Enhanced Oil Recovery Field Screening In Wyoming

Undergraduate Research Day– April 30th 2016

Prepared for The University of Wyoming

Group Seven

John Baldwin, Kyle Scalise, Dylan Morin,

Jordan Polzin (Jake Duda –Not Present)

Presentation Outline

- Executive Summary
- Project Phases Overview
    1. Planning
    2. Data Collection
    3. Data Analysis
        - Algorithm
    4. Ranking
- Top Fields
- Concluding Remarks

Executive Summary

- An extensive review of Wyoming's oil and gas fields has been performed.
- A refined look at which Wyoming fields could experience Enhanced Oil Recovery (EOR) success in a downturn economy was our was main endeavor.
- A specific approach of utilizing low cost operations in regards to secondary oil recovery for determination of ideal EOR candidates.

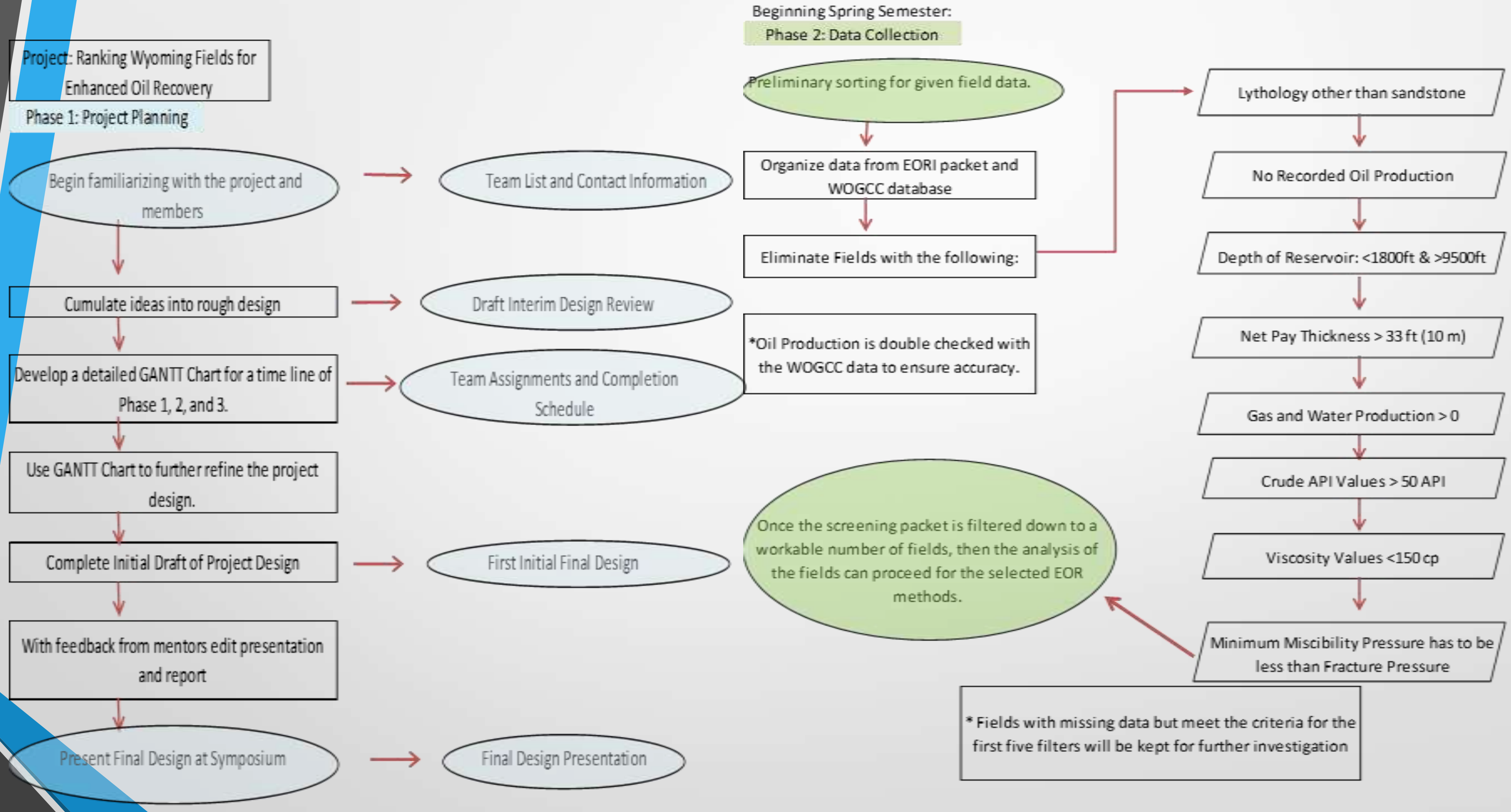
Project Overview

- **Phase 1: Planning**
  - How we designed a project to filter out fields that don't apply to enhanced oil recovery and rank the fields that do from a large Wyoming Database.
- **Phase 2: Data Collection**
  - How we gathered all of our data and made it reliable.
- **Phase 3: Data Analysis**
  - How we took our fields and ranked them based on potential enhanced oil recovery effectiveness.
- **Phase 4: Ranking**
  - How we considered reservoir characteristics & field history to rank the remaining fields.

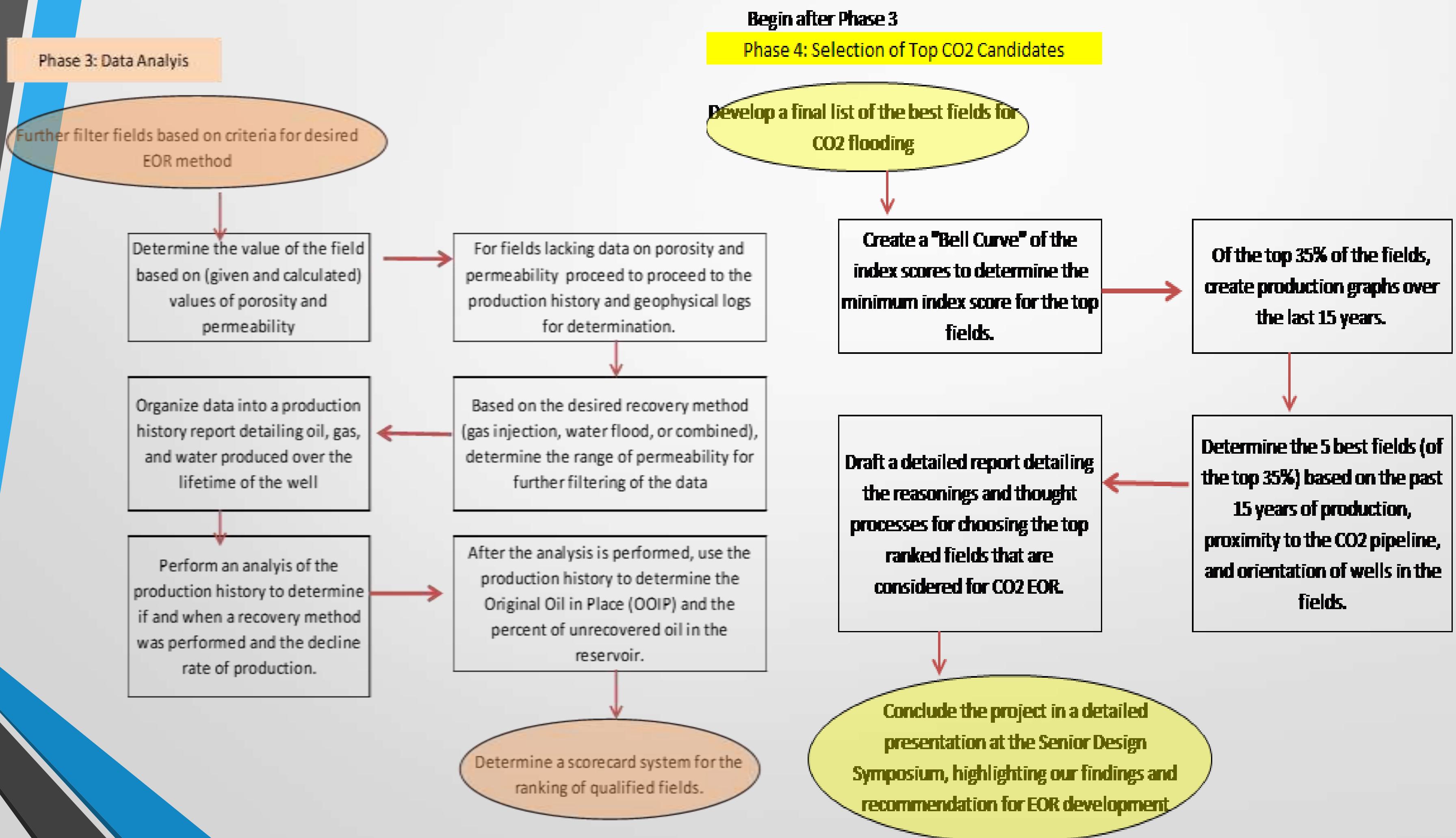
Phase 1: Planning

- Our project was completed with the aid of a Work Flow and Gantt Chart, which sole purpose is to schedule out the project.
- The workflow detailed our initial design to complete the project. The workflow changed drastically as we progressed through the project becoming a little more experienced.
- The Gantt Chart helped guide us through the expected duration of certain steps in the project, but with limited experience, was usually inaccurate.
- Certain steps were a lot quicker than we thought, and other steps took much longer than expected. This will be indicated in the Gantt chart as well.

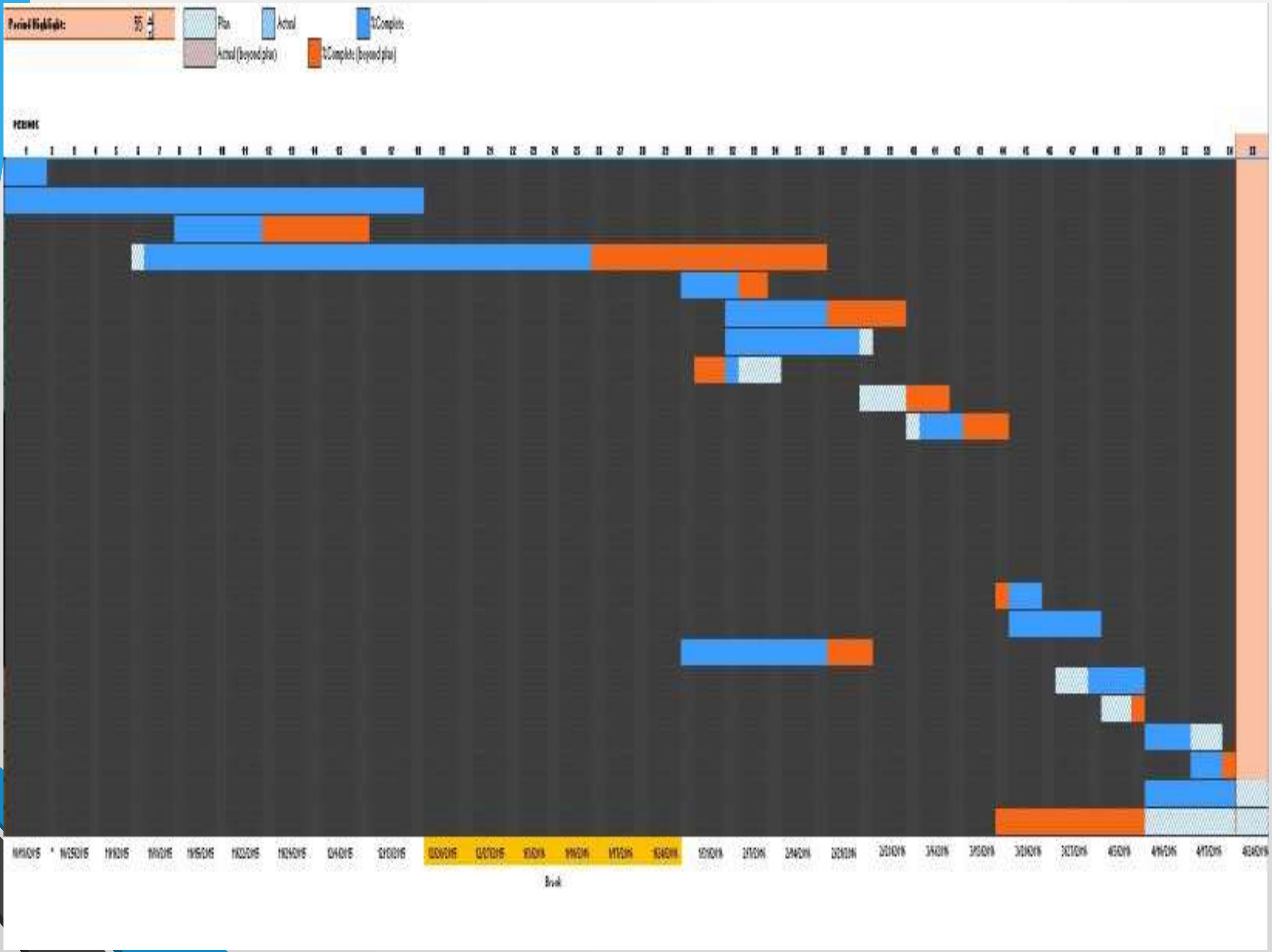
Project Phases



Project Phases



Gantt Chart



Phase 2: Data Collection

- We were first given a data packet listing all the oil and gas fields in Wyoming.
- We noticed missing data for important parameters on a lot of fields and sometimes the data received was inconsistent after checking other sources.
- In order to come up with justifiable results, the data had to be reliable.

Phase 2: Data Collection

- By checking other sources (AAPG Datapages & WOGCC) and in an attempt to fill in missing data, the resulting data set was ready for screening.
- Time constraints led to making considerations in relying on certain data parameters and eliminating fields that lacked such data.

Phase 2: Data Collection

- Our group ascertained that CO_2 Flooding would be the most efficient and economical for enhanced oil recovery in Wyoming.
- This allowed us to narrow our selected fields based on optimal CO_2 flooding reservoir criteria.
- Proper justifications will be detailed later.
- The assumption that CO_2 flooding would be our enhanced oil recovery method was our first major decision of the project.

Why we chose CO_2 Flooding

- Initially, we considered all EOR methods: Thermal, Enhanced Water flooding, and Gas Injection
- Originally targeted Water Alternating Gas (WAG) as the main EOR method
- No proper screening criteria existed for WAG, thus a new screening needed to be accomplished
- Changed to CO_2

CO_2 Justifications

- Wyoming fields contain light oil accumulations which correspond to more effective sweep efficiencies with CO_2.
- However, the most important consideration is the fact steam injections, polymer floods, nitrogen injection, etc.
  - Most Wyoming reservoirs don't match the criteria for these methods.
  - And mainly the other methods are more costly and the abundance of CO_2 in Wyoming makes it an attractive injection fluid.

CO_2 Justifications

- Wyoming is abundant with productive sandstone reservoirs. Sandstone reservoirs see good responses from CO_2 injection.
- The CO_2 pipeline traversing across Wyoming makes CO_2 transportation affordable to certain fields.
- Success with CO_2 injection in Wyoming is common.
- Wyoming generates a lot of CO_2 through various resources, which makes it a ideal situation for those seeking the injection fluid.

Phase 3: Data Analysis Summary

- The excel database of Field numbers were screened for CO_2 EOR suitability
- The fields that didn't fit into the CO_2 criteria were immediately eliminated.
- The remaining fields were put into an algorithm which gave a direct score based on the applicability of a field to CO_2 Injection.

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.

Table 3—Summary of Screening Criteria for EOR methods ("EORI")

Preliminary Screening Criteria

Parameters	Screening Criteria
Lithology	Sandstone
Cumulative Oil Produced (bbls)	>0
Average Depth Field (ft)	1800< ft <10000
Net Pay (ft)	<32
Oil Viscosity (cP)	<10
Oil API	<50

Algorithm

- The algorithm was done in Mathematica
- We were able to use the algorithm to compute an index score detailing CO_2 Potential Effectiveness.
- We did this by altering the algorithm's criteria to CO_2 parameters and inputted our remaining field's parameters.

Additional Screening Criteria

TABLE 3—CO_2 FLOODING

Description

CO_2 flooding is carried out by injecting large quantities of CO_2 (30% or more of the hydrocarbon PV) into the reservoir. Although CO_2 is not first-contact miscible with the crude oil, the CO2 extracts the light-to-intermediate components from the oil and, if the pressure is high enough, develops miscibility to displace the crude oil from the reservoir (MMP). Immiscible displacements are less effective, but they recover oil better than waterflooding (see below and Table 3 of Ref. 1 for immiscible criteria).

Mechanisms

CO_2 recovers crude oil by (1) swelling the crude oil (CO_2 is very soluble in high-gravity oils); (2) lowering the viscosity of the oil (much more effectively than N_2 or CH_4); (3) lowering the interfacial tension between the oil and the CO_2/oil phase in the near-miscible regions; and (4) generation of miscibility when pressure is high enough (see below).

Technical Screening Guides

	Recommended	Range of Current Projects
Crude Oil		
Gravity, °API	>22	27 to 44
Viscosity, cp	<10	0.3 to 6
Composition	High percentage of intermediate hydrocarbons (especially C_5 to C_{12})	
Reservoir		
Oil saturation, % PV	>20	15 to 70
Type of formation	Sandstone or carbonate and relatively thin unless dipping.	
Average permeability	Not critical if sufficient injection rates can be maintained.	
Depth and temperature	For miscible displacement, depth must be great enough to allow injection pressures greater than the MMP, which increases with temperature (see Fig. 7 of Ref. 1) and for heavier oils. Recommended depths for CO_2 floods of typical Permian Basin oils follow.	

	Oil Gravity, °API	Depth must be greater than (ft)
For CO_2-miscible flooding	>40	2,500
	32 to 39.9	2,800
	28 to 31.9	3,300
	22 to 27.9	4,000
	<22	Fails miscible, screen for immiscible*
For immiscible CO_2 flooding (lower oil recovery)	13 to 21.9	1,800
	<13	All oil reservoirs fail at any depth

At <1,800 ft, all reservoirs fail screening criteria for either miscible or immiscible flooding with supercritical CO_2.

Limitations

A good source of low-cost CO_2 is required.

Problems

Corrosion can cause problems, especially if there is early breakthrough of CO_2 in producing wells.

*All reservoirs with oils with gravities greater than 22° API can qualify for some immiscible displacement at pressures less than the MMP. In general, the reduced oil recovery will be proportional to the difference between the MMP and flooding pressure achieved. [These arbitrary criteria have been selected to provide a safety margin of approximately 500 feet above typical reservoir fracture depth for the required miscibility (MMP) pressures, and about 300 psi above the CO_2 critical pressure for the immiscible floods at the shallow depths. Reservoir temperature is included and assumed from depth. See Fig. 7 of Ref. 1 and text for the depth/temperature/MMP relationship.]

Table 3 – CO2 Flooding ("Taber")

Improved Algorithm

	Oil Gravity, °API	Depth must be greater than (ft)
For CO_2-miscible flooding	>40	2,500
	32 to 39.9	2,800
	28 to 31.9	3,300
	22 to 27.9	4,000

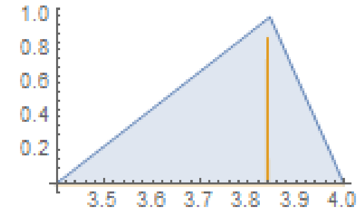
- We created an algorithm for each specific range of API values based off of the new lookup table
- Oil gravity API is the controlling parameter
- For instance, the Well Draw field from the Teapot reservoir possesses a 43 API value
- This Field was screened with the >40 API CO_2 Algorithm

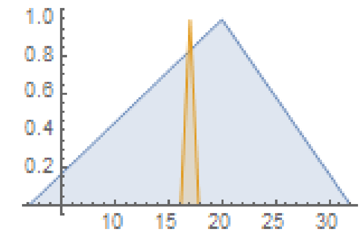
Inputting Values into the Algorithm

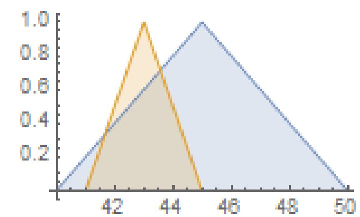
```
(* CO2 Inj Reservoir A *)

{dmmin, dmmean, dmmax} = {6908.5, 6917, 6925.5};
{thmin, thmean, thmax} = {16.15, 17, 17.85};
{vmin, vmean, vmax} = {6, 6.33, 6.6};
{gmin, gmean, gmax} = {41, 43, 45};

{drmin, drmean, drmax} = {2500, 7000, 10000};
{thrmin, thrmean, thrmax} = {2, 20, 32};
{vrmin, vrmean, vrmax} = {.3, 1.5 , 10};
{grmin, grmean, grmax} = {40, 45, 50};
```

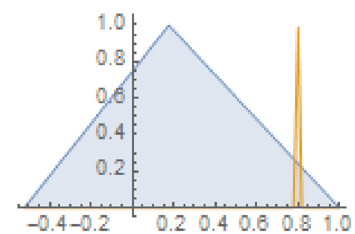
Utilized CO_2 algorithm for remaining fields

VARIABLE	MINIMUM	MOST LIKELY	MAXIMUM	INDEX
Depth	6908.5	6917	6925.5	0.999865
Thickness	16.15	17	17.85	0.97216
API Gravity	41	43	45	0.809524
Viscosity	6	6.33	6.6	0.42718
TOTAL	->	->	->	0.803803





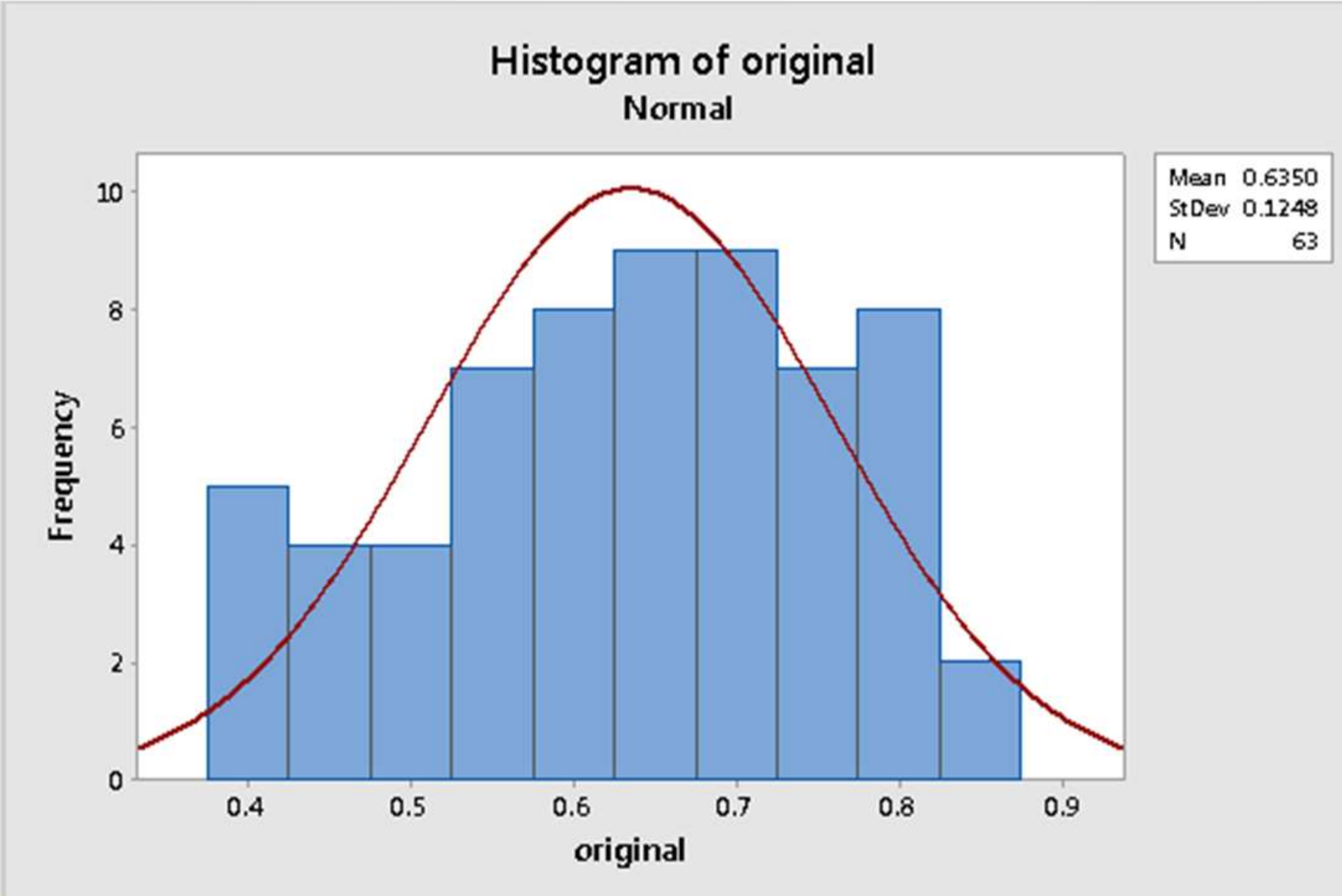




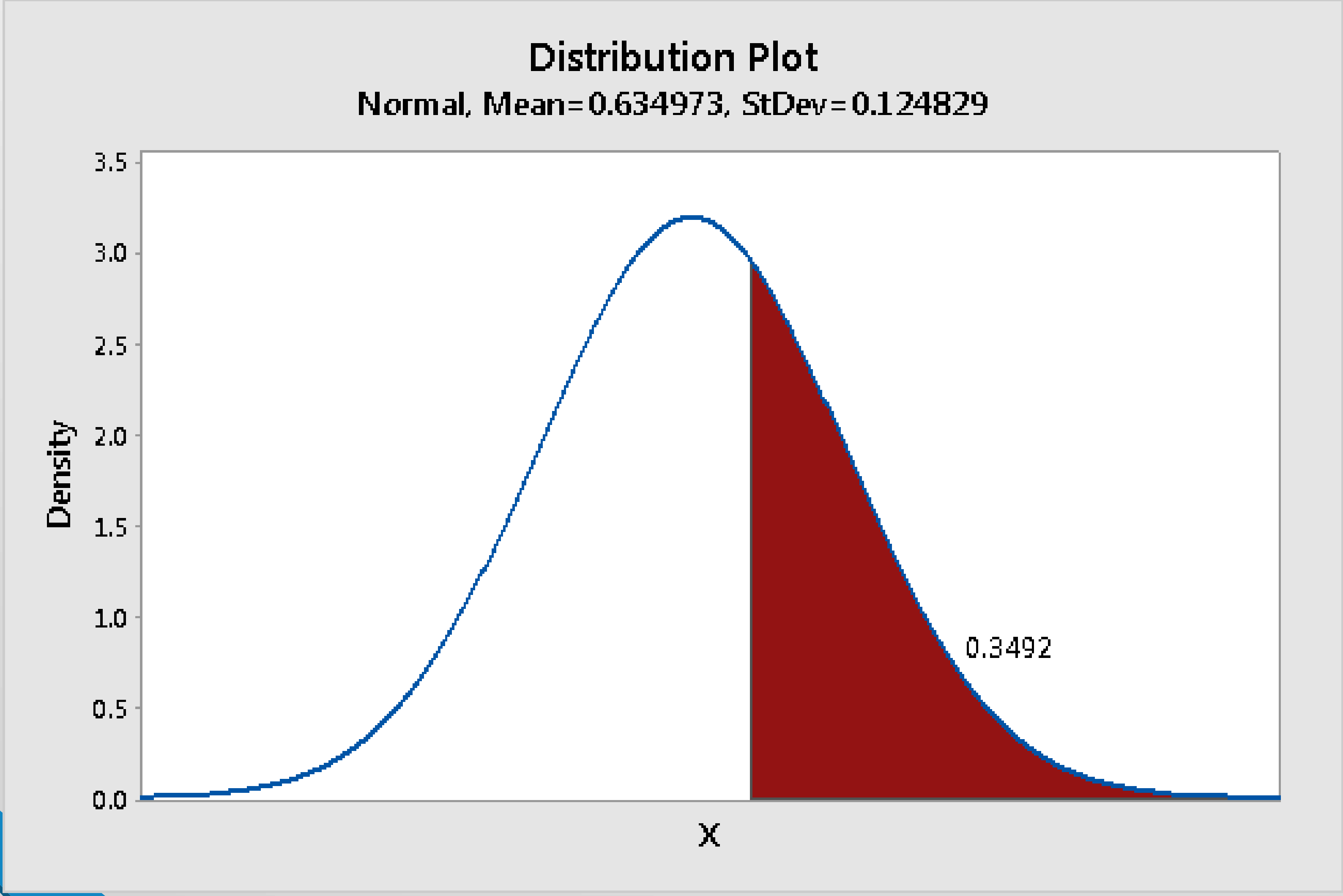
Distribution Curve of CO_2 Index Scores

- The top 35% obtained from the Distribution Curve analysis corresponded to index scores greater than .7
- .7 Index score seems like an appropriate cut-off for final ranking
- Fields with CO_2 index scores less than .7 were eliminated from final ranking contention
- This elimination process reduced the number of Fields down to a manageable number

Distribution Curve of CO_2 Index Scores



Distribution Curve of CO_2 Index Scores



Phase 4: Ranking Summary

- **EOR Quality:**
- With the index score we were able to rank the fields based on viability to CO_2 flooding.
- **Reservoir/Field Quality:**
  - Other considerations were utilized as well to ensure accurate results.
    - Production Histories
    - Proximity to CO_2 Pipeline
    - Well Spacing

Top Five Fields

CO_2 Index Score	Field Name	Reservoir	Basin/Regional Setting
0.803803	WELL DRAW	TEAPOT	POWDER RIVER BASIN
0.803425	FLAT TOP	TEAPOT	SOUTH FLANK POWDER RIVER BASIN
0.787608	SALT CREEK EAST	LAKOTA	EAST FLANK CASPER ARCH
0.766509	BIG HAND	DAKOTA	EAST CENTRAL POWDER RIVER BASIN
0.757462	BARBER CREEK	FERGUSON	WEST CENTRAL POWDER RIVER BASIN

CO_2 Pipeline in Wyoming

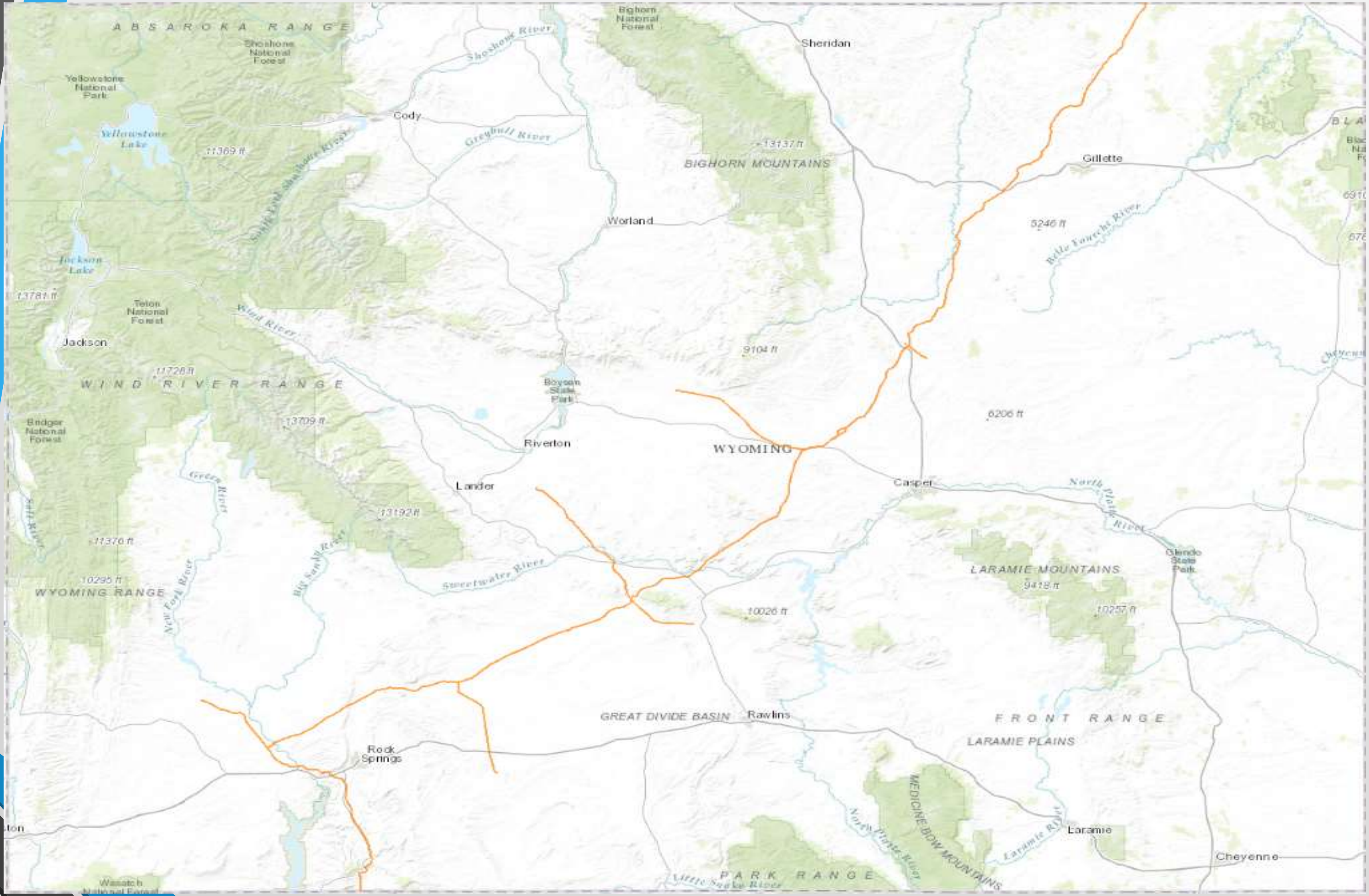


Figure 1—CO2 Pipeline in Wyoming (EORI)

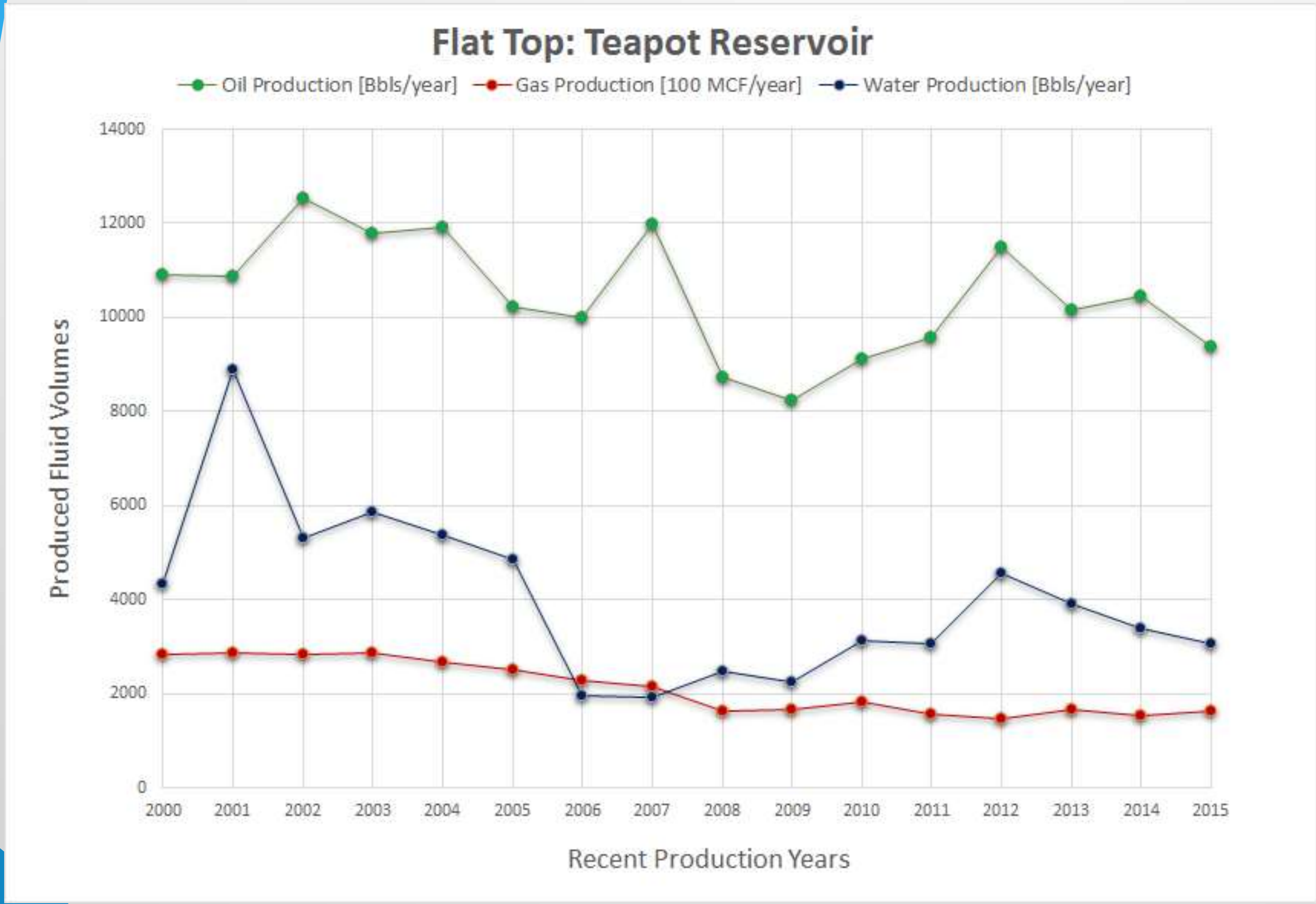
Flat Top – Teapot Reservoir

- **CO_2 Injection Index Score:** 0.803
- **Proximity to CO_2 pipeline:** 74 Miles
- **Current EOR method:** H_2O Injection
- **Current EORI CO_2 Flood target:** Yes
- **Well spacing:** 320 acres per well, 19 producing wells, 44 abandoned producers, 13 Dry holes
  - Well spacing is poor for potential injection scenario

Flat Top - Teapot Reservoir

Figure 2—Flat Top—Teapot Reservoir (EORI)

Flat Top - Teapot Reservoir



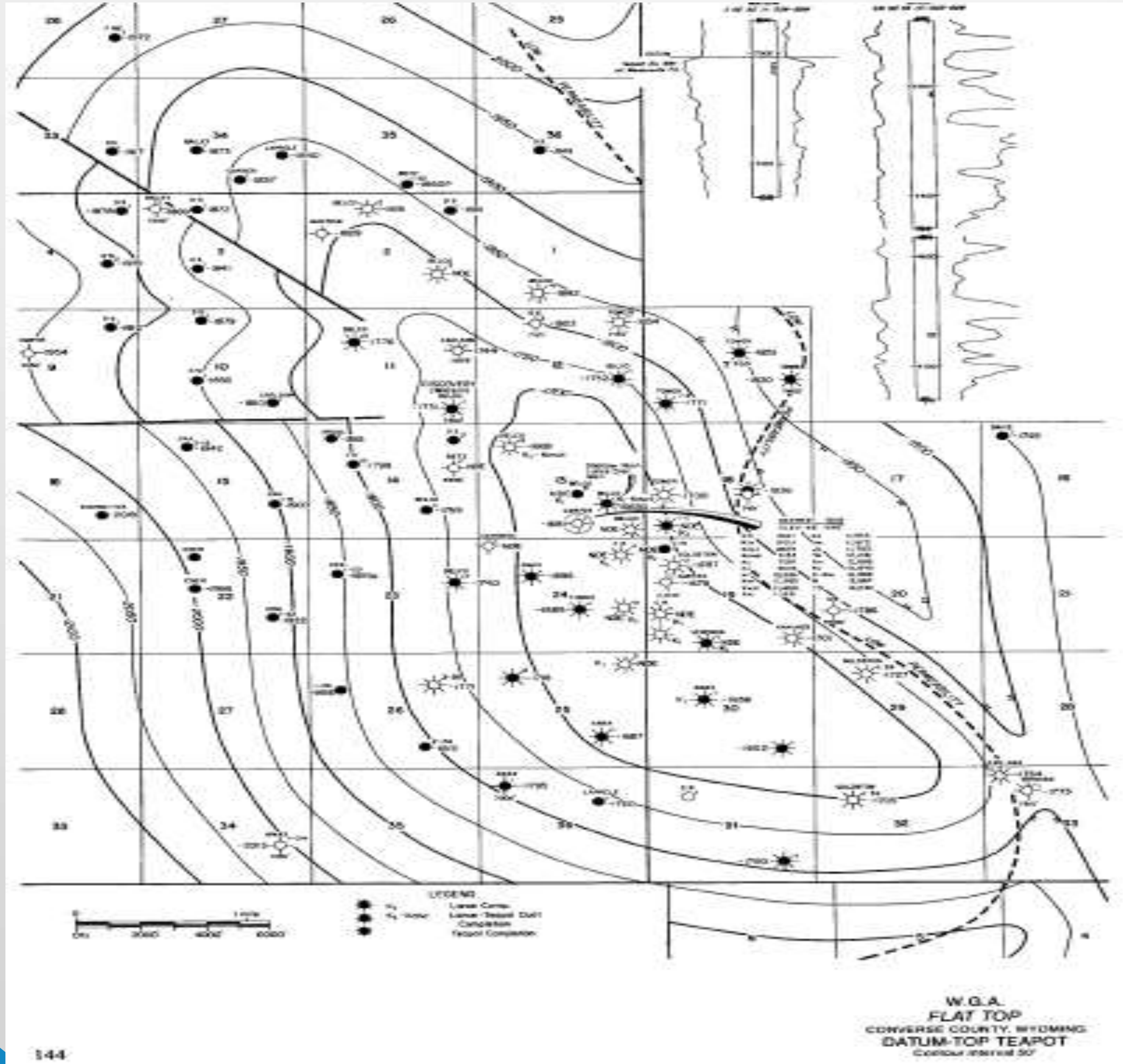


Figure 2—Flat Top Field Map (AAPG)

Well Draw – Teapot Reservoir

- **CO_2 Injection Index Score:** 0.804
- **Proximity to CO_2 pipeline:** 70 Miles
- **Current EOR method:** H_2O Injection
- **Current EORI CO_2 Flood target:** Yes
- **Well spacing**: 160 acres per well, 479 producing wells, 23 abandoned, 56 dry holes, 23 shut-in wells
  - <u>Well spacing is moderate for potential injection scenario</u>

Well Draw – Teapot Reservoir

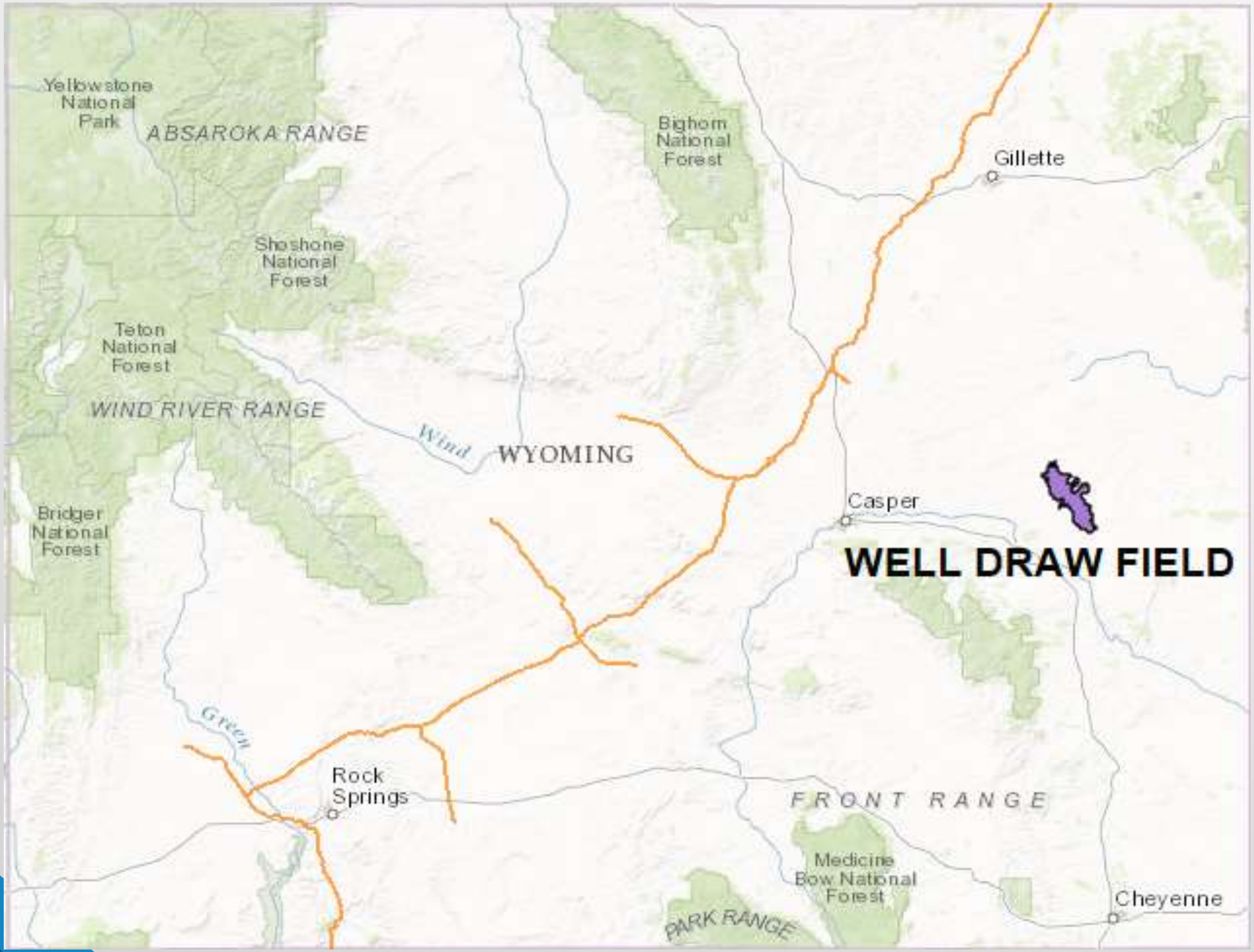
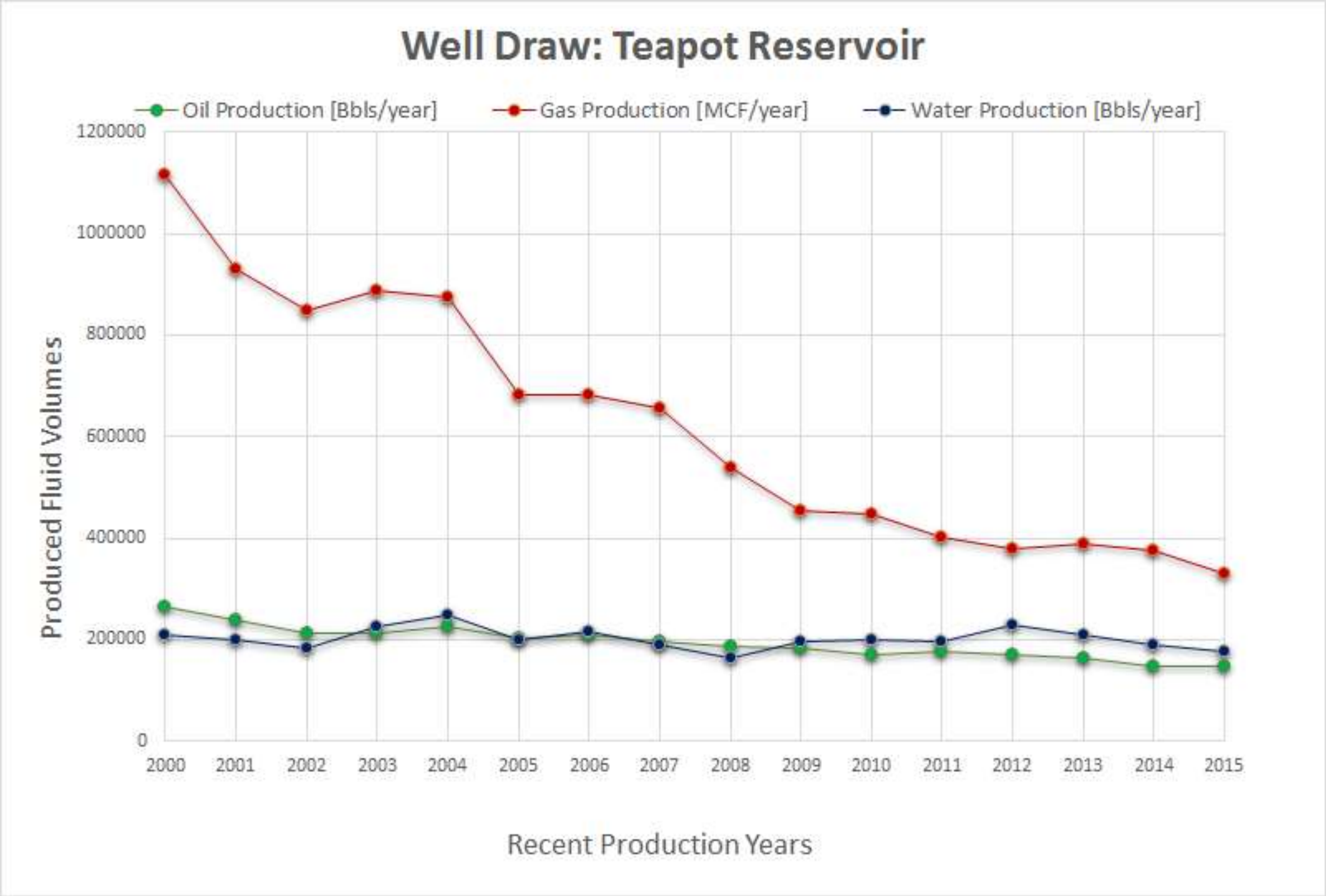


Figure 4: Well Draw—Teapot Reservoir (EORI)

Well Draw - Teapot Reservoir



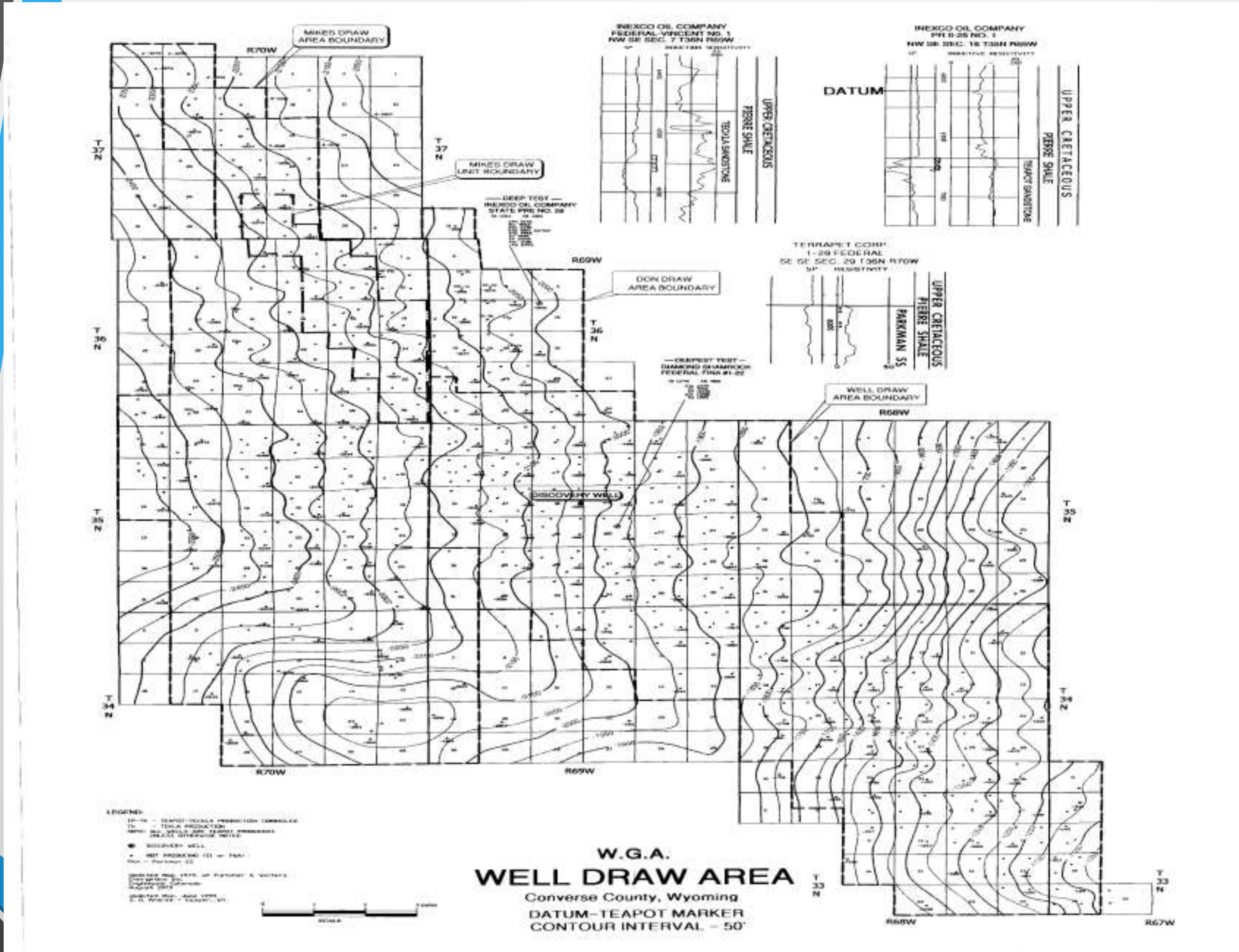


Figure 5: Well Draw Field Map (AAPG)

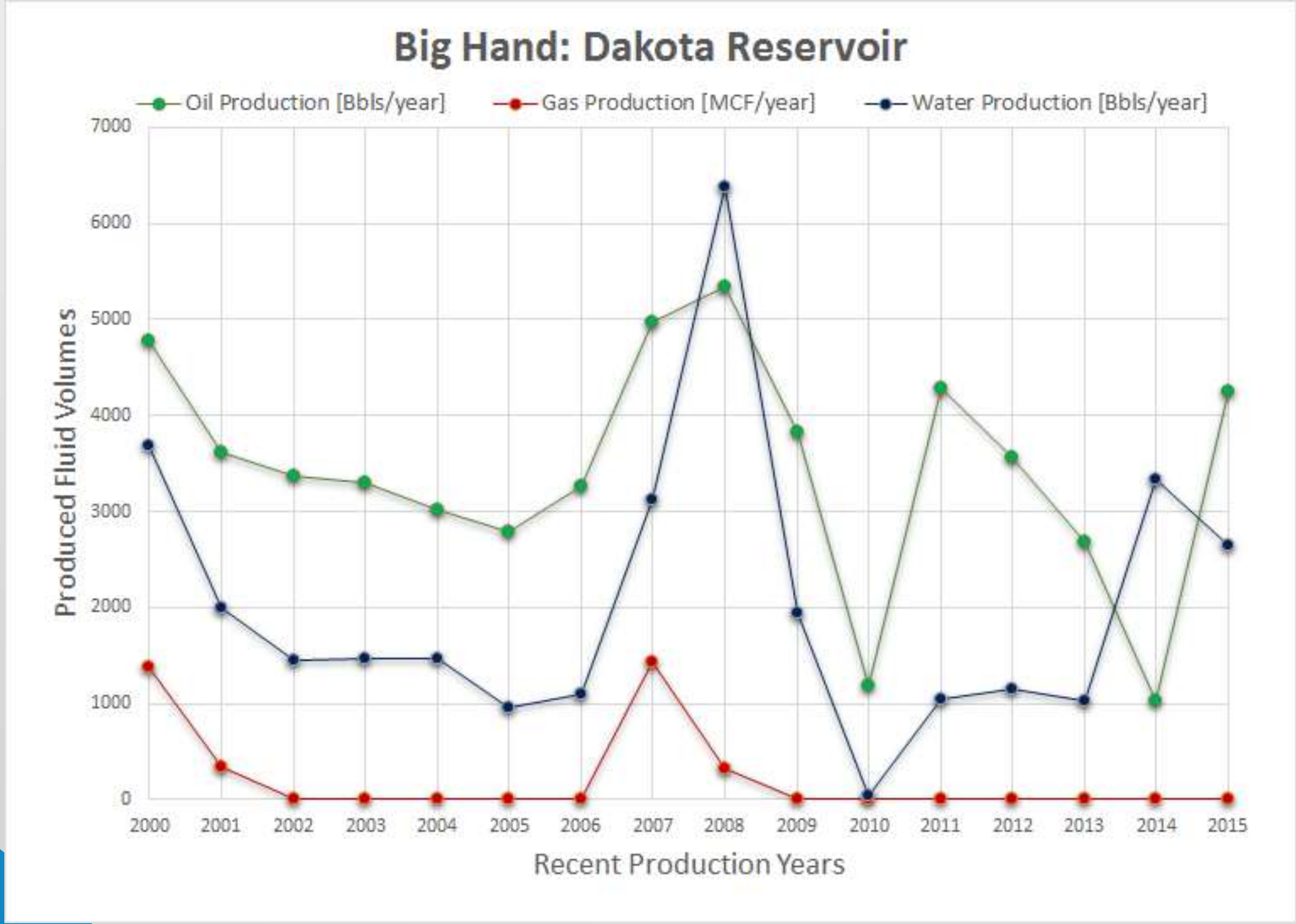
Big Hand – Dakota Reservoir

- **CO_2 Injection Index Score:** 0.766
- **Proximity to CO_2 pipeline:** 29 Miles
- **Past EOR method:** H_2O Injection
- **Current EORI CO_2 Flood target:** Yes
- **Well spacing:** 160 acres per well, 11 producing wells, 4 injection wells, 32 abandoned wells
  - <u>Well spacing is moderate for potential injection scenario</u>

Big Hand – Dakota Reservoir

Figure 6: Big Hand—Dakota Reservoir (EORI)

Big Hand - Dakota Reservoir



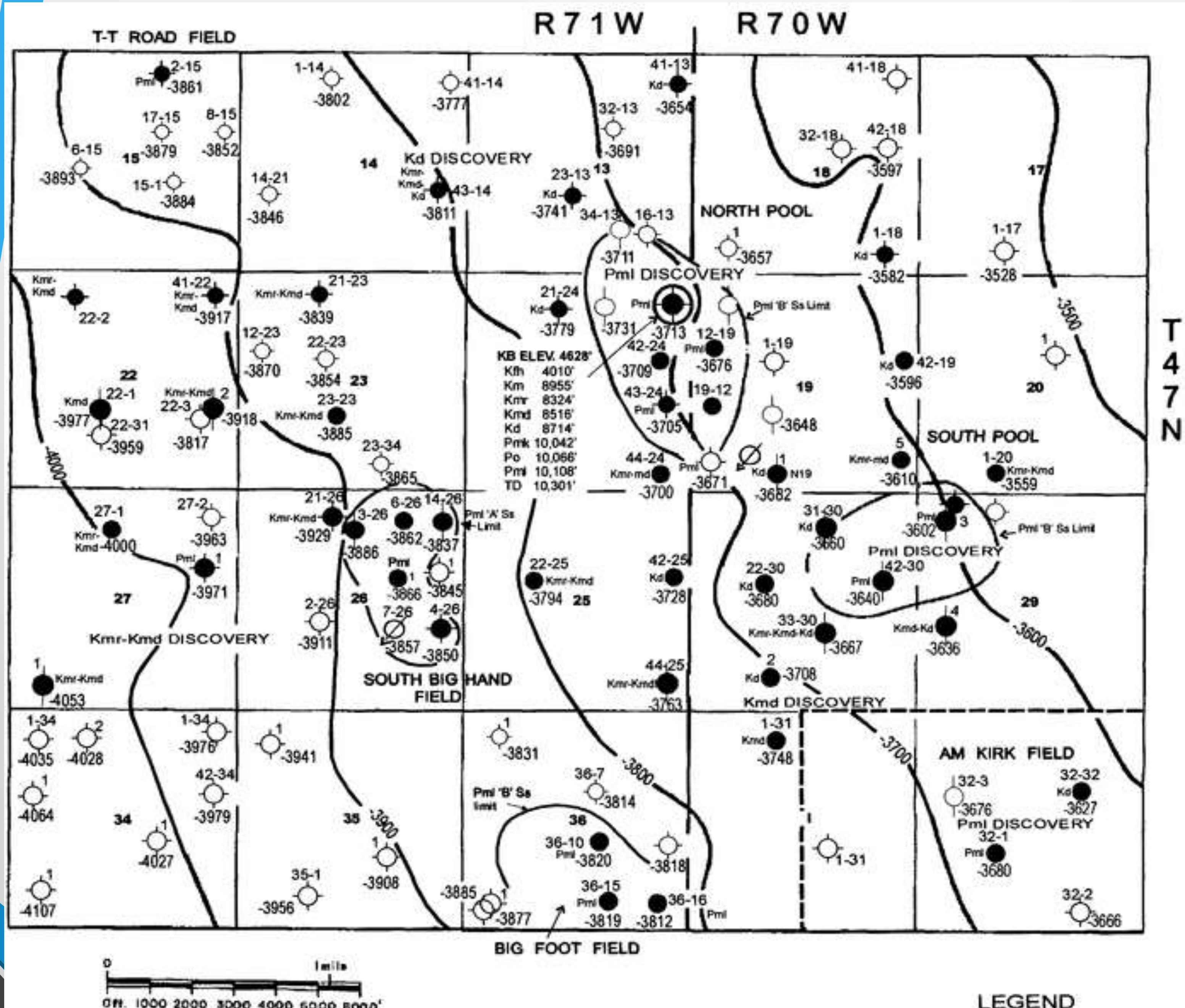


Figure 7: Big Hand Field Map (AAPG)

Barber Creek - Ferguson Reservoir

- **CO_2 Injection Index Score:** 0.757
- **Proximity to CO_2 pipeline:** 7.18 Miles
- **Past EOR method:** H_2O Injection
- **Current EORI CO_2 Flood target:** Yes
- **Well spacing:** 80 acres Spacing, 42 Producing Wells, 10 abandoned producers, 24 dry holes
  - <u>Well spacing is very good for potential injection scenario</u>

Barber Creek–Ferguson Reservoir

Figure 8: Barber Creek—Ferguson Reservoir (EORI)

Barber Creek - Ferguson Reservoir

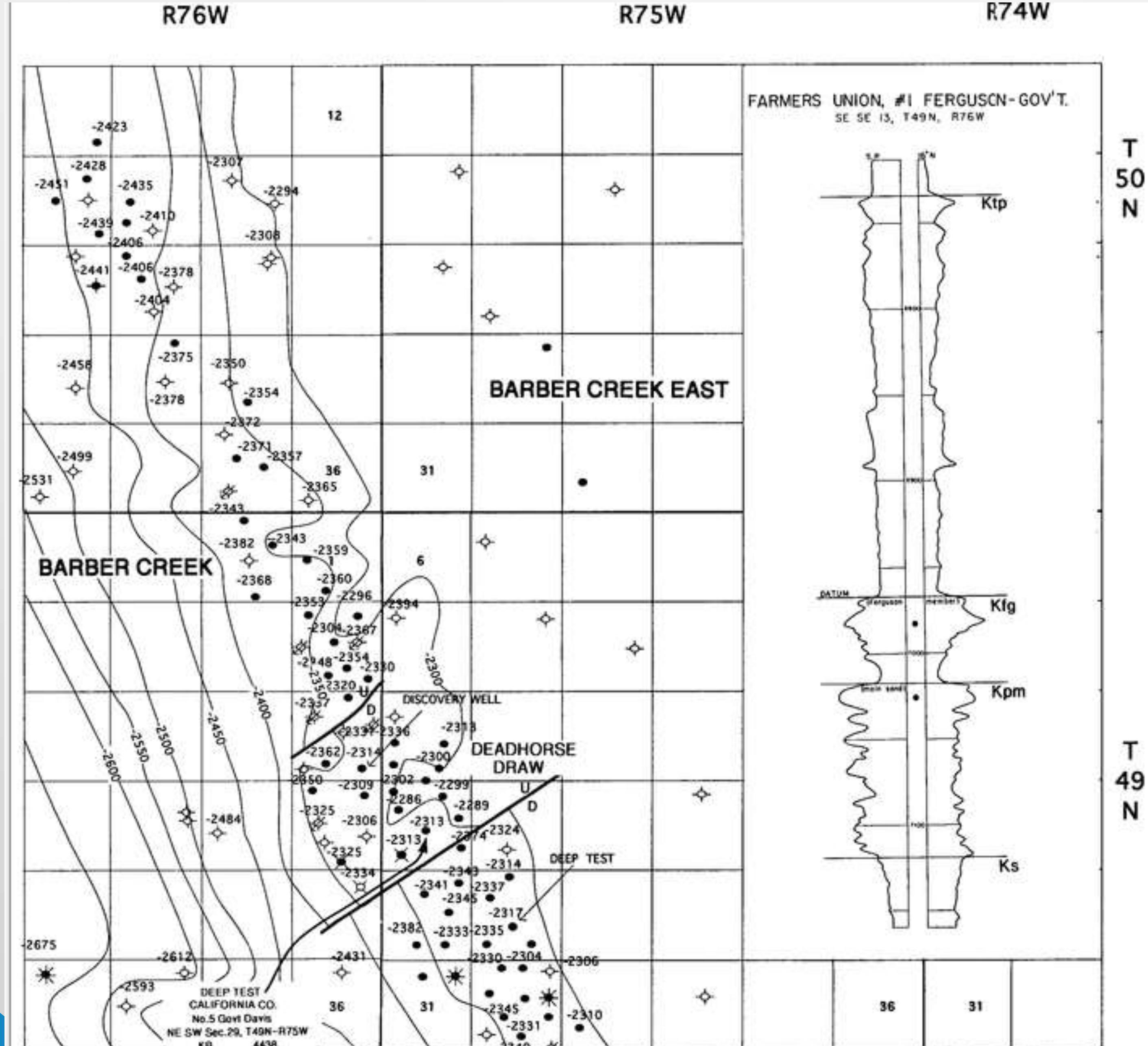


Figure 9: Barber Creek Field Map (AAPG)

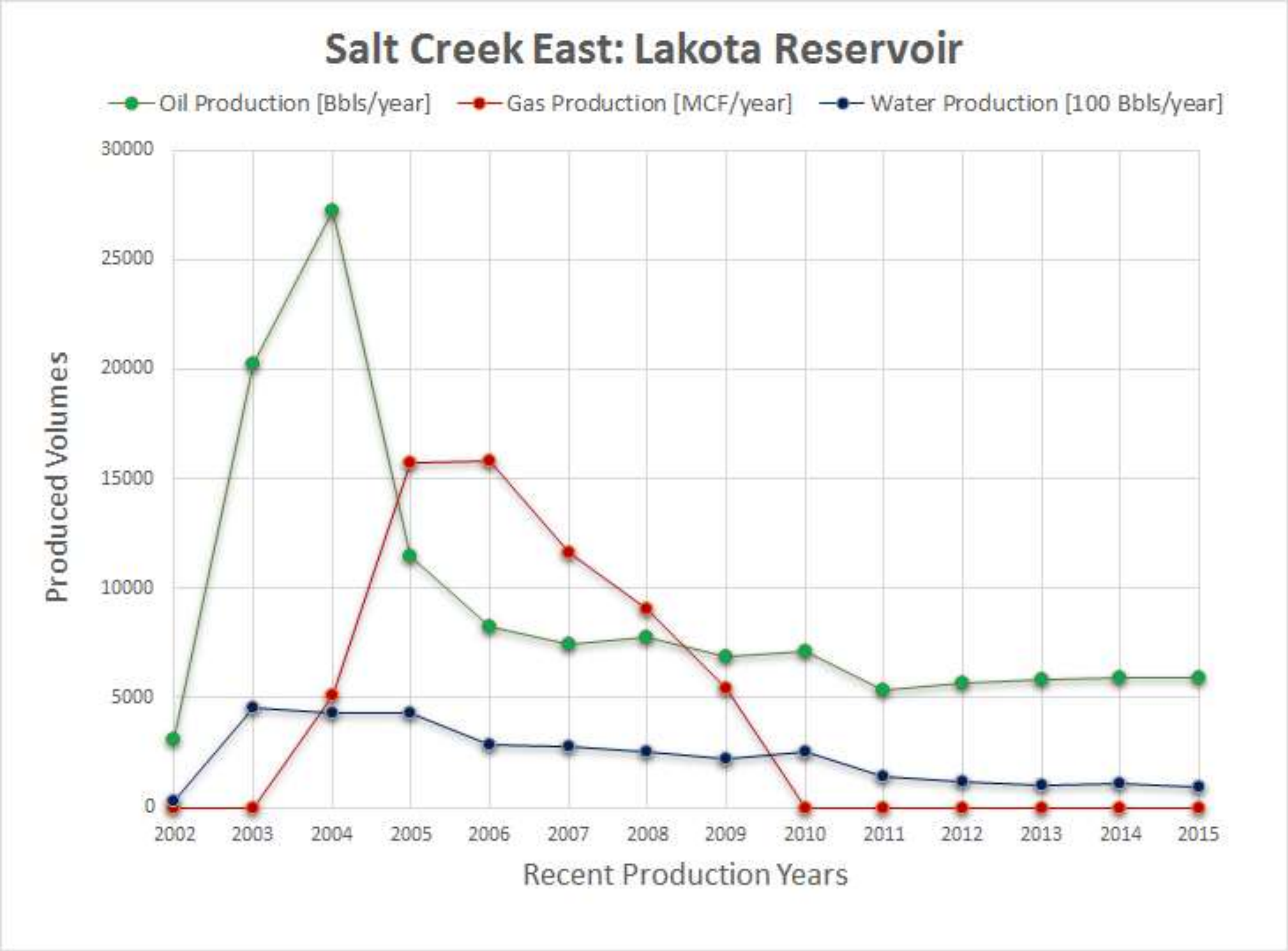
Salt Creek East – Lakota Reservoir

- **CO_2 Injection Index Score:** 0.788
- **Proximity to CO_2 pipeline:** 5 Miles
- **Past EOR method:** H_2O injection
- **Current CO_2 Flood target:** Yes
- **Well spacing:** 44 acres per well, 17 producing wells, 1 injection well, 9 abandoned wells
  - <u>Well spacing is very good for potential injection scenerio</u>

Salt Creek East - Lakota Reservoir

Figure 10: Salt Creek East (EORI)

Salt Creek East-Lakota Reservoir



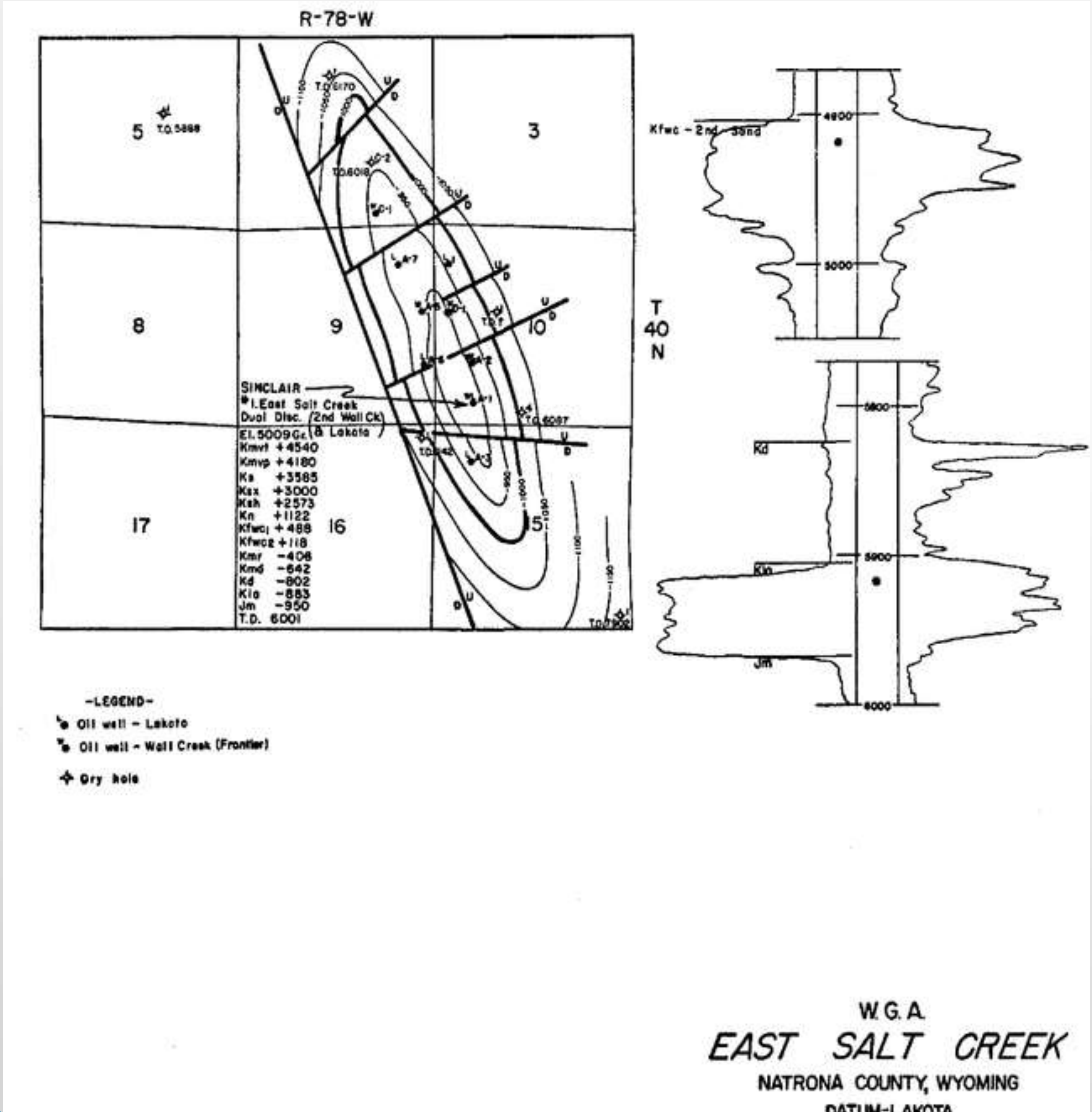


Figure 11: Salt Creek Field Map (AAPG)

Anadarko in Salt Creek

- In 2003 Anadarko purchased acreage in the Salt Creek Field from Howell Petroleum.
- By obtaining a 3-D seismic data set, analyzing flow patterns, and utilizing CO_2 injection, they had the field producing at rates of 7000 BOPD. Anadarko also built a pipeline leading to the field shown below.
- With Salt Creek obtaining an index score value of .788 we feel confident in our results.
- Through the use of modern technology on a century old field, Anadarko has seen success in the Salt Creek Field.

Conclusions

- We took an enormous data set and were able to filter it down to the optimal fields pertaining to an enhanced oil recovery process.
- This was achieved by relying on technical skills developed through the University, and by becoming an effective team.
- We're proud of the results we have obtained and have presented to you.

Acknowledgements

- Dr. Vladimir Alvarado
- Enhanced Oil Recovery Institute
- Dr. Xuebing Fu

Main References

1. *Wyoming Oil and Gas Conservation Commission. Web. 28 Apr. 2016. <http://wogcc.state.wy.us/>.*
2. *Enhanced Oil Recovery Institute. Web. 28 Apr. 2016. <http://eori.wygisc.org/>.*
3. *AAPG Datapages/Archives. Web. 28 Apr. 2016. <http://archives.datapages.com/>*
4. *Taber, J. J., F. D. Martin, and R. S. Seright. EOR Screening Criteria Revisited-Part 2: Applications and Impact of Oil Prices. Society of Petroleum Engineers. New Mexico Petroleum Recovery Research Center, Aug. 1997. Web. Jan. 2016.*

Thank You

Questions?