

ENHANCED OIL RECOVERY SCREENING

Final Project Report

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Executive Summary

Team #1 was tasked with investigating the suitability of Wyoming oilfields for enhanced oil recovery (EOR). The end deliverable consisted of an overall top five ranking of fields based on their EOR potential, along with a completed data set for the top two fields. Data for this project was provided by the Enhanced Oil Recovery Institute (EORI) at the University of Wyoming. Any necessary supporting data was sourced from the Wyoming Oil & Gas Conservation Commission (WOGCC) and academic literature.

Since the State of Wyoming does not produce heavy (thick) oil, screening was focused on the non-thermal EOR methods that are commercially used. These included the injection of nitrogen, flue gas, miscible hydrocarbons, CO₂, and immiscible gases, as well as polymer, surfactant, and alkaline solutions (chemical flooding). Screening took into account the specific rock and fluid requirements for each of these methods.

The project was split into six phases based on the level of complexity and the time required for the tasks involved. These phases were: Research EOR Methods, Initial Field Screening, EOR Method Evaluation/Screening, Initial Ranking, Field Level Investigation, and Final Ranking & Production Estimation. The first four phases were executed during the fall semester, with completion on November 30, 2015. The last two phases were executed during the spring semester, with completion on April 15, 2016.

A comprehensive risk analysis was performed for the project. The risks identified included: data quality, scheduling, team dynamics, scope variations, stakeholder interests, communication, and data interpretation. These risks were rated using a five-by-five risk assessment matrix. Unknown risks were accounted for through ongoing risk assessments and through the scheduling of buffer time for unexpected delays. The risk analysis provided the team with a proactive mitigation plan, which prevented any delays due to known risks.

A data review found the EORI data to be accurate for the purpose of the team's investigation. Although the WOGCC data was of varying quality, outside academic literature allowed for cross checking of the data for accuracy and supplementation.

The team successfully produced an overall top five ranking of candidates for EOR. The fields included: Hartzog Draw, Wertz, Powell, Well Draw, and Lost Soldier. The top two fields were specified for nitrogen injection, followed by two for immiscible gas injection and one for chemical flooding. Top five rankings were also developed for each EOR method. All rankings were based purely on the estimated amount of oil that EOR could recover. In addition, all of the top two fields were reinvestigated to obtain any and all missing data.

The team recommends that all of the top five fields be advanced to their own individual studies on implementation and economics, preferably led by the operators. The team agrees with nitrogen and immiscible gas flooding being the top EOR methods, but stresses that chemical and CO₂ flooding could be economical alternatives if more information becomes available.

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Nomenclature

ASP	Alkaline/Surfactant/Polymer
EOR	Enhanced Oil Recovery
EORI	Enhanced Oil Recovery Institute
GOR	Gas-Oil Ratio
MMSCF	1 Million Standard Cubic Feet
MMSTB	1 Million Stock Tank Barrels
MSTB	1,000 Stock Tank Barrels
OOIP	Original Oil in Place
RF	Recovery Factor
SCF	Standard Cubic Feet (At Standard Conditions)
STB	Stock Tank Barrel (42 Gallons)
WAG	Water-Alternating-Gas
WOGCC	Wyoming Oil & Gas Conservation Commission

1 Introduction

The purpose of this report is to summarize the design and completion of the Enhanced Oil Recovery Screening project undertaken by Team #1.

The objective of the EOR Screening project was to evaluate oilfields in the State of Wyoming for EOR suitability and potential. The final deliverable consisted of a top five ranking of fields, with complete data sets provided for the top two candidates. The Enhanced Oil Recovery Institute (EORI) at the University of Wyoming provided the initial data set, while additional data was sourced from the Wyoming Oil & Gas Conservation Commission (WOGCC) and academic literature.

Screening was performed based on the individual rock and fluid requirements for each of the EOR methods investigated. Due to the fact that Wyoming is not a producer of heavy, or viscous (thick), oil, the project focused on non-thermal EOR methods. All of the EOR methods investigated follow essentially the same principle of injecting a gas or liquid into the formation in order to recover more of the original oil in place (OOIP). However, each type of EOR achieves this increased recovery through different means. Presented below are each of the EOR methods considered with a brief description:

Nitrogen & Flue Gas Flooding

Nitrogen and flue gas flooding enhance recovery through displacement. These gases vaporize the lighter components of crude oil and can be miscible or immiscible depending on the reservoir pressure and crude oil composition. In certain circumstances, they can provide a gas drive. [1]

Hydrocarbon Miscible Flooding

Hydrocarbon miscible flooding consists of the injection of light hydrocarbons, which generates miscibility. This allows for the oil to swell and decrease in viscosity, thus improving recovery. The hydrocarbons can be in a gas or liquid phase during injection.

Carbon Dioxide Flooding

CO₂ flooding injects CO₂ into the reservoir at or near supercritical conditions. It can lower viscosity and thereby increase recovery. CO₂ can also strip the light to intermediate components from the crude oil and develop miscibility at high enough pressures. [1]

Immiscible Gas Flooding

Immiscible gas flooding operates on principles similar to those for CO₂ flooding. Unlike the previous methods, however, miscibility is not achieved. Displacement is the primary means for enhancing recovery. [1]

Polymer Flooding

Polymer flooding is a method of enhanced waterflooding, where a polymer is added to the water. It decreases water mobility, thereby improving recovery by offering a greater sweep efficiency. Polymer flooding will increase the viscosity of the waterflood. [1]

Surfactant Flooding

Another enhanced waterflooding method, surfactant flooding improves recovery through the decrease of oil/water interfacial tension. Recovery is also aided by the solubilization and emulsification of oil and through mobility enhancement. It can be deployed along with a polymer or alkaline solution. [1]

Alkaline Flooding

Alkaline flooding is enhanced waterflooding where basic (alkaline) solutions are employed. Recovery is enhanced through the reduction of surface tension via the production of surfactants in the reservoir, as well as the alteration of wettability. Oil can also be emulsified or entrained in the solution. Alkaline flooding can be performed with a surfactant and a polymer for alkaline/surfactant/polymer (ASP) flooding. [1]

Chemical Flooding

Since all of the enhanced waterflooding methods (alkaline, surfactant, and polymer) looked at over the course of the project had similar requirements and mechanisms, they were all wrapped up into a single EOR method termed chemical flooding. This allowed for flexibility in recommendations since alternative options like ASP floods could be considered within the scope of the project. Since modern waterflooding operations often include an entire chemical cocktail, the change to a chemical flooding category was beneficial.

Table 1 summarizes the screening criteria for the EOR methods discussed.

Detail Table in Ref. 16	EOR Method	Oil Properties			Reservoir Characteristics					
		Gravity (°API)	Viscosity (cp)	Composition	Oil Saturation (% PV)	Formation Type	Net Thickness (ft)	Average Permeability (md)	Depth (ft)	Temperature (°F)
Gas Injection Methods (Miscible)										
1	Nitrogen and flue gas	> 35 ↗ <u>48</u> ↗	< 0.4 ↘ <u>0.2</u> ↘	High percent of C ₁ to C ₇	> 40 ↗ <u>75</u> ↗	Sandstone or carbonate	Thin unless dipping	NC	> 6,000	NC
2	Hydrocarbon	> 23 ↗ <u>41</u> ↗	< 3 ↘ <u>0.5</u> ↘	High percent of C ₂ to C ₇	> 30 ↗ <u>80</u> ↗	Sandstone or carbonate	Thin unless dipping	NC	> 4,000	NC
3	CO ₂	> 22 ↗ <u>36</u> ↗ ^a	< 10 ↘ <u>1.5</u> ↘	High percent of C ₅ to C ₁₂	> 20 ↗ <u>55</u> ↗	Sandstone or carbonate	Wide range	NC	> 2,500 ^a	NC
1–3	Immiscible gases	> 12	< 600	NC	> 35 ↗ <u>70</u> ↗	NC	NC if dipping and/or good vertical permeability	NC	> 1,800	NC
(Enhanced) Waterflooding										
4	Micellar/ Polymer, ASP, and Alkaline Flooding	> 20 ↗ <u>35</u> ↗	< 35 ↘ <u>13</u> ↘	Light, intermediate, some organic acids for alkaline floods	> 35 ↗ <u>53</u> ↗	Sandstone preferred	NC	> 10 ↗ <u>450</u> ↗	> 9,000 ↘ <u>3,250</u>	> 200 ↘ <u>80</u>
5	Polymer Flooding	> 15	< 150, > 10	NC	> 50 ↗ <u>80</u> ↗	Sandstone preferred	NC	> 10 ↗ <u>800</u> ↗ ^b	< 9,000	> 200 ↘ <u>140</u>
Thermal/Mechanical										
6	Combustion	> 10 ↗ <u>16</u> →?	< 5,000 ↓ <u>1,200</u>	Some asphaltic components	> 50 ↗ <u>72</u> ↗	High-porosity sand/ sandstone	> 10	> 50 ^c	< 11,500 ↘ <u>3,500</u>	> 100 ↗ <u>135</u>
7	Steam	> 8 to <u>13.5</u> →?	< 200,000 ↓ <u>4,700</u>	NC	> 40 ↗ <u>66</u> ↗	High-porosity sand/ sandstone	> 20	> 200 ↗ <u>2,540</u> ↗ ^d	< 4,500 ↘ <u>1,500</u>	NC
—	Surface mining	7 to 11	Zero cold flow	NC	> 8 wt% sand	Mineable tar sand	> 10 ^e	NC	> 3:1 overburden to sand ratio	NC
<p>NC = not critical. Underlined values represent the approximate mean or average for current field projects. ^aSee Table 3 of Ref. 16. ^b> 3md from some carbonate reservoirs if the intent is to sweep only the fracture system. ^cTransmissibility > 20 md-ft/cp ^dTransmissibility > 50 md-ft/cp ^eSee depth.</p>										

Table 1: EOR Screening Criteria (Arrows Indicate if Values are Better or Worse for Given Range) [2]

Due to the nature of the screening project, the scope of the project remained broad until particular fields came into focus. The following sections describe how the team worked towards that objective and the final deliverable.

2 Project Workflow

2.1 Overview & Flow Chart

The project was split into six phases: four completed in the fall semester and two in the spring semester. The workflow was designed to facilitate the progression of the project while still considering the amount of work required in the time periods available. In the following figures, the full workflow is presented as a flow chart, with detailed descriptions of the phases in the subsequent sections. The tables below serve as a key for the flow chart and its acronyms.





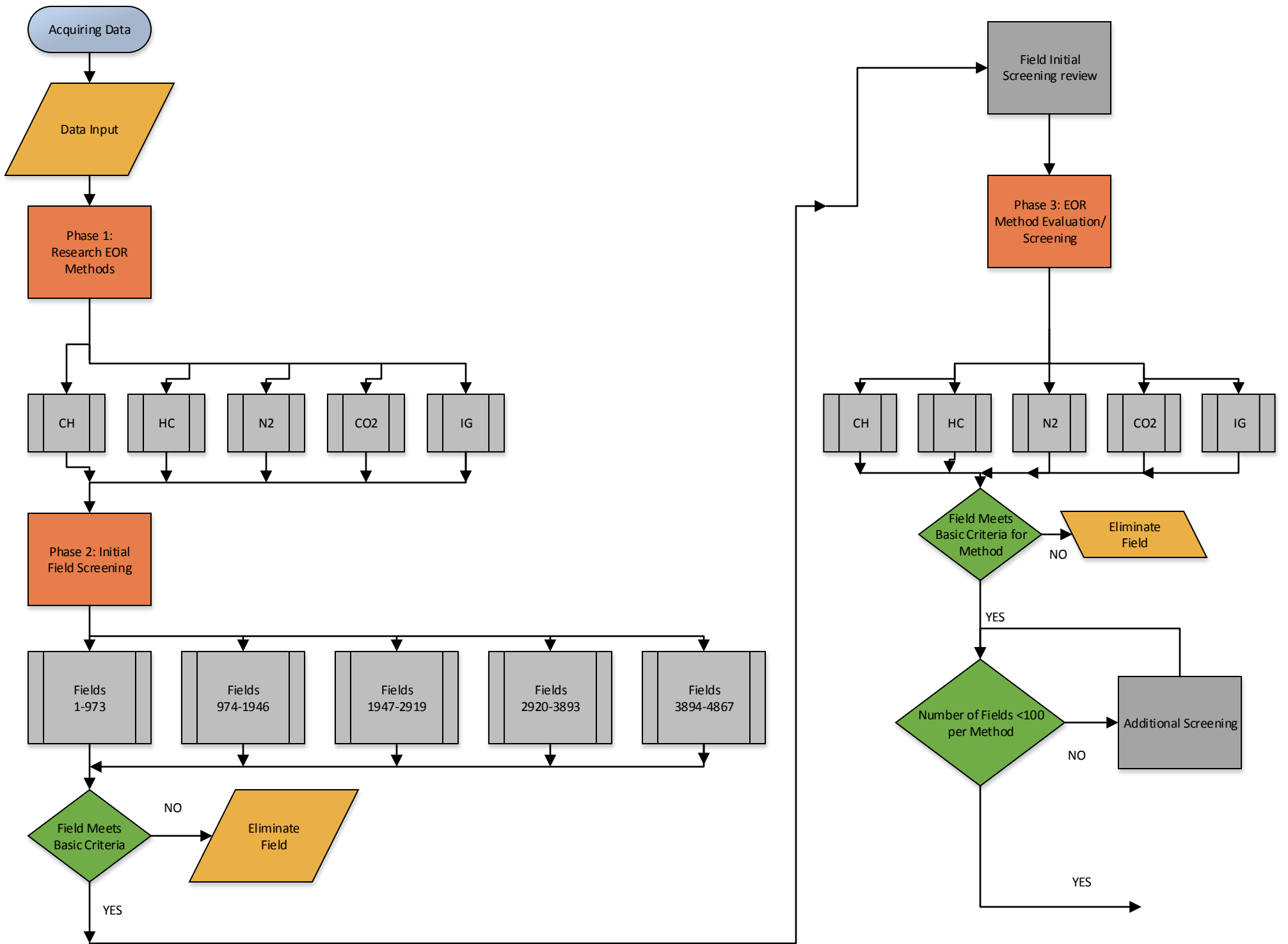
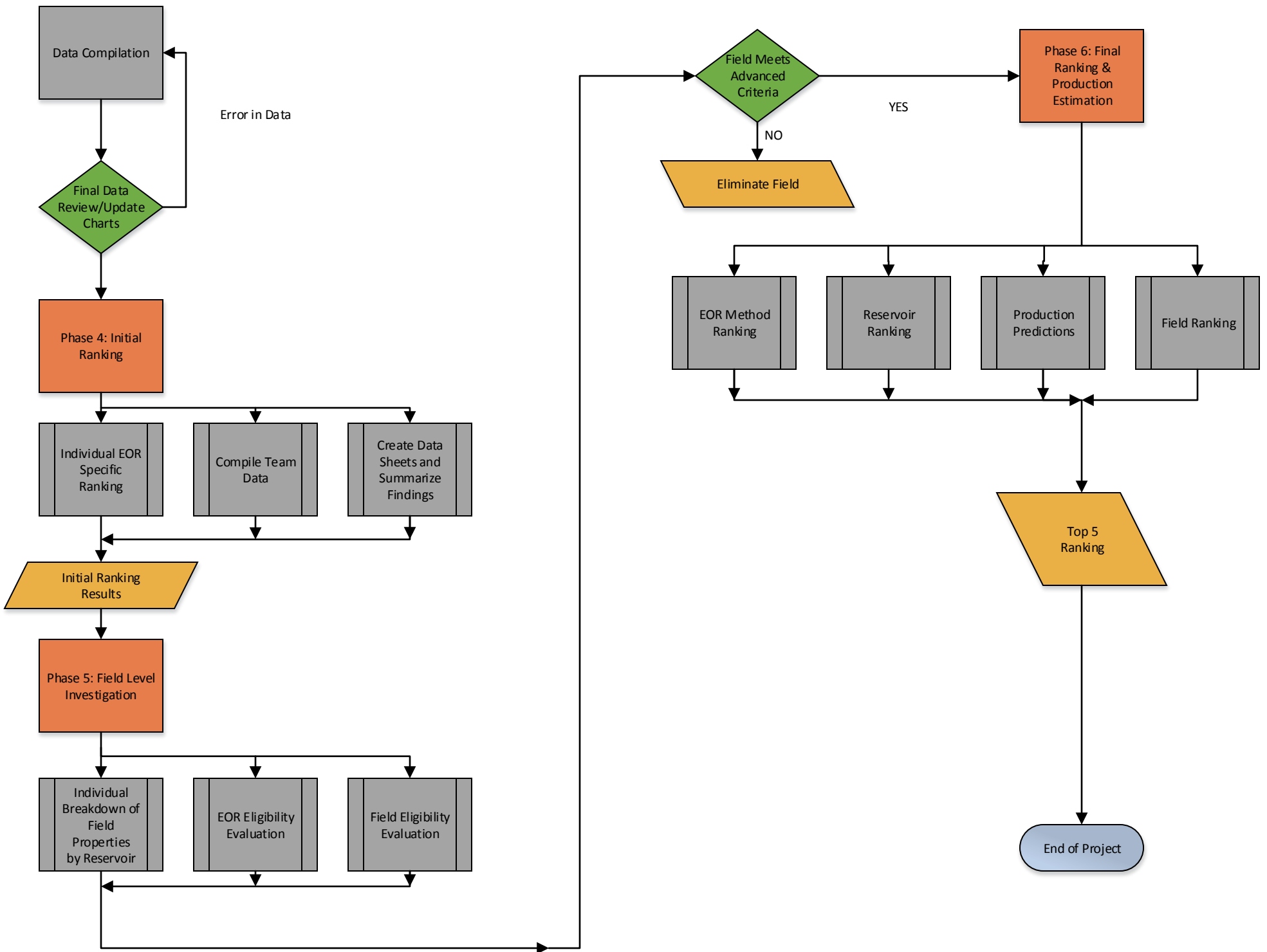
Shape	Meaning
	Start/End
	Input/Output
	Step
	Sub-Step
	Decision Point

Table 2: Flow Chart Shape Key

Acronym	Meaning
CH	Chemical Flooding
CO2	Carbon Dioxide Flooding
HC	Hydrocarbon Miscible Flooding
IG	Immiscible Gas Flooding
N2	Nitrogen & Flue Gas Flooding

Table 3: Flow Chart Acronym Key





2.2 Research EOR Methods

In order to select the best candidate fields for EOR, the team first spent time familiarizing themselves with the different types of commercially used, non-thermal EOR methods. Each team member was assigned a type of EOR method to research. The purpose of this phase was to develop the understanding necessary to perform a proper evaluation. That included, but was not limited to, determining the various rock and fluid properties required for a particular EOR method.

2.3 Initial Field Screening

After the data packet containing the 4,867 reservoirs to be investigated was obtained from the EORI, the Initial Field Screening of the candidates took place. Data for each of the fields was formatted so that the reservoir properties, lithology, geologic structures, and oil properties in the field were organized individually. Next, the actual screening and the addition of production data from the WOGCC database were performed. Each team member was responsible for 973 fields. The elimination of fields was based on production history. Fields with a cumulative production below 10,000 stock tank barrels (10 MSTB) and/or an ultimate gas-oil ratio (GOR) value above 1 million standard cubic feet per stock tank barrel (1 MMSCF/STB) were removed from the data set. Due to the large size of the original data set, these numbers were selected because many of the fields never produced or had significant oil production. This made these fields unfeasible for the scope of the project. Furthermore, fields with a GOR above 1 MMSCF/STB were assumed to be primarily gas fields.

2.4 EOR Method Evaluation/Screening

The fields that possessed enough information to be screened based upon the requirements of the various EOR methods investigated were further vetted during this step. Each member examined the remaining fields that passed the Initial Field Screening for the quantifiable parameters needed to meet their specific EOR method's requirements. The main fluid properties examined included API gravity, viscosity, and sulfur content. The primary reservoir characteristics considered included basic formation lithology, net pay thickness, porosity, permeability, depth, and temperature. Fields either advanced or were eliminated based on the outcome of this evaluation.

2.5 Initial Ranking

A preliminary, high-level investigation of the remaining fields (by EOR method) was performed to evaluate the initial potential of the fields prior to the end of the fall semester. The Initial Ranking served as a tool to shift the focus from screening large numbers of fields for data to a more in-depth investigation of the top fields' EOR potential. The fields were ranked according to the known data and a high-level knowledge of the fields. Due to the large number of fields having desirable characteristics for EOR, it was best to proceed with the fields having the greatest production and largest cumulative production to reservoir area

ratio. The rankings were considered tentative because of the high-level nature of the step and the number of candidates meeting the EOR requirements..

2.6 Field Level Investigation

The fields still present for each EOR method were investigated further using the WOGCC database. This research recovered additional information on the fields that was not present in the initial EORI data, such as detailed lithology descriptions, well counts, completion descriptions, production methods, and injection activity. The investigation of the fields was prioritized based on their initial rankings, with a focus on characteristics that were not easily quantifiable. Promising fields became the subject of academic literature searches and breakdowns by reservoir in order to gauge if they were in secondary recovery (a requirement for any further advancement) and to develop detailed histories. This phase provided the detailed information necessary to successfully complete the Final Ranking & Production Estimation phase.

2.7 Final Ranking & Production Estimation

With the most prospective fields identified and researched, the additional volumes of OOIP that could potentially be recovered with EOR implementation had to be calculated to determine a top five ranking for each EOR method, as well as an overall top five ranking. This first involved back calculating OOIP based on the cumulative production from the reservoir of interest using a recovery factor (RF). The base RF chosen was 30% considering that the fields were in secondary recovery. [3] Since the WOGCC does not keep electronic production records prior to 1978, recovery factors needed to be adjusted based on field/reservoir discovery dates. The equations developed are displayed below:

Short Term Recovery Factor Equation (1948-1977 Discovery):

$$RF = 0.3 - \frac{0.3}{37 \text{ Years}} * (\# \text{ of Years in Production Prior to 1978}) \quad (1)$$

Long Term Recovery Factor Equation (1900-1948 Discovery):

$$RF = 0.3 - \left[\frac{0.3}{37 \text{ Years}} * (\# \text{ of Years in Production Between 1978 and 1948}) + \frac{0.3}{37 \text{ Years}} * 0.66 * (\# \text{ of Years in Production Prior to 1948}) \right] \quad (2)$$

With the RFs calculated, OOIP could then be back calculated using the ratio of cumulative production to RF. [3] Since the RFs account for the fact that the cumulative production only goes back to 1978, those production values could be used with accuracy. The following equation was used:

$$OOIP = \frac{\text{Cumulative Production : 1978 to Present}}{RF} \quad (3)$$

The cumulative incremental production if a successful EOR project was implemented was then calculated based on the percentage of OOIP the project could recover. With the exception of two chemical flooding candidates with special circumstances that are outlined in our Results section, an average of 10% OOIP recovery was used based on the typical range of EOR recoveries being 5% to 15% of OOIP. [1] Since detailed reservoir characterization and stratigraphy were outside the scope of the project, the team believed that an average value was sufficient. Although small variations in recovery could make a large difference, quantifying an exact advantage/disadvantage for a given EOR method was not attainable without more information. The simple equation used to calculate cumulative recovery is presented below:

$$\text{Cumulative EOR Recovery} = \text{OOIP} * 10\% \quad (4)$$

These cumulative values were used as the basis for the final top five rankings for each EOR method, as well as for the overall top five ranking that was the team's primary deliverable. If fields qualified for more than one EOR method, the reservoir properties and field history were reviewed to determine the best fit. The top two candidates received a final investigation to develop a full dataset for each, as requested by the EORI.

2.8 Workflow Changes

Although the project workflow was not altered in structure for the duration of the project, scope variations and minor changes were necessary.

Due to the large amount of data, a broad scope was maintained until the Field Level Investigation phase. The team felt that this was necessary to avoid becoming stuck on specific data and potential dead-ends. Once the Field Level Investigation phase was reached, the scope of the project was allowed to zero in on more specific field properties and non-quantifiable data, such as field histories and literature.

The one notable workflow change that occurred was wrapping alkaline, surfactant, and polymer flooding into a chemical flooding category. As the Introduction section explains, the team found this to be a necessary change due to the fact that all three methods had similar screening criteria and are often utilized in combination. [1]

Overall, the project workflow did not change a large amount from its initial design. The team attributes this to good planning and design during the fall semester.

3 Project Schedule

3.1 Description

As presented in the Project Workflow section, the project was split into six phases. The first four phases were considered high-level and were achievable using only quantifiable data. As a result, they were completed by the end of the fall semester in accordance with the schedule below. The spring semester was devoted to the final two phases since they required in-depth data acquisition and the assembly of the team's final deliverable. Buffer time was provided at the end of the project to allow for final presentation and report preparation. The team was fortunate in that it was not needed for unforeseen delays. A gantt chart is presented in a subsequent section. However, a list of the six main project phases with their completion dates is presented below:

- Research EOR Methods: October 30, 2015
- Initial Field Screening: November 2, 2015
- EOR Method Evaluation/Screening: November 13, 2015
- Initial Ranking: November 30, 2015
- Field Level Investigation: March 18, 2016
- Final Ranking & Production Estimation: April 15, 2016

3.2 Schedule Alterations

The schedule did not change from its initial design. This was due to the team adding adequate buffer time to each phase.

3.3 Gantt Chart

The gantt chart for the project is included on the following page.

Step Description	Assigned To	Start Date	Due Date	Completed	Duration (days)	Q1			Q2			Q3		
						Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
<input type="checkbox"/> Phase 1: Research EOR Methods		12/10/15	30/10/15	<input checked="" type="checkbox"/>	18									
Nitrogen and Flue Gas	AN	12/10/15	29/10/15	<input checked="" type="checkbox"/>	17									
Hydrocarbon	DB	12/10/15	29/10/15	<input checked="" type="checkbox"/>	17									
CO2	ER	12/10/15	29/10/15	<input checked="" type="checkbox"/>	17									
Immiscible Gases	LC	12/10/15	29/10/15	<input checked="" type="checkbox"/>	17									
Chemical Flooding	RY	12/10/15	30/10/15	<input checked="" type="checkbox"/>	18									
<input type="checkbox"/> Phase 2: Initial Field Screening		30/10/15	02/11/15	<input checked="" type="checkbox"/>	3									
Reservoir Review: 1-973	RY	30/10/15	30/10/15	<input checked="" type="checkbox"/>	1									
Reservoir Review: 974-1946	DB	30/10/15	30/10/15	<input checked="" type="checkbox"/>	1									
Reservoir Review: 1947-2919	AN	30/10/15	30/10/15	<input checked="" type="checkbox"/>	1									
Reservoir Review: 2920-3893	ER	30/10/15	30/10/15	<input checked="" type="checkbox"/>	1									
Reservoir Review: 3894-4867	LC	30/10/15	30/10/15	<input checked="" type="checkbox"/>	1									
Final Initial Screening Review	RY & LC	02/11/15	02/11/15	<input checked="" type="checkbox"/>	1									
<input type="checkbox"/> Phase 3: EOR Method Evaluation/Screening		03/11/15	13/11/15	<input checked="" type="checkbox"/>	10									
Nitrogen and Flue Gas	AN	03/11/15	12/11/15	<input checked="" type="checkbox"/>	9									
Hydrocarbon	DB	03/11/15	12/11/15	<input checked="" type="checkbox"/>	9									
CO2	ER	03/11/15	12/11/15	<input checked="" type="checkbox"/>	9									
Immiscible Gases	LC	03/11/15	12/11/15	<input checked="" type="checkbox"/>	9									
Chemical Flooding	RY	03/11/15	12/11/15	<input checked="" type="checkbox"/>	9									
Final Review of Data/Update Charts	All	13/11/15	13/11/15	<input checked="" type="checkbox"/>	1									
<input type="checkbox"/> Phase 4: Initial Ranking		14/11/15	30/11/15	<input checked="" type="checkbox"/>	16									
Individual EOR Specific Ranking	All	14/11/15	17/11/15	<input checked="" type="checkbox"/>	3									
Compile Team Data	All	18/11/15	20/11/15	<input checked="" type="checkbox"/>	2									
Create Data Sheets and Summarize Findings	All	23/11/15	30/11/15	<input checked="" type="checkbox"/>	7									
<input type="checkbox"/> Phase 5: Field Level Investigation		30/11/15	18/03/16	<input checked="" type="checkbox"/>	109									
Individual Break Down of Field Properties by Reservoir	All	30/11/15	10/12/15	<input checked="" type="checkbox"/>	10									
Individual Break Down of Field Properties by Reservoir	All	25/01/16	19/02/16	<input checked="" type="checkbox"/>	25									
EOR Eligibility Evaluation	All	22/02/16	03/03/16	<input checked="" type="checkbox"/>	10									
Field Eligibility Evaluation	All	04/03/16	18/03/16	<input checked="" type="checkbox"/>	14									
<input type="checkbox"/> Phase 6: Final Ranking and Production Estimation		18/03/16	15/04/16	<input checked="" type="checkbox"/>	28									
EOR Method Ranking	All	18/03/16	24/03/16	<input checked="" type="checkbox"/>	6									
Production Predictions	All	25/03/16	31/03/16	<input checked="" type="checkbox"/>	6									
Reservoir Ranking	All	01/04/16	07/04/16	<input checked="" type="checkbox"/>	6									
Field Ranking	All	08/04/16	15/04/16	<input checked="" type="checkbox"/>	7									
Top 5 Ranking	All	08/04/16	15/04/16	<input checked="" type="checkbox"/>	7									

4 Risk Assessment

4.1 Introduction

When dealing with a technical research project like a field screening for the State of Wyoming, it is crucial to ensure project quality by taking risks into consideration. Some of the risks that were taken into consideration for this field screening project included:

- Data Quality
- Scheduling
- Team Dynamics
- Scope Variations
- Stakeholder Interests
- Communication
- Data Interpretation

Although these risks can clearly be evaluated and understood, it is also important to take into consideration the unknown risks and/or project complications that occur throughout a project's duration. During the initial planning portion of this project, it was apparent that the team's knowledge of project risks was considerably restricted, leaving the team with a large level of unknown risk. Throughout the project's progression, known risks increased and allowed for progressively fewer unknowns to be present. This risk assessment allowed the team to strategically rate and evaluate known risks, while allowing for specific time contingencies in preparation for any unknown challenges that may have been encountered. Each identified risk was rated low, medium, or high based on a 3x3 risk assessment matrix. As the project progressed, the team transitioned to a 5x5 matrix for more specific categorization. The new matrix gave low, moderate, high, or extreme ratings. The ratings allowed for associated mitigation actions to be implemented. This ensured the accuracy and success of the project.

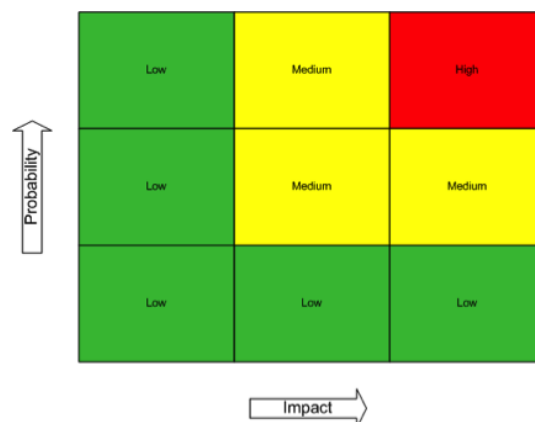


Figure 1: Original Three-by-Three Risk Assessment Matrix

Likelihood	Impact				
	Insignificant	Minor	Moderate	Major	Severe
Almost certain	Moderate	High	High	Extreme	Extreme
Likely	Moderate	Moderate	High	High	Extreme
Possible	Low	Moderate	Moderate	High	Extreme
Unlikely	Low	Moderate	Moderate	Moderate	High
Rare	Low	Low	Moderate	Moderate	High

Figure 2: Revised Five-by-Five Risk Assessment Matrix

4.2 Risks & Mitigation

Overview

Risk	Probability	Impact	Rating
Data Quality	4	4	High
Scheduling	3	4	High
Team Dynamics	2	2	Moderate
Scope Variations	4	2	Moderate
Stakeholder Interests	3	4	High
Communication	2	2	Moderate
Data Interpretation	4	4	High

Table 4: Overview of Risk Assessment Results

Data Quality

The first primary risk that was evaluated throughout the duration of the project was the possibility of receiving poor quality data within the data package from the EORI. This was evident by the amount of missing data that was encountered. This risk was rated "high," with a 4 in both probability and impact as it was seen as an evident possibility when receiving the data package. To combat this, it was decided to eliminate all fields that required significant data entry since it would have been unachievable to obtain it given the short project timeline. The data screening allowed for the risk to be mitigated as much as possible, ensuring that critical data was not missing further along in the project. This risk progressively grew throughout the project as the quality and quantity of WOGCC data that was available, accurate, and not outdated was limited for many fields. Mitigation was achieved by using

external academic sources separate from the WOGCC data.

With the completion of the project, it was apparent that a great deal of the data that was received was of mixed quality and requires updated information from operators to ensure accuracy for future projects. The data quality risk mitigation plan allowed for the team to be prepared for the issues that were encountered, including delays due to data clarity and confirmation, as well as the several cases of candidate elimination due ongoing EOR projects.

Scheduling

In relation to the previously discussed known and unknown risks, it was important to incorporate buffer time to ensure project stability when project complications arose. The "high" rating that was designated for schedule delays included a probability of 3 with a severity of 4 as this was not a project that could be delayed. By including several small time blocks designated as project review periods, mitigation was achieved while maintaining the deliverable and project deadlines that were required throughout the duration of the project.

With the completion of this project, the team identified two areas of delay that included final investigations of candidates for eligibility, as well as a final data quality review. These delays within the project were successfully mitigated, allowing for no actual delays. In many cases, project delays within the schedule were resultant of team dynamic issues, where many project disagreements had the chance to arise.

Team Dynamics

For this project, team dynamics was rated the lowest at a rating of 2 for probability and 2 for severity, resulting in an overall "moderate" risk rating. This rating was designated prior to the start of the project as all team members attended a meeting to discuss strengths and weaknesses, as well as experience in relation to the project. By establishing this early on, it allowed for the team members to show their strengths while also laying out that tie breaking decision power went to the team leader if gridlock was encountered.

With the completion of this project, the team encountered slight team dynamic issues in regards to the way that certain phases of the project should be completed. This issue was brought to the entire team's attention at one of the weekly team meetings, allowing for all to participate in a unanimous decision on how the project was to be carried out. This group vote allowed for the decision to be made in a fair manner. This conflict was of minimal damage to the project as few time delays were encountered. In the end, it was apparent that the team dynamics underlined a strong level of cooperation and success within.

Scope Variations

This risk was rated in regards to the possibility of project scope variations. Since the project involved the screening of producing fields within Wyoming for EOR potential, it involved having a broad investigation scope until certain areas of focus were determined. This risk

was rated with a probability of 4 and a severity of 2 resulting in a "moderate" risk rating. Mitigation was achieved by allowing the project to maintain a dynamic scope until the list of possible candidates was reduced to a top five based on the investigated method of EOR. Considering the broadness of the project scope, the team predicted that some level of stakeholder conflict would be encountered.

The interests of a project's stakeholders strongly influence a project's overall success or failure, thus emphasizing the importance of maintaining positive and proactive stakeholder relations. By allowing for close interaction between all stakeholders throughout the duration of the project, the scope was allowed to shape itself based on advice from the team's advisors, both from the university and the EORI.

The largest level of variation that occurred during the project was the team's decision to remove any collaboration between EOR methods, ensuring the most unbiased candidate screening. This only involved a slight increase in the total time required due to the individual EOR investigations. Other than that slight variation, this project was completed according to the initial plan.

Stakeholder Interests

Due to the level of importance that a stakeholder carries, it was decided to consider this as a primary project risk. This risk was rated using the matrix to have a probability of 3 along with a severity of 4, resulting in a "high" risk rating. This risk was mitigated throughout the project by underlining the importance of communication between team members and team mentors. By maintaining frequent and detailed communication with the team's mentors, it allowed for beneficial team guidance and project recommendations, ensuring that the project client was happy.

With the completion of the project, no issues were encountered as all risk mitigation tactics were followed. This can be attributed to the high level of communication between the team leader and the team's designated project mentor.

Communication

Inter-team communication was taken into consideration since much of the project was completed individually and combined at team meetings throughout the course of the project. This risk was rated a level 2 in both probability and severity, resulting in a "moderate" risk rating overall. The strategies that were implemented to ensure mitigation included multiple proactive meetings per week on top of designated class times, thus allowing for the team to stay in-sync and connected as the project progressed. On top of these meetings, a web based email group was created to allow for member help at any time outside of the meetings if challenges were encountered.

Communication risk mitigation tactics allowed for a high level of success during the project since all team members had the ability to communicate constantly. This eliminated the

possibility of being uninformed on project progress and any changes that occurred. A high level of communication also allowed for all team updates and deliverables to be successfully completed on time. The overall success that was achieved during the project was heavily related to the level and quality of communication that was maintained.

Data Interpretation

Data interpretation can be classified as the most critical project activity since all predictions, conclusions, and recommendations that were made relied on the accuracy of data interpretation. Due to the seriousness of this risk it was rated at a probability of 4 with a severity of 4, resulting in an overall risk rating of "high." Mitigation was achieved by designating deliverable review times in the schedule to ensure that data was interpreted correctly before proceeding to the next step. This minimized the possibility of proceeding on with the project with incorrect interpretations.

Overall, the risk mitigation tactic was effective as several data discrepancies were discovered and corrected. The mitigation tactics that were put in place allowed for interpretation challenges to be solved as a team, ensuring that all interpretations were completed using the same procedure. This was crucial to the accuracy of team predictions and overall candidate rankings. By integrating team communication into to data interpretation, the team was able to proactively re-evaluate the strategies that were being used for data interpretation, thereby increasing the quality of the results and enhancing productivity.

4.3 Conclusion

With the conclusion of this risk assessment, it is also important to consider the secondary risks that were not discussed or directly encountered during the project. These risks included office ergonomics and atmosphere, as well as the mental wellbeing and physical wellbeing of each team member and mentor associated with the success of the project. It is also important to note that throughout the duration of this project no unforeseen risks arose, although it was predicted as a possibility.

Risk assessment within this project was proactive and ensured that unknown risks were minimized as much as possible as the team's knowledge of known risks progressed. The team successfully mitigated any minor dynamic risks that were encountered once they were brought to the team's attention. By carefully planning the processes that were followed within the project, team members were able to increase productivity while enhancing efficiency.

The goal of this risk assessment was to create a level of project foresight that would allow for the most streamlined success of candidate screening, while minimizing the level of errors that may have been encountered. Overall, this assessment proved to be instrumental for the success of the team and the completion of the project.

5 Data Review

5.1 Overview

The data set provided by the EORI was a Microsoft Excel document containing information on 4,867 fields within the State of Wyoming. Data was compiled for the document from the main database used by the EORI. The values in the document describe rock and fluid characteristics using a large spectrum of properties. Since the EORI operates using public data and the results of various studies, the relative quality of the information and its acquisition method were unable to be determined. Therefore, the data was assumed to be correct.

In addition to the EORI dataset, the WOGCC database and other academic sources were utilized throughout the progression of the project. The information in the WOGCC database closely aligned with the information provided in the EORI dataset, which supported the accuracy of both sources. Due to multiple academic sources citing similar information, the details obtained in the outside research appeared to be highly reliable.

5.2 Findings

Throughout the completion of the research, the data provided by the EORI proved to be accurate and complete for the purposes of the project. Some of the fields with lesser production and importance had no information available beyond their names and producing formations. Other insignificant fields possessed missing values in various key reservoir properties, as well. The unavailable data warranted the elimination of many fields from the project. No major data anomalies surfaced during the investigation and the data appears to be accurate when compared to other data sources.

The team relied heavily on the WOGCC database throughout the Field Level Investigation phase of the project. The database was utilized in order to pull well files containing current completions, current production methods, and detailed lithology descriptions beyond those found in the EORI dataset. Due to the non-standardized nature of the well files, the quality varies between operators. In addition, the timespan of the records adds to their varied nature. The team mitigated this issue by sourcing outside literature when additional clarity was needed. The production volumes, as well as the statuses of the wells within each field, aided greatly in the completion of the project by determining current field maturities. They were the primary data derived from the WOGCC.

6 Results

6.1 Overall

As discussed in the Project Workflow section, the top five fields by EOR method and the top five overall fields were decided on by calculating the volume of OOIP that could be recovered with EOR implementation. The overall top five fields are presented below, along with their

ideal EOR method. Detailed descriptions of the fields can be found in the subsequent sections covering each EOR method.

Field	Formation	EOR Method	EOR RF	Est. EOR Production
Hartzog Draw	Shannon	Nitrogen	10%	38.1 MMSTB
Wertz	Madison	Nitrogen	10%	14.0 MMSTB
Powell	Frontier	Immiscible Gas	10%	10.2 MMSTB
Well Draw	Teapot	Immiscible Gas	10%	7.80 MMSTB
Lost Soldier	Tensleep	Chemical	3%	7.50 MMSTB

Table 5: Overall Top Five Fields

6.2 Nitrogen & Flue Gas Flooding

Results and field/reservoir information are presented in the following table with any additional field information discussed thereafter. The rankings are based on the incremental OOIP that can be recovered with the implementation of EOR.

Property	Hartzog Draw	Wertz	Lost Soldier	Glenrock South	Salt Creek
Ranking	1	2	3	4	5
Formation Name	Shannon	Madison	Flathead	Muddy	Sundance-2
Field Discovery Year	1976	1921	1916	1950	1889
Formation Discovery Year	1976	1921	1916	1950	1989
# of Producers	215	57	114	33	988
# of Injectors	149	67	102	9	614
# of Dormant Wells	26	7	4	3	112
# of PA'd Wells	29	43	253	256	2,676
# of Spuds	0	11	8	0	528
Porosity [%]	12	12	5	20	16
Permeability [mD]	8.0	15.0	0.6	200.0	15.0
Oil API Gravity [°]	36	35	35	38	37
Oil Viscosity [cP]	7.90	8.13	8.39	7.15	7.44
Temperature [°F]	177	147	141	136	96
Cumulative Oil (1978+) [MMSTB]	110	24.5	8.24	1.62	0.310
OOIP [MMSTB]	381	140	46.2	8.67	3.55
Est. EOR Recovery of OOIP [%]	10	10	10	10	10
Est. EOR Production [MMSTB]	38.1	14.0	4.62	0.867	0.355

Table 6: Nitrogen & Flue Gas Flooding: Top Five Field Properties

Hartzog Draw (Shannon Sandstone)

The Hartzog Draw field produces from the argillaceous Shannon Sandstone. During the first year of development (through September 1976), 16 wells were drilled and initial projections of ultimate field size and oil recovery were modeled after Heldt Draw. Nearly all wells were hydraulically fractured and required artificial lift shortly after being completed. Ultimately, 177 producing wells were completed and approximately 32 million barrels of oil were recovered during primary field development. Hartzog Draw was unitized for secondary recovery in 1980. Waterflood development began in 1981 and included an infill drilling pilot project in the center of the field. Excellent waterflood response supported further infill drilling by the end of 1985. Approximately 115 infill wells will have been drilled, covering the major portion of the field. Predicted primary and secondary recovery was 128 million stock tank barrels, or 39% of OOIP. [4] Currently, the field is in tertiary recovery. CO₂ injection was planned, but production stopped due to the current economic conditions in the oil and gas industry. Therefore, the most economic and efficient recovery method should be used in order to start producing again.

Wertz (Madison Limestone)

The Wertz field produces from the limestone and dolomite of the Madison Formation. Primary production was attributed to fluid expansion, water influx, and gravity drainage. [5]

Lost Soldier (Flathead Sandstone)

Lost Soldier produces from the Flathead Sandstone. No additional information was obtained outside of the contents of the table.

Glenrock South (Muddy Sandstone)

Glenrock South produces from the Muddy Sandstone. No additional information was obtained outside of the contents of the table.

Salt Creek (Sundance-2 Sandstone)

Salt Creek produces from the Sundance-2 Sandstone. Production has since ceased as of September 2013.

6.3 Hydrocarbon Miscible Flooding

Results and field/reservoir information are presented in the following table with any additional field information discussed thereafter. The rankings are based on the incremental OOIP that can be recovered with the implementation of EOR.

Property	Rozet	Glenrock South	Springen Ranch	Poison Spider West	Worland
Ranking	1	2	3	4	5
Formation Name	Muddy	Muddy	Muddy	Frontier	Frontier
Field Discovery Year	1959	1950	1968	1948	1946
Formation Discovery Year	1959	1950	1968	1948	1946
# of Producers	39	33	3	0	36
# of Injectors	23	9	3	1	1
# of Dormant Wells	2	3	0	2	1
# of PA'd Wells	148	256	88	14	28
# of Spuds	1	0	0	0	0
Porosity [%]	20	20	21	7	18
Permeability [mD]	58.0	200.0	226.0	0.73	72.0
Oil API Gravity [°]	38	38	38	42	38
Oil Viscosity [cP]	7.82	7.15	6.70	6.38	5.87
Temperature [°F]	145	136	155	238	155
Cumulative Oil (1978+) [MMSTB]	3.81	1.62	1.39	0.168	0.00807
OOIP [MMSTB]	17.1	8.67	5.35	0.942	0.0466
Est. EOR Recovery of OOIP [%]	10	10	10	10	10
Est. EOR Production [MMSTB]	1.71	0.867	0.535	0.0942	0.00466

Table 7: Hydrocarbon Miscible Flooding: Top Five Field Properties

Rozet (Muddy Sandstone)

The Rozet field produces from the argillaceous Muddy Sandstone. No additional information was obtained outside of the contents of the table.

Glenrock South (Muddy Sandstone)

Glenrock South produces from the Muddy Sandstone. No additional information was obtained outside of the contents of the table.

Springen Ranch (Muddy Sandstone)

Springen Ranch produces from the Muddy Sandstone. No additional information was obtained outside of the contents of the table.

Poison Spider West (Frontier Sandstone)

Poison Spider West produces from the Frontier Sandstone. No additional information was obtained outside of the contents of the table.

Worland (Frontier Sandstone)

The Worland field produces from the Frontier Sandstone. No additional information was obtained outside of the contents of the table.

6.4 Carbon Dioxide Flooding

Results and field/reservoir information are presented in the following table with any additional field information discussed thereafter. The rankings are based on the incremental OOIP that can be recovered with the implementation of EOR.

Property	Hartzog Draw	Steamboat Butte	Steamboat Butte	Halverson	Quealy
Ranking	1	2	3	4	5
Formation Name	Shannon	Tensleep	Phosphoria	Dakota	Dakota
Field Discovery Year	1976	1943	1943	1961	1921
Formation Discovery Year	1976	1944	1943	1961	1934
# of Producers	215	41	41	16	19
# of Injectors	149	25	25	6	0
# of Dormant Wells	26	10	10	7	1
# of PA'd Wells	29	36	36	38	18
# of Spuds	0	13	13	0	1
Porosity [%]	12	12	16.5	14	18
Permeability [mD]	8.0	41.0	6.11	51.0	19.3
Oil API Gravity [°]	36	28	32	41	33
Oil Viscosity [cP]	7.90	14.90	9.66	6.53	9.20
Temperature [°F]	177	147	143	147	108
Cumulative Oil (1978+) [MMSTB]	110	10.3	1.74	0.818	0.331
OOIP [MMSTB]	381	62.7	10.6	3.54	2.35
Est. EOR Recovery of OOIP [%]	10	10	10	10	10
Est. EOR Production [MMSTB]	38.1	6.27	1.06	0.354	0.235

Table 8: Carbon Dioxide Flooding: Top Five Field Properties

Hartzog Draw (Shannon Sandstone)

Please see the results for Hartzog Draw in the Nitrogen & Flue Gas Flooding section. The reservoir has favorable conditions for both nitrogen and carbon dioxide flooding. [6]

Steamboat Butte (Tensleep Sandstone & Phosphoria Formation)

Located in the western half of the Wind River Basin, the Steamboat Butte field was discovered utilizing seismic data along with surface information. [7] Two formations, the Tensleep and the Phosphoria, are candidates for carbon dioxide injection.

The reservoir possesses an anticline that acted as a structural trap to accumulate hydrocarbons. However, the basin is topographic in addition to being structural. Thrust faulting played an important role in the development of the basin. The Tensleep formation is an aeolian Pennsylvanian age sandstone whose source rock is most likely the Paleozoic Phosphoria Formation. The sandstone in the Tensleep formation is brown to light brown, fine grained, medium to well sorted, and sub-angular. The Phosphoria carbonate formation is Permian age. The carbonate in the Phosphoria is grey to light grey, cherty, pyritic, vuggy limestone. Despite a gross thickness of 250 feet, the net pay is usually less than 30 feet. [7]

Both the Tensleep and the Phosphoria produce black oil. All of the wells utilize pumping equipment to aid in production. [7] Due to its smaller reservoir potential, there is scarce literature on the formations beyond a geological study that utilized the reservoir as a model to help predict other small oil accumulations. One can conclude from the graphs of production, in addition to the well count information, that waterflooding is being implemented. However, the success of the waterflood is unknown.

Halverson (Dakota Sandstone)

The Halverson field is located in Campbell County. Due to the small nature of the field, no academic literature was found containing additional information on the field. Given the relatively insignificant size of the Dakota reservoir compared to other carbon dioxide injection candidate fields, this was relatively unsurprising. The lithology of the field is fine to medium sandstone. [8] The vast majority of the wells are PA'd at this point in time, with the peak of the field potentially only having had 61 producing wells. The oil production rate is steadily declining and it appears that a small number of water injection wells are implemented at this moment.

Quealy (Dakota Sandstone)

The Quealy field is located in the western part of the Laramie Basin. After three failed oil wells and a resulting seismic evaluation, the Dakota formation was successfully drilled in 1934. The reservoir is a narrow, elongated anticline with thrust faulting and many small normal faults. Formed in the Lower Cretaceous, the Dakota formation is comprised of light gray, medium-grained sandstone. The pay section of the Dakota formation is around 30 feet thick. The produced oil is green and a waterdrive is present. At this stage in the field's

life, water encroachment is a production problem. The water encroachment has warranted plugging the Dakota formation in many wells. [8]

6.5 Immiscible Gas Flooding

Results and field/reservoir information are presented in the following table with any additional field information discussed thereafter. The rankings are based on the incremental OOIP that can be recovered with the implementation of EOR.

Property	Powell	Well Draw	Kitty	Rozet	Glenrock South
Ranking	1	2	3	4	5
Formation Name	Frontier	Teapot	Muddy	Muddy	Dakota
Field Discovery Year	1954	1973	1965	1959	1950
Formation Discovery Year	1954	1973	1965	1959	1950
# of Producers	66	224	147	39	33
# of Injectors	0	3	0	23	9
# of Dormant Wells	1	2	7	2	3
# of PA'd Wells	46	155	171	148	256
# of Spuds	0	2	0	1	0
Porosity [%]	15	12	10	20	14
Permeability [mD]	100.0	157.0	10.0	58.0	33.0
Oil API Gravity [°]	48	43	38	38	34
Oil Viscosity [cP]	5.87	6.33	6.39	7.82	8.50
Temperature [°F]	209	146	169	145	136
Cumulative Oil (1978+) [MMSTB]	20.6	21.8	5.75	3.81	2.93
OOIP [MMSTB]	102	78.0	23.2	17.1	15.7
Est. EOR Recovery of OOIP [%]	10	10	10	10	10
Est. EOR Production [MMSTB]	10.2	7.80	2.32	1.71	1.57

Table 9: Immiscible Gas Flooding: Top Five Field Properties

Powell (Frontier Sandstone)

The Powell field produces from the Frontier Sandstone. No additional information was obtained outside of the contents of the table.

Well Draw (Teapot Sandstone)

Well Draw produces from the Teapot Sandstone. No additional information was obtained outside of the contents of the table.

Kitty (Muddy Sandstone)

The Kitty field produces from the Muddy Sandstone. No additional information was obtained outside of the contents of the table.

Rozet (Muddy Sandstone)

The Rozet field produces from the Muddy Sandstone. No additional information was obtained outside of the contents of the table.

Glenrock South (Dakota Sandstone)

Glenrock South produces from the Dakota Sandstone. No additional information was obtained outside of the contents of the table.

6.6 Chemical Flooding

Results and field/reservoir information are presented in the following table with any additional field information discussed thereafter. The rankings are based on the incremental OOIP that can be recovered with the implementation of EOR.

Property	Lost Soldier	Steamboat Butte	Wertz	Murphy Dome	Glenrock South
Ranking	1	2	3	4	5
Formation Name	Tensleep	Tensleep	Tensleep	Tensleep	Dakota
Field Discovery Year	1916	1943	1921	1949	1950
Formation Discovery Year	1930	1944	1937	1949	1950
# of Producers	114	41	57	44	33
# of Injectors	102	25	67	0	9
# of Dormant Wells	4	10	7	1	3
# of PA'd Wells	253	36	43	42	256
# of Spuds	8	13	11	3	0
Porosity [%]	10	12	10	13	14
Permeability [mD]	31.0	41.0	20.0	59.2	33.0
Oil API Gravity [°]	33	28	35	34	34
Oil Viscosity [cP]	9.34	14.90	8.20	8.71	8.50
Temperature [°F]	125	147	141	121	136
Cumulative Oil (1978+) [MMSTB]	63.0	10.3	38.3	6.58	2.93
OOIP [MMSTB]	250	62.7	180	36.1	15.7
Est. EOR Recovery of OOIP [%]	3	10	3	10	10
Est. EOR Production [MMSTB]	7.50	6.27	5.40	3.61	1.57

Table 10: Chemical Flooding: Top Five Field Properties

Lost Soldier (Tensleep Sandstone)

The Lost Soldier field produces from the aeolian Tensleep Sandstone, which is of Pennsylvanian age. The field is situated near Bairoil, WY. The field was slow to develop, but now boasts good well counts. [9]

Waterflooding was initiated in Lost Soldier in the 1970s, with CO₂ flooding coming along in the 1980s. The field is currently producing under a CO₂ water-alternating-gas (WAG) flood. With the WAG flood providing an incremental recovery of 13% of OOIP, the total recovery in Lost Soldier is projected to reach nearly 63%. [9] This field was selected for chemical flooding, despite the existing EOR project, due to the fact that chemical flooding has been considered for integration with the WAG flood. This was indicated by the operator as a measure to improve reservoir conformance. [10] For example, introducing a gel when a pattern is on water can help improve the recovery over water alone. The incremental recovery of OOIP if chemical WAG flooding were implemented would likely be small (around 3% on the low side based on literature) since it would only help improve the current flood, but the scale of the field warrants the consideration of such a project. [11] OOIP has been increased by 10 MMSTB for project purposes to account for technological advances and further exploration since the last literature values were developed. [9] Literature values were used as a starting point due to their availability for this well-studied field.

Steamboat Butte (Tensleep Sandstone)

Please see the results for Steamboat Butte in the Carbon Dioxide Flooding section. The reservoir has favorable conditions for both types of EOR.

Wertz (Tensleep Sandstone)

Like Lost Soldier, the neighboring Wertz field produces from the Tensleep Sandstone and is situated near Bairoil, WY. [12]

Waterflooding was initiated in Wertz in the 1970s, with CO₂ flooding coming along in the 1980s. The field is currently producing under a CO₂ WAG flood. With the WAG flood providing an incremental recovery of 10% of OOIP, the total recovery in Wertz is projected to reach nearly 56%. [12] This field was selected for chemical flooding, despite the existing EOR project, due to the fact that chemical WAG flooding has been considered just as it has for Lost Soldier. [10] The incremental recovery of OOIP would also be around 3% if chemical WAG flooding were implemented. [11] However, the scale of Wertz also warrants the consideration of such a project. Like for Lost Soldier, OOIP has been increased by 10 MMSTB to account for technological advances and further exploration since the last literature values were developed. [12]

Murphy Dome (Tensleep Sandstone)

Murphy Dome produces from the Tensleep Sandstone. No additional information was obtained outside of the contents of the table.

Glenrock South (Dakota Sandstone)

Glenrock South produces from the Dakota Sandstone. No additional information was obtained outside of the contents of the table.

7 Summary

This report covered Team #1's non-thermal EOR screening for the State of Wyoming from design to execution. 4,867 reservoirs were screened to determine their suitability for nitrogen, flue gas, hydrocarbon miscible, carbon dioxide, immiscible gas, and chemical flooding. The final deliverable was a top five ranking of fields based on EOR suitability, with data collection performed for the top two fields.

The project was split into six phases, with the first four completed during the fall semester and the last two during the spring semester. The breakdown was based on the complexity of the various steps and their required completion times. The project wrapped up on April 15, 2016.

A comprehensive risk analysis found data quality, scheduling, team dynamics, scope variations, stakeholder interests, communication, and data interpretation to be the primary project risks. A proactive mitigation program was put into place during the fall semester and prevented any project delays. The team's data review concluded that the EORI data was accurate, but that the WOGCC data required supplementation with outside literature.

The team developed a comprehensive top five ranking for each EOR method investigated. An overall ranking was also created. These rankings were based strictly on the additional amount of OOIP that could be recovered through EOR implementation. As part of the top five ranking deliverable, the top two fields were also part of a deeper investigation where any and all missing data was obtained.

8 Conclusions

8.1 Overall

Team #1 identified five high quality candidates for EOR implementation. Potential recoverable oil with EOR ranges from 7.5 MMSTB to 38.1 MMSTB, making them lucrative prospects. Nitrogen and immiscible gas injection gave the best candidates, while implementing a chemical flood with the existing CO₂ WAG in Lost Soldier's Tensleep rounded out the top five. Although hydrocarbon miscible injection and carbon dioxide flooding produced candidates, they were not competitive enough to be included in the overall top five.

8.2 Nitrogen & Flue Gas Flooding

Nitrogen flooding provided the best EOR candidates, with the top candidate offering a potential recovery of over 38.1 MMSTB.

Nitrogen creates energy to increase pressure and drive oil into the wellbore. This promotes additional recovery. The additional benefits of using nitrogen in comparison to other gases are that it is cheaper, inert, noncorrosive, and oxygen free. Also, the incremental production and EOR recovery are high. [1] Taking all of this into account, the team sees the nitrogen flooding candidates as the most promising.

8.3 Hydrocarbon Miscible Flooding

Although screening yielded candidates, hydrocarbon miscible flooding did not provide potential reservoirs with good recoveries. The estimated EOR production for this method topped out at 1.7 MMSTB and fell rapidly downwards. The team does not see hydrocarbon miscible flooding as a competitive option.

8.4 Carbon Dioxide Flooding

CO₂ flooding provided some of the best and worst EOR candidates. It shares Hartzog Draw with nitrogen flooding as a candidate, which could recover over 38.1 MMSTB, but also produced Quealy as a candidate. Quealy's EOR production was calculated to be only 235 MSTB.

The team decided that CO₂ flooding was viable for some candidates, but was not cost competitive compared with other EOR methods that share candidates (i.e. nitrogen and chemical flooding). However, it's worthwhile to keep the method in mind considering its success in the Rockies.

8.5 Immiscible Gas Flooding

Immiscible gas flooding provided the third and fourth most promising EOR candidates. One EOR recovery value was over 10 MMSTB. Part of this can be attributed to having a broad definition for immiscible gases, but the method is also cost competitive. The team sees immiscible gas flooding as a top EOR method.

8.6 Chemical Flooding

Chemical flooding only had one candidate in the top five, but some of its numbers were competitive. EOR recoveries ranged from 7.5 MMSTB down to 1.5 MMSTB.

The main advantage of chemical flooding is that it is easy to implement in fields with existing waterfloods. Start up costs are low as the infrastructure may already exist. The cost per barrel produced is also reasonable and recoveries can be high. [1] Due to these factors, the team sees chemical flooding as an excellent option.

9 Recommendations

The team recommends that the top five fields be advanced to their own independent studies on implementation and economics. The EOR recoveries calculated make the initial impression that all five fields could make lucrative projects. It's preferable to have the operator perform such a project in-house or through a consultant. The operator will possess the correct economic information, cores, fluid samples, and access to reservoir models that can be used for more accurate simulations. Such information would enable better decision making, especially based on the current oil price.

The team also recommends that alternative options like CO₂ and chemical flooding be considered for the top five candidates. Further studies could reveal that these methods are advantageous over those initially identified.

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