2.3: Reputation-based Blockchain ETS

Khaqqi et al believed that the critical element holding back the success of a blockchain ETS is the lack of a reputation model present in the pricing of carbon tokens. Often, markets can increase in quality and therefore grow when there is a way to remove systemic information asymmetry [KSHK18] (as an example consider online marketplaces and seller scores). Therefore, Khaqqi et al proposed the incorporation of the 'carbon reputation' of a seller into the pricing of carbon tokens. As observerd in Equation 2.1, changing the 'reputation' parameter to factor a seller's carbon emissions can influence the price offered to agents buying tokens in the ETS blockchain [KSHK18].

$$\mathrm{PV} = \frac{\mathrm{askingprice}}{\mathrm{reputation} - \mathrm{basedfactor}} \tag{2.1}$$

Despite offering a solution with more system throughput than both Ethereum and Bitcoin-based offerings there has not been a general movement towards a carbon market with reputation pricing. A weakness of the architecture employed by Khaqqi et al is the requirement that prices must automatically reflect the 'carbon reputation' of sellers in the marketplace. Forcing reputation systems upon users is disrespecting of user freedom, and should be made an option and not a requirement for participating in the system. Moreover, as The Economist stated: public criticism and politics are key factors holding back the success of a carbon market [The20]. Hence, a system driven by on-chain energy certificates would make a blockchain ETS more usable driving longstanding adoption of a carbon market. Moreover, to garner public support a dividend payout from the system to the public and end customers would help in getting necessary political support [The20].

2.3.4 Hyperledger Carbon Market

In 2018 Yuan et al developed a carbon market using the permissioned blockchain network Hyperledger Fabric [YXLZ18]. The researchers identified that a core issue holding back the success of existing ETS systems was a lack of trust along with data security problems associated with centralised carbon markets. The researchers determined the Hyperledger project as offering a customisable ledger structure well suited to the security needs of a distributed carbon market. As such, a simple architecture comprising of nodes offering an environmental agency, approver, traders and a trading centre was designed. The ‘approver’ in the Hyperledger ETS system manually inspects projects and allocates permits to allow for access to a ‘trading centre’ (as seen in Figure 2.4).

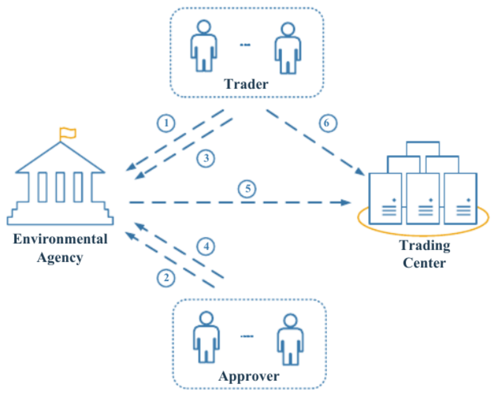

Figure 2.4: Hyperledger Carbon Market

The algorithms employed in trading carbon permits are trivial by design - the trading mechanism employs a smart contract checking the number of permits in the seller’s account. If the seller has a valid number of permits, then the trade is executed and carbon permits are allowed to be traded between market participants [YXLZ18]. The architecture employs a single Hyperledger *channel* allowing for the ordering of transactions between both the environmental agency and the trading centre. Interaction with the blockchain happens through a HTTP server offering RESTful APIs. Within the Hyperledger blockchain there are two smart contracts: an application contract (AC) for the environmental agency and a trading contract (TC) for emissions trading [YXLZ18].

The Hyperledger carbon market's innvoation comes from using the new technology of Hyperledger - which offers superior TPS performance and architectural modularity. Yuan et al were able to get the Hyperledger carbon market to handle up to 340 requests per second [YXLZ18] - significantly more than what the Ethereum blockchain offers. Despite the success coming from Hyperledger adoption the proposed system is trivial and requires significant manual approval on the behalf of a centralised environment agency. A better approach would make use of an existing form of automation (such as certification) to spend permits. Moreoever, making smart contracts more complex through *optional* carbon reputations would improve the quality of the market for carbon [KSHK18].

2.4 Enterprise Energy Markets

2.4.1 PowerLedger

PowerLedger is a private energy company based in Australia who launched a blockchain microgrid in 2016. The company is Australia's first peer-to-peer energy trading network [KPR18]. PowerLedger allows for access to the energy market using a *POWR* token, which provides electrical units (in kWh) and market pricing mechanisms. *POWR* tokens are subsequently escrowed for a *Spark* token to access the PowerLedger ecosystem. PowerLedger provides a public blockchain layer built using Ethereum for coin markets which links to PowerLedger's private permissioned blockchain [KPR18].

PowerLedger offers a pragmatic solution to energy markets. PowerLedger highlights how trust can be delivered to an energy market hosting a consortium of energy sources.

Although not driven by energy certification, PowerLedger demonstrates the technical feasibility of a blockchain for energy in a diverse and growing market.

2.4.2 SOLShare

SOLShare is a blockchain-based energy market for Bangladesh. The blockchain offers an effective solution due to the presence of over four million rooftop panels and batteries powering the electricity grid of Bangladesh [Fai18]. The platform requires a proprietary technology called a *SOLBox* allowing for a user to either sell or buy electricity. SOLShare provides a motivating example of an energy blockchain application delivering value and trust to hundreds of customers [Fai18].

2.5 Hyperledger

The Hyperledger project is an open-source collection of tools and frameworks that are created for developing permissioned blockchains. A permissioned blockchain contrasts directly with popular public blockchains such as Bitcoin and Ethereum: precisely because agents on the blockchain are able to be identified. The Hyperledger project follows a philosophy of modularity and interoperability of the blockchain, meaning the vision of Hyperledger is to have blockchains with a pluggable architecture that can seamlessly communicate with another Hyperledger blockchain [Hyp18].

2.5.1 Hyperledger Fabric

One of the most popular Hyperledger frameworks is Hyperledger Fabric: a modular and extensible framework for developing blockchain applications [ABB$^+$18]. The primary technological innvoation of Fabric is the introduction of a novel 'execute-order-validate' paradigm for transactions. A 'execute-order-validate' architecture means that transactions with accompanying smart contracts are first executed by peers on the network before being sent to a specified ordering service, which broadcasts the transactions amongst the blockchain network (as observed in Figure 2.5). The 'execute-order' architecture directly contrast with Ethereum's 'order-execute' approach which requires *active replication* of transactions amongst all nodes in the system, thereby making consensus difficult to achieve.

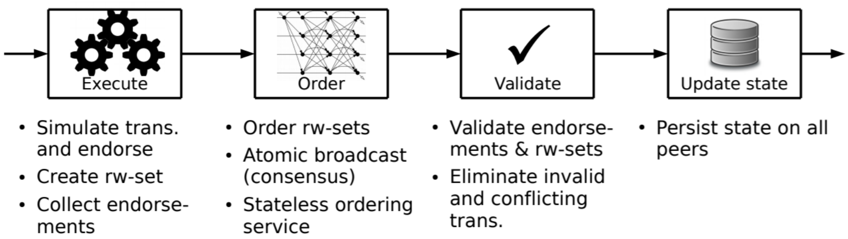

Figure 2.5: Execute-order Architecture

During the execution phase of Fabric a client creates a *transaction proposal* to send to a collection of endorsers on a specific *channel*. The proposal contains an item called *chaincode* acting as a program running inside a secured Docker container which has the ability to manage and manipulate the state of the ledger. A client will collect endorsements from nodes until an *endoresement policy* has been satisfied, whereby the transaction is then sent to the ordering service. The technological innovation associated with the execution phase is the toleration of non-determinism in transactions, meaning non-determinism only threatens the life of a particular transaction and not consensus on the blockchain. The execution phase of Fabric allows for a smart contracts in a carbon market to be written in a general programming language like Go or Javascript [ABB$^+$18].

The ordering phase of Fabric established a 'total ordering' of transactions on a channel allowing for consensus in the system to be achieved [ABB$^+$18]. Fabric has specific nodes labeled *Ordering Service Nodes* (OSN) whose purpose is to order transactions (and not engage in either execution or validation of transactions). Along with the OSNs there is an accompanying protocol called *gossip* allowing for blocks to be distributed efficiently amongst peers on the ledger (see Figure 2.6). Through the separation of ordering to specific nodes, Fabric is able to make system consensus modular. Hence, a popular consensus algorithm in Fabric is *Raft*: a Crash Fault Tolerant (CFT) consensus algorithm. The *Raft* algorithm uses a 'leader follow' approach where a leader is elected per channel to do the ordering of transactions [OO14]. By using Fabric with *Raft* as a consensus algorithm a carbon market would be able to replicate a theoretical TPS of up to 3420 [ABB+18]. Moreoever, such a carbon market would be modular with a modifiable consenus algorithm suiting the requirements of market participants.

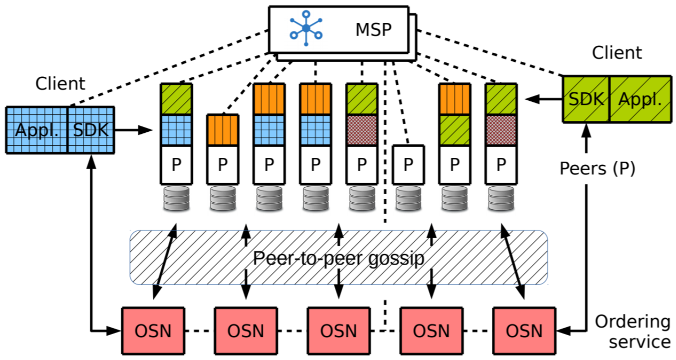

Figure 2.6: Hyperledger Architecture

The final phase of Fabric is the validation phase whereby *validation system chaincode* is run by nodes to check the validity of transactions [ABB+18]. As part of the validation phase a check is performed to determine if the endorsement policy for transaction chaincode is satisfied. Due to the enterprise focus of Hyperledger, transactions that are determined as *invalid* are persisted to the ledger to allow for easier auditing of transaction. The validation phase of Hyperledger fosters trust in a carbon market by ensuring market fraud is persisted to the blockchain and caught in subsequent audits on the state of the ledger.

2.6 Problem Statement

The success of the long-term adoption of a blockchain-based carbon market is reliant on the trust market patiticpants place into the system. Previous blockchain carbon markets have been held back by inefficient implementations with low system throughput - such as the bitcoin-based emissions trading scheme [KAS15]. Often, when more innovative blockchain architectures are researched for carbon markets they come coupled with features such as 'reputation' pricing that participants may want to opt-out of [KSHK18]. Within the literature for carbon markets, there is a need for a solution that is both easy-to-use whilst also respecting of the freedom of participants.

I suggest a new approach to carbon markets with energy certificates. Instead of relying on manual permit approvals, I suggest a novel approach to carbon markets where producers of carbon can automatically consume carbon tokens through the use of energy certificates. I will motivate my certificate-driven carbon market with the use of on-chain hydrogen certificates. Consuming carbon tokens will therefore become a natural part of the lifecycle of a hydrogen certificate. Such a carbon market has the objective of rapidly incentivising the use of cleaner sources of hydrogen energy.

To encourage transparency in carbon markets, I will use the high throughput blockchain Hyperledger Fabric. Hyperledger offers a permissioned blockchain allowing for hydrogen producers to be identified when consuming carbon tokens. Moreoever, I will provide the option for buyers of carbon tokens to filter prices according to the carbon reputation of sellers, thereby encouraging the ethical exchange of carbon tokens.

2.7 Aims and Outcomes

This thesis aims to use on-chain hydrogen energy certificates to outline how carbon markets can be efficiently run using a blockchain. I propose an implementation of a carbon market using Hyperledger Fabric, with the assumption that an already existing certification scheme exists. Developed alongside the carbon market blockchain will be a user interface to allow for the exchange of carbon tokens between market participants.

The outcome of the thesis is a blockchain application with an architecture performing the automatic spending of carbon tokens using hydrogen energy certificates. The application is intended to be used by producers of hydrogen energy who are seeking to buy and sell carbon tokens to deal with an associated level of emissions resulting from hydrogen production. The aim of the thesis is not to solve the economic problem of developing an efficient market for carbon - instead the technical feasibility of a blockchain carbon market employing energy certificates is explored.

The primary outcomes are listed below:

1. Ability to purchase carbon tokens from other hydrogen producers.
2. Ability to sell carbon tokens to other hydrogen producers.
3. Ability to view hydrogen certificates requiring payment with carbon tokens.
4. Ability to filter token sale offers based on the ‘carbon reputation’ of a hydrogen producer.
5. Creation of a user interface for a seller to interact with a carbon market.

Chapter 3

Project Plan

The decomposition of the project can be divided into three parts: a user interface for interacting with the carbon market, a *RESTful* HTTP server for interfacing with Fabric and smart contracts on the blockchain. An observation of Figure 3.1 details how the certificate-based carbon market operates from a high-level overview.

3.1 Smart Contracts

The smart contract component in the Fabric blockchain will make extensive use of the following architectural patterns: token template, token registry, policy contract and burned token [QXB+21]. The token template pattern will allow for the creation of a *Carbon Token* which is transferred between hydrogen producers who are looking to purchase and sell tokens. The burned token pattern will allow for tokens to be burned upon supplying a hydrogen certificate. After the token is burned, the on-chain smart contract for the emissions trading scheme marks the particular certificate as 'spent'. Token registry will track which individuals have ownership of particular tokens and will allow tokens to be transferred between different owners. The token policy pattern specifies how the associated level of hydrogen attached to a hydrogen certificate is spent on carbon tokens within the on-chain emissions trading contract.

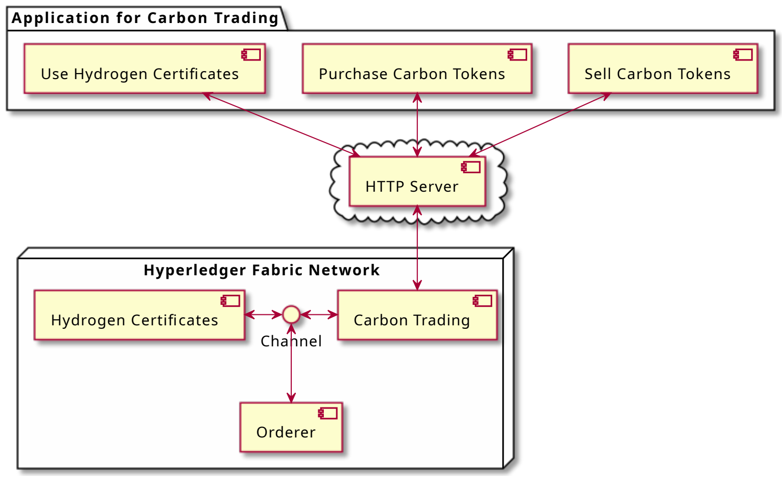

Figure 3.1: Certificate-based Carbon Market Architecture

3.1.1 Token Transfers

Hydrogen producers will be allowed to transfer tokens between each other at an agreed price. The market for transferring tokens will operate through a producer creating an offer for the sale of a quantity of tokens at a given price per token. A hydrogen producer looking to purchase more tokens will purchase a number of tokens from the seller at a given quantity. As observed in Algorithm 1, the purchaser of tokens has the ability to consume a certain number of tokens from an offer at an agreed upon price per token.

3.1.2 Token Burning

The user can submit a hydrogen certificate to the on-chain emission trading scheme smart contract. The smart-contract will check if the hydrogen certificate has previously been supplied to the system. If the certificate has not been submitted, then the smart-

Algorithm 1 Offer Acceptance

procedure AcceptOffer(*sellerId*, *buyerId*, *offerId*, *price*)
    let tS be *tokens(sellerId)*
    let price be *getOfferPrice(offerId)*
    if quantity > tS **then** reject
    if *!hasFunds(buyerId, quantity, price)* **then** reject
    swapTokens(buyerId, sellerId, quantity)

contract maps the emissions in the certificate to the carbon tokens contained inside the hydrogen producers carbon account. If the user has a sufficient number of carbon tokens, then the tokens will be subtracted from the account balance and 'burned'.

3.1.3 Direct Token Purchases

The user will be allowed to purchase tokens from the emissions trading scheme smart contract. Recently, literature has been proposed allowing for the construction of a game-theoretic approach to pricing within blockchain energy markets [JZLY20]. The economic intution behind the pricing model is the construction of a *Stackelberg Competition* environment where consumers continually outbid another until equilibrium is achieved. Since the aim of the thesis is the technical implementation of an emissions trading blockchain, such a pricing feature would be out of scope. Initially, users will be allowed to purchase tokens from the emissions trading smart contract at a set price. As a stretch goal, an auction environment will be constructed allowing for a *Stackelberg* competition environment.

3.2 HTTP Server

The HTTP server will provide API endpoints to interface with the Fabric blockchain. The Fabric SDK will be extensively used on the API layer. The server will employ the *express* JavaScript framework for *Node.js*. The use-case for an HTTP Server comes from the requirement for a user-interface to interact with the Fabric blockchain.

3.3 User Interface

The user interface will allow for hydrogen energy producers to interact with the Fabric blockchain to purchase, sell and spend carbon tokens. The user interface will be created using Facebook's *React* framework for use in browsers on a mobile or desktop device. A collection of epic user stories are supplied in Table 3.1. Epic user stories number one to seven are considered fundamental to the aims and outcomes of the project. Epic user story number eight allows for the creation of an auction environment for the purchasing of carbon tokens at a low price from the carbon token authority, and will be a stretch goal for the thesis.

No	**Epic User Story**	**Description**
1	As a hydrogen producer, I would like to directly purchase more carbon tokens to emit more carbon.	A producer wants to purchase tokens directly from the emissions trading scheme.
2	As a hydrogen producer, I would like to sell carbon tokens on a secondary market to remove excess carbon token resources.	A producer wants to sell excess tokens on a secondary market.
3	As a hydrogen producer, I would like to purchase carbon tokens from a token sale offer to emit carbon more cost-efficiently.	A producer wants to purchase carbon tokens - preferably at a price cheaper than what is offered on the primary market.
4	As a hydrogen producer, I would like to spend carbon tokens on energy certificates to meet my environmental commitments.	Spend carbon tokens on energy certificates - allows a producer to subsequently trade the hydrogen asset in a commodity market.
5	As a hydrogen producer, I would like to view all hydrogen sale offers to find the most cost-efficient offer.	Producer wants to find the most cost-efficient carbon sale offer.
6	As a hydrogen producer, I would like to observe the number of carbon tokens inside my account so I can plan for future Hydrogen production.	Hydrogen producer would like to view the number of tokens to plan for future production.
7	As a hydrogen producer, I would like to filter carbon sale offers based on carbon reputation to find the most environmentally friendly offers.	Environmentally conscious producer wants to filter offers according to the carbon reputation of sellers.
8	As a hydrogen producer, I would like to bid in a carbon token auction to find low prices for carbon emissions.	An auction will be offered for producers to purchase tokens at timed intervals - mechanism of adding carbon token inflation.

Table 3.1: Epic User Stories for Producer Interaction

3.4 Deployment

Deployment of the application is suitable for a cloud provider offering technical solutions for blockchain applications. Amazon Web Services (AWS) offers a product called *Blockchain on AWS* allowing for the deployment of permissioned blockchains (including Hyperledger Fabric) on high-performance compute environments. Moreoever, the AWS service *Amplify* would allow for the hosting of the user interface for Hydrogen producers to interact with the Fabric blockchain. The HTTP server would be suitable for running on an AWS service such as *Lambda* or *EC2* depending on the scale of growth in the hydrogen production market. The load-balancing features of *EC2* would help to deal with a rapidly growing hydrogen market, with an unknown number of participants.

3.5 Thesis Timeline

The thesis timeline outlined in Table 3.2 shows the sequential nature of project. The primary step, which also consumes the most effort will be smart contract programming using Hyperledger Fabric. The smart contracts will be programmed using JavaScript, thereby unifying the entire technical stack under a single programming lanaguage. I have undertaken research into Hyperledger Fabric and installed the *fabric samples* on my development machine. The effort estimation for smart contract programming is high due to the work involved in understanding the Fabric SDK and the relevant libraries for getting *chaincode* to execute on Fabric. My approach for completing the implementation of the thesis is to focus on the low-level technicalities first: the completion of the *express* API happens after the *chaincode* for the carbon market is constructed. The smart contract programming will take up to six weeks as a result of the learning curve associated with Fabric. The API construction will take up to three weeks to achieve, since I have some experience with the *express* framework. The construction of the user interface for the carbon market will take a further three weeks, as I also have experience with the creation of applications using *React*. Any time remaining will be spent on making improvements to the system along with the attempting of stretch goals related to blockchain pricing models.

Week	Thesis A	Thesis B	Thesis C
1			
2			
3	Blockchain patterns		
4		Smart contract programming	User interface finalisation
5			
6			
7	Ethereum Auction Example		Improvements and stretch goal
8		API construction	
9	Problem domain and definition		
10	Literature Review		
11			
12			
13			

Table 3.2: Timeline for Thesis

Chapter 4

Project Dependent Preparations

Chapter 5

Conclusion

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Appendix 1

Appendix 2