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Historic IOR/EOR practices in the Minnelusa

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The Science of Enhanced Oil Recovery

Outline

- Introduction:
  - Why EOR in the Minnelusa?
  - Historical Development of Minnelusa EOR
- Summary of EOR in Wyoming
- N. Rainbow Ranch EOR Project
- What is Next in Improving Minnelusa Oil Recovery
- Closing Remarks

Why EOR in the Minnelusa?

- Minnelusa is a clean sandstone with good permeability
- Fresh Fox Hills Water is available for water injection
- Primary Production is low (5-15% OOIP)
- Confined Reservoirs with Good Communication
- Waterflooding is successful; 2-5 times Primary
- Waterflooding Ultimate Oil Recovery Limited (~ 35% OOIP)
    - Viscous Oil, High Permeability Variation & Good Residual Oil Saturation
    - Waterflood Efficiency Poor

Historical Development of Minnelusa EOR

- Polymer Flooding – Improve Mobility Ratio (SE Kuehne Ranch, Kuehne Ranch)
- Cat-An Process – Combining Cationic and Anionic polymers to provide more resistance to flow than polymer (W. Semlek, OK, Kummerfeld)
- Phillips Petroleum first developed the “layered process” which was first injected in the Hamm Unit in Mid-70’s (Stewart Ranch)
  - Found sequential injection of HPAM / aluminum citrate (AlCit) created higher RRF than straight polymer

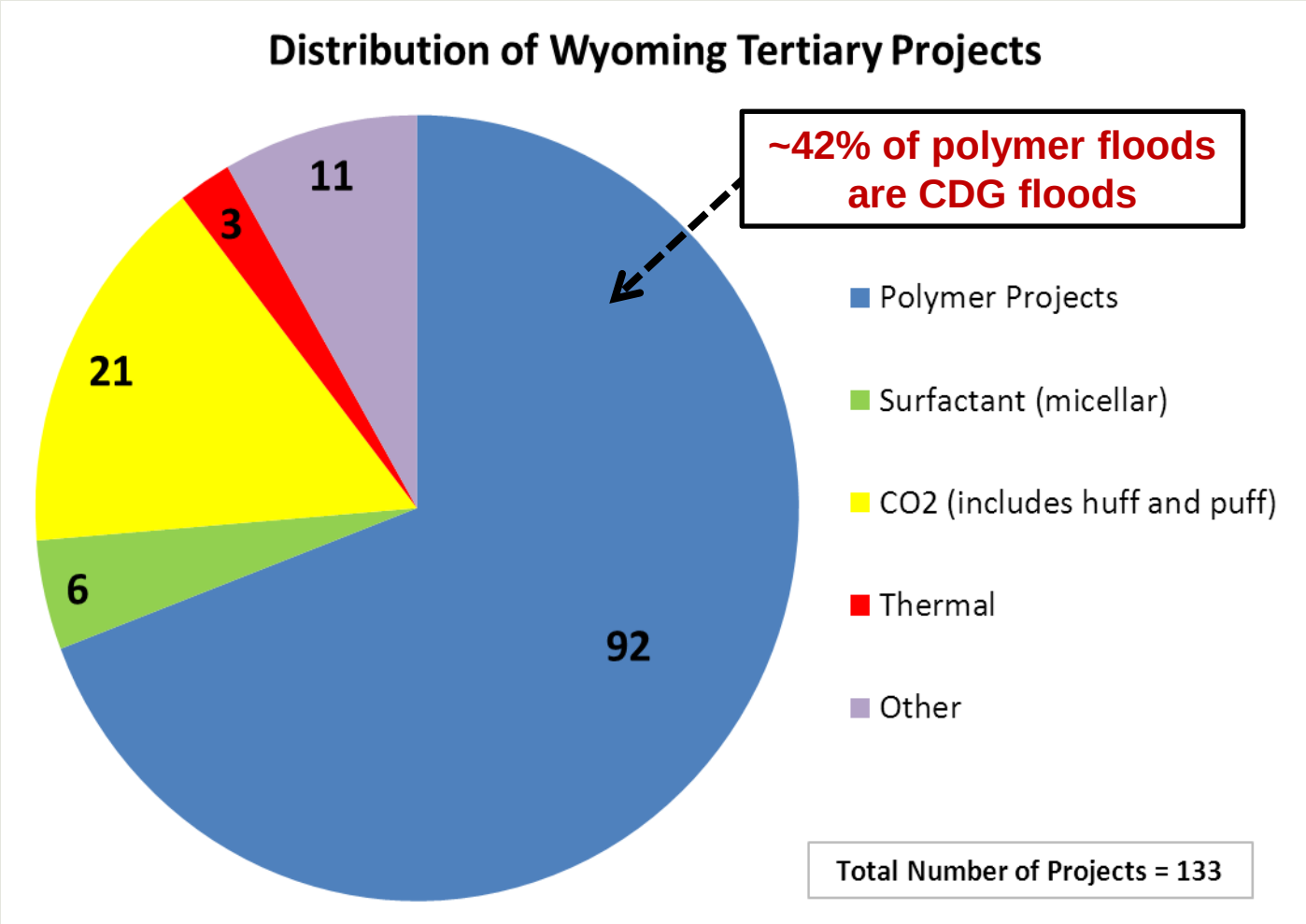
Historical Development of Minnelusa EOR

- Colloidal Dispersion Gel (CDG) Process – CDGs (weak gels) generate higher viscosities & RRF than polymer solutions at lower concentrations (Edsel, Alpha,OK)
- The first CDG flood was implemented in 1985 in the Edsel Minnelusa Unit, Crook County, WY
  - The flood switched from the layered to the CDG process
  - Results showed an incremental recovery of 11.5 % OOIP
- MARCIT Bulk Gel Process – strong gels formed with Cr crosslinker to significantly reduce flow in high permeability channels (N. Rainibow Ranch, Ash, Indian Creek)

Summary of EOR Projects in Wyoming

Wyoming Tertiary Projects:
2008 Wyoming O&G Stats, The WOGCC

Chemical Flooding Dominates

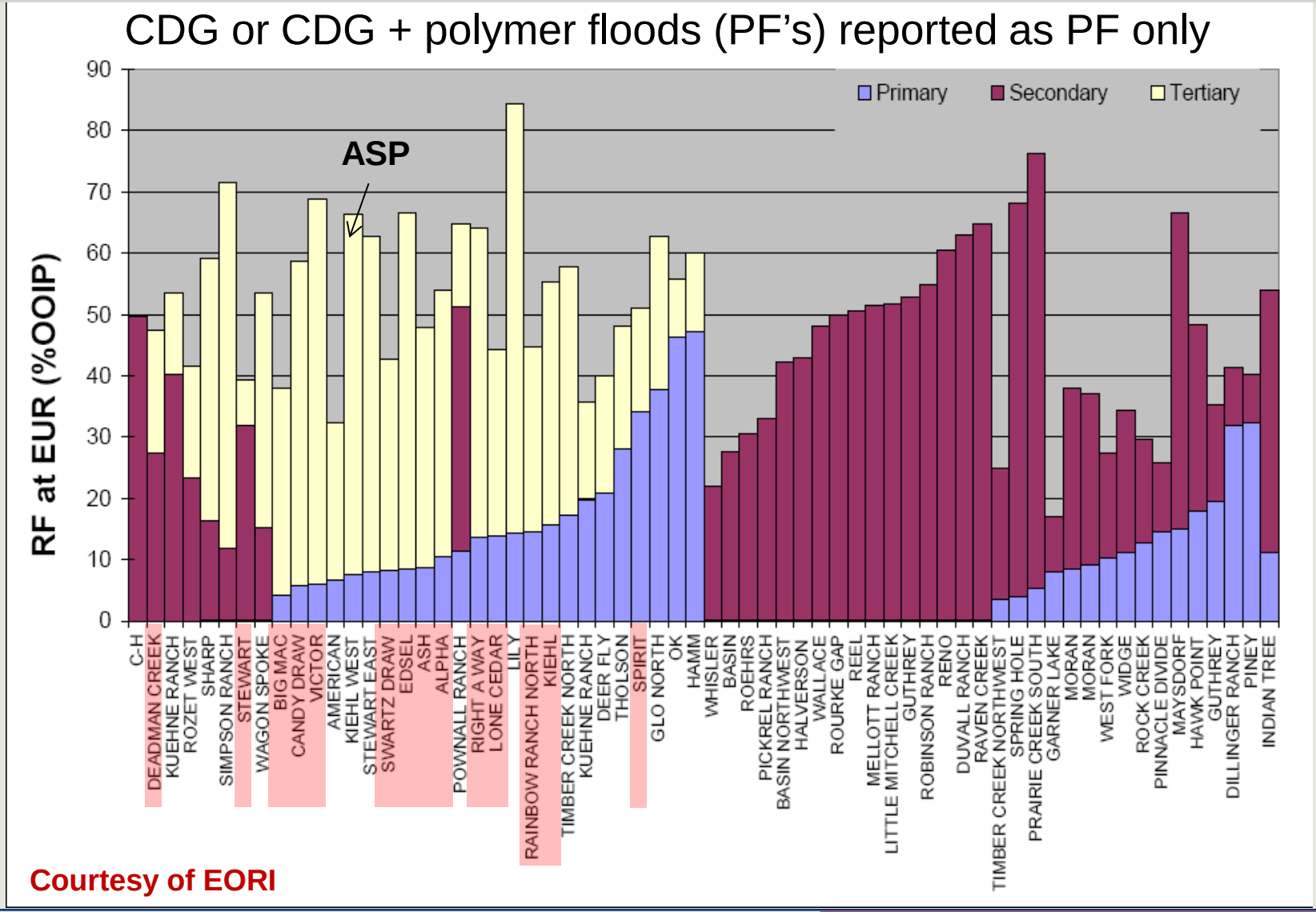


Evaluation of Chemical Flooding in the Minnelusa Formation, PRB, WY*

- EORI publication evaluated the EUR of 32 chemical (mostly polymer) and waterfloods
- The primary conclusions were:
  - Chemical flooding improves recovery by an average of 9% OOIP compared to waterflooding
  - Chemical flooding produces more oil sooner
  - The sooner you start EOR the more oil you recover

*Thyne, G., Alvarado, V., Murrell, G., Evaluation of Chemical Flooding in the Minnelusa Formation, Powder River Basin, Wyoming. *Search and Discovery*, Article # 50239, February 26, 2010.

Minnelusa Production Analysis



Courtesy of EORI

N. Rainbow Ranch EOR Project

N. Rainbow Ranch Unit (SPE-27773 Updates)

- Summary of reservoir and fluid properties (R71W – T49N)

Formation	Minnelusa
Depth	9,500 ft
Porosity	19.7%
Water Saturation	20%
Temperature	202°F
Permeability Range	1 - 1,000 mD
Perm. Variation (DP)	0.9
Oil Gravity	26°API
Oil Viscosity	3.94 cP

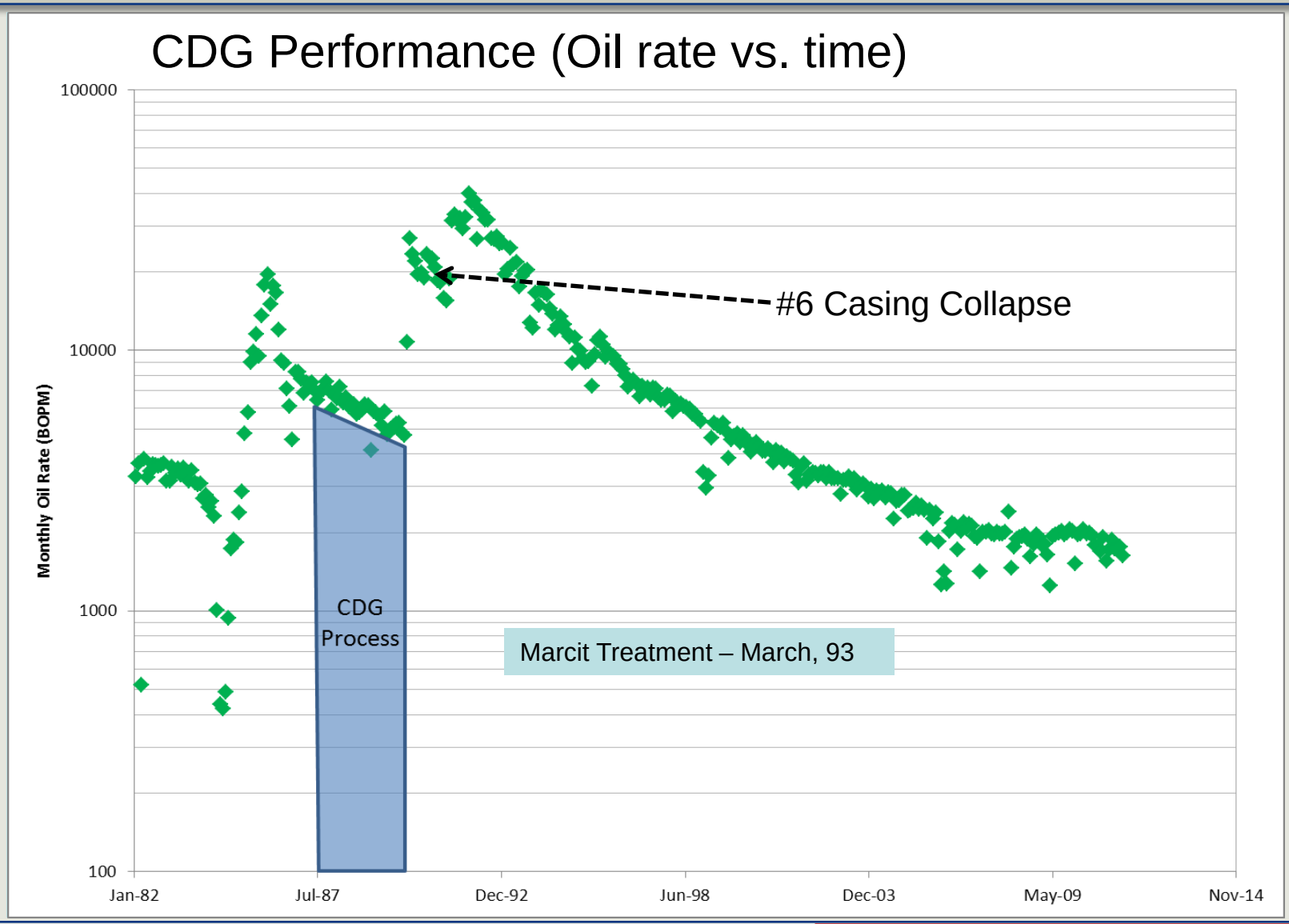
N. Rainbow Ranch Unit (SPE-27773 Updates)

- Summary of CDG treatment design:

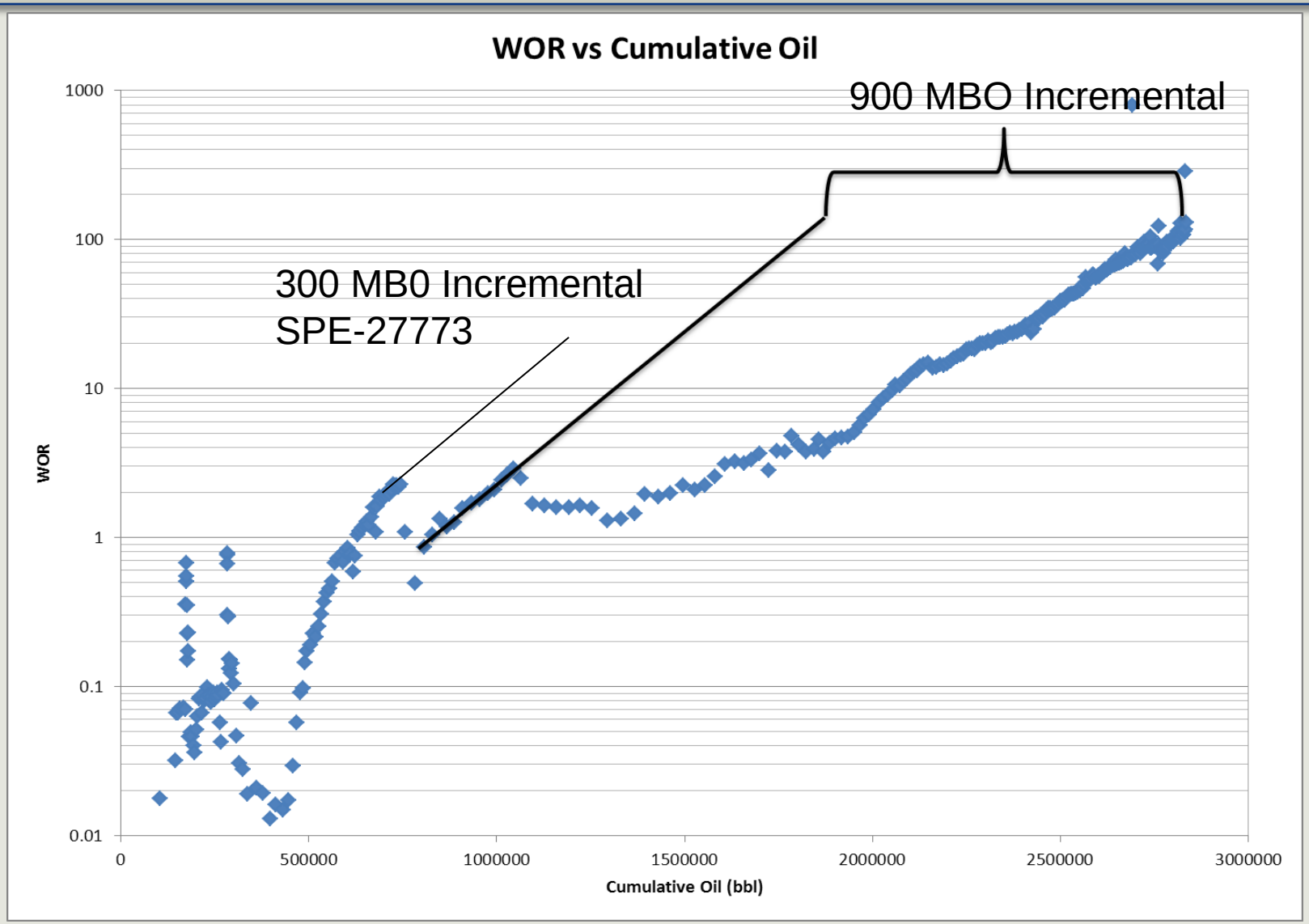
Stage	Injection bbls	Product*	Pounds	Concentration mg / l
1	81,000	Cationic Polymer	22,000	775
2	46,000	Anionic Polymer	22,500	1,400
3	198,000	Anionic Polymer Al-Citrate	83,100 71,000	1,200 1,000
4	654,000	Anionic Polymer Al-Citrate	68,700 76,000	300 330

* Polyacrylamide polymers

N. Rainbow Ranch Unit (SPE-27773 Updates)



N. Rainbow Ranch Unit (SPE-27773 Updates)



N. Rainbow Ranch Unit Summary Conclusions

- Approximately 12% PV was injected over the life of chemical flood
- CDGs using high molecular weight polymer were successfully injected into a non-fractured, high permeability sandstone formation
- Total recovery to date of 49.4% OOIP
- Preliminary incremental recovery estimates were estimated in 8.0% of OOIP (SPE-27773). Current analysis suggests an incremental recovery of 15.7% OOIP
- Updated results estimate a development cost of $1 per incremental barrel

ASP Flooding

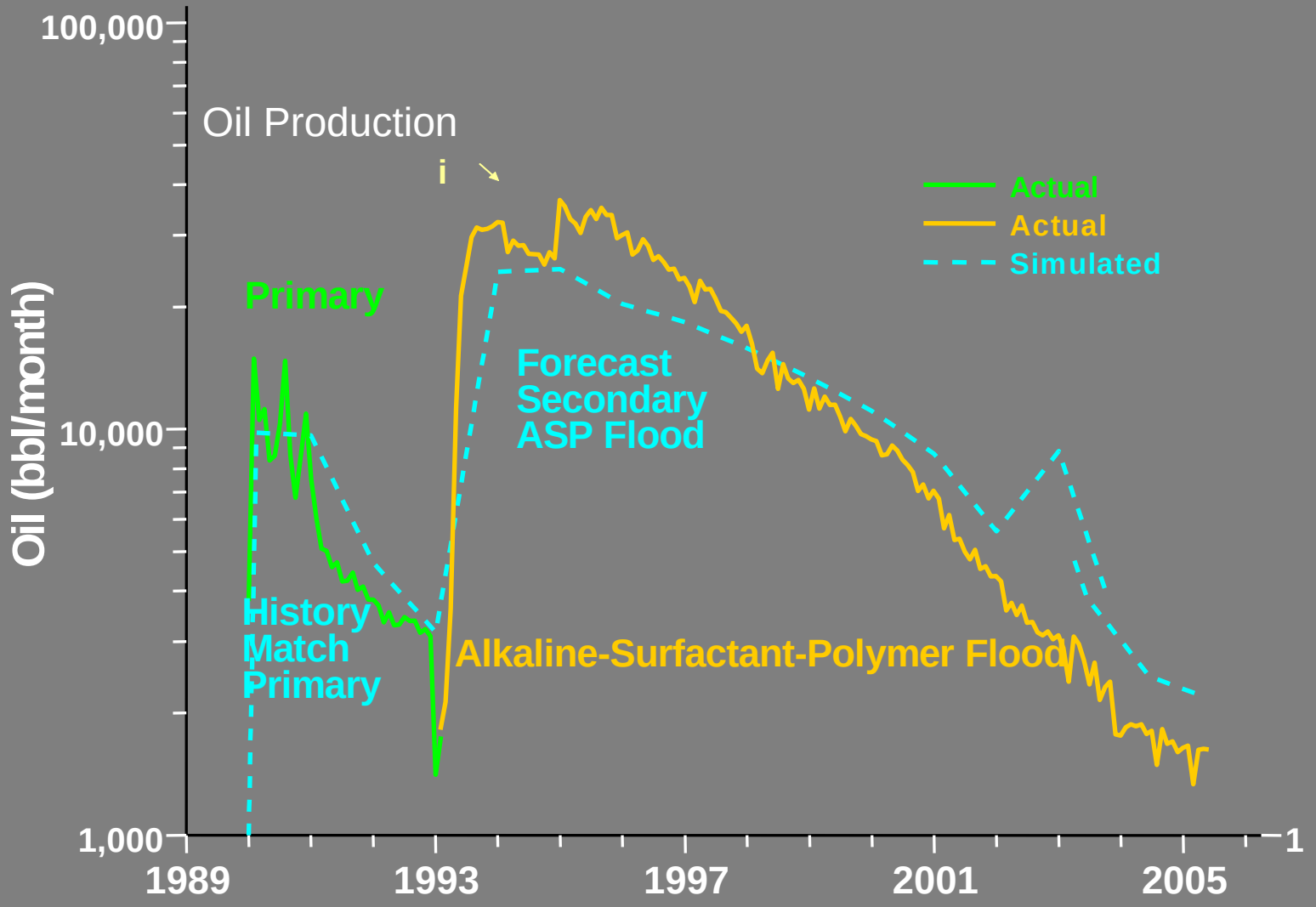
ASP Flooding

- First ASP Flood ever carried out in Minnelusa lower sand at West Kiehl Unit
  - Started in September 1987
  - Used Petrostep B100, Soda Ash and Pusher 700
- First ASP Flood started at the beginning of Secondary Recovery: Cambridge Minnelusa Unit
  - Started in 1993
  - Used Petrostep B100, Soda Ash, Alcoflood 1275A

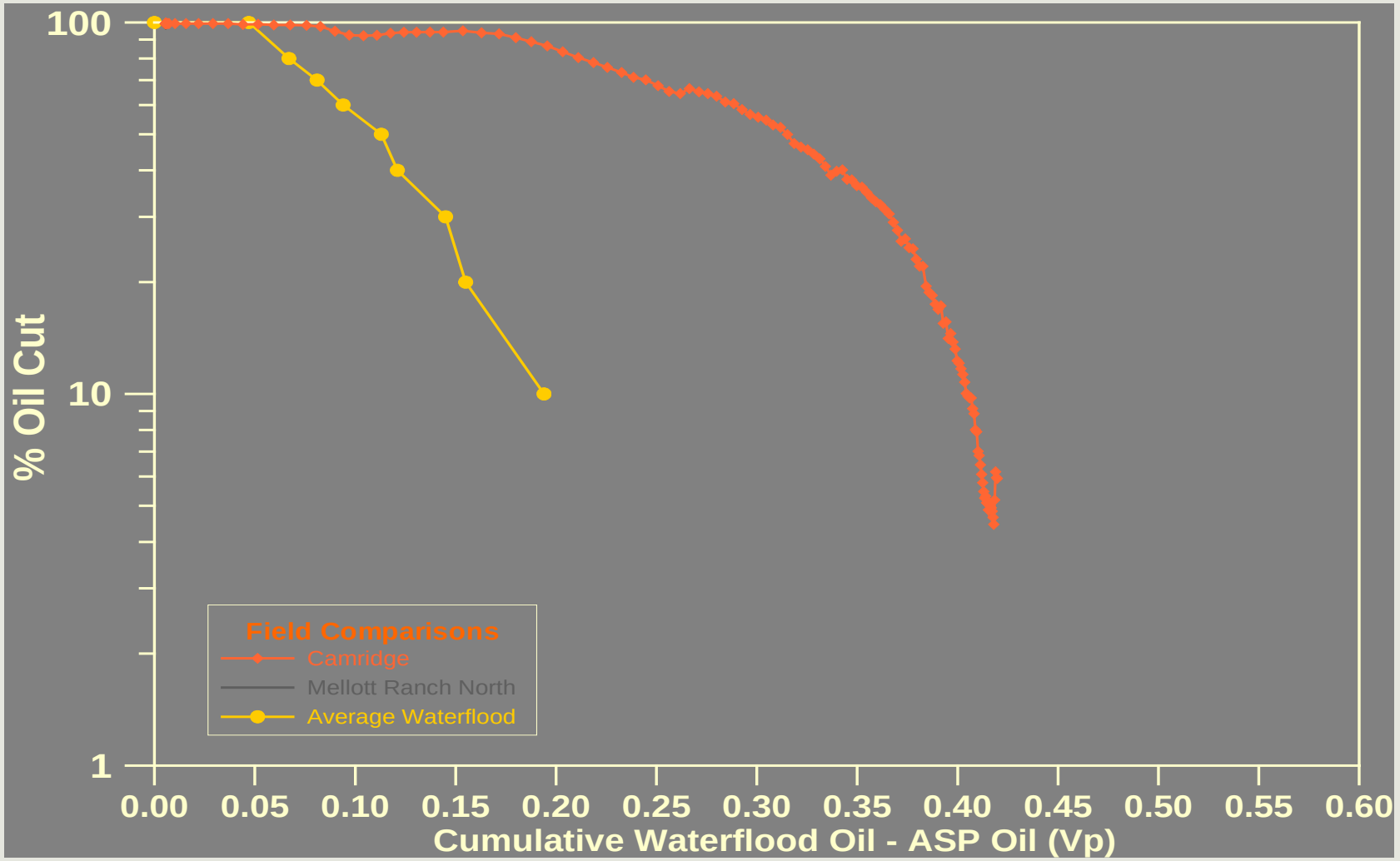
Cambridge Field Conditions SPE 55633

Formation	Minnelusa Upper B
Depth	7,108 ft
Temperature	132 F
Pore volume	7,117 Mbbl
OOIP	4,900 Mbbl
Thickness	29 ft
Average porosity	18%
Average Permeability	845 mD
Initial water saturation	31.6%
Oil API gravity	20
Oil viscosity	31 cPs
Flood date	1993-1998

Cambridge Field Pilot Test Results



Delayed decline in Oil Production



Cambridge Recovery Summary

- Ultimate Oil Recovery 69.6 %OOIP
- Primary and Water flood 36.2 %OOIP
- ASP Incremental Recovery 33.4 %OOIP

- Cost per Incremental Barrel 4.07 $/bbl (2.94$/bbl)

- Chemical cost and facilities
  - 750m lb Petrostep B-100 @ $2.00/lb
  - 1,350m lb Alcoflood 1275A @ $1.20/lb
  - 10,200m lb Na2CO3 @ $0.12/lb
  - Facilities @ $1.0MM ($170M)

- Incremental oil = 1.3MM bbl, Value @ 50$/bbl = $65MM

What is Next in Improving Minnelusa Oil Recovery

- Mature Floods with High WOR
- Need a Combination of Sweep Improvement with Reduction in Sor
- Start with Sweep Improvement – CDG or Marcit
- Follow with ASP or SP
- Follow with Polymer
- Ultimate Oil Recovery > 60% OOIP

Closing Remarks

Closing Remarks

- Minnelusa is a great formation to try EOR
    - Clean sandstone, fresh water, successful waterflood, small confined reservoirs)
- Sweep improvement Processes have proven successful in improving oil recovery economically
- ASP Projects have shown good incremental oil recovery, although economics are more challenging than sweep
- Since most Minnelusa reservoirs are mature water/EOR floods, future EOR is challenging