BIS Innovation Hub

Project Mariana

Cross-border exchange of wholesale CBDCs using automated market-makers

Interim report, June 2023

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Publication date: June 2023

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Acronyms, abbreviations and definitions

AMM	Automated market-maker. For the purpose of Mariana, this is a decentralised exchange using a bonding curve and a liquidity pool to price and exchange tokenised assets (ie a constant function market-maker).
API	Application programming interface.
Bridge	A bridge enables the transfer of tokenised assets across different DLT networks.
Bonding curve	A bonding curve is a function determining the relative price of the assets traded through the AMM.
CFMM	Constant function market-maker.
CBDC	Central bank digital currency.
CHF	Swiss franc.
DeFi	Decentralised finance.
DLT	Distributed ledger technology.
EUR	Euro.
ERC	Ethereum request for comment. ERCs describe standards on Ethereum.
ERC-20	ERC-20 is a standard for fungible tokens.
FX	Foreign exchange.
FXGC	FX global code.
Liquidity pool	A liquidity pool is a smart contract with the ability to hold and transfer tokenised assets based on pre-defined logic.
LP token	A liquidity pool (LP) token represents the relative share of a deposit in the liquidity pool.
On-chain, off-chain	On-chain (off-chain) usually refers to data that are stored and processed on (or outside) a blockchain.
PoC	Proof of concept.
Relayer	A relayer is a communication protocol between different DLT networks.
RTGS system	Real-time gross settlement system.
SGD	Singapore dollar.
Slippage	Slippage is the difference between the current spot price and the realised price of a trade.
Smart contract	A smart contract is a program stored on a distributed ledger technology (DLT) that self-executes on the basis of pre-defined logic.
wCBDC	A wholesale CBDC (wCBDC) is a CBDC available to commercial banks and other financial institutions.

1. Introduction

Tokenisation may be on the horizon, with the potential to change the financial system. Today, the largest financial market in the world is the foreign exchange (FX) market (Chaboud et al (2023)), trading approximately $7.5 trillion a day (BIS (2022)). How might we trade and settle FX in a future tokenised world?

In the context of the G20's goal to improve cross-border payments, several projects have shown the feasibility of cross-border and FX transactions using wholesale central bank digital currency (wCBDC) arrangements and distributed ledger technology (DLT) platforms (Bech et al (2023), BISIH et al (2022b) and BISIH (forthcoming)).[1]

Project Mariana expands on these wCBDC experiments with the aim of improving the effectiveness, safety and transparency of FX trading and settlement. The project contributes to two key dimensions: first, it combines FX trading and settlement in cross-border transactions into a single instantaneous step using wCBDCs, as one possible mechanism for eliminating credit and settlement risk. Second, given the diversity of technological solutions used in emerging domestic CBDC arrangements, it tests cross-border interoperability through wCBDC mobility beyond domestic boundaries and with a uniform technical wCBDC standard. Interoperability may allow for flexibility in a future tokenised financial system in which central banks' autonomy is retained in the domestic context, while avoiding walled gardens. The project thereby offers one possible approach to future-proofing the various domestic and regional wCBDC arrangements now under development.

More specifically, Project Mariana expands on previous experimental work in three dimensions, borrowing from emerging decentralised finance (DeFi) technology.

First, the project explores joint trading and settlement in wCBDCs using a so-called automated market-maker (AMM), expanding on previous cross-border wCBDC projects that focused on settlement only (BISIH et al (2021), BISIH et al (2022a) and BISIH et al (2022b)). AMMs are smart contracts[2] that use liquidity pools to automatically exchange tokenised assets, as opposed to the traditional process of matching buyers and sellers, eg using limit order books.

Second, it tests a common standard for fungible wCBDC tokens, including design features based on central bank requirements. This uniform technical standard allows for (i) interoperability of the different wCBDCs within the same protocol, in particular the AMM; and (ii) the implementation of governance mechanisms at the token level without necessarily controlling the underlying platform or relying on a third party (ie a platform operator).

Third, Mariana investigates asset mobility between different blockchain-based networks using so-called bridges, expanding on previous projects that tested wCBDC

[1] Arrangements involving multiple CBDCs are commonly called multi-CBDC arrangements (Auer et al (2021)).

[2] A smart contract is a program stored on a DLT that self-executes upon pre-defined logic. A smart contract may (i) be a tokenised asset; (ii) hold and transfer tokenised assets; and (iii) interact with other smart contracts, among others.

settlement on a common platform. The bridges were designed to allow for the seamless and safe transfer of wCBDCs between networks with a combination of on-chain governance and robust and managed off-chain communication.

Project Mariana is a joint proof of concept (PoC) between the BIS Innovation Hub, Bank of France, Monetary Authority of Singapore and Swiss National Bank. The project is purely experimental and does not indicate that any of the involved central banks intend to issue CBDC or endorse DeFi or a particular technological solution.

This interim report describes the Mariana experimental setup in detail. Section 2 outlines the project and its objectives. Section 3 details the solution design. The final report, to be published later this year, will discuss project findings, central bank considerations and possible future areas of work.

2. Project overview

2.1 Scope and objectives

Today's FX markets are complex, involving a wide range of (i) actors (eg commercial banks, brokers, asset managers, corporates and central banks); (ii) instruments (eg spot, swaps and futures); (iii) activities (eg funding, hedging and proprietary trading); (iv) trading venues (eg primary venues, secondary electronic communication networks and multi-dealer platforms); and (v) settlement arrangements (eg correspondent banks and multicurrency settlement systems).

Project Mariana abstracts from most of these complexities, building an experimental setup focusing on FX spot trading and settlement using hypothetical euro (EUR), Swiss franc (CHF) and Singapore dollar (SGD) wCBDCs, commercial banks[3] and central banks. More specifically, it explores the feasibility of an international FX interbank market using wCBDCs on a blockchain-based network. This network is interlinked with domestic platforms using bridges to facilitate the wCBDC transfer.

Project Mariana is a PoC with three objectives: (i) to examine a wCBDC token design based on a uniform technical standard and incorporate governance features that meet central bank requirements; (ii) to design bridges for the seamless and safe wCBDC transfer between domestic platforms and an international network; and (iii) to develop an FX interbank market using an AMM. The feasibility focus of the PoC is complemented by operational and policy considerations, such as wCBDC governance aspects, as well as trade-offs associated with bridges and FX trading and settlement using an AMM.

A number of aspects are out of scope for Project Mariana, in particular AMM governance models (eg type and activities of operators), governance models for the domestic platforms, non-functional aspects (eg technical performance and privacy), linkages or integration with existing systems and processes (eg real-time gross settlement (RTGS) systems and remuneration of central bank money) and legal aspects (eg domestic platform and wCBDC legal status).

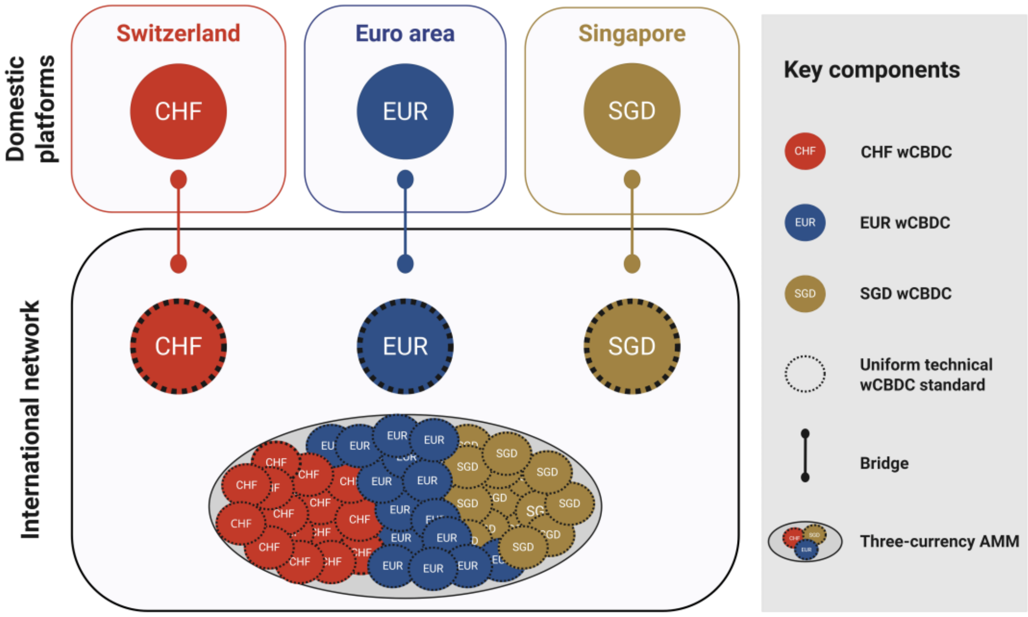
2.2 High-level architecture and use cases

The high-level architecture of Project Mariana consists of domestic platforms from Switzerland, the euro area and Singapore (Graph 1). It has three main elements: wCBDCs, bridges and the AMM. And it includes two types of actor, namely central banks and commercial banks.

3 This report refers to commercial banks for simplicity. Depending on the access policy by a central bank, access to wCBDC may include other financial institutions.

Central banks issue wCBDCs on their respective domestic platforms and determine access.[4] Each central bank operates and manages its jurisdiction's bridge (eg determining access).

Mariana high-level architecture Graph 1



Commercial banks with access to the respective domestic platform can transfer wCBDC to the international network (and vice versa). On the international network, commercial banks can use the wCBDC for transactions with the AMM and other banks. The AMM enables decentralised FX trading and settlement using wCBDCs.

Table 1 presents an overview of the two types of actor and their roles. With the given actors and roles, the project targets two main use cases:

1. FX transactions to facilitate cross-border payments (eg commercial banks acting on behalf of corporates or end-users making cross-border payments, and to facilitate global liquidity management).
2. Liquidity provision by commercial banks to facilitate FX transactions.

[4] Central banks may manage or operate the relevant domestic platform. Detailed governance considerations related to the domestic platforms are out of scope for this PoC.

Mariana high-level architecture — Table 1

	Commercial banks	Central banks
Roles	• Request wCBDC issuance and redemption on the respective domestic CBDC platform(s). • Transfer wCBDC between a domestic platform and the international network. • Provide (remove) liquidity to (from) the AMM in the international network. • Transfer wCBDC to other commercial banks within the international network. • Exchange wCBDCs via AMM in the international network.	• Manage issuance and redemption of wCBDC on the domestic platform. • Manage access to wCBDC on the domestic platform and the international network. • Manage and operate bridges; manage wCBDC transfer between the domestic platform and the international network.

2.3 Functional requirements

As part of the project scoping, functional requirements were developed for the three core components of the experimental architecture – the wCBDCs, the bridges and the AMM. The resulting requirements presented in Table 2 were informed by business and policy considerations through the engagement of key stakeholders, including central banks and industry participants.

wCBDC and bridge requirements are driven by basic central bank governance considerations, ensuring that (i) central banks can manage wCBDC issuance, access and transfer; and (ii) wCBDC on the domestic platform and the international network are always convertible one to one. AMM requirements promote a robust, fair, liquid, open and transparent FX market supported by resilient infrastructure, building on the relevant principles from the FX Global Code (FXGC).[5]

5 www.globalfxc.org/fx_global_code.htm.

Functional requirements Table 2

wCBDC requirements	(T1) Each central bank is the sole issuer of its wCBDC. (T2) Each central bank grants wCBDC access to selected commercial banks, with the ability to apply different eligibility criteria to the domestic platforms and to the international network. (T3) Each central bank may block specific or all commercial banks from receiving or transferring wCBDCs. (T4) Each central bank may retrieve wCBDC from blocked commercial banks. (T5) Each central bank may monitor transactions involving its wCBDC intraday.
Bridge requirements	(B1) Each bridge enables the transfer of wCBDC between the respective domestic platform and the international network. Each domestic platform is connected to the international network with one bridge. (B2) Each central bank manages access to the respective bridge and the transfer of wCBDC. (B3) Each central bank's balance sheet remains unaffected by the transfer of wCBDC between the respective domestic platform and the international network. (B4) wCBDCs on the respective domestic platforms and the network are fungible. Authorised commercial banks can convert wCBDC between the domestic platform and the international network 24/7.
AMM requirements	(A1) The AMM aims to provide a reference price for FX transactions. (A2) FX rates are transparent to all market participants (GXGC Principle 12). (A3) The mechanism determining the FX rate minimises the impact from large transactions (FXGC Principle 9). (A4) Access to the AMM is transparent to participating commercial banks (FXGC Principle 37). (A5) Disproportionate liquidity provision to the AMM is possible, ie commercial banks can provide and remove liquidity in just one currency. (A6) Liquidity providing commercial banks may query their current holdings in the liquidity pool at any time (FXGC Principles 27 and 31). (A7) The AMM does not incentivise undesirable trading practices (FXGC Principle 9).

3. Mariana solution design

The solution design describes the implementation of the architecture with related use cases, actors and roles (Section 2.2) in the context of the defined scope and objectives (Section 2.1) and requirements (Section 2.3).

For the purely explorative purposes of this PoC and to reduce the overall complexity of the implemented solution, the domestic platforms, as well as the international network, are based on Ethereum. Domestic platforms are permissioned versions of Ethereum (Hyperledger Besu or Quorum) and the international network is an Ethereum testnet (Sepolia).

3.1 wCBDC design

The design of wCBDC is based on best practices in the public blockchain space: (i) building on a uniform and widely used technical standard; (ii) allowing the implementation of governance features; and (iii) enabling upgradeability.

wCBDC uniform technical standard: the EUR, SGD and CHF wCBDCs are based on a uniform technical standard, specifically the so-called ERC-20.[6] This smart contract standard is widely used for fungible tokens on Ethereum and compatible blockchains. In Mariana, it enables (i) the use of the three currencies within the same protocol, in particular the AMM; and (ii) the implementation of central bank governance features.

Central bank governance features: central banks may implement dedicated governance features on their respective wCBDC, building on the ERC-20 standard. Specifically, this allows for on-chain management of the wCBDC. For Project Mariana, the following features were implemented based on the relevant requirements (Table 2):

- *Issuance and redemption of wCBDC* – each central bank can issue and redeem (often called "mint" and "burn") its own wCBDC (Requirement T1). In Mariana, the domestic platforms are used to issue and redeem wCBDC. wCBDC is issued directly into commercial bank accounts. To redeem wCBDC, commercial banks send wCBDC to the central bank account.
- *Control of access to wCBDC* – each central bank can control access to its wCBDC by maintaining lists of entities eligible to hold, transfer and receive wCBDC – "whitelists" – (Requirement T2). Mariana implements dedicated whitelists for each of the domestic platforms, bridges and the wCBDCs on the international network, allowing for differentiated access.
- *Recovery of wCBDC* – each central bank can retrieve wCBDC from blocked commercial banks, so-called wCBDC recovery (Requirement T4), eg because banks have been removed from the relevant whitelist due to sanctions

[6] ERC-20 is a smart contract and a technical standard for fungible tokens on Ethereum. Existing stablecoins are typically based on ERC-20.

(Requirement T3). The recovery of wCBDCs is an emergency/backup feature allowing central banks to control their wCBDC in circulation.

- *Ability to pause wCBDC transactions* – each central bank can pause transactions involving its wCBDC (Requirement T3). Pausing also prevents a central bank from issuing, redeeming and recovering its wCBDC, and updating the associated whitelists, among other functions.

wCBDC upgradeability: upgradeability of the wCBDC enables the central bank to change features and remove potential issues in the smart contract code without operational disruptions.[7] This precludes the need for central banks to collect and redeem outdated wCBDC and re-issue its updated equivalent.

3.2 Bridge design

The bridges implemented in Project Mariana enable wCBDC mobility between domestic platforms and the international network. They are managed and operated by the respective central bank and used by commercial banks to transfer wCBDC between a domestic platform and the international network.

Each bridge is implemented as a set of two smart contracts – one for the domestic platform (domestic bridge account) and one for the international network (international bridge account). So-called relayers enable communication between the two smart contracts, facilitating the transfer of wCBDCs between the bridge accounts. Specifically, for a wCBDC transfer from a domestic platform to the international network, the domestic bridge account takes wCBDCs into custody and emits a message that is processed by the relayer. After the successful processing, the international bridge account issues a corresponding amount of wCBDC. For the reverse transaction, the wCBDC is redeemed on the international network and released from custody on the respective domestic platform.

Central bank requirements guide the bridge design related to access (Requirement B1), control over wCBDC in circulation (Requirement B2) and availability (Requirement B3).

- *Access:* central banks manage the smart contracts, the relayers and access to the bridge. In Project Mariana, all commercial banks with wCBDC on the domestic network have access to the corresponding bridge.
- *Control over wCBDC:* the bridge mechanism ensures that no wCBDC is unintentionally issued or redeemed. In addition, it cannot transfer any asset other than the respective wCBDC.
- *Availability:* to support 24/7 availability and operational resilience, the bridge relies on multiple relayers and a consensus mechanism for transaction approval. In the Mariana PoC, each transaction requires the approval of two out of three

[7] The implementation uses a proxy pattern.

relayers.[8] In addition, relayers are unidirectional, ie they transmit information from the domestic bridge account to the international one (or vice versa).

3.3 AMM design

Project Mariana tested an AMM of the constant function market-maker (CFMM) type (Xu et al (2023)). A CFMM is a smart contract that holds tokens in a liquidity pool and acts as a counterparty for liquidity-taking trades (ie FX transactions). The prices for these trades are determined through a fixed pricing function, the bonding curve (Mohan (2022)).

The *liquidity pool* underpinning the AMM is designed as a three-token pool, made up of EUR, SGD and CHF wCBDC. It requires two distinct actors – liquidity providers and takers (see below). Combining all currencies in one pool increases the potential size of the pool and reduces fragmentation, increasing its chance of providing a reference price (Requirement A1).

The liquidity providers to the AMM are the commercial banks. They can deposit one, two or all three currencies, using liquidity from the pool for imbalanced deposits (Requirement A5). In return, they receive a token representing the relative share of their deposit in the pool (liquidity pool tokens or LP tokens). This share determines the compensation for their deposit, which is paid by liquidity takers through transaction fees. LP tokens also allow participants to track their holdings in the pool over time (Requirement A6).

Liquidity takers can trade currencies against the pool, facing transaction fees and so-called slippage. Transaction fees can vary depending on how balanced the pool is (ie how far away the pool is from an equal proportion of currencies). Slippage is the difference between the current spot price and the realised price of a trade. It is determined by the bonding curve and the amount of liquidity in the pool. The current spot price can be queried using an application programming interface (API) for the AMM smart contract (Requirement A2), which is an FXGC transparency requirement.

The *bonding curve* determines the price at which currencies are traded. CFMM can implement a wide range of bonding curves, and many different specifications have been proposed and used (Xu et al (2023)). For Project Mariana, a hybrid function market-maker (HFMM) was chosen, specifically Curve V2 (Egorov (2021)).[9] This HFMM combines the constant product bonding curve with a constant sum pricing mechanism, with two key characteristics. First, it keeps slippage around currently traded prices small, as the HFMM may adjust liquidity concentration around the current trading price (Requirement A3). This feature also limits profitability of undesirable trading practices like front running (Requirement A7). Second, it provides

[8] Three is the minimum number of relayers required to test the setup and related consensus mechanism. This approach could be generalised to any "*m* of *n*" strategy, where *m* is the number of approvals of *n* relayers.

[9] The selection of Curve V2 was solely for experimental purposes. It does not reflect any endorsement of the protocol or any of its products by any of the involved institutions.

options to control the cost for liquidity takers through the adjustment of parameters. The parameters of the bonding curve were calibrated using a data set of historical FX transactions in the three involved currencies, with the primary goal of gauging the pool size that is required to offer competitive transaction costs.

Participation in the AMM, both from liquidity providers and takers, can be queried through an API (Requirement A4).

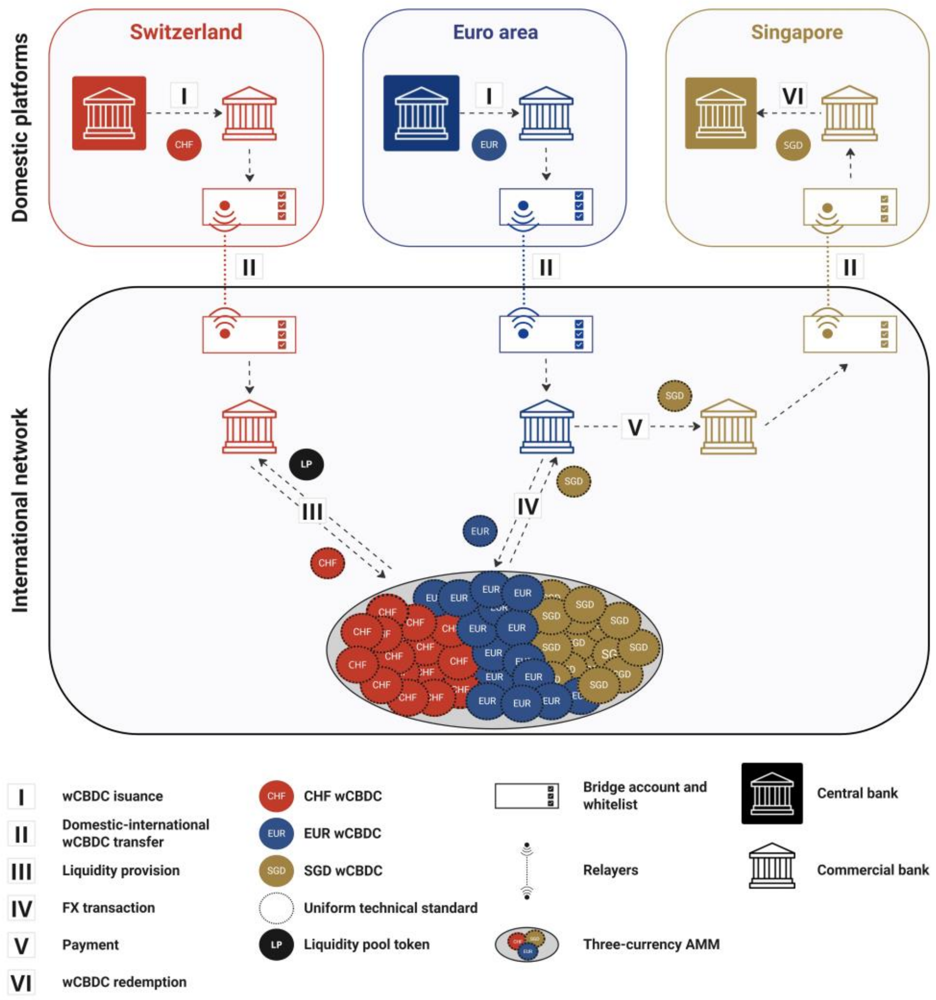
3.4 Overview with use cases

Based on the three core components, the overall solution design is presented in Graph 2. It shows (i) the three domestic platforms with their respective central banks; (ii) three commercial banks (one from each jurisdiction for illustrative purposes); (iii) the bridges, including the bridge accounts, the whitelists and the relayers; and (iv) the international network with the three-currency AMM. The commercial banks are represented on both the respective domestic platforms and the international network. All three commercial banks are whitelisted for their respective bridges (eg the Swiss commercial bank for the bridge between Switzerland's domestic platform and the international network). As a minimum requirement for the example shown in Graph 2, on the international network, the Swiss commercial bank has access to the CHF wCBDC, the euro area commercial bank to the EUR wCBDC and the SGD wCBDC, and the Singaporean commercial bank to the SGD wCBDC. Access to wCBDC is determined by the wCBDC whitelists managed by the respective central banks.

Use case 1 is an FX transaction to facilitate cross border payments. It is illustrated using the euro area commercial bank and the Singaporean commercial bank executing a cross-border payment from the euro area to Singapore. In a first step, the euro area commercial bank requests issuance of EUR wCBDC (process I). It then transfers the EUR wCBDC to the international network using the bridge (process II). On the international network, the euro area commercial bank (i) executes the FX transaction, paying EUR wCBDC to receive SGD wCBDC using the AMM (process IV); and (ii) pays SGD wCBDC to the Singaporean bank (process V). The Singaporean bank transfers the newly received SGD wCBDC to the Singaporean platform (process II). Finally, it redeems the wCBDC (process VI).

Use case 2 is a liquidity provision by commercial banks to facilitate FX transactions. It is illustrated using the Swiss commercial bank. The Swiss commercial bank requests issuance of CHF wCBDC on the domestic platform (process I). It then transfers the CHF wCBDC to the international network using the bridge (process II). On the international network, the Swiss commercial bank provides liquidity to the AMM, ie it pays CHF wCBDC to the AMM in return for a corresponding amount of LP tokens (process III).

Mariana solution design | Graph 2



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