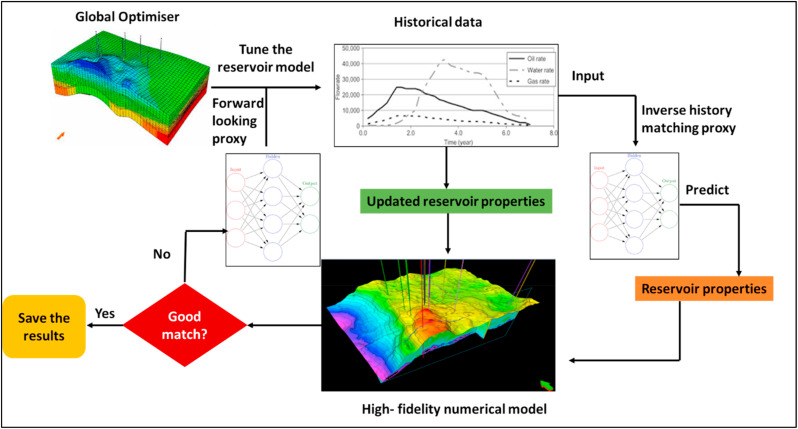
**3.2. Reservoir engineering**

[Reservoir engineering](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/reservoir-engineering) deals with fluid flow through [porous media](https://www.sciencedirect.com/topics/engineering/porous-medium), production forecasting and field optimization. Numerical simulations modelling and experimentations are required for preparing subsurface property maps and PVT analysis. Modelling is done on huge volume of data to prepare static model and dynamic models. Data from seismic, well log, core analysis, past performance of the reservoir are integrated using machine learning algorithms for appraisal planning and stochastic field development plans. Complex pressure transient analysis and [deconvolution](https://www.sciencedirect.com/topics/engineering/deconvolution) of pressure data are carried out using algorithms pertaining to Artificial Neural Network, [Genetic Algorithm](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/genetic-algorithms), Response Surface Model (RSM), etc. These GA models are very helpful for reservoir history matching and preparation of P90. P50 and P10 production profiles using the guidelines of Project Resource Management Systems (PRMS). Huge data volume is utilised to prepare reservoir maps which are refined iteratively based on new data up-gradation in database.

ANN is used for estimation of reservoir properties like permeability and porosity from many years. The study can be performed by applying different [machine learning methods](https://www.sciencedirect.com/topics/engineering/machine-learning-method) like K Nearest Neighbours (KNN), Support Vector Regression (SVR), Kernel Ridge Regression (KRR), Adaptive Boosting and Collaborative Filtering to predict [reservoir fluid](https://www.sciencedirect.com/topics/engineering/reservoir-fluid) properties. [Onwuchekwa (2018)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib50) found that collaborative filtering that was developed for consumer product recommendation system was utilised effectively for their reservoir study. The synthetic reservoir model can be used for numerical simulation for reservoir oil. [Teixeira and Secchi (2019)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib65) used optimization algorithm to identify optimum control to maximize to total oil production. The [parametric study](https://www.sciencedirect.com/topics/engineering/parametric-study) can carried out by comparing various [machine learning techniques](https://www.sciencedirect.com/topics/engineering/machine-learning-technique) to predict permeability and [seismic attributes](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/seismic-attributes) and wireline data. The performance of Superior Vector Mechanism (SVM) was superior compared to other methods for permeability prediction (Anifowose et al.*,* 2019). Anifowose et al.*,* 2019 created intelligent model with Extreme Gradient Boosting method to predict reservoir response based on [injector](https://www.sciencedirect.com/topics/engineering/injector) wells. [Nwachukwu et al. (2018)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib47) selected five cases like homogeneous [reservoir water](https://www.sciencedirect.com/topics/engineering/reservoirs-water) flood, channelized reservoir water flood, 20-model ensemble water flood, and CO2 flood in heterogeneous reservoir with complex topography. [Fig. 6](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "fig6) represents artificial intelligence assisted history matching workflow for reservoir properties tuning.



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Fig. 6. [Reservoir modelling](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/reservoir-modeling) outline using [artificial neural network](https://www.sciencedirect.com/topics/engineering/artificial-neural-network).

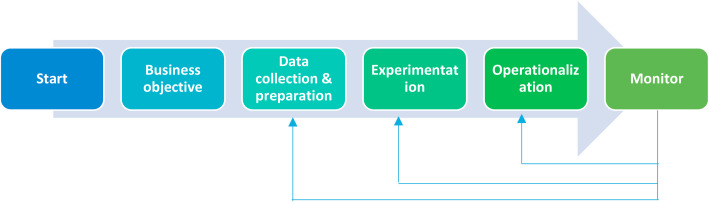
**3.3. Drilling engineering**

There are several problems in drilling like stick sleep vibrations, [loss of circulation](https://www.sciencedirect.com/topics/engineering/loss-of-circulation), bit wear, excessive torque, [borehole](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/boreholes) instability etc. The machine learning has potential to solve these problems ([Noshi and Schubert, 2018](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib46)). The machine learning method was proposed by [Aliouane and Ouadfeul (2014)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib6) to prepare [poisson's ratio](https://www.sciencedirect.com/topics/engineering/poissons-ratio) map which is useful to identify drilling direction and rock characteristics information. The machine learning method was applied by [Castineria et al. (2018)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib19) to check quality of large drilling data, obtain crucial information and predict non-productive time. This method was helpful in reduction in labour cost to check quality of large drilling data. The Byesian network (BN) can be applied on deep water drilling for Managed Pressure Drilling operations (MPD) and Under Balanced Drilling (UBD) operations. [Bhandari et al. (2015)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib16) suggested that the BN can be effectively used for risk analysis and failure prediction for [offshore industry](https://www.sciencedirect.com/topics/engineering/offshore-industry). The drilling parameters like Weight of Bit (WOB), [Rotary Speed](https://www.sciencedirect.com/topics/engineering/rotary-speed) (RPM) and [Rate of Penetration](https://www.sciencedirect.com/topics/engineering/rate-of-penetration) (ROP) were controlled by automation. The information like alternative bit or rig equipment up gradation, estimate abrasively and expected bit wear can be obtained by a machine learning algorithm ([Dunlop et al.](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib25)*[,](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib25)*[2011](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib25)).

**3.4. Production engineering**

The advance machine learning methods creates novel work flow which reduces load on engineers. There are several applications of machine learning in production engineering in oil and gas industries. The analysis of large data in short period of time for decision making is one of the challenging task. Machine learning methods can be used for production pattern data recognition. [Subrahmanya et al. (2015)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib62) obtained the data point with highest information value with active learning. The information from wells was combined from labelled and unlabelled sources with semi supervised learning. The data was checked, verified and restored by using algorithms. The correction analysis of well logging data, quality control of physical and chemical fluid properties and separation among base production and well interventions were analysed by researcher ([Andrianova et al.](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib10)*[,](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib10)*[2018](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib10)). The [ANN model](https://www.sciencedirect.com/topics/engineering/artificial-neural-network-model) can predict [closure pressure](https://www.sciencedirect.com/topics/engineering/closure-pressure) with learning from patterns in data. The output data are generally compared with actual results to minimize error. [Nande (2018)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib45) suggested that ANN model is capable to predict closure pressure efficiently. The Support Vector Regression Model was used by [Shen et al. (2019)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib61) to predict wrinkling in mechanically lined pipelines. [Saghir et al. (2018)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib58) explained the importance of edge analytics for oil and gas industries. The real time [anomaly detection](https://www.sciencedirect.com/topics/engineering/anomaly-detection) was carried out by edge analytics for electric [submersible pump](https://www.sciencedirect.com/topics/engineering/submersible-pump) operated wells.

Continuous Integration/Continuous Deployment (CICD) practices in ML are yet another important applications in oil and gas industry ([Fig. 7](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "fig7)). Advanced CICD should include an accurate and reproducible Machine Learning (ML) pipeline with the mechanisms for tracking, model lineage and version control. This is especially helpful in acknowledging conceptual drift where the performance of a statistical model deteriorates over time due to changes in data and input-output relationships modelled previously ([Zliobaite et al., 2016](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib77)).



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Fig. 7. Workflow of CICD modern Machine Learning pipeline ([Hajizadeh, 2019](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib31)).

Most of the [offshore installations](https://www.sciencedirect.com/topics/engineering/offshore-installation) have already outlived their construction life expectancy. Their lower productivity isn't the only issue; they also have risk in aspects of social safety and environmental effects. The option is to deactivate them and lose the oil and gas they currently generate, or to invest heavily in upgrading or reinforcing them. The offshore energy sector has long relied on digital twins–or digital copies of a system –to track the health of tangible assets such as pipelines, drills, valves, and other machinery. Experts can anticipate the behaviour of a structure and determine its maintenance needs by using LiDAR to produce 3D point clouds and analytics for plant construction, extending its lifetime significantly. However, these simulations are quite "static," in that they do not account for all of the changes in an asset's actual, real-life physical conditions that could affect its performance over time. Novel control methods have been created to connect data from IIoT sensors about actual environmental loads with a virtual replica of the asset.

[Table 2](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "tbl2) represents some of the studies conducted with the help of artificial intelligence for production of oil and gas.

Table 2. Use of Artificial intelligence in oil and gas production.

| **Method** | **Input parameters** | **Output parameters** |
| --- | --- | --- |
| Artificial neural network([Al- Fattah et al., 2001](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib3)) | GDP growth rate, footage drilled, wells drilled, annual depletion, gas prices and other resources are all factors to consider. | Production of gas |
| Back propagation([Osman, 2001](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib51)) | Temperature, heat, superficial gas velocity, and superficial liquid velocity are all factors to consider. | Liquid holdup |
| Graph neural network + Improved particle swami optimization([Yan et al., 2014](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib71)) | capacity to produce liquids | Water content |
| Back propagation([Xu et al., 2015](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib70)) | Number of open injection wells, newly opened production wells, and old wells with efficient treatment; remaining geological reserves; total number of production wells; monthly injection–production ratio; kernel function; number of open injection wells, newly opened production wells, and old wells with efficient treatment | Monthly oil and liquid producing capacity |
| Principal component analysis + Adaptive particle swarm optimization + Least squares support vector machine([Feng and Han, 2015](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib28)) | Number of open wells, open injection wells, newly opened production wells, and old wells with efficient treatment; injection–production ratio; water content; number of open wells, open injection wells, newly opened production wells, and old wells with efficient treatment | Oil production |
| Artificial neural network([Gaurav, 2017](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib29)) | horizontal permeability; porosity; velocity | Oil production |
| Back propagation([Salem et al., 2018](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib59)) | diagenesis; deep; GR log; neutron log; density log; sonic log; deep resistivity log | Porosity; permeability |
| Multi-layer perceptron neural network([Ghahfarokhi et al., 2018](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib30)) | regular flowing time; distributed temperature sensing; distributed acoustic sensing | Gas production |
| Artificial neural network + Adaptive network-based fuzzy inference system([Khan et al., 2018a](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib38), [Khan et al., 2018b](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib39)) | calliper; porosity; gamma ray; density; neutron; three separate resistivities; gamma ray; density; neutron | Water saturation |

**4. Recent advances in artificial intelligences in oil and gas industry**

As the [oil and gas industry](https://www.sciencedirect.com/topics/engineering/petroleum-industry) becomes more competitive and unpredictable, companies are actively seeking innovative approaches to be more efficient through the streamlining of production, reducing costs, and improving worker safety, among other things. Many executives are looking to digitization to insulate themselves from market shocks, remain profitable at lower oil prices, and generate competitive advantage during recovery. The path forward lies in leveraging artificial intelligence (AI) and machine learning-based technologies that are maturing quickly and being adopted across the value chain. Countless industries have discovered the benefits of these emerging technologies, and thus we will continue to see more AI applications developed in the future.

Let's examine real-world AI applications in the oil and gas industry.

(a)

Optimizing Subsurface Data Analysis – Total S.A. and Google Cloud

Oil and gas companies must collect and study a substantial amount of data before and after drilling into the Earth. To boost efficiency in day-to-day operations, they need to be able to solve complex exploration and production problems before they end up wasting loads of money on drilling into an unproductive well. Total S.A., an oil and gas company based in France, partnered with Google Cloud in 2018 to jointly develop AI solutions that optimize subsurface data analysis for exploration and production.

Wind the clock back a couple of decades and you'll learn that Total isn't new to implementing AI. The company started applying AI and [machine learning algorithms](https://www.sciencedirect.com/topics/engineering/machine-learning-algorithm) to characterize oil and gas fields back in the 1990s. Jump forward to 2013 and you'll see that they implemented [predictive maintenance](https://www.sciencedirect.com/topics/engineering/predictive-maintenance) technology for turbines, pumps, and compressors, resulting in savings of several hundred million dollars. Now they're taking it to the next level with Google Cloud. Together, their technologies will make it possible to interpret subsurface images from seismic studies using [computer vision](https://www.sciencedirect.com/topics/engineering/computervision) technology. In addition, their AI solutions will automate the analysis of technical documents using [natural language processing](https://www.sciencedirect.com/topics/engineering/natural-language-processing). Altogether, these solutions will allow Total to explore and assess oil and gas fields much faster and more effectively.

(b)

Detecting [Oil Seeps](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/oil-seep) With AI-Powered Robots – [ExxonMobil](https://www.sciencedirect.com/topics/engineering/exxonmobil) and MIT

Everyone knows ExxonMobil as one of the leading oil and gas giants. They also invest their money into pretty cool AI projects. In 2016, the industry titan teamed up with the Massachusetts Institute of Technology (MIT) to design AI robots for ocean exploration. Brian Williams, an MIT professor and a core designer of the software for NASA's Mars [Curiosity Rover](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/curiosity-rover), is one of the key members of this deep-sea initiative, further adding to the cool factor.

More specifically, ExxonMobil plans to use this deep-sea AI robot to boost its natural seep detection capabilities. According to the National Oceanic and Atmospheric Administration, naturally occurring oil seeps from the seafloor are the largest source of oil entering the world's oceans, accounting for nearly half of the oil released into the ocean environment every year. ExxonMobil's AI-powered robots will be able to detect these oil seeps in order to greatly reduce exploration risk and lessen harm to marine life.

ExxonMobil researcher and engineers are collaborating with MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) to develop self-learning, [submersible](https://www.sciencedirect.com/topics/engineering/submersibles) artificial intelligence robots for exploration of ocean subsurface. The programming, or "intelligence," of the robots will enable them to work independently in conditions as extreme as those found on Mars, as well as adjust mission settings on their own to investigate unexpected abnormalities. The new technologies promising application would be to observe the oceans, charting deep areas and studying how they evolve over time and assessing their condition.

(c)

Precision Drilling With Machine Learning Algorithms – Shell

Shell is yet another industry titan doing exciting things with AI applications. This time around, Shell is adopting reinforcement learning to control its drilling equipment, essentially using a reward system based on the AI's choices. For example, a machine learning model is trained on historical data from Shell's extensive drilling records, as well as simulations to steer the drill into the subsurface. It also takes into account data from [seismic surveys](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/seismic-survey), temperature, pressure, and other data points from the [drill bit](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/drill-bits). Then the geosteerer, or the person operating the drilling machine can provide input via reward or penalty functions to help the machinery adapt to changing subsurface conditions. This helps the geosteerer to better understand the environment they're working in, leading to faster, more accurate results and less damage to machinery.

Innovation doesn't stop there, though. Shell is always looking for big ideas to push the boundaries of what's possible in the oil and gas industry. Through their Shell Game Changer initiative, the company regularly makes calls for AI proposals focused on machine learning from both individuals and start-ups all over the globe. Whether it's investing in these ideas or straight up collaborating on a project, Shell is leading the way to help solve some of the industry's greatest challenges.

At each stage of the process, artificial intelligence is being implemented or tested. To manage its drill rigs, the company has recently adopted reinforcement learning, a type of "semi-supervised" machine learning. Whereas machine learning can function either with labelled or unlabelled data (supervised or unsupervised learning), reinforcement learning takes a middle path by including a reward system that is depending on the success of the AI's "choices." Algorithms that steer drills via the subsurface are developed using available information from Shell's drilling record as well as data acquired through simulated explorations. It includes mechanical data from the drill bit, such as pressures and temperatures, as well as data from seismic studies on the subsurface. As an outcome, a Shell geosteerer — the human programmer of the drilling machine–is capable of understanding the situation in which they are working, resulting in faster outcomes and less wear and tear on machinery.

(d)

Boosting Productivity With Predictive Maintenance – Aker BP and Spark Cognition

Unplanned [downtime](https://www.sciencedirect.com/topics/engineering/downtime) can be a costly nightmare for offshore oil and gas platforms—to the tune of $2–3 million in a single day for catastrophic asset failures. Too many companies rely on outdated methods, prompting some to emphasize data and analytics to make maintenance decisions. Aker BP, an independent upstream oil and gas company in Norway, partnered with Spark Cognition to deploy an AI-powered predictive maintenance solution to their unmanned Tambar platform, where a significant amount of unplanned downtime is driven by problems with a critical multi-phase pump.

Spark Cognition developed and deployed a normal behaviour model of the multi-phase pump into its AI-powered predictive maintenance software, which then alerted deviations from normal subsystem behaviour. Over a period of six months, the AI software alerted Aker BP operators and SMEs to a potential multi-phase pump trip caused by a failing seal, of which previous failures resulted in over $10 million in lost production. Aker BP and Spark Cognition were able to prevent pump failure, increasing production by hundreds of thousands of dollars for each day of downtime avoided.

Aker BP is adopting SparkCognition's analytics tool SparkPredictⓇ on offshore production facilities as part of a new transformation programme to boost productivity with superior predictive maintenance skills. Aker BP's complete fleet of [production platforms](https://www.sciencedirect.com/topics/engineering/production-platforms) will be supplemented by SparkCognition's AI systems, which will monitor all [centerline](https://www.sciencedirect.com/topics/engineering/centerline) and [subsea systems](https://www.sciencedirect.com/topics/engineering/subsea-system) for over 30 [offshore structures](https://www.sciencedirect.com/topics/engineering/offshore-structures). With powerful AI algorithms, SparkCognition is committed to promoting society's most essential interests," says the company. SparkPredict analyses sensor information using [machine learning techniques](https://www.sciencedirect.com/topics/engineering/machine-learning-technique) to identify inefficient processes and impending faults before they happen. Aker BP will increase productivity and efficiency by installing SparkPredict on its offshore production platforms, accelerating its ambition to provide unrivalled value to its clients across the world.

**5. Enablers and challenges in upstream oil and gas industry using artificial intelligence and machine learning**

In order to minimize uncertainty, the primary step is to create system that can handle several hypotheses for achieving optimized solution. Efficient AI and machine learning approach was developed by [Anifowose et al. (2017a)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib12) overcome this obstacle. To tackle this issue in machine learning hypothesis of Hybrid Intelligent System (HIS) was developed. It had been proved that the HIS has such tremendous capacity to boost the forecasts of oil field reserves leading to better discovery, much more effective extraction, expanded development and highly productive use of energy supplies ([Anifowose et al.](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib13)*[,](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib13)*[2017b](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib13)). Considering the present oil market situations, machine learning seems to have increasingly widespread over the last five years, especially in alleviating drilling issues even in actual time as well as in [oil drilling](https://www.sciencedirect.com/topics/engineering/well-drilling) automation and technology. Machine learning has also been most promising to enable this to achieve greater [rate of penetration](https://www.sciencedirect.com/topics/engineering/rate-of-penetration) (ROP) and lesser CPF levels, and many other [performance measures](https://www.sciencedirect.com/topics/engineering/performance-measure-psi) like 10k meter of well drilling per day ([Noshi and Schubert, 2018](https://www.sciencedirect.com/science/article/pii/S2096249521000429#bib46)).

[Hawedi et al. (2011)](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib33) suggested a data-driven methodology for evaluating well performance in two cases, predicting only for current well and predicting for a potential well that is expected to be drilled. The whole method is much more detailed relative to the step - wise regression evaluation in which it provides further data sources such as geological map details, output restriction such as tube head pressure as well as positions representing dynamic [reservoir characterisation](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/reservoir-characterization) of non-traditional wells without providing a present model ([Cao et al.](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib18)*[,](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib18)*[2016](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib18)). Machine learning (ML) will greatly boost the exploration of oil and enhance the interpretation of [seismic data](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/seismic-data), develop extraction techniques to make it more effective. The major problem confronting the oil sector nowadays is really the ecological risk that comes with both the extraction and production of oil. However the idea is, through advanced technical approaches, different systems will be created which is much more environmentally sustainable ([Brekke, 2020](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib17)). Artificial Neuro [Fuzzy Inference System](https://www.sciencedirect.com/topics/engineering/fuzzy-inference-system) (ANFIS) produces marginally improved performance, but the prediction is really not necessarily influenced when [ANN](https://www.sciencedirect.com/topics/engineering/artificial-neural-network) is being utilised, as well as the neural network is already capable of generating a realistic working formula ([Khan et al., 2018b](https://www.sciencedirect.com/science/article/pii/S2096249521000429#bib39), [Khan et al., 2018a](https://www.sciencedirect.com/science/article/pii/S2096249521000429#bib38)).

While some oil and gas companies, like ONGC, OIL, Reliance, Shell are jump-starting their AI initiatives by investing aggressively in startups and R&D, several challenges are preventing them to massively and rapidly implement AI in the exploration and production of oil and gas. That is not an oil and gas specific problem, but a commonplace in applying AI at this stage of its development. Based on research, the critical challenges are related to the profile of people the industry requires, the central importance of data, and the need for open collaboration. These three issues are discussed below

**5.1. People**

The success of artificial intelligence critically depends on human intelligence. AI solutions are not generic – they cannot be just bought. Even when developed by third parties AI solutions have to be customized to the business context and database of a company. Thus, to actively use AI in processes and products, companies must grow in-house teams composed of data and AI specialists. These teams should be able to support development of AI infrastructure (algorithms and datasets) and, at least to customize tools that companies will later utilize in their operations. That means that oil and gas companies will become (partially) data-driven companies and, that AI specialists will become irreplaceable in supporting almost all innovation efforts in oil and gas companies in the next 10 years. However, finding and retaining AI talent is a very challenging task. There is a significant shortage of AI talent on the job market and with more and more companies getting into AI and forming their own AI groups, prospects are not good for the next decade. This is especially true for oil and gas companies. Next, to compete with tech giants like Google, Yandex, IBM, and Amazon, leading universities and cool startups worldwide over the same talent – oil and gas companies have to fight negative attitudes toward fossil fuel industries. That is not an easy neither a cheap task.

Although AI's entrance into the [oil and gas industry](https://www.sciencedirect.com/topics/engineering/petroleum-industry) announces "*the end of*[*petroleum engineering*](https://www.sciencedirect.com/topics/engineering/petroleum-engineering)*as we know it*, [petroleum engineers](https://www.sciencedirect.com/topics/engineering/petroleum-engineer) will not disappear. Just their role and required skillset will change. To successfully innovate in the AI-era, next to data scientists oil and gas companies will need petroleum engineers with a strong sense of data science and the ability to identify and design tasks to be solved by AI. Their role will be to ensure that the right problems are identified for applying AI, that the right data is collected and that solutions fit the physical and process reality. Over time, this will become a crucial role, as otherwise the wrong questions may be asked and existing human mistakes amplified, as it happened in the case of Google's breast cancer detection solution based on [mammograms](https://www.sciencedirect.com/topics/engineering/mammogram). So, it is not that just data science and AI skills are in demand due to the adoption of AI, but a new way of thinking about problems oil and gas companies face, rooted in deep understanding of the processes and the core logic of tasks. Thus, the new role of petroleum engineers will be more and more critical. To prepare the next generation of petroleum engineers for it, some universities like Skolkovo Institute of [Science and Technology](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/science-and-technology) (Russia) and West Virginia University (US), already started implementing special educational programs that are a healthy mix of data science and petroleum studies.

Next to working more with data and data scientists, petroleum engineers will have to learn how to work with AI assistants – products similar to Alexa and Siri, but focused on industry applications. In these new partnerships, the challenge will be to combine best from the two sides – AI's ability to deal with a lot of data, find patterns and relations, and petroleum engineers' deep industry domain knowledge. Although AI is expected to be dominantly used by humans to augment their decision-making abilities rather than replace them [49], this will be a challenging task as many questions related to trust and fear of losing jobs may arise. There is an unsolved issue also related to people – the legal view on AI's recommendations. There could be cases when an [AI tool](https://www.sciencedirect.com/topics/engineering/artificial-intelligence-tool) recommends an action leading to a loss in money, production, or even severe health or environmental issues. In this case, we have no clear understanding of responsibility-sharing between the AI algorithm itself, the AI algorithm user, or the AI algorithm developer. With the development of AI tools, this question will rise more and more often. So the parallel establishment of the legal base is expected here. The practice says that the algorithms and their developers are not responsible, but the responsibility is still with the decision-makers getting the advice from the AI and AI users. Thus, to benefit from the opportunity to extend decision-making capabilities significantly, companies will have to create not only strategies *for AI*, but strategies *with AI* as well.

**5.2. Data**

AI tools need the good quality data of a suitable volume to be trained and then to work properly in the operational mode. While using smarter algorithms may help in getting better results from datasets of limited size, no manipulation can help with bad data. Thus, access to big and quality data is a crucial enabler and barrier for AI applications' successful development. Oil and gas fields generate large amounts of raw data. Still, it is not a guaranty for success as there are known issues with the quality and accuracy of field data and overall lack of large volumes of labelled data in the oil and gas industry. Training datasets have to be carefully collected through the well-planned workflow- and situation-specific multi-year procedure To enhance the value of data oil and gas companies possess or can access, they will have to redesign and adjust their organizational structures and processes. Data challenges (across industries, not only in the oil and gas) drive technical efforts in improving AI systems and their further practical usage in the exploration and production of oil and gas.

**5.3. Open collaboration**

Artificial intelligence is born in open and collaborative environment as a consequence of academia being a leading force in AI research for decades, almost without any business influences. This created culture of free sharing and open publishing which companies across industries (and across the globe) had to embrace as a standard to succeed in the era of AI] once they joined the race.

While open innovation is becoming standard in the tech sector, oil and gas companies are not famous for their joint industry projects, especially between competitors and especially not in strategic domains such as AI. Even though many companies announce bringing some of their data to the open-source and claim the necessity of cross-company and cross-border data sharing, the reality is rather pessimistic now. The UK's oil and gas National Data Repository is one of the first large oil and gas open data releases. It contains 130 terabytes of geophysical, infrastructure, field, and well data, covering more than 12,500 [wellbores](https://www.sciencedirect.com/topics/engineering/wellbore), 5000 [seismic surveys](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/seismic-survey), and 3000 pipelines ([Oil and Gas Authority, 2019](https://www.sciencedirect.com/science/article/pii/S2096249521000429" \l "bib49)). The opportunities for machine learning and artificial intelligence applications based on available data are highlighted (offshoretechnology.com, 2019).

University labs are another important source of novel AI technology and AI talent, Thus, oil and gas companies should re-think strategies for collaborating and interacting with universities.

**5.4. Impact of COVID-19 in oil and gas industry and AI as a solution**

The oil and gas sector is entering a different normal of pandemic situation and, as a result, lower crude prices and geopolitical issues are leading to excess supply, and some main industry innovations. Although consumption is expected to grow as the world recovers from the pandemic normalises its relations and output quotas, industry players must be adaptable to the new reality. They must concentrate on improving their supply chain and activities, lowering manufacturing, distribution, and transportation costs. Artificial intelligence (AI) has the potential to change the oil and gas industry's value chain. AI models are often used as isolated point solutions with little overall benefit. Disappointment over performance influences future plans as benefits begin to plateau quickly.

The sector still concentrate on different across reservoir, geology, geophysics, engineering, and drilling as it integrates cross-domain data. These divisions were created to increase productivity across the company, with a single team in charge of all geotechnical needs. This operational division, which was created in the past to meet cost-cutting needs, prevents the oil and gas industry from adopting broader cross-functional AI use cases.

**6. Conclusions**

In this paper, we have gone through the recent advancements in the field of AI and machine learning and its applications in [oil and gas industries](https://www.sciencedirect.com/topics/engineering/petroleum-industry). Representative cases using machine learning in exploration, reservoir, drilling and production are presented in this paper. The literature review of oil and gas industry is well-poised to take benefits of machine learning regarding their abilities of processing big data and fast computational speed. Many monitored learning methods have been defined and described throughout this paper. Machine learning has the potential of unequivocally changing the numerous critical actions made every day by administrators and engineers in the oil and gas sector. The future advantages of information can be achieved if appropriate techniques are used to implement different data types or structures and convert it into useful information that contributes to intelligent judgements. Many such solutions utilizing [ANN](https://www.sciencedirect.com/topics/engineering/artificial-neural-network), ALM, supervised learning, fuzzy logic, linear regression and PCA could be enforced to counteract various difficulties found in oil and gas industries and helps in maturing for profitable strategies. In the forthcoming years, the increase of machine learning utilization may begin to expand rapidly, as well as its value will also be significantly utilised throughout the oil and gas industries