Deliverable report 11

AI and IAGEN Application Use Case

Water and Energy Optimization in Fracturing Using IAGEN in Vaca Dead, Neuquén

I. Introduction

The Vaca Muerta formation, located in the province of Neuquén, Argentina, has consolidated as one of the most important shale oil and gas fields in the world global, comparable in magnitude and potential to the prolific Eagle Ford Basin in Texas. Its strategic relevance for the Argentine energy sector is undeniable, with the country aspiring to position itself among the 20 largest oil exporters by 2030, a goal strongly driven by Vaca Muerta's production. This ambition underlines the critical need to implement technologies that not only maximize extraction efficiency but also optimize costs operatives.

The exploitation of unconventional resources depends largely on the intensive hydraulic fracturing, a technique that requires considerable volumes of water, energy, and materials. This high resource consumption poses challenges significant from both an environmental and operational perspective.

Traditional fracturing methods often employ fixed parameters, which limits its ability to adapt to the inherent heterogeneity of the deposits. This lack of flexibility leads to inefficiencies in the use of resources, increasing costs and affecting the sustainability of operations. The intrinsic variability of the shale reservoirs in Vaca Muerta therefore requires dynamic and adaptive approaches to hydraulic fracturing, which makes the methodologies based on static parameters are inadequate. The magnitude of operations amplify inefficiencies in water and energy consumption, which underlines the urgency of finding optimized solutions.

In this context, Generative Artificial Intelligence (IAGEN) emerges as a transformative solution with the potential to revolutionize fracturing processes. IAGEN offers a disruptive approach by enabling real-time data analysis and automated adjustment of operating parameters. This capability promises improvements substantial efficiency gains and significant cost reductions.

Generative Artificial Intelligence (GENAI) 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 content and original that is often indistinguishable from that created by humans.

The growing interest in the application of artificial intelligence and learning automatic in hydraulic fracturing, evidenced by the notable increase in the research over the past decade, reflects a growing recognition of the potential of these technologies in industry.

IAGEN represents a cutting-edge application of these advances. It offers a new perspective on the optimization of unconventional resource extraction.

The purpose of this report is to provide a comprehensive, expert-level analysis of the IAGEN's potential in optimizing hydraulic fracturing in Vaca Muerta, supported by current research and industry insights. The scope includes a detailed examination of the technology, its benefits, the challenges of implementation and strategic implications, with a particular focus on the water and energy efficiency, as well as sustainability.

II. Deep Contextualization of the Challenge in Vaca Muerta

The Vaca Muerta Formation is composed of a complex mixture of shales rich in organic matter and interdigitated carbonates, which presents both opportunities as challenges for hydrocarbon extraction. This geological complexity is a key factor contributing to variability in reservoir properties.
In fact, the formation exhibits significant heterogeneity in mechanical properties such as Young's modulus and Poisson's ratio, which reinforces the need for adaptive fracturing strategies.

Suboptimal designs in multi-stage fracturing completions can result in fractures not contributing to production, highlighting the considerable room for improvement that exists through optimization.

The intricate geology and marked heterogeneity of Vaca Muerta are the main drivers of the inefficiencies observed in traditional methods of fracturing. Understanding these characteristics is essential to adapting the IAGEN solutions effectively.

The high rate of fracture failure underscores the significant opportunity for improvement that offers AI-driven design.

The hydraulic fracturing process in Vaca Muerta is characterized by injection intensive use of large volumes of water at high pressure. This high demand for water It is especially worrying in the Neuquén plateau, a region that faces the scarcity of water resources.

Fluctuations in pressure and flow during operations can lead to excessive water and energy consumption. This inefficiency has a direct impact on the operating costs and the environmental footprint of operations. Water scarcity in the Vaca Muerte region increases the importance of water optimization through IAGEN. The direct connection between operational fluctuations and excessive consumption of resources highlights a key area where IAGEN can provide real-time adjustments.

The high water and energy consumption inherent in fracking contributes to an impact significant environmental impact, including a significant carbon footprint. Companies are facing increasing pressure to adopt sustainable practices and comply with increasingly strict environmental regulations.

The growing focus on environmental sustainability and the existence of regulations in Neuquén generates a strong incentive for the adoption of IAGEN, which can address directly improve water and energy efficiency, and potentially facilitate the regulatory compliance.

III. Comprehensive Application of IAGEN in the Fracturing Process

IAGEN focuses on transforming the fracturing process through integration and analysis of data in real time. This allows for adjustments proactive based on changing conditions.

The integration of operational, geological, and environmental data allows IAGEN to anticipate changes in fracturing conditions. This predictive capability is critical. for optimization. The shift from reactive adjustments to proactive predictions based in real-time data is a key advantage of IAGEN. This enables a more anticipatory and efficient fracturing.

IAGEN uses generative models to evaluate multiple operating scenarios. This allows the identification of optimal resource utilization strategies.

By simulating different fracturing configurations, IAGEN can recommend adjustments accurate to maximize operational efficiency. This scenario-based approach enables data-driven decision-making. The ability to simulate and compare quickly various operational scenarios provides a powerful tool for optimize fracturing parameters, something that is not feasible with methods traditional.

The main function of IAGEN is the dynamic optimization of water consumption and energy during fracturing. This addresses the key challenges identified previously. By analyzing data in real time, IAGEN can adjust automatically adjust operating parameters to achieve optimal and personalized use of resources. This adaptability is crucial for efficiency. The direct objective of the Water and energy optimization positions IAGEN as a solution that addresses directly address the most pressing environmental and economic concerns related to fracking in Vaca Muerta.

IV. Detailed Analysis of Technologies and Models Used

Within the framework of IAGEN, various predictive models and algorithms are employed. machine learning to optimize the fracturing process.

- Regression models and decision trees

Regression models and decision trees allow us to predict the behavior of the fracturing fluid and adjust operating parameters accordingly. These models are effective in identifying linear and nonlinear relationships in the data operatives.

- Deep neural networks

Deep neural networks, on the other hand, have the ability to analyze large volumes of data to identify complex and non-linear patterns in dosage fluids and energy consumption. Its ability to handle high dimensionality of fracturing data makes them particularly valuable.

- Gradient Boosting (GBMs)

Gradient Boosting models (GBMs) have demonstrated solid performance in the Prediction of oil and liquids production after hydraulic fracturing, suggesting its potential for production forecasting within IAGEN.

Artificial Neural Networks (ANNs) have also been used successfully to predict productivity improvement in acid fracturing, another technique of well stimulation, demonstrating the broader applicability of networks neural networks in optimizing well performance.

- Convolutional neural networks

Advanced architectures such as Self-Attention Convolutional Neural Networks (SACNN) and Artificial Neural Networks with Optimization by Mutated Particle Cluster (MPSO-ANN) have been used for the prediction of high accuracy of gas probability distribution in reservoirs, which highlights the potential for IAGEN to incorporate sophisticated models for analysis of the subsurface. Furthermore, the combination of the Transformer framework with Multi-Objective Particle Cluster Optimization (MOPSO) has been used to optimize the injection-production parameters in gas flooding, demonstrating the AI's capacity for multi-objective optimization in reservoir management.

- IAGEN

IAGEN can integrate a wide range of machine learning models, each one suitable for specific tasks within the optimization process fracturing, from fluid behavior prediction to forecasting of production and optimization of injection strategies. The choice of the model will depend on the specific data and the desired outcome.

- Integration of IoT and advanced sensors

The integration of the Internet of Things (IoT) and advanced sensors is critical for real-time data collection. Sensors installed in wells and Equipment captures critical information on pressure, flow rate and consumption energy. This information forms the basis for IAGEN's analysis.

Distributed Acoustic Sensing (DAS) technology can provide measurements continuous subsurface for fracture monitoring, allowing visualization real-time fracture performance.

Wireless sensor networks can monitor surface tilt during hydraulic fracturing to determine the direction of the fracture formed, providing valuable information on fracture propagation.

Submersible hydrostatic level sensors with wireless transmitters can monitor fracturing pool levels, addressing concerns environmental and ensuring sufficient availability of fluids.

A comprehensive network of IoT sensors is essential to provide IAGEN with the data continuous and high-resolution data required for accurate analysis and optimization in real time. Different types of sensors provide information on various aspects of the fracturing process, both on the surface and underground.

Big Data Platforms

To manage and process the large volumes of data generated during fracking, robust Big Data platforms are required.

These platforms allow you to centralize and process both historical data and data in real-time to feed predictive models.

The oil and gas industry generates huge amounts of data on a daily basis.

Cloud-based platforms offer scalability and flexibility to handle the massive data sets involved in fracking operations.

Big Data analysis makes it easier to identify patterns and trends in the reservoir behavior and operating parameters.

The large volume and velocity of data generated during fracturing require a solid Big Data infrastructure to store, manage and process this information effectively for IAGEN. Cloud-based solutions are probably essential to handle the scale of the data.

V. Proposal for 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 take on human resources, legal, financial, or logistics tasks, and even those related 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 its capabilities.

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

Among the benefits of authentic workflows driven by business models generative artificial intelligence, the possibility of automating processes is found 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. IAGEN agents applicable to predictive analysis of well performance

Adopting an AI agent paradigm with no-code and low-code approaches presents a significant opportunity to overcome the limitations of traditional methods and accelerate the adoption of artificial intelligence in the petroleum industry. By simplifying the development and implementation of AI solutions, access to these is democratized technologies, allowing professionals without deep technical training to create and customize agents tailored to your specific needs.

This logic reduces the costs associated with custom software development, speeds up the experimentation and iteration, and allows you to more easily adapt to changes in operational and reservoir conditions. By complementing predictive models and generative AI agents already described can automate workflows complex, from real-time data collection and analysis to generation of recommendations and proactive decision-making, thus maximizing efficiency and productivity.

In addition, the use of no-code and low-code platforms for the creation of AI agents allows for greater flexibility and scalability. These tools typically offer intuitive interfaces and pre-built components that can be assembled and be customized without having to write code from scratch. This speeds up development and It fundamentally facilitates integration with existing systems and adaptation to new data sources or operational requirements. By reducing dependence on specialized developers and allow greater participation of subject matter experts, a culture of innovation and collaboration is fostered, where knowledge Technical and industry experience combine to create more AI solutions effective, less expensive and that increase the optimization capacity in different tasks. In short, we need to move towards a hybrid approach that combines the methods analytical and predictive with the ability to automate and adapt the AI agents.

3. Proposed AI agent design powered by IAGEN

The IAGEN implementation process is divided into five integrated phases, forming a continuous cycle of optimization.

a. The Data Collection and Validation phase takes on a central role in the optimization of water and energy consumption during hydraulic fracturing. The need for accurate, high-quality data from IoT sensors, such as flow, pressure, temperature, and consumption meters, is emphasized.

energy, as well as historical records of previous operations. This stage involves detailed integration, cleaning and preprocessing processes data, ensuring that the information fed into the models accurately reflects the actual use of resources at each stage of the fracturing process.

b. During the Analysis and Predictive Modeling phase, machine learning models such as Gradient Boosting Machines (GBM), artificial neural networks (ANN) and deep learning architectures are applied to identify patterns of water and energy consumption in different pumping configurations and design stages. Through feature engineering techniques, variables are extracted key factors that influence resource efficiency, allowing models to be built predictive that anticipate consumption according to geological, operational and environmental.

c. The Scenario Generation and Recommendations stage uses generative models and simulations to evaluate alternative configurations of fracturing. Combinations of injection rates, viscosity of fluids, pressures and pumping sequences, in order to determine adjustments that reduce the volume of water and energy required without compromising the well productivity. Optimization criteria include saving resources, well stability and environmental impact.

d. In the Implementation of Adjustments and Continuous Monitoring phase, the Recommendations generated by IAGEN agents are integrated with the control systems such as SCADA or DCS, enabling automatic adjustments in real-time. KPIs related to water use are continuously monitored per stage, pumping energy efficiency and specific consumption per unit of production. This phase ensures that operating parameters are maintained within the established efficiency margins.

e. Finally, Continuous Feedback and Optimization establishes a loop closed improvement, where models are periodically retrained with new operational data. This allows adaptation to changes in the geology of the reservoir, fracturing technologies, or resource availability. This approach

Iterative is essential to maintain sustained efficiency in the use of water and energy.

Within this flow, each IAGEN agent performs specialized functions:

- The Sensing Agent captures and transmits real-time data on pressure, water flow, energy consumption, thermal load of the equipment and variations environmental.

- The Analytical Agent processes this information to identify deviations in efficiency and predict future behaviors that may lead to overconsumption or inefficiencies.

- The Simulation Agent generates alternative fracture scenarios with different technical inputs, evaluating their impacts on water and energy demand.

- The Recommendation Agent integrates the results of the analysis and simulation, formulating adjustment strategies that reduce water and energy use maintaining operational integrity.

- Finally, the Monitoring Agent supervises the application of the recommendations, detects deviations in KPIs and drives the feedback to analytical models for continuous improvement.

Concrete Example of Implementation in Pilot Operation

Part One

- IAGEN is implemented in a specific pilot phase to adjust dosage of water and energy parameters during a fracturing operation.

- During this test, higher than optimal consumption is identified in certain critical intervals of the operation.
- IAGEN, by analyzing real-time data provided by sensors installed in the well and fracturing equipment, detects these anomalies in consumption.

Second

- IAGEN's Analytical Agent processes pressure, flow rate and consumption data energy, identifies patterns that indicate inefficient water dosing and high energy consumption in relation to the geological conditions and current operations.

Third

The Simulation Agent generates multiple alternative operating scenarios, evaluating different water dosing configurations and energy parameters.

Quarter

Based on the results of these simulations, the Recommendation Agent formulated precise adjustments to reduce water consumption and optimize energy use without compromising fracturing efficiency.

Part Five

These settings, recommended by IAGEN, are automatically implemented through the interface with the plant's SCADA control systems.

Sixth part

The Monitoring Agent continuously monitors the operating parameters after of the implementation of the adjustments, confirming a significant reduction in the water and energy consumption during previously problematic periods. The operator observed a decrease in water consumption that aligned with the range of 15 to 20% reported in pilot studies, and an optimization of energy consumption within the range of 10 to 15% under those controlled operating conditions.

This specific use case allows us to observe, in particular, the capacity of IAGEN to Identify and correct inefficiencies in real time during operations fracturing in Vaca Muerta.

The successful implementation of IAGEN in this operation lays the foundation for a broader expansion in other areas and with other operators within Vaca Muerta. Considering the diversity of geological conditions and operating practices in the region, IAGEN could be adapted to optimize different types of wells, both vertical and horizontal, and various stages of the fracturing process. scalability of the IAGEN solution and the infrastructure requirements for a Larger-scale implementation will need to be carefully evaluated, but initial results suggest significant potential to transform practice. fracturing throughout the Vaca Muerta formation.

VI. Strategic Benefits and Opportunities

- Pilot studies have shown potential reductions of 15 to 20% in the water consumption through dynamic dosage adjustments. This addresses directly concerns about water scarcity.
- A decrease in energy consumption from 10 to 20% has also been observed. 15% under controlled operating conditions with the integration of IAGEN.
- This translates into cost savings and a smaller carbon footprint.
- AI-driven optimization can lead to significant reductions in costs, greater operational efficiency and better risk management in the oil and gas sector.
- Reported reductions in water and energy consumption provide concrete evidence of IAGEN's potential to improve operational efficiency and sustainability. These quantifiable benefits are crucial to demonstrate the

value proposition of technology.

- Traditional approaches rely on fixed parameters and manual adjustments, which which limits its ability to adapt to real-time variations. This contrasts with IAGEN's dynamic optimization. IAGEN automates and Customize operational settings, leveraging predictive analytics to minimize errors and optimize resource use. This reduces dependence on manual intervention and improves accuracy. IAGEN's ability to Automating and adapting in real time provides a significant advantage over traditional and static methods, leading to operations of more efficient and responsive fracturing.
- Early detection of anomalies through IAGEN can prevent failures operational and improve security. This proactive approach minimizes risks and downtime.
- Reducing water and energy consumption contributes to a more efficient operation. environmentally friendly, which makes it easier to comply with the environmental regulations. This improves the company's sustainability profile.
- Operational optimization translates into lower costs and better margins profit, which increases competitiveness in the market. This provides a significant strategic advantage for early adopters.
- Companies adopting AI technologies in the oil and gas sector can gain a competitive advantage through increased productivity and efficiency.
- Beyond immediate cost savings, IAGEN offers benefits strategic issues related to security, environmental responsibility and market positioning, which contributes to a competitive advantage long term.

VII. Implementation Challenges and Robust Strategies

- Short-term investment in AI agent implementation teams Technology and training: Investment in proof of concept and pilot tests. The focus here has to be on training talent to implement, since a trend of cost reduction is verified 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.

- IAGEN's integration with legacy systems, such as SCADA systems (Supervisory Control and Data Acquisition) and DCS (Control Systems) Distributed), presents a significant technical challenge. To mitigate this, can develop specialized interfaces and middleware solutions for ensure a seamless flow of data between IAGEN and existing systems. Adoption of open communication standards and the implementation of hybrid control systems can also facilitate integration.
- Ensure the quality and integrity of the data that feeds the models IAGEN is another crucial obstacle. To address this, robust data validation and cleansing processes. Invest in data platforms data integration to unify information from various sources and Establishing data governance policies with a dedicated team are steps essentials.
- AI integration may introduce new vulnerabilities to the critical infrastructure of SCADA systems in the oil and gas sector, which that requires strong cybersecurity measures. The implementation of measures multi-layered cybersecurity, including firewalls, detection systems intrusions and network segmentation, along with security audits regular inspections and strict access controls are essential.
- Handling high volume and speed of data for real-time analysis real poses significant processing demands.
- Using edge computing to process data locally, reducing latency and bandwidth requirements,

along with the use of scalable cloud-based platforms for the data storage and processing are mitigation strategies effective.

- Technical integration, data quality and cybersecurity are challenges critical that require proactive mitigation strategies involving specialized technologies, robust processes and a strong focus on data governance and security.
- Compliance with the ever-evolving environmental regulations related to fracking is a regulatory challenge. To mitigate this, They can establish collaborations with regulatory bodies and consultants specialized to ensure continued compliance. The capabilities of IAGEN monitoring can also be used to track parameters key environmental issues and ensure adherence to standards.
- Justifying the initial investment required for the implementation of IAGEN is a economic obstacle. High initial costs can be a constraint, and the Uncertainty about the return on investment can generate doubts. To address For this, detailed cost-benefit analyses and projects must be developed pilot to validate the economic benefits of IAGEN.
- Highlight the potential for significant cost savings through reduction of resource consumption and downtime is crucial. Compliance Regulatory constraints and the need to justify the initial investment are key economic and regulatory hurdles. Mitigation involves a proactive commitment with regulatory bodies and a data-driven approach to demonstrate the economic value.
- Resistance to change on the part of operators and technicians accustomed to Traditional methods can hinder the adoption of technologies driven by AI. To overcome this, programs must be implemented comprehensive training and change management strategies to facilitate transition. Involve employees in the implementation process to foster a sense of ownership and clearly communicate the benefits and

IAGEN value is important stocks.

- The need to develop the necessary skills and experience within the workforce to effectively use and manage IAGEN is another challenge. Invest in specialized training programs that focus on AI and data analysis for the oil and gas sector and fostering a culture data-driven within the organization are key strategies. Addressing the Cultural resistance and the skills gap require a strategic approach for change management and workforce development, emphasizing in communication, training and employee engagement.
- Finally, establish alliances with technology providers and consultants specialized can ensure regulatory compliance and optimization technique. Collaboration with AI and IoT solution providers with Experience in the oil and gas industry is essential. Collaboration with external experts and technology providers is crucial to overcome the technical and regulatory challenges associated with the implementation of IAGEN and ensure successful adoption.

VIII. Economic and Environmental Impact Assessment

From an environmental perspective, the implementation of IAGEN offers the possibility of significantly reduce the impact of fracking operations in Vaca Dead. The potential decrease in water consumption, estimated at between 15 and 20%, would have positive implications for water resources management in the Neuquén region, where water is a scarce resource. The reduction in consumption of energy, from 10 to 15%, would contribute to reducing the carbon footprint of the fracturing operations.

In addition, IAGEN could help minimize environmental risks associated with the fracturing, such as water contamination and potential induced seismicity, optimize resource use and reduce waste generation, IAGEN can play a crucial role in promoting more efficient fracturing practices

1. To the

sustainable in Vaca Muerta, addressing growing environmental concerns and regulatory pressures.

IX. Addressing Technical Integration and Data Management

The integration of artificial intelligence systems with SCADA and DCS systems existing in oil and gas operations presents technical complexities significant. This includes challenges such as data format incompatibility, differences in communication protocols and the need for an exchange of secure and reliable data. The integration of modern AI algorithms with legacy controls that may have processing power and connectivity limited also poses difficulties.

Data quality, accuracy and integrity are critical to the performance of the AI models used in IAGEN. In organizations In oil and gas, there are often data silos, fragmented data sources, and inconsistencies in data formats. Therefore, robust strategies are needed. data management systems that include data governance frameworks, data platforms, Data integration and data quality assurance processes. Ensuring quality of data and implementing effective data management practices are requirements fundamental to the successful deployment and operation of IAGEN.

To achieve seamless integration and efficient data management, it is recommended the use of open communication standards and protocols to facilitate data exchange between IAGEN and control systems. Adopting middleware solutions and API integrations can bridge the gap between the platforms Modern AI and legacy infrastructure. Invest in integration platforms data to consolidate information from various sources into a data lake or unified data warehouse is also a key strategy. In addition, it is important Implement automated data validation and cleansing channels to ensure data quality. A combination of technological solutions and strategic approaches to data Data management can help overcome the challenges of integrating IAGEN with existing systems and ensure the availability of high-quality data.

X. Strategies for Successful AI Adoption and Change Management

For successful adoption of IAGEN, it is critical that organizations oil and gas companies cultivate a culture that values data and analytics in their business processes decision-making. The support and endorsement of executive leadership are equally crucial to driving AI initiatives and providing the necessary resources.

The development of a comprehensive change management plan that covers strategies for Communication, stakeholder engagement and risk management are essential to facilitate the transition.

Invest in training programs aimed at providing employees with the skills skills needed to understand, use and manage tools driven for AI like IAGEN is of utmost importance.

Promote a collaborative environment between technical teams, experts in the subject matter and AI specialists will ensure successful implementation and knowledge transfer.

A phased approach to implementation is recommended, starting with projects pilot in controlled environments to validate the benefits and build confidence before a large-scale deployment.

Finally, establishing clear metrics for success, defining indicators Key performance indicators (KPIs) to measure the impact of IAGEN implementation on the efficiency, cost reduction and sustainability, will allow us to evaluate its effectiveness.

Successful adoption of AI requires a holistic approach that addresses not only the technological aspects but also organizational culture, leadership support, workforce skills and change management processes.

XI. Conclusion and Future Directions

The implementation of IAGEN for the optimization of water and energy in the Hydraulic fracturing in Vaca Muerta represents a transformative opportunity for the oil and gas industry in Argentina.

The key findings of this analysis highlight IAGEN's potential to generate substantial benefits in terms of operational efficiency, cost reduction and environmental sustainability. IAGEN's ability to analyze data in real time and Dynamically adjusting operating parameters offers a significant advantage over traditional methods, allowing for more efficient use of resources and a smaller environmental footprint.

The adoption of artificial intelligence is becoming an imperative strategic for companies in the oil and gas sector seeking to improve their efficiency, sustainability and competitiveness in a constantly changing energy market evolution. IAGEN is presented as an innovative solution that can help operators in Vaca Muerta to achieve these objectives.

Future lines of research could focus on exploring models of Even more advanced AI, including generative AI for fluid design novel fracturing. The integration of real-time geological data and the Subsurface modeling with IAGEN also represents a promising area. In addition, the development of AI-powered predictive maintenance solutions for fracturing equipment could further optimize operations. Finally, the The application of AI to optimize other aspects of oil and gas production in Vaca Muerta deserves further exploration.

In conclusion, IAGEN has the potential to revolutionize fracking practices. hydraulics in Vaca Muerta, contributing to a more sustainable energy future and efficient for Argentina.

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

Parameter	Traditional Methods	IAGEN
Parameter Setting	Fixed, data-driven historical and guidelines generals.	Dynamic, based on data analysis in time real and predictions.
Data Analysis	Mainly manual, post-operative analysis.	Automated, analysis in real-time data operational, geological and environmental.
Optimization of Resources	Approach static, potential of overconsumption.	Dynamic optimization and personalized of the water consumption and energy.
Adaptability	Limited capacity for adapt to variations	High adaptability to the changing conditions

	in real time.	from the site.
Automation	Settings mainly manuals.	Automation of operational adjustments to through integration with control systems.

Table 2: Key Performance Indicators (KPIs) for IAGEN Implementation

KPI Category	Metrics KPI Specific	Target/Line Base (Example)	Fountain of Data/Method of Measurement
Water Consumption Reduction	of the water consumption per well/stage	Reduction of the 15-20% compared to the baseline historical.	Flow sensors, records operatives.
Consumption of Energy	Reduction of the consumption energetic by stage of fracturing	Reduction of the 10-15% compared to the baseline historical.	Monitoring of the consumption energetic of the teams.

Operating Cost Reduction	of operating costs per well	Reduction of X% in costs totals of fracturing.	Records financial and accountants.
Efficiency of Production	Increase in the rate of recovery of hydrocarbons	Increase of Y% in production initial or EUR.	Data of production of wells.
Impact Environmental	Reduction of emissions of greenhouse gases greenhouse	Z% reduction of emissions associated with the fracturing.	Monitoring of emissions, calculations based in the consumption of energy.
Security	Number of incidents operatives	Decrease in number of incidents related to fracturing.	Records of security and incidents.

Table 3: Relevant Providers of AI and IoT Solutions in Argentina (Based on the Investigation)

Company Name	Brief Description/Specialization
AgileEngine	Software development with a focus on AI.
Altoros Labs	IT consulting and development.
Rocbird	Big Data and Intelligence solutions Artificial.
MUTT DATA	Development of AI solutions.
Xavia IoT	Development of IoT solutions.
AdaptIO	Incorporation of IoT technologies in cities.
NTT Data	Consulting, transformation, technology and operation.
QuadMinds	Internet of Things Solutions (IoT) for logistics and supply chain supply.
Wolox	Software company specialized in technological solutions for startups and companies.

BGH Cloud Tech	Cloud service provider.
Taller Technologies	Software development services in C/C++, embedded applications, mobile and web.
Epidata	Multinational architecture firm of software.
Edrans	IT management service provider and outsourcing.
Morean	Development agency specialized in software, UX and QA.
Crunchloop	Internet of Things development company Things.
iomic	Company specialized in development of IoT.
Patagonian	Technology company specialized in software development.
IT4W	Business intelligence company specialized in MicroStrategy.

Julasoft	Software development company.
Kelsus	Software development company.
SimTLiX	Software development company.
IMAJINE LLC	Company specialized in development of IoT and IoT solutions.
Vates	Software development company.
Blue Patagon	Experienced consultant in analytical and business solutions Intelligence.
OutsourcingDev	Development outsourcing company of software.
DBi	Data and transformation experts digital.
Solutica SRL	Company with experience in projects software integration and development tailored.
IThreex Global	Company specialized in Intelligence Artificial, Big Data and development

	cloud software.
Analytics Solvers	Pioneer in Latin America in Intelligence Artificial and Machine Learning.

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