Tokenization: Overview and Financial Stability Implications

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Tokenization: Overview and Financial Stability Implications [*]

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Abstract

In this paper we outline tokenization, which is a new and rapidly growing financial innovation in crypto asset markets, and we discuss potential benefits and financial stability implications. Tokenization refers to the process of constructing digital representations (crypto tokens) for non-crypto assets (reference assets).[1] As we discuss below, tokenizations create interconnections between the digital asset ecosystem and the traditional financial system. At sufficient scale, tokenized assets could transmit volatility from crypto asset markets to the markets for the crypto token's reference assets.

Keywords: tokenization, crypto-assets, blockchain, decentralized finance, DeFi, Financial stability and risk, financial innovations, interconnections

JEL Classification Numbers: D49, D53, G00, G10, G20, G23

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[*]The opinions are the authors' and do not represent those of the Federal Reserve System or its staff.

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[1]For additional information and other details of tokenization, please see: The tokenisation continuum (bis.org).

1. Tokenization design features

The term "tokenization" refers to the process of linking reference assets to crypto tokens via design features that link the token's price to the value of the token's reference asset.[2] In the strictest sense, tokenization would allow for a crypto token holder to have a legally enforceable ownership claim over the token's reference asset.[3] So far, tokenization projects have been typically financed and developed by small venture-capital backed crypto companies. In addition, financial firms such as Santander, JP Morgan, and Franklin Templeton, have announced crypto related projects or pilot programs relating to tokenization.[4]

As is the case with stablecoins, tokenizations have widely varying design features and characteristics.[5] In general, a tokenization involves five design features: 1) a blockchain, 2) a reference asset, 3) a mechanism to assess the value of the reference asset, 4) a means to store and/or provide custody for the reference asset, and 5) a mechanism to facilitate redemptions of the token and/or the reference asset. Taken together, these components generate links between the crypto markets and the markets for the reference assets. These design choices can help distinguish token types and help determine each type's impact on traditional financial markets.

The first tokenization design element that we outline is the underlying blockchain on which the crypto tokens are issued, stored, and transacted. Some crypto tokens are issued on private permissioned blockchains, and others are issued on public permissionless blockchains. A permissioned blockchain is generally controlled by a centralized entity that grants approval to selected users in an isolated ecosystem.[6] Crypto tokens issued on permissionless blockchains (Bitcoin, Ethereum, Solana, etc.) are broadly accessible and can be used with fewer restrictions. Crypto tokens on permissionless blockchains can also be incorporated into decentralized finance (DeFi) protocols such as decentralized exchanges.[7] Crypto token issuers retain far less control over crypto tokens issued on permissionless blockchains than do issuers of crypto tokens on permissioned blockchains. Please see Table 1 for examples of tokens issued on permissioned and permissionless blockchains.[8]

Another component of tokenizations is the crypto token's reference asset. Reference assets

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[2]While tokenization can occur on non-blockchain distributed ledgers, in this paper we focus on blockchain-based tokenizations.

[3]For additional information and other details of tokenization, please see: Aldasoro *et al.* (2023)

[4]For an example, see The Clearing House (2022)

[5]See Azar *et al.* (2022), and Baughman *et al.* (2022) (among many others) for more information regarding various stablecoin design features.

[6]For more information, see Polge *et al.* (2021)

[7]See Carapella *et al.* (2022) for more information on DeFi.

[8]The issuer of tokenized assets on a permissioned blockchain can control the governance of the blockchain, the level of transparency on the blockchain, and the uses of the tokenized asset.

can be categorized in various ways: off-chain vs. on-chain, tangible vs. intangible, etc.[9] Off-chain reference assets can be physical (e.g. real estate and commodities) or intangible (e.g. intellectual property rights and traditional financial securities like stocks and bonds) and exist outside of the crypto-asset ecosystem.[10] Tokenizations with physical/off-chain reference assets generally involve an off-chain agent, such as a bank, to assess the value of the reference asset and provide custodial services. Tokenizations that reference other on-chain crypto-assets can incorporate smart contracts to provide custody and valuation assessments.

The final design element of many tokenizations is a mechanism for redemption. Similar to certain stablecoins, tokenizations allow for crypto token holders to exchange crypto tokens with the token's issuer for the reference assets.[11] A token redemption option can exist for both off- and on-chain reference assets and generates a link between markets for the tokenized asset and markets for the reference asset, as we discuss in more detail below. Also, tokenized assets can be traded in secondary markets, such as centralized crypto exchanges and DeFi exchanges.

Some tokenizations that reference other on-chain debt or equity securities do not incorporate redemption mechanisms, but still confer ownership or other rights to the crypto token holder. In these cases, the tokenization process involves representing the legal claims over the cash flows associated with other on-chain financial assets, or any other obligations of the entity issuing those financial assets.

2. The current size of tokenization markets, and specific examples of tokenized assets

Using press releases, news articles, and public data sources, we estimate that the market value of tokenized assets on permissionless blockchains is \$2.15 billion as of May 2023. This includes a wide range of tokens issued by decentralized protocols such as Centrifuge and traditional companies such as Paxos Trust.[12] A comprehensive set of time-series data is difficult to obtain due to the wide variety of tokenization designs and varying levels of

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[9]For a full description of types of reference assets, see OECD (2020).

[10]An example is the issuance of tokenized corporate bonds through Obligate's decentralized finance platform by Muff Trading AG, a Swiss physical commodities trading boutique specializing in sourcing precious metals and raw materials from South America. See Sandor (2023).

[11]See Baughman *et al.* (2022) for a discussion of stablecoin redemption mechanisms.

[12]Token issuers on permissioned blockchains tend to release less data than issuers on permissionless blockchains. Therefore, our estimate of the total size of the tokenization market only contains projects on permissionless blockchains.

transparency. Therefore, we capture a subset of tokenization projects by utilizing open-source data from DeFi Llama in Figures 1 and 2 to highlight the growing trend of tokenization in DeFi. Figure 1 shows that total value locked (TVL) in the entire DeFi ecosystem has remained roughly constant since June 2022.[13] However, in Figure 2 we show that the TVL in categories related to real world assets have grown since July 2021, both in absolute values and as a share of the overall DeFi ecosystem. As of May 2023, roughly $700 million of our estimated $2.15 billion are locked in DeFi.

Many new tokenization projects have been recently announced which reference many types of assets including agricultural commodities, gold, other precious metals, real estate, and a variety of financial securities.

In Table 2 we list examples of tokenizations to illustrate the range of reference assets. Specific examples of recently developed tokenized assets referencing agricultural commodities include SOYA, CORA, and WHEA which reference soybeans, corn, and wheat respectively. These tokens were part of a pilot project launched in March 2022 in Argentina by a joint-venture between Santander and the crypto-firm Agrotoken.[14] The claims on the underlying commodities embedded in these tokens, and the infrastructure to validate and process transactions and redemptions, are designed to be sufficiently robust to allow for Santander to accept these tokens as collateral for loans. Santander and Agrotoken stated that they hope to introduce similarly designed commodities tokens in the larger markets of Brazil and the US in the future.[15]

Other examples of non-financial reference assets are gold and real estate. The market capitalization of tokenized gold is roughly $1 billion as of May 2023.[16] Two coins dominate 99% of this market, Pax Gold (PAXG) issued by Paxos Trust Company and Tether Gold (XAUt) issued by TG Commodities Limited. Both issuers equate each of their coins to one fine Troy Ounce of gold that is custodied by the issuers themselves and meets the standards set by the London Bullion Market Association (LBMA). PAXG and XAUt are redeemable for the underlying gold subject to idiosyncratic restrictions and fees.[17] PAXG can also be

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[13]Total value locked (TVL) refers to the total value of all digital assets that are locked or staked in smart contracts on decentralized finance platforms. For more information on TVL, see Carapella *et al.* (2022).

[14]In December 2022 Agrotoken raised a $5 million seed round led by Xperiment VC. For more information, see Engler (2023).

[15]For more details, see Santander (2022).

[16]https://coinmarketcap.com/view/tokenized-gold/.

[17]For example, PAXG can be redeemed for USD, allocated gold, or unallocated gold, see appendix for further details. Redeemers are charged a minimum of 20 basis points on the value of the underlying gold. Allocated gold can only be delivered to vaults in London and unallocated can only be credited to a Loco London bank account. XAUt can be redeemed for only allocated gold which must be delivered to a Swiss address and the redeemer is charged 25 basis points on the gold price in the Swiss gold market and cost of delivery.

redeemed for USD at current gold prices while XAUt can be redeemed for proceeds from Tether selling the underlying gold in the Swiss gold market on holders' behalf. Overall, these two designs are similar, resulting in similar prices in PAXG and XAUt that also closely follow the price of gold futures.

Relative to commodities like agriculture and gold, reference assets like real estate are less uniform, with less liquid markets and values that are harder to assess, and involve more complex legal and tax processes for ownership and transactions. These issues pose significant challenges for tokenizations. One example of a tokenized real estate project issuer is Real Token Inc. (RealT) which collects an inventory of residential properties and tokenizes a variety of legal rights on them. Each property is owned by a limited liability Company (LLC) that is legally independent of Real Token Inc.[18] The property itself is not directly tokenized, rather the membership interests in the LLC are tokenized. Therefore, each property corresponds to its own LLC whose membership can be fractionalized into shares for co-ownership. For example, tokenized properties by RealT are "REALTOKEN-15634-LIBERAL-ST-DETROIT-MI" and "REALTOKEN-25097-ANDOVER-DR-DEARBORN-MI."[19] RealTokens were primarily developed for international investors as a way to own domestic US real estate and collect rental income. As of September 2022, RealT tokenized 970 units of property valued at over $52 million.[20]

Finally, there are tokenizations referencing financial assets such as stocks, bonds, and exchange-traded funds (ETFs). Tokenized stocks provide token holders with similar economic exposures as holders of the reference stock. However, the prices of the tokenized stock and its reference stock may differ, partly due to the former being able to trade 24/7 and partly due to the token's intrinsic properties, such as programmability and composability in various DeFi applications, which may also affect the token's liquidity.[21] We illustrate these dynamics in Figures 3, 4, and 5 that show the prices of Meta (META) and META's corresponding crypto token (Bittrex FB) as well as each of their volumes.[22]

There are tokenized versions of existing stocks issued on traditional, regulated exchanges

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[18]https://faq.realt.co/en/articles/3922308-who-holds-the-deed-to-the-house-who-owns-the-property.

[19]See https://coinmarketcap.com/currencies/15634-liberal-st-detroit-mi-48205/ and https://coinmarketcap.com/currencies/realtoken-25097-andover-dr-dearborn-mi/.

[20]RealT (2022).

[21]See Paz (2021). Furthermore, in some cases, holding the tokenized stock does not automatically transfer shareholder rights. See item 10 in the Appendix for further details.

[22]Bittrex announced on November 14, 2022 that it would shut down the offering of tokenized securities due to the collapse of FTX and Alameda. These securities had been offered through Bittrex's relationship with FTX and Alameda. For more information, see Bittrex's announcement, Bittrex Global (2022). Today, the tokenized stock is traded on DeFi exchange DeFiChain DEX which is how prices after November 14, 2022 are derived.

and tokenized versions of stocks, such as OSTK (Overstock.com Inc.), that are entirely issued on a blockchain.[23] The Swiss based platform Akionariat is an example of a firm that currently offers tokenization services of stocks for Swiss companies. U.S. companies such as Amazon (AMZN), Tesla (TSLA), and Apple (AAPL) each have tokenized stocks that are currently or have been previously traded on crypto exchanges such as Bittrex and FTX.[24]

In early 2023, Ondo Finance launched OUSG, OSTB, and OHYG, tokenized ETFs referencing Blackrock U.S. Treasuries ETF, PIMCO Enhanced Short Maturity Active ETF, and Blackrock iBoxx High Yield Corporate Bond ETF respectively. These tokens represent deposits in the reference ETFs and qualify as securities, but Ondo Finance also holds a "small portion" of USDC and USD in reserve for liquidity purposes.[25] Ondo Finance is the manager of these funds with Clear Street serving as prime broker and custodian of the securities and Coinbase serving as custodian of the stablecoins.

3. Potential Benefits of Tokenization

Tokenizations have potential to provide a variety of benefits, including granting investors access to markets that are otherwise inaccessible or costly to enter. For example, real estate tokenizations might allow for investment in a fraction of the underlying asset, with investors able to purchase shares in specific commercial buildings or residential investments, as opposed to real estate investment trusts (REITs) where investors own shares of a portfolio of real estate investments.

More generally, the programmability of crypto tokens and the ability to leverage smart contracts, allows for additional features that can be embedded into the tokenized asset which might also benefit markets for the underlying reference assets. For example, liquidity saving mechanisms could be implemented in the settlement of the tokenized asset even if they are not implementable for its real-world counterpart.[26] These attributes might lower barriers to entry for a wider set of investors, resulting in more competitive and liquid markets, and better price discovery.

Tokenizations might also facilitate lending through the use of tokens as collateral, as in the case of tokenized grain discussed above, where lending secured by the reference asset might be more costly or impossible. Moreover, transactions in the tokenized asset can settle more quickly than transactions in their respective real-world reference assets, as well as

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[23]OSTK was converted into common stocks in 2022. See Keely (2022).

[24]https://coinmarketcap.com/view/tokenized-stock/.

[25]For information on the underlying assets of tokens issued by Ondo Finance, see https://ondo.finance/ousg.

[26]For more details on liquidity saving mechanisms see Martin and McAndrews (2008).

transactions in financial reference assets. Traditional securities settlement systems, such as Fedwire Securities Services and the Depository Trust and Clearing Corporation (DTCC), settle trades on a gross or net basis throughout the settlement cycle, which is typically a business day following the trade.[27]

The existing empirical evidence on ETFs, which are the closest financial instrument to tokenization in terms of representing other assets, might suggest a mechanism by which tokenizations may also improve the liquidity of the markets for the reference assets. The academic literature on ETFs documents a strong positive correlation between the liquidity of the ETF and the underlying securities and finds that additional trading activity for ETFs results in higher information efficiency for the underlying securities in the ETF.[28] For tokens, a similar dynamic would imply that greater liquidity for tokens in crypto markets might be associated with more accurate prices in the markets for the token's reference assets.

4.   Financial Stability Implications of Tokenizations

The overall value for tokenized markets in the low single-digit billions remains small relative to both crypto-asset markets and the traditional financial system, and does not represent a material financial stability concern. However, if tokenizations continue to grow in number and scale, they may introduce fragilities to crypto asset markets, and introduce financial stability vulnerabilities to the traditional financial system.

The primary longer-term financial stability implications of tokenization relate to the interconnections that tokenization create between the digital asset ecosystem and the traditional financial system via tokenization redemptions mechanisms. For example, at sufficient scale a fire-sale of tokenized assets might reverberate through traditional financial markets, as price dislocations in crypto markets provide incentives for market participants to buy the token, redeem it for its reference asset, and sell the latter. Therefore, tokenizations may provide a means for a shock to be transmitted from crypto markets to the market for the reference assets of crypto tokens.

A stress transmission vulnerability might be a more prominent concern for tokenizations whose reference assets aren't liquid. Examples might include real estate, or other less liquid reference assets. A similar concern is discussed in the academic literature on ETFs, where there's a strong correlation between liquidity, price discovery and volatility of ETFs and

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[27]Today, securities such as equities and bonds are maintained in electronic book-entry accounts at centralized securities depositories (CSDs), typically via an indirect holding system where intermediaries (e.g. custodians, brokers) hold securities on behalf of their clients with the CSDs.

[28]See Madhavan and Sobczyk (2016), Ben-David, I., Franzoni, F. and Moussawi, R. (2016), and Liebi (2020).

those of the underlying assets.[29] Like ETFs, it is conceivable that greater liquidity in crypto asset markets might improve liquidity in the markets for the underlying reference assets, but also transmit volatility from crypto markets to the markets for the underlying reference assets.

Another financial stability concern is runs on the issuer of tokenized assets. Tokenized assets with a redemption option might suffer from similar issues as those arising for collateralized stablecoins, such as Tether. Any uncertainty surrounding the tokens' collateralization levels, especially if accompanied by a lack of disclosures and accurate information about the issuers, might raise investors' incentives to redeem the reference assets, thus triggering a fire sale of tokenized reference assets.

Transmission of volatility can also be exacerbated by nuances applicable to venues where crypto assets trade but not to venues where reference assets trade (or vice versa). Crypto exchanges allow continuous, 24/7 trading of crypto assets, while most reference asset markets are only open during business hours. The timing mismatch in trading hours might have unpredictable implications for investors or institutions in a stress event. For example, an issuer of a tokenized asset with a redemption option may face a fire-sale on the weekend. Because the reference asset is held off-chain, redeemers are unable to quickly procure reference assets as traditional markets would be closed. The inability to meet redemptions may perpetuate the fire-sale, decreasing the value of the asset to the point that it may threaten the solvency of any institution holding a sizeable share of the tokenized asset on its balance sheet. Furthermore, if such an institution would benefit from injections of liquidity from traditional money markets, they would be unable to obtain funding on a weekend. Hence, a sizeable fire sale, could quickly reduce the market value of affected institutions' and the issuer's assets, undermining their abilities to borrow and, thus, their solvency. Another example might relate to automated margin calls mechanisms in DeFi exchanges, that trigger a need to liquidate or redeem crypto tokens, which could have unpredictable implications for the markets for reference assets (especially in a stress event).

As tokenization techniques and the markets for tokenized assets develop, it is possible that tokenized assets could become reference assets themselves for certain trades in crypto and traditional financial markets. To the extent that crypto asset prices are more volatile than their real-world counterparts, such tokenizations may transmit volatility to traditional financial markets.

As tokenizations grow in size and scale, traditional financial institutions may become more exposed to crypto asset markets either by direct ownership of tokenized assets or by

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[29]For example, see Ben-David *et al.* (2018).

using tokens as collateral for other financial instruments.[30] Examples of this might include tokenized grain used to collateralize loans to farmers by the bank Santander, as we describe above, and ongoing initiatives to tokenize various money market instruments, such as the tokenization of U.S. government money market funds by Ondo Finance.

In addition, despite being similar in spirit to J.P. Morgan's first use of tokenized ownership interests in Money Market Fund (MMF) shares as collateral for repo and securities lending transactions, the impact of Ondo Finance's initiative on traditional financial markets could be involved in a wider range of uses and create more interconnections. Ondo Finance's tokens are deployed on the public blockchain Ethereum rather than on an institution's permissioned blockchain, implying that Ondo Finance has no control over how users and DeFi protocols choose to deploy such tokens.[31] As of May 2023, Ondo Finance's tokenized ETFs make up 32% of the market value of assets issued by decentralized protocols related to real world assets, the largest project in this category, according to DeFi Llama, and OUSG can be used as collateral for the publicly accessible and 19th largest lending protocol Flux Finance.[32]

Finally, similar to the role of securitization during the GFC, tokenization can potentially disguise riskier or illiquid reference assets as safe and easily tradeable, possibly encouraging higher leverage and risk-taking. A sudden reversal of these positions could then trigger systemic events.

5.   Conclusion

This note aims to provide a background on tokenization, and to discuss its potential benefits as well as financial stability risks. Currently the scale of tokenization is quite small, both when taken together or when measured relative to the market size of each token's reference asset. However, many projects involving various categories of reference assets are in development, suggesting that tokenization may become a larger part of the digital asset ecosystem. Among the benefits of tokenization, lowering barriers to entry into otherwise inaccessible markets and improving the liquidity of such market are the most prominent. The financial stability risks of tokenization mainly relate to the interconnections that tokenization creates between the digital asset ecosystem and the traditional financial system, possibly transmitting shocks or volatility from one to the other or possibly raising incentives to run

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[30]While interconnections between the digital and traditional financial systems remain limited at the moment, financial network theory indicates that the interconnections between two markets need not be large for a shock in one market to spread to the other. See Chang and Chuan (2023).

[31]See J.P. Morgan (2022).

[32]See https://defillama.com/protocol/ondo-finance. For an example of how OUSG can be used as collateral, see https://fluxfinance.com/.

on issuers failing to provide a transparent account of the mechanism linking the reference asset to its tokenized counterpart.

Appendix

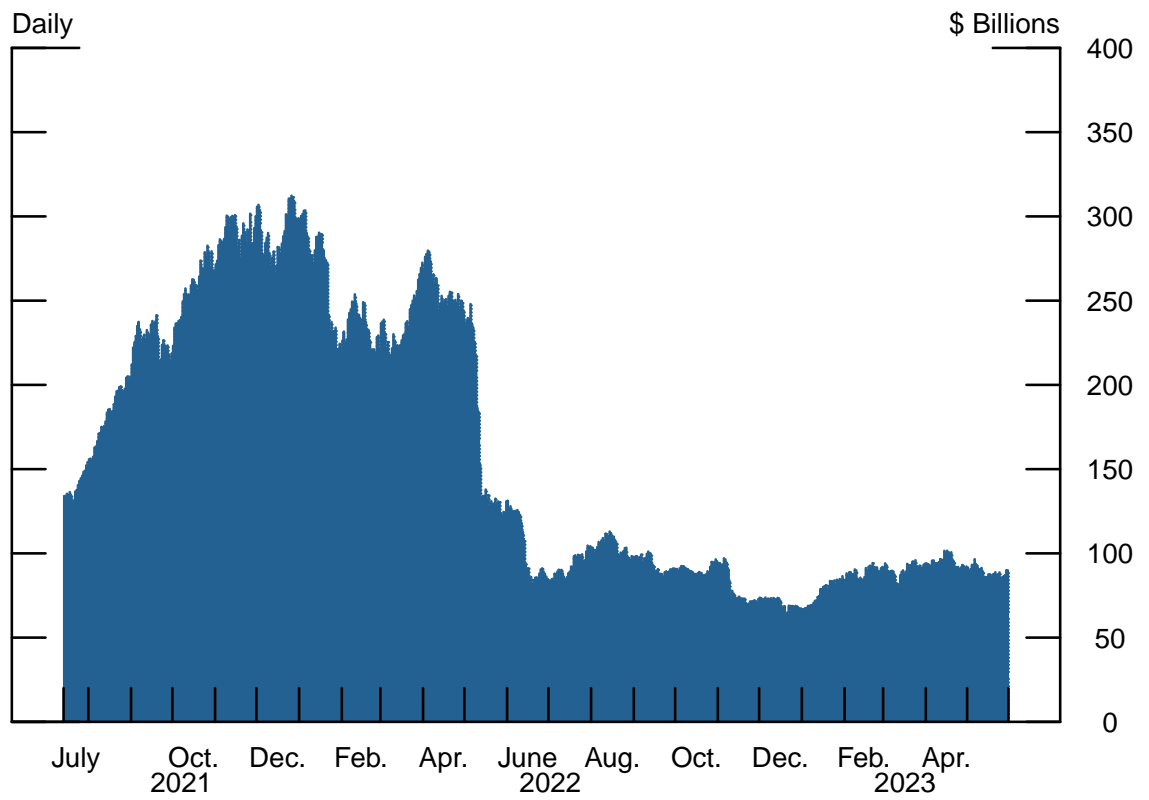Table 1: Tokenization Examples with Blockchain Characteristics

Token Issuer	Token Name	Token Blockchain	Blockchain Type	First Issued
European Investment Bank	Bond-specific tokens	GS DAP	Permissioned	Nov-22
European Investment Bank	Bond-specific tokens	HSBC Orion	Permissioned	Jan-23
Onyx by J.P. Morgan	Repo security-specific tokens	Onyx Digital Assets	Permissioned	Nov-20
Obligate	Bond-specific tokens	Polygon	Permissionless	Mar-23
Franklin Templeton	BENJI	Stellar & Polygon	Permissionless	Apr-23
Ondo Finance	OUSG	Ethereum	Permissionless	Jan-23
RealT Tokens	Multiple, property specific tokens	Ethereum	Permissionless	Nov-21
MatrixDock	STBT	Ethereum	Permissionless	Feb-23
Lofty	Multiple, property specific tokens	Algorand	Permissionless	Aug-22
Tangible	USDR	Polygon	Permissionless	Oct-22
Aktionariat	DAKS	Ethereum	Permissionless	Jan-21
Agrotoken	SOYA	Ethereum	Permissionless	Mar-21
Agrotoken	CORA	Ethereum	Permissionless	Sep-21
Agrotoken	WHEA	Ethereum	Permissionless	Dec-21
Paxos Trust Company	PAXG	Ethereum	Permissionless	Sep-19
TG Commodities Limited	TXAUT	Ethereum	Permissionless	Jan-20
Vave	Property-specific token, bundled token	Ethereum	Permissionless	Aug-23
Toucan Protocol	TCO2	Polygon& Celo	Permissionless	Oct-21
Centrifuge	DROP/TIN	Ethereum	Permissionless	Jun-21
Goldfinch	Pool-specific tokens	Ethereum	Permissionless	Nov-21

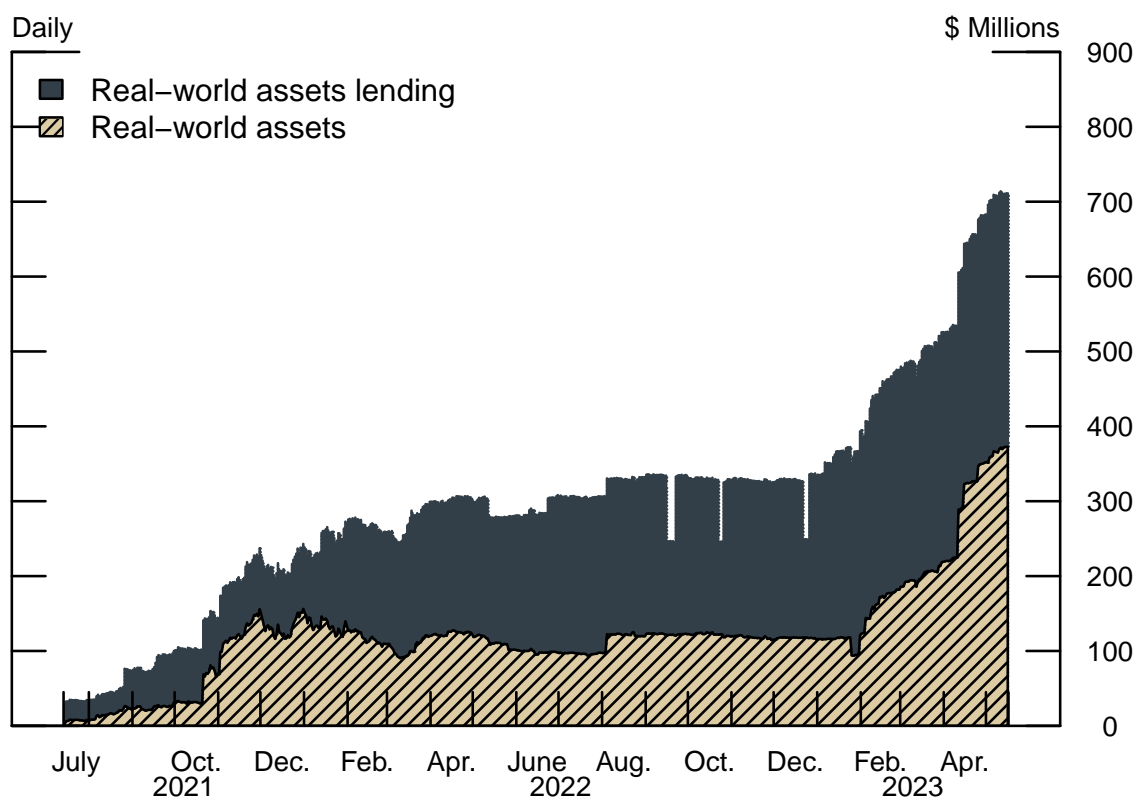Table 2: Tokenization Examples with Reference Asset Characteristics

Token Issuer	Token Name	Reference Asset	Reference Category	Redemption Option	On or Off-chain Asset
European Investment Bank	Bond-specific tokens	Bonds	Financial asset	No	On-chain
Onyx by J.P. Morgan	Repo security-specific tokens	Intraday repo	Financial asset	No	On and off-chain
Obligate	Bond-specific tokens	Corporate Bonds	Financial asset	No	On-chain
Franklin Templeton	BENJI	MMMF shares	Financial asset	Yes	On and off-chain
Ondo Finance	OUSG	iShares Short Treasury Bond ETF	Financial asset	Yes	Off-chain
RealT Tokens	Multiple, property specific tokens	Residential properties	Real asset - Real estate	No	Off-chain
MatrixDock	STBT	Short-term Treasury Bill	Financial asset	Yes	Off-chain
Lofty	Multiple, property specific tokens	Residential Properties	Real asset - Real estate	No	Off-chain
Tangible	Real USD	Real Estate	Real asset - Real estate	Yes	Off-chain
Tangible	Item specific Tangible NFTs (TNFTs)	Wine, gold, watches, or real estate	Real asset - Other	Yes	Off-chain
Aktionariat	DAKS	Private Equity Investments	Real asset - Other	No	Off-chain
Agrotoken	SOYA	Soybeans	Real asset - Commodity	Yes	Off-chain
Agrotoken	CORA	Corn	Real asset - Commodity	Yes	Off-chain
Agrotoken	WHEA	Wheat	Real asset - Commodity	Yes	Off-chain
Paxos Trust Company	PAXG	1 fine Troy ounce of gold	Real asset - Commodity	Yes	Off-chain
TG Commodities Limited	TXAUT	1 fine Troy ounce of gold	Real asset - Commodity	Yes	Off-chain
Toucan Protocol	TCO2	Carbon credits	Real asset - Other	No	Off-chain
Centrifuge	DROP/TIN	Pools of reference assets	Multiple assets	Yes	Off-chain
Goldfinch	Pool-specific tokens	Pools of reference assets	Financial asset	Yes	Off-chain

Figure 1: TVL Across All DeFi Categories

Daily $ Billions

Source: DeFi Llama.

Figure 2: TVL in DeFi Categories Related to Real-World Assets

Note: Real-world assets lending refers to the specific category of DeFi lending protocols that collateralize loans with tokenized assets that reference real-world assets. Real-world assets refer to the category of protocols that involve the tokenization and trading of real-world assets.
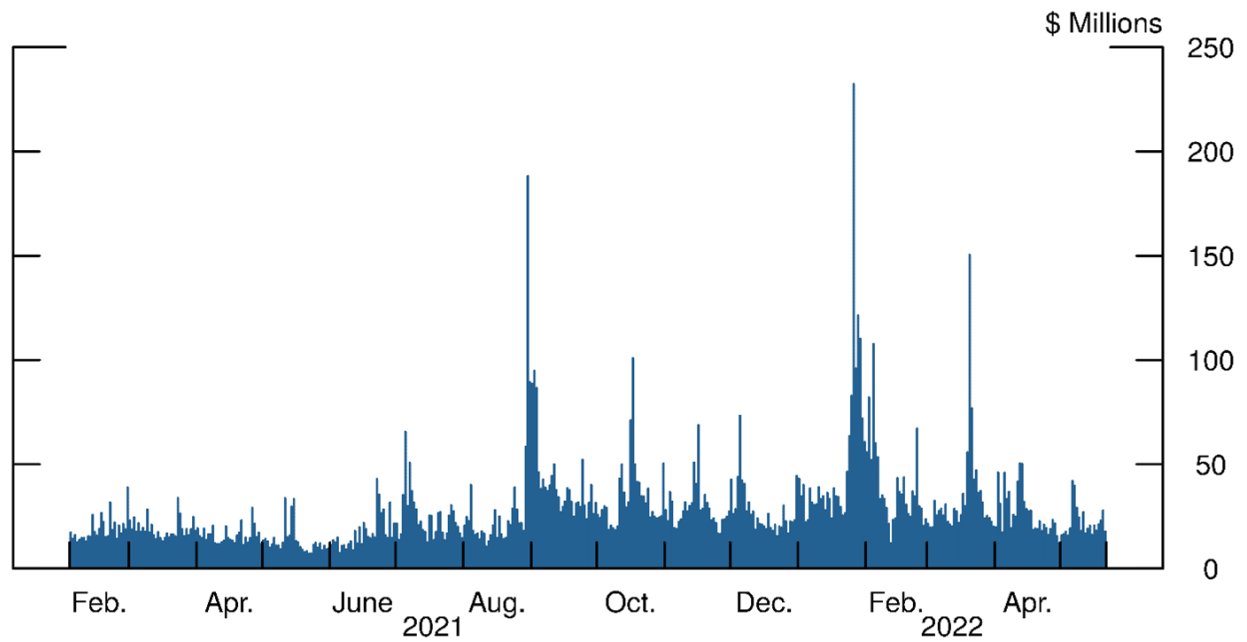Source: DeFi Llama.

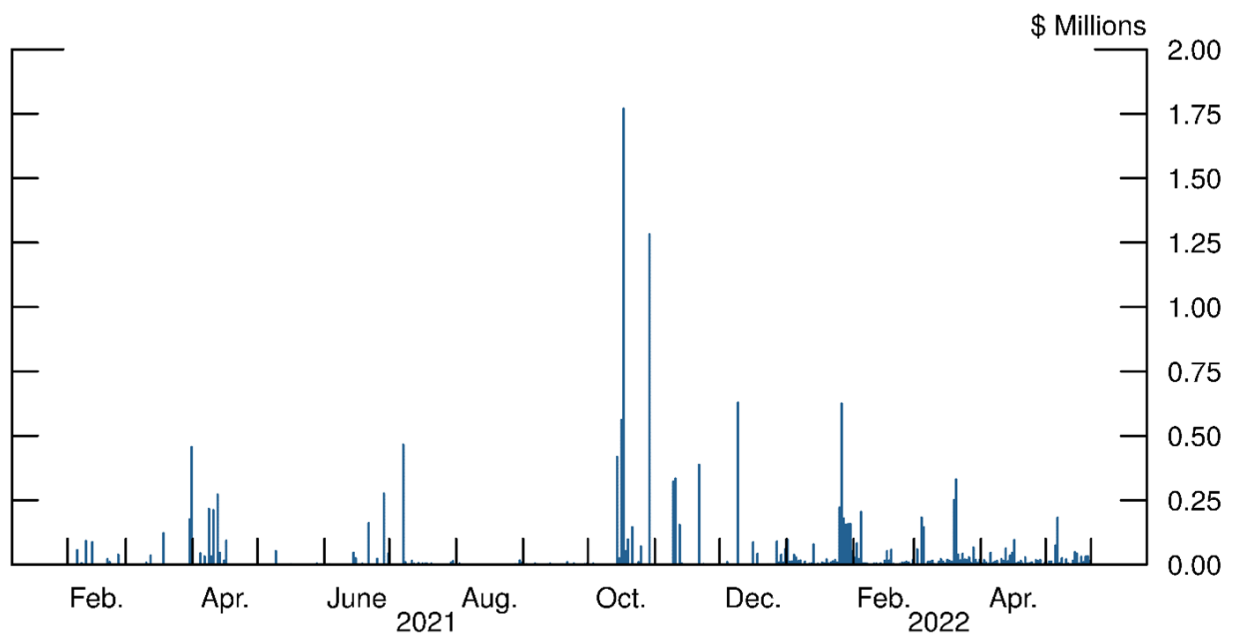Figure 3: Meta Stock and Tokenized Stock Prices

Note: Bittrex FB refers to the tokenized stock of META listed by crypto exchange Bittrex.
Source: Yahoo Finance & Coinmarketcap.

Figure 4: Daily Trading Volume of META on NASDAQ

Figure 5: Daily Trading Volume of Bittrex FB

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Details of some Tokenization Projects

Digital Bonds Issued by the European Investment Bank

The European Investment Bank, the lending arm of the European Union, has issued several bonds on multiple blockchains. The first issuance occurred on a combination of private and public blockchains operated and accessed via HSBC Orion and was denominated in pound sterling.[33]. The bond was for 50 million pounds. The blockchain serves as the record of legal ownership of the bonds and serves as the framework to manage the floating rate instrument and lifetime events. The bond will be held in digital accounts on HSBC Orion.

The second bond was a euro-denominated bond issued on Goldman Sachs' private blockchain, GS DAP.[34] The €100 million, 2-year bond was issued on GS DAP, a tokenization platform developed and operated by Goldman Sachs Bank Europe (GBSE). Investors could use traditional currency to purchase and pay for the bond, which was represented in the form of security tokens. The joint lead managers — Goldman Sachs Bank Europe SE, Santander and Société Générale — then settled the underwriting against the issuer using a representation of central bank money in the form of central bank digital currency (CBDC) tokens. These tokens were provided by the Banque de France and the Banque centrale du Luxembourg. Société Générale Security Securities Services (SGSS Luxembourg) serves as the on-chain custodian and GSBE serves as the account keeper for the CBDC. The bond features instant settlement at T+0. Secondary trading is OTC only and is settled using fiat cash off chain on a free of payment basis. Bond coupons are paid out in fiat EUR and GSBE serves as the paying agent for distributing these payments to bond holders.

J.P. Morgan's Onyx Platform

The Onyx blockchain-based platform operated by J.P. Morgan has the ability to tokenize and transact digital assets. Onyx is based upon a permissioned blockchain and primarily serves institutional clients. It has served as the underlying blockchain for several projects, including a cross-currency transaction involving tokenized Japanese Yen and Singapore Dollar deposits, as well as Singapore Government Securities Bonds, for the Monetary Authority of Singapore.[35] In the future, J.P. Morgan has stated that it aims to tokenize U.S. Treasuries or money market funds on Onyx.[36]

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[33]European Investment Bank (2023)

[34]European Investment Bank (2022)

[35]Monetary Authority of Singapore (2022)

[36]Allison (2022)

The Onyx platform has also completed the settlement of intraday repo transactions between J.P. Morgan's broker dealer and banking entities.[37] Both the collateral and cash legs of the repo transaction can be settled using Onyx. For repo transactions, the cash transactions are settled using J.P. Morgan's JPM Coin, a blockchain-based bank account. The platform has settled $300 billion since its launch in 2020.

Obligate

Obligate is a blockchain-based debt securities protocol which allows companies to issue bonds and commercial paper directly on blockchains.[38] The protocol facilitated a euro-denominated bond issuance for Siemens, a German industrial firm, on the Polygon network, for $64 million.[39] Obligate also facilitated issuance for Muff Trading AG, a Swiss physical commodities trading firm. Investors received ERC-20 tokens in their crypto wallets when purchasing the bonds. The Muff Trading bonds were funded using the USDC stablecoin and all future bonds will be denominated in USDC according to their website. Issuers are required to go through a KYC process.

Investors will be able to access Obligate through their existing crypto wallet. For each investment, the investor holds the respective eNote (ERC-20 token), which carries the right to receive payment at maturity or collateral in the case of a default.[40] The tokens can only be redeemed at maturity.

Franklin Templeton's Tokenized Money

Market Mutual Fund Franklin Templeton, a US-based asset manager, offers a U.S. Government Money Fund tokenized on the Stellar and Polygon public blockchains.[41] Investors can purchase BENJI tokens, each of which represents one share of the Franklin OnChain U.S. Government Money Fund and which aim to maintain a stable $1.00 share price.[42] The BENJI tokens can be redeemed at any time for $1.00. The official record of share ownership is maintained on a "proprietary blockchain-integrated system that currently utilizes the Stellar blockchain network for transaction activity". The fund has 92.5% of its total assets in U.S. Agency, with the rest in Cash. The tokens can be purchased and held in wallets

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[37]BusinessWire (2020)

[38]Sandor (2023)

[39]Siemens (2023)

[40]See https://fluxfinance.com/

[41]Franklin Templeton (2023), Khatri (2023).

[42]See Franklin OnChain U.S. Government Money Fund overview: https://www.franklintempleton.com/investments/options/money-market-funds/products/29386/SINGLCLASS/franklin-on-chain-u-s-government-money-fund/FOBXX#portfolio.

through the Benji Investments app. The fund currently has over \$272 million in assets under management. The project operates on the Stellar and Polygon blockchains.

Ondo Finance

Ondo Finance offers several tokenized securities, including OUSG, OSTB, OHYG, and OMMF, tokenized ETFs referencing Blackrock U.S. Treasuries ETF, PIMCO Enhanced Short Maturity Active ETF, Blackrock iBoxx High Yield Corporate Bond ETF, and U.S. Money Mark Funds, respectively. Returns for the OMMF tokens are airdropped to token holders on a daily basis, while returns on other tokens such as the OHYG are automatically reinvested into the underlying fund assets. Token holders receive traditional fund accounting reports from third-party service providers which validate the fund's assets.

Tokens can be redeemed daily, although redemptions can take multiple days to settle. If the fund has USDC on hand, the redemption occurs immediately. If not, the fund sells ETF share for USD, transfers USD from Clear Street to Coinbase, swaps USD for USDC, then pays out the USDC to the token holder.

RealT

RealT collects an inventory of residential properties and tokenizes a variety of legal rights on them. Each property itself is owned by a Limited Liability Company (LLC) that is legally independent of Real Token Inc.[43] The property itself is not directly tokenized, rather the membership interests in the LLC are tokenized. Therefore, each property corresponds to its own LLC whose membership can be fractionalized into shares for co-ownership. For example, tokenized properties by RealT are "REALTOKEN-15634-LIBERAL-ST-DETROIT-MI" and "REALTOKEN-25097-ANDOVER-DR-DEARBORN-MI."[44] RealTokens are mostly intended for international investors to own domestic real estate and collect rental income. As of September 2022, RealT has tokenized 970 units of property valued at over \$52 million.[45] Legally, RealT has a registered company in Delaware called Real Token LLC. This entity exists to simplify the process of conducting an investment security offering when placing each property under a Series LLC and offering membership shares to earn returns.[46] RealT tokens can be used as collateral for the DeFi lending protocol RMM which is based on the

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[43]https://faq.realt.co/en/articles/3922308-who-holds-the-deed-to-the-house-who-owns-the-property.

[44]See https://coinmarketcap.com/currencies/15634-liberal-st-detroit-mi-48205/,https://coinmarketcap.com/currencies/realtoken-25097-andover-dr-dearborn-mi/.

[45]RealT (2022).

[46]https://faq.realt.co/en/articles/7143772-what-s-the-difference-between-realtoken-inc-and-realtoken-llc

Aave protovol V2. As of now, only non-U.S. users can access RMM and borrow DAI. Other cryptocurrencies may be expanded to in the future.[47]

MatrixDock

MatrixDock issues stablecoins (STBT) that are each pegged to 1 USD and backed by U.S. treasury securities with maturities within 6 months and reverse repurchase agreements. They can be minted or redeemed. To mint, users must deposit USDC/USDT/DAI which will mint STBT tokens once the underlying T-bill subscription and/or reverse repo is "confirmed." STBT redemption can be requested through MatrixDock's app or by transferring STBT to the Issuer's dedicated address. The timeline for redemption is T+4 (New York Banking Day only). If holders redeem STBT prior to its maturity, the Execution Price is calculated as the T-bill settlement price divided by the fair market value ("FMV") on the preceding day. The T-bill settlement price can be lower than the fair market price for such T-bill on the preceding day, causing the STBT/USD ratio (the "Execution Price") to be less than 1. It is unclear how the settlement price is determined. The final settlement amount is calculated as the STBT redemption amount * Execution Price * (1 - 0.1% redemption fee).[48]

Lofty

Lofty is a platform that provides the ability to fractionally own U.S. rental properties through the Algorand blockchain.[49] They operate very similarly to RealT where properties are transferred from sellers to Lofty by placing each property under an independent LLC and membership shares of the LLC are tokenized. The returns from holding these tokens come from rental income and property appreciation.[50] It is unlikely that there would be an option to redeem as the reference asset is a legal claim to the returns generated by the token, not the property itself.

Tangible

Tangible is an NFT marketplace for Real World Assets.[51] They allow users to convert wines, gold bars, watches, and real estate as NFTs. The real-world items are custodied with Tangible and stored in their secure storage facilities. Users can purchase and own Tangible NFTs (TNFTs) using the platform's native stablecoin Real USD which is primarily backed

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[47]https://realt.co/understanding-the-technical-mechanisms-realted-to-rmm/

[48]MatrixDock (2023).

[49]https://learn.lofty.ai/en/articles/3788501-what-is-lofty

[50]https://learn.lofty.ai/en/articles/6145558-how-the-lofty-marketplace-works

[51]See https://docs.tangible.store/

by tokenized, yield-producing real estate (real estate TNFTs) but also DAI, TNGBL, and USDR.Rental income from Real USD's real estate TNFTs is paid out to Real USD holders in the form of a daily rebase projected to range between 10 - 15% APY. All TNFTs are redeemable for their reference assets only when holders own all fractions of the TNFT. Real USD is minted 1:1 with DAI and can be redeemed/burnt 1:1 for DAI.[52]

Aktionariat

Aktionariat is a platform provider for legal security tokens only available in Switzerland. They issue their equity in the form of tokenized shares called DAKS. The Aktionariat platform also provides the tools needed for other firms to tokenize and trade their equity. As Aktionariat is capable of holding and transacting with both tokenized and traditional stock, the price of the shares will depend on the total supply, including the shares that are non-tokenized, and the firm's valuation. It is not possible to fractionalize tokenized shares on Aktionariat. The price is adjusted upwards for each investment made and down for each share repurchased by the firm as the relationship between shares outstanding and the price is assumed to be linear.[53] There is a distinction between holding the tokenized share and being legally recognized as its shareholder. The latter requires holders to traditionally register off-chain as shareholders with the firm and therefore, it could be the case that a token is transferred but not the shareholder rights. Token holders who do not register as a shareholder are not entitled to the dividend payments or the right to vote at the general assembly, but would be recognized as owners of the shares by tax authorities. Aktionariat constructs a shareholder registry from tracking transactions on the blockchain and a mapping between addresses and shareholders stored in an off-chain database. Aktionariat updates the shareholder registry accordingly as transactions take place. However, due to the differentiation between being a shareholder and a token holder, a token transfer may not necessarily lead to a change in the registry.[54] Firms may also convert back to a traditional share system by repurchasing all their tokenized stocks from shareholders and "burning" them. There seems to be no redemption feature for token holders.

Agrotoken

Agrotoken is a provider of tokenized agricultural commodities. Their SOYA, CORA, and WHEA tokens reference soybeans, corn, and wheat, respectively. Each token represents 1 ton of the reference commodity. The commodities can be tokenized for 30, 60, or 90 day

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[52]Tangible (2023)
[53]https://www.aktionariat.com/documentation/tokenization-checklist
[54]https://www.aktionariat.com/documentation/shareholder-registry

periods and can be renewed until the maximum contract date. An exporter or collector is designated as the "Oracle" and is responsible for safeguarding the Proof of Grain Reserve, which certifies that each token has a ton of grain backing it. The protocol operates on the Ethereum public blockchain and each token is an ERC-20. The tokens are "detokenized" automatically when the period ends.

The pilot launched in March 2022 in Argentina by a joint-venture between Santander and Agrotoken.[55] The claims on the underlying commodities embedded in these tokens, and the infrastructure to validate and process transactions and redemptions, are designed to be sufficiently robust to allow for Santander to accept these tokens as collateral for loans. In partnership with Visa, Agrotoken has created a card accepted by 80 million shops and businesses associated with its tokenized grains program. The firm is effectively linking Argentine farmers and exporters who have surplus grains with a global business network.[56]

Paxos Trust

Paxos Trust Company is a financial institution specializing in blockchain infrastructure and payment systems. They are also the custodian for various crypto-related projects such as the stablecoin Pax Dollar (USDP) in addition to Pax Gold (PAXG). PAXG is available 24/7 to be settled, only available on the Ethereum blockchain, and comprises of around half of the tokenized gold market. One PAXG token equates to one fine Troy Ounce of gold and is redeemable for the underlying gold itself (allocated), gold entitlements/credit (unallocated), or can directly be sold for USD through Paxo's platform.[57] Physical redemptions can only be made for full bars of gold which ranges from 370 to 430 fine Troy Ounce. A holder cannot physically redeem one PAXG for one fine Troy Ounce of gold. When redemptions are made, PAXG are remapped to different gold bars. For example, if a redeemer has 430 PAXG, each of which are associated with 430 different gold bars, then they are entitled to a gold bar that may not be the exact ones their coins were originally mapped to.[58] Unallocated gold is similar to a bank deposit where holders are entitled to the gold stored by the custodian upon request but do not technically own the gold. This gold is also being invested and utilized in other ways by the custodian. To redeem for unallocated gold, a holder must have a Loco London bank account. Paxos Trust Company is also regulated by the New York State Department of Financial Services (NYDFS).

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[55]Engler (2023)

[56]Vassigh (2022)

[57]Paxos (2022)

[58]Cascarilla (2019)

TG Commodities Limited

TG Commodities Limited is the issuer of Tether Gold (XAUt) and is based in London. It is not legally the same entity as Hong Kong-based Tether Limited who issues the stablecoin Tether (USDT), but they would both be considered the same issuer Tether. One XAUt token equates to one fine Troy Ounce of gold and are redeemable for the underlying gold itself or for fiat currency after the underlying gold is sold in the off-chain, Swiss gold market. All XAUt tokens are backed by allocated gold and holders can search which specific gold bars are associated with their XAUt via Tether Gold's "Look-up Website."[59] Redemptions can only be made for full bars of gold which ranges from 385 to 415 fine Troy Ounce. For example, a holder cannot redeem one XAUt for one fine Troy Ounce of gold. When redemptions are made, XAUt are remapped to different gold bars. For example, if a redeemer has 430 XAUt, each of which are associated with 430 different gold bars, then they are entitled to a gold bar, but may not be the exact ones their coins were originally mapped to. After this redemption, the remaining XAUt supply is remapped to the current gold supply instantaneously.[60]

Toucan Protocol

Toucan Protocol allows users who own carbon credits in registries to tokenize their credits and users to purchase them. The tokenized carbon credits are called TCO2s which are programmed as NFTs and can be differentiated by the carbon credit's project and specifications by adding an additional name to it (i.e. TCO2-GS-0001-2019). Toucan also manages 2 pools: the Base Carbon Pool and the Nature Carbon Pool to enhance liquidity by pooling similar carbon credits together. The Nature Carbon pool only takes TCO2 tokens linked to nature-based projects (nature-based credit).

Toucan Protocol bridges its crypto-based registry to traditional carbon registries to tokenize carbon credits. Holders can retire TCO2 directly from the blockchain the TCO2 lives on (Celo or Polygon). Therefore, TCO2 are not redeemable since holders of TCO2 who would want to redeem for carbon credits are most likely aiming to retire them. If a holder wants to keep their carbon credits off-chain, they may open a standard registry account and transfer the credits there to retire. Pool tokens may be redeemed for the TCO2 tokens within the pool.[61]

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[59]See https://gold.tether.to/

[60]Tether (2022)

[61]For more details, please refer to Toucan's documentation, Toucan (2023)

Centrifuge

Centrifuge is an open DeFi protocol and marketplace for real-world asset pools. Owners of real-world assets act as originators and create pools of assets that are fully collateralized. The protocol is asset-class agnostic and has pools for assets across several categories such as mortgages, trade invoices, microlending, and consumer finance. Centrifuge integrates into other DeFi protocols. For example, it is the mechanism that hosts the RWA pools for MakerDAO.

The tokenization of real-world assets is carried out by asset originators, who set up the pools. Each pool is linked to a special purpose vehicle (SPV) that takes over legal ownership of assets from the asset originator in order to keep the assets in the pool bankruptcy remote and separate from the asset originator's business. The real-world assets are tokenized as NFTs and linked to off-chain data. Investors put stablecoins, typically DAI, into the pools. In return, they receive TIN and DROP tokens which represent junior and senior tranches of the pool, respectively. TIN and DROP tokens can be redeemed in regular intervals.[62] Returns to investors come from fees paid by the borrowers who obtain financing from the pools, and investors can also earn rewards in CFG tokens.

Goldfinch

Goldfinch is a decentralized credit protocol that facilitates crypto borrowing with loans fully collateralized off-chain. There are three main types of participants: Investors, Borrowers, and Auditors.[63] Investors can also become Members by supplying capital to a Goldfinch Membership Vault to support the protocol's growth.

Borrowers are off-chain lending businesses. They propose deal terms for credit lines, known as Borrower Pools, to the protocol. Investors supply capital to Pools either directly to individual Pools or indirectly through an automatic process that allocates capital across the protocol. Investors can redeem their token on specific dates, such as once per quarter.

Borrowers use their credit lines to draw down USDC from their Pool. They then exchange the USDC for fiat currency, which they lend out to end-borrowers in their local markets.

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[62]https://docs.centrifuge.io/learn/epoch/#the-investredeem-process
[63]Goldfinch (2021)

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