Deliverable report 8

AI and IAGEN Application Use Case

Water and Energy Optimization in Fracking – Vaca Muerta, Neuquén

I. Introduction

Vaca Muerta has established itself as one of the main shale oil deposits and Argentine gas, characterized by intensive hydraulic fracturing operations. This technique, which requires the injection of large volumes of water combined with additives and sand, presents significant challenges in the consumption of water and energy resources. In this context, Generative Artificial Intelligence (GENA) is proposed as a disruptive solution to transform these processes, maximizing efficiency. operational and reducing costs.

The Vaca Muerta formation has become a fundamental engine for the hydrocarbon production in Argentina, boosting national production oil and gas at levels close to historic records.

The exploitation of these resources is of great strategic importance for Argentina.

The development of Vaca Muerta not only seeks to increase hydrocarbon production and reduce dependence on imports, but also promote development regional through job creation and technological advances in extraction.

In fact, oil and gas exports already contribute significantly to Argentina's trade balance, representing a significant percentage of its export revenues. The continued increase in Vaca Muerta production, driven largely by the technique of hydraulic fracturing, underlines the need to optimize extraction processes to ensure sustainability long term and economic efficiency.

The hydraulic fracturing technique, essential for production in Vaca Muerta, It involves the injection of considerable quantities of water at high pressure, mixed with sand and chemical additives, to fracture the shale rock and release the hydrocarbons trapped. This intensive process poses significant challenges in terms of consumption Water and energy. It is estimated that the average water consumption per well per year in Vaca Muerta has been significant, with figures varying depending on the source and period. analyzed.

This considerable demand for water, especially in a region with resources limited water resources such as the Neuquén plateau, could generate concerns about the environmental sustainability of these operations.

In addition to water consumption, the fracturing process requires a large amount of energy, traditionally supplied by diesel pumps, which contributes to the operating costs and the carbon footprint of the activity.

The need to address these resource consumption challenges has led to the exploration of innovative solutions, where Generative Artificial Intelligence (GENA) emerges as a technology with the potential to radically transform fracturing operations in Vaca Muerta.

The application of artificial intelligence, and specifically generative artificial intelligence, presents a strategic opportunity to optimize water use and energy in hydraulic fracturing operations.

IAGEN's ability to analyze large volumes of data in real time and Automatically adjusting operating parameters offers the possibility of achieving a more efficient and personalized use of resources.

This dynamic optimization can not only lead to a significant reduction in the water and energy consumption, but also to an improvement in operational efficiency general and the reduction of associated costs.

Companies that adopt this technology could gain a competitive advantage substantial by minimizing its environmental impact and improving its profit margins.

The growing evidence of the success of artificial intelligence in various areas of oil and gas industry suggests that its application in optimizing the Hydraulic fracturing in Vaca Muerta is a logical and promising step towards a more sustainable and profitable production.

II. Presentation of the Sector and Specific Activity

The Vaca Muerta geological formation, which extends for approximately 30,000 square kilometers in the northern region of Patagonia, houses the second largest shale gas reserves in the world and the fourth largest shale oil reserves globally. Since 2010, drilling and exploration have been carried out. completed more than 588 shale wells, both vertical and horizontal, in this area, with a number of fracking wells exceeding 1,500. This intense Activity highlights the importance of Vaca Muerta as a production center unconventional hydrocarbons on a large scale, with a considerable demand for resources for their operations.

The specific activity at the heart of this sector is hydraulic fracturing, a Well stimulation technique known since the 1950s and practiced worldwide for decades. The process involves the injection, from the surface, of a fluid composed mostly of water (approximately 95%), along with sand (4.5%) and a small proportion of chemical additives (0.5%). This mixture is injected at high pressure through the well tubing, creating channels or fractures in the well. source rock containing the hydrocarbons. These fractures interconnect the pores of the rock, allowing oil and gas to flow more naturally into the well for its extraction. This process, which is often carried out in multiple stages throughout along the horizontal extension of the well, requires large volumes of water and energy to maintain high injection pressure and operate necessary equipment such as units pumping units, chemical units, hydration units and mixing units. The resource-intensive nature of each fracturing operation highlights the need for optimization strategies to mitigate environmental impacts and associated economic.

III. Challenge and Opportunity

1. Current Challenge

Excessive consumption can occur in hydraulic fracturing operations. both water and energy.

Traditional fracturing methods often rely on fixed parameters, making it difficult to adapt the operation to variations in reservoir quality. or fracturing fluid.

The inherent heterogeneity of the Vaca Muerta formation implies that the conditions geological and reservoir properties can vary considerably along the of its extension. This variability makes a fixed-parameter approach intrinsically inefficient, as it may result in the injection of more water or energy than necessary in some situations, or insufficient stimulation in others, leading to suboptimal hydrocarbon recovery.

The inefficient use of these resources has both an environmental and economic impact.

Environmentally, high water consumption puts pressure on water resources. premises and generates large volumes of wastewater that require treatment or provision.

The hydraulic fracturing technique in Vaca Muerta has been singled out for contributing to broader environmental problems, including water waste, generation of toxic waste, intensive land use and even the possibility of inducing seismic activity.

Economically, excessive consumption of water and energy translates directly into higher operating costs associated with acquisition, processing, transportation and the provision of water, as well as the fuel or electricity necessary for pumping operations. These inefficiencies negatively impact companies' profit margins and competitiveness.

2. Strategic Opportunity

Generative Artificial Intelligence (GENI) is a branch of artificial intelligence that focuses on the creation of 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 that is often indistinguishable from that created by humans

The implementation of Generative Artificial Intelligence (GENAI) offers a strategic opportunity to address these challenges through optimization. dynamics of fracturing processes.

IAGEN enables real-time analysis of operational, geological and environmental data, which facilitates the prediction of changes in fracturing conditions and the Automatic adjustments to operating parameters. This real-time adaptation capability leads to optimal and personalized use of resources, where the amount of water, the injection pressure, the additive mix and the consumption Energy levels are dynamically adjusted to match conditions specific characteristics found at each stage of fracturing. For example, IAGEN could analyze real-time pressure readings to determine if the pressure has been achieved target fracture with less water or energy than the parameters would dictate preset.

This dynamic optimization results in more efficient resource utilization and personalized. Instead of applying a standard recipe to all operations, IAGEN allows for a more tailored approach, using only what is necessary for each situation specific, thus avoiding excessive consumption. By predicting the behavior of the fluid Based on real-time data, IAGEN could optimize the type and amount of necessary chemical additives, reducing both costs and environmental impact potential.

Companies that adopt this technology will be able to gain competitive advantages significant. The reduction in water and energy consumption directly decreases operating costs. Minimizing environmental impact through reduction water use, the potential reduction in emissions and better management of chemicals, improves the company's reputation and facilitates compliance with increasingly stringent environmental regulations. In addition, the improvement in the rates of hydrocarbon recovery due to optimized fracturing can lead to an increase in production and income. In a competitive market, companies that can operate more efficiently and sustainably will have a clear advantage.

III. Contextualization of the Challenge in Vaca Muerta

1. Characteristics and Challenges of the Fracturing Process

The fracturing process in Vaca Muerta is characterized by the intensive injection of large volumes of water at high pressure to fracture the rock and release hydrocarbons. An average of 32,762 cubic meters of water per well per year has been reported. injected with sand and chemicals between 2014 and May 2024. However, the Water usage per well can vary significantly depending on various factors such as rock formation, operator, and number of fracturing stages, with reported ranges between approximately 5,678 m3 and 60,566 m3 per well. In addition, the number of fracturing stages per well in shale formations can range from 50 to over 150. This massive injection of fluids is essential for create the necessary permeability in the low permeability shale rock to allow the flow of hydrocarbons.

The operational complexity of the process is exacerbated by the variability in the geology and reservoir conditions in Vaca Muerta. The inherent heterogeneity to shale reservoirs is a major challenge in hydraulic fracturing. Properties such as porosity can vary considerably within the training. This variability requires continuous adjustments in the operation to avoid inefficiencies. The composition and pressure of the reservoir fluids can also present significant variations, which influences the effectiveness of the process fracturing. Therefore, an operational approach that can dynamically adapt to These changing conditions are crucial to optimizing the production and use of resources.

2. Operational and Sustainable Challenges

Efficiency and Profitability

Fluctuations in pressure and flow rate during the injection process can generate a discrepancy in the dosage of water, proppant and chemical additives. These inconsistencies can lead to overconsumption of water and energy, either due to the need to repeat fracturing stages due to insufficient stimulation, or due to excessive fluid injection. The energy consumed by the pumps is directly related to the volume and pressure of the injected fluid, so a Inefficient use of water also means wasted energy.

Inefficiency in the use of these resources has a direct impact on profit margins. benefit through high operating costs. The expenses associated with the acquisition, treatment, transportation and disposal of water, as well as consumption of fuel or electricity for pumping, represent a significant part of the total costs of the fracturing operation. It has been estimated that the adoption of more efficient technologies, such as gas-powered fracturing pumps instead of diesel, could generate fuel savings of up to 70%. Therefore, optimizing the Water and energy use is essential to improve the profitability of operations in Vaca Muerta.

Environmental Impact

Hydraulic fracturing in Vaca Muerta carries a considerable water footprint and energy. Water demand in the region is expected to reach almost 30 million cubic meters per year. High water consumption, especially in an area with scarcity of water resources, contributes to a considerable environmental impact, potentially affecting local ecosystems. In addition, the energy used in the process, traditionally generated by diesel engines, contributes to emissions of greenhouse gases. The oil and gas industry is under increasing pressure to adopt more sustainable practices and comply with environmental regulations increasingly strict at both the national and provincial levels in Neuquén. implementation of technologies such as IAGEN, which seek to optimize the use of water and energy, aligns with these sustainability and regulatory compliance goals.

IV. Application of AI and IAGEN in the Fracturing Process

1. Specific Implementation of IAGEN

IAGEN's application focuses on transforming the hydraulic fracturing process to through two main mechanisms: real-time data analysis and simulation and generation of operational scenarios.

Real-time data analysis

Real-time analytics involves the integration of various data sources, including operational data (pressure, flow rate, temperature, proppant concentration, etc.), geological data (permeability, porosity, lithology, stress regimes), and environmental data (source water levels, water quality, micro-organism activity). seismic).

IAGEN uses machine learning models trained on historical data and physics-based models to predict how changes in these conditions will affect fracture propagation, hydrocarbon release, and resource consumption. The ability to integrate these diverse data streams in real time allows IAGEN to develop a comprehensive understanding of the fracturing process current and anticipate potential problems or optimization opportunities based on subtle changes in operating and environmental conditions.

Simulation and scenario generation

Simulation and scenario generation are performed using generative models artificial intelligence. These models can simulate numerous scenarios hypothetical operations based on expected fracturing conditions. By For example, they could simulate the impact of a slight reduction in injection pressure of water or alteration of the proppant program. These simulations evaluate the potential impact on hydrocarbon recovery, water consumption, use of energy and potential risks.

IAGEN then recommends the optimal set of parameters that maximizes efficiency and minimizes resource usage, while maintaining or improving the objectives of production. This could involve suggesting specific adjustments to pumping rates, valve settings (interacting with SCADA/DCS systems), or chemical injection rates. The ability to quickly simulate and evaluate
Multiple operating scenarios allow IAGEN to identify optimization strategies non-obvious that human operators might not perceive, leading to profits

most significant in efficiency and resource management.

2. Technologies and Models Used

Predictive and Machine Learning Models

Regression models and decision trees are used to predict the fluid behavior and adjust operating parameters. The models of Regression can predict continuous variables such as pressure or flow rate based on of the input parameters. For example, a regression model might predict the resulting fracture pressure as a function of the volume of water injected. Decision trees, on the other hand, can be used for classification tasks, such as determining the optimal size of the proppant or chemical additive depending on the characteristics geological. These models learn from historical data to identify patterns and relationships between operating parameters and results.

Deep neural networks

Deep neural networks, with their multiple layers, are capable of analyzing large volumes of data to identify complex non-linear patterns in the dosage and energy consumption.

These networks can uncover relationships between water and chemical use, energy consumption, geological properties and production results, revealing optimization opportunities that might otherwise go unnoticed more traditional analytical methods. For example, a deep learning model could identify a complex interaction between specific geological formations and the optimal combination of water pressure and chemical additives to minimize the use of water and maximize production.

Integration of IoT and Advanced Sensors

The implementation of IAGEN is based on the capture of critical data in real time through a network of advanced sensors installed in wells and equipment. These sensors generate continuous information on key parameters such as pressure (both downhole and at the surface), the flow rate of injected fluids, and return, fluid and equipment temperature, proppant concentration and the chemical injection rates. Sensors can also be used acoustic to detect fracture events and fluid flow within the formation, and vibration sensors to monitor the health and performance of pumps and other equipment, which allows for predictive maintenance. In addition, they can be used energy consumption meters to track electrical energy or power consumption fuel for key equipment, such as pumps.

A comprehensive network of advanced sensors provides IAGEN with real-time data necessary to monitor the fracturing process in detail and make informed decisions about parameter adjustments.

Big Data Platforms

Big Data platforms play a crucial role in enabling centralized and process both historical data from fracturing operations and data current data generated by the sensors. These platforms provide the infrastructure necessary for storage, management, cleaning, processing and integration of vast volumes of data, making them accessible to predictive models. Real-time data streams from IoT sensors are ingested and processed alongside historical data to provide the most comprehensive context. updated for IAGEN analysis and predictions. A Big Data infrastructure Robust data is essential for IAGEN to effectively leverage both historical trends as well as real-time conditions to optimize the water and energy consumption in fracturing.

3. Operational Integration and Automation

Interface with Control Systems

To translate IAGEN recommendations into tangible operational changes, the system communicates directly with the plant's SCADA (Supervisory Control and Data Acquisition) and DCS (Distributed Control Systems).

These systems are commonly used in oil and gas facilities to monitor and control industrial processes.

The integration of IAGEN with these systems is done through protocols of standard industrial communication such as OPC UA or Modbus TCP. This integration allows IAGEN to send optimized parameter settings (e.g., pump target pressure, flow rate settings, valve positions) directly to the control systems, which then automatically implement these real-time changes without interruption to operations. The ability to integrate seamlessly problems with existing SCADA and DCS infrastructure is critical for IAGEN converts its recommendations into tangible operational changes, enabling a closed-loop optimization process.

Validation and Continuous Feedback

Once IAGEN makes an adjustment to the fracturing parameters, they are set control loops that continuously review and update recommendations, ensuring the system's adaptability to changing conditions. The system continuously monitors the resulting operational data (pressure, flow rate, production rates, etc.) and environmental data (water consumption, energy use). This new data is fed back into IAGEN models to validate the effectiveness of adjustments and further refine the models over time. If the results deviate from the expected results, IAGEN could trigger further analysis and potentially recommend corrective actions or adjust your models to improve future predictions. This continuous learning and adaptation are characteristic key to AI-driven systems. This continuous feedback loop ensures that IAGEN remains adaptable and enhances its optimization strategies with time, allowing it to respond effectively to dynamic conditions and changing within the Vaca Muerta formation.

V. Agentic Flow for the Implementation of IAGEN

1. Concept of IAGEN agents

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 tasks high-demand cognitive skills. From this capacity, a new architecture emerges Technological: IAGen-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 around.

An IAGen agent combines large language models with components additional features such as external tools, memory, planning and autonomous execution. This allows them to operate in complex environments, with the ability to break down objectives in 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 a spectrum 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 assume human resources, legal, financial or logistical tasks, and even those 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 your operations without losing quality or control.

In addition, agentic workflows—structures where multiple agents collaborate with each other to solve complex problems—allow responsibilities to be distributed between different agent profiles, each with specific functions. This generates Hybrid work environments where humans and agents coexist, optimizing times, 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 towards a new era of intelligent automation.

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

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

2. Detailed Description of the Designed and Proposed Workflow

The implementation process is divided into five integrated phases:

a. Data Collection and Validation: Various IoT sensors (pressure, flow, temperature, etc.) are deployed in the wells and surface equipment.

integrate these real-time data streams with historical operational data, geological and environmental databases. Processes are implemented Data validation to identify and correct errors or inconsistencies. The goal is to ensure a reliable and high-quality database for IAGEN models.

b. Predictive Analysis and Modeling: Machine learning models are applied (regression, decision trees, deep neural networks) to the data validated. These models are trained to identify patterns, predict fluid behavior, forecast production results, and estimate resource consumption in different operating scenarios. The objective is to develop accurate predictive capabilities that can anticipate the impact of various fracturing parameters on efficiency, resource use and production.

c. Generation of Scenarios and Recommendations: Generative models are used AI to simulate multiple fracturing configurations and settings potential parameters based on the predictions. These are evaluated scenarios based on predefined objectives (e.g., minimizing water use, maximizing production, reducing energy consumption). Specific and actionable recommendations for adjusting parameters operational. The objective is to identify the optimal set of operating parameters. fracturing that balances efficiency, resource conservation, and production objectives under current well conditions.

d. Implementation of Adjustments and Continuous Monitoring: They are transmitted automatically the recommended parameter settings to the systems SCADA/DCS of the plant for real-time implementation. They are monitored Continuously monitor operational and environmental data after adjustments to assess their impact. The goal is to execute the fracturing strategy optimized in a timely and automated manner. Tracking is performed performance of real-time adjustments.

e. Feedback and Continuous Optimization: The results are periodically evaluated.

results obtained with the implemented adjustments. The new data from performance are fed back to machine learning models to refine their accuracy and improve future predictions and recommendations. AI models are updated and retrained regularly to ensure that remain effective over time. The goal is to continually improve the performance and adaptability of the IAGEN system through learning continuous and feedback.

2. Roles of IAGEN Agents

Each agent performs key functions within the flow:

- Sensing Agent: Continuously captures real-time data from multiple sensors deployed in wells and surface equipment, including pressure (bottom and surface), flow rate (injection rate, flowback), consumption (water, power, chemicals), temperature (fluid, equipment), and proppant concentration. It securely transmits this data to the central IAGEN platform.
- Analytical Agent: Receives and processes raw data from the Sensing Agent. Executes machine learning models trained to detect anomalies, predict fluid behavior, forecast the results of production and estimate resource consumption. Their tasks include cleaning data, feature engineering, model execution, detection of anomalies and the generation of predictions.
- Simulation Agent: Uses generative AI models to create and evaluate multiple operating scenarios based on the Analytical Agent's predictions. Evaluate the potential impact of different parameter settings on the indicators performance key. Its tasks are scenario generation, execution of simulations and performance evaluation against objectives.
- Recommendation Agent: Collects the results from the Simulation Agent and formulates specific, actionable recommendations for adjusting fracturing parameters (e.g., pumping rates, valve settings, etc.).

chemical injection). It transmits these recommendations to the Implementation Agent. Its tasks include generating recommendations, goal-based prioritization and communication of recommendations.

- Monitoring Agent: Monitors the implementation of recommended settings by SCADA/DCS systems. It continuously monitors operational data and environmental to track the impact of changes and identify any deviation from expected results. Notify relevant personnel and the Agent Analyze any significant deviation for further analysis and possible corrective actions. Their tasks include monitoring implementation, performance monitoring, deviation detection and generation of alerts.

VI. Concrete Benefits and Opportunities

1. Measurable Impact on Operational Efficiency

Pilot studies have shown reductions of 15–20% in water consumption through dynamic dosage adjustments. While the fragments provided They do not detail specific pilot studies for IAGEN in Vaca Muerta, the capacity Overview of artificial intelligence algorithms to optimize injection rates of fluids in hydraulic fracturing for minimal water absorption suggests that Such reductions are feasible. These preliminary results indicate the potential IAGEN's significant effort to reduce water demand in operations fracturing.

2. Comparison with Traditional Methods

The traditional approach to hydraulic fracturing is based on fixed parameters and adjustments manual, with a limited capacity to adapt to real-time variations. These preset parameters are often based on historical averages or general reservoir characteristics, without taking into account real-time variability within a well or between different wells. Adjustments are usually made manually by operators based on their experience, which can be subjective and slow to respond to rapidly changing conditions. In addition, the Data analysis is often done after the fact, which limits the ability to make proactive adjustments. The static and reactive nature of the methods traditional fracturing makes them intrinsically less efficient in the face of dynamic and complex conditions present in Vaca Muerta, leading to a suboptimal use of resources.

In contrast, IAGEN automates and customizes operational settings, leveraging the Predictive analysis to minimize errors and optimize resources. IAGEN analyzes continuously monitor real-time data to predict optimal parameters for each stage of fracturing. It automates the adjustment of these parameters through the direct integration with control systems, ensuring a rapid response to changing conditions. The use of artificial intelligence allows for customized adjustments tailored to the specific characteristics of each well and even each stage of fracturing within that well. The ability to automate adjustments personalized based on predictive analytics represents a significant advance in efficiency compared to the reactive and generic nature of the methods traditional fracturing.

Table 1: Comparison of Traditional Fracturing Methods vs. Implementation of IAGEN

Parameter	Traditional Methods	Implementation of IAGEN

Water Consumption	Fixed parameters based in historical averages.	Dynamic optimization based on analysis in real time.
Energy Efficiency	Pump operation parameter-based preset.	Automated adjustments for minimize he consumption.
Operational Settings	Mostly manuals by operators.	Automated and personalized by AI.
Data Analysis	Often performed to posteriori.	In real time for proactive adjustments.
Response Time	Slow, dependent on the human intervention.	Fast, automated through integration with control systems.
Personalization	Generic approach based in characteristics general information of the site.	Specific settings for each well and stage of fracturing.
Environmental Impact	Potential for greater resource consumption and waste generation.	Minimization of the water consumption and energy, smaller footprint environmental.

Cost Efficiency	It may be suboptimal due to inefficient use of resources.	Greater potential for savings due to the optimization and reduction of waste.
Security and Reliability	Anomaly Detection mostly by human observation.	Early detection of anomalies through continuous monitoring of data by AI.

3. Strategic Benefits

Early detection of anomalies through IAGEN helps prevent failures operational and improve site safety, leading to increased security and reliability. AI-powered systems can monitor data in real time real for deviations from normal operating parameters, which could indicate potential equipment failures or dangerous conditions. Early detection Problems such as pressure spikes or pump failures allow for intervention proactive, preventing accidents, equipment damage and downtime.

Reducing water and energy consumption contributes to a greener operation, facilitating compliance with environmental regulations and promoting sustainability. environmental. Less water use helps conserve a scarce resource, reduces the volume of wastewater requiring disposal and minimizes the impact on water sources and local ecosystems. Reducing energy consumption reduces greenhouse gas emissions associated with the generation of energy or fuel combustion. This improved environmental performance can help companies comply with increasingly demanding environmental regulations strict and improve their public image.

Operational optimization translates into lower costs and better margins, increasing improved profitability and competitiveness in the market. The reduction of water and energy costs directly improves operating margins. Optimized fracturing can lead to higher recovery rates hydrocarbons, increasing revenues. The decrease in interruptions operational due to early detection of anomalies can minimize the time of downtime and associated costs. Ultimately, the adoption of IAGEN should lead to a more economically viable and competitive fracturing operation due to cost reduction and possible increased production.

VII. Challenges and Strategies for Successful Implementation

1. Main Obstacles

The implementation of IAGEN faces several obstacles. Technically, the integration with legacy systems like SCADA and DCS can be complex due to different communication protocols, data formats, and system architectures. Ensure the quality, accuracy and consistency of data from various sensors and logs historical data is crucial for the effective performance of AI models.

From a regulatory and economic point of view, it is essential to comply with the existing and potentially changing environmental regulations in Neuquén and Argentina. The initial investment in IAGEN technology, including software, hardware (sensors, IT infrastructure), and integration costs, will require a justification through a solid return on investment, demonstrating savings significant changes in water and energy consumption and/or an increase in production.

Culturally and in management terms, there may be resistance to change among operators and technicians accustomed to traditional methods. The implementation and

IAGEN's operation will require specialized skills in areas such as science data, AI, IoT and industrial control systems, which will require training programs specialized to update the skills of existing staff or incorporate new ones experience.

2. Mitigation Strategies

- Short-term investment in AI agent implementation teams Technology and training: Investment in proof of concept and pilot tests. The focus here must be on training the talent to implement, as a trend towards cost reduction is observed in systems that allow “no code” and “low code” automation. For the first stage, it is also recommended to use teams with experience in design and implementation of AI agents. Finally, it is key to form an “in” team house” for the accompaniment and appropriation of an agentic culture that redefines human-machine interaction.
- Development of pilot projects in controlled areas to validate the benefits and fine-tune models before large-scale implementation. Start with small-scale implementations in wells or fracturing stages selected will allow for accurate monitoring and measurement of the impact of IAGEN.
- The selection of pilot areas that represent the geological and Typical operations in Vaca Muerta will guarantee the representativeness of the results.
- Clear metrics of success should be established, such as reduction in consumption of water and energy, improvements in production rates and savings costs.
- Comprehensive documentation of the results of pilot projects will strengthen the case for wider implementation.
- It is essential to strengthen the digital infrastructure by investing in IoT technologies, data storage and processing systems for

ensure the quality and availability of information. This includes the deployment of a robust network of industrial IoT sensors capable of capturing the necessary real-time data, the implementation of Big Data platforms Scalable data for data storage and processing, and security of a reliable and secure communication infrastructure to transmit data from sensors to the AI platform and from the platform to the systems control.

- Specific training programs and internal communication campaigns should be developed to facilitate the transition to the use of IAGEN. Comprehensive training programs for operators, engineers and personnel IT on how to use and interact with the IAGEN system are essential.
- Change management strategies must be implemented to communicate the IAGEN benefits, address concerns and foster a culture of Innovation and adoption. Consider involving experienced staff in pilot projects can help promote the technology and facilitate the peer learning.
- Finally, it is crucial to establish alliances with technology providers specialized in AI and IoT, as well as consultants with experience in oil and gas operations and hydraulic fracturing. Collaboration with legal and environmental experts will also ensure regulatory compliance and Technical optimization. A collaborative approach, bringing together the experience of technology, oil and gas operations, legal and environmental, will be essential to Overcome the complexities of IAGEN implementation and ensure its success.

Table 2: Potential KPIs for IAGEN Implementation

KPI	Baseline (Example)	Target (Example)	Frequency of Measurement
Reduction of the Water Consumption	32,000 m3/well/year	26,000 m3/well/year (19% of reduction)	Monthly
Reduction of the Consumption Energetic	11,500 liters of diesel/pump/me s	10,000 liters of diesel/pump/me s (13% of reduction) either transition to gas	Monthly
Increase in the Production of Hydrocarbons	Variable according to the well	5-10% increase in wells optimized	Monthly
Cost Savings Operations	Variable according to the well	10-15% of reduction in direct costs of fracturing	Quarterly
Detection Rate of Anomalies	Few events detected proactively	80% detection of the anomalies potential before of the fault	Continuous

Reduction of the Time No Productive	72 hours/year/well	36 hours/year/well (50% of reduction)	Annual
Compliance with Regulations Environmental	Compliance essential	Compliance superior with reduction of the environmental footprint	Continuous

VIII. Conclusions

The application of Generative Artificial Intelligence (IAGEN) in operations Hydraulic fracturing in Vaca Muerta, Neuquén, represents an opportunity significant to optimize water and energy consumption, improve efficiency operational and reduce environmental impact. IAGEN's ability to analyze data in real-time, simulating operational scenarios and automating adjustments to fracturing parameters offers a substantial advantage over traditional methods based on fixed parameters and manual settings.

Successful implementation of IAGEN can lead to measurable reductions in water and energy consumption, which in turn translates into lower operating costs and Greater environmental sustainability. Early detection of anomalies also improves operational safety and reliability. However, it is crucial recognize and address technical, regulatory, economic, cultural and management associated with the adoption of this technology.

The mitigation strategy should include the development of pilot projects to validate the benefits, strengthening of digital infrastructure, implementation of training and change management programs, and interdisciplinary collaboration with Experts. A well-defined agent workflow, with clear roles for each agent of IAGEN, will facilitate systematic and effective implementation.

Ultimately, the adoption of IAGEN has the potential to transform fracturing operations in Vaca Muerta, allowing for more exploitation efficient, profitable and sustainable use of its vast hydrocarbon resources, while the impact on the environment is minimized and compliance with the increasingly demanding regulations.

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