DECODING CBDC:

A PRACTICAL GUIDE TO A CBDC DESIGN AND IMPLEMENTATION

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Ripple is a leader in enterprise blockchain technology offering a comprehensive platform for minting, managing, transacting, and redeeming Central Bank Digital Currencies (CBDCs). **Ripple is currently engaged globally with Central Banks on CBDC projects. These projects include:**

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PART 2: ASSESSING THE CBDC PROVIDER LANDSCAPE

Introduction

According to the Atlantic Council's CBDC tracker, there are now 105 countries that are exploring central bank digital currencies (CBDCs) and around 50 countries that are in an advanced phase of digital currency exploration (development, pilot, or launch).[1] As central banks continue to go further in this space, they are increasingly looking for technology partners and vendors that can operationalize their unique design principles and adhere to established best practices for resiliency, performance, interoperability, sustainability, and more. In response to these developments, the number of CBDC technology partners, providers, vendors, and infrastructures in the space has increased. While this has led to greater choice for central banks, it has also made it less straightforward to assess and differentiate between the available options. And as the IMF and others have noted, it is even more challenging to do so as much of the technology is rapidly evolving and remains untested in a real-world environment.[2]

In our last white paper, we thought critically about the key core technology and design decisions for CBDC and considered some of the important features that central banks should ponder in their CBDC journey. The technology supporting CBDC involves multiple layers, from the core ledger technology at the back-end, to connectivity gateways at the middle layer, to user onboarding, KYC, and funding and withdrawal solutions at the front-end.[3] Choosing the right technology stack is key to successful CBDC implementation and is an important building block paving the way for wide-scale adoption. In this paper, we aim to analyze the CBDC vendor landscape and compare several DLT networks and full-stack solutions now available for use in CBDC pilots and implementation. In doing so, we hope to better inform central banks who must make difficult technology and design decisions in an ever-fluid market.

"There is a gap in the conversation between central bank decision makers and tech solution providers: while providers focus on what is possible under optimal conditions, central bankers worry about risk and adverse consequences. There is also a disparity in the level of the conversation: decision-makers think about requirements at a business, policy and regulatory level whereas providers describe their functionality at a technical level. The result is that it can be difficult to have the right conversations to match solutions with needs." – Jeff Stewart, independent CBDC expert (formerly of the Bank of Canada and Payments Canada)

[1] https://www.atlanticcouncil.org/cbdctracker/

[2] https://www.imf.org/en/Publications/fintech-notes/Issues/2022/02/07/Behind-the-Scenes-of-Central-Bank-Digital-Currency-512174

[3] https://www.bis.org/publ/othp42_system_design.pdf

Defining the CBDC provider landscape

It is helpful to first define the types of players active in the market for CBDC technology and the specific roles they are taking on, as it can be difficult to understand who is doing what and in which areas. Even with CBDC being so new, there are some players that are more established in the space than others, even if most have not been involved in live CBDC implementations. Some of the most experienced include R3, whose Corda network has been involved in several successful CBDC pilots and Proofs-of-Concept (POCs) globally, as well as Bitt, which has been the primary technology partner and solutions provider two live CBDC implementations.[4] Ripple is currently engaged globally with more than a dozen central banks, with pilots underway in Palau and Bhutan. Looking at the landscape holistically, the types of market players tend to fall into four groups, summarized below. Regardless of their specific role, CBDC partners and providers should be familiar with the entire payments value chain to be able to best support implementation.

Transaction networks/infrastructures – This refers to the specific infrastructure or network that is used for the core CBDC ledger. Although the core ledger need not be DLT-based, much of the CBDC exploration globally have involved the use of DLT-based networks. Examples include the Algorand network, Ethereum, Hedera Hashgraph, Hyperledger Besu, Fabric, and Iroha, R3's Corda platform, Ground X's Klatyn, Prosper Ledger, Ripple's CBDC Private Ledger, and the Stellar network. Cloud providers may also emerge in the space as CBDC infrastructure providers. Amazon Web Services (AWS), for example, has designed a reference architecture for central banks based on its existing product line of cloud-supported databases, products, and APIs.[5]

End-to-end solution providers – Such players offer full-stack infrastructure solutions covering all aspects of a central bank's technolology needs (e.g. core ledger, issuance, business applications, front-end software, etc.). Some providers have tailored their solutions specifically toward central banks (e.g. Bitt, EMTECH, G+D), while others work with a broader range of players on digital cash and stablecoin issuance (e.g. EMTECH, ConsenSys, ProsperUs, Ripple). The landscape for solution providers has become much more competitive over recent years, with an increasing number of players now active in the space, from digital asset networks, enterprise blockchain companies, fintechs, as well as legacy software and hardware companies. More and more are attempting to attract central banks by offering a whole host of other consultancy services and access to proprietary sandboxes to demonstrate thought leadership and expertise.

Technology partners - Many central banks have opted to hire vendors acting as third-party consultancy or technical partners responsible for driving the entire development process (from a project management perspective) from conception and platform design to testing and go-live. Examples include Accenture, which has worked closely with the Swedish Riksbank throughout its e-krona pilots, and IBM, which supported the central banks of Saudi Arabia and the UAE as part of the BIS' Project Aber.[6] [7] [8] Such companies do not necessarily offer their own technology stack, but rather work closely with the central bank to source the most appropriate technologies and solutions. Bringing in this type of vendor can bring in valuable third-party perspectives and project management resources, but it can also add greater complexity and cost to implementation efforts.

Research partners – Another type of partnership model is emerging among some of the advanced economy central banks, namely working with an academic institution or initiative to explore the various

[4] Bitt was the technology provider for the Eastern Caribbean Central Bank and the Central Bank of Nigeria's retail CBDC projects.

[5] "Central bank digital currency (part 2): Technology options and performance criteria," 2021. Amazon Web Services.

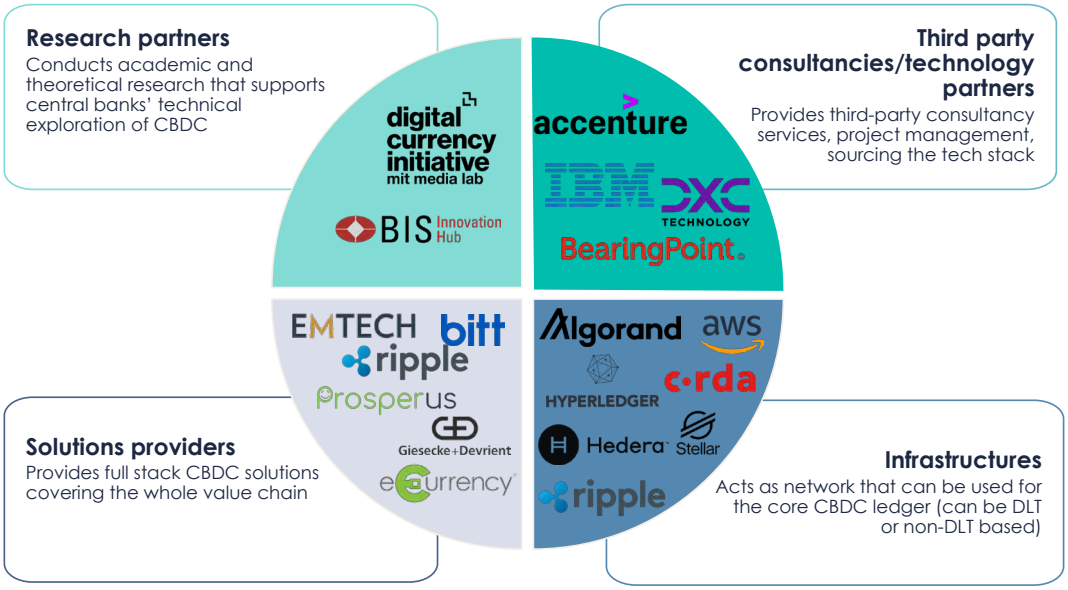
[6] https://www.riksbank.se/en-gb/payments--cash/e-krona/technical-solution-for-the-e-krona-pilot/

[7] https://www.cemla.org/fintech/docs/2020-Implementing-CBDC.pdfhttps://www.sama.gov.sa/en-US/News/Documents/Project_Aber_report-EN.pdf

[8] https://www.sama.gov.sa/en-US/News/Documents/Project_Aber_report-EN.pdf

technical challenges associated with CBDC issuance. For example, MIT's Digital Currency Initiative has worked with the Federal Reserve Bank of Boston for several years, and has recently formed partnerships with the Bank of Canada and Bank of England.[9]

CBDC technology solutions and infrastructure providers*



*These categories are not necessarily mutually exclusive, and vendors can act in different roles. For example, some protocols also offer their own solutions (Ripple), and some solutions providers also offer their own ledger or transaction network (ProsperUs).

Differentiating the current market offerings

With a better understanding of who is doing what in the market, we next aim to clarify and differentiate the various offerings. We begin with a comparison of DLT-based technologies that can be considered for CBDC.

Comparing DLT-based infrastructures in a CBDC context

There are many different DLT-based infrastructures available for use at present, and it can be difficult for many of them to articulate their key areas of differentiation in a CBDC context. Central banks may prefer working with networks that have already been live for at least several years or that have been previously used in successful CBDC pilots or implementations, given their proven production readiness as well as demonstrated ability to process tens of millions of transactions and billions of dollars in value. Examples of such networks and platforms include the Algorand, Hedera Hashgraph, Hyperledger Besu, Fabric, and Iroha, R3's Corda protocol, and Ripple's CBDC Private Ledger. Another key area of differentiation are the use cases for which the network is best suited. Indeed, wholesale and retail CBDC typically have drastically different requirements in terms of scalability, resiliency, and security. For example, wholesale CBDCs tend to support the existing central/corporate banking relationships and enable new efficiencies in those banking relationships. Retail CBDCs must be usable at scale by all citizens.

[9] https://dci.mit.edu/research/2022/3/31/mit-digital-currency-initiative-dci-announces-research-collaboration-with-the-bank-of-england-on-central-bank-digital-currency

The following table offers a comparison of how a select group of these different infrastructures compare across various characteristics, including the type of infrastructure, access, scalability and throughput, and their unique selling proposition. As noted, most have not yet been tested in real-world CBDC scenarios.

Comparison of select DLT networks available for use in CBDC pilots/implementation

	Algorand	Hedera Hashgraph	Hyperledger Fabric	Corda (R3)	(Ripple)	Stellar
Type of infrastructure[10]	Side chain of public Algorand Ledger	Application network on public ledger	Layer-2	Layer-1	Side chain of public XRP Ledger	Layer-1
Access	Private, permissioned	Private, permissioned or public	Private, permissioned	Private, permissioned	Private, permissioned	Public
Scalability	1,000 TPS - 3,000 TPS[11]	10,000 TPS[12]	3,000 TPS, possibly as high as 20,000 TPS[13]	200-300 TPS, assuming 4 Corda nodes[14]	10,000 + TPS dependent on network design/ topology[15]	1,000-10,000 TPS[16]
Unique selling proposition	Robustness	Speed to Settlement, Finality, Energy efficiency; governance[17]	Modularity	Enterprise-grade	Enterprise-grade with production experience; carbon neutral	Enhanced compliance capability
Notable partnerships	Marshall Islands	Haiti	Eastern Caribbean, Saudi Arabia and UAE (BIS Project Aber)	Kazakhstan, Sweden, various BIS projects	Bhutan, Palau	Ukraine

Comparing full-stack CBDC solutions

As CBDC exploration has become more ubiquitous among emerging market central banks, there has been a corresponding increased demand for end-to-end solutions that go far beyond providing just an infrastructure layer. A full-stack solution enables central banks to implement CBDC with a complete toolkit for managing CBDC across the entire value chain, whether for retail cases or wholesale cases. In addition to the core functionalities relating to issuance and redemptions, a full stack solution provides the modules and applications for the monitoring, administration, as well as an integration layer to interoperate with other systems and third-party applications. Many also include modules to support intermediary and end-user access. A key consideration for central banks is how modular and flexible the stack is; any end-to-end solution should be flexible enough to implement different design choices and to evolve as these choices change over time in accordance with a staged roadmap or implementation strategy.

[10] Layer-1 is a term used to describe the underlying main blockchain architecture. Layer-2 refers to an overlaying network or canvas that lies on top of the underlying network. Layer-2 networks aim to solve the scalability and sustainability issues that many Layer-1 infrastructures such as the Bitcoin network face.

[11] https://www.algorand.com/resources/blog/algorand-building-scalable-sustainable-blockchain-ecosystem

[12] Interview with Hedera

[13] https://www.sciencedirect.com/science/article/pii/S2405959521001399

[14] https://www.r3.com/blog/just-how-energy-efficient-is-your-blockchain/

[15] https://ripple.com/insights/ripple-pilots-a-private-ledger-for-central-banks-launching-cbdcs/

[16] https://openknowledge.worldbank.org/bitstream/handle/10986/36764/Central-Bank-Digital-Currencies-for-Cross-border-Payments-A-Review-of-Current-Experiments-and-Ideas.txt?sequence=2&isAllowed=y

[17] A 2021 research report by University College London found that Hedera Hashgraph was the most energy efficient blockchain compared to Algorand, Cardano, Ethereum 2.0, Polka Dot, and Tezos. See the following link for more information: https://hedera.com/ucl-blockchain-energy

In the following table, we analyzed how the different solutions compare to one other based on the types of features and functionalities offered. Looking across these solutions, several common features stand out. For one, all the solution providers claim interoperability with existing payment systems, and most claim interoperability with ISO 20022-based payment systems. Other common features include mobile wallet support, access to a testing environment, and support for programmable payments.

Example of a full-stack CBDC solution

Source: ProsperUs

In terms of differences, not all solution providers offer the flexibility to integrate with different infrastructures or types of infrastructures. Bitt and EMTECH claim to be able to integrate with any centralized ledger or blockchain network, for example, while other providers like ProsperUs and Ripple leverage their own infrastructure layer. Moreover, although most providers indicate that they provide some level of support for offline payments, there is a wide range of capabilities in this area, ranging from hardware-based solutions allowing for consecutive offline payments to DLT-based solutions that are trying to leverage non-internet-based servers. A similar point can be made with respect to the type of programmable payments that are supported (e.g. smart contracts, code chains, programming language used, etc.)

Comparison of full-stack CBDC infrastructure solutions

	Codefi Payments[18]	DCMS[19]	EMTECH CBDC[20] infrastructure	G+D Filia[21]	Prosper-Coin[22]	Ripple CBDC Platform[23]
Vendor	ConsenSys	Bitt	EMTECH	G+D	ProsperUs	Ripple
Type of ledger	DLT	Can integrate with centralized and DLT-based infrastructures	Can integrate with centralized and DLT-based infrastructures	Can integrate with centralized and DLT-based infrastructures	DLT	DLT

	Codefi Payments[18]	DCMS[19]	EMTECH CBDC[20] infrastructure	G+D Filia[21]	Prosper-Coin[22]	Ripple CBDC Platform[23]
DLT networks that can currently be used with the solution	Consensus Quorum or Hyperledger Besu	Any, in theory	Hedera Consensus Service	-	Prosper-Ledger	Permissioned side chain of XRPL
ISO 20022 interoperability	Yes	Yes	Yes	Yes	Yes	Yes
Programmable payments	Yes	Yes	Yes	Yes	Yes	Yes
Offline payments support[24]	No	Yes	Yes	Yes[25]	Yes	Yes
Mobile wallet support	Yes (MetaMask)	Yes	Yes	Yes	Yes	Yes
POS support	No	Yes	Yes	Yes	Yes	Yes
Testing sandbox	Yes	Yes	Yes	Yes	Yes	Yes
Partnership countries	Australia, Hong Kong, South Africa, South Korea, Thailand, etc.	Belize, Eastern Caribbean, Nigeria	Bahamas, Haiti	Brazil, Ghana, Thailand	France, Libya, Tunisia	Bhutan, Palau

Further considerations for sourcing CBDC technology stack

Outside of choosing the right technology partners and solutions, there are several other broader considerations that central banks should add to their evaluation checklist. These include whether/how to:

- Choose a single provide or multiple providers
- Build a unique bespoke solution or choosing a pre-packaged solution that can be customized
- Choose an on-premise solution or look for a managed service for operation
- Leverage open-source code or proprietary software

Takeaways from CBDC end-to-end solutions analysis

Common features	Areas of differentiation
• ISO 20022 interoperability • Mobile wallet support • POS support • Access to sandbox testing environments	• Specific infrastructure layer that can be used with the solution • Type of programmable payments supported • Offline payment capabilities • Number of past implementations • Experience running enterprise production payments network • Sustainability approach

[18] https://consensys.net/codefi/payments/

[19] https://www.bitt.com/product/dcms/central-banks

[20] Interview with EMTECH.

[21] https://www.gi-de.com/corporate/Payment/Central_Bank_Digital_Currencies/GD_brochure_filia.pdf. Also conducted an interview with G+D.

[22] Interview with ProsperUs.

[23] Interview with Ripple.

[24] Any kind of offline payment support resulted in a "Yes" in this column.

[25] Offline payments settle as soon as one-party is on the internet. Payments can also settle through non-internet servers.

For one, central banks must consider whether to work with a single provider of a "package" solution or to leverage internal development resources or work with multiple different vendors as needed.[26] Working with multiple vendors may be preferable for larger central banks who seek greater control over the development process and who have a greater ability to leverage internal resources (e.g. Canada, China, United States). For smaller central banks, however, working with a single provider may be preferable, as these institutions often have fewer in-house expertise and internal resources to manage multiple vendor relationships.[27]

A second consideration is whether it is beneficial to bring in or partner with a third-party consultancy that can drive the entire development process from conception and platform design to testing and go-live. As noted, such companies do not necessarily offer their own technology stack, but rather work closely with the central bank to source the most appropriate technologies and solutions. They may provide valuable third-party perspectives on technology but they can also add to the cost and complexity of a CBDC project.

An additional consideration for central banks involves the type of solution or solutions that can be sourced. There exists a spectrum of solutions on the market today from completely custom-built from scratch to fully production and turnkey. Whether to choose a turnkey solution or one that is custom-built will depend on time-to-market considerations as well as cost.

A final consideration is whether the vendor can offer a managed service for operation. Full business process outsourcing for national payments infrastructure has been a popular model for some time in both advanced and emerging markets. Notable examples include Vocalink's operation of Faster Payments in the UK and Worldline's operation of the real-time payment system in Aruba. A managed service for CBDC infrastructure and solutions could potentially be an attractive proposition for smaller central banks with a more limited ability to make the technical and operational investments required on-premises.

Conclusion

In this paper, we took a detailed look at the provider landscape for CBDC infrastructure and solutions, offering insights for central banks as they begin the process of sourcing CBDC technologies and solutions. That said, the space is rapidly evolving and our analysis represents only a snapshot of the features and functionalities of the available networks and solutions. The limitations or trade-offs of using of a particular network or solution that exist today may only be fleeting. Central banks must therefore be vigilant in terms of who is active in the market, how solutions are evolving, and which vendors best meet their needs.

[26] Ibid.

[27] It should be noted that a few advanced economy central banks such as the Bank of Canada, Federal Reserve and Bank of England have explored an alternative model for exploring back-end infrastructure options for CBDC through their collaboration and research partnerships with MIT's Digital Currency Initiative. https://dci.mit.edu/project-hamilton-building-a-hypothetical-cbdc

Appendix: List of CBDC solution, and infrastructure providers

Organization	Headquarters	Year founded	Area of focus in CBDC space	Notable partnerships
Accenture	Ireland	1989	End-to-end development support	BIS, Canada, France, Kazakhstan, Singapore, South Africa, Sweden, Switzerland
Algorand	USA	2017	Network provider	Marshall Islands
AWS	USA	2006	Cloud computing platforms and managed services	None identified
Bitt	Barbados	2013	End-to-end solution provider	Belize, Eastern Carribbean, Nigeria, Ukraine
Celo	USA	2017	Network provider, CBDC sandbox	-
ConsenSys	USA	2014	Building enterprise blockchain applications and infrastructure based on Ethereum, CBDC sandbox	Australia, BIS, Hong Kong, South Africa, South Korea, Thailand
eCurrency Mint	Ireland	2011	End-to-end solution provider; digital bearer instruments	Jamaica
EMTECH	USA	2019	End-to-end solution provider	Haiti
Fluency	UK	2019	End-to-end solution provider	-
G+D	Germany	1852	End-to-end solution provider	Brazil, Ghana, Thailand
Giori Digital	Switzerland	2012	End-to-end development support; solution provider	Uruguay
Ground X (Kakao)	South Korea	2018	Network provider	South Korea
Hedera	USA	2018	Network provider	-
IBM	USA	1911	End-to-end development support	BIS, France, Saudi Arabia, UAE
IDEMIA	France	2007	Offline payment solutions	-
Industria	Bulgaria	2002	End-to-end solution provider	-
M10	USA	2019	Network provider	-
Mastercard	USA	1966	CBDC sandbox, POS support	Bahamas
Nahmii	Norway	2018	Building enterprise blockchain applications and infrastructure based on Ethereum	Norway
NZIA	Bahamas	2019	End-to-end solution provider	Bahamas
Partior	Singapore		Network provider	Australia, BIS, Malaysia, Singapore, South Africa
ProgressSoft	Jordan	1989	End-to-end solution provider	-
ProsperUs	UK	2018	Network provider and end-to-end solution provider	France, Libya, Tunisia
R3	USA	2014	Network provider, CBDC sandbox	Kazakhstan, Sweden, various BIS projects (Dunbar, Helvetia, Jura)
Ripple	USA	2012	Network provider and end-to-end solution provider	Bhutan, Palau
Soramitsu	Japan	2016	End-to-end solution provider	Cambodia, Laos
Stellar	USA	2014	Network provider	Ukraine
Tezos	Luxembourg	2018	Network provider	-
Visa	USA	1958	CBDC sandbox, POS support, offline payments	-
WhisperCash	-	2019	Fully offline CBDC solution provider	-
Zynesis	Singapore	2011	Network builder and provider	Bahamas