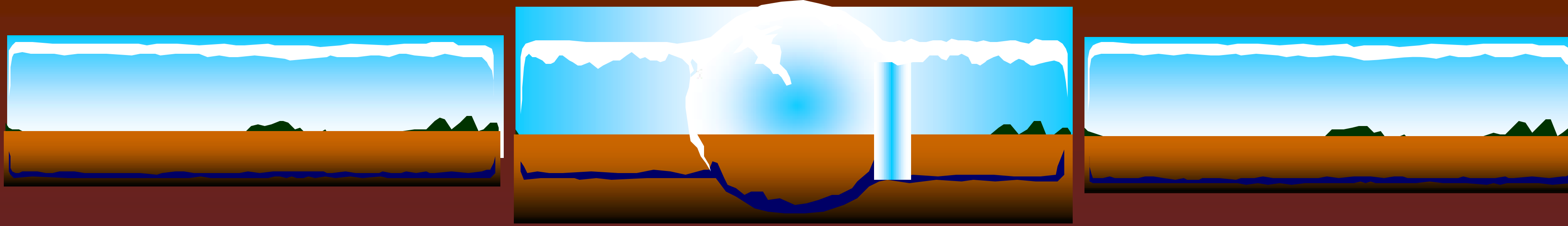

DOE's EGS Program Review

- Evaluation of Oil–Industry Stimulation Practices for Engineered Geothermal Systems

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Project Objective

- Increase & evaluate stimulation effectiveness in EGS wells:
  - Evaluate techniques & methods commonly used in hydraulic fracturing of oil & gas wells.
- *Cancelled tasks:*
  - *Study EGS field test data &*
  - *reconcile with calibrated model (EGS at Desert Peak)*

EGS Problem

- Complex, extensive fracture networks from hydraulic stimulation (as used in oilfield reservoirs) allow economical heat extraction from low permeability rock:
  - Identify oilfield equivalents.
  - Improve fluid diversion & penetration.
  - Study applicability of direct diagnostics.
- Improve reservoir design & development: Isolating stimulation zones, reservoir stimulation design, reservoir stimulation & fracture propping.

Background/Approach (1)

1) Identify oilfield equivalents.
2) Improve fluid diversion & penetration.
3) Study applicability of direct diagnostics.

Background/Approach (2)

1) Identify oilfield equivalents.
   a) Evaluate existing mapping datasets.
   b) Account for fracture physics in EGS.
   c) Develop calibrated fracture model.
   d) Conduct sensitivity study.
2) Improve fluid diversion & penetration.
3) Study applicability of direct diagnostics.

Background/Approach (3)

1) Identify oilfield equivalents.
2) Improve fluid diversion & penetration.
   a) Evaluate propped versus water fractures.
   b) Evaluate zonal isolation & diversion.
   c) Evaluate alternating growth / re-orientation.
3) Study applicability of direct diagnostics.

Background/Approach (4)

1) Identify oilfield equivalents.
2) Improve fluid diversion & penetration.
3) Study applicability of direct diagnostics.
    a) Evaluate applicability of direct diagnostics.
    b) *Evaluate EGS field test data. (cancelled)*
    c) *Reconcile with calibrated model. (cancelled)*

Results/Accomplishments (1)

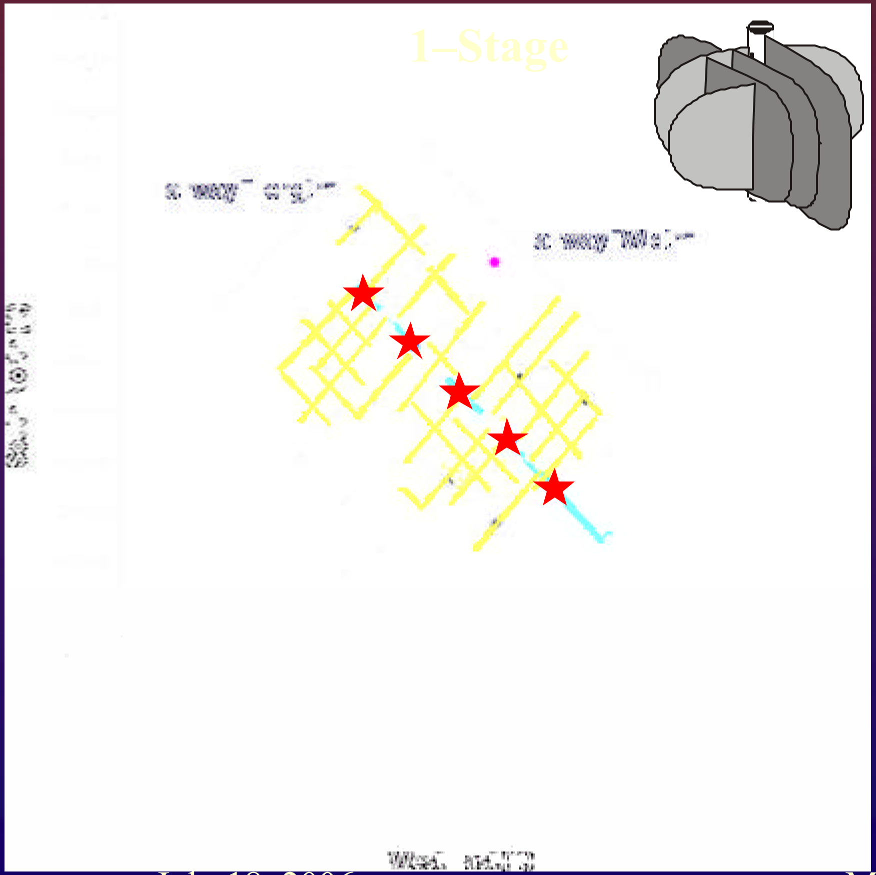
1) "Evaluation of Oil–Industry Stimulation Practices for Enhanced Geothermal Systems: Lessons Learned from the Barnett Shale," GRC Transactions, 2005.
2) "Developing Calibrated Fracture Growth Models for Various Formations and Regions Across the United States," Society of Petroleum Engineers (SPE) paper, 2005.
3) "Creating Extensive and Complex Fracture Networks for Enhanced Geothermal Systems: An Overview of Oilfield Stimulation and Diversion Techniques," GRC Transactions, Vol. 30, 2006.
4) "Evaluation of Oil-industry Stimulation Practices for Engineered Geothermal Systems," Final Report, DOE EGS, 2006.

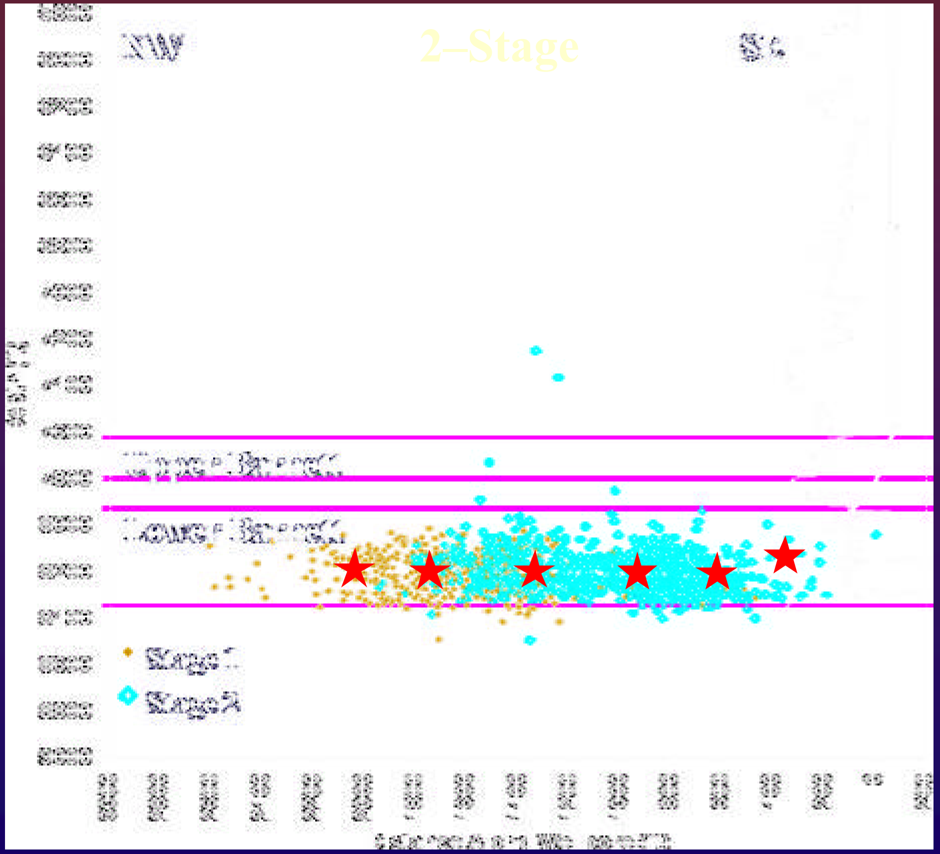
Results/Accomplishments (2)

1) "Evaluation of Oil–Industry Stimulation Practices for Enhanced Geothermal Systems: Lessons Learned from the Barnett Shale"
   - Fracture mapping of hydraulic stimulations in low permeability formations.
   - Complex, extensive fracture networks:
     - Due to interaction between induced hydraulic fractures & natural fractures.
     - Significant volumes & fracture surface areas.
   - Water fracturing in low permeability formations:
     - Drastically reduces cost compared to proppant / gel fracturing.
     - Appears adequate for EGS.
   - <u>Vertical wells:</u> Commercial productivities.
   - <u>Horizontal wells:</u> Maximize contact area between well & fracture network at greater cost. Also possible for EGS.

Results/Accomplishments (3)

Micro-seismic mapping of water(-sand) fracturing in uncemented horizontal wellbore.





Results/Accomplishments (4)

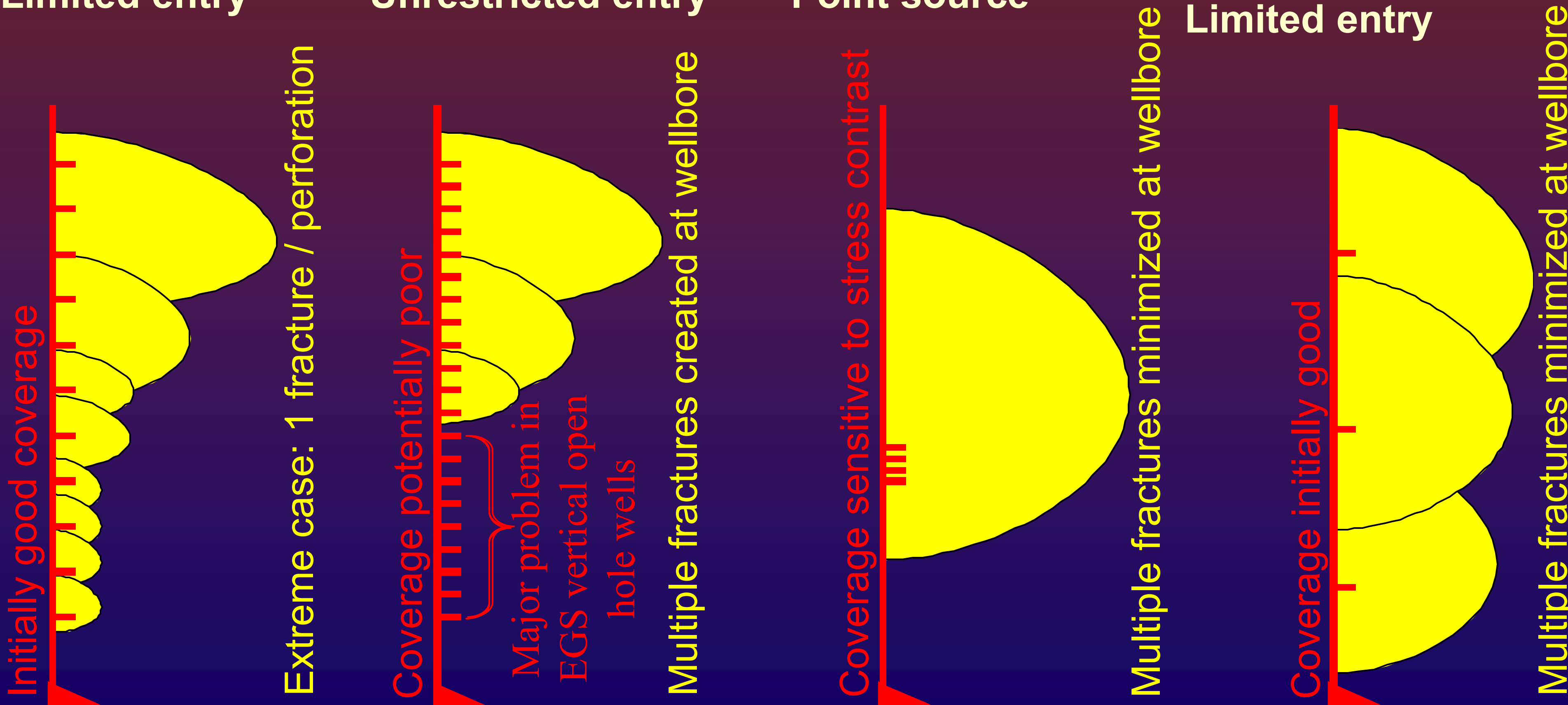
3) "Creating Extensive and Complex Fracture Networks for Enhanced Geothermal Systems: An Overview of Oilfield Stimulation and Diversion Techniques"

Alternating rates, gel viscosities, proppant slugs & pump-ins / shut-ins to create stress shadowing, combined with:

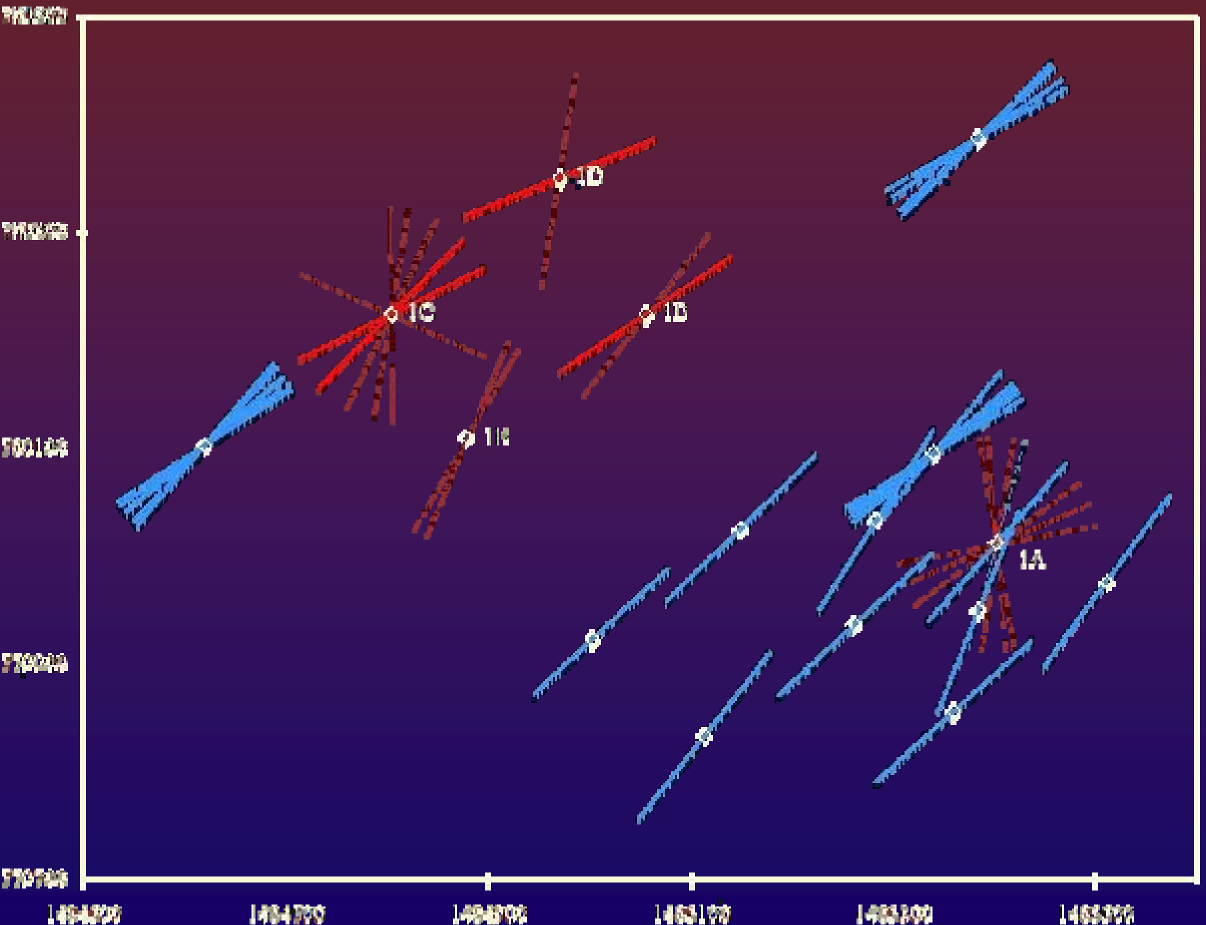
- ❖ Deviated / horizontal cased wellbore *for excellent height control & lateral diversion*; coiled tubing fracture treatments *for quick execution*: Lateral & vertical diversion.
- ❖ Deviated / horizontal uncemented slotted liner with various perforation intervals *for limited entry fracturing with single treatment at high slurry rate*: Lateral diversion.
- ❖ Horizontal open hole with hydra-jet / propellant initiation: Lateral diversion.

Results/Accomplishments (5)

Limited entry | **Unrestricted entry** | **Point source** | **Multiple point source Limited entry**



Results/Accomplishments (6)



Fracture re-orientation in Lost Hills Field, CA

—— Low rate steam

- - High rate steam

- - High rate water propped

Fracture lengths greatly exaggerated for clarity.

Conclusion

- Project objective will be achieved by project completion date.
  - Inspiration to discover novel & improved techniques to improve effectiveness of EGS development.
  - Differences between oilfield & EGS necessitate further study.
  - *Cancelled: Evaluation of EGS field test data & reconciliation with calibrated model.*

APPENDIX

Peer Review (1)

1) Barnett Shale, TX versus EGS; limited data.
2) Sedimentary / metamorphic versus crystalline.
3) Oilfield versus EGS conditions.
4) Shear (EGS) versus tensile (oilfield) failure.

Peer Review (2)

1) Barnett Shale, TX versus EGS; limited data.

- ***Stimulation of natural fractures in low-permeability reservoirs.***
- Comparison table for reservoir properties.
- Stimulation strategy could overcome oilfield-EGS differences.
- Qualitative (not quantitative) lessons learned.
- Co-PI: GeothermEx.
- Studied alternative oilfield reservoirs.

Peer Review (3)

	Barnett Shale	**EGS**
maximization	heat transfer	drainage
fracture area	high	
fracture spacing	high	low
fracture conductivity	high	low
inter–well distance	low treatment–offset	high injector–producer

Peer Review (4)

2) Sedimentary / metamorphic versus crystalline.
   - ❖ Fracture height containment (composite layering):
     - ❖ No stratification: Presumed absent in EGS.
     - ❖ Rock mechanical heterogeneity: Possibly present in EGS.
     - ❖ Long, vertical open-hole intervals perhaps not optimal.

Peer Review (5)

3) Oilfield versus EGS conditions.
   - Focus on applicability of oilfield techniques to EGS.
   - Cost / benefit analysis at GRC 2006 meeting.

Peer Review (6)

4) Shear (EGS) versus tensile (oilfield) failure.
   - Barnett Shale, TX:
     - Combination of shear & tensile.
     - Tip balance via alternating rates & viscosities.