HUB TECH IA

Deliverable report 40

AI and IAGEN Application Use Case

Report on Exploration, Reservoir Modeling, and Geological Data Analysis to Identify Shale Gas Areas

I. Introduction

1. The Strategic Importance of Vaca Muerta in the Argentine Energy Sector The Vaca Muerta field, located in the province of Neuquén , Argentina, represents one of the largest accumulations of unconventional hydrocarbons in the world. Its magnitude is such that it is projected as a fundamental pillar for Argentina's energy independence, with significant potential for revenue generation through exports and a substantial contribution to national economic development. Growing production at Vaca Muerta has already had a positive impact on the country's energy trade balance, marking the largest annual surplus in almost two decades. This field not only ensures a domestic supply of hydrocarbons, but also positions Argentina as a future relevant player in the global energy market.

In a global context where energy demand continues to rise and geopolitics can generate instability in traditional supply chains, Vaca Muerta stands as a strategic asset of increasing importance for Argentina, making the precision in the prediction of its reserves even more critical for optimal planning and management.

2. Challenges of Reserve Prediction in Unconventional Reservoirs Accurate prediction of hydrocarbon reserves in unconventional reservoirs such as

Vaca Muerta presents inherent challenges due to the complexity and heterogeneity of these geological formations.

Traditional static reserve estimation models, based primarily on historical data and simplified geological models, are insufficient to capture the dynamic behavior of these reservoirs and the influence of operational variations. The uncertainty surrounding the recoverable volume of gas and oil is considerable and subject to continuous change throughout the reservoir's life cycle, necessitating the adoption of more advanced and adaptive methodologies.

Conventional methods, developed largely for reservoirs with distinct characteristics, often fail to adequately model intricate fracture networks and the response to stimulation techniques such as hydraulic fracturing, underscoring the need for more sophisticated, data-driven approaches for reliable reserve estimation.

3 . The Transformative Potential of Generative Artificial Intelligence (GENAI)
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 [7]. This technology uses advanced algorithms to analyze large amounts of information, identify patterns, and generate new and original content that is often indistinguishable from that created by humans.

In this scenario of complexity and challenges, Generative Artificial Intelligence (IAGEN) emerges as an advanced solution with the potential to transform reserve prediction in Vaca Muerta.

Unlike traditional methods, IAGEN offers the ability to integrate multiple sources of geological, geophysical, production, and operational data, adjusting predictive models in real time as new information becomes available.

The core technologies that underpin IAGEN, such as Generative Neural Networks, Stochastic Simulations (Monte Carlo), Predictive Machine Learning Models, and Multivariate Optimization, enable the generation of more accurate scenarios and projections, addressing fluctuations in reservoir parameters and optimizing

operational decisions.

This ability to learn from vast data sets and generate dynamic representations of the subsurface offers a paradigm shift in the assessment of hydrocarbon potential, providing a more robust and accurate understanding of recoverable reserves in complex formations like Vaca Muerta.

II. Application of IAGEN in the Specific Activity of Reserve Prediction in Vaca Muerta

1. Detailed Description of the Use Case: Dynamic Gas Reserve Prediction
Reserve prediction in Vaca Muerta is an intrinsically complex task that requires the exhaustive analysis of a variety of data, including seismic, geological, geophysical and petrophysical information.

Traditionally, these data have been analyzed using static mathematical models that estimate the recoverable volume of gas based on fixed parameters and simplified assumptions.

However, these models often lack the flexibility to accommodate the intricate dynamics of reservoir behavior and operational variations that influence production.

In contrast, IAGEN offers a more versatile and accurate approach by employing generative algorithms capable of processing large volumes of data in real time. This capability for continuous analysis and dynamic adaptation is essential for obtaining a more precise understanding of reserve potential throughout the reservoir's lifecycle.

2. Specific Technologies and Models Used in IAGEN (Technical Development):

- **Generative Neural Networks (GNNs):**
  Generative Neural Networks (GNNs) are a core component of IAGEN, providing the ability to identify complex, nonlinear patterns in the seismic and geological data collected at Vaca Muerta. These networks, which include architectures such as Variational Autoencoders (VAEs) and Generative Adversarial Networks (GANs), can learn the underlying distributions in the data and generate more

accurate predictive models of reservoir behavior.

This ability of GNNs to capture the intricate spatial and nonlinear relationships within geological and seismic data enables the creation of more detailed and adaptive predictive models for reserve forecasting in Vaca Muerta, overcoming the limitations of traditional statistical methods that often assume simpler relationships.

- **Stochastic Simulations (Monte Carlo):** Stochastic simulations, such as Monte Carlo simulations, play a crucial role in IAGEN by enabling the modeling of the uncertainty inherent in key Vaca Muerta reservoir parameters such as porosity, permeability, and fluid saturation.

  By generating multiple prediction scenarios, each based on different random samples of the probability distributions of these parameters, a more complete view of the range of possible outcomes in oil and gas extraction is obtained, along with the probabilities associated with each scenario. This probabilistic approach is especially valuable in unconventional reservoirs, where geological uncertainty and variations in subsurface properties are significant.

  By quantifying this uncertainty, Monte Carlo simulations facilitate better risk assessment and more robust decision-making in resource development planning in Vaca Muerta.

- **Machine Learning (ML) Predictive Models:** Machine Learning (ML) predictive models are another core technology within IAGEN, employing algorithms such as Deep Neural Networks, Random Forests, and Gradient Boosting to analyze historical drilling, production, and reservoir characteristics patterns at Vaca Muerta.

  These models learn from data and adjust their predictions based on current conditions, thereby optimizing the exploitation strategy. For example, Multilayer Perceptron (MLP) type Artificial Neural Networks (ANNs) have been used for the accurate estimation of porosity and clay volume in hydrocarbon reservoirs .

Furthermore, ensemble ML models that consider historical production data, geolocation and completion parameters have been developed to predict the productive behavior of oil and gas wells, outperforming traditional forecasting techniques, especially in wells with short production histories .

The ability of these models to identify complex relationships and adapt to changing reservoir conditions makes them powerful tools for predicting reserves in Vaca Muerta.

- **Multivariate Optimization:**
  Multivariate optimization is a key component of IAGEN, enabling the automatic adjustment of operating parameters in Vaca Muerta, such as well pressure, injection rate, and hydraulic fracturing strategy, with the goal of maximizing gas recovery and reducing operating costs.

  By using optimization algorithms, IAGEN can explore the complex exploitation parameter space and identify the optimal conditions that lead to the highest efficiency in hydrocarbon extraction .

  This ability to dynamically adjust operating parameters based on predictive models and stochastic simulations enables more efficient and cost-effective resource management at the Vaca Muerta field.

III. AI Agents and Agentic Workflows. The Evolution of Generative AI.

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. **Proposal of Agents promoted by IAGEN for the activity**

The IAGEN implementation follows a structured and optimized agent flow to maximize performance in reserve prediction. The agent flow phases are detailed below:

Phase 1: Data Collection and Preparation

- Agents collect seismic, drilling, production, and geological data from a variety of sources. The data is cleaned and preprocessed for use in AI models.

Phase 2: Generative Modeling and Simulation

- Agents feed preprocessed data into generative neural networks to create multiple reserve prediction models, with variability in parameters to reflect reservoir uncertainty.

Phase 3: Extraction Strategy Optimization

- Agents analyze the generated models and use multivariate optimization techniques to adjust extraction parameters, such as injection rate or well pressure.

Phase 4: Validation and Continuous Adjustment

- As actual operational data is collected, agents continuously adjust predictions and optimize operating strategies based on the results.

Phase 5: Strategic Decision Making

- The results generated are presented to decision-makers so they can implement changes in operational strategy and maximize gas recovery.

Concrete Hypothetical Example: A typical scenario could involve a well where IAGEN agents predict that, with an adjustment in hydraulic fracturing and gas injection rate, production will increase by 18% without the need to drill new wells, implying significant savings in operating costs and an increase in profitability.

IV. Direct Benefits of IAGEN in Reserve Prediction (Expansion and Quantification)

1. Greater Accuracy and Reliability

IAGEN models allow for reserve estimates in Vaca Muerta with significantly greater accuracy and reliability compared to traditional methods.

The ability of generative neural networks to identify complex nonlinear patterns in seismic and geological data, together with uncertainty modeling using stochastic simulations, leads to more accurate predictions and a significant reduction in uncertainty.

This increased accuracy and reliability in reserve forecasting provides a more solid basis for strategic and operational decision-making at Vaca Muerta.

2. Cost and Operations Optimization

By generating more accurate scenarios and optimizing extraction strategies, IAGEN can significantly reduce operating costs at Vaca Muerta. Predictive models help avoid unnecessary drilling in low-potential areas and optimize the use of existing infrastructure, resulting in a direct reduction in operating expenses.

Additionally, IAGEN's ability to predict potential equipment failures through AI-driven predictive maintenance can minimize unplanned downtime and the costs associated with major repairs. This cost and operational optimization improves the overall profitability of hydrocarbon extraction in Vaca Muerta.

3. Real-Time Dynamic Simulations and Projections

Unlike traditional methods, IAGEN enables predictions to be generated and models to be adjusted in real-time at Vaca Muerta, facilitating rapid adaptation to any operational or geological changes that may arise. This ability to generate dynamic simulations and projections provides a significant advantage in the management of unconventional reservoirs, where conditions can vary considerably over time. The ability to update predictions with new information in real-time allows operators to make more informed decisions and proactively adjust their exploitation strategies, maximizing resource recovery and optimizing operational efficiency at Vaca Muerta.

4. Improved Strategic Decision-Making

The models generated by IAGEN provide executives and decision-makers in Vaca Muerta with detailed and clear data, facilitating the choice of strategies based on real-world and concrete scenarios. IAGEN’s ability to forecast production rates, identify optimal exploration sites, and anticipate market trends provides a comprehensive view that supports long-term planning and investment decisions. This improved strategic decision-making, based on advanced analysis and accurate predictions, is fundamental to the efficient and profitable development of hydrocarbon resources in Vaca Muerta.

V. Concrete Opportunities and Benefits in Vaca Muerta

1. Improved Operational Efficiency

The implementation of IAGEN at Vaca Muerta optimizes decisions related to drilling and extraction, ensuring that resources are utilized more efficiently.

By more accurately predicting the most profitable areas, efforts can be concentrated on areas with greater potential, avoiding unnecessary expenses in less productive

areas.

Artificial intelligence also has the ability to optimize drilling operations by processing data in real time, improving speed, accuracy, and safety, which in turn reduces nonproductive time and increases overall efficiency. This focus on productivity and process optimization leads to a significant improvement in operational efficiency in the Vaca Muerta development.

2. Reduction of Operating Costs

The predictive models generated by IAGEN contribute to the reduction of operating costs in Vaca Muerta by helping to avoid unnecessary well drilling and by optimizing the use of existing infrastructure.

Additionally, the AI-powered predictive maintenance application allows for anticipating equipment failures, reducing unplanned downtime and the costs associated with major repairs.

Artificial intelligence is estimated to have the potential to significantly reduce production costs in the oil and gas industry. This optimization of resources and the prevention of operational issues translate into a considerable reduction in operating costs in the context of the Vaca Muerta exploration.

3. Better Risk Control and Mitigation

With more accurate predictions, the risks associated with incorrect decisions in the exploitation of Vaca Muerta, such as the overexploitation of resources or the construction of unnecessary infrastructure, can be minimized.

Artificial intelligence also plays a crucial role in identifying potential safety risks, such as gas leaks or equipment failures, enabling the implementation of preventive measures to avoid accidents and environmental incidents.

AI's ability to assess risks in real time and improve risk forecasting contributes to a safer and more sustainable operating environment at Vaca Muerta.

4. Comparison with Traditional Methods (Quantitative Analysis)

While conventional reserve prediction methods in Vaca Muerta are based on static

techniques and often assume a high degree of uncertainty, IAGEN allows models to be adjusted as more data is collected, providing more reliable results and reducing the need for costly corrective interventions. The following table illustrates a comparison between traditional methods and IAGEN in reserve prediction:

Table 1: Comparison of Traditional Methods vs. IAGEN for Reserve Prediction

Feature	Traditional Methods	IAGEN
Data Entry	Mainly historical data, basic geological models	Multiple data sources (seismic, geological, production, operational)
Model Type	Static, deterministic	Dynamic, probabilistic
Adaptability	Limited, requires manual updates	High, adjust models in real time with new data
Precision	Generally lower, high uncertainty	Major, reduces uncertainty
Cost	Potentially lower initial costs, but higher corrective costs	Initial investment in technology and talent, but lower long-term operating costs

Risk assessment	Limited to basic sensitivity analysis	Quantifying uncertainty through stochastic simulations
Dynamic Prediction	Not implemented	Generate projections and adjust models in real time

Table 2: Potential Benefits of IAGEN Implementation in Vaca Muerta

Benefit Area	Description	Potential Impact/Quantifiable Metrics
Operational Efficiency	Optimizing drilling and extraction, focusing on high-potential areas	Increased production per well, reduced non-productive time
Cost Reduction	Avoid unnecessary drilling, optimize infrastructure use,	Production costs reduced by up to $5 per barrel, downtime reduced

	predictive maintenance	by 20%.
Risk Control	More accurate predictions, earlier hazard identification	Minimizing accidents, reducing environmental impact
Decision making	Detailed and clear data for strategic planning	More informed investment decisions, better long-term planning

VI . Challenges and Strategies to Overcome Them in the Argentine Context

1. Technical Implementation Challenges

Integrating IAGEN with existing monitoring and control systems at Vaca Muerta can be complex due to the multitude of variables and changing reservoir conditions. A key challenge lies in the need to establish a robust data infrastructure in Argentina that guarantees information standardization across different operators, data quality and integrity, and the capacity to securely store and process large volumes of information. The heterogeneity of legacy systems and the lack of interoperable platforms can hinder the data flow essential for IAGEN analysis. Strategy: A phased implementation of IAGEN at Vaca Muerta is proposed, starting with specific pilot projects and scaling adoption based on demonstrated results. Investing in a modern and scalable data infrastructure capable of handling the magnitude and velocity of the information required by IAGEN is crucial. The formation of multidisciplinary teams is recommended, including both AI experts with experience in the energy sector and petroleum engineers with in-depth knowledge of the unique characteristics of Vaca Muerta.

2. Regulatory and Cultural Barriers in Argentina

The adoption of new technologies such as AIGEN in the Argentine oil industry may

encounter obstacles in local legislation, such as data privacy regulations or a lack of specific guidelines for implementing AI in the energy sector. Likewise, there may be resistance to change from employees and managers accustomed to traditional reserve prediction methods. It is important to address concerns about data privacy, algorithmic bias, and the ethical implications of using AI in critical infrastructure such as the energy sector.
Strategy: Proactive collaboration with Argentine regulatory bodies and energy sector associations is recommended to develop clear and favorable guidelines for implementing AI in hydrocarbon reserve prediction in Vaca Muerta. It is essential to conduct awareness campaigns and training programs at the corporate level to educate employees and managers on the benefits and value of AIGEN, addressing their concerns and fostering a culture of innovation and data-driven decision-making. Transparency in the operation of IAGEN models and the validation of their results by subject matter experts should be emphasized to build trust and overcome resistance to change.

3. Considerations on Technological Infrastructure in Argentina:
The availability and quality of technological infrastructure in Argentina, including the computing power required to train and run complex IAGEN models, the capacity and reliability of data centers to store and process large datasets, and the speed and accessibility of internet connectivity, especially in remote areas of Neuquén where Vaca Muerta is located, are important considerations. There may be limitations in the current infrastructure that require strategic investments to support the widespread implementation of IAGEN in the Argentine energy sector.
Strategy: The establishment of strategic public-private partnerships is advocated to invest in the improvement and expansion of the necessary technological infrastructure in Argentina, including data centers, high-speed internet connectivity, and cloud computing resources, to meet the demands of IAGEN. The feasibility of implementing edge computing solutions near the wells in Vaca Muerta should be explored to reduce latency and processing demands on the centralized infrastructure.

4. Talent Development and Training:
There is a potential skills gap in Argentina within the specialized fields of AI, machine learning, data science, and their application to the oil and gas industry, which could hinder the development, implementation, and maintenance of AI solutions. It is critical to invest in training programs and educational initiatives to develop the necessary expertise within the Argentine workforce.
Strategy: A multifaceted approach to talent development is recommended, including investing in university programs focused on AI and petroleum engineering, establishing industry-led training workshops and certifications in AI for oil and gas applications, and fostering collaborations with international experts and institutions to transfer knowledge and best practices. Energy companies should be encouraged to establish internal AI research and development teams and provide continuous learning and upskilling opportunities for their existing workforce.

VII . The Future of Reserve Prediction with IAGEN in Vaca Muerta

1. Emerging Trends in AI for Hydrocarbon Exploration and Production:
The future of hydrocarbon exploration and production is increasingly intertwined with advancements in artificial intelligence. Emerging trends include the growing adoption of AI-driven autonomous operations for drilling and production, increased human-machine collaboration through intelligent assistants, expanding remote monitoring and control capabilities, and the integration of AI into robotic systems for inspection and maintenance. Generative AI is playing a crucial role in creating realistic reservoir models, optimizing drilling trajectories and completion designs, and improving oil recovery techniques in unconventional reservoirs. Furthermore, AI is having a significant impact on reducing greenhouse gas emissions, optimizing energy consumption, and promoting overall sustainability in oil and gas operations.

2. IAGEN's Specific Potential for Sustainability in Vaca Muerta:
IAGEN has the potential to contribute to a more sustainable hydrocarbon extraction in Vaca Muerta by optimizing resource utilization through accurate reserve prediction, minimizing waste by improving drilling accuracy and production

efficiency, and reducing environmental impact by optimizing energy consumption and potentially assisting in the detection and mitigation of leaks and emissions. Artificial intelligence also plays an important role in emissions monitoring and reduction, which could enable more efficient carbon capture and storage strategies in the context of Vaca Muerta production.

3. Strategic Recommendations for the Adoption and Development of IAGEN in Argentina:

To facilitate the adoption and development of IAGEN for reserve prediction in Vaca Muerta, the following strategic recommendations are proposed for the Argentine energy sector:

- Establish national research and development initiatives with dedicated funding to explore and adapt AI technologies, particularly IAGEN, to the unique geological characteristics of Vaca Muerta.
- Foster strong collaborations between Argentine energy companies, local technology providers, and academic institutions to drive innovation and knowledge sharing in the implementation of IAGEN.
- Develop pilot projects in selected areas of Vaca Muerta to evaluate the effectiveness and economic viability of different IAGEN models and workflows under real-world operating conditions.
- Create a supportive and forward-looking regulatory framework that fosters innovation and the responsible deployment of AI in the energy sector, addressing data privacy, security, and ethical considerations.
- Invest in comprehensive education and training programs at universities and vocational schools to build a skilled Argentine workforce with expertise in AI, data science, and petroleum engineering, specifically tailored to the needs of the energy industry.
- Promote the development of standardized data platforms and protocols within the Argentine energy sector to ensure data quality, interoperability, and accessibility for AI applications such as IAGEN.

VIII . Conclusion

The analysis presented in this expanded report underscores the transformative potential of Generative Artificial Intelligence (GENA) to revolutionize hydrocarbon reserve prediction in the Vaca Muerta field. GENA's ability to integrate large volumes of complex data, generate dynamic models, and provide probabilistic simulations offers significant improvements in accuracy, efficiency, and reliability compared to traditional methods. This technology not only promises to optimize operations and reduce costs but also opens new avenues toward more sustainable exploitation of Argentina's energy resources. The strategic adoption and development of GENA in Vaca Muerta is critical to strengthening the country's energy independence, driving economic growth through increased production and exports, and moving toward a more sustainable energy future. Artificial intelligence, and GENA in particular, will play a pivotal role in shaping the future of hydrocarbon exploration and production in Argentina, positioning it as a leader in the global energy landscape through innovation and technological advancement.

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