Deliverable report 53

AI and IAGEN Application Use Case

Treatment and recycling of fracking water in Vaca Muerta

I. Introduction.

The technique of hydraulic fracturing, essential for the extraction of oil and gas from shale in the Vaca Muerta formation, demands the use of vast quantities of water, estimated at around 30 million liters per well. Of this volume injected at high pressure to fracture the rock and release hydrocarbons, between 20% and 40% returns to the surface in the form of *flowback* or return fluid.

This return fluid not only contains the water originally injected, but also a complex mixture of substances carried over from the formation geological and the chemical additives used in the fracturing process. By Due to its volume and composition, *flowback* management represents a challenge. significant from both an environmental and logistical perspective.

The boom in activity in Vaca Muerta has caused a proportional increase in the generation of return water.

This situation underlines the critical importance of properly managing the *flowback* water in Vaca Muerte. Efficient management would reduce the pressure on water resources in the region, minimizing environmental impacts adverse events and meet the standards necessary for the continuity of the operations.

In this context, the treatment and recycling of the return fluid has become a strategic priority for operating companies, where the incorporation of artificial intelligence (AI) emerges as a promising solution. The magnitude of water consumption and the constant increase in *flowback* volumes indicate increasing pressure on water resources and management infrastructure waste, which makes the adoption of technologies that improve efficiency, like AI, a necessity for the long-term sustainability of operations in Vaca Muerta.

II. Challenges in return fluid management

Return water from hydraulic fracturing has a complex and potentially contaminating chemical composition. Upon returning to the surface, the *flowback* carries with it residues of the chemical additives used, such as fracturing gels, as well as elements present in the reservoir rock, which resulting in a liquid with high salinity and a high load of dissolved solids. Studies and experiences in the basin have detected the presence of compounds hazardous; returned additives and substances may be toxic, flammable and even carcinogenic, and there have been warnings about possible traces of elements natural radioactives and heavy metals in the *flowback.*

The presence of carcinogenic substances not only entails direct risks to the health, but also increases regulatory scrutiny and public concern around *flowback management,* which could affect the social license to operate of the companies in Vaca Muerta. This complex composition classifies the fluid as return as a delicate industrial waste, normatively catalogued as special or hazardous waste.

The potential environmental impacts are considerable if *flowback* is not managed properly. It can contaminate soils and underground aquifers in the event of leaks or improper disposal, generating risks to the health of local communities and affecting other economic activities.

Temporary storage in pools or tanks requires the implementation of specific engineering measures, such as waterproof coatings and systems monitoring, to prevent spills. Traditional disposal through sump wells (deep injection) carries its own risks, including increased of induced seismicity in areas where they were not previously recorded perceptible seismic movements, and the possibility of migration of contaminants in the long-term underground.

On the other hand, truck transport from the deposits to the plants Treatment carries risks of accidents and emissions, as well as high costs;

In just one year, 4,800 water truck trips were recorded. contaminated in Neuquén.

The logistical burden and risks associated with the transportation of large volumes of *flowbacks* highlight the value of on-site or near-site treatment solutions, which can reduce the need for extensive transportation.

Managing the return flow in Vaca Muerta involves technical challenges (due to its polluting composition), operational challenges (increasing volumes, logistics), and regulatory challenges, which require innovative solutions.

III. Application of AI in the treatment and recycling of return fluid

A typical internal treatment scheme begins with phase separation: Degassing equipment and liquid-solid separators remove free hydrocarbons and particles (sand, clays) from the return water. Effective phase separation is a crucial first step, as it reduces the load on the treatment stages. subsequent treatment. Then, physicochemical processes adjust parameters such as pH and precipitate metals; for example, the dosage of coagulants or stabilizers help to group fine solids.

Filtration and centrifugation systems remove remaining suspended solids, while special units can remove volatile organic compounds. To reduce high salinity, desalination technologies such as osmosis are applied.

reverse or mechanical evaporators; these require overcoming problems of scaling and membrane fouling. Finally, the treated water is stored for reuse in new fractures, and the reject concentrates (brine, sludge) are managed as waste.

The incorporation of AI models in these processes could raise significantly improve efficiency and controllability. Learning techniques Automatic well flowback detectors can predict the quality of incoming flowback in real time, based on sensor data (pH, conductivity, turbidity, hydrocarbon content) and well operating parameters. This makes it possible anticipate, for example, a salinity peak or the presence of a certain heavy metal, and proactively adjust chemical dosage or settings Membranes. Artificial neural network (ANN) models have already shown success in optimizing complex water treatment processes, learning from data historical to continuously improve performance.

Algorithms can also be trained to optimize the treatment sequence: decide the optimal flow rate through each module, when to regenerate or clean filters, or what mixture of coagulants removes contaminants at the lowest cost. An applied example is the use of *feedforward* networks with predictive control, which, According to studies, it could significantly reduce desalination costs and purification of the water produced, making the recycling option not only environmentally attractive but also the most economical for the company.

Another key area is real-time monitoring and event detection through AI. Traditional SCADA systems already collect data from sensors in the operations, but AI allows us to go beyond fixed alarms: vision algorithms computerized and multivariate analysis can detect subtle patterns that indicate an incipient problem at the treatment plant. For example, cameras and AI could identify changes in water turbidity or color that anticipate a solids overload, activating adjustments before a threshold is breached quality limit. Similarly, AI can recognize risk conditions such as a tank approaching its maximum capacity and execute automatic actions (close valves, divert flows) to avoid spills.

These “virtual operators” work 24/7 complementing human supervision, and have been shown to reduce errors and response times in oil operations digital.

Ultimately, AI can transform water treatment by optimizing processes. such as chemical dosing and quality control. It can improve Efficiency in wastewater treatment through automation processes and problem prediction. It can also help detect pathogens in water and optimize resource recovery and can analyze large data sets to understand and predict how power plants operate treatment and make better decisions in real time. It has been shown that Application of this technology can save between 20 and 30% in expenses operational and also reduce raw material costs.

The wide range of successful applications of AI in general water treatment industrial indicates significant potential for similar benefits in the context specific to *flowback* water management in the oil and gas industry.

Today, Generative AI also offers significant opportunities for optimization in the activity. Generative Artificial Intelligence (GENI) is a branch of artificial intelligence that focuses on the creation of new content, such as models, images, code or text, from existing data 7. This technology uses advanced algorithms to analyze large amounts of information, identify patterns and generate new and original content that is often indistinguishable from that created by humans.

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

1. **Concept of IAGEN agents**

In recent years, generative artificial intelligence (GAI) has revolutionized the way we interact with technology, allowing the development of systems capable of generating content, answering complex questions and assisting in high-demand cognitive tasks.

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From this capacity, a new technological architecture emerges: agents powered by IAGen. These agents are not simple conversational interfaces, but autonomous systems that can interpret instructions, make decisions, perform tasks and learn from their interactions with the environment.

An IAGen agent combines large language models with components additional features such as external tools, memory, planning and execution autonomous. 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 the real-time context changes. These qualities distinguish them from traditional chatbots, and open up a spectrum of more sophisticated and customizable.

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 linked to the technical areas of production processes, acting as assistants intelligent devices that collaborate with human teams. This ability to integrate knowledge and execute tasks autonomously transforms the way in which Organizations can scale their operations without losing quality or control.

In addition, agentic workflows—structures where multiple agents collaborate with each other to solve complex problems—allow responsibilities to be distributed between different agent profiles, each with specific functions. This generates

Hybrid work environments where humans and agents coexist, optimizing times, costs, and results. The ability to connect agents with tools such as Google Drive, CRMs or document management platforms further expands their capabilities.

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

Among the benefits of authentic workflows 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, from responsible design to human oversight. Therefore, Understanding its architecture, its operational logic and its potential impacts is essential for its effective and safe adoption in various contexts professionals.

2. IAGEN-driven agent design proposal applicable to the activity

a. Workflow objective

Maximize the reuse of fracturing water, minimizing risks, costs and waste, by deploying intelligent agents connected to sensors, systems SCADA, databases and analysis tools.

b. Workflow

Data Integration and Preprocessing Agent

Role: Collects and normalizes data from multiple sources (IoT sensors, SCADA, laboratory, meteorology, well history).

Connected tools: SCADA APIs, SQL databases, data clouds, spreadsheets calculation.

Functions:

- Detects errors and data gaps.
- Standardizes formats.
- Informs the Predictive Agent.

Flowback Quality Predictive Agent

Role: Predicts return water composition and risks in real time.

Models used: neural networks, multivariate regressions.

Inputs: variables such as pH, salinity, turbidity, heavy metals.

Actions:

- Estimates treatment needs.
- Informs the Process Control Agent.

Treatment Control and Optimization Agent

Role: Adjusts operating parameters in real time to optimize treatment.

Connections: actuators, valves, pumps, chemical dispensers.

Tasks:

- Decide optimal doses of coagulants.
- Adjust treatment sequence (filtering, desalination, etc.).
- Coordinates cleaning and predictive maintenance.

Machine Vision and Security Agent

Role: Detects visual anomalies and triggers automatic responses.
Technology: AI cameras, multispectral detection algorithms.
Functions:

- Alert for abnormal turbidity.
- Detects dangerous tank levels.
- Executes autonomous actions (closes valves, reports faults).

- **Direct benefits and comparison with traditional methods**

AI-assisted treatment and recycling approach offers tangible benefits on traditional flowback management methods.

In terms of *efficiency and costs,* intelligent process optimization can Reduce the cost per cubic meter of treated water, making recycling more profitable than conventional disposal. By dynamically adjusting the dosage of chemical reagents according to the actual water quality, avoiding excessive use of inputs, generating economic savings and fewer by-products (sludge, salts). Likewise, maximizing the recovery of reusable water implies that the operator needs to buy or extract less fresh water for future fracking, with the consequent savings.

A study suggests that by implementing predictive control with AI in plants treatment, operating costs decrease to the point that reuse is no longer just an ecological measure to become the economically optimal option. This contrasts with traditional methods where most of the waste is often discarded. part of the flowback in injection wells, incurring transportation costs and payment to third parties, in addition to the waste of water resources.

In terms of *operating times,* AI allows for faster decision-making and response to changing conditions. In a traditional scheme, samples of return water could be sent to the laboratory and days later the treatment could be adjusted; With AI models, the system adapts parameters in real time, avoiding delays in subsequent fracturing operations. This means that the time of conditioning of water for reuse is minimized, potentially reducing the cycle between fractures on a well pad. In addition, intelligent automation Reduces unplanned downtime: for example, *predictive maintenance* algorithms anticipate failures in pumps or filters (by analyzing vibrations, pressures, flow rates) and They schedule maintenance at opportune times. This would avoid interruptions surprises that in conventional methods could stop the treatment and make operations more expensive.

Operational safety and reduced environmental impact are two other areas of strengthening. An AI-optimized system requires less manual intervention.
continuous, which means less personnel directly exposed to water contaminated or at risk in the plant. While previously it was necessary to have operators monitoring tanks and valves to prevent incidents, today a good part of This monitoring is done by smart sensors; technicians can monitor remotely and only intervene when the system requests it. This reduces the risk of workplace accidents and exposure to hazardous chemicals. From the point of view Environmentally, the main benefit is that a much larger fraction of the return water can be reused rather than discarded.

In recent experiences, reuse rates close to 80% of the flowback meant hundreds of cubic meters of water that were not poured or injected, but reincorporated into the production cycle. This not only preserves natural water sources (by reducing extraction from rivers or aquifers), but also reduces the operation's environmental footprint by generating less final liquid waste. Compared with traditional disposal methods (e.g., evaporation in ponds or simple dilution), an optimized process minimizes diffuse emissions, better controls effluents, and ensures greater compliance with regulatory limits.

quality.

In short, unlike conventional flowback management –characterized by be reactive, resource-intensive and focused on final disposal–, the management AI-powered smart is *proactive,* efficient and focused on the circular water economy.

While traditional methods viewed flowback primarily as a waste to be disposed of, modern practices treat it as a resource: AI makes it easier to extract value (reusable water, even exploitable by-products) where previously there was only an environmental liability. This translates into key differences: (1) *Monitoring Continuous vs. intermittent:* IoT and AI sensors monitor water quality second by second, versus sporadic manual sampling in classic methods. (2) *Adaptive vs. Fixed Control:* Algorithms adjust pumps, valves, and dosage accordingly. dynamically according to the conditions, while in traditional plants the Setpoints are static and require human intervention to change. (3) *Comprehensive vs. segmented optimization:* AI can optimize the entire water management system (treatment, storage, reinjection) as a whole, something impractical manually when there are dozens of variables; for example, it may Balance in real time how much water to recycle on site and how much to divert to disposal external so as not to overload any unit. (4) *Traceability and compliance:* a Digital system records every liter treated, mixed or disposed of, facilitating reports automatic to the authorities, unlike traditional paperwork prone to errors.

Thanks to these differences, operations that adopt AI achieve greater reliability in flowback management, avoiding surprises and optimizing results compared to conventional methodology.

V. Challenges and implementation strategies

Despite the benefits, the adoption of AI in frac water treatment It entails challenges that require clear strategies for its effective implementation in Vaca Muerta.

From a technical point of view, one of the main obstacles is the Data availability and quality. AI models are only as good as the data.

with which they train; in unconventional deposits, the composition of the flowback can vary significantly from well to well and over time, which requires collecting a large amount of representative data. This involves installing sensors in the field (for physical-chemical variables, flow rates, etc.) and ensuring their Calibration and maintenance. Integrating these new data streams with existing systems (SCADA, laboratory records) may require IT infrastructure upgrades and secure communication protocols at remote locations.

Likewise, the development of reliable predictive models requires knowledge integrated expert: it is not enough to apply a generic algorithm, it is necessary incorporate into the model the chemical and operational rules specific to the treatment of flowback. This integration of engineering knowledge with AI is challenging and often require a multidisciplinary approach, combining data scientists with engineers process and water specialists.

It is recommended to make a short-term investment in implementation equipment. of AI agents in technology and training. Investment in testing is required concept and pilot testing. The focus here has to be on developing talent to implement, since a trend of cost reduction in systems is verified that allow “no code” and “low code” automation. For the first stage, also It is recommended to use teams with experience in design and implementation of AI agents. Finally, it is key to form an in-house team for the accompaniment and the appropriation of an agentic culture that redefines human-machine interaction.

There are also regulatory and cultural barriers to the adoption of these technologies. Environmental standards, although strict in terms of results (effluent quality, traceability), do not always explicitly contemplate the use of AI-based systems. This can create uncertainty about how they will accept authorities an automated process: for example, ensuring that an algorithm autonomous control will comply without fail with the discharge limits.

Companies must work hand in hand with regulators, demonstrating Transparency in the operation of its intelligent systems (audits of algorithms, redundancy of security measures) to gain trust.

At the organizational level, there may be resistance to change on the part of operators and middle managers accustomed to traditional methods. The introduction of AI It usually requires staff training to interpret the recommendations of the models and to manage exceptions when intervention is necessary Manually. Overcoming this cultural gap involves showing *positive results* early on (e.g., a significant reduction in costs or incidents) that help align the entire team with the new way of working.

Economically, the challenge lies in the initial capital and the justification of the Investment. Implementing AI in water treatment involves spending on sensors. additional software platforms, custom model development, and possibly field communication infrastructure (networks for data transmission). data). For some operators, especially the medium-sized or new ones in Vaca Muerta, It can be difficult to allocate budget to something they perceive as experimental. Here It is crucial to develop a gradual strategy: start with low-risk pilot projects that allow for calculating return on investment. For example, a single on-site treatment plant or a specific module (such as membrane control) could be equipped with AI and the efficiency improvement measured over several months.

If the pilot shows, say, a 15% savings in chemical costs and 10% more reused water, that data helps convince management to scale up the project. solution. Additionally, there are ways to mitigate costs: collaborate with research institutions or technology startups seeking to validate their algorithms in real-life environments, or take advantage of government incentives.

To overcome technical barriers, an effective strategy is to form the team appropriate with the relevant skills. This involves having AI experts (data scientists, developers) working side by side with engineers of the company's water processes. Together they must clearly define the *cases of* most valuable *uses* to address with AI – for example, optimizing reuse in consecutive fractures, or minimize solids in the water to protect pumps– from so that solutions focus on specific business objectives and measurable.

Another key aspect is to plan the implementation in phases: first digitize and Automate current operations (if a plant still requires a lot of manual actions, equip it with basic sensors and controls), then introduce descriptive analytics (performance dashboards), then predictive analytics (models that advise actions), and finally prescriptive analytics with autonomous AI. A phased roadmap can facilitate the absorption of change and enables learning.
at each stage.

During AI deployment, it is advisable to maintain *redundancies* and backup plans. contingency: for example, if the automated system were to fail, ensure that there is a manual operating mode that ensures incident-free continuity. This addresses reliability concerns while the technology matures.

Integration strategies also involve sharing knowledge and standardize good practices. Since several operators face the same challenge of return water, collaborative initiatives (such as industry consortia or pilot spaces in conjunction with regulatory bodies) can accelerate the learning curve.

Imagine a *demonstration project* in Vaca Muerta where multiple companies and the provincial government to test different AI solutions for flowback treatment, By disseminating results, it could generate confidence and reduce the perception of risk.

In short, the obstacles to adopting AI – whether technical, regulatory or economic – can be overcome with careful planning and piloting, with solutions tailored to local reality. The key is to align innovation with business objectives and environmental policies: thus, AI will not be seen as an imposed black box, but as an enabling tool for more efficient management.
Safe, clean and efficient water use in Vaca's unconventional reservoirs
Dead.

VI. Conclusion and recommendations

The management of the return fluid in Vaca Muerta represents a critical point where The environmental, operational, and economic dimensions of the unconventional oil industry converge. This report highlights how the treatment and recycling of Fracking water, supported by artificial intelligence tools, can transform a problem—the millions of liters of contaminated flowback—into a opportunity for continuous improvement.

Key findings indicate that it is technically feasible and beneficial to reuse much of the return water after proper conditioning, and that the AI can boost such reuse to higher levels of efficiency, reducing costs and risks simultaneously. In contrast to traditional methods of "use and throw away", smart optimization promotes a circular model where the water is kept within the production cycle as long as possible, decreasing the water footprint of shale and waste generation.

Looking ahead, concrete next steps are recommended to capitalize on these opportunities in Vaca Muerta. First, operating companies should Identify specific pilots for the application of AI in flowback treatment, ideally in collaboration with technology providers and with the support regulatory from the outset. These pilot projects will serve to adapt the solutions to local specificities (geology, water chemistry, available infrastructure) and generate local data that refine models.

Second, it is advisable that the public sector and research institutions Local governments actively support these efforts, whether by facilitating controlled experimentation (temporary permits, regulatory flexibility for pilots) or through incentives that accelerate private investment in clean technologies.

Third, the industry as a whole must foster training and the sharing of best practices around digitalization and artificial intelligence.
training for engineers and operators in analysis tools

data, as well as inter-company workshops to discuss results of different reuse strategies will help accelerate the adoption curve.

In conclusion, Vaca Muerta has the opportunity to be a benchmark in management sustainable water use in unconventional developments. The combination of policies Appropriate environmental practices, advances in AI and corporate commitment can lead to a model where each barrel of oil produced requires fewer liters of water extracted and less waste generated. Leveraging AI to optimize the life cycle Flowback will not only help to comply with current regulations in Neuquén, but which will prepare the sector for more demanding environmental standards and boost its public reputation.

The recommendations presented here invite entrepreneurs in the sector to adopt a proactive vision: investing in innovation today to ensure competitiveness and sustainability of its operations tomorrow.

With firm steps in this direction, the shale oil & gas industry in Argentina will be able to continue its growth while minimizing its water and environmental impact, demonstrating that energy development and water care can – and should – go hand in hand the hand.

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