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AI Is Getting Smarter By Combining Statistics With Vital Laws Of Science

By Adrien Caudron
and T.C. Zoboroski

As oil and gas operators face mounting technological and environmental challenges, artificial intelligence has emerged as a transformative force. It is helping the industry navigate the exceptional complexity of subsurface geological systems, intricate fluid dynamics and vast, diverse datasets, all while adhering to increasingly stringent operational constraints.

AI has a long history in oil and gas. Neural networks, decision trees and other machine learning techniques have been integral to some tasks for decades, with roots tracing back to the 1990s. Initial applications included seismic data analysis and reservoir modeling, while the early 2000s saw the introduction of AI-powered predictive maintenance systems.

Today, many companies also use generative AI to prepare and analyze data or simplify back-office tasks. However, neither traditional machine learning nor generative AI will prove suitable for all the challenges the industry faces, especially the most technical ones. To leverage AI's full capabilities, operators and service companies must enhance AI's probability-based predictions with laws of science that govern real-world phenomena.

Better known as science-based AI or physics-informed AI, this approach has numerous strengths. First, it can produce outcomes that rigorously adhere to physical laws without introducing inconsistent predictions or hallucinations. In many oil field applications, such reliability is critical for safety. It also maximizes the chance that AI will point users toward the best investments or optimizations.

Second, science-based AI can generate useful insights from fragmented and often limited data sources. Like any data analytics technique, it will yield more reliable results with clean, consistent and thorough data, but it also adapts well to noise and works even on smaller datasets where a traditional machine-learning approach would fail. Given the cost associated with gathering downhole measurements and the amount of inference the industry relies on to understand subsurface events, that strength is valuable.

Finally, science-based AI can provide transparent, scientifically grounded reasoning. This last point is particularly crucial, as it transcends the opaque "black box" solutions characteristic of early AI implementations, addressing the industry's need for interpretable and trustworthy AI.

Traditional Approaches

In making the case for science-based or physics-informed AI, it's worth highlighting that it builds on other approaches' accomplishments. In upstream operations, predictive maintenance based on machine learning has become so common that companies who fail to adopt it risk falling behind their peers.

Modern predictive maintenance delivers efficiency gains largely because of AI's ability to analyze data at speeds no human can match. By monitoring real-time sensor data to identify emerging issues and extremely subtle warning signs, AI can predict equipment failures in advance. This transforms maintenance from reactive to proactive, a change that has proven to minimize downtime, optimize schedules and extend asset lifecycles.

Meanwhile, generative AI is revolutionizing processes inside and outside the oil and gas industry thanks to its remarkable ability to rapidly search, analyze and sort through massive amounts of data. Because generative AI can be activated with simple, natural language prompts, it can be extremely accessible. However, it still needs to be applied carefully to yield reliable results.

In oil and gas production, generative AI excels at accelerating data preparation, curation and delivery, which can streamline processes and enhance efficiency across functional areas. Notable applications include process safety management, where it can improve risk assessment and mitigation strategies, and supply chain logistics optimization, where it can enhance inventory management and procurement processes.

Why First Principles Matter

Given how much AI can achieve, why bother incorporating scientific principles into it? The ultimate goal is to match the accuracy of the compute-intensive mathematical and financial modeling companies conduct to guide major decisions, and do it at a lightning-fast speed so more scenarios can be considered. This leads to consistently trustworthy answers to revenue-shaping questions, such as "how can we accelerate time to market?" and "what is the most efficient way to develop this oil and gas field?"

By strategically coupling AI with science, science-based AI generates solutions that are not only statistically probable, but also scientifically sound. While generative AI merely tries to create novel outputs and insights based on its training data, science-based AI looks for solutions that are simultaneously consistent with the training data and with the fundamental physical laws of nature.

To understand those laws' impact, consider lithology predictions. A generative AI model could analyze thousands of well logs, then predict the lithology a new well will encounter by leveraging patterns from similar geological formations. This approach, while powerful and capable of producing plausible predictions, primarily relies on sophisticated pattern-matching and semantic associations. However, it cannot fully account for unique geological conditions or physical constraints that are poorly represented in its training data. In complex scenarios, it might overlook critical anomalies or suggest physically impossible formations because it does not understand fundamental geological principles.

The risk of such mistakes could be reduced by fine-tuning the generative AI model using domain-specific knowledge and pairing it with external agents. However, it is even more effective to switch to a specialized model that accounts for the relevant laws of nature.

The laws each model should consider vary from application to application. If a model tries to replicate every law, or to simulate each one with exacting precision, it will sacrifice the speed that makes AI appealing. Instead, models should approximate the phenomena that are likely to affect the outcomes of interest.

In the oil and gas space, that still means simultaneously accounting for multiple physical principles. For example, rock particles, gases, fluids and chemicals interact continuously within reservoirs, workover systems and surface facilities, and those interactions are governed by several different physical laws.

Industry AI models also need to consider data at multiple scales. From microscopic pore throats in reservoir rock to field-wide surface operations spanning hundreds of square kilometers, each scale introduces its own physics and complexities. Modern AI architectures are evolving to handle these multiscale challenges, connecting molecular-level interactions to field-scale operations in unified models.

Ensemble Modeling's Power

If accounting for so many variables sounds like a Herculean task, it is. The key to making it manageable—and therefore possible to do within a reasonable time frame and at an affordable cost—lies in to leveraging existing work and building on established foundations. Each physical law corresponds to various mathematical models, providing a fundamental framework—akin to a skeleton in anatomy. Yet, just as a body requires muscles, tendons, and intricate systems to function, these models need additional layers of complexity to accurately represent real-world phenomena.

In the realm of AI, this comprehensive approach is known as "ensemble modeling." This technique combines diverse models to yield predictions that are more accurate and robust than those produced by a single model or algorithm alone. The power of ensemble modeling lies in its ability to harness the strengths of multiple approaches while mitigating their individual weaknesses. Understanding how to do that takes experience, and the entire ensemble must go through careful training based on the specifics of the problem users are trying to solve.

The left side of Figure 1 shows the inputs that go into developing such ensemble models. In addition to following the laws of science, the ensemble models' outputs can be given other constraints, such as the amount of capital available or the minimum distance between wells in a given area.

Like any AI model, the ensemble model's accuracy depends on relevant training data. Some of this data comes from experiments and measurements, but it's often possible and worthwhile to enrich that empirical information with simulated data.

Even a well-designed ensemble model may need to be rebuilt and retrained if the operator wants to use it in an area with different geology or fluid properties. While it is getting faster, building ensemble models takes time. However, when they are made with appropriate care, the models can deliver accurate results at a fraction of the cost historically required.

Applications So Far

Reservoir management is one of the most complex areas where science-based AI models are already delivering results. Traditionally, decline curve analysis or reservoir simulation and field management relied on historical oil and gas production data and manual interpretation and calibration. This process can take several months and sometimes delivers inaccurate results, delaying vital decisions for months and potentially basing them on insights that misrepresent an oil field's true economic value.

Conventional techniques yield incorrect assessments partly because they assume future production will follow predictable trends, sometimes failing to account for dynamic reservoir conditions or operational changes (such as new wells, workover efforts or enhanced oil recovery techniques). In contrast, AI algorithms guided by the laws of flow dynamics and simplified geological and production engineering equations can significantly improve accuracy while dramatically accelerating outputs.

Several papers published by the Society of Petroleum Engineers demonstrate science-based AI's effectiveness. For example, "AI-Powered, Lightning-Fast Production Modeling of Multi-Well and Multi-Bench Unconventional Development," which appeared in October 2023, describes an extremely fast reservoir proxy ensemble model designed to guide decisions in a complex unconventional play.

The science-based ensemble model significantly accelerated decision-making while giving extra insights to the end user, such as model explainability and confidence scores. This enabled the company's experts to improve their knowledge and forecast production before drilling. With science-based AI, they could make the most appropriate decision faster, potentially extending the lifetime value of the field and saving millions of dollars in costs.

To validate the science-based AI model, the oil and gas operator compared its results with ones from a traditional, physics-based reservoir simulation platform. As shown in Figure 2, the projections mirrored each other almost perfectly. The science-based AI model's extremely fast results do come with a minor accuracy degradation versus traditional physics-based simulation.

The science-based AI model needs to be used diligently. It is designed to produce accurate results for low-porosity and low-permeability formations and should not be applied in an oil and gas field with different properties.

AI's value can be maximized by adopting a hybrid workflow. Instead of relying on a single tool, engineers can narrow the design space with a fast predictive

FIGURE 1

Science-Based Ensemble Modeling's Inputs and Outputs

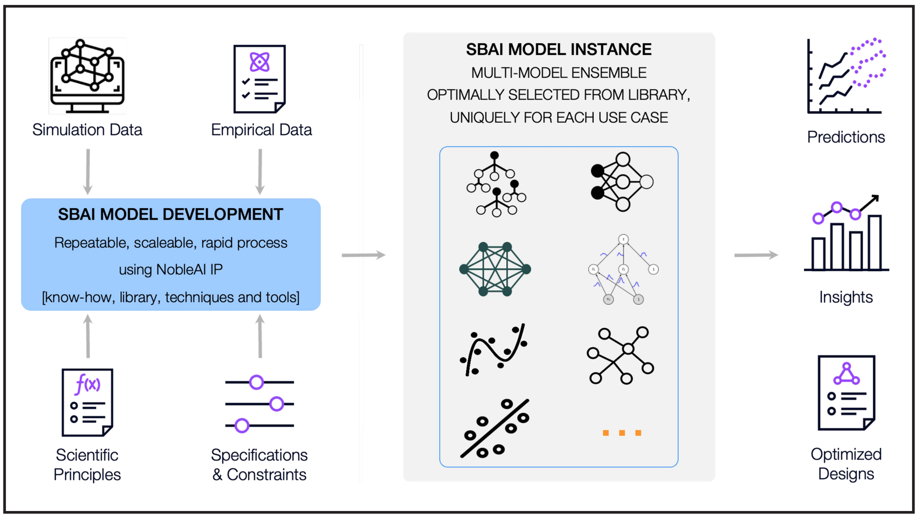
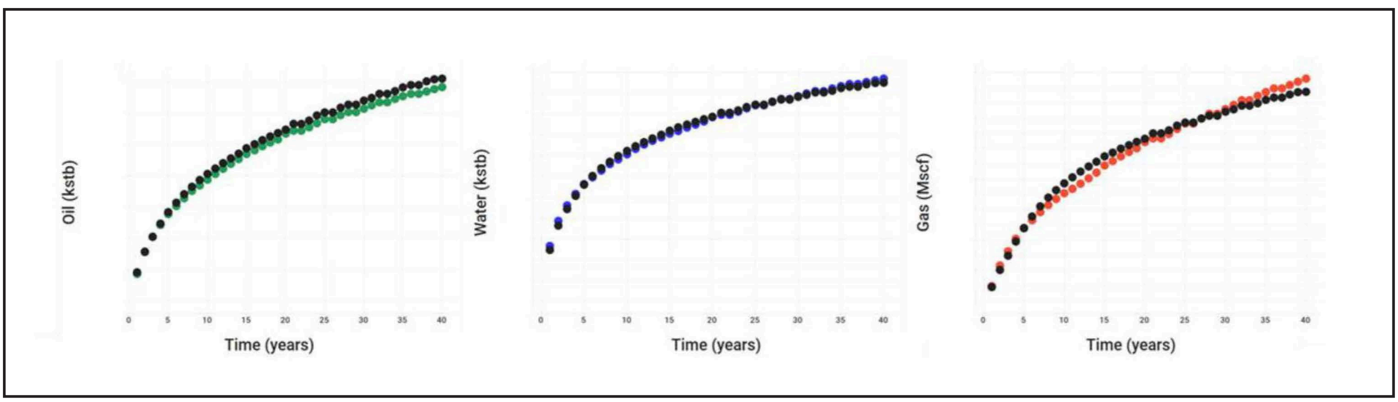


FIGURE 2

Production Profile Comparison Between Simulation Results (black) and AI Model (green, blue and red)



Source: *AI-Powered, Lightning-Fast Production Modeling of Multi-Well and Multi-Bench Unconventional Development (SPE-214818-MS)*

model, then validate the final decision with more detailed physics-informed or science-based models.

Drilling

Drilling presents another compelling example of AI's transformative potential. Traditionally, well planning relied on historical data, predictive physics models and human expertise. This conventional method's track record stretches back decades, but it takes time, requires considerable resources, and remains prone to mistakes. These realities sometimes contribute to inefficiencies and cost overruns, and in increasingly rare cases, devastating accidents.

Science-based AI can streamline well planning by analyzing data quickly. Once drilling begins, AI can combine real-time well and operations data with physics-based models to dynamically identify potential hazards. For example, they can integrate geological, geophysical and real-time drilling engineering data to surgically identify pore pressure anomalies in minutes that would have once taken weeks to model.

The impact of that speed cannot be overstated. When drilling teams get unambiguous early warnings, they can take steps to mitigate hazards long before those hazards put the crew at risk.

The Path Forward

Other upstream applications for science-based AI include virtual flow metering, a technique for estimating oil, gas and water flow rates when it is impractical to measure them directly, and asset performance management workflows, such as ones for optimizing equipment's power consumption and predictive maintenance. These solutions integrate physical principles with sensor data for real-time predictions, adapting to various scenarios without retraining. By combining domain knowledge and machine learning, they form the foundation for digital twin models, effectively managing the complex nature of oil and gas processes.

While AI technologies offer tremendous potential, it's essential to acknowledge their current limitations. Physics-informed and science-based AI models still require human expertise for validation and interpretation. These models work best when complementing, rather than replacing, human judgment, particularly in complex scenarios where domain knowledge and experience are crucial for decision-making.

Since AI evolves rapidly, organizations that want to use it well must foster a culture of continuous learning. Companies that continue to invest in people as well as technology will get more out of both. Their teams will know when AI can reveal insights that inspire safer, faster and more profitable ways to deliver critical subsurface resources. ❒

ADRIEN CAUDRON

Adrien Caudron is the senior director of solutions engineering and the leader of the operations excellence team at NobleAI. Caudron has more than 20 years of experience in energy, AI and sustainability. His career includes several executive leadership roles in strategic management and business development for Aspentech, Emerson and IFPen (French Institute of Petroleum and New Energies). He holds an M.S. in geological engineering from the ENSG school in Nancy, France, and is also an instructor for the AI and data analytics programs at UC Berkeley.

T.C. ZOBOROSKI

T.C. Zoboroski heads NobleAI's energy division, helping companies leverage AI and machine learning techniques and scientific principles to gain actionable insights from limited, secure data. His 28-year career includes roles at Amazon Web Services, Dell and Halliburton that involved supporting technology adoption and digital transformations. Zoboroski has also led several key technology integrations related to mergers and acquisitions. He holds a degree from Texas A&M University and has completed the business school's President's Leadership Excellence Program.