Digital Architecture Department
Digital Architecture Concept
For: Open Innovation Challenges Pilot

Authors
Brezhnev Joya Miranda | Brezhnev.joya@ecopetrol.com.co
Walter Arroyo Caicedo | Walter.arroyo@ecopetrol.com.co

DS
BJM

Vice-presidency for Science, Technology and Innovation

July 2025

1. Context

This concept, issued by the Architecture team, aims to establish clear technical guidelines and premises that must be observed during the explanation, selection, and development phases of pilot solutions within the framework of open innovation challenges. These solutions, led by entrepreneurs and the innovation leadership, must align with the guidelines defined by the VTI Architecture team. It is essential to understand that a pilot is not a final solution, but rather a controlled stage of technical and functional validation, where a null hypothesis is tested against an alternative until sufficient evidence is obtained to justify its formal closure. Only then can its transfer to the VTI Project Solutions Management area be considered for industrialization. This transition involves meeting the minimum criteria for the delivery and assurance of the pilot solution. Within this framework, pilot solutions are expected to consider basic aspects from their design, such as: modular and scalable architecture, use of non-production data, integration outside the edge or level 3 application layer, the impracticality of integration with production systems or production data repositories, the predominant use of mirror or dummy data, compliance with cybersecurity standards, data traceability, monitoring, backup, failure recovery, and a basic operating model.

These considerations are essential to ensure that the solutions from Pilot to Industrialization evolve safely, sustainably, and in line with the digital strategy of ECOPETROL and its Business Group. The innovation challenges to be considered in this concept are the following:

- How could we determine in real time the particle diameter of suspended solids and/or heavy oils and/or hydrocarbons in injection water to make faster decisions aimed at mitigating the risk of well plugging?
- How could we capture suspended solids and precipitates in the fluid in industrial water transport pipelines so they can be removed from the system, thus reducing solid carryover and sediment buildup?
- How could we capture hydrogen sulfide (H2S) diluted in gas during the hydrocarbon extraction, collection, separation, and treatment stages to protect the integrity of the equipment and the health of the operators?

Also considered part of the Architecture concept is the input document issued by the Cybersecurity Architect to the Innovation team, a document titled (Digital Architecture Concept. Cybersecurity_ Requirements, Challenges, Open Innovation).

2. Proposed Architecture Concept

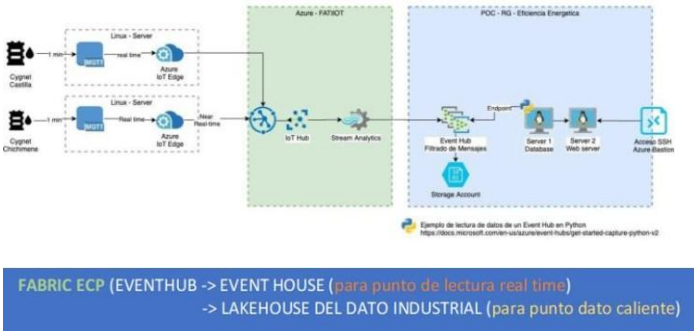
The CONTRACTOR must comply with the following technical requirements that must be considered in the deliverables described below:

Technical reports/progress reports and deliverables must be submitted in Spanish.

- Architecture diagrams/PPTs/Words must be submitted in an editable version in Draw.io or Visio.
- A digital file with the creation of the analytical model and its respective adjustment, which must generate the petrophysical and geological parameters that define the producing field of incidence and their concordance with those measured in the reservoir.
- A report with curves and tables showing the model's predictability of the historical curves for the problem to be solved and their cumulative results.
- Presentation of the model's predictions with all possible optimization scenarios generated, as well as the prioritization of the optimization actions that constitute the efficient frontier for the analyzed field area.
- Presentation of the recommendation plans generated in the form of a curve and table, associated cash flow, and prediction of the baseline and incremental scenarios for the proposed optimization actions, e.g., well/sand/pump/system/others.
- The following technical aspects, described in section 4.1 below, must also be considered and incorporated into the architecture.

4.1. TECHNICAL ASPECTS (Architecture)

The CONTRACTOR must present a diagram of the proposed solution architecture for this Pilot Project (following APA v7 standards with an illustration). For example, the following image shows the proposed solution architecture for the Pilot Project:



XXXXXXX Name od ARQ Diagram XXXXXXX
Illustration 1: Proposed architecture for the Pilot

- The CONTRACTOR must provide a description of the solution with the following:

Factory name	Name of the solution	Feature(s) it covers functionally	Type of architecture offered	Prioritized quality attributes
XXXX	XXXX	XXXX	XXXX	XXXX

- The CONTRACTOR may provide a SaaS-type solution in the Azure cloud (Microsoft). If the proposed solution is hosted in another cloud, it must detail the solution architecture, integration mechanism for data ingestion, and justify the cost-efficiency, performance, and/or technical quality attributes that accompany it.

- The CONTRACTOR must use authentication components for ECOPETROL users from the outset using the Microsoft Entra ID service (formerly Azure Active Directory).

- It must comply with SOC 2 Type II compliance and encrypt data at rest, in transit, and in use.

- Web and data exchange components must use modern and secure communication protocols such as HTTPS, TLS 1.3, MQTT, OPC UA, AMQP, among others.

- For the purposes of the Pilot test only, manual data transfer will be allowed using Excel, CSV, or other files to a secure blob storage account hosted in ECOPETROL's Azure data center. ECOPETROL will provide a finite SAS (shared access signature) token. These files/documents/JSON/objects/others will be consumed by the CONTRACTOR according to the timestamp and/or sampling agreed upon with the ECOPETROL functional team in the inception or sprint phase, batches, or time-based events defined in the design, for the analysis and prediction of the proposed analytical model.

- Definitions for testing the automation of data ingestion from its source must be jointly agreed upon by ECOPETROL and the CONTRACTOR, where the business and the CONTRACTOR, in mutual agreement on efforts and costs, analyze options to minimize and streamline development in this Pilot stage. The focus will be on evaluating the functionalities and expected results of the solution described in the objectives.

- If the Pilot is considered successful based on the functional definitions and business techniques established in If this document is not approved and there is a functional intention to industrialize the solution, this architecture will be repealed, and a new solution architecture must be defined that considers ECOPETROL's Target Enterprise Architecture guidelines for industrialization.

- The review and quality assurance of the data delivered based on operational limits (upper, lower), null, negative, empty, or similar, is the CONTRACTOR's responsibility. The CONTRACTOR must review and analyze that these data flows comply with data quality rules. This filtering and cleansing of outliers or anomalous values is the CONTRACTOR's responsibility as the CONTRACTOR's expert in the problem being solved in its proposal.

- If the CONTRACTOR's solution architecture for the Pilot offers the infrastructure deployment layer to be installed as PaaS/IaaS, this must be enabled in the Azure data center.

- ECOPETROL must safeguard business input and output data in a controlled and/or defined resource pool area for the Pilot/Sandbox, and not in official DEV/QA or PRD environments for industrialized solutions.

- If the CONTRACTOR offers a SaaS solution (Software as a Service licensing and consumption mode) in the solution architecture for the Pilot that meets all the functionalities required/requested by the business and complies with the technical requirements described in section 4.0, it must guarantee data ingestion from the data domain layer (OneLake or Blob) and the data delivery mechanism defined by ECOPETROL. Additionally, it must guarantee the return of the data resulting from the runs or output files in the data domain established by ECOPETROL in its OneLake.

- The solution implemented by the provider must comply with the non-functional requirements (NFR) established by ECOPETROL, such as (number of connected users, concurrency, data volume capacity processed, response times, among others).

- Upon completion of the first stage of the Pilot Program and delivery of a product satisfactory to ECOPETROL's functional business user, the CONTRACTOR must submit a table of the Licensing Scheme and Cost Lines or additional items

(quantity of equipment, systems, storage, increase in processing units, real-time instrumented data by package, volumes, number of users, universal readers, advanced users, specialized service lines for analytical patterns and/or recommendations for improvement in performance/efficiency/energy/others, and in general, whatever is applicable to its business model for the licensing of the proposed solution). This information is provided in order to project and establish a baseline for possible industrialization, without ECOPETROL being obligated to the execution of the proposal, costs, or execution of new Contract orders.

- ECOPETROL's use of Azure DevOps must be guaranteed to ensure and version the application's lifecycle, including documentation, data flows, data dictionaries, solution architecture diagrams in their various layers, source code in GIT repos if ECOPETROL's intellectual property applies, ARM pipeline, infrastructure deployment if applicable, as the deployment is in Ecopetrol's data center, and general information relevant to the solution of the Pilot and architectural documentation of the third-party obligations (whether IaaS or SaaS).

- It must be ensured that the delivery of data and storage of information for this Pilot's tool/solution once the Contract with the supplier is finalized are duly secured in an official ECOPETROL repository.

- The solution architecture proposal is adapted to bidders who deliver a SaaS-type architecture but is subject to data collection from secure repositories in ECOPETROL's Azure and not directly. Also, an architectural proposal within ECOPETROL's Azure infrastructure leverages Azure DevOps and Azure Active Directory to ensure authentication and asset lifecycle management. This facilitates seamless integration with ECOPETROL's existing systems and ensures that all critical data and operations are carried out in highly secure and centralized environments, aligned with the organization's cybersecurity standards, with a focus on infrastructure integration and corporate security.

- Given the nature of this pilot, the data provided by ECOPETROL must be controlled and simulated. It is preferable to use simulated data (dummies) rather than real data (liquid) to evaluate the methodology and analytical process before full implementation. Dummy data allows the system to be tested in a controlled and secure environment, identifying potential problems or improvements without affecting ECOPETROL's real volumetric data or compromising asset security. If the functional owners consider the use of real and/or production data, they must request approval from the functional owner of the business data and sign a confidentiality agreement (annexed to this document) between the interested parties.

- The CONTRACTOR must implement controls and procedures to ensure the secure deletion of ECOPETROL's information, as long as it is no longer required for the product or service provided. The secure deletion must be certified through a report delivered to the Contract Controller upon completion.

- The result of the Pilot does NOT constitute any obligation to industrialize the solution architecture for ECOPETROL S.A. This result, along with other criteria (including, but not limited to, the business case), may be considered during the decision-making process without any contractual obligation.

3. General Considerations

Technological solutions derived from open innovation challenges must be built within a rigorous technical framework that allows for the validation of value hypotheses without compromising the stability of the organization's digital ecosystem. In this sense, every pilot must be conceived as a controlled experimentation phase, assessing whether the null hypothesis (that the solution does not generate differential value) can be rejected with sufficient evidence in favor of an alternative hypothesis. This validation must be carried out before formally closing the pilot phase and transferring the solution to the VTI Project Solutions Management area for industrialization. Therefore, it is essential that the pilot consider the following from its design: enterprise architecture guidelines, secure network segmentation, data traceability, integration with existing systems, and compliance with industrial cybersecurity standards. It must also include monitoring, backup, and failover capabilities, as well as a basic operating model. If the Pilot meets or exceeds expectations and the corresponding approval for industrialization is granted, a basic deliverable must be provided that shows the Entrepreneur the path for

delivery to the digital operations area, explaining what must be done following the formal Transition to Service process, ensuring that the future solution is ready to operate in production environments with support, scalability, and sustainability. These considerations ensure that the pilots not only test ideas, but also enable viable solutions aligned with the digital strategy of Ecopetrol and its Business Group.

4. Conclusions

- Open innovation pilots should be conceived as controlled environments for technical and business validation, where the viability of an alternative hypothesis is tested against a null hypothesis.
- From an architectural perspective, it is essential to establish clear guidelines that ensure that each pilot, regardless of its digital, physical, or hybrid nature, meets criteria for comprehensive security, data traceability, interoperability, and scalability.

- Additionally, it is essential that every pilot consider, from its initial phase, not only technical and functional viability, but also the financial sustainability of its eventual industrialization. Many pilots begin without clarity about the OPEX costs associated with licensing, specialized services, or hidden components that emerge when scaling. Therefore, entrepreneurs should be required to conduct an early evaluation of these elements, including cost models, scalability scenarios, and contractual conditions. This comprehensive view allows for informed decisions, avoiding unexpected cost overruns, and ensuring that the proposed solutions can be operated sustainably in productive environment.

- Successful pilots should not be viewed as isolated innovation exercises, but rather as precursors to solutions that could be integrated into ECOPETROL's digital ecosystem. Therefore, it is the responsibility of the innovator and architect to ensure that, at the time of closing a pilot, there is a clear definition of the technical, operational, and financial requirements for its transition to the VTI Solutions Management area. This includes documentation of actual and projected costs, validation of compliance with cybersecurity, interoperability, support, and continuity guidelines, as well as preparation for the formal delivery process for Project Solutions. Only in this way can we ensure that innovation is not only viable, but also governable and aligned with the digital strategy of ECOPETROL and its Business Group.

- These types of initiatives not only enable innovative solutions but also strengthen the practice of Enterprise Architecture as a strategic discipline within Ecopetrol and the GE. Successfully executing pilots demonstrates the added value that segment, solution, and company architects deliver daily: in-depth business knowledge, mastery of digital technologies, and the ability to define sustainable solutions. Furthermore, these spaces should serve as bridges for relationships with the business areas, consolidating a collaborative network that facilitates synergy between local and corporate architectures and ensures that each solution built is aligned with ECOPETROL's long-term objectives.

5. Appendices

- Annex 1. Guide for Pilots at Ecopetrol.
- Annex 2. Sample template for Ecopetrol Pilot Technical/Functional Specifications (ETF).
- Annex 3. Guide to ATAM criteria to be selected and applied.
- Annex 4. Architecture presentation template.
- Annex ARQ-01_Solution Design Document.

6. Versions

Version	Date	Changes
V1	25/07/2025	Structuring the architecture concept with the minimum viable requirements, recommendations, and

		established definitions for open innovation challenges.

7. Authors

Name and surname	Register	Digital Signature
Brezhnev Joya Miranda	E0229352	Brezhnev Joya Miranda