IDEAL SOLUTIONS ENGINEERING

Enhanced Oil Recovery Screening

Final Presentation

Apr.29/2017

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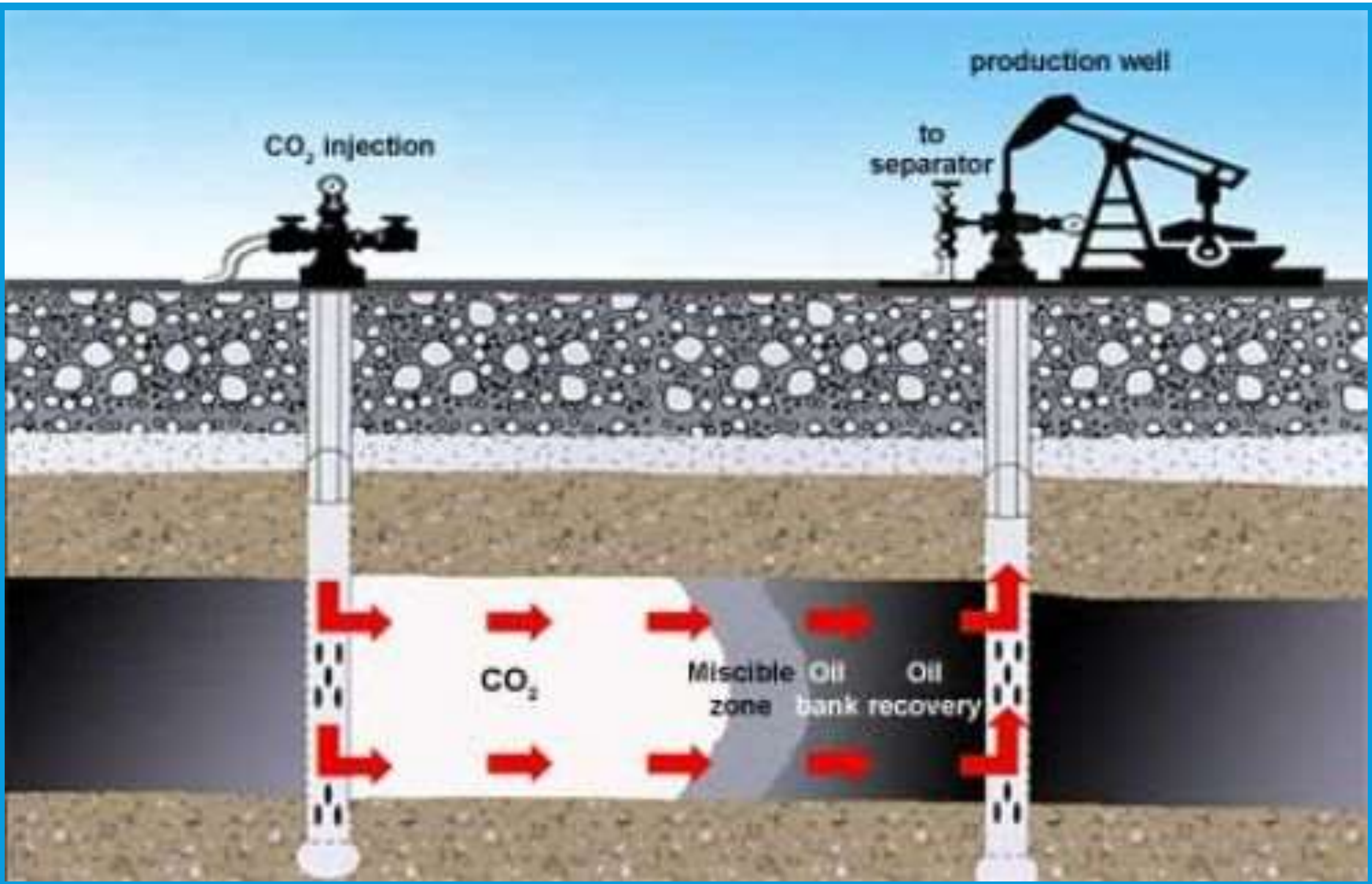
INTRODUCTION

- Enhanced Oil Recovery (EOR) screening
  - Utilizing an Enhanced Oil Recovery Institute (EORI) database
  - Review of 1400 fields/reservoirs data

- Different methods used for EOR
  - Gas Injection (CO_2, N_2, Natural Gas)
  - Chemical Injection (Polymer, Surfactant)
  - Thermal (Steam Flooding, Combustion)
  - Water Flooding

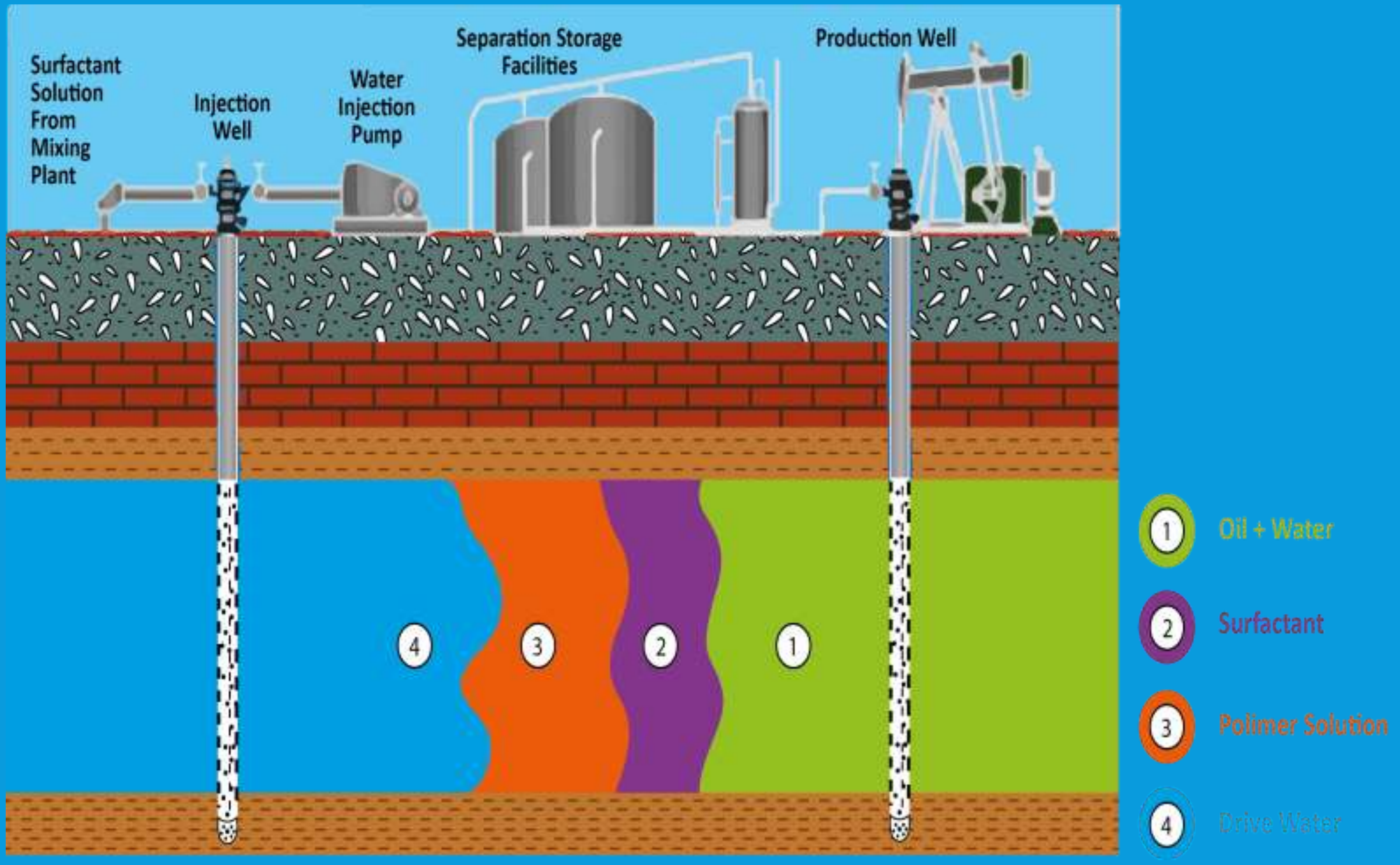
EOR TYPES

- Gas Injection
  - Most commonly used
  - Good oil displacement
  - Relies on temperature, pressure, and crude composition
  - Uses CO_2, N_2, or natural gas
  - Increases total displacement efficiency



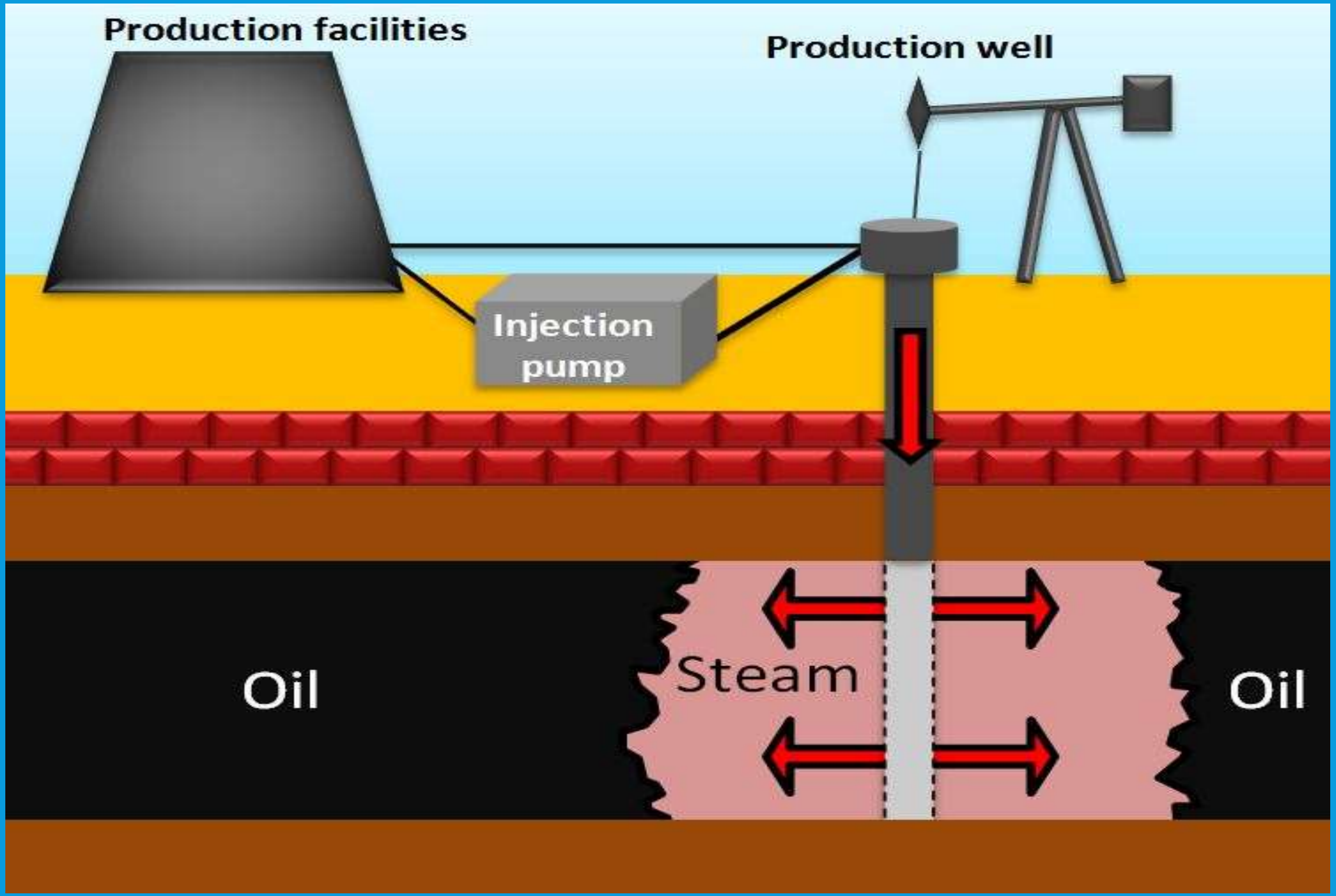
EOR TYPES

- Chemical Injection
  - Aids mobility and reduces surface tension
  - Uses surfactants to lower interfacial tension
  - Special formulation of water, oil, surfactants is most efficient



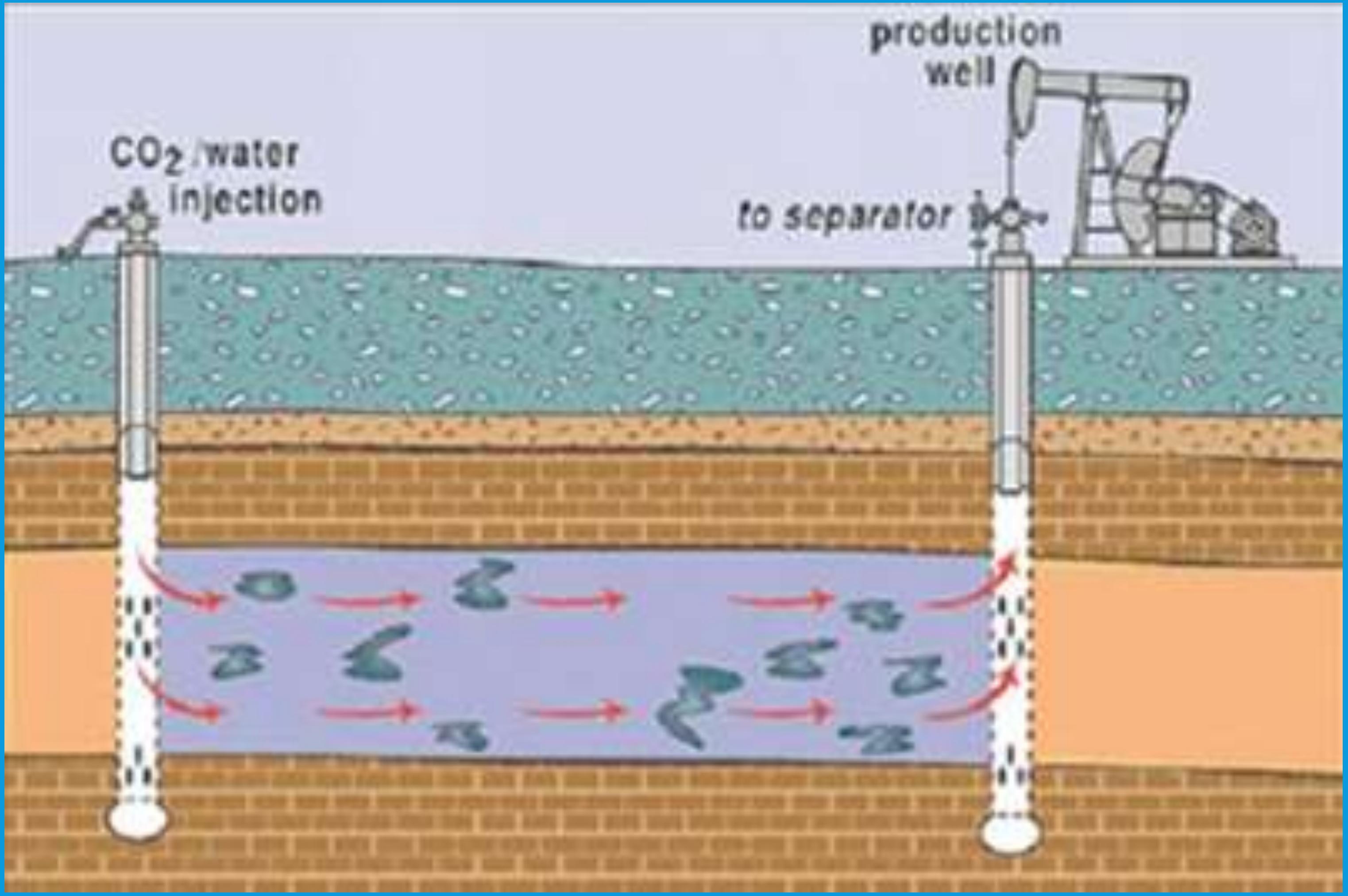
EOR TYPES

- Thermal Methods
  - Most commonly in use today
  - Includes steam flooding and combustion
  - Steam is pumped into the well and condenses to hot water
  - Some of the oil evaporates
  - Decreases viscosity
  - Increases permeability



EOR TYPES

- Water Flooding
  - Commonly used method
  - Water injection is used to increase reservoir pressure
  - Water displaces oil from pore spaces
  - Draw back:
    - Takes a long time to complete



PROJECT OBJECTIVES

- Screened 1400 fields according to screening criteria such as production history, API gravity, lithology, net pay, permeability, porosity, temperature
- Narrowed down fields/reservoirs by calculating OOIP and feasibility using WyRit and WOGCC to get our data (288 fields were finalized)
- Used Sword software to analyze our fields and design decline curves
- Performed decline curve analysis of 20 fields based on distance to the pipeline

TIMELINE

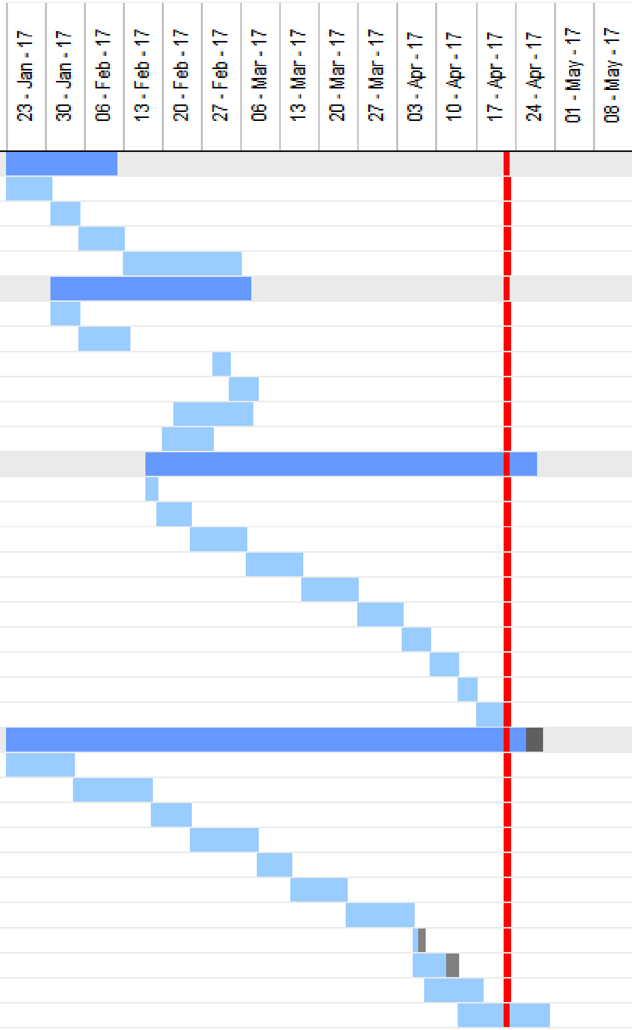
- Completed Tasks
  - Initiation & Planning
    - 100%
  - Execution
    - 100%
  - Project Milestones
    - 96%
  - Drafting Final Project Report
    - 80%

Ideal Solutions Engineering - EOR Screening
PETE 4736

Today's Date: 22-Apr-17 Saturday
(vertical red line)

Start Date: 24-Jan-17 Tuesday

Task #	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**Initiation**		23-Jan-17	**11-Feb-17**	20	100%	15	20	0
1.1	Team Formation	Team	23-Jan-17	**30-Jan-17**	8	100%	6	8	0
1.2	Project Selection	Team	31-Jan-17	**4-Feb-17**	5	100%	4	5	0
1.3	Project Approval	Team	5-Feb-17	**12-Feb-17**	8	100%	5	8	0
1.4	Project Presentation Sign Up	Dalveer	13-Feb-17	**5-Mar-17**	21	100%	15	21	0
2	**Planning**		31-Jan-17	**7-Mar-17**	36	100%	26	36	0
2.1	Initial Project Plan Overview	Moataz	31-Jan-17	**4-Feb-17**	5	100%	4	5	0
2.2	Discussion of Project Schedule & Assignments	Abdullah	5-Feb-17	**13-Feb-17**	9	100%	6	9	0
2.3	Revision of Initial Project Plan	Zach	1-Mar-17	**3-Mar-17**	3	100%	3	3	0
2.4	Implementing Revision of Final Project Plan	Ahmed	4-Mar-17	**8-Mar-17**	5	100%	3	5	0
2.5	Oral Progress Report Prep	Dalveer	22-Feb-17	**7-Mar-17**	14	100%	10	14	0
2.6	Software License Acquisition	Dalveer	20-Feb-17	**28-Feb-17**	9	100%	7	9	0
3	**Execution**		17-Feb-17	**27-Apr-17**	70	100%	50	70	0
3.1	Gather Production Data	Abdullah	17-Feb-17	**18-Feb-17**	2	100%	1	2	0
3.2	Review all Provided Data	Moataz	19-Feb-17	**24-Feb-17**	6	100%	5	6	0
3.3	Peer Review of Data Gathered	Team	25-Feb-17	**6-Mar-17**	10	100%	6	10	0
3.4	Develop Screening Techniques	Dalveer	7-Mar-17	**16-Mar-17**	10	100%	8	10	0
3.5	Apply Ranking Criteria	Zach	17-Mar-17	**26-Mar-17**	10	100%	6	10	0
3.6	Decline Curve Analysis	Ahmed	27-Mar-17	**3-Apr-17**	8	100%	6	8	0
3.7	EOR Cost Criteria	Zach	4-Apr-17	**8-Apr-17**	5	100%	4	5	0
3.8	Logistical Considerations (Pipelines ETC)	Zach	9-Apr-17	**13-Apr-17**	5	100%	4	5	0
3.9	Recommendations	Team	14-Apr-17	**16-Apr-17**	3	100%	1	3	0
3.10	Project Review	Team	17-Apr-17	**21-Apr-17**	5	100%	5	5	0
4	**Project Milestones**		23-Jan-17	**28-Apr-17**	96	97%	70	93	3
4.1	Team Brainstorming	Team	23-Jan-17	**3-Feb-17**	12	100%	10	12	0
4.2	Drafting Project Plan	Moataz	4-Feb-17	**17-Feb-17**	14	100%	10	14	0
4.3	Preparing Schedule	Dalveer	18-Feb-17	**24-Feb-17**	7	100%	5	7	0
4.4	Final Revision of Draft Plan	Abdullah	25-Feb-17	**8-Mar-17**	12	100%	8	12	0
4.5	Testing Sword Software	Moataz	9-Mar-17	**14-Mar-17**	6	100%	4	6	0
4.6	Status Report	Dalveer	15-Mar-17	**24-Mar-17**	10	100%	8	10	0
4.7	Drafting Final Project Report	Zach	25-Mar-17	**5-Apr-17**	12	100%	8	12	0
4.8	Discussion of Peer Reviews	Team	6-Apr-17	**7-Apr-17**	2	50%	2	1	1
4.9	Final Revision Project Report	Team	6-Apr-17	**13-Apr-17**	8	75%	6	6	2
4.10	Practice Presentation, Final Report	Team	8-Apr-17	**17-Apr-17**	10	100%	6	10	0
4.11	Present Final Presentation	Team	14-Apr-17	**29-Apr-17**	16	100%	11	16	0



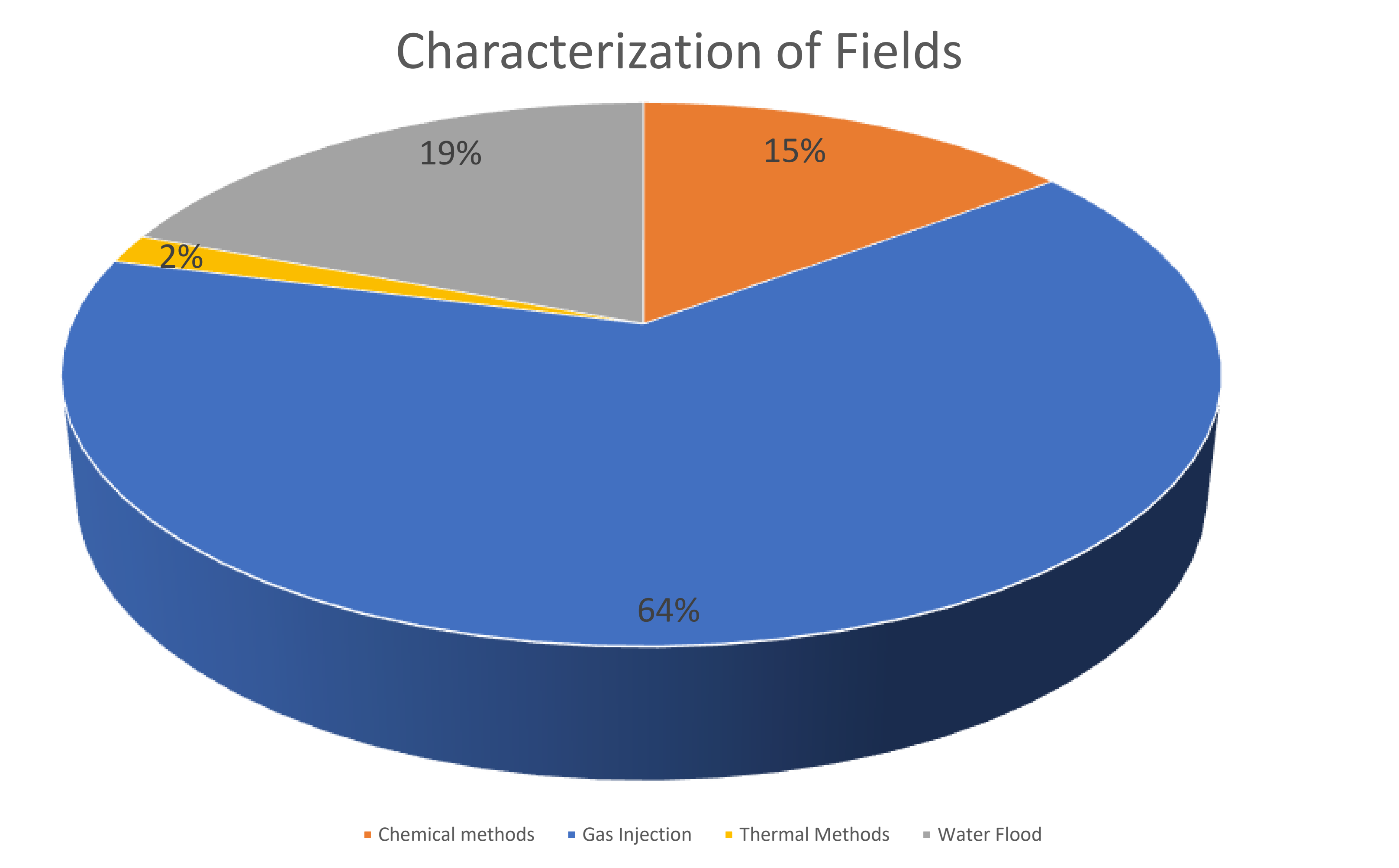
RISK ANALYSIS

- Is to minimize the probability of something going wrong along with minimizing the negative impact on the environment and society.
- Qualitative risks which are critical to the project's success include:
  - Software:
    - Sword: utilizes historical data, may not be suitable as a stand-alone tool
    - WyRit: web based, will pose challenges during field use, may not include all parameters required for technical analysis
    - WOGCC: may not include all required parameters needed for technical analysis
  - Economical Risks:
    - Prospective ranking directly linked to $52 per barrel for the 20 fields, which effects profit potential

RESULTS EOR CHARACTERIZATION

288 Fields Characterized:

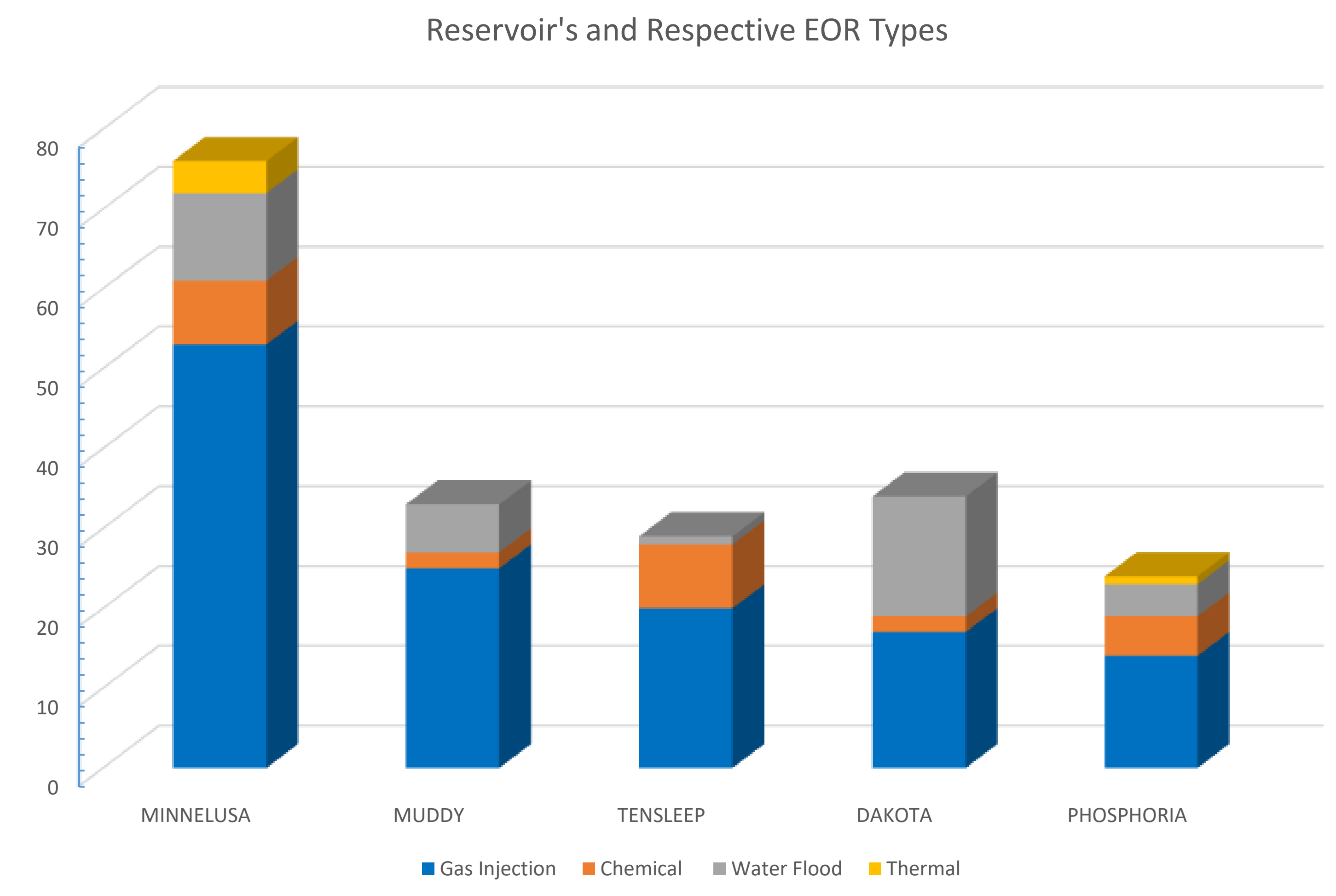
- Gas Injection - 64%
  - CO_2
- Water Flood - 19%
- Chemical Methods - 15%
  - Polymer & Surfactant
- Thermal Methods - 2%
  - Steam & Combustion



RESULTS FOR DIFFERENT RESERVOIRS

- Using the 288 fields characterized
  - 38 types of reservoirs were characterized for the fields

- Notable Reservoirs: Primarily characterized for CO_2 gas injection
  - Minnelusa
  - Muddy
  - Tensleep
  - Dakota
  - Phosphoria



SWORD

- IRIS – International Research Institute of Stavanger
  - Located in Norway
  - Point of Contact: Roman Berenblyum (Technical Manager)

- Software designed for fast screening predictions
  - Uses historical data collected by Oil and Gas EOR experts
    - Data is collected world wide for various EOR applications
  - Typically used for pre-simulation in order to save costs
    - Numerical simulators or modelling can be expensive

TECHNICAL ANALYSIS

One case for EOR characterization will be thoroughly examined, this is where we conduct:

- Applicability Screening
  - Characterizing the field
- Verify Results
  - Quality checking
- Recovery Factor
  - Percentage recoverable
- Decline Curve Analysis
  - Production Rate vs Time
  - Production Rate vs Cumulative Production

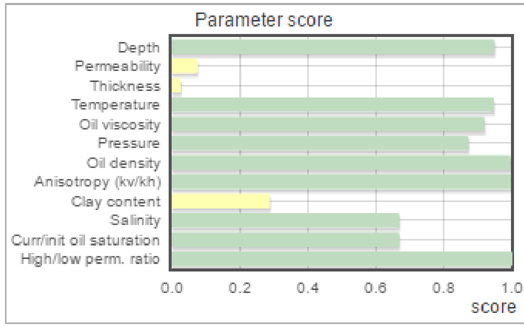
APPLICABILITY SCREENING

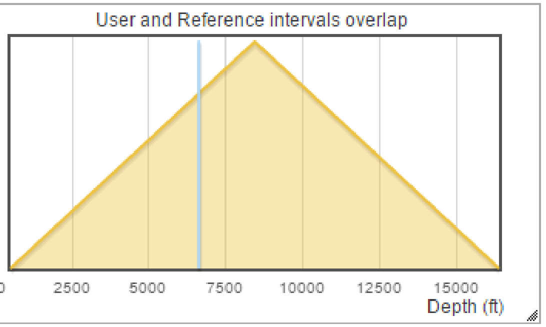
- Entering Parameters
  - Depth (ft)
  - Permeability (md)
  - Thickness (ft)
  - Oil Viscosity (cp)
  - Pressure (psi)
  - Oil Density (°API)
- Results will be verified using criteria applicable to Wyoming
  - As Sword criteria is referencing the North Sea
- **Field/Reservoir: Clareton/Muddy**
  - **Resulted in:**
    - **Gas Injection**

Applicability screening → **Applicability evaluation**

Method	Score	Violations
Gas injection	0.699	0
Water flooding	0.575	1
Chemical methods	0.472	2
Thermal methods	0.374	3

Parameter	Unit	User			Reference intervals			Score
		Min	Max	Comfort center	Min	Max	Comfort center	
Depth	ft	6628	6629	6628.5	492.126	1.64E04	8448.163	0.948
Permeability	md	92	94	93	1	5000	2500.5	0.072
Thickness	ft	8	10	9	6.562	426.509	216.535	0.023
Temperature	Fahrenheit	142	144	143	32	212	122	0.946
Oil viscosity	cp	6	7	6.5	0.2	10	5.1	0.918
Pressure	psi	5303	5304	5303.5	1160.302	7251.887	4206.095	0.87
Oil density	deg API	44	42	42.994	86.192	17.447	45.375	0.995
Anisotropy (kv/kh)	%	1	10	5.5	1	10	5.5	1
Clay content	%	0	5	2.5	0	30	15	0.286
Salinity	g/l	0	20	10	0	40	20	0.667
Curr/init oil saturation	%	70	100	85	40	100	70	0.667
High/low perm. ratio		1	20	10.5	1	20	10.5	1





VERIFY RESULTS

- Results are then verified using this table which has oil properties and reservoir characteristics which are more applicable to Wyoming

- Ensuring each individual performs quality check of Sword's results

- **Resulted in:**
  - **CO_2 Miscible**

TABLE 3—SUMMARY OF SCREENING CRITERIA FOR EOR METHODS

		Oil Properties			Reservoir Characteristics					
Detail Table in Ref. 16	EOR Method	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↗48↗	<0.4↘0.2↘	High percent of C_1 to C_7	>40↗75↗	Sandstone or carbonate	Thin unless dipping	NC	>6,000	NC
2	Hydrocarbon	>23↗41↗	<3↘0.5↘	High percent of C_2 to C_7	>30↗80↗	Sandstone or carbonate	Thin unless dipping	NC	>4,000	NC
3	CO_2	>22↗36↗[a]	<10↘1.5↘	High percent of C_5 to C_{12}	>20↗55↗	Sandstone or carbonate	Wide range	NC	>2,500[a]	NC
1–3	Immiscible gases	>12	<600	NC	>35↗70↗	NC	NC if dipping and/or good vertical permeability	NC	>1,800	NC
					(Enhanced) Waterflooding					
4	Micellar/ Polymer, ASP, and Alkaline Flooding	>20↗35↗	<35↘13↘	Light, intermediate, some organic acids for alkaline floods	>35↗53↗	Sandstone preferred	NC	>10↗450↗	>9,000↘3,250	>200↘80
5	Polymer Flooding	>15	<150, >10	NC	>50↗80↗	Sandstone preferred	NC	>10↗800↗[b]	<9,000	>200↘140
					Thermal/Mechanical					
6	Combustion	>10↗16→?	<5,000 ↓ 1,200	Some asphaltic components	>50↗72↗	High-porosity sand/ sandstone	>10	>50[c]	<11,500↘3,500	>100↗135
7	Steam	>8 to 13.5→?	<200,000 ↓ 4,700	NC	>40↗66↗	High-porosity sand/ sandstone	>20	>200↗2,540↗[d]	<4,500↘1,500	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

NC = not critical.
Underlined values represent the approximate mean or average for current field projects.
[a]See Table 3 of Ref. 16.
[b]> 3md from some carbonate reservoirs if the intent is to sweep only the fracture system.
[c]Transmissibility >20 md-ft/cp
[d]Transmissibility >50 md-ft/cp
[e]See depth.

VERIFICATION

- Even though there were no violations, we still performed a violation check
  - To ensure Sword has characterized the field correctly.
- Table showing the parameters for Clareton/Muddy field compared to Screening criteria table.
  - Even though API gravity did not pass, Dr. Alvarado has advised us that we should use good engineering judgement when assessing what criteria do and do not pass. Since the value of API gravity is within 10 degrees API we have deemed it passable.

Parameters	Values for Clareton/Muddy	Screening Criteria Table
API Gravity (°API)	44	Between 22 and 36 °API
Viscosity (cp)	7	Between 1.5 and 50 cp
Net Thickness (ft)	10	Wide Range
Average Permeability (md)	94	Not Critical
Depth (ft)	6,629	Greater than 2,500 ft
Temperature (°F)	144	Not Critical

RECOVERY FACTOR

- Using historical data collected world wide
  - The software will interpolate between 1-30 cases
  - Our selection for number of cases was 8
    - More cases reduced our confidence interval and substantially resulted in skewed scenarios

- **Resulted in**
  - **CO_2 Miscible**
    - **Recovery factor of 63%**
    - **Confidence Interval of 82%**

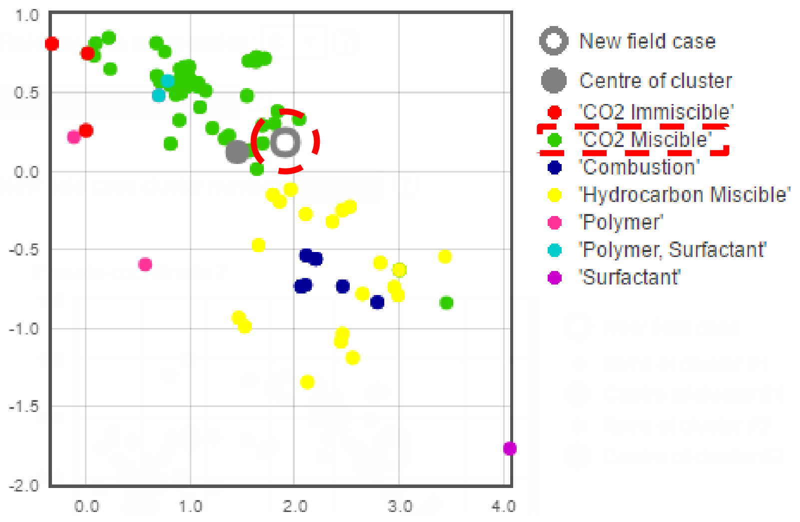
Recovery factor estimation → **Field case analysis**

Field case parameters

Parameters

Porosity (%)	Permeability (md)	Depth (ft)	Oil gravity (deg API)	Oil viscosity (cp)	Oil temperature (Fahrenheit)
12	93.00	6628.00	43.00	6.26	143.00

Field case analysis



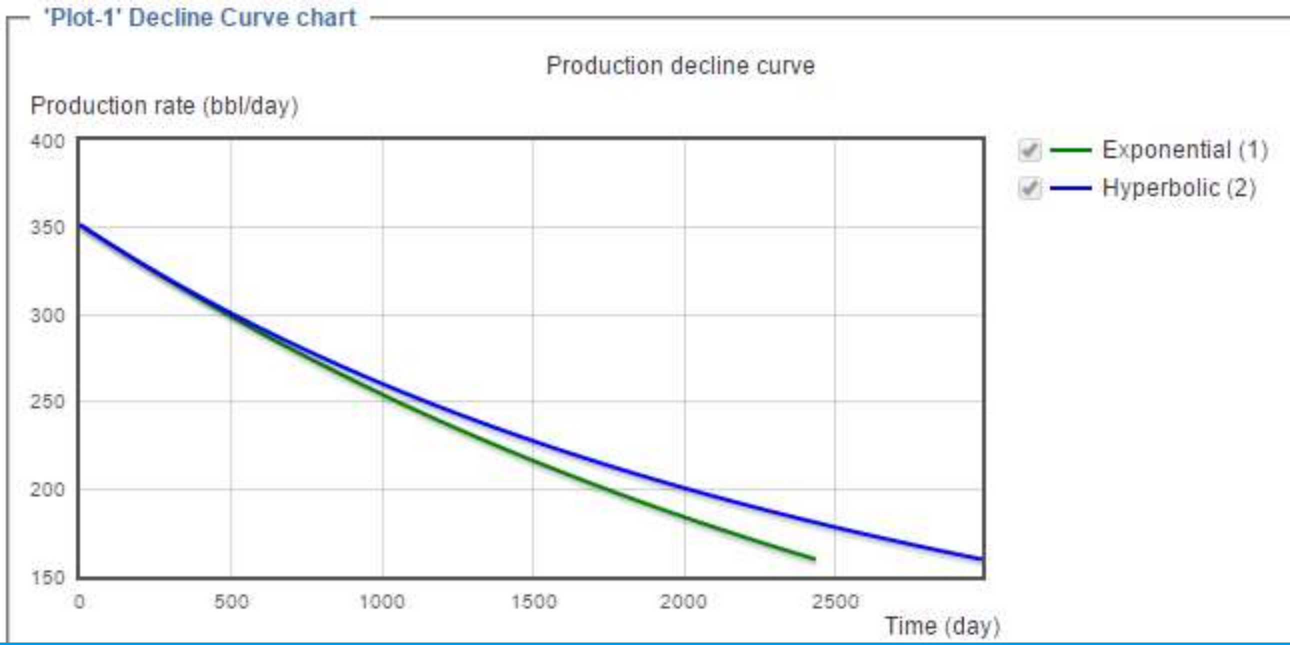
Results

IOR/EOR methods (interpolation in automatically chosen cluster)

	Method	Number of cases in interpolation	Interpolated recovery factor (%)	Confidence	Confidence index - interpolation cases (%)
1	CO2 Miscible	8	63	Good	82
2	Hydrocarbon Miscible	8	51	Poor	4

DECLINE CURVE ANALYSIS

- Using production data we found:
  - Initial Production Rate (bbl/d)
    - **351 bbl/d**
  - Abandonment Rate (bbl/d)
    - **159 bbl/d**
  - Effective Decline Rate (%/Month)
    - **.98%**
- Production Rate (bbl/d) vs. Time (day)
  - Exponential
  - Hyperbolic

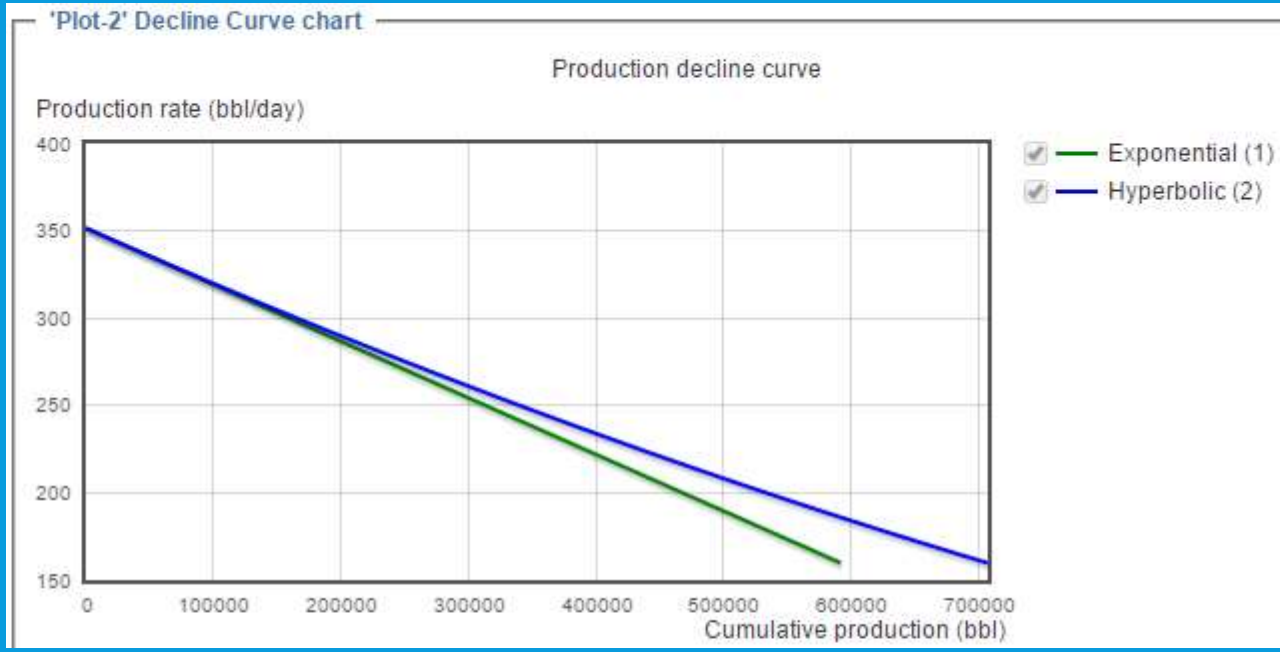


- Allowed us to determine which profile was suitable:
  - **Exponential provided shorter term production output over 7 years**
  - **Hyperbolic provided long term production output over 8 years**

	Years
Exponential	7
Hyperbolic	8

DECLINE CURVE ANALYSIS

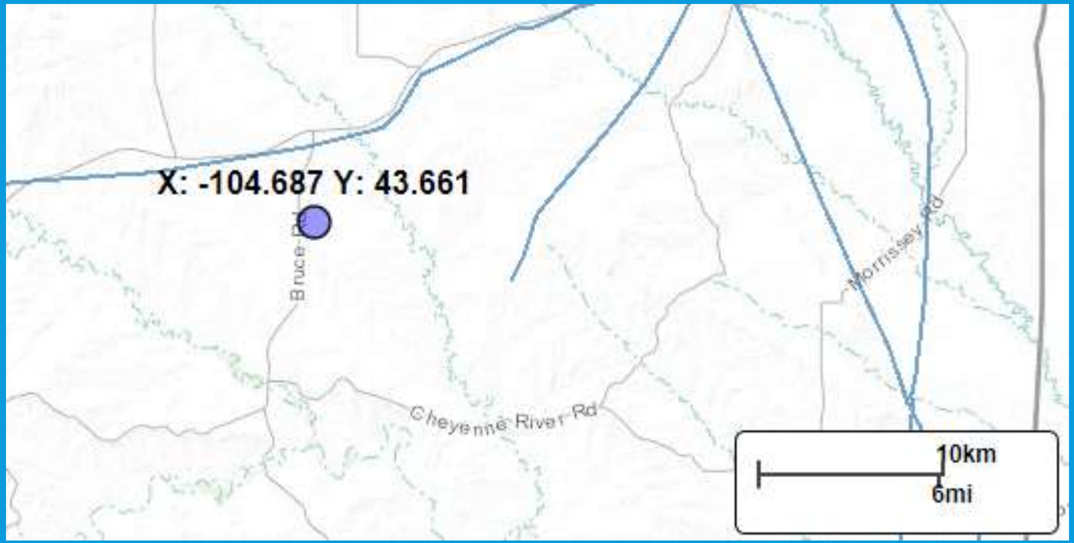
- Production Rate (bbl/d) vs. Cumulative Production (bbl)
  - Exponential
  - Hyperbolic



- Allowed us to better determine the cumulative production output for each of the profiles
  - **Exponential yielded 592,000 bbl**
  - **Hyperbolic yielded 707,000 bbl**

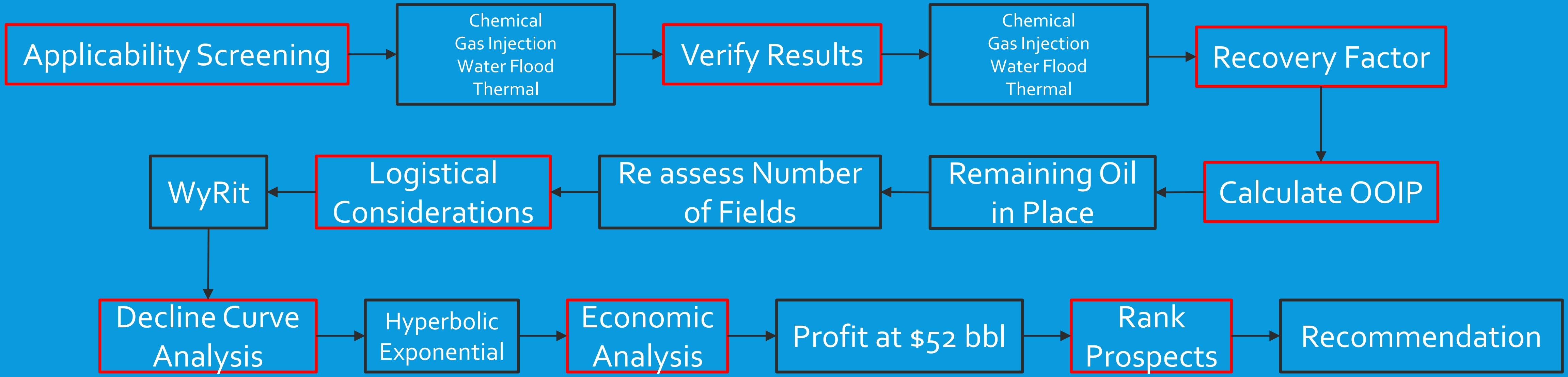
LOGISTICAL CONSIDERATIONS

- Using WyRit
  - We selectively chose 20 fields within 6 miles of a pipeline
    - This was done to minimize costs for future transportation of oil
  - This was done by using:
    - Latitude:
      - **44.661**
    - Longitude:
      - **-104.687**



ACTUAL WORK PATH

- Below is the work path taken, which varies from our initial plan
- Initial plan didn't include OOIP calculation



ECONOMIC CONSIDERATIONS

- Need to find OOIP for all 288 fields
  - Had most of the variables provided by Nick Jones
  - Needed water saturation and oil formation volume factor

$$OOIP = \frac{7758 * A * h * \varphi * (1 - S_w)}{B_{oi}}$$

- Water Saturation from core records and averaged them
  - .755
- Formation Volume Factor from literature: B_{oi}= 1.15 (SPE-68285-PA)

ECONOMIC CONSIDERATIONS

- After finding OOIP, we calculated the oil remaining in the field
  - Used production records from WOGCC

$$Oil\ Remaining = OOIP - Total\ Production$$

- Next, we calculated the recoverable oil remaining in the field

$$Recoverable\ Oil\ Remaining = Oil\ Remaining * Recovery\ Factor$$

- To find the dollar value of the recoverable reserves:

$$Value\ of\ Reserves\ [\$] = \frac{\$52}{bbl} * Recoverable\ Oil\ Remaining$$

ECONOMIC CONSIDERATIONS

- Our scope was limited to screening individual fields to select the best EOR method that can be applied to the field.
- Economic considerations outside of the scope of our project
  - We did not apply state or federal taxes to our net profit.
  - We did not account for the cost of various EOR Methods
  - We did not account for production and transportation costs

ECONOMIC RANKING

Profit for 20 fields of each of the methods

- Chemical methods
  - 6 fields
- Gas injection
  - 5 fields
- Water flood
  - 5 fields
- Thermal
  - 4 fields

CHEMICAL METHODS

Chemical Methods				
Prospect #	Field Name	Recovery Factor	Oil Recovered (BBLS)	Profit BT $52
1	TABLE ROCK	0.49	60,375,125	$3.1 Billion
2	BOWER	0.38	19,499,164	$1 Billion
3	SKULL CREEK	0.38	17,332,968	$901 Million
4	ROCKY POINT	0.4	6,653,652	$345 Million
5	SUPERHORNET	0.46	2,919,093	$151 Million
6	SAGE CREEK	0.42	2,067,486	$107 Million

CO_2 INJECTION

Gas Injection				
Prospect #	Field Name	Recovery Factor	Oil Recovered (BBLS)	Profit BT $52
1	CLARETON	0.63	45,888,281	$2.4 Billion
2	ANSCHUTZ RANCH EAST	0.53	20,593,215	$1 Billion
3	BARBER CREEK WEST	0.29	1,245,605	$64 Million
4	ADON ROAD	0.31	531,506	$27 Million
5	AM-KIRK	0.52	120,073	6.2 Million

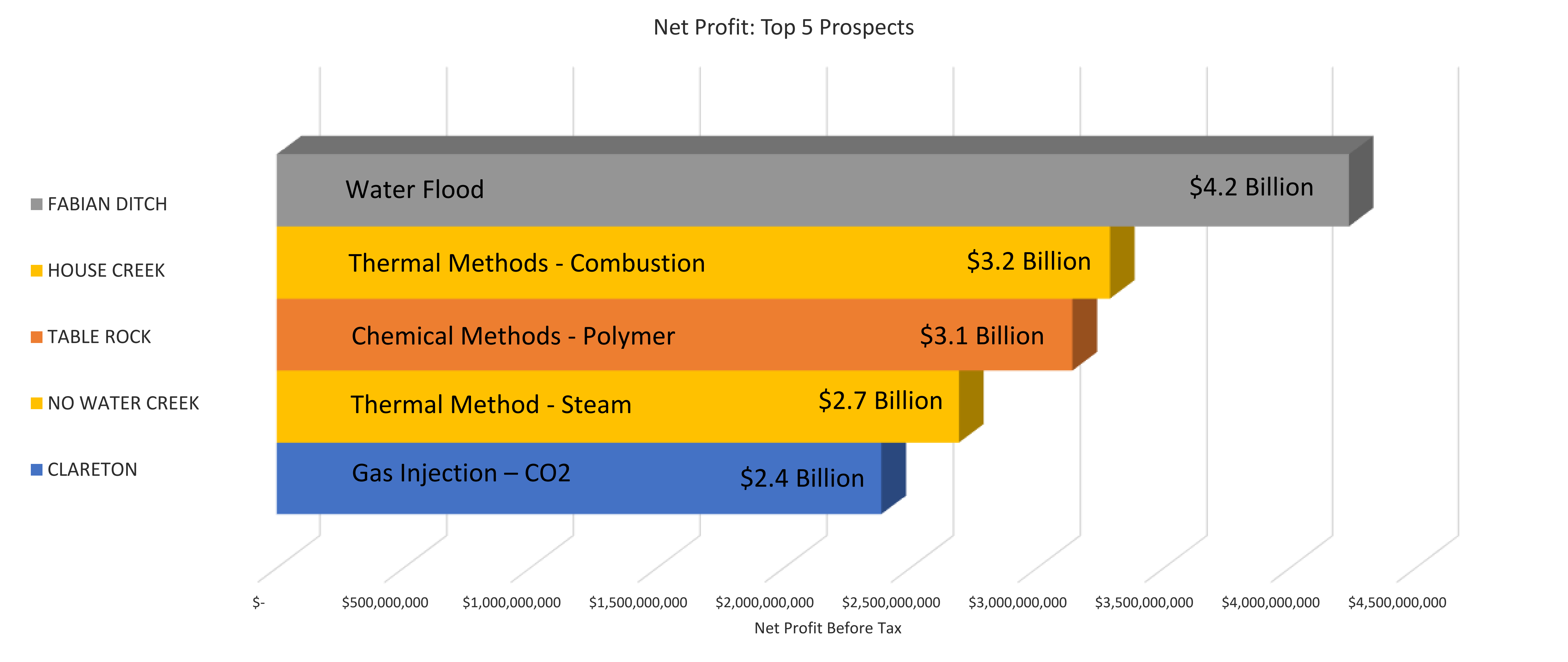
WATER FLOOD

Water Flood				
Prospect #	Field Name	Recovery Factor	Oil Recovered (BBLS)	Profit BT $52
1	FABIAN DITCH	0.72	81,437,753	$4.2 Billion
2	DEAD HORSE CREEK	0.37	17,391,965	$904 Million
3	RENO EAST	0.42	3,147,631	$163 Million
4	BUCK DRAW	0.49	2,807,781	$146 Million
5	BREEN	0.42	2,338,252	$121 Million

THERMAL METHODS

Thermal Methods				
Prospect #	Field Name	Recovery Factor	Oil Recovered (BBLS)	Profit BT $52
1	HOUSE CREEK	0.33	63,219,613	$3.2 Billion
2	NO WATER CREEK	0.44	51,770,222	$2.7 Billion
3	TIMBER CREEK	0.45	10,041,131	$522 Million
4	FD	0.46	3,458,149	$179 Million

TOP 5 PROSPECTS



GOING FORWARD

- Development of a reservoir model for the top 5 prospects
  - Fabian Ditch
  - House Creek
  - Table Rock
  - No Water Creek
  - Clareton
- Finding costs for the different methods
  - Chemical Methods
  - Gas Injection
  - Water flood
  - Thermal Methods

SUMMARY

- Four methods have been used for EOR: Gas Injection, Chemical Injection, Thermal, Water Flooding.
- Narrowed down the number of fields from 1400 to:
  - 288 fields
- Using WyRit and WOGCC to get our data also Sword software to analyze our fields and design decline curves
- Risk Analysis
  - Software and Economics
- Results
  - EOR Characterization of 288 fields (64% Gas Injection, 19% Water flood, 15% Chemical Methods and 2% Thermal Methods)
- Technical Analysis
  - Applicability Screening, Verify Results, Recovery Factor and Decline Curve Analysis (Exponential and Hyperbolic)
- Logistical considerations
- Economic Consideration
  - Profit for 20 fields of each of the methods
  - Top 5 prospects (Fabian Ditch, House Creek, Table Rock, No Water Creek and Clareton)
- Going Forward
  - Development of a reservoir model for the top 5 prospects
  - Finding costs for the four different methods we have used in our project

SPECIAL THANKS TO:

- Professors
  - Doug Cuthbertson
  - Dr. Brian Toelle
- Chemical Engineering Department Head
  - Dr. Vladimir Alvarado
- Enhanced Oil Recovery Institute (EORI)
  - Nick Jones (Sr. Geologist)
- International Research Institute Stavanger (IRIS)
  - Roman Berenblyum (Technical Manager)

REFERENCES

- "How Does Water Injection Work?" *RIGZONE Empowering People in Oil and Gas*. RIGZONE, n.d. Web. 28 Apr. 2017.
- OrangeCast. "Gary Dolberry on Enhanced Oil Recovery." *HubPages*. HubPages, 27 Aug. 2008. Web. 28 Apr. 2017.
- "Trends in Enhanced Oil Recovery." *Shale Play Water Management*. N.p., n.d. Web. 28 Apr. 2017.
- V. Alvarado, G. T. (2008). Screening Strategy for Chemical Enhanced Oil Recovery in Wyoming Basins SPE 115940. *SPE Annual Technical Conference* (p. 12). Denver, Colorado: SPE International.
- Vargo, J., Turner, J., Bob, V., Pitts, M. J., Wyatt, K., Surkalo, H., & Patterson, D. (2000). Alkaline-Surfactant-Polymer Flooding of the Cambridge Minnelusa Field. *Society of Petroleum Engineers*
- Zerkalov, Georgy. "Steam Injection for Enhanced Oil Recovery." *Steam Injection for Enhanced Oil Recovery*. Stanford University, n.d. Web. 28 Apr. 2017.

QUESTIONS?

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