C_4Coin: The Carbon-Negative Blockchain

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v1.1

"There are a herd of environmental black elephants gathering out there. Global warming, deforestation, ocean acidification, and mass biodiversity extinction just to name four. When they hit, we will claim they were black swans that no one could have predicted, but, in fact, they are black elephants, very visible right now. We're just not dealing with them with the scale and speed that is necessary."

-Adam Sweidan via Thomas Friedman's *Thank You For Being Late*

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Contents

1 Introduction

C_4Coin aims to build a carbon-negative public-permissioned blockchain. The C_4Coin project will achieve this goal by providing the first viable economic incentive to voluntarily retire carbon credits.

Since the Kyoto Protocol in 1997,[1] the world has agreed on carbon credits (one metric ton of CO_2 or equivalent offset) as a mechanism for financially incentivizing conservation efforts. Many regional governments have enacted compliance carbon trading schemes with mixed results.[2,3,4,5] Meanwhile, the voluntary carbon market suffers from oversupply[6] due to the lack of a financial incentive to retire credits.

The C_4Coin network will create this incentive through a two-token model. First, CO2KNs (See-Oh-tokens) will each be equivalent to one carbon credit. Second, C_4Coins will function as traditional crypto-assets, usable as fuel for distributed applications (dApps). A Proof-of-Burn consensus mechanism will link the creation of C4Coins to the staking and burning of CO2KNs.

Representing carbon credits as CO2KNs will create several significant benefits. First, the ability to retire CO2KNs through network consensus and earn C_4Coins will give CO2KNs added value compared to traditional credits. Additionally, hosting these credits on a blockchain will streamline the process of carbon trading, allowing for interoperability between differing standards and reducing transaction fees.

The C_4Coin blockchain will feature a virtual machine similar to Ethereum's, allowing developers to create dApps. C_4Coins will fuel these dApps. Because the network's consensus mechanism requires retiring carbon credits, the C_4Coin network (and any dApps using it) will lead to emissions reductions. This innovation improves on existing blockchain technologies, which are inherently wasteful.[7] Given the choice of two blockchains that are otherwise functionally identical, the logical developer would choose to deploy on the environmentally conscious network.

By creating a carbon-negative blockchain economy, C_4Coin will provide a tangible incentive for environmentalism. In the absence of unified government efforts, C_4Coin aims to mobilize individuals, communities, and businesses to combat climate change.

From this introduction, it should be clear that several aspects of the project require further explanation. This paper will first provide a brief overview of the carbon credit space. Next, it will spell out in detail the problems C_4Coin aims to solve. Finally, the paper will present the technical details of C_4Coin's proposed solution and the team's vision for the project's long-term future.

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[1] United Nations Framework Convention for Climate Change, "Kyoto Protocol," Accessed 2017-11-17, http://unfccc.int/kyoto_protocol/items/2830.php.

[2] Alexander Jung, "The EU's Emissions Trading System Isn't Working," Translated by Ella Ornstein, 2012, accessed February 15, 2012, http://www.spiegel.de/international/business/hot-air-the-eu-s-emissions-trading-system-isn-t-working-a-815225.html.

[3] California Air Resources Board, "Compliance Offset Program," Accessed 2017-11-15, https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm.

[4] The EU Emissions Trading System (EU ETS), "Use of International Credits," Accessed 2017-11-15, https://ec.europa.eu/clima/policies/ets_en.

[5] Carbon Action Reserve, "Reserve FAQs," Accessed 2017-11-14, http://www.climateactionreserve.org/resources/faqs/.

[6] Environmental Finance, "Low Prices, But High Hopes for the Voluntary Carbon Market," South Pole Group. Accessed 2017-12-08, https://www.southpole.com/news/low-prices-but-high-hopes-for-the-voluntary-carbon-market.

[7] Sebastiaan Deetman, "Bitcoin Could Consume as Much Electricity as Denmark by 2020," 2016, accessed March 29, 2016, https://motherboard.vice.com/en_us/article/aek3za/bitcoin-could-consume-as-much-electricity-as-denmark-by-2020.

2 Carbon Credits

This section will provide a brief introduction to carbon offsets. It will cover offset methodologies, the present state of carbon-offset markets worldwide, and the life-cycle of carbon offsets within these systems. Readers already familiar with carbon offsets may find it helpful to skim the following until §3.

2.1 Offset Methodologies

Many types of carbon credits exist under the UNFCCC's Clean Development Mechanism (CDM) standards,[8] the Verified Carbon Standard (VCS),[9] as well a range of other standards. It would be impractical to discuss all approved carbon-offset methodologies at length here. For the sake of simplicity, this section will examine the following two broad types of carbon offsetting:

1. Avoidance projects that prevent future carbon emissions. For example, a renewable energy source may generate energy in excess of its operational requirement and distribute this energy back into the grid. By doing so, the renewable energy source reduces the net energy demand of the grid, thereby decreasing the amount of energy fossil fuel plants must produce. Typically, the owner of the renewable energy source is eligible to earn a carbon credit for every metric tonne of CO_2-equivalent (tCO_2e) of emissions offset in this manner.[10]

2. Sequestration projects that remove greenhouse gases that have already been emitted into the atmosphere. When a forestry initiative regenerates formerly degraded land, it can be considered a sequestration project.[11] Sequestration projects make up only a small portion of total approved methodologies across all standards.[12]

As was mentioned above, thousands of methodologies exist for sequestration and avoidance projects under a variety of standards.[13] For the purposes of understanding the problems that C_4Coin aims to solve, these two general offsetting methods–avoidance and sequestration–provide sufficient background to understand carbon markets.

2.2 The State of Carbon Markets Today

This section will describe the state of carbon markets worldwide and how the C_4Coin blockchain can improve on the current system.

Carbon trading consists of compliance and voluntary markets. There are two types of compliance markets: Carbon Taxes and Cap-and-Trade schemes.[14] Carbon Taxes require companies to pay a fee based on how much they pollute into the atmosphere. In a Cap-and-Trade system, regulation requires companies to keep their total carbon emissions below a certain level. If a company is unable to stay

[8] United Nations Framework Convention for Climate Change, "Registry Functions," Accessed 2017-11-16, http://unfccc.int/kyoto_protocol/registry_systems/registry_functions/items/4066.php.

[9] VCS, "Verified Carbon Standard," Accessed 2018-04-24, http://verra.org/project/vcs-program/.

[10] United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM), "CDM Methodology Booklet," 2016, 7, https://cdm.unfccc.int/methodologies/documentation/1611/CDM-Methodology-Booklet_fullversion.pdf.

[11] Ibid., 8.

[12] Ibid., 9-12.

[13] See Ex. 1 for a list of Standard-Setting Bodies

[14] Lawrence H Goulder and Andrew R Schein, "Carbon Taxes Versus Cap and Trade: a Critical Review," *Climate Change Economics* 4, no. 03 (2013): 1350010.

below this limit, it must purchase and retire carbon credits.[15] The voluntary market, by contrast, is reliant on altruistic motives. Voluntary credits tend to be cheaper and more plentiful due to a higher degree of innovation enabled by more flexible standards.

Including compliance and voluntary markets, the price of a carbon credit ranges from $1 to over $130 per credit.[16] Connecting separate markets could eventually contribute to a more uniform price globally. This prospect appears increasingly likely as China (pilot system trading around $2.00)[17] seeks to link to California's Cap-and-Trade system (currently trading at $15.40),[18] which is also considering linking with Quebec ($14.75)[19] and other Canadian provinces.

The largest carbon trading systems in the world are compliance markets, with over $52 billion in worldwide trading as of 2017.[20] Compliance markets exist in a number of governments throughout the world (Ex. 2). The European Union's market is particularly robust. Currently the world's largest, it is soon expected to be second to China's Cap-and-Trade system which launched in December 2017.[21]

There are a number of challenges associated with participating in compliance systems, perhaps the foremost of which is that compliance markets are not standardized worldwide. Instead, each jurisdiction has its own stringent, disparate regulations as to what qualifies as a carbon credit that can be traded, auctioned, or retired. As a result, compliance markets struggle to operate across borders.[22,23]

The voluntary carbon market features around $200 million of yearly trading worldwide, with a volume of about 65 million metric tonnes and an average global price of $3 per metric tonne.[24] Any individual or business wishing to offset their carbon footprint can purchase carbon credits on the voluntary market.[25] Voluntary carbon credits are verified by a number of non-governmental standard-setting bodies (Ex. 1). Retiring a voluntary carbon credit does not qualify for compliance purposes, but anyone can voluntarily purchase and retire a compliance credit.

The voluntary market represents a major growth opportunity. If just 17% of the potential global voluntary carbon market were developed, it would be larger than all of the world's compliance markets put together.[26] Moreover, by entering the voluntary market, individuals and small businesses–although not covered by Cap-and-Trade or Carbon Tax schemes–can contribute enormously toward meeting the world's emissions reduction targets.

[15] Robert N Stavins, "Experience With Market-Based Environmental Policy Instruments," *Handbook of environmental economics* 1 (2003): 355–435.

[16] World Bank, *State and trends of carbon pricing 2015* (World Bank Publications, 2015).

[17] International Carbon Action Partnership, "China - Guangdong pilot system," Accessed 2017-11-12, https://icapcarbonaction.com/en/?option=com_etsmap&task=export&format=pdf&layout=list&systems[]=73.

[18] Climate Policy Initiative, "California Carbon Dashboard," Accessed 2017-11-13, http://calcarbondash.org.

[19] International Carbon Action Partnership, "Canada - Québec Cap-and-Trade System," Accessed 2017-11-12, https://icapcarbonaction.com/en/?option=com_etsmap&task=export&format=pdf&layout=list&systems[]=73.

[20] World Bank, "Carbon Pricing Dashboard, 2016," Accessed 2017-11-10.

[21] Ken Silverstein, "China Launches a Cap-and-Trade Program to Cut Carbon Emissions," 2017, accessed December 23, 2017, https://www.environmentalleader.com/2017/12/china-launches-cap-trade-program-cut-carbon-emissions/.

[22] California Air Resources Board, "Compliance Offset Program."

[23] The EU Emissions Trading System (EU ETS), "Use of International Credits."

[24] Steve Zwick, "Building on Paris, Countries Assemble The Carbon Markets Of Tomorrow," 2016, accessed November 9, 2017, http://www.ecosystemmarketplace.com/articles/building-on-paris-countries-assemble-the-carbon-markets-of-tomorrow/.

[25] Carbon Trade Exchange, "What is CTX?," Accessed 2017-11-16, http://www.ctxglobal.com/about/.

[26] Compliance markets encompass 7 GtCO2e, or approximately 12% of global emissions according to Kossoy et. al "State and Trends," 21. Therefore, total global emissions are roughly 58 GtCO2e annually and 15% of 51 is 7.7.

2.3 Issuance, Verification, Trading, and Retirement

This section provides an overview of how a carbon-offset project developer complies with the established protocols.[27,28]

A project developer begins by identifying a potential carbon-offset project. Once a potential project has been identified, the developer must contract a third party to conduct a baseline greenhouse gas (GHG) study.[29] This study measures the amount of carbon emitted under a "business-as-usual" scenario, before the offsetting project is operational.

Upon completion of the baseline GHG study, the project developer is required to either choose an appropriate approved methodology, or submit a new methodology document for the offset project.[30] The methodology document details the algorithm that, using the results of the baseline GHG study describes a list of activities that will reduce total GHG output relative to the baseline scenario. New methodologies must be submitted to a standard-setting body for approval.[31] This approval process is rigorous and may involve several rounds of revision and independent review by approved experts. If a new methodology is approved, it is registered in the standard-setting body's database as a verified methodology.[32] Verified methodologies can be reused in the future as long as they are adjusted to meet the specific conditions of the new offset project.[33]

Once the project developer has an approved methodology, they must complete a Project Design Document (PDD) that explains the project-specific application of the selected verified methodology. The developer must submit the PDD for validation by an accredited third party. Upon validation, the project can be registered in the standard-setting body's project database.[34]

Inherent in the project design is a monitoring plan.[35] This plan contains specific instructions enabling a third-party verifier to observe the project over time and determine that amount of GHGs mitigated is in line with the expectations set in the PDD. As part of the PDD verification, the standard-setting body coordinates with the third-party verifier to set up an in-person audit of the offset project. This carbon audit is based on the instructions laid out in the monitoring plan.

After a project has been audited, the third-party verifier reports back to the standard-setting body, comparing the project's actual performance with the predicted performance detailed in the methodology proposal and PDD. The standard-setting body issues one carbon credit into the developer's account for each metric ton of GHGs that the project actually avoids or reduces.

For the developer to sell credits to another entity, the buyer must also have a

[27] Much of this section is written by Reed Shapiro, the Director of Business Development at Carbon Credit Capital (CCC). This writing does not necessarily reflect the opinions of CCC. His expertise is a trustworthy source due to his years of experience in the carbon-offset industry. Any inaccuracies created during the editing process are the responsibility of the C4Coin authors.

[28] United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM), "CDM Methodology Booklet."

[29] United Nations Framework Convention for Climate Change (UNFCCC) Clean Development Mechanism (CDM), "CDM accreditation standard," Accessed 2017-11-10.

[30] United Nations Framework Convention for Climate Change (UNFCCC) Clean Development Mechanism (CDM), "Propose a new methodology," Accessed 2017-11-14.

[31] Ibid.

[32] Ibid.

[33] United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM), "CDM Methodology Booklet."

[34] United Nations Development Programme, "Clean Development Mechanism, a User's Guide," 2003. http://www.undp.org/content/undp/en/home/librarypage/environment-energy/climate_change/mitigation/undp_cdm_manual.html.

[35] Carbon Action Reserve, "Program and Project Documents," Accessed 2017-11-15, http://www.climateactionreserve.org/how/program/documents/.

registry account. Transactions between registry accounts typically cost a fee. Credits held in a registry account can be sold, held as financial assets, or retired.

Retirement transactions are similar to sales. However, a buyer does not need a registry account if they intend to retire credits immediately after purchasing. Typically, the buyer specifies a number of credits they would like to retire, and the project developer invoices them at an agreed price per credit. Once paid, the developer schedules the retirement of the purchased credits with the standard-setting body or registry. These credits are identified by serial number and permanently removed from circulation.

3 Problems

3.1 Ecological

Climate change is causing a global ecological crisis. Greenhouse gases trapped in the atmosphere are raising Earth's average temperature and devastating the environment. Glaciers are melting. Sea levels are rising. Precipitation levels are shifting, leading to historic droughts around the world.[36] Warmer waters are strengthening hurricanes.[37] It is difficult to look at the evidence and conclude that climate change is a hoax or non-issue, but millions of Americans remain skeptical,[38] adding to the challenge of organizing climate-conservation action.

This challenge is worsened by the fact that working to halt or reverse climate change is expensive.[39] Even businesses that accept the reality of the problem have no incentive to change their usual practices if they could lose profits and fall behind competitors. The current state of business optimizes for maximum immediate profit, leaving little room for environmental concerns.[40]

3.2 Political and Economical

Each compliance market around the world is crafted by a different set of legislators with different challenges and motivations in mind. This type of inconsistency creates difficulties when confronting any global issue on an inter-governmental level.

Additionally, taking action on climate change can appear to stifle the economy. Politicians don't want bad press for proposing policies that restrict economic growth, and businesses don't want extra expenses. In many countries, politicians are reliant on polluting businesses for funding.[41] Moreover, a small but vocal segment of the voting population refuses to accept the reality of climate change.[42] These challenges make it difficult for politicians to advocate for carbon regulations, further hindering the development of compliance markets.

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[36] Terrell Johnson, "California Isn't Alone: Historic Droughts Happening Around The World," 2015, accessed July 28, 2015, https://weather.com/science/environment/news/california-historic-drought-world-brazil-africa-korea.

[37] Michael E. Mann, Thomas C. Peterson Peterson, and Susan Joy Hassol, "What We Know About the Climate Change-Hurricane Connection," 2017, accessed September 8, 2017, https://blogs.scientificamerican.com/observations/what-we-know-about-the-climate-change-hurricane-connection/.

[38] Cary Funk and Brian Kennedy, "The Politics of Climate," 2016, accessed November 10, 2017, http://www.%20pewinternet.%20org/2016/10/04/the-politics-of-climate.

[39] Climate Policy Info Hub, "The Costs of Mitigation: An Overview," Accessed 2017-11-10, http://climatepolicyinfohub.eu/costs-mitigation-overview.

[40] Wikipedia, "Dodge v. Ford Motor Co.," Accessed 2017-11-07, https://en.wikipedia.org/wiki/Dodge_v._Ford_Motor_Co..

[41] Federal Election Commission, "2018 Political Action Committee Summary by Type," Accessed 2017-11-12, http://classic.fec.gov/disclosure/pacSummary.do?cf=phome.

[42] Funk and Kennedy, "The Politics of Climate."

Environmental degradation is an external cost insufficiently incorporated into mainstream economics. Therefore, a market-driven approach can successfully combat climate change only if a financial incentive exists to protect the environment.

3.3 The Wasteful Nature of Blockchain Consensus

Proof-of-Work (PoW) consensus is wasteful.[43] PoW deters malicious actors from engaging with the network by requiring expensive CPU (or GPU) resources to participate.[44] It has been predicted that the Bitcoin network will consume more electricity per year than the country of Denmark by 2020.[45] This figure does not account for the resources expended purchasing the required computer chips.[46]

An environmentally conscious project cannot reasonably be created on such a wasteful network. It is essential for any carbon token solution to present a green consensus mechanism.

4 Network Architecture

This section describes the proposed network architecture for C_4Coin. The C_4Coin blockchain approaches the problems spelled out in Section 3 from an infrastructural perspective. First, a public permissioned blockchain can solve several inefficiencies in carbon markets. Specifically, a distributed carbon registry would significantly lower the costs of trading and retiring credits by removing the need for transactional oversight. Furthermore, immutable blockchain records contain the entire history of each credit on the system. Tokenizing credits migrated from multiple existing registries onto one blockchain enables interoperability between carbon standards on one market interface.

Most importantly, the C_4Coin Proof-of-Burn consensus mechanism resolves the voluntary carbon market's biggest failure: a lack of incentive to retire credits. This market failure results in an oversupply of carbon credits.[47] By providing this missing incentive, currently unusable credits gain utility and an entire economy can be built on combating climate change. For the C_4Coin blockchain to be carbon-negative, CO2KNs used in consensus must be burned. This ensures the carbon credits that the tokens represent cannot be spent twice, and that users earning C_4Coins through consensus have done verifiable work to benefit the environment.

The C_4Coin solution is market-driven and does not depend on innovative ecological science. Rather, the C_4Coin solution depends only on the fact that increasing the retirement of carbon credits will help curb global warming. As the supply of carbon credits decreases, the price will rise.[48] This increased price will incentivize investment in carbon mitigation technologies as previously economically unfeasible methods become profitable.

[43]Marc Pilkington, "11 Blockchain technology: principles and applications," *Research handbook on digital transformations*, 2016, 225.

[44]Satoshi Nakamoto, *Bitcoin: A peer-to-peer electronic cash system*, 2008.

[45]Deetman, "Bitcoin Could Consume as Much Electricity as Denmark by 2020."

[46]John Leonard, "Cryptocurrency Miners Are Hiring Boeing 747s to Deliver GPUs," 2017, accessed July 31, 2017, https://www.theinquirer.net/inquirer/news/3014813/cryptocurrency-miners-are-hiring-boeing-747s-to-deliver-gpus.

[47]Environmental Finance, "Low Prices, But High Hopes for the Voluntary Carbon Market."

[48]Adam Smith and John Ramsay McCulloch, *An Inquiry into the Nature and Causes of the Wealth of Nations* (A. / C. Black / W. Tait, 1838), Book 1, Ch 7.

The remainder of this section will detail:

1. How carbon credits can be represented as digital tokens,
2. How CO2KNs are traded on the network,
3. How this public permissioned blockchain achieves network consensus, and
4. How the monetary policy for C_4Coins will be managed.

4.1 Carbon Token Generation

All CO2KNs will be generated from off-chain data. This generation will occur through off-chain software systems that push data from trusted, legally-bound third parties into dedicated 'Oracle' smart contracts.

On-chain carbon offset methodology specifications will be implemented as a set of smart contracts. These smart contracts will refer to the data being pushed to the various Oracles. The data will be sourced from methodology specific project-monitoring APIs built by third parties. If the smart contract determines that the baseline and additionality criteria of the project are valid, tokens will be generated and distributed to user wallets. For some methodologies, users will sign the data submitted to the third-party web API, allowing the network to validate the data's origination without requiring personally identifiable information beyond a public key. While project monitoring will be centralized, users generating offsets will not need to share personally identifiable information with the network.

Despite the failsafes programmed into the system, companies generating CO2KN may attempt to submit fraudulent data to receive more tokens. To prevent this, C_4Coin will enter into legal agreements with these companies to enforce the continued validity of their data. These agreements will be hashed and uploaded to the chain, visible to all network users. The team will upload an example form of this agreement to c4coin.org and the C_4Coin GitHub repository as they become available.

4.2 Carbon-Offset Tokens: CO2KN

This section discusses the structure of CO2KN tokens. CO2KNs will be implemented using an EIP20 token interface, with one token corresponding to one metric ton of carbon offset. These tokens will also be composed of a hash of metadata, A, indicating:

- The project developer's public key, and
- The identifier of the generation methodology (§4.1) used to create the tokens.

While the PoB mechanism is insensitive to metadata, metadata will allow the network infrastructure to host both the voluntary and compliance markets. By linking token creation with methodology metadata (establishing token origins), users will be able to identify which tokens meet their requirements. However, the inclusion of this data in the tokens will mean some transactions may involve conflicting metadata.

To illustrate, suppose a user decides to send 7 tokens. Their wallet consists of 5 tokens with metadata A_1 and 5 tokens with metadata A_2, where A_1 and A_2 represent metadata identifying different methodologies. Given the metadata conflict, the user must either send two transactions and pay two transaction fees, or the metadata must transform to reflect both origins. Since the ultimate goal is to determine the origin of the tokens and avoid unnecessary fees, the tokens should be sent with new metadata, B, that consists of:

- The sender's public address,
- The composite transaction identifier,
- The date of the current transaction, and
- The number of times metadata has been replaced on these tokens.

Continuing the example, if the user decided to send 5 tokens with metadata A_1 and 2 tokens with metadata A_2, the recipient would receive 7 tokens of metadata B_1. Since metadata B_1 contains information identifying the transaction in which tokens were combined, mapping algorithms will be able to determine the composition of tokens with metadata B.

Wallet solutions may either store a user's tokens in their aggregated form (metadata B), or in the form of some number of tokens, W, with metadata A_1, X tokens with metadata A_2, Y tokens with metadata B_1, Z tokens of metadata B_2 and so on. If a user wants to turn tokens with metadata B into tokens with metadata $A_1, \ldots, A_z$, the generation API will support "unpacking" by mapping the submitted tokens, removing them from circulation, and reissuing tokens with clean metadata. A fee will be charged based on the difficulty of the mapping transaction.

4.3 Proof-of-Burn Consensus

This section describes the C_4Coin consensus mechanism. It begins with an overview of the Tendermint Practical Byzantine Fault Tolerance (PBFT) protocol,[49] the basis for C_4Coin's proposed implementation. This section then discusses the modifications necessary to run Proof-of-Burn within Tendermint and the resulting crypto-economic analysis.

4.3.1 Tendermint PBFT

Several Proof-of-Stake protocols exist today.[50] Many have been mathematically proven, but few have seen practical usage, largely due to their difficulty of implementation. Byzantine Fault Tolerance-based protocols are the most widely used, as they are easier to understand and backed by decades of research. These protocols are usually used in a semi-trusted, permissioned setting.

Tendermint is a Practical Byzantine Fault Tolerant (PBFT) Proof-of-Stake protocol well-suited for use on a blockchain network. It has been formally verified[51] and performs better than Proof-of-Work blockchains provided that the number of nodes does not exceed a certain threshold.

Tendermint is a semi-synchronous protocol with an upper limit for the voting and pre-commit phases. It operates in an asynchronous manner unless there are nodes offline or network delays. In those cases, the protocol will wait a fixed amount of time to receive messages. This design allows Tendermint to support up to 200 transactions per second.[52]

[49] The Authors, "Tendermint Introduction," Accessed 2018-04-24, http://tendermint.readthedocs.io/projects/tools/en/master/introduction.html.

[50] Ouroboros and Snow White are two good examples.

[51] Ethan Buchman, "Tendermint: Byzantine fault tolerance in the age of blockchains" (PhD diss., 2016).

[52] Tendermint, "Ethermint, Architecture, Motivation," Accessed 2018-04-15, http://ethermint.readthedocs.io/en/master/architecture/future-architecture.html?highlight=200.

When a transaction is sent to the memory pool, it is broadcast to a set of validators listed in a smart-contract. The protocol iterates through the list of validators, selecting one to propose the next block. This proposer broadcasts their proposed block, and the validators vote on whether it is valid. If two-thirds or more of the participants vote to approve, the network sends a pre-commit message. Once two-thirds or more of the participants have received this message and confirmed that the block has been signed by the proposer, the new block is added to the chain. If a two-thirds majority cannot be reached, the next proposer on the list is selected and the process repeats.

Tendermint was designed to be modular, capable of supporting a Proof-of-Stake weighted voting and rewards scheme. C_4Coin will adapt this technology to create a public-permissioned blockchain. Validators on this chain will be nodes hosted by C_4Coin, trusted partners, and some public participants. To achieve this, C_4Coin will develop a Proof-of-Burn protocol based on Tendermint PBFT.

Proof-of-Stake balances incentives by rewarding the nodes hosting the network. The trustworthiness of a given node is measured by the absolute stake (number of tokens) it is willing to forfeit for malicious actions. If a node acts maliciously, its absolute stake is slashed. As long as a node stakes (places tokens into escrow) without acting maliciously, it will receive block and gas rewards proportional to its relative stake. A node's relative stake is a dynamic number that is a function if its absolute stake over the total network stake for each voting round. Block rewards issue new tokens into circulation based on the network's monetary policy, while gas rewards are based on collected transaction fees.

Validators on the C_4Coin network will only receive gas rewards if no users are staking or burning tokens. In this case, all validators will have an equal stake and equal voting power. Light clients can delegate their stake to these validators, increasing their selected validator's relative stake and voting power. Once a validator becomes a delegate, it is eligible to receive block rewards.

4.3.2 Design

While most Proof-of-Stake protocols use a one-token model, the C_4Coin network will use a two-token model. In traditional Proof-of-Stake, a user's stake and rewards are denominated in the same tokens. Instead, CO2KNs will be burned for rewards of a different token, C_4Coin.

To enter Proof-of-Stake and receive C_4Coins as a reward, a user will send CO2KNs to a trusted validator's bond smart contract. This contract will reward the user proportionally to their stake after each block proposal until the user's stake is depleted. The amount of CO2KNs staked will define the validator's absolute stake, which will decay throughout the life-cycle of participation. This absolute stake can be used to determine the relative stake, which leads to the staking function.

Relative stake per delegate S_{rel} corresponds to the voting power of a block proposer with address d in a validator list v. *The relative stake* will be used to choose how often a validator will propose a block in a proposal round:

$$S_{rel}(v, d) = \frac{v[d].Stake}{TotalStake(v)}$$

where

$$TotalStake(v) = \sum_{i=1}^{|v|} v[i].Stake$$

A block proposer is eligible to earn block and gas rewards according to:

$R = R_{block} + R_{gas}$ where R_{block} and R_{gas} are the block and gas rewards.

The block reward is the distribution of new C_4Coins, while the gas reward is equal to the total gas fees per block. Since Tendermint does not have any forks during its execution, the block rewards will only be distributed to the block proposer.

Block rewards are a function of the block number according to the following deflationary formula:

$$R = R_{block}(b) = R_{initial} \cdot P_{dec}^{\frac{b-1}{(BlocksPerEra)}}$$

where the initial block reward, the percentage decrease and number of blocks per era are constants to be defined by the monetary policy based on the total number of C_4Coins to be created (§4.4).

Gas rewards depend on the amount of gas used by dApps on the network. Users can increase the amount of time they stake their CO2KN. The longer the bond commitment time, the more a minter will accumulate gas rewards.

An optimal decreasing monotonic function will be determined to ensure a user's CO2KN stake is exhausted during the life-cycle of participation. The next two subsections explain how two types of decay–exponential decay and linear decay–might work.

In the case that no CO2KNs are staked, only trusted validators will be able to add blocks to the blockchain. These trusted validators will be assumed to have a stake of 1 CO2KN. Also, in this event, these nodes will only receive gas rewards, not block rewards. These nodes will be hosted by C_4Coin and charge a fixed, minimum gas price.

4.3.3 Exponential Decay

If CO2KNs decay at an exponential rate, a user's absolute stake gradually decreases over a sequence of slots throughout epochs according to the following function:

$$S(s) = S_0 e^{-\lambda s \Delta t}$$

where S_0 is the initial amount staked, λ is the age factor and Δt is the slot interval taken as a constant.

The stake decay function $S(s)$ represents the absolute stake of a minter, $v[d].Stake$, as a function of slot number. As slots are proposed, the slot count is incremented and the absolute stake is decremented according to the decay function.

The block time between slots can be modeled as a constant, Δt. If there are $s = k$ slots from the initial stake time, $t_0 = 0$, the absolute stake will decay until a minimum stake S_{min} is reached:

$$S_{min} = S_0 e^{-\lambda s \Delta t}$$

Therefore, given an initial stake amount, the finite staking duration can be derived by solving for the number of slots k:

$$k = \frac{-ln\frac{S_{min}}{S_0}}{\lambda \Delta t}$$

Staking more CO2KNs will therefore require a longer stake duration.

To encourage longer staking times and increase network participation, a constant divider can be added, $\rho > 1$, against the decay constant, effectively increasing the staking time.

$$\rho k = \frac{-\rho ln\frac{S_{min}}{S_0}}{s\lambda \Delta t}$$

$$S(s) = S_0 e^{\frac{-\lambda}{\rho s \Delta t}}$$

However, the initial absolute stake, S_0, must be adjusted to a new initial stake amount, $S_\emptyset$, to maintain the same total decay amount and eligibility for reward:

$$S_0 \int e^{-\lambda t} dt = S_\emptyset \int e^{-\lambda \rho t} dt$$

Solving for for the adjusted initial stake:

$$S_\emptyset = S_0 \, \frac{\int e^{-\lambda t} dt}{\int e^{-\lambda \rho t} dt}$$

$$S_\emptyset = S_0 \rho$$

This would create incentives for minters with varying stakes to select longer staking durations.

4.3.4 Linear Decay

If CO2KNs decay at a linear rate the decay function is:

$$S(s) = S_0 - B_r s \Delta t$$

The pledged stake, S_0, and the burn rate, B_r, will be chosen by the minter. The number of slots required to deplete a user's stake can be determined using the initial stake amount.

$$k = \frac{S_0}{B_r \Delta t}$$

where the burn rate must be

$$B_{min} \leq B_r \leq B_{max}$$

The maximum burn rate, B_{max}, gives the shortest duration, or minimum number of slots k_{min}. Since users will stake varying amounts of CO2KNs, the maximum burn rate should be parametric to the initial amount staked. For larger stakes, the burn-rate must be proportionally increased by a constant scaling factor $n > 1$.

$$B_{max} S_0 = n S_0$$

A maximum amount of steps k_{max} can be used to create an upper-bound on staking duration.

$$k_{max} = \frac{S_0}{B_{min} \Delta t}$$

After each slot, the slot count is incremented, effectively decreasing a user's absolute stake. This continues until the stake reaches zero. By holding rewards in a bond contract until a user's entire staking life cycle has ended, disincentives can be maintained. Minters can withdraw their stake early (between epochs) at the cost of some of their gas rewards.

4.4 Network Tokens: C_4Coins

The goal of this section is to open a dialogue about C_4Coin's monetary policy. The monetary policy proposed in this section is based on Ethereum Classic, but is currently under development. Community feedback will be paramount for composing an ideal policy.

The C_4Coin token is the utility token used to run the C_4Coin network. It is a disinflationary crypto-asset, meaning that it reduces to a near-zero inflation rate within two decades. Annual block rewards (the base amount of C_4Coin received for successfully proposing a block) will decrease by 10% per era (about 2.4 years). Each era will contain 5,000,000 epochs.

Since C_4Coins will be required to run smart contracts on the network, this demand for C_4Coins will help to prioritize the virtual machine's computations.

5 Conclusion

C_4Coins is an innovative project with the potential to combat climate change globally. Current carbon markets are not adequately addressing environmental degradation. The C_4Coin network takes the carbon market framework and expands on it by increasing the number of people who can create, trade, and be rewarded for retiring offsets. Incentivizing individuals, businesses, and communities to clean up the atmosphere presents the most realistic opportunity to protect the earth.

6 Contact Information

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7 Exhibits

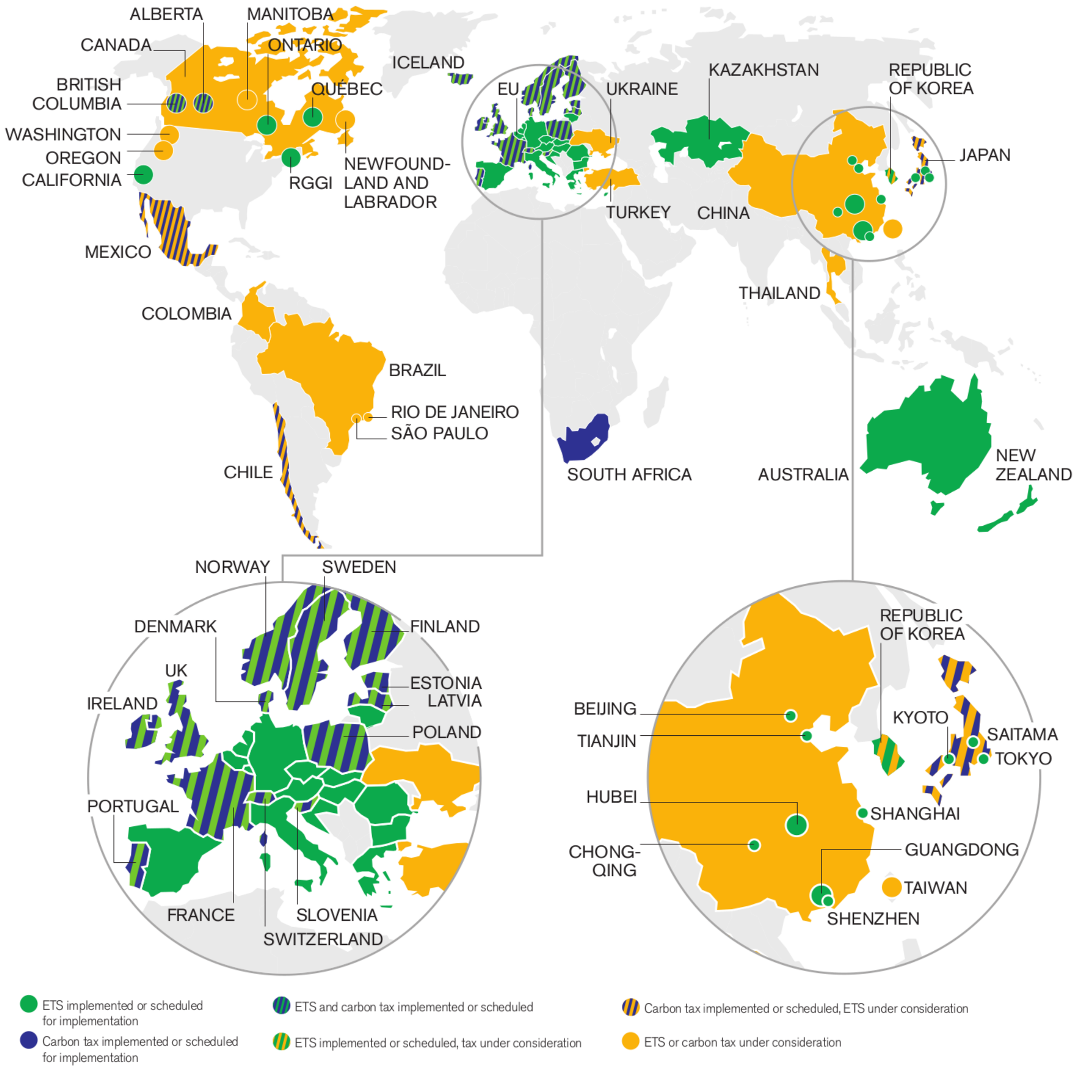
7.1 Exhibit 1

List of Voluntary Standard Setting Bodies

Number	Entity	Website
1	Verified Carbon Standard (VCS)	http://www.v-c-s.org
2	American Carbon Registry (ACR)	http://americancarbonregistry.org
3	REDD+	http://www.un-redd.org
4	Clean Development Mechanism (CDM)	http://cdm.unfccc.int/index.html
5	CCBA	http://www.climate-standards.org
6	Gold Standard	https://www.goldstandard.org
7	Climate Action Reserve (CAR)	http://www.climateactionreserve.org

7.2 Exhibit 2

Chart of Compliance Carbon Markets[53]



[53]World Bank, "Carbon Pricing Dashboard, 2016."

7.3 Exhibit 3

Comparison of current, approximate practical and theoretical TPS for Bitcoin, Ethereum, and Visa circa summer 2017.[54]

Technology	Practical TPS	Theoretical TPS
Bitcoin	3-4	7
Ethereum	15	30
Visa	1,667	56,000

[54] Jan Vermeulen, “Bitcoin and Ethereum vs Visa and PayPal - Transactions per second,” 2017, accessed November 10, 2017, https://mybroadband.co.za/news/banking/206742-bitcoin-and-ethereum-vs-visa-and-paypal-transactions-per-second.html.

8 Definitions

- **Application Programming Interface (API):** A set of clearly defined methods of communication between various software components.
- **Bitcoin:** The first decentralized cryptocurrency, which was launched in 2009 by Satoshi Nakamoto. It uses a **Proof-of-Work Consensus Mechanism**.
- **Blockchain:** a method for coalescing a single source of objective sequential data amongst a distributed network.
- **Block:** A file containing a designated amount of compound data.
- **C_4Coin:** The name of the network as well as the network token that **Smart Contracts** must use as a fuel to continue running. (See 4.4)
- **Cap-and-Trade:** A carbon trading system under which companies must purchase credits to counteract emissions above a regulatory maximum. (See 2.1.2)
- **Carbon Credit:** A certificate that represents one metric tonne of CO_2 or equivalent offset.
- **Carbon Credit Registry:** A body denoting who retired **Carbon Credits** and confirming that individual credits comply with the registry's specific standards.
- **Carbon Tax:** A government tax on greenhouse gas emissions. (See 2.1.2)
- **CO2KN (Pronounced "See-Oh-Token"):** A tradable **Carbon Credit** built on the **C_4Coin Blockchain**. It is also the name of the company operating the **C_4Coin Blockchain**.
- **Coinbase transaction:** The first transaction in the creation of a new **Block**. Only **Miners** can make this transaction. There is no input into this transaction, instead this transaction is the block rewards.
- **Compliance Carbon Market:** Government-mandated systems for reducing emissions like **Cap-and-Trade** or **Carbon Taxes**. (See 2.1.2 and Ex. 2)
- **Consensus Mechanism:** The algorithm by which a distributed **Blockchain** comes to agree on the data to be added to the next **Block** for the purposes of immutable storage.
- **Crypto-asset:** A unique piece of data with provable ownership.
- **Cryptocurrency:** A digital currency using encryption to regulate the generation of units of currency and verify transactions.
- **Decentralized Application (dApp):** An application that runs on a distributed **Blockchain** rather than a centralized server.
- **Epoch:** a sequence of **Blocks** using the same validators.
- **Ethereum:** A **Blockchain** that allows users to build smart contracts and **dApps**. It was launched in 2015 and currently uses a **Proof-of-Work Consensus Mechanism**.
- **Genesis Block:** The first **Block** in a **Blockchain**.

- **Initial Token Offering (ITO, a.k.a. ICO):** The first time a **Crypto-asset** is made available for sale.
- **Miner:** An individual operating a **Node** organizing **Blocks** in a **Proof-of-Work Consensus Mechanism**. **Miners** use computer processing power as a resource to determine the next **Block** and obtain rewards. The term is sometimes used to describe users who organize **Blocks** in other **Consensus Mechanisms** as well.
- **Minter:** An individual operating a **Node** organizing **Blocks** in a **Proof-of-Burn Consensus Mechanism**. (See 4.3)
- **Node:** A computer that hosts an entire **Blockchain** and organizes **Blocks**.
- **Proof-of-Burn (PoB):** A **Consensus Mechanism** proposed by Iain Stewart where **Proof-of-Work** is simulated by spending **Crypto-Assets** instead of real-world resources.
- **Proof-of-Stake (PoS):** A **Consensus Mechanism** where users put **Crypto-Assets** into escrow. If a user's **Node** behaves honestly and without malfunctions, they receive a reward. If they fail to do so, they lose the staked **Crypto-Assets**.
- **Proof-of-Work (PoW):** A **Consensus Mechanism** where users who organize **Blocks** must use CPU or GPU power to solve complex cryptographic codes to win **Blocks**. This process is resource-intensive. (See 3.3).
- **Retired:** A term used to describe **Carbon Credits** that have been applied as emission reductions and can no longer be traded.
- **Smart Contract:** A contract that is run by a computer with no human input. These programs form the foundation of **dApps**. Most common on the **Ethereum** platform.
- **Solidity:** A programming language on **Ethereum** similar to JavaScript, which allows for writing **Smart Contracts**.
- **Voluntary Carbon Market:** A carbon market where businesses or individuals can buy and retire **Carbon Credits** of their own volition. (See 2.1.2)

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