# Deliverable report 11

## AI and IAGEN Application Use Case

## Water and Energy Optimization in Fracturing Using IAGEN in Vaca Muerta, Neuquén

### I. Introduction

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

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

Traditional fracturing methods often employ fixed parameters, limiting their ability to adapt to the inherent heterogeneity of reservoirs. This lack of flexibility leads to inefficiencies in resource utilization, increasing costs and impacting the sustainability of operations. The intrinsic variability of the Vaca Muerta shale reservoirs therefore requires dynamic and adaptive approaches to hydraulic fracturing, rendering methodologies based on static parameters inadequate. The magnitude of the operations amplifies inefficiencies in water and energy consumption, underscoring the urgency of finding optimized solutions.

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

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

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

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

The purpose of this report is to provide a comprehensive, expert-level analysis of IAGEN's potential for optimizing hydraulic fracturing in the Vaca Muerta region, supported by current research and industry insights. The scope includes a detailed examination of the technology, its benefits, implementation challenges, and strategic implications, with a particular focus on 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 mix of organic-rich shales and interfingered carbonates, presenting both opportunities and challenges for hydrocarbon extraction. This geological complexity is a key factor contributing to the variability in reservoir properties. Indeed, the formation exhibits significant heterogeneity in mechanical properties such as Young's modulus and Poisson's ratio, reinforcing the need for adaptive fracturing strategies.

Suboptimal designs in multistage 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 primary drivers of the inefficiencies observed with traditional fracturing methods. Understanding these characteristics is critical to effectively adapting IAGEN solutions.

The high failure rate in fractures underscores the significant opportunity for improvement offered by AI-driven design.

The hydraulic fracturing process in Vaca Muerta is characterized by the intensive injection of large volumes of water at high pressure. This high demand for water is particularly worrying in the Neuquén plateau, a region facing water resource scarcity.

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

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

The growing focus on environmental sustainability and the existence of regulations in

Neuquén create a strong incentive for the adoption of IAGEN, which can directly address water and energy efficiency and potentially facilitate regulatory compliance.

## III. Comprehensive Application of IAGEN in the Fracturing Process

IAGEN focuses on transforming the fracturing process through real-time data integration and analysis. This enables proactive adjustments 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 on real-time data is a key advantage of IAGEN. This enables a more proactive and efficient approach to fracturing.

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

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

IAGEN's primary function is the dynamic optimization of water and energy consumption during fracturing. This addresses the key challenges identified above. By analyzing real-time data, IAGEN can automatically adjust operating parameters to achieve optimal and customized resource utilization. This adaptability is crucial for efficiency. The direct focus on water and energy optimization positions IAGEN as a solution that directly addresses the most pressing environmental and economic concerns related to fracturing in Vaca Muerta.

## IV. Detailed Analysis of Technologies and Models Used

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

- Regression models and decision trees

Regression models and decision trees allow fracturing fluid behavior to be predicted and operating parameters to be adjusted accordingly. These models are effective in identifying linear and nonlinear relationships in operating data.

- Deep neural networks

Deep neural networks, on the other hand, have the ability to analyze large volumes of data to identify complex, nonlinear patterns in fluid dosing and energy consumption. Their ability to handle the high dimensionality of fracturing data makes them particularly valuable.

- Gradient Boosting (GBMs)

Gradient Boosting Models (GBMs) have demonstrated strong performance in predicting oil and liquids production after hydraulic fracturing, suggesting their potential for production forecasting within IAGEN.

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

- Convolutional neural networks

Advanced architectures such as Self-Attention Convolutional Neural Networks (SACNN) and Mutated Particle Cluster Optimization-ANN (MPSO-ANN) have been employed for high-accuracy prediction of gas probability distributions in reservoirs, highlighting the potential for IAGEN to incorporate sophisticated models for subsurface analysis. Furthermore, the combination of the Transformer framework with Multi-Objective

Particle Cluster Optimization (MOPSO) has been used to optimize injection-production parameters in gas flooding, demonstrating the potential of AI for multi-objective optimization in reservoir management.

- IAGEN

IAGEN can integrate a wide range of machine learning models, each suited for specific tasks within the fracturing optimization process, from fluid behavior prediction to production forecasting and injection strategy optimization. The choice of 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 on wells and equipment capture critical information on pressure, flow, and energy consumption. This information forms the basis for IAGEN's analysis.

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

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

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

A comprehensive IoT sensor network is essential to providing IAGEN with the continuous, high-resolution data necessary for accurate, real-time analysis and optimization. Different types of sensors provide insight into 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 and real-time data 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 facilitates the identification of patterns and trends in reservoir behavior and operating parameters.

The sheer volume and velocity of data generated during fracking requires a robust Big Data infrastructure to effectively store, manage, and process this information for IAGEN. Cloud-based solutions are likely essential to manage the scale of the data.

## V. Agentic Flow Proposal for the Implementation of IAGEN

### 1. IAGEN Agents Concept

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

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

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

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

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

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

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

## 2. IAGEN 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 oil and gas industry. By simplifying the development and deployment of AI solutions, access to these technologies is democratized, allowing professionals without deep technical training to create and customize agents tailored to their specific needs.

This logic reduces the costs associated with custom software development, streamlines experimentation and iteration, and allows for easier adaptation to changes in operating and reservoir conditions. By complementing the predictive and generative models described above, AI agents can automate complex workflows, from real-time data collection and analysis to proactive decision-making and recommendation generation, thereby maximizing efficiency and productivity.

Furthermore, the use of no-code and low-code platforms for creating AI agents allows for greater flexibility and scalability. These tools typically offer intuitive interfaces and pre-built components that can be assembled and customized without the need to write code from scratch. This accelerates development and fundamentally facilitates integration with existing systems and adaptation to new data sources or operational requirements. By reducing the dependence on specialized developers and allowing greater involvement of subject matter experts, a culture of innovation and collaboration is fostered, where technical knowledge and industry experience combine to create more effective, less expensive AI solutions that increase optimization capabilities for different tasks. In short, we must move toward a hybrid approach that combines analytical and predictive methods with the automation and adaptation capabilities of AI agents.

3. **Proposed AI Agent Design Powered by IAGEN**

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

a. The Data Collection and Validation phase plays a central role in optimizing water and energy consumption during hydraulic fracturing. Emphasizes the need for accurate, high-quality data from IoT sensors, such as flow, pressure, temperature, and energy consumption meters, as well as historical records of previous operations. This stage involves detailed data integration, cleaning, and preprocessing processes, ensuring that the information fed into the models accurately reflects actual resource use at each stage of the fracturing process.
b. During the Predictive Analysis and Modeling phase, machine learning models such as Gradient Boosting Machines (GBM), artificial neural networks (ANN), and deep learning architectures are applied to identify water and energy consumption patterns across different pumping configurations and stage designs. Using feature engineering techniques, key variables that influence resource efficiency are extracted, enabling the construction of predictive models that anticipate consumption based on geological, operational, and environmental parameters.
c. The Scenario Generation and Recommendations stage uses generative models and simulations to evaluate alternative fracturing configurations. Combinations of injection rates, fluid viscosities, pressures, and pumping sequences are analyzed to determine adjustments that reduce the volume of water and energy required without compromising well productivity. Optimization criteria include resource savings, wellbore stability, and environmental impact.
d. In the Continuous Monitoring and Adjustment Implementation phase, the recommendations generated by IAGEN agents are integrated with control systems such as SCADA or DCS, enabling automatic adjustments in real time. KPIs related to water use by stage, pumping energy efficiency, and specific consumption per production unit are continuously monitored. This phase ensures that operating parameters remain within established efficiency margins.

e. Finally, Continuous Feedback and Optimization establishes a closed loop of improvement, where models are periodically retrained with new operating data. This allows them to adapt to changes in reservoir geology, fracturing technologies, or resource availability. This iterative approach is critical to maintaining sustained efficiency in water and energy use.

**Within this flow, each IAGEN agent performs specialized functions:**

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

- The Analytical Agent processes this information to identify deviations in efficiency and predict future behaviors that could 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 analysis and simulation, formulating adjustment strategies that reduce water and energy use while maintaining operational integrity.

- Finally, the Monitoring Agent oversees the implementation of recommendations, detects deviations in KPIs, and sends feedback to the analytical models for continuous improvement.

**Concrete Example of Implementation in Pilot Operation**

Part One

- IAGEN is being implemented in a specific pilot phase to adjust water dosage and energy parameters during a fracturing operation.
- During this test, higher than optimal consumption is identified at certain critical operating intervals.
- IAGEN, by analyzing real-time data provided by sensors installed in the well and fracturing equipment, detects these consumption anomalies.

Second

- IAGEN's Analytical Agent processes pressure, flow, and energy consumption data, identifying patterns that indicate inefficient water dosing and high energy consumption relative to current geological and operational conditions.

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 made 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 operating parameters after implementing the adjustments, confirming a significant reduction in water and energy consumption in previously problematic intervals. The operator notes a decrease in water consumption that is in line with the 15 to 20% range reported in pilot studies, and an optimization of energy consumption within the 10 to 15% range under these controlled operating conditions.

This specific use case allows us to specifically observe IAGEN's ability to identify and correct inefficiencies in real time during fracturing operations in Vaca Muerta.

The successful implementation of IAGEN at this operation lays the groundwork for 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 well types, both vertical and horizontal, and various stages of the fracturing process. The 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 fracturing practices throughout the Vaca Muerta formation.

**VI. Strategic Benefits and Opportunities**

- Pilot studies have demonstrated potential reductions in water consumption of 15 to 20% through dynamic dosage adjustments. This directly addresses concerns about water scarcity.
- A 10 to 15% reduction in energy consumption has also been observed 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 cost reductions, increased operational efficiency, and improved risk management in the oil and gas sector.
- The 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 demonstrating the technology's value proposition.
- Traditional approaches rely on fixed parameters and manual adjustments, limiting their ability to adapt to real-time variations. This contrasts with IAGEN's

dynamic optimization. IAGEN automates and customizes operational adjustments, leveraging predictive analytics to minimize errors and optimize resource use. This reduces reliance on manual intervention and improves accuracy. IAGEN's ability to automate and adapt in real time provides a significant advantage over traditional, static methods, leading to more efficient and responsive fracturing operations.

- Early detection of anomalies through IAGEN can prevent operational failures and improve safety. This proactive approach minimizes risks and downtime.
- Reducing water and energy consumption contributes to a more environmentally friendly operation, which facilitates compliance with environmental regulations. This improves the company's sustainability profile.
- Operational optimization translates into lower costs and improved profit margins, which increases market competitiveness. This provides a significant strategic advantage for early adopters.
- Companies that adopt AI technologies in the oil and gas sector can gain a competitive advantage through increased productivity and efficiency.
- Beyond immediate cost savings, IAGEN offers strategic benefits related to safety, environmental responsibility, and market positioning, contributing to a long-term competitive advantage.

## VII. Implementation Challenges and Robust Strategies

- Short-term investment in AI agent implementation teams in technology and training: Investment is required in proofs of concept and pilot testing. The focus here must be on developing the talent needed to implement these solutions, as there is a trend toward cost reduction in systems that enable "no-code" and "low-code" automation. For the first stage, it is also recommended to recruit teams with experience in AI agent design and implementation. Finally, it is key to form an in-house team to support and foster an agentic culture that redefines human-machine interaction.
- Integrating IAGEN with legacy systems, such as SCADA (Supervisory Control and

Data Acquisition) and DCS (Distributed Control Systems), presents a significant technical challenge. To mitigate this, specialized interfaces and middleware solutions can be developed to ensure seamless data flow between IAGEN and existing systems. Adopting open communication standards and implementing hybrid control systems can also facilitate integration.

- Ensuring the quality and integrity of the data that feeds IAGEN's models is another crucial hurdle. To address this, robust data validation and cleansing processes must be implemented. Investing in data integration platforms to unify information from diverse sources and establishing data governance policies with a dedicated team are essential steps.
- The integration of AI can introduce new vulnerabilities to the critical infrastructure of SCADA systems in the oil and gas sector, requiring robust cybersecurity measures. Implementing multi-layered cybersecurity measures, including firewalls, intrusion detection systems, and network segmentation, along with regular security audits and strict access controls, is critical.
- Handling the high volume and velocity of data for real-time analysis places significant processing demands.
- Using edge computing to process data locally, reducing latency and bandwidth requirements, along with employing scalable cloud-based platforms for data storage and processing, are effective mitigation strategies.
- Technical integration, data quality, and cybersecurity are critical challenges 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, collaborations with specialized regulatory agencies and consultants can be established to ensure ongoing compliance. IAGEN's monitoring capabilities can also be used to track key environmental parameters and ensure adherence to standards.
- Justifying the initial investment required for IAGEN implementation is an economic obstacle. High initial costs can be a constraint, and uncertainty about

the return on investment can raise concerns. To address this, detailed cost-benefit analyses and pilot projects should be developed to validate the economic benefits of IAGEN.

- Highlighting the potential for significant cost savings through reduced resource consumption and downtime is crucial. Regulatory compliance and the need to justify the initial investment are key economic and regulatory hurdles. Mitigation involves proactive engagement with regulatory bodies and a data-driven approach to demonstrating economic value.
- Resistance to change among operators and technicians accustomed to traditional methods can hinder the adoption of AI-powered technologies. To overcome this, comprehensive training programs and change management strategies must be implemented to facilitate the transition. Involving employees in the implementation process to foster a sense of ownership and clearly communicating the benefits and value of AIGEN are important actions.
- The need to develop the necessary skills and experience within the workforce to effectively use and manage AIGEN is another challenge. Investing in specialized training programs focused on AI and data analytics for the oil and gas sector and fostering a data-driven culture within the organization are key strategies. Addressing cultural resistance and the skills gap requires a strategic approach to change management and workforce development, emphasizing communication, training, and employee engagement.
- Finally, establishing partnerships with specialized technology providers and consultants can ensure regulatory compliance and technical optimization. Collaboration with AI and IoT solution providers with experience in the oil and gas industry is critical. Collaboration with external experts and technology providers is crucial to overcome the technical and regulatory challenges associated with AIGEN implementation and ensure successful adoption.

## VIII. Economic and Environmental Impact Assessment

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

Furthermore, IAGEN could help minimize environmental risks associated with fracking, such as water contamination and potential induced seismicity . [1] By optimizing resource use and reducing waste generation, IAGEN can play a crucial role in promoting more sustainable fracking practices in Vaca Muerta, addressing growing environmental concerns and regulatory pressures.

**IX. Addressing Technical Integration and Data Management**

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

Data quality, accuracy, and integrity are critical to the performance of the AI models used in IAGEN. Oil and gas organizations often face data silos, fragmented data sources, and inconsistent data formats. Therefore, robust data management strategies are needed, including data governance frameworks, data integration platforms, and data quality assurance processes. Ensuring data quality and implementing effective data management practices are fundamental requirements for the successful deployment and operation of IAGEN.

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

**X. Strategies for Successful AI Adoption and Change Management**

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

Developing a comprehensive change management plan that encompasses communication strategies, stakeholder engagement, and risk management is essential to facilitating the transition.

Investing in training programs aimed at equipping employees with the skills needed to understand, use, and manage AI-powered tools like IAGEN is of utmost importance.

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

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

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

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

**XI. Conclusion and Future Directions**

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

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 adjust operating parameters offers a significant advantage over traditional methods, enabling more efficient resource utilization and a smaller environmental footprint.

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

Future research could focus on exploring even more advanced AI models, including generative AI for the design of novel fracturing fluids. Integrating real-time geological data and subsurface modeling with AIGEN also represents a promising area. Furthermore, developing AI-powered predictive maintenance solutions for fracturing equipment could further optimize operations. Finally, the application of AI to optimize other aspects of oil and gas production in Vaca Muerta warrants further exploration.

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

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

| Parameter | Traditional Methods | IAGEN |
| --- | --- | --- |
| Parameter Setting | Fixed, based on historical data and general guidelines. | Dynamic, based on real-time data analysis and predictions. |
| Data Analysis | Mainly manual, post-operation analysis. | Automated, real-time analysis of operational, geological, and environmental data. |
| Resource Optimization | Static approach, potential for overconsumption. | Dynamic and personalized optimization of water and energy consumption. |
| Adaptability | Limited capacity to adapt to real-time variations. | High adaptability to changing reservoir |

| | | |
|---|---|---|
| | | conditions. |
| Automation | Mainly manual adjustments. | Automation of operational adjustments through integration with control systems. |

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

| KPI Category | Specific KPI Metric | Target/Baseline (Example) | Data Source/Measurement Method |
|---|---|---|---|
| Water Consumption | Reduction of water consumption per well/stage | 15-20% reduction from the historical baseline. | Flow sensors, operating records. |
| Energy Consumption | Reduction of energy consumption per fracturing stage | 10-15% reduction from the historical baseline. | Monitoring the energy consumption of the equipment. |
| Operating Costs | Reduction of operating costs | X% reduction in total fracturing | Financial and accounting |

| | | | |
|---|---|---|---|
| | per well | costs. | records. |
| Production Efficiency | Increased hydrocarbon recovery rate | Y% increase in initial production or EUR. | Well production data. |
| Environmental Impact | Reduction of greenhouse gas emissions | Z% reduction in emissions associated with fracking. | Emissions monitoring, calculations based on energy consumption. |
| Security | Number of operational incidents | Decrease in the number of fracking-related incidents. | Security and incident logs. |

Table 3: Relevant AI and IoT Solution Providers in Argentina (Research Based)

| Company Name | Brief Description/Specialization |
|---|---|
| AgileEngine | Software development with a focus on AI. |

| | |
|---|---|
| Altoros Labs | IT consulting and development. |
| Rocbird | Big Data and Artificial Intelligence solutions. |
| 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 (IoT) solutions for logistics and supply chain. |
| Wolox | Software company specializing in technological solutions for startups and businesses. |
| BGH Cloud Tech | Cloud service provider. |
| Taller Technologies | Software development services in C/C++, embedded, mobile, and web applications. |

| | |
|---|---|
| Epidata | Multinational software architecture company. |
| Edrans | IT management and outsourcing services provider. |
| Morean | Development agency specializing in software, UX and QA. |
| Crunchloop | Internet of Things development company. |
| iomic | Company specialized in IoT development. |
| Patagonian | Technology company specialized in software development. |
| IT4W | Business intelligence company specializing in MicroStrategy. |
| Julasoft | Software development company. |
| Kelsus | Software development company. |
| SimTLiX | Software development company. |

| | |
|---|---|
| IMAJINE LLC | Company specialized in the development of IoT and IoT solutions. |
| Vates | Software development company. |
| Blue Patagon | Consultant with experience in analytical solutions and Business Intelligence. |
| OutsourcingDev | Software development outsourcing company. |
| DBi | Experts in data and digital transformation. |
| Solutica SRL | Company with experience in integration projects and custom software development. |
| IThreex Global | Company specialized in Artificial Intelligence, Big Data, and cloud software development. |
| Analytics Solvers | Pioneer in Latin America in Artificial Intelligence and Machine Learning. |

Sources cited

1. Argentina's Vaca Muerta: 10 Years of Fracking and Local Resistance - NACLA |, accessed March 17, 2025, https://nacla.org/argentina-vaca-muerta-fracking-resistance

2. An Overview of Recent Developments and Understandings of ..., accessed: March 17, 2025, https://www.mdpi.com/2076-3417/14/4/1366
3. Argentina oil and gas sector: Vaca Muerta shale can drive near-term growth and fuel medium-term opportunities - Deloitte, accessed: March 17, 2025, https://www2.deloitte.com/us/en/insights/economy/americas/vaca-muerta-argentina-energy-sector-boom.html
4. Systematic Analysis of Novel Machine Learning Techniques for Hydraulic Fracturing Optimization - Preprints.org, accessed: March 17, 2025, https://www.preprints.org/manuscript/202404.1945
5. Robotics and artificial intelligence in unconventional reservoirs: Enhancing efficiency and reducing environmental impact., accessed: March 17, 2025, https://wjarr.com/sites/default/files/WJARR-2024-3185.pdf
6. The Vaca Muerta Tribunal Delegation - Rights of Nature Tribunal, accessed: March 17, 2025, https://www.rightsofnaturetribunal.org/vaca-muerta/
7. Balancing energy security and a healthy environment | SEI, accessed: March 17, 2025, https://www.sei.org/publications/energy-environment-vaca-muerta-fracking/
8. Defending communities from fracking's advance in Argentina - Aida-americas.org, accessed: March 17, 2025, https://aida-americas.org/en/blog/defending-communities-fracking-s-advance-argentina
9. Argentina and fracking - Global Energy Monitor - GEM.wiki, accessed: March 17, 2025, https://www.gem.wiki/Argentina_and_fracking
10. Argentina Lays Regulatory Foundation to Breathe Life Into Vaca Muerta - JPT, accessed March 17, 2025, https://jpt.spe.org/argentina-lays-regulatory-foundation-breathe-life-vaca-muerta
11. AI-Based Estimation of Hydraulic Fracturing Effect - OnePetro, accessed: March 17, 2025, https://onepetro.org/SJ/article-pdf/26/04/1812/2475386/spe-205479-pa.pdf/1
12. An Artificial Intelligence-Based Model for Performance Prediction of Acid Fracturing in Naturally Fractured Reservoirs - PMC, accessed: March 17, 2025, https://pmc.ncbi.nlm.nih.gov/articles/PMC8173587/

13. A Review of AI Applications in Unconventional Oil and Gas Exploration and Development, accessed: March 17, 2025, https://www.mdpi.com/1996-1073/18/2/391
14. Innovative Artificial Intelligence Approach in Vaca Muerta Shale Oil Wells for Real-Time Optimization, accessed March 17, 2025, https://www.researchgate.net/publication/335884274_Innovative_Artificial_Intelligence_Approach_in_Vaca_Muerta_Shale_Oil_Wells_for_Real_Time_Optimization
15. IoT for Oil & Gas: Ultimate Control | softengi.com, accessed March 21, 2025, https://softengi.com/blog/iot-for-oil-and-gas/
16. IoT for Oil and Gas Industry: Advantages, Features, and Use Cases..., accessed: March 22, 2025, https://a-team.global/blog/iot-for-oil-and-gas-industry-advantages-features-and-use-cases/
17. Sensori™ fracture monitoring service - Halliburton, acceso: marzo 21, 2025, https://www.halliburton.com/en/products/sensori-fracture-monitoring-service
18. Application of Machine Learning in Hydraulic Fracturing: A Review | ACS Omega, accessed: March 22, 2025, https://pubs.acs.org/doi/10.1021/acsomega.4c11342
19. Frac Pond Level Monitoring Wireless Solution Case Study, accessed: March 17, 2025, https://oleumtech.com/solutions/case-study-wireless-frac-pond-level-monitoring-solution
20. www.cloudera.com, accessed March 22, 2025, https://www.cloudera.com/content/dam/www/marketing/resources/datasheets/big-data-streaming-and-predictive-analytics-in-oil-and-gas.pdf?daqp=true
21. Big Data in Oil and Gas Industry | Innowise Blog, accessed: March 23, 2025, https://innowise.com/blog/big-data-in-oil-and-gas/
22. Oil & Gas Industry - Composable | Intelligent DataOps, accessed: March 23, 2025, https://composable.ai/oil-and-gas/
23. Big Data in Oil and Gas: Unlocking Insights for Success, accessed: March 23, 2025, https://www.quantzig.com/case-studies/big-data-analytics-in-oil-and-gas-industry/
24. Big Data in Oil & Gas: Adoption, Use Cases, Benefits - ScienceSoft, accessed: March

23, 2025, https://www.scnsoft.com/oil-gas/big-data
25. Edge AI in Action in The Oil & Gas Industry - barbara.tech, accessed: March 17, 2025, https://www.barbara.tech/blog/edge-ai-in-action-in-the-oil-gas-industry
26. AI & ML in Oil & Gas Market Size, Share | CAGR of 11%, accessed: March 24, 2025, https://market.us/report/ai-ml-in-oil-gas-market/
27. (PDF) Problems of integrating artificial intelligence with SCADA ..., accessed: March 24, 2025, https://www.researchgate.net/publication/389384425_Problems_of_integrating_artificial_intelligence_with_SCADA_systems
28. Advancements in the integration and optimization of control systems: Overcoming challenges in DCS, SIS, and PLC implementations for, accessed: March 24, 2025, https://oarjpublication.com/journals/oarjms/sites/default/files/OARJMS-2022-0095.pdf
29. Control Systems in the Oil and Gas Industry: Challenges and Innovation, accessed: March 24, 2025, https://industrialautomationco.com/blogs/news/control-systems-in-the-oil-and-gas-industry-challenges-and-innovations
30. Digital Transformation in Oil and Gas: Leveraging AI for Predictive Maintenance - OGGN, accessed: March 24, 2025, https://oggn.com/digital-transformation-in-oil-and-gas-leveraging-ai-for-predictive-maintenance/
31. AI in Oil and Gas: Preventing Equipment Failures Before They Cost Millions, accessed: March 25, 2025, https://energiesmedia.com/ai-in-oil-and-gas-preventing-equipment-failures-before-they-cost-millions/
32. Legacy Systems Are Draining Your Profits: The Urgent Need for AI Integration, accessed: March 18, 2025, https://www.capellasolutions.com/blog/legacy-systems-are-draining-your-profits-the-urgent-need-for-ai-integration
33. Digital transformation in oil and gas—how energy companies can fix legacy data for

the best AI advantage | Kearney, accessed: March 18, 2025, https://www.kearney.com/industry/energy/article/digital-transformation-in-oil-and-gas-how-energy-companies-can-fix-legacy-data-for-the-best-ai-advantage
34. AI in Oil and Gas: Preventing Equipment Failures Before They Cost Millions - Insights Global, accessed: March 19, 2025, https://www.insights-global.com/ai-in-oil-and-gas-preventing-equipment-failures-before-they-cost-millions/
35. Drilling Down: How AI is Changing the Future of Oil and Gas - Sand Technologies, accessed: March 26, 2025, https://www.sandtech.com/insight/drilling-down-how-ai-is-changing-the-future-of-oil-and-gas/
36. AI in Oil and Gas: 7 Best Practices for Data Readiness - IPT Global, accessed: March 26, 2025, https://iptglobal.com/blog/ai-in-oil-and-gas-7-best-practices-for-data-readiness/
37. AI spells opportunity and manageable risk for the oil and gas industry - DNV, accessed: March 26, 2025, https://www.dnv.com/article/ai-spells-opportunity-and-manageable-risk-for-the-oil-and-gas-industry/
38. Data Quality Management in the Oil and Gas Sector - DQLabs, accessed: March 26, 2025, https://www.dqlabs.ai/blog/data-quality-management-in-the-oil-and-gas-sector/
39. Fueling the Future: The Intersection of AI and the Oil & Gas Industry | Oliva Gibbs LLP, accessed: March 26, 2025, https://www.jdsupra.com/legalnews/fueling-the-future-the-intersection-of-5255081/
40. AI in Oil and Gas Market Size, Growth and Forecast 2032 - Credence Research, accessed: March 26, 2025, https://www.credenceresearch.com/report/artificial-intelligence-ai-in-oil-and-gas-market
41. The great AI debate in the oil and gas industry: balancing job loss concerns with the thriving potential of AI applications - Kent, accessed: March 26, 2025, https://kentplc.com/news-insights/the-great-ai-debate-in-the-oil-and-gas-industry-balan

cing-job-loss-concerns-with-the-thriving-potential-of-ai-applications
42. From Resistance to Advocacy: Strategies for Overcoming Organizational Resistance to AI - Cognizant, accessed: March 27, 2025, https://www.cognizant.com/nl/en/insights/blog/articles/from-resistance-to-advocacy
43. Energy Industry Upgrade Using Artificial Intelligence? - EnergyNow.com, accessed: March 27, 2025, https://energynow.com/2024/03/energy-industry-upgrade-using-artificial-intelligence/
44. Industrial AI for technical professionals in the energy sector | AI..., accessed: March 27, 2025, https://www.dnv.com/training/industrial-ai-for-technical-professionals-in-the-energy-sector/
45. AI in Energy, Oil, and Gas - Courses - Tonex Training, accessed: March 27, 2025, https://www.tonex.com/training-courses/ai-in-energy-oil-and-gas/
46. AI Adoption In The Energy Grid - Tonex Training, accessed: March 27, 2025, https://www.tonex.com/training-courses/ai-adoption-in-the-energy-grid/
47. Welcome to the AI Academy | SLB, accessed: March 27, 2025, https://www.slb.com/products-and-services/delivering-digital-at-scale/artificial-intelligence-solutions/innovation-factori/ai-academy
48. Introduction to AI for the Energy Industry - NExT Training, accessed: March 28, 2025, https://www.nexttraining.net/course/introduction-to-ai-for-the-energy-industry/17966
49. Change management in tech adoption | DWF Group, accessed: March 28, 2025, https://dwfgroup.com/en/news-and-insights/insights/2024/11/how-to-handle-the-but-why-change-management-in-tech-adoption
50. Effective Change Management in Oil and Gas Project Execution - OGCS Global, accessed: March 28, 2025, https://www.ogcsglobal.com/news3/effective-change-management-in-oil-and-gas-project-execution
51. How to Apply Change Management to Technology Transformation - Prosci, accessed: March 28, 2025, https://www.prosci.com/blog/technology-transformation
52. Change management's key role in adopting new technology - Process Excellence

Network, accessed: March 28, 2025, https://www.processexcellencenetwork.com/events-change-management-business-transformation/blog/change-managements-key-role-in-adopting-new-technology
53. Digital Transformation of the Oil & Gas Industry (2025) - Whatfix, accessed: March 28, 2025, https://whatfix.com/blog/oil-gas-digital-transformation/
54. Resistance to AI: Governance and Cultural Challenges - Allganize's AI, accessed: March 28, 2025, https://www.allganize.ai/en/blog/resistance-to-ai-governance-and-cultural-challenges
55. AI in Oil and Gas: AI solutions for the Energy Industry - 7Puentes, accessed: March 28, 2025, https://www.7puentes.com/ai-solutions-for-oil-and-gas/
56. AI & ML in Oil & Gas Market Size, Forecasts Report 2025-2034, accessed: March 28, 2025, https://www.gminsights.com/industry-analysis/ai-and-ml-in-oil-gas-market
57. Top AI Companies in Argentina - Feb 2025 Rankings | DesignRush, accessed: March 28, 2025, https://www.designrush.com/agency/ai-companies/ar
58. Industrial AI | Recognize the power of Artificial Intelligence, accessed: March 28, 2025, https://www.ifs.com/ai
59. Oil and Gas Operations Powered by AI - NVIDIA, accessed: March 28, 2025, https://www.nvidia.com/en-sg/industries/energy/oil-gas-operations/
60. Top IoT companies in Argentina - Feb 2025 Reviews - GoodFirms, accessed: March 28, 2025, https://www.goodfirms.co/internet-of-things/argentina
61. Top Internet of Things Companies in Argentina - Feb 2025 Rankings..., accessed: March 17, 2025, https://clutch.co/ar/developers/internet-of-things
62. IoT Companies | IoT Solutions for the Oil and Gas Industry - Offshore Technology, accessed: March 28, 2025, https://www.offshore-technology.com/buyers-guide/leading-iot-companies-oil-and-gas/
63. YPF | IoT Application in the Oil and Gas Industry - PTC, accessed: March 17, 2025, https://www.ptc.com/en/case-studies/ypf-optimizes-communications-and-data-connectivity
64. Top Big Data Analytics Companies in Argentina - Mar 2025 Reviews - GoodFirms, accessed: March 17, 2025, https://www.goodfirms.co/big-data-analytics/argentina

65. Top Big Data Analytics Companies in Argentina - Mar 2025 Rankings | Clutch.co, access: March 28, 2025, https://clutch.co/ar/it-services/analytics
66. Team - Analytics Solvers, accessed: March 28, 2025, https://analyticssolvers.com/en/team/
67. Machine Learning and Hydraulic Fracture Simulation to Speed Up..., accessed: March 28, 2025, https://library.seg.org/doi/10.15530/urtec-2020-1353
68. Odin Ai | ai for oil and gas, accessed: March 28, 2025, https://www.skyfrac.com/
69. Integration of Real-Time Monitoring and Data Analytics To Mitigate Sand Screenouts During Fracturing Operations - JPT, accessed: March 29, 2025, https://jpt.spe.org/integration-of-real-time-monitoring-and-data-analytics-to-mitigate-sand-screenouts-during-fracturing-operations
70. US oil companies use AI for faster shale drilling to mitigate OPEC production cuts, accessed: March 29, 2025, https://www.worldoil.com/news/2024/3/14/us-oil-companies-use-ai-for-faster-shale-drilling-mitigating-opec-production-cuts/
71. How AI investors can ride the oil and gas boom | Equifund, accessed: March 29, 2025, https://equifund.com/blog/ai-investors-can-ride-oil-gas-boom/
72. Can oil and gas companies reduce their emissions at Vaca Muerta? - Dialogue Earth, accessed: March 29, 2025, https://dialogue.earth/en/business/can-oil-and-gas-companies-reduce-their-emissions-at-vaca-muerta/
73. UN Spotlight on Impacts of Argentina's Vaca Muerta Fracking Project on Indigenous Rights and Climate Change - Center for International Environmental Law | CIEL, accessed: March 29, 2025, https://www.ciel.org/news/un-spotlight-impacts-argentinas-vaca-muerta-fracking-project-indigenous-rights-climate-change/
74. In Argentina, enormous fracking potential and opposition to match - The World from PRX, accessed: March 29, 2025, https://theworld.org/stories/2016/07/30/argentina-enormous-fracking-potential-and-opposition-match

75. How to incorporate digital transformation into SCADA master planning - Control Engineering, accessed: March 29, 2025, https://www.controleng.com/how-to-incorporate-digital-transformation-into-scada-master-planning/
76. Maximizing the impact of AI in the oil and gas sector | EY - US, accessed: March 29, 2025, https://www.ey.com/en_us/insights/oil-gas/maximizing-the-impact-of-ai-in-the-oil-and-gas-sector
77. 26 Real-Time Decision Support in Optimizing Well... - Earthdoc, accessed: March 29, 2025, https://www.earthdoc.org/content/papers/10.3997/2214-4609.202477026?crawler=true&mimetype=application/pdf
78. KPI Guide: Oil & Gas Equipment & Services Industry KPIs for Investment Professionals - Visible Alpha, accessed: March 29, 2025, https://visiblealpha.com/energy/oil-gas/oil-gas-equipment-services-industry-kpis/
79. Swap Over Optimization Software - Completions - Corva, accessed: March 29, 2025, https://www.corva.ai/energy/completions/shrink-npt-and-swap-over-times
80. Optimizing Hydraulic Fracturing - DeepData, accessed: March 29, 2025, https://www.deepdata.com/optimizing-hydraulic-fracturing/
81. Quantifying Drilling Efficiencies - Why Drilling Metrics Matter - Boart Longyear, accessed: March 29, 2025, https://www.boartlongyear.com/insite/quantifying-drilling-efficiency-and-why-drilling-metrics-matter/
82. Enhancing Fracking Efficiency with FracSol's TWM - Revsolz, accessed: March 29, 2025, https://www.revsolz.com/blog/enhancing-fracking-efficiency-with-frac-sol-s-twm-empowering-engineers-with-real-time-insights
83. How to Calculate (and Improve) Pump Efficiency - WellAware Blog, accessed: March 30, 2025, https://blog.wellaware.us/blog/how-to-calculate-pump-efficiency
84. Magnetic Flowmeters for Fracking - Seametrics, accessed: March 30, 2025,

https://www.seametrics.com/applications/fracking/
85. An Artificial Intelligence Method for Flowback Control of Hydraulic Fracturing Fluid in Oil and Gas Wells - MDPI, accessed: March 30, 2025, https://www.mdpi.com/2227-9717/11/6/1773
86. Artifical Intelligence rises in drilling performance - Halliburton, accessed: March 30, 2025, https://www.halliburton.com/en/resources/the-rise-of-artificial-intelligence
87. Real Time Hydraulic Fracturing Pressure Prediction with Machine Learning - ResearchGate, accessed: March 30, 2025, https://www.researchgate.net/publication/338721846_Real_Time_Hydraulic_Fracturing_Pressure_Prediction_with_Machine_Learning
88. Engineered AI: Unapologetically optimized for the energy industry - SLB, accessed: March 30, 2025, https://www.slb.com/resource-library/insights-articles/engineered-ai-unapologetically-optimized-for-the-energy-industry