Deliverable report 46

AI and IAGEN Application Use Case

Reservoir modeling for the creation of multiple realistic subsurface scenarios that capture the geological complexity of Vaca Muerta

I. Introduction

The oil and gas industry has undergone a significant transformation in recent decades, driven by the need to optimize production and improve profitability, especially in the exploitation of unconventional resources. Within this context, the Vaca Muerta formation, located in Argentina, has established itself as one of the largest shale gas and oil fields in the world.

This strategic relevance demands the adoption of cutting-edge technologies such as Generative Artificial Intelligence (GENA) to maximize the efficiency and sustainability of its operations.

Despite the growing focus on renewable energy, natural gas is projected to be a key transition fuel.

However, modeling unconventional reservoirs like Vaca Muerta presents inherent challenges due to their geological complexity. These reservoirs are characterized by low permeability. This complexity makes it difficult to develop a single, universally applicable reservoir model. Extremely low permeability necessitates the implementation of hydraulic fracturing, which generates intricate networks of induced fractures that interact with pre-existing natural fractures in ways that are not yet fully understood.

Traditional modeling techniques often have limitations in capturing the dynamic behavior of these reservoirs, particularly the complex interaction between hydraulic fractures and the shale rock matrix, as well as the long transient flow regimes that can extend over months or even years. Conventional reservoir engineering methodologies frequently assume boundary-dominated flow and well-characterized reservoirs, which is not applicable to unconventional reservoirs like Vaca Muerta, which can remain in transient flow for extended periods. The effectiveness of hydraulic fracturing, a mainstay of production, is difficult to accurately predict and model using conventional methods, impacting long-term production forecasts.

Generative Artificial Intelligence (GENI) is emerging as a technology with disruptive potential to address these limitations.

Generative Artificial Intelligence (GENI) is a branch of artificial intelligence that focuses on creating new content, such as models, images, code, or text, from existing data. This technology uses advanced algorithms to analyze large amounts of information, identify patterns, and generate new and original content that is often indistinguishable from human-created content.

Unlike traditional AI, which focuses on classification or prediction based on input data, IAGEN learns the underlying distribution of data and can generate new samples that plausibly fall within that distribution. In reservoir modeling, this means IAGEN can create multiple realistic subsurface scenarios, simulate complex geological features, and even generate synthetic seismic data, offering a powerful tool to complement limited real-world data and explore a wider range of possibilities.

By learning the intricate relationships within geological and production data, IAGEN can generate reservoir models that respect underlying geological concepts while being constrained by available measurements. This enables a more balanced approach between geological understanding and data-driven insights, potentially leading to more accurate predictions and improved decision-making compared to traditional, purely deterministic or overly simplified models.

The primary objective of this revised and expanded report is to provide a comprehensive analysis of AIGEN applications in reservoir modeling for the Vaca Muerta Formation. The report will cover the technical aspects of AI models, their application in *upstream* oil and gas operations (specifically exploration and production), economic and environmental implications, and strategic recommendations for the industry.

II . Limitations of Traditional Reservoir Modeling Techniques in Vaca Muerta

Conventional reservoir modeling methodologies, such as traditional numerical simulation techniques, rely heavily on detailed geological and petrophysical data, as well as significant computational resources to model large-scale reservoirs like Vaca Muerta. Building accurate numerical models of Vaca Muerta requires a detailed understanding of numerous parameters (reservoir, fluids, completion, hydraulic fracturing). The computational demands of simulating fluid flow through these complex and heterogeneous formations can be considerable, often requiring high-performance computing clusters and long simulation run times. Furthermore, the accuracy of these models is intrinsically linked to the quality and resolution of the input data, which can be limited and uncertain in unconventional environments.

On the other hand, empirical methods and decline curve analysis, although simple and based on historical production data, have limitations in capturing complex reservoir behavior, predicting long-term performance under changing operating conditions (such as choke management), and accounting for the impact of geological heterogeneity and well completion strategies . While decline curve analysis and empirical models can provide initial estimates of well performance, they often fail to capture the underlying physics of fluid flow in unconventional reservoirs. These methods struggle to account for factors such as well-well interference, the effectiveness of stimulation treatments, and the impact of geological variations across the vast Vaca Muerta area. Their predictive power is also limited when operating parameters or development strategies change significantly.

A significant limitation of traditional techniques lies in their inability to capture the complexity of fractures.

Traditional modeling approaches often represent these fractures as simplified planar features, failing to capture the true complexity of the induced fracture network, including branching, tortuosity, and interaction with natural fractures. This simplification can lead to significant discrepancies between model predictions and actual well performance. Furthermore, traditional models often struggle to accurately represent the interaction between hydraulic fractures and the natural fracture system, which can significantly impact reservoir permeability, fluid flow paths, and ultimately, well productivity.

Traditional models often fail to accurately represent this complex interaction, which can either enhance production by creating more extensive fracture networks or hinder it by generating complexity and fracture containment problems. Understanding and modeling this interaction is crucial for optimizing stimulation designs.

III . Advanced Applications of IAGEN in Reservoir Modeling

IAGEN, particularly through the use of Generative Adversarial Networks (GANs) and Variational Autoencoders (VAEs), offers a promising path to overcome the limitations of traditional reservoir modeling techniques at Vaca Muerta. GANs and VAEs can learn the complex spatial relationships and patterns present in geological data (e.g., training images of subsurface formations) and then generate new, realistic realizations of the reservoir that exhibit similar statistical properties and geological characteristics. This enables the creation of detailed models that go beyond the limitations of traditional geostatistical methods, which often rely on simpler assumptions about spatial continuity and variability. The ability to generate multiple high-resolution models also facilitates a more robust assessment of geological uncertainty.

IAGEN can also be used to simulate reservoir behavior (pressure, flow rates, fluid saturation) under various production scenarios, including different well completion and stimulation strategies (e.g., varying stage spacing, proppant volume, injection rates), and even to generate synthetic production data that can be used to train other AI models. IAGEN can be used to build proxy models, or surrogate simulators, that can quickly predict reservoir response to different production strategies. By training with data generated from detailed numerical simulations or historical production, these AI-driven simulators can provide fast and accurate forecasts, allowing engineers to efficiently explore a wide range of development scenarios and optimize production parameters without the computational cost of running full-scale numerical simulations for each scenario.

Furthermore, IAGEN is capable of generating conditional reservoir models that are consistent with observed well data (e.g., well logs, core data, pressure measurements), reducing uncertainty and improving prediction accuracy by focusing model generation on plausible subsurface scenarios. By conditioning the generative process on available well data, IAGEN can create reservoir models that are not only geologically realistic but also respect specific measurements taken at well locations. This integration of data constraints into the model generation process leads to a reduction in uncertainty associated with subsurface representation and ultimately results in more reliable predictions of reservoir performance far from wells.

Advanced seismic and geological data analysis is enhanced by the use of Convolutional Neural Networks (CNNs) and deep learning. CNNs excel at analyzing spatial data such as seismic images. By training CNNs with labeled seismic data (e.g., with identified faults, fractures, or facies), these models can learn to automatically recognize these features in new, unseen seismic volumes. This automation significantly speeds up the interpretation process, reduces the subjectivity associated with manual interpretation, and can reveal subtle geological details that human interpreters might miss, leading to a more accurate understanding of the reservoir's structural framework and property distribution. CNNs can also be used for automated seismic interpretation at Vaca Muerta, including the identification of subtle geological features such as thin layers beneath the seismic tuning, automated fault and fracture detection, and seismic facies classification to delineate areas with similar reservoir characteristics.

Other deep learning architectures, such as Recurrent Neural Networks (RNNs) and their variants such as LSTMs and GRUs, and Transformer models, are well-suited to analyzing sequential geological data such as well logs and core data to predict continuous reservoir properties (e.g., porosity, permeability, TOC) or classify lithofacies along the wellbore and even extrapolate these properties far from well locations. RNNs and Transformers are designed to process sequential data and can capture temporal (in the case of depth-recorded well logs) and spatial dependencies in geological datasets. By training these models on well log and core data, they can learn the relationships between different geological measurements and predict reservoir properties in missing data intervals or in areas between wells. Transformer models, with their attention mechanisms, are particularly effective at capturing long-range dependencies in these sequential datasets, potentially outperforming traditional RNNs on tasks such as 3D geological modeling from sparse data.

IAGEN also plays a crucial role in optimizing well placement and drilling strategies at Vaca Muerta. By integrating IAGEN-generated reservoir models with optimization algorithms, it is possible to explore a vast design space of potential well locations and drilling trajectories. AI can simulate production from these different scenarios, taking into account complex factors such as well interference and drainage patterns, and identify the well configurations most likely to maximize resource recovery and economic returns. This data-driven approach to well placement can significantly reduce the risk of drilling unproductive wells and optimize field development plans. Additionally, AI algorithms can optimize drilling parameters in real time during drilling operations at Vaca Muerta, improving rate of penetration (ROP), preventing drilling hazards, and reducing drilling costs by dynamically adjusting parameters such as flow rates, pressure, and bit configuration based on real-time sensor data and geological information.

Finally, IAGEN improves the petrophysical characterization of the Vaca Muerta reservoir by integrating diverse petrophysical data (well logs, core analysis, seismic attributes, production data, geochemical data) to create more accurate and complete reservoir characterizations. By training IAGEN models with large datasets of integrated petrophysical measurements, the complex nonlinear relationships between different types of data and reservoir properties can be learned. Once trained, these models can be used to predict petrophysical properties in areas where only limited data are available, or to generate more complete and consistent reservoir characterizations by resolving inconsistencies between different data sources. This integrated approach can lead to a more holistic and accurate understanding of reservoir properties and their spatial distribution. Additionally, AI can predict petrophysical properties (e.g., permeability, porosity, fluid saturations) at unsampled locations within Vaca Muerta, reducing the need for extensive and costly well drilling programs by providing reliable estimates of reservoir quality away from existing wells.

IV. AI Agents powered by IAGEN

1. **IAGEN Agents Concept**

In recent years, generative artificial intelligence (GAI) has revolutionized the way we interact with technology, enabling the development of systems capable of generating content, answering complex questions, and assisting with highly demanding cognitive tasks. From this capability, a new technological architecture has emerged: GAI-powered agents. These agents are not simple conversational interfaces, but autonomous systems that can interpret instructions, make decisions, execute tasks, and learn from their interactions with the environment.

An IAGen agent combines large language models with additional components such as external tools, memory, planning, and autonomous execution. This allows them to operate in complex environments, with the ability to break down objectives into steps, coordinate multiple actions, interact with digital systems (such as databases, APIs, or documents), and adapt to context changes in real time. These qualities distinguish them from traditional chatbots and open up a range of more sophisticated and customizable applications.

At the organizational level, these agents are being used to automate processes, generate data analysis, assist in decision-making, and improve the user experience, both internally and externally. For example, they can take on human resources, legal, financial, or logistics tasks, and even tasks linked to the technical areas of production processes, acting as intelligent assistants that collaborate with human teams. This ability to integrate knowledge and execute tasks autonomously transforms the way organizations can scale their operations without losing quality or control.

Furthermore, agentic workflows—structures where multiple agents collaborate to solve complex problems—allow responsibilities to be distributed among different agent profiles, each with specific functions. This creates hybrid work environments where humans and agents coexist, optimizing time, costs, and results. The ability to connect agents with tools such as Google Drive, CRMs, or document management platforms further expands their capabilities.

The development of IAGen-powered agents represents a crucial step toward a new era of intelligent automation.

Among the benefits of authentic workflows powered by generative AI models is the ability to automate entire production processes, end-to-end, and even add value by leveraging the capabilities of language models based on these technologies.

However, its implementation also poses technical, ethical, and legal challenges, ranging from responsible design to human oversight. Therefore, understanding its architecture, operational logic, and potential impacts is critical for its effective and safe adoption in diverse professional contexts.

2. IAGEN-driven agent design proposal for the activity

General Role:

Act as **a technical co-pilot** assisting geologists, reservoir engineers, and strategic decision-makers in:

- Generating realistic geological models with generative AI.
- Simulation of production scenarios.
- Well location optimization.
- Assessment of uncertainty and operational risk.
- Data-driven drilling and completion recommendations.

Agent Capabilities

Data ingestion and preparation

- Integration of seismic, petrophysical and production data.
- Cleaning, outlier detection, and standardization.
- Automatic conversion of sensor and log data to trainable formats.

Model generation with AI

- Using **GANs and VAEs** to create conditional geological realizations.
- Application of **CNNs** for automated seismic interpretation.
- Well log modeling with **Transformers** and **RNNs** for property prediction (TOC, porosity, etc.).

Scenario simulation

- Generation of proxy models trained with historical and synthetic data.
- Prediction of behavior under different completion schemes (spacing, proppant volume, etc.).

Optimization of strategies

- Massive evaluation of well configurations using **evolutionary algorithms and reinforcement learning** .
- Real-time drilling suggestions during operations (ROP, pressure, etc.).

Uncertainty and risk analysis

- Generation of multiple probabilistic subsurface scenarios.
- Sensitivity assessment and visualization of expected production ranges.

Generation of executive reports

- Automatic reports with visualizations, technical and economic KPIs.
- Justification of decisions and models used (explainable AI).

Proposed workflow summarized

1. **Initial input** : Subsurface data (seismic, logs, cores, production).

2. **Generative Modeling** : Realistic Scenarios Using IAGen.

3. **Simulation and analysis** : Predictions under different strategies.

4. **Optimization** : Search for optimal strategies.

5. **Decision making** : Suggestions with uncertainty and return analysis.

6. **Real-time monitoring** (optional): Operational adjustments based on continuous data.

How could it be implemented?

- **Platform** : Jupyter + Python backend (PyTorch, TensorFlow) + visualization (Plotly, Dash, Streamlit).

- **Data** : Integration with existing databases of operating companies, well sensors, .LAS, .SEGY files.

- **Interface** : Web or embedded in field planning software (Petrel, DecisionSpace).

V. Quantifiable and Strategic Benefits of IAGEN in Reservoir Modeling

The use of AIGEN in modeling unconventional reservoirs like Vaca Muerta has been shown to significantly improve the accuracy of production predictions. AI models are capable of learning complex, nonlinear relationships directly from large datasets, allowing them to capture the intricate factors that influence production more effectively than traditional methods, which often rely on simplified physical models.

IAGEN can also identify optimal production strategies to maximize the recovery factor and ultimate recovery at Vaca Muerta. By simulating a wide range of production scenarios and analyzing the resulting reservoir behavior, IAGEN can identify the optimal combination of operating parameters and recovery techniques that will lead to the highest possible ultimate recovery from Vaca Muerta.

The adoption of AIGEN at Vaca Muerta also presents considerable potential for reducing operating and exploration costs . AI-driven predictive maintenance can anticipate equipment failures, reducing unplanned downtime and maintenance costs. AI can also optimize drilling parameters to improve efficiency and reduce drilling time and costs. Furthermore, AI can analyze energy consumption patterns to identify areas for optimization, leading to lower energy costs. These cost reductions can significantly improve the economic viability of Vaca Muerta development. Furthermore, AI can improve the success rate of exploration activities at Vaca Muerta, reducing the number of dry holes and associated costs by more accurately identifying promising drilling locations based on the analysis of vast geological and geophysical datasets.

IAGEN also optimizes modeling and simulation time at Vaca Muerta by automating and accelerating reservoir modeling and simulation workflows. This enables faster turnaround times for subsurface studies and more agile decision-making in field development planning. Traditional reservoir modeling workflows often involve numerous manual and time-consuming steps, from data preparation and model building to simulation and analysis. IAGEN can automate many of these tasks, such as simulation syntax generation, model ensemble creation, and rapid results analysis, significantly reducing the time required for subsurface studies and enabling faster responses to business needs.

Finally, AIGEN improves decision-making and reduces uncertainty in Vaca Muerta. The detailed information and predictions provided by AI can help companies make better decisions about how to develop and manage the deposit. This can lead to more effective strategies, reduced risks, and, ultimately, greater success in resource extraction.

Table 1: Comparison of Traditional vs. IAGEN Reservoir Modeling Techniques

Feature	Traditional Techniques	IAGEN
Fracture Modeling	Geometric simplifications	Capturing complexity and networks
Nonlinear Flow	Difficulty representing	Greater modeling capacity
Uncertainty Quantification	Computationally intensive	Efficient generation of multiple realizations
Data Integration	Separate workflows	Integrated platforms
Computational Cost	High	Potential for efficient proxy models
Precision	Limited by assumptions	Greater accuracy with data learning

Table 2: Quantifiable Benefits of AI in the Oil and Gas Industry

Benefit Area	Improvement/Quantified Statistics

Production Forecast Accuracy	Increase in oil reserves from 8% to 20%
Drilling Cost Reduction	Potential reduction of $5 per barrel
Reducing Downtime	20% reduction in unplanned downtime
Increase in Resource Recovery	No general figure is specified
Reduction of Operating Costs	Potential 15% reduction in operating expenses
Gas Distribution Prediction Accuracy	R-squared value of up to 0.9731

VI . Challenges and Strategies for Implementing IAGEN in the Oil and Gas Industry

The successful implementation of AIGEN in reservoir modeling at Vaca Muerta depends largely on data quality and availability. The effectiveness of any AI application, including AIGEN for reservoir modeling, relies on the availability of sufficient, high-quality training data.

In the oil and gas sector, particularly for unconventional reservoirs like Vaca Muerta, data can be scarce and unevenly distributed. Challenges include accessing historical data, addressing missing and outlier values, integrating data from diverse sources (seismic surveys, well logs, production history), and ensuring that data is properly labeled and formatted for training AI models.

Addressing these data quality and availability issues is a fundamental requirement for the successful implementation of IAGEN. Furthermore, the persistent issue of data silos within oil and gas companies operating in Vaca Muerta and the urgent need for integrated data platforms and data governance strategies to facilitate seamless data sharing and accessibility for IAGEN applications are crucial.

Another significant challenge is the need for advanced computational infrastructure. Training deep learning models, which often underpin AIGEN, can be computationally intensive and time-consuming, requiring specialized hardware such as graphics processing units (GPUs) and significant processing power. For the complex geological structures and large datasets involved in Vaca Muerta modeling, access to adequate high-performance computing (HPC) resources or scalable cloud computing platforms is crucial to enable the development and deployment of effective AIGEN solutions within a reasonable timeframe.

The shortage of specialized talent represents another obstacle. Successful application of AIGEN in reservoir modeling requires professionals with a solid understanding of both the fundamental principles of petroleum engineering and geosciences and the technical capabilities of AI and machine learning. The current talent pool with this specific skill set is limited, necessitating investments in specialized training programs, collaborations with academic institutions, and upskilling initiatives for existing oil and gas professionals to close this gap and foster innovation in this field.

Resistance to change and the adoption of new technologies within the Vaca Muerta oil and gas industry, which has traditionally relied on well-established workflows and simulation tools, can also be a challenge. Overcoming inertia and encouraging the adoption of new technologies requires clearly demonstrating the tangible benefits of AIGEN in terms of increased accuracy, efficiency, and cost savings through successful pilot projects and case studies. Building confidence in the reliability and interpretability of AI-driven results (Explainable AI) and providing comprehensive training and ongoing support are also crucial to facilitating widespread adoption of AIGEN within the industry.

Finally, regulatory and compliance considerations related to the use of AI in critical decision-making processes within the oil and gas sector operating in Argentina must be considered, particularly regarding privacy, data security, and the potential for algorithmic bias. The oil and gas sector operates under strict regulatory frameworks related to safety, environmental protection, and resource management. The implementation of AI in areas such as reservoir modeling and production optimization must comply with these regulations. Data privacy and security considerations are also paramount, especially when dealing with sensitive subsurface and operational data. Furthermore, ensuring that AI algorithms are fair, unbiased, and transparent is crucial to avoid unintended negative consequences and maintain stakeholder trust.

To overcome these challenges, strategies are proposed such as investing in a robust data management infrastructure and talent development programs focused on interdisciplinary skills, fostering strong collaboration between domain experts and AI specialists to ensure that domain knowledge is effectively integrated into AI models, implementing well-defined pilot projects with clear objectives to demonstrate the value of AIGEN, and establishing clear guidelines and best practices for the ethical and responsible use of AI in reservoir modeling.

Recommendation Short-term investment in AI agent implementation teams in technology and training:

Investment in proofs of concept and pilot testing is required. The focus here must be on developing the talent needed to implement the solution, as there is a trend toward cost reduction in systems that enable "no-code" and "low-code" automation. For the first stage, it is also recommended to recruit teams with experience in the design and implementation of AI agents. Finally, it is key to form an in-house team to support and foster an agentic culture that redefines human-machine interaction.

VII . Conclusions and Strategic Recommendations

In summary, Generative Artificial Intelligence presents significant potential to revolutionize reservoir modeling in Vaca Muerta, overcoming the limitations of traditional techniques and offering substantial benefits in terms of accuracy, efficiency, cost reduction, and decision-making. However, its implementation entails challenges related to data quality and availability, the need for advanced computational infrastructure, a shortage of specialized talent, and resistance to change. It is crucial to consider both the positive economic implications and potential environmental challenges associated with the development and implementation of AI.

For oil and gas companies seeking to adopt AIGEN for reservoir modeling in Vaca Muerta, strategic investments in data management infrastructure and talent development programs focused on interdisciplinary skills are recommended. Fostering strong collaboration between domain experts and AI specialists is critical to ensuring that domain knowledge is effectively integrated into AI models. Prioritizing pilot projects with clear and measurable objectives to demonstrate the value of AIGEN and establishing robust ethical guidelines for its responsible use are essential steps. A phased approach to adoption is suggested, starting with specific applications and progressively scaling up as expertise and infrastructure develop.

For researchers, key areas for future research and development include improving the interpretability and explainability of complex AI models, developing AI techniques that can effectively handle data sparsity and uncertainty, exploring the integration of physics-based models with data-driven AI approaches for increased accuracy and reliability, and developing standardized benchmarks and validation metrics for IAGEN models in the oil and gas domain.

For decision-makers in Argentina, it is recommended to foster an environment that encourages innovation while ensuring privacy, data security, and environmental sustainability. Consider incentives for companies that invest in AI infrastructure and training, as well as regulations that promote transparency and the ethical use of AI technologies. It is also important to support research and development initiatives focused on sustainable AI practices within the energy sector.

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