ALBERTA INNOVATES

CLEAN RESOURCES FINAL REPORT PACKAGE

Project proponents are required to submit a Final Report Package, consisting of a Final Public Report and a Final Financial Report. These reports are to be provided under separate cover at the conclusion of projects for review and approval by Alberta Innovates (AI) Clean Resources Division. Proponents will use the two templates that follow to report key results and outcomes achieved during the project and financial details. The information requested in the templates should be considered the minimum necessary to meet AI reporting requirements; proponents are highly encouraged to include other information that may provide additional value, including more detailed appendices. Proponents must work with the AI Project Advisor during preparation of the Final Report Package to ensure submissions are of the highest possible quality and thus reduce the time and effort necessary to address issues that may emerge through the review and approval process.

Final Public Report

The Final Public Report shall outline what the project achieved and provide conclusions and recommendations for further research inquiry or technology development, together with an overview of the performance of the project in terms of process, output, outcomes and impact measures. The report must delineate all project knowledge and/or technology developed and must be in sufficient detail to permit readers to use or adapt the results for research and analysis purposes and to understand how conclusions were arrived at. It is incumbent upon the proponent to ensure that the Final Public Report **is free of any confidential information or intellectual property requiring protection**. The Final Public Report will be released by Alberta Innovates after the confidentiality period has expired as described in the Investment Agreement.

Final Financial Report

The Final Financial Report shall provide complete and accurate accounting of all project expenditures and contributions over the life of the project pertaining to Alberta Innovates, the proponent, and any project partners. The Final Financial Report will not be publicly released.

ALBERTA INNOVATES

CLEAN RESOURCES FINAL PUBLIC REPORT TEMPLATE

1. PROJECT INFORMATION:

Project Title:	**Digital Technologies in Reservoir Interpretation and Production Prediction**
Alberta Innovates Project Number:	G2020000133
Submission Date:	2020-03-02
Total Project Cost:	$459,200
Alberta Innovates Funding:	$200,000
AI Project Advisor:	Bryan Helfenbaum

2. APPLICANT INFORMATION:

Applicant (Organization):	University of Calgary
Address:	2500 University Dr. NW, Calgary, AB T2N 1N4
Applicant Representative Name:	Zhangxing (John) Chen
Title:	Professor, NSERC/Energi Simulation Industrial Research Chair
Phone Number:	403-220-7825
Email:	zhachen@ucalgary.ca

3. PROJECT PARTNERS

Please provide an acknowledgement statement for project partners, if appropriate.

RESPOND BELOW

This project is partly supported by Tartan Energy Group Inc.

A. EXECUTIVE SUMMARY

Provide a high-level description of the project, including the objective, key results, learnings, outcomes and benefits.

RESPOND BELOW

The primary objective of the oil and gas industry is to find hydrocarbon deposits and determine economical strategies for recovering them. In pursuit of this goal, oil and gas professionals must perform complex tasks on 3D volumetric representations of the subsurface. These complex tasks require the analysis of large quantities and varieties of geological, reservoir and production data. However, there is a growing knowledge gap between the exploration of this high-volume data and the ability to effectively extract its useful information, particularly in reservoir interpretation and production prediction. High-impact decisions are made as a result of the analysis of geological, reservoir and production data, often with time constraints. However, the traditional methods used to interpret reservoirs and predict production cannot effectively use historical information and reservoir data. The processes of well logging interpretation and history matching are time consuming and subjective. Numerical reservoir simulation models provide a relatively reliable and appropriate approach to conduct a reservoir analysis but are laborious and time consuming. It is increasingly necessary to develop effective digital technologies to maximize the benefits of a growing data explosion and extract useful information to help select scenarios that lead to profitable oil recovery. In this project, machine learning (ML) technologies have been developed for reservoir exploration, reservoir property investigation, and production prediction. Through the development of these ML technologies, we have delivered a novel reservoir interpretation and production prediction workflow together with Tartan Energy Group Inc. while providing breakthrough technologies to the petroleum industry. These technologies offer the promise of transformational solutions to the economic and environmental challenges in the recovery of heavy oil and bitumen resources while training much needed advanced digital skills within Alberta.

B. INTRODUCTION

Please provide a narrative introducing the project using the following sub-headings.

- **Sector introduction:** Include a high-level discussion of the sector or area that the project contributes to and provide any relevant background information or context for the project.
- **Knowledge or Technology Gaps:** Explain the knowledge or technology gap that is being addressed along with the context and scope of the technical problem.

RESPOND BELOW

Sector introduction. This project has advance Reservoir Engineering through artificial intelligence techniques such as machine learning. Machine learning can leverage historical relationships between logging responses and various components of a reservoir to provide an intelligent system for performing reservoir interpretation. Machine learning empowered history matching will provide fast, quality validations and global robustness. Reservoir production prediction and optimization using these new techniques will be efficient in maximizing oil recovery processes while reducing environmental impacts.

Knowledge Gap. The primary goal of the oil and gas industry is to find hydrocarbon deposits and determine economical strategies for recovering them. In pursuit of this goal, oil and gas professionals must perform complex tasks on 3D volumetric representations of the subsurface. These complex tasks require the analysis of large quantities and varieties of geological, reservoir and production data. However, there is a growing knowledge gap between the exploration of this high-volume data and the ability to effectively extract its useful information, particularly in reservoir interpretation and production prediction. It has been the objective of this project that addresses this knowledge gap.

C. PROJECT DESCRIPTION

Please provide a narrative describing the project using the following sub-headings.

- **Knowledge or Technology Description:** Include a discussion of the project objectives.
- **Updates to Project Objectives:** Describe any changes that have occurred compared to the original objectives of the project.
- **Performance Metrics:** Discuss the project specific metrics that will be used to measure the success of the project.

RESPOND BELOW

KNOWLEDGE DESCRIPTION. The objectives of this project are:

1) automatically classify water, oil and gas layers based on well logging curves using machine learning;

2) create a system that automatically interprets reservoir properties on the basis of a curve that combines reservoir parameters such as porosity, permeability, and oil saturation and can compare all well logging curves to determine the type of a reservoir;

3) create a system that will suggest optimal parameters for a reservoir model using data driven techniques to improve the history matching process;

4) create a system that leverages all data to support production optimization and reduce environmental impacts that is tested and validated on a variety of datasets; and

5) integrate the system with existing tools created by the reservoir simulation group at the University of Calgary.

Updates to Project Objectives. There have been no changes that have occurred compared to the original objectives of the project. All the project objectives have been achieved.

Performance Metrics. The TRL advancement, "$ in Data-Enabled Innovation", "$ in Digital Transformation for Business Innovation", and "$ Future Investment" have all been achieved without any deviation. The number of students and sector HQP trained have been as planned, with at least three students involved in this project and at least three HQP trained. Two published papers have been achieved, and another two papers have been submitted, waiting for their acceptance:

1. Z. Huang, M. Yang, B. Yang, W. Liu and Z. Chen, Data-Driven Model for Predicting Production Periods in the SAGD Process, *Petroleum,* accepted for publication in September 2021, in press.
2. Z. Huang and Z. Chen, Comparison of different machine learning algorithms for predicting the SAGD production performance, *Journal of Petroleum Science and Engineering*, Volume 202, July 2021, Article 108559.
3. W. Liu, Z. Chen and Y. Hu, A novel data-driven method for safety assessment of pipelines, *International Journal of Pressure Vessels and Piping*, in revision.
4. M. Ghoroori, M. A. Mirza, Z. Chen and G. Hui, Cognitive data-driven modeling for detection of induced seismicity in the Fox Creek area, Alberta, *Scientific Reports* (*Nature*), in revision.

For Project Success metrics:

- The "% accuracy of classification of water, oil and gas layers based on specific well logging curves" has been exceeded, with accuracy rates approaching 80% so far.
- The "% accuracy of match between real data and ML based history match in the same time or better" has been greatly exceeded, with accuracy exceeding 90%.
- The "% improved speed of history matching" has exceeded targets for well-trained models, with speed exceeding 90%.
- The "% increase in predicted output through ML based production prediction and selection of parameters" have been exceeded, with an increase exceeding 95%.

D. METHODOLOGY

Please provide a narrative describing the methodology and facilities that were used to execute and complete the project. Use subheadings as appropriate.

RESPOND BELOW

A sufficient amount of data was gathered to perform the development of the machine learning techniques. Following that we have performed statistical analysis of the data to understand and characterize the data. Training, testing and validation datasets have been obtained. In order for a model to be trained, it needs to periodically be tested with a validation dataset. Through calculating an error rate the model yields on the validation set at any given point, we can know how accurate it is. A test dataset has also been used for evaluation after the training phase (utilizing training and validation sets) has been completed. This step is critical to test the generalizability of the model. Next, a thorough review of attempts to apply machine learning to reservoir interpretation has been reviewed and combined with our existing tools to provide solutions that meet industrial needs. We have then investigated current research applying machine learning to history matching techniques, based on this and the industrial needs, developed machine learning based solutions, and compared with other methods such as Ensemble Kalman filter techniques. Finally, we have leveraged this procedure to develop methods to provide reservoir production prediction and test on data available.

E. PROJECT RESULTS

Please provide a narrative describing the key results using the project's milestones as sub-headings.

- Describe the importance of the key results.
- Include a discussion of the project specific metrics and variances between expected and actual performance.

RESPOND BELOW

At the end of Milestone 1 the following work was completed:

- The required data was collected, characterized, and treated. An intensive investigation into the data requirements was conducted.

- Background research was conducted on existing methods of Machine Learning (ML). The project team selected and implemented a starting set of ML algorithms and worked with their industry partner to validate these algorithms for reservoir interpretation, history matching and production prediction.

At the end of Milestone 2 the following work has been completed:

- We have developed a working prototype demonstrating the proposed methodology for knowledge transfer and the reuse of known logging interpretation results using machine learning.

It has been used to automatically divide a reservoir layer into different classes such as oil, water and gas.

- We have conducted comprehensive research of this prototype to perform history matching and optimization, including utilization of machine learning techniques.
- We have performed benchmarking, validation, and performance engineering to improve this prototype that applies machine learning to optimize history matching.
- We have integrated the new Machine Learning (ML) technologies with the existing suite of reservoir simulators and developed visualization tools to show results.

F. KEY LEARNINGS

Please provide a narrative that discusses the key learnings from the project.

- Describe the project learnings and importance of those learnings within the project scope. Use milestones as headings, if appropriate.
- Discuss the broader impacts of the learnings to the industry and beyond; this may include changes to regulations, policies, and approval and permitting processes

RESPOND BELOW

In preparing for the automated interpretation of well logs, the team has discovered that ensemble machine learning (ML) algorithms perform better than single algorithms for reservoir interpretation using well logging data. Among all the algorithms, XGBoost (extreme gradient boosting) and LightGBM (light gradient boosting) perform the best for large sets of data with great randomness, since they can effectively distinguish reservoir classes. With a small data set or less randomness, ANN (artificial neural network) performs the best. These three algorithms can be used to automate the outcomes.

In benchmarking, validation and performance engineering tasks, the team has discovered that fluid level, representing bottom hole pressure, shows a strong correlation with oil production and that adding it as an input feature highly improves the prediction accuracy of a ML model. Additional physical parameters, such as water cut and gas-oil contact, have been recommended to be added for improving prediction accuracy. It has been determined that the use of ML without the use of fluid levels has comparative performance to numerical simulation in predicting the cumulative oil production. Use of fluid levels in the ML algorithms significantly improved the accuracy.

In preparing for the history matching and optimization, the team has discovered that artificial neural network (ANN), extreme gradient boosting (XGBoost) and light gradient boosting (LightGBM) machine learning methods have proven to have the most precedent in similar applications in the literature based on the intended purpose in this project.

G. OUTCOMES AND IMPACTS

Please provide a narrative outlining the project's outcomes. Please use sub-headings as appropriate.

- **Project Outcomes and Impacts:** Describe how the outcomes of the project have impacted the technology or knowledge gap identified.
- **Clean Energy Metrics:** Describe how the project outcomes impact the Clean Energy Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Program Specific Metrics:** Describe how the project outcomes impact the Program Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Project Outputs:** List of all obtained patents, published books, journal articles, conference presentations, student theses, etc., based on work conducted during the project. As appropriate, include attachments.

RESPOND BELOW

Project Outcomes and Impacts. This project has achieved the following outcomes:

- Creation of a system that automatically interprets reservoir properties based on a curve that combines reservoir parameters such as porosity, permeability, and oil saturation and can compare all well logging curves to determine the type of a reservoir;
- Development of a system that suggests optimal parameters for a reservoir model using data driven techniques to improve the history matching process;
- Establishment of a system that leverages all data to support production optimization and reduce environmental impacts that is tested and validated on a variety of datasets; and
- Integration of these systems with existing tools created by the Reservoir Simulation Group at the University of Calgary.

Heavy oil and bitumen recovery have an integral role in the Alberta economy and a prominent place in the Canadian economy. The development of new recovery processes that reduce the environmental footprint and foster economic benefits is imperative for Alberta and Canada. This development inevitably relies on key emerging technologies such as big data analytics and artificial intelligence. These technologies offer the promise of transformational solutions to the economic and environmental challenges in the recovery of heavy oil and bitumen resources. A new generation of pervasive computing devices and tools that have been developed in this prject will drive the creation of new opportunities in multiple fields by identifying patterns unknown previously. The petroleum industry will have the capability to capture detailed real-time data at lower costs, boost field and plant performance by 6-8%,

and reduce GHG emissions by 5%.

Clean Energy Metrics. There have been no changes to the clean energy metrics as described in the *Work Plan, Budget and Metrics* workbook. The development of artificial intelligence, machine learning, data analytics, scientific computing and extended reality technologies and competencies in Alberta will support potential commercialization opportunities, three HQSP have been trained in simulation, machine learning and visualization developing talent needed for this potential commercialization, and the innovation in this project has been used to enhance the existing tools, raising them to a TRL of at least 4.

Program Specific Metrics: There have been no change to the program specific metrics as described in the *Work Plan, Budget and Metrics* workbook.

Project Outputs. The following peer-reviewed journal articles and invited conference presentations have been generated as a result of this project:

1. Z. Huang, M. Yang, B. Yang, W. Liu and Z. Chen, Data-Driven Model for Predicting Production Periods in the SAGD Process, *Petroleum,* accepted for publication in September 2021, in press.
2. Z. Huang and Z. Chen, Comparison of different machine learning algorithms for predicting the SAGD production performance, *Journal of Petroleum Science and Engineering*, Volume 202, July 2021, Article 108559.
3. W. Liu, Z. Chen and Y. Hu, A novel data-driven method for safety assessment of pipelines, *International Journal of Pressure Vessels and Piping*, in revision.
4. M. Ghoroori, M. A. Mirza, Z. Chen and G. Hui, Cognitive data-driven modeling for detection of induced seismicity in the Fox Creek area, Alberta, *Scientific Reports* (*Nature*), in revision.
5. Z. Chen, "Digitization Drives Energy Efficiency" (*Invited Presentation*), Research Night, Women in Science and Engineering (WISE), Calgary, Canada, October 8, 2021.
6. Z. Chen, "Digitation Drives Energy Efficiency" (*Invited Presentation*), Young Scientists 4.0 (Virtual Conference), The Global Energy Association, Russia, July 15, 2021.
7. Z. Chen, "Digitation Drives Energy Efficiency" (*Invited Presentation*), Celebration of Excellence & Engagement, Royal Society of Canada, Toronto, Canada, November 23-29, 2020.

H. BENEFITS

Please provide a narrative outline the project's benefits. Please use the subheadings of Economic, Environmental, Social and Building Innovation Capacity.

- **Economic:** Describe the project's economic benefits such as job creation, sales, improved efficiencies, development of new commercial opportunities or economic sectors, attraction of new investment, and increased exports.
- **Environmental:** Describe the project's contribution to reducing GHG emissions (direct or indirect) and improving environmental systems (atmospheric, terrestrial, aquatic, biotic, etc.) compared to the industry benchmark. Discuss benefits, impacts and/or trade-offs.
- **Social:** Describe the project's social benefits such as augmentation of recreational value, safeguarded investments, strengthened stakeholder involvement, and entrepreneurship opportunities of value for the province.
- **Building Innovation Capacity:** Describe the project's contribution to the training of highly qualified and skilled personnel (HQSP) in Alberta, their retention, and the attraction of HQSP from outside the province. Discuss the research infrastructure used or developed to complete the project.

RESPOND BELOW

Economic and Environmental Benefits. As described above, heavy oil and bitumen recovery have an integral role in the Alberta economy and a prominent place in the Canadian economy. The development of new recovery processes that reduce the environmental footprint and foster economic benefits is imperative for Alberta and Canada. This development inevitably relies on key emerging technologies such as big data analytics, artificial intelligence, virtual reality, and augmented reality. These technologies offer the promise of transformational solutions to the economic and environmental challenges in the recovery of heavy oil and bitumen resources. A new generation of pervasive computing devices and tools that have been developed in this project to gather and transmit data will drive the creation of new opportunities in multiple fields by identifying patterns unknown previously. The petroleum industry will have the capability to capture detailed real-time data at lower costs, boost field and plant performance by 6-8%, and reduce GHG emissions by 5%. Capitalizing on these opportunities requires the development of simulation software that can scale to meet the needs of an increasingly data-intensive industry, automate workflows using artificial intelligence, and utilize the latest interactive visual computing hardware and software techniques to provide efficient analyses and interactions with data.

Social Benefits. This project has been led by the Principal Investigator, Dr. Zhangxing (John) Chen under his Reservoir Simulation and Modelling Research Program. All communications related to this project have included the industry partner Tartan Energy, the PI, the project manager and the graduate students. This team has worked closely with Tartan Energy, and regular monthly meetings have been held with Tartan Energy to report progress and ensure the project has moved in alignment with their needs. Tartan Energy Group Inc. is a high-tech company advancing the development and production of oil and gas resources. Working together with our industrial partner Tartan Energy, it has provided the

opportunity to innovate within the energy sector while building high-value information technology expertise that can advance many other sectors. Two junior petroleum engineers at Tartan Energy have been trained during this project.

Building Innovation Capacity. Dr. Chen has a long history of training many successful highly qualified and skilled personnel (HQSP). He has graduated 75 PhD and 76 MSc students and trained 48 post-doctoral fellows in his career. Most of these trainees work in the private and public sectors in Canada, and 46 have become faculty members in 16 countries. Two PhD students and a MSc student have been trained during this project, and this project has also helped fund one research staff position at the University of Calgary and trained two junior petroleum engineers at Tartan Energy. They have been trained in complex machine learning technologies applied to the petroleum and digital industries. These technologies are entirely transferable to other industries. Development of cutting-edge digital technologies will encourage even more students from across Canada and beyond to come to our province, as reservoir data is big and complex, providing an attractive training opportunity for bright and curious scholars.

I. RECOMMENDATIONS AND NEXT STEPS

Please provide a narrative outlining the next steps and recommendations for further development of the technology developed or knowledge generated from this project. If appropriate, include a description of potential follow-up projects. Please consider the following in the narrative:

- Describe the long-term plan for commercialization of the technology developed or implementation of the knowledge generated.
- Based on the project learnings, describe the related actions to be undertaken over the next two years to continue advancing the innovation.
- Describe the potential partnerships being developed to advance the development and learnings from this project.

RESPOND BELOW

It was at TRL 2 at the start of the project, and it is now at TRL 4 at the end of the project. The Principal Investigator (PI) Dr. Chen has led a large NSERC/Energi Simulation Industrial Research Chair (IRC) program in reservoir simulation at the University of Calgary that consists of a number of companies in Alberta since 2008. This project has significantly strengthened and will continue to strengthen the IRC by creating a system that suggests optimal parameters for a reservoir model using data driven techniques to improve the history matching process and a system that leverages all data to support production optimization and reduce environmental impacts. All these new advances will be integrated into the existing tools developed by the IRC program. A committee will be formed with such companies as Energi Simulation, Computer Modelling Group (CMG) Ltd., and IBM, together with Alberta Innovates, to commercialize these digital tools.

J. KNOWLEDGE DISSEMINATION

Please provide a narrative outlining how the knowledge gained from the project was or will be disseminated and the impact it may have on the industry.

RESPOND BELOW

This work will foster the transfer of new knowledge gained through applying artificial intelligence to complex problems that create economic and environmental benefits for Albertans. The collaboration with private and public sectors unites the guidance and access to domain problems and data with bright graduate students. Artificial intelligence, virtual reality and augmented reality are high-impact technologies that, when combined, will lead to revolutionary tools that can be commercialized and contribute to diversification of the economy. We have a variety of prototype tools created and with the advances from this work, we have the potential to move the tools into the broader community commercially. As mentioned above, two papers have been published, two more are expected to publish and three invited presentations have been made through this project ensuring that the results of this work advance knowledge through the research literature. Our team is also very committed to engaging with the business community in Alberta as well as the general public. We have participated in many local and international conferences and symposiums, and we have also hosted public outreach events and had programs where we train high school students in innovative technologies in virtual reality, augmented reality, and artificial intelligence. Much of the work we do applying artificial intelligence to problems in the oil and gas sector allows us to communicate the value and intricacies of these technologies using subject matter that is related and relevant to the local community.

K. CONCLUSIONS

Please provide a narrative outlining the project conclusions.

- Ensure this summarizes the project objective, key components, results, learnings, outcomes, benefits and next steps.

RESPOND BELOW

It is necessary to develop digital technologies that provide crucial insight into the large data sets available today to help select optimal petroleum recovery scenarios. In this project, machine learning (ML) technologies have been developed for reservoir exploration, reservoir property investigation, and

production prediction. Through the development of these ML technologies, we have delivered a novel reservoir interpretation and production prediction workflow together with the industrial partner Tartan Energy Group Inc. These technologies offer the promise of transformational solutions to the economic and environmental challenges in the recovery of heavy oil and bitumen resources while training much needed advanced digital skills within Alberta. Alberta has a unique opportunity to combine strength in oil and gas innovation with emerging technologies. The confluence of these two industries is the ideal place for innovation, as it follows the path of least resistance by advancing an incumbent sector while creating future opportunities and growth.