RPPR submitted to the US DOE NETL
DE-FE0010799

Small Molecular Associative Carbon Dioxide (CO_2) Thickeners for Improved Mobility Control

Quarterly Research Performance Progress Report
Start date: 1/1/14
End date: 3/31/14

Principal Authors: Robert Enick PI
Bayer Professor of Chemical and Petroleum Engineering
(412)624-9649 or (412)277-0154

April 14, 2014

DUNS Number DUNS: 00-451-4360

Department of Chemical and Petroleum Engineering
1249 Benedum Engineering Hall
University of Pittsburgh, Pittsburgh PA 15261

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EXECUTIVE SUMMARY

The objective of this project is to promote the application of a CO_2 thickener for CO_2 EOR, and to then test the thickener in a single injection well pilot test. During Phase 1 – the current and initial phase of this project - various CO_2 EOR operators will be contacted by email, phone, and during in-person meetings in an attempt to establish a relationship that will facilitate such a field trial should the thickener be successfully developed. The field test would be conducted during Phase 2 of this NETL award.

The design, synthesis, purification and initial assessments of CO_2 solubility and (for compounds that dissolve in CO_2) viscosity enhancement are underway under separate ARPA-E funding. In all cases the thickeners are designed to be relatively small molecules that aggregate in solution to induce large increases in viscosity at low concentration. Ultrahigh molecular weight polymers are not being considered because our prior research has shown that only the prohibitive expensive and environmentally persistent fluoroacrylate-functionalized polymer can thicken CO_2 at reservoir conditions. Our team has begun the synthesis of Type 1, Type 2, and Type 3 small associative molecules under separate ARPA-E funding. Type 1 refers to molecules with CO_2-philic cores and aromatic associating groups at each end of the molecule. Type 2 refers to molecules with CO_2-philic cores and CO_2-reactive amine groups at each end of the molecule. Type 3 thickeners, which are two-component systems composed of a CO_2-philic compound with a pendent electron donating group (component 1) or a pendent electron-receiving group (component 2).

During this quarter we have received one letter of commitment for this project from one major CO_2 EOR operator; Tabula Rasa. Our contact for obtaining this letter was Tracy Evans. The letter was signed by Tracy Evans, Chief Operating Officer of Tabula Rasa Partners LLC. We successfully concluded discussions with Lillian Lo, reservoir Engineering Fellow of Enhanced Recovery Technology at ConocoPhillips. These discussions led to a verbal agreement for a letter of commitment, which should be obtained during the next quarter

As noted previously, Denbury Resources appears to be particularly interested in this project because their CO_2 flooding strategy is focused on gas cycling (not WAG). Therefore Denbury Resources is particularly interested in CO_2-soluble additives such as surfactants (the objective of a separate NETL RUA project) and CO_2-thickeners (this NETL-funded project).

2. ACCOMPLISHMENTS

Major goals:

The major goal of this project is to establish a relationship with several CO_2 EOR operators that will allow for the rapid and effective assessment of a CO_2 thickener in lab-scale tests that would provide enough information to give the operators confidence to conduct a pilot test of the thickener in the field. Therefore we intend to foster these relationships and to employ field data and fluid and rock samples from patterns in which CO_2 mobility control with a CO_2 thickener would be attractive to these operators.

The most important accomplishments during this quarter was obtaining one letter of commitment from Tabula rasa and obtaining one verbal agreement for a letter from Conoco Phillips.

Accomplishments under these goals

Task 1 – Project Management, Planning, and Reporting

The PMP has been provided to NETL, and was sent along with this quarterly to verify its submission.

Task 2 – Letters of commitment, Field Site Data and Samples

During this quarter we received one more letter of commitment, bringing our total to three (Denbury, Kinder Morgan and Tabula Rasa).

Task 3 – Approaches for Laboratory Testing of Thickened CO_2

We have no changes to our previously submitted lab testing plan. This outline has already been presented to David D'Souza of Denbury Resources, and is found below.

- Conducting the core floods at or near reservoir temperature and pressure that is commensurate with the fields that may be used in future field tests.
- The core shall be waterflooded and oil-flooded to emulate geologic history, and then waterflooded to emulate decades of waterflooding that often precedes CO_2 flooding (unless, of course, the field under consideration was not waterflooded prior to CO_2 injection).
- Three core flooding experiments: (1) The baseline or "control" core flood shall employ continuous CO_2 injection. (2) The second run shall use a water-alternating-pure CO_2 WAG injection strategy at a 1:1 ratio. (3) Finally, thickened CO_2 shall be continuously injected.
- Repeating each test to verify the reproducibility of the results.
- Conducting a displacement that accounts for the heterogeneity of most formations by using (a) a very heterogeneous core, or (b) a co-axial "core-within-a-core", or (c) a core with longitudinal, irregular, rough-walled fracture(s) extending the length of the core, (d) or two fairly homogeneous parallel cores with different permeabilites.
- Use of a slug (fraction of a pore volume) of CO_2 thickener followed by CO_2. Check dispersion of the thickener in the CO_2.
- Use of the newly developed DOE-CO_2 simulator by U. T. Austin (or other simulator) for simulation of core floods with thickened CO_2. Add visualization (from CT scanner experiments and simulator results) to convince other operators that the injection of thickened CO_2 is a better option that the prolonged injection of pure CO_2 or WAG for the

recovery of oil.

The plans shall be reviewed and agreed upon by the Recipient, the CO_2 EOR Operator(s) and NETL.

Task 4 – Technical Status of APRA-E Research

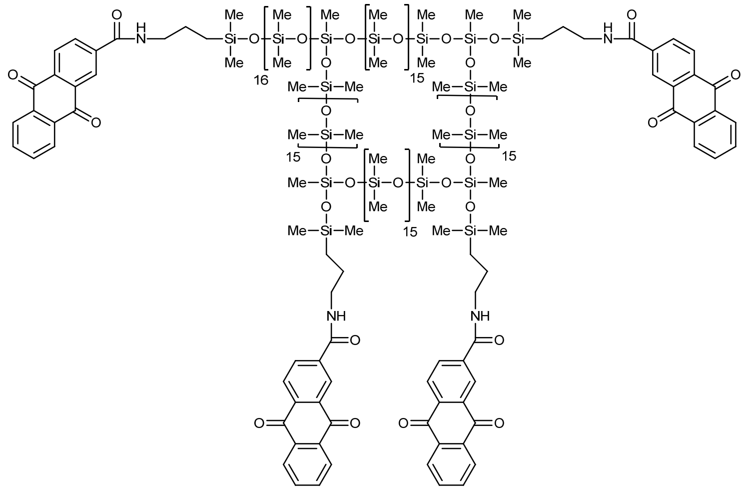
Our team has now synthesized over 100 Type 1, Type 2, and Type 3 small associative molecules thickeners. About half of the ARPA-E funding supports our collaborators at GE Global Research in Niskayuna NY. Type 1 refers to molecules with CO_2-philic cores and aromatic associating groups at each end of the molecule, or small rigid sugar-based gelators. Type 2 refers to molecules with CO_2-philic cores and CO_2-reactive amine groups at each end of the molecule. Type 3 thickeners, which are two-component systems composed of a CO_2-philic compound with a pendent electron donating group (component 1) or a pendent electron-receiving group (component 2).

Type 1 molecules made to date include triphenoxymethanes, simple organogelators, silicone oligomers with aromatic end groups, and polyether (specifically polypropylene glycol, PPG) oligomers with aromatic end groups, and sugar-based small molecule thickeners. We have begun working on the "universal gelator" molecule bis-(R,β-dihydroxy ester (an oxygenated hydrocarbon molecule with two hydroxyls and an isopropyl group on each end) which is capable of thickening an incredibly diverse set of solvents (2H,3H-perfluoropentane (HPFP) and 1H,1H-heptafluorobutanol (HFB), water, toluene, cyclohexane, a 10:1 hexane-chloroform-hexane mixture, dichloromethane, water, CS_2, and even lager and wine! These solvents were gelled with less than 1wt% of the universal gelator, with the exception of the dichloromethane, which required about 5wt%.

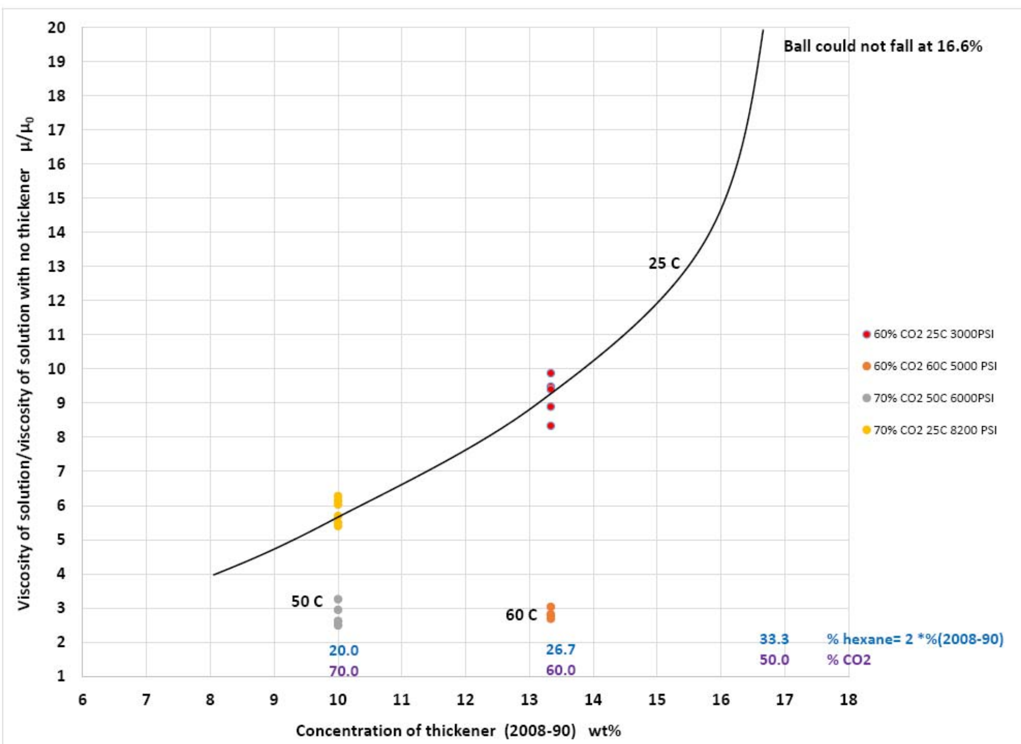
Type 2 molecules made to date include silicone oil oligomers with terminal primary and/or secondary amines, PPG oligomers with terminal primary and/or secondary amines, and silicone oil oligomers terminated with amide groups leading to aromatic groups.

Type 3 thickeners have been made solely with silicone oil based A and silicon oil based B compounds. About a dozen A + B combinations have been made to date.

We have begun the testing of CO_2 solubility and viscosity enhancement of these compounds. We are achieving success in CO_2-solubility, and recently found that the anthraquinone group is particularly effective at intermolecular associations. For example, in the following molecule the structure of a thickener is shown. The silicone portions $-(Si\text{-}CH_3CH_3O)_n$- (shown as –(Si-MeMeO)$_n$-) promote solubility in CO_2, while the aromatic group anthraquinone composed of three benzene rings and two =O groups provide intermolecular associations.



This compound forms transparent rigid gels in liquids like hexane in dilute concentration; and while not soluble in CO_2, the compound (which is designated as 2008-90) was capable of thickening CO_2-rich solutions (mixtures of CO_2 and hexane) as in the following figure.



We continue modifying this compound and developing new compounds that can thicken CO2 without the need for a co-solvent.

Training and professional development

Dissemination of results

As described in the accomplishment section, we have made five companies aware of our three-pronged (Types 1,2 and 3) approach for development of a CO_2 thickener.

We gave a presentation on our work at the AIChE conference in San Francisco.

We submitted an abstract of our ARPA-E + NETL funded work on CO_2 thickeners for the 2014 IOR conference in Tulsa, which has been accepted for presentation (the SPE paper is due Fen 10 2014).

Plans for next quarter

We intend to keep making CO_2 thickener candidate molecules under ARPA-E funding.
We intend to obtain a fourth letter of commitment.

3. PRODUCTS

1.Our presentation at AIChE National Meeting was:

The CO_2-Solubility and Viscosity Enhancing Potential of CO_2-Philes Functionalized With Aromatic Groups, was presented at the 2013 AIChE Annual Meeting in San Francisco, CA. Date: **Wednesday, November 6, 2013**

Wednesday, November 6, 2013: 8:30 AM
Union Square 14 (Hilton)

Jason J. Lee[1], **Stephen Cummings**[1], Robert J. Perry[2], Eric J. Beckman[1] and **Robert Enick**[3], (1)Chemical Engineering, University of Pittsburgh, Pittsburgh, PA, (2)Global Research, General Electric, Niskayuna, NY, (3)University of Pittsburgh, Department of Chemical and Petroleum Engineering, Pittsburgh, PA

The low viscosity of CO_2 at typical enhanced oil recovery (EOR) conditions is responsible for a poor mobility ratio that causes viscous fingering and poor sweep efficiency, leading to reduced efficiency and yield. To overcome this problem, there is a need to develop CO_2-soluble additives that will increase the effective viscosity of CO_2 without the use of a co-solvent. The only known polymeric direct thickener poly(fluoroacrylate-co-styrene) (polyFAST) has been shown to significantly increase the viscosity measured by falling cylinder viscometry and Berea sandstone core mobility experiments. The proposed mechanism of aggregation responsible for this viscosity enhancement is believed to be π-π stacking between aromatic rings. However, high molecular weight polymers like polyFAST require significant amounts of expensive fluorinated moieties in order to impart solubility. In addition to their cost, fluorinated compounds have undesirable environmental impacts. Therefore, this work focuses on the development of less expensive and safer hydrocarbon-based CO_2 thickeners. Because our prior studies have demonstrated that unacceptably high pressures are required to dissolve non-fluorous polymers, this study entails the use of small, associating compounds to create a thermodynamic illusion of a polymer. Each CO_2 thickening candidate consists of at least one non-fluorous CO_2-philic segments and at least two slightly CO_2-phobic functionalities that promote intermolecular aggregation (e.g. aromatic groups). Solubilities of a range of newly synthesized molecules in CO_2 and their associated viscosity enhancing abilities will be presented. Preliminary results indicate that it is possible to design such novel CO_2-thickening candidates that are up to 1wt% soluble in CO_2 at pressures commensurate with EOR.

2.The PI (Dr. Enick) completed a chapter on CO_2 EOR state-of-the-art for The Catalyst Group newsletter. This report, which includes a highlight the thickener developments, was distributed to the subscribers of the newsletter in the fall of 2013.

3.The abstract for the April 2014 SPE IOR meeting in Tulsa was accepted and is being presented by Jason Lee.

Development of Small Molecule Thickeners for CO_2 EOR and CO_2 Fracturing

The only known CO_2 thickener (a compound that dissolves in CO_2 and increases it viscosity significantly when present in dilute concentration) is a fluoroacrylate-styrene random copolymer that is probably too expensive for commercial application. High pressure CO_2 has also been thickened via the dissolution of high molecular weight polydimethylsiloxane (PDMS, silicone oil) or polyvinyl acetate (PVAc), but this strategy requires several wt% of the polymer and the addition of large concentrations of an organic solvent (e.g. 20% toluene + 80% CO_2), which is also impractical for commercial use. Because the utilization of high molecular weight polymers no longer appears to be a viable strategy for affordably thickening CO_2 at EOR conditions, we are assessing the use of novel small molecules that self-assemble into viscosity-enhancing supramolecular structures in dense CO_2. Small molecules can actually increase fluid viscosity just as effectively as high molecular weight polymers when compared at similar concentrations. For example, tributyltin fluoride and hydroxyaluminum di(2-ethyl hexanoate) are remarkable thickeners of light hydrocarbons even when present at concentrations well below 1wt%. In this presentation, three types of novel CO_2 thickening candidates are designed, synthesized and assessed for solubility in CO_2 and viscosity-increasing capabilities. Each small molecule possesses a "CO_2-philic" segment that promotes dissolution in CO_2; the CO_2-philic segments are low-cost oligomeric versions of CO_2-soluble polymers. Three different types of slightly "CO_2-phobic" functional groups known to promote intermolecular associations in hydrocarbon and/or aqueous systems are also included in the thickener structure. The foremost challenge in the molecular design is selecting the appropriate type and number of associating groups needed to enhance viscosity, while not rendering the compound insoluble in CO_2. A variety of prospective CO_2 thickeners have been synthesized and the solubility of these candidates in CO_2, and their ability to thicken CO_2, will be presented.

4. We will be presenting our work at a poster session in Midland in May 2014 at the AAPG Section Meeting

Robert Enick
Abstract for Southwest AAPG section meeting
Sunday 11-May-14 8:00 AM to Wednesday 14-May-14 5:00 PM CDT
Midland Center

105 N. Main Street
Midland TX 79701 USA

CO_2 soluble surfactants and thickeners for CO_2 IOR

There have been over a dozen field tests of SAG (aqueous surfactant solution-alternating-CO_2 gas) conformance and mobility control in the 1980s and 1990s. Most of these tests were technical successes but the economics of the process were hampered by the extremely low price of oil. Given the large amount of oil that remains in the ground after CO_2 EOR and the current price of oil, it's not surprising that there has been renewed interest in additives for improved conformance and or mobility control during CO_2 EOR. For example, there have been recent developments in the dissolution of surfactants in the high pressure CO_2 (rather than, or in addition to, the use of additives in the injected brine). The first example is the use of a slightly CO_2-soluble (0.02-0.2 wt%) non-ionic surfactant designed to stabilize CO_2-in-brine foams that are generated in-situ. This can allow an operator to continuously inject only CO_2 with dissolved surfactant (GS), with foam formation occurring as the soapy CO_2 mixes with the in-situ brine. Alternately, one can alternately inject brine and CO_2 gas containing dissolved surfactant (WAGS). Finally, one could consider injecting a brine-based soap solution containing an ionic surfactant alternately with CO_2 containing a non-ionic surfactant (SAGS). CO_2-soluble surfactants are already available on a commercial scale for use in such processes. A second CO_2 additive of interest to CO_2 EOR operators is a CO2 thickener. The ideal thickener would be an inexpensive, safe compound that could be added to high pressure CO_2 in dilute concentration (~0.1 wt%), where it would dissolve without the need to heat the CO_2. The resultant transparent, stable solution could be easily tailored to have a viscosity that is the same as the oil being displaced simply by varying the concentration of the dissolved thickener. This would eliminate all of the problems associated with the low viscosity (i.e. high mobility) of CO_2, possibly eliminating the need for WAG during CO_2 EOR. Although it is simple to thicken water and oils, CO2 is notoriously difficult to thicken. A review of the long history of failed attempts to thickener CO_2 will be presented, along with an overview of the only CO_2 thickener identified to date (an expensive proof-of-concept compound), and the new inexpensive compounds currently bring assessed in our labs.

4. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Dr. Eric Beckman and Dr. Enick are supported by this NETL project.

Collaborators solely related to thickener development (funded by ARPA-E) include Steven Cummings (post doc at Pitt), Jason Lee (PhD student at Pitt), Aman Dhuwe (PhD student) Robert Perry, Michael O'Brien and Mark Doherty (GE chemists).

Informal collaborations have also been made with engineers at Denbury, Kinder Morgan, ConocoPhillips, and Tabula Rasa.

Collaborations with SCAL (core flooding) will not commence until Phase 2 of this project.

Name:	Robert Enick
Project Role:	PI
Nearest person month worked:	1
Contribution to Project:	Leading the project, contacting companies..
Funding Support:	NETL (this award) and ARPA-E
Collaborated with individual in foreign country:	No
Country(ies) of foreign collaborator:	No
Travelled to foreign country:	No
If traveled to foreign country(ies), duration of stay:	N/A

Name:	Eric Beckman
Project Role:	PI
Nearest person month worked:	1
Contribution to Project:	Thickener development and strategies for introducing thickeners into CO_2 for lab- and field-tests.

Funding Support:	NETL (this award) and ARPA-E
Collaborated with individual in foreign country:	No
Country(ies) of foreign collaborator:	No
Travelled to foreign country:	No
If traveled to foreign country(ies), duration of stay:	N/A

Name:	Jason Lee
Project Role:	PhD
Nearest person month worked:	6
Contribution to Project:	Thickener synthesis and testing
Funding Support:	ARPA-E
Collaborated with individual in foreign country:	No
Country(ies) of foreign collaborator:	No
Travelled to foreign country:	No
If traveled to foreign country(ies), duration of stay:	N/A

Name:	Aman Dhuwe
Project Role:	PhD
Nearest person month worked:	6
Contribution to Project:	Thickener synthesis and testing
Funding Support:	ARPA-E
Collaborated with individual in foreign country:	No
Country(ies) of foreign collaborator:	No
Travelled to foreign country:	No
If traveled to foreign country(ies), duration of stay:	N/A

Name:	Steve Cummings
Project Role:	PhD
Nearest person month worked:	6
Contribution to Project:	Thickener synthesis and testing
Funding Support:	ARPA-E
Collaborated with individual in foreign country:	No
Country(ies) of foreign collaborator:	No
Travelled to foreign country:	No
If traveled to foreign country(ies), duration of stay:	Visited his family in Great Britain for vacation

Name:	Robert Perry
Project Role:	Chemist at GE
Nearest person month worked:	6
Contribution to Project:	Thickener synthesis and testing
Funding Support:	ARPA-E
Collaborated with individual in foreign country:	No
Country(ies) of foreign collaborator:	No
Travelled to foreign country:	No
If traveled to foreign country(ies), duration of stay:	N/A

Name:	Michael O'Brien
Project Role:	Chemist at GE
Nearest person month worked:	6
Contribution to Project:	Thickener synthesis and testing
Funding Support:	ARPA-E
Collaborated with individual in foreign country:	No
Country(ies) of foreign collaborator:	No
Travelled to foreign country:	No
If traveled to foreign country(ies), duration of stay:	N/A

Name:	Mark Doherty
Project Role:	Chemist at GE
Nearest person month worked:	6
Contribution to Project:	Thickener synthesis and testing
Funding Support:	ARPA-E
Collaborated with individual in foreign country:	No
Country(ies) of foreign collaborator:	No
Travelled to foreign country:	No
If traveled to foreign country(ies), duration of stay:	N/A

5. IMPACT

The most obvious impact of this work will be the improved rate of oil recovery and increased amount of recoverable oil should a thickener be designed.

This work, along with the PI's recent NETL-sponsored review of mobility control and up-coming review of CO_2 EOR (including thickeners), has helped to re-invigorate interest in CO_2 mobility control. Specifically, this project is providing a springboard for the introduction of a research product into a rapid field application.

This project combines basic research, chemistry, chemical engineering, and petroleum engineering, and is an excellent example of how a team consisting of chemists, chemical engineers and petroleum engineers can address energy-related problems.

6. CHANGES/PROBLEMS

None to date.

7. SPECIAL REPORTING REQUIREMENTS

Under the ACCOMPLISHMENTS section we have reported on our progression the ARPA-E sponsored project related to the synthesis of a thickener.

8. BUDGETARY INFORMATION

Cost Plan Status
DE-FE0010799

	OND 12	JFM 13	AMJ 13	JAS 13	OND 13	JFM 14	AMJ 14	JAS 14	OND 14	JFM 15	AMJ 15	JAS 15
Projected Spending	FY13Q1	FY13Q2	FY13Q3	FY13Q4	FY14Q1	FY14Q2	FY14Q3	FY14Q4	FY15Q1	FY15Q2	FY15Q3	FY15Q4
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**
Federal amount	$18,750.00	$18,750.00	$18,750.00	$18,750.00	$18,750.00	$18,750.00	$18,750.00	$18,750.00	$0.00	$0.00	$0.00	$0.00
Federal budget cumulative	$18,750.00	$37,500.00	$56,250.00	$75,000.00	$93,750.00	$112,500.00	$131,250.00	$150,000.00	$150,000.00	$150,000.00	$150,000.00	$150,000.00
Cost Share	$16,830.00	$16,830.00	$16,830.00	$16,830.00	$16,830.00	$16,830.00	$16,830.00	$16,830.00	$0.00	$0.00	$0.00	$0.00
Cost Share budget cum.	$16,830.00	$33,660.00	$50,490.00	$67,320.00	$84,150.00	$100,980.00	$117,810.00	$134,640.00	$134,640.00	$134,640.00	$134,640.00	$134,640.00
Project Total	$35,580.00	$35,580.00	$35,580.00	$35,580.00	$35,580.00	$35,580.00	$35,580.00	$35,580.00	$0.00	$0.00	$0.00	$0.00
Project Cumulative Budget	$35,580.00	$71,160.00	$106,740.00	$142,320.00	$177,900.00	$213,480.00	$249,060.00	$284,640.00	$284,640.00	$284,640.00	$284,640.00	$284,640.00

Actual Spending	FY13Q1	FY13Q2	FY13Q3	FY13Q4	FY14Q1	FY14Q2	FY14Q3	FY14Q4	FY15Q1	FY15Q2	FY15Q3	FY15Q4
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**
Federal amount	$0.00	$0.00	$0.00	$43,481.05	$10,787.60	$41,824.43	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Federal actual cumulative	$0.00	$0.00	$0.00	$43,481.05	$54,268.65	$96,093.08	$96,093.08	$96,093.08	$96,093.08	$96,093.08	$96,093.08	$96,093.08
Cost Share	$0.00	$19,735.03	$19,735.03	$19,735.24	$19,735.24	$19,735.24	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Cost Share actual cum.	$0.00	$19,735.03	$39,470.06	$59,205.30	$78,940.54	$98,675.78	$98,675.78	$98,675.78	$98,675.78	$98,675.78	$98,675.78	$98,675.78
Project Total	$0.00	$19,735.03	$19,735.03	$63,216.29	$30,522.84	$61,559.67	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Project Cumulative Actuals	$0.00	$19,735.03	$39,470.06	$102,686.35	$133,209.19	$194,768.86	$194,768.86	$194,768.86	$194,768.86	$194,768.86	$194,768.86	$194,768.86

Variance	FY13Q1	FY13Q2	FY13Q3	FY13Q4	FY14Q1	FY14Q2	FY14Q3	FY14Q4	FY15Q1	FY15Q2	FY15Q3	FY15Q4
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**
Federal amount	$18,750.00	$18,750.00	$18,750.00	-$24,731.05	$7,962.40	-$23,074.43	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Federal actual cumulative	$18,750.00	$37,500.00	$56,250.00	$31,518.95	$39,481.35	$16,406.92	$16,406.92	$16,406.92	$16,406.92	$16,406.92	$16,406.92	$16,406.92
Cost Share	$16,830.00	-$2,905.03	-$2,905.03	-$2,905.24	-$2,905.24	-$2,905.24	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Cost Share cumulative	$16,830.00	$13,924.97	$11,019.94	$8,114.70	$5,209.46	$2,304.22	$2,304.22	$2,304.22	$2,304.22	$2,304.22	$2,304.22	$2,304.22
Project Total	$35,580.00	$15,844.97	$15,844.97	-$27,636.29	$5,057.16	-$25,979.67	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Project Variance Cumulative	$35,580.00	$51,424.97	$67,269.94	$39,633.65	$44,690.81	$18,711.14	$18,711.14	$18,711.14	$18,711.14	$18,711.14	$18,711.14	$18,711.14

Tabula Rasa
PARTNERS

January 20, 2014

Robert Enick
Department of Chemical and Petroleum Engineering.
University of Pittsburgh
1249 Benedum Hall
Pittsburgh PA 15261
rme@pitt.edu

Dear Prof. Enick:

As per our discussion at the Midland CO2 Conference, it is my understanding that you are researching a small molecule CO2 thickener for improved CO2 mobility control, with funding from ARPA-e (for the design of the molecule itself) and NETL (for lab-scale testing and core studies to demonstrate viability in porous media). In order for your NETL-sponsored lab tests to closely replicate meaningful field conditions, TRP is willing to provide you with the following items related to Seminole East Field, Gaines County, Texas.

The reservoir temperature – 108 deg F
The CO2 pressure at the injector wellhead – 1,800 psig
The CO2 injection well bottom-hole injection pressure – 3500 psi
The producing well bottom-hole pressure – 1,500 psi
The MMP for the oil – Approximately 1,350 psi
Samples of 1" diameter and 2" diameters horizontal plugs form an oil-rich zone,
1 gallon of crude oil
1 gallon of produced brine
A brief history of the pattern's production

TRP's information will be used to conduct lab-scale tests that are designed to demonstrate whether the CO2 thickener would be a viable candidate for a single injection well field test. After TRP has had an opportunity to evaluated the tests and experiments conducted we would be willing to discuss the possibility of performing a field test of the thickener

Sincerely,

Ronald T. Evans

Chief Operating Officer

100 Allentown Parkway, Suite 211

Allen, Texas 75002

tevans@tr-energy.net

(281) 668-8485