Oil & Natural Gas Technology

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Clean and Secure Energy from Domestic Oil Shale and Oil Sands Resources

Quarterly Progress Report (October - December 2013)

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EXECUTIVE SUMMARY

The Clean and Secure Energy from Domestic Oil Shale and Oil Sands Resources program, part of the research agenda of the Institute for Clean and Secure Energy (ICSE) at the University of Utah, is focused on engineering, scientific, and legal research surrounding the development of these resources in Utah.

In Task 2, outreach and education efforts focused on disseminating results of work from various subtasks through the publication of papers in peer-reviewed journals and throughout participation at conferences. The website has also been updated with links to all recent publications.

Task 3 focuses on utilization of oil shale and oil sands resources with CO_2 management. In Subtask 3.1, researchers collected emission factors and inventory data for oil and gas production in the Uinta Basin. They also submitted revisions to a paper that has been accepted for publication in the International Journal of Greenhouse Gas Control. The Subtask 3.2 research team performed simulations of fluid flow through the TEA-C burner using STAR-CCM+. Subtask 3.3 and 3.4 researchers developed models for the number of permits to drill and the decline curves associated with the various fields in the Basin to predict total conventional oil and gas production. Validation/uncertainty quantification (V/UQ) will be performed using a Monte Carlo approach that samples from the distributions of parameter values for the drilling and decline curve models.

Task 4 projects are related to liquid fuel production by in-situ thermal processing of oil shale. The status of Subtasks 4.1, 4.2, and 4.8 has not changed from last quarter; researchers continue to work on drafting final reports. The Subtask 4.3 and 4.9 research teams submitted a second paper for publication. Work on additional milestones, to be completed using funds that were internally reallocated, can begin next quarter now that the funds are in place. Subtask 4.7 researchers studying the geomechanical reservoir state continued testing at unconfined conditions to assess performance on creep conditions where temperature is applied and a constant load is maintained.

Task 5 projects provide analyses of the environmental, legal, economic, and policy framework. The remaining topical report (Subtask 5.3), an analysis of policy and economic issues associated with using simulation to assess environmental impacts, will be submitted in Feburary of 2014. All Task 6 projects (economic and policy assessment of a domestic unconventional fuels industry) are now complete.

Task 7 researchers are focused on research relevant to their industrial partner, American Shale Oil (AMSO). The Subtask 7.1 team initiated two numerical efforts. One is the processing of AMSO axial and radial performance data as a function of stress-temperature-grade-confining pressure. Two is the assessment of subsidence potential using Itasca Corporation software. The Subtask 7.3 research team updated the geometrical representation of the heater in their simulations to better represent the actual heater used by AMSO. They also created a co-simulation which uses two simulation regions to capture both the small, convective fluid time scales occurring in the diesel fuel inside the lower lateral and the larger, conductive time scales occurring inside the shale formation.

PROGRESS, RESULTS, AND DISCUSSION

Task 1.0 - Project Management and Planning

There were no schedule/cost variances or other situations requiring updating/amending of the Project Management Plan (PMP) in this quarter.

Task 2.0 -Technology Transfer and Outreach

Technology transfer and outreach efforts are focused on communicating project results through publication of papers and reports, through responses to requests for visits and interviews, and through updates of the Clean and Secure Energy from Domestic Oil Shale and Oil Sands Resources Program pages on the ICSE website. In this quarter, researchers published several papers and presented their work at the 33rd Oil Shale Symposium; these efforts are detailed in the various subtask summaries below. Dr. Jennifer Spinti fielded questions from several reporters during this quarter, including a reporter from The Wall Street Journal and an editor/producer based in Estonia. Researchers in Subtasks 3.1, 3.3, and 3.4 had several meetings with the Utah Division of Air Quality (DAQ) with regard to leveraging work by both ISCE and DAQ related to emissions estimates from conventional oil and gas production in the Uinta Basin. Lastly, the website (http://www.oilshalesands.utah.edu) has been updated with links to recent publications.

Task 3.0 - Clean Oil Shale and Oil Sands Utilization with CO_2 Management

Subtask 3.1 – Lifecycle Greenhouse Gas Analysis of Conventional Oil and Gas Development in the Uinta Basin (PI: Kerry Kelly, David Pershing)

During this quarter, the team received comments and revised the paper they submitted to the International Journal of Greenhouse Gas Control describing the use of oxyfiring to meet a low-carbon fuel standard for transportation fuels produced from Utah unconventional fuels. The paper was accepted and will be published in the first quarter of 2014.

They also began focusing efforts again on collecting emission factors and inventory data for oil and gas production in the Uinta Basin. DAQ has been gathering emission data for the Uinta Basin, and the team met with DAQ to learn about their data collection efforts. They are focused on criteria pollutant emissions from non-tribal lands in the basin, and they have developed some activity-based emission factors (i.e., g VOC per spud event or g VOC per volume of natural gas produced). Although data-gathering efforts by the Subtask 3.1 team has focused on GHG emissions for the entire basin (both tribal and non-tribal lands), DAQ's activity-based emission factors and production-scaling strategies will serve as a useful model for this subtask. The team is currently reviewing the DAQ's data and expanding the emission factors and emissions to include both tribal and non-tribal lands.

Subtask 3.2 - Flameless Oxy-gas Process Heaters for Efficient CO_2 Capture (PI: Jennifer Spinti)

The Subtask 3.2 team focused its efforts this quarter on performing simulations of flow through the complex geometry of the TEA-C burner. The computational mesh for the burner is shown in Figure 1. The velocity field at the outlet plane of the burner, shown in Figure 2, will provide the inlet boundary condition for ARCHES simulation of the IFRF furnace. This simulation was run in STAR-CCM+ using non-reacting flow with a RANS turbulence model in order to obtain the velocity profile as accurately as possible given the complexity of the TEA-C burner design, including swirl vanes and constricted outlets.

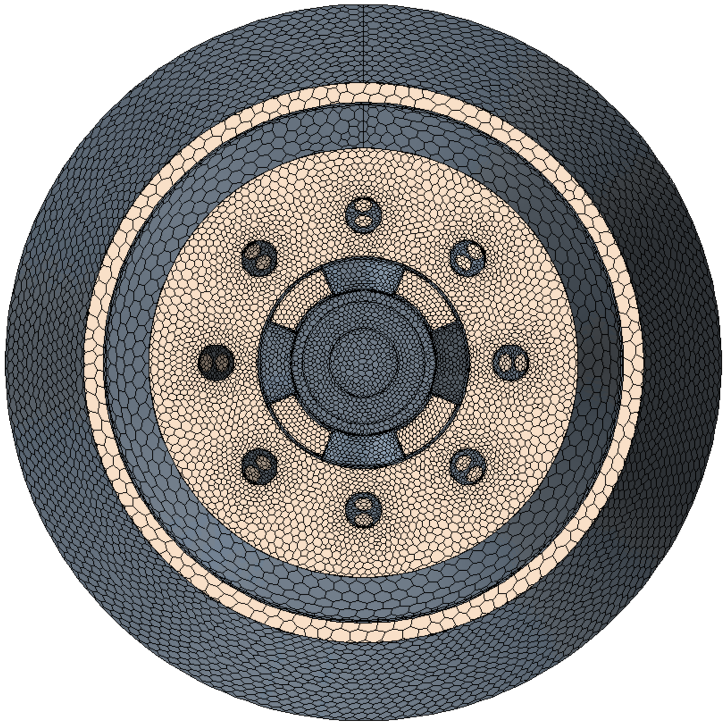

Figure 1. STAR-CCM+ computational mesh (plan view) used for simulations of fluid flow through the TEA-C burner.

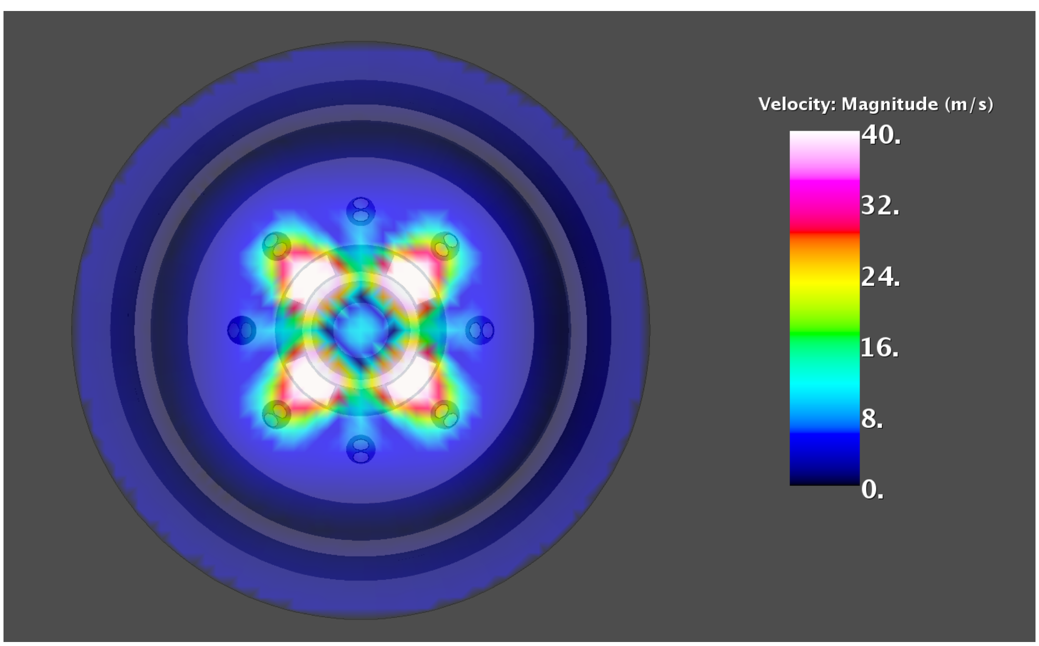

Figure 2. Velocity field at burner exit plan from STAR-CCM+ simulation of TEA-C burner.

A spatial filter, written in Python, will be used to overlay the STAR-CCM+ solution on the ARCHES computational mesh. Some time was spent this quarter learning Python in preparation for writing the necessary filtering script.

Subtask 3.3 - Development of Oil and Gas Production Modules for $CLEAR_{uff}$ (PI: Terry Ring)

Over this quarter, research on this subtask has focused on analyzing drilling and production data in the Utah Division of Oil, Gas and Mining (DOGM) database to develop a model for predicting (1) the amount of drilling activity in the Uinta Basin as a function of a set of predictor variables, and (2) fitting decline curve functions to historic production data.

As discussed in previous quarterly reports, the Subtask 3.3 and 3.4 teams chose an empirical model to fit drilling activity. Based on the data available in the DOGM database, researchers have elected to use the number of applications for permits to drill (APD) approved as the dependent variable and energy prices as predictor variables. A listing of the empirical models tested thus far is shown in Table 1.

Table 1. Empirical models for predicting drilling activity in the Uinta Basin.

Model	Equation	By
1	$APD_i = a + b \cdot OP_i + c \cdot APD_{i-1}$	Field
2	$APD_i = a + b \cdot OP_i + c \cdot OP_{i-1} + d \cdot OP_{i-2} + e \cdot APD_{i-1}$	Field
3	$APD_i = a + b \cdot OP_i + c \cdot APD_{i-1}$	Basin
4	$APD_i = a + b \cdot OP_i + c \cdot OP_{i-1} + d \cdot OP_{i-2}$	Field
5	$APD_i = a + b \cdot OP_i + c \cdot GP_i + d \cdot APD_{i-1}$	Field
6	$APD_i = a + b \cdot OP_i + c \cdot OP_{i-1} + d \cdot OP_{i-2} + e \cdot GP_i + f \cdot GP_{i-1} + g \cdot GP_{i-2} + h \cdot APD_{i-1}$	Field
7	$APD_i = a + b \cdot OP_i + c \cdot OP_{i-1} + d \cdot OP_{i-2} + e \cdot GP_i + f \cdot GP_{i-1} + g \cdot GP_{i-2}$	Field
8	$APD_i = a + b \cdot OP_i + c \cdot GP_i + d \cdot APD_{i-1}$	Basin

In Table 1, *APD* is the # of APDs approved, *i* is the time step (months), *OP* is oil price, *GP* is the gas price, and all lower case variables are fitted model coefficients. APDs are aggregated by either field (the eight most productive gas and oil fields in the Basin) or by the entire Basin, and the form of the model is fitted to each. Each model is fitted to data in the 1999 to 2004 time period and is tested against data in the 2006 to 2013 time period. A plot of the predictions of each model versus the actual APD approval data is shown below in Figures 3 and 4 for oil and gas APDs, respectively.

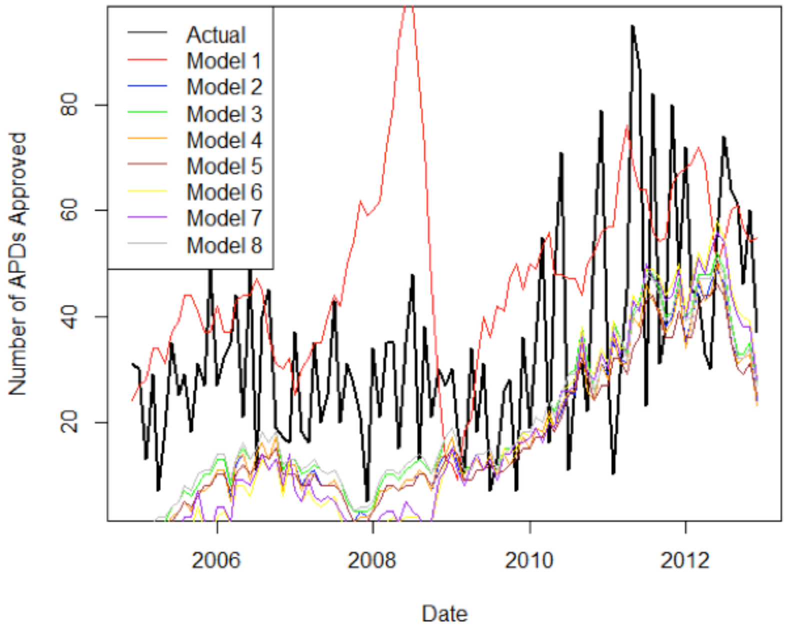

Figure 3. Comparison of predicted versus actual oil APD approvals.

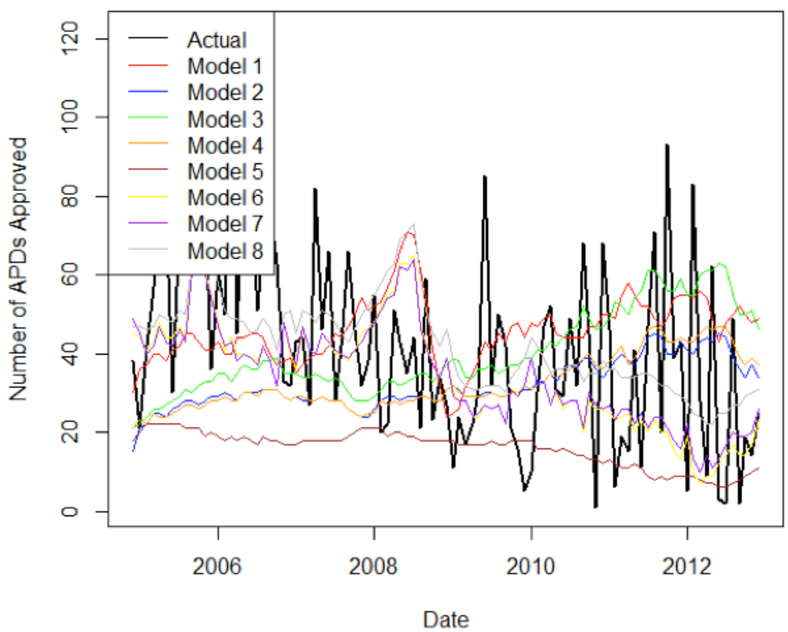

Figure 4. Comparison of predicted versus actual gas APD approvals.

None of the models investigated thus far exactly track the actual data, but overall the difference between the total predicted versus actual APD approvals is reasonably small (i.e. the fits track the average approval rates).

Oil and gas production rates are being modeled according to the following three decline curve functions:

$$p = \alpha \cdot (1 + \theta \cdot \delta \cdot t)^{-\frac{1}{\theta}} \quad (1)$$

$$p = \frac{\alpha}{1 + \theta \cdot t} \quad (2)$$

$$p = \alpha \cdot \exp\left(-\frac{t}{\theta}\right) \quad (3)$$

In these equations, *p* is the production rate in barrels of oil per month or thousand standard cubic feet of gas per month, *t* is time, and *α*, *θ*, and *δ* are all fitted coefficients. The equations are commonly referred to as the (1) exponential, (2) hyperbolic, and (3) harmonic decline curves and have been in used in petroleum engineering to describe actual decline curves for decades (Arps, 1945). Team members have attempted to fit each type of decline curve to production data for gas and oil wells aggregated over the entire basin, aggregated over each production field, and for individual wells. Individual well fits have been problematic as some wells have production histories which are challenging to fit with the decline curve equations, but the aggregated data are readily fit by each of the curves shown above. Plots of the basin aggregate fits are shown below in Figures 5 and 6 for oil and gas production, respectively.

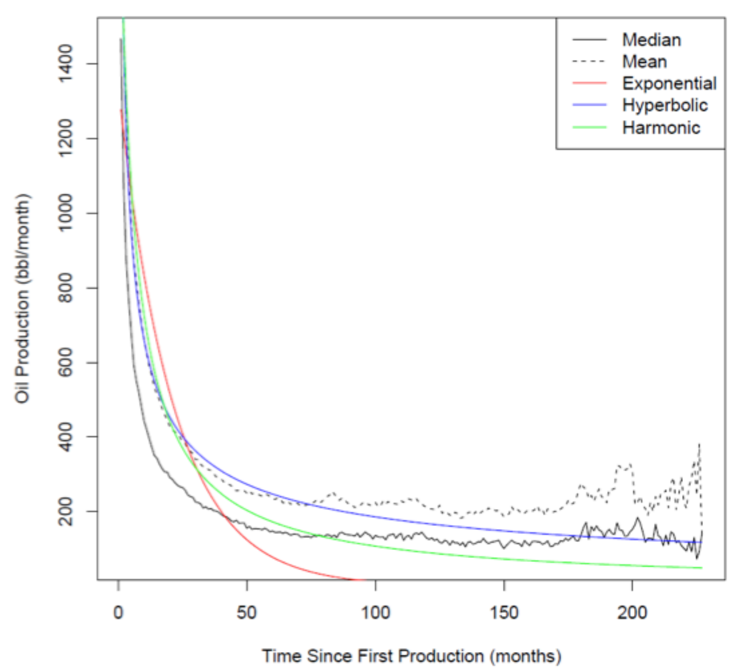

Figure 5. Decline curves fit to oil production from oil wells in the Uinta Basin.

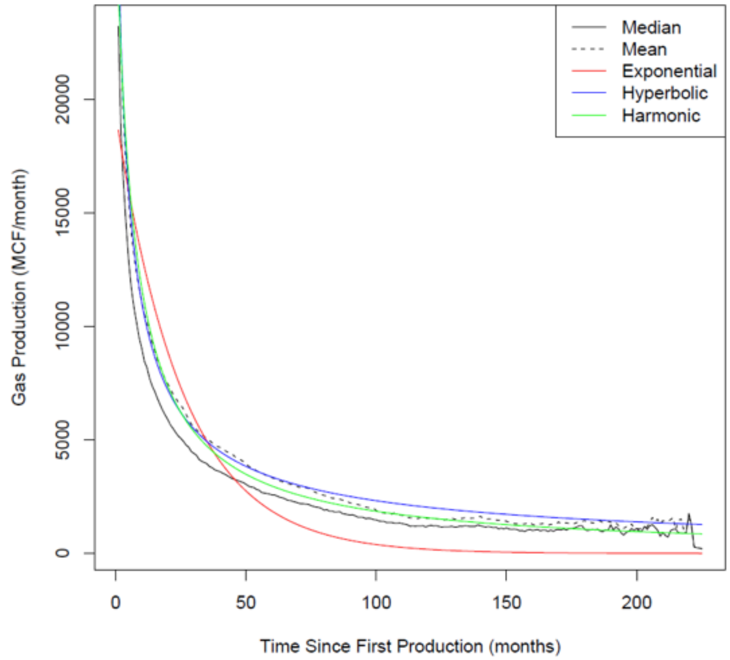

Figure 6. Decline curves fit to gas production from gas wells in the Uinta Basin.

Subtask 3.4 - V/UQ Analysis of Basin Scale CLEAR$_{uff}$ Assessment Tool (PI: Jennifer Spinti)

The milestone that was due in this quarter, to demonstrate full functionality of V/UQ methodology for conventional oil development in Uinta Basin, has been delayed until the next quarter. However, significant progress was made toward developing and implementing a methodology. Based on the work described under Subtask 3.3, the focus of the V/UQ has been shifted to a Bayes Monte Carlo approach (Sohn et al., 2000). In this approach, a prior distribution of model parameters is determined and model outcomes that result from sampling these distributions of model parameters are compiled.

In Subtask 3.3, decline curves were fit to individual wells in a given field. Figures 7 and 8 illustrate the distribution of model parameters that result from fitting the data for each individual well in one particular field to an exponential decline curve. In a like manner, distributions of parameters for the modeling of APDs can be generated by looking at successive time windows for fitting the data. In the next step, all of these parameter distributions are sampled using a Monte Carlo approach to determine the range of predicted outcomes (in this case total production of oil and gas) that might result. A more complete description of the application of this approach to oil and gas production in the Uinta Basin will be described in the next quarterly report.

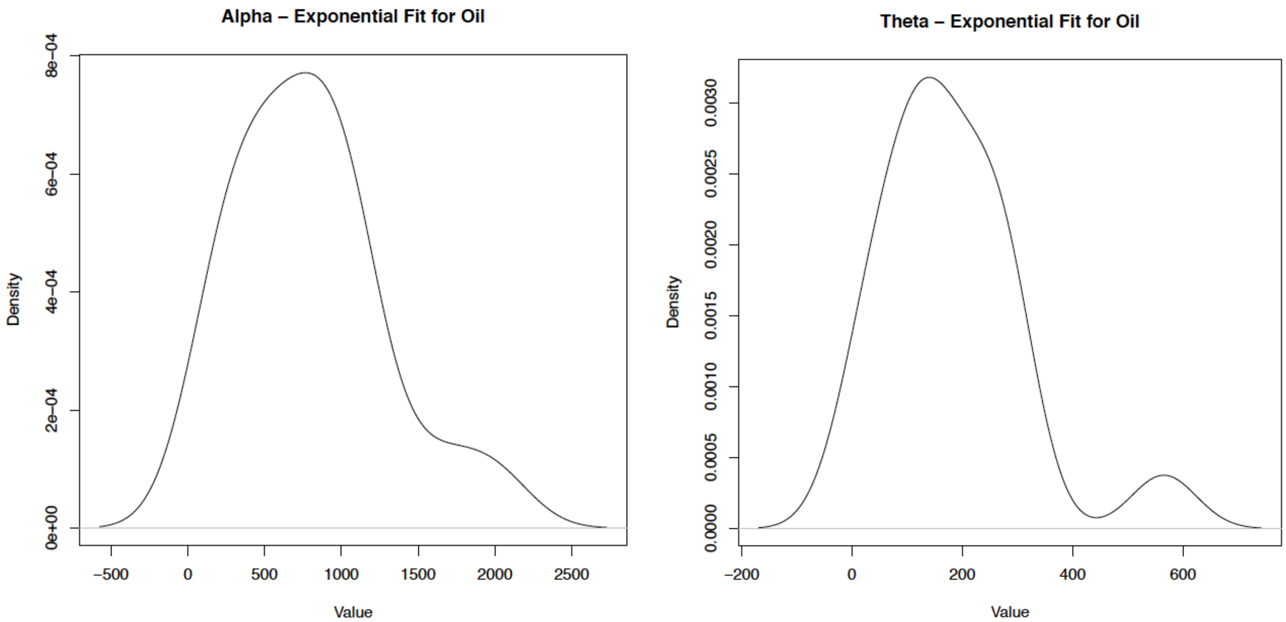

Figure 7. Parameter distributions for exponential decline curve fits of production data from Field 665 in Utah’s Uinta Basin.

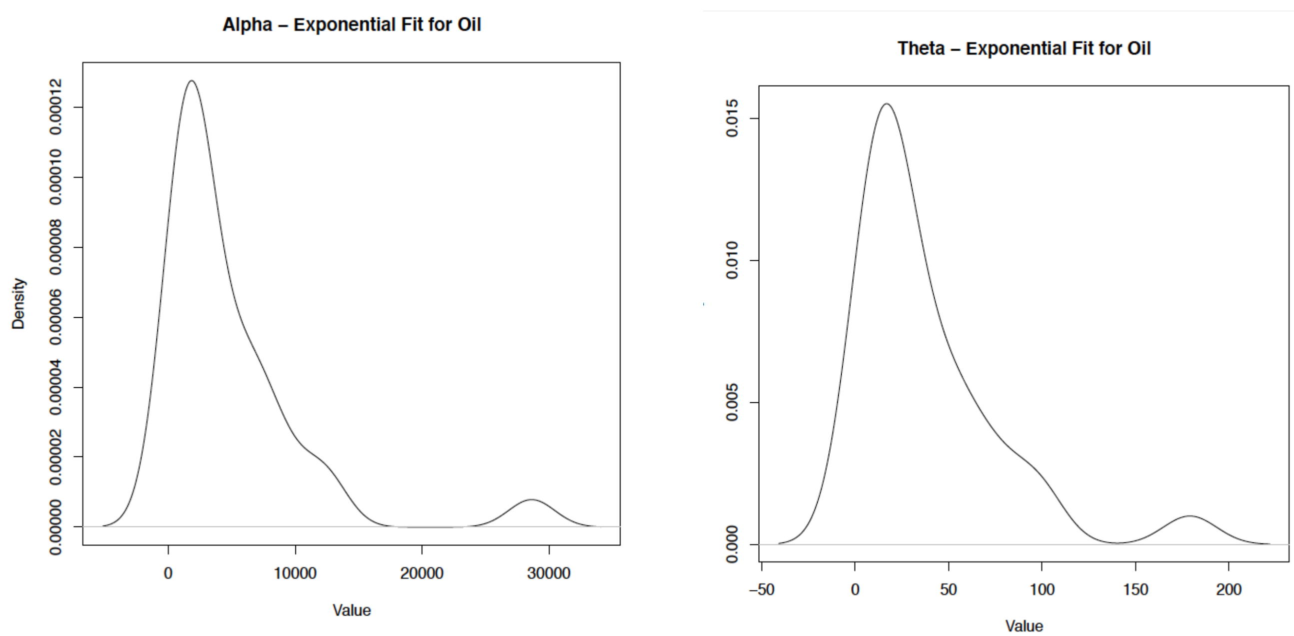

Figure 8. Parameter distributions for exponential decline curve fits of production data from Field 55 in Utah’s Uinta Basin.

Task 4.0 - Liquid Fuel Production by In-situ Thermal Processing of Oil Shale/Sands

Subtask 4.1 (Phase II) - Development of CFD-based Simulation Tools for In-situ Thermal Processing of Oil Shale/Sands (PI: Philip Smith)

This project was on hiatus as the project team for Subtask 4.1 spent the past quarter focusing on running cases for Subtask 7.3 in preparation for a conference. In the next quarter, the team will complete the analysis of results from their simulations of thermal processing of rubblized oil shale and will issue their final deliverable, a topical report.

Subtask 4.2 - Reservoir Simulation of Reactive Transport Processes (PI: Milind Deo)

A draft of the final topical report was prepared during this quarter. A final version will be submitted during the next quarter. A summary of the conclusions from that report is included here.

Thermogravimetric analysis (TGA) and other analytical techniques were used to study the effects of four variables on the pyrolysis of oil shale. The four variables studied were: size of core, heating regime (isothermal vs. non-isothermal), pressure (ambient vs. 500 psi), and temperature. It was found that the larger the core, the more coke and gas were produced. This finding provided the conclusion that secondary reactions occurred inside of the core. It was found that a non-isothermal constant heating rate was dampened by heat transport effects when the size of the core was one inch in diameter. This finding provided the inference that isothermal heating regimes are more adept at providing the heat needed for pyrolysis of oil shale in bulk. It was found that pressure lowered the temperature gradient in larger core samples. This finding supported the hypothesis that gas in the annulus and pores provides resistance to heat and mass transport through the core, resulting in higher yields of coke and gas at higher pressures. Finally, it was found that the highest oil yield occurred at 400°C and was therefore dependent on the isothermal heating temperature. These findings lead to a problem of optimization of time, energy, product distribution, and yield.

Modeling oil shale pyrolysis at different operating conditions reduces expenses encountered in pilot processes. Optimizing the operating conditions with the simulation before the process is begun will make the initial start-up closer to the final best conditions. This pre-optimizing is needed when performing in situ pyrolysis due to the time gap between start-up and oil recovery, in which the oil may be degraded through secondary reactions.

Future work should adjust the TGA kinetic models to larger sample sizes. This will allow for a better quantification and identification of oils recovered, simulation of how the rock will crack and fracture due to the thermal expansion. The larger sample will also allow for a mineralogy study to check reactions and products caused from the presence of minerals.

Experiments using a homogenous material with known porosity and permeability would allow for a better kinetic model for the secondary reactions. It may also lead to a better understanding of the complex multiphase thermodynamics experienced in the oil shale. Understanding thermo-dynamics will allow for pressure to enter into the kinetic expression. These experimental findings will make oil shale a more viable source of long-term energy.

Subtask 4.3 – Multiscale Thermal Processes (PI: Milind Deo, Eric Eddings)

There are two deliverables left for this project: (1) A topical report describing CPD/shale & oil generation (pyrolysis) models including summary of their applications/limitations and (2) a paper on combined kerogen/bitumen structures & CPD reaction model submitted to a journal such as *Energy & Fuels*. The due date for both of these deliverables has been extended to August 2014. The contract period was extended and additional funds were allocated to this subtask for work to complete the following two milestones:

1. Perform additional TGA oil shale pyrolysis experiments to resolve differences between Fletcher group & Deo group TGA data at 1 K/min heat rate.

2. Extend CPD model for oil shale to include additional chemical structure features specific to oil shale.

However, this extension did not occur until early January of 2014. There was a four-month period at the end of 2013 when this subtask was not funded at BYU while approval was being sought for the extended funding. Work will continue on the milestones and deliverables now that funding is in place.

In addition, Dr. Fletcher gave a paper in October at the 33rd Oil Shale Symposium in Golden, Colorado. Dr. Pugmire also presented a related paper from Subtask 4.9. Both papers were well-received and both presenters had good discussions with people from AMSO and Enefit.

<u>Subtask 4.4 - Effect of Oil Shale Processing on Water Compositions (PI: Milind Deo)</u>

This project has been completed.

<u>Subtask 4.5 - In Situ Pore Physics (PI: Jan Miller, Chen-Luh Lin)</u>

This project has been completed.

<u>Subtask 4.6 - Atomistic Modeling of Oil Shale Kerogens and Oil Sand Asphaltenes (PI: Julio Facelli)</u>

This project has been completed.

<u>Subtask 4.7 - Geomechanical Reservoir State (PI: John McLennan)</u>

This quarter the Subtask 4.7 researchers acquired additional Skyline 16 samples for further characterization. They continued to test at unconfined conditions to assess performance on creep conditions where temperature is applied and a constant load is maintained. They are also developing real-time permeability data as pyrolysis progresses.

They will return to performing triaxial compression tests in the triaxial loading frame in the upcoming quarter. These (and the measurements described above) are being enfranchised in the representations of constitutive behavior (deformation as a function of time, temperature, grade and stress) being carried out in Subtask 7.1.

<u>Subtask 4.8 - Developing a Predictive Geologic Model of the Green River Oil Shale, Uinta Basin (PI: Lauren Birgenheier)</u>

Due dates for the final deliverables, including a Topical Report and the uploading of all data to the ICSE repository, were extended until March of 2014. The project team focused on finishing all data and models for the ICSE repository during this quarter. These are essentially ready for uploading. Progress has been made on the topical report and it is expected to be completed by the due date.

Subtask 4.9 - Experimental Characterization of Oil Shales and Kerogens (PI: Julio Facelli)

The final deliverable, a series of two papers on the combined kerogen/bitumen structures and the CPD reaction model, has been completed as described below. Additionally, Dr. Pugmire presented work from this subtask at the 33rd Oil Shale Symposium in Golden, Colorado. Dr. Pugmire has been helping to assemble data from different investigators (Mark Solum and Charles Mayne) at the University of Utah and is working with Dr. Fletcher at BYU. The project team spent this quarter working on two additional papers:

1. A paper on the NMR analyses of the three oil shale samples studied by the group (GR1-3), as well as the bitumen extracted and the demineralized kerogen. This paper was submitted to *Energy and Fuels* last quarter. One reviewer provided extensive comments. Modifications were made to the paper and a response to the review was submitted. A second review came back with even more comments. The reviewer visited Dr. Pugmire and Dr. Fletcher during this quarter to discuss their results. They resubmitted the paper, and it was accepted and published in the journal in January of 2014.

2. A paper on the analysis of the pyrolysis products from kerogen, including NMR analyses of the char and tar samples obtained at different temperatures, GC/MS analyses of the tar samples, and FTIR analysis of the light gases. This paper was completed and submitted to *Energy & Fuels* as Part II of the first paper sent to the same journal.

A copy both papers has been submitted to the program manager, Mr. Robert Vagnetti.

Task 5.0 - Environmental, Legal, Economic and Policy Framework

Subtask 5.1 – Models for Addressing Cross-Jurisdictional Resource Management (PI: Robert Keiter, John Ruple)

This project has been completed.

Subtask 5.2 - Conjunctive Management of Surface and Groundwater Resources (PI: Robert Keiter, John Ruple)

This project has been completed.

Subtask 5.3 - Policy and Economic Issues Associated with Using Simulation to Assess Environmental Impacts (PI: Robert Keiter, Kirsten Uchitel)

The project PI, Ms. Uchitel, will be submitting the final Topical Report for review during the next quarter.

6.0 – Economic and Policy Assessment of Domestic Unconventional Fuels Industry

Subtask 6.1 Engineering Process Models for Economic Impact Analysis (PI: Terry Ring)

This project has been completed.

Subtask 6.2 - Policy analysis of the Canadian oil sands experience (PI: Kirsten Uchitel)

The topical report was edited in accordance with comments received from Robert Vagnetti at NETL and was submitted in final form to OSTI. The project is now completed.

Subtask 6.3 – Market Assessment Report (PI: Jennifer Spinti)

This project has been completed. Jon Wilkey presented this work at the 33rd Oil Shale Symposium in Golden, Colorado. The conclusions of the report have been somewhat controversial within the oil shale development community and that controversy was reflected in the reception of the paper at the Symposium.

7.0 – Strategic Alliance Reserve

Subtask 7.1 – Geomechanical Model (PI: John McLennan)

In this quarter, work proceeded on the segmented linearization and development of constitutive modelling surfaces on AMSO data. The project team is initiating numerical efforts on two fronts. First, AMSO data from two different vendors have been processed for axial and radial performance as a function of stress-temperature-grade-confining pressure. One Ph.D. candidate, Thang Tran, and two undergraduate students are compiling this information. In-house testing data will be added to the dataset in the upcoming quarter. Second, another graduate student, Walter Glauser, has been assessing subsidence potential. In particular, how much surface deformation could occur with conversion of kerogen and removal of the liquid and gaseous products? He has started with analytical calculations using the nucleus of strain method (after Geertsma) and is expanding his analysis to numerical computations. Relatively small subsidence potential is seen from the preliminary analyses. Of greater concern will be the potential reduction in permeability. Mr. Tran is also initiating numerical computations using Itasca Corporation software.

Team members have also done preliminary permeability experiments on a Skyline 16 sample in a newly commissioned relative permeability apparatus at the Energy & Geoscience Institute at the University of Utah. The permeability of a three-inch-long sample of White River oil shale was too small to measure (possibly picodarcies), an expected result. The project team is considering modifications where disks rather than sample plugs are used to accelerate the measurements (steady-state). Concurrently, they have been developing methods to measure permeability as pyrolysis proceeds.

They continue to work on “Version 1” of the geomechanical model, one of the subtask deliverables. As mentioned previously, team members have added triaxial testing (on an AMSO sample, CT scanned last quarter along with the Skyline 16 samples) from the work being done for Subtask 4.7 to increase the mechanical properties data available. Subsidence and compaction are being evaluated to meet the upcoming deliverable. The testing in Subtask 4.7 will also provide some basis for inferring permeability and porosity relationships with temperature.

Subtask 7.2 – Kinetic Compositional Models and Thermal Reservoir Simulators (PI: Milind Deo)

Project has been terminated.

Subtask 7.3 – Rubblized Bed High Performance Computing Simulations (PI: Philip Smith)

In the past quarter, researchers have continued to develop high performance simulations of the AMSO in-situ thermal processing of oil shale. They have updated geometry of the heater to represent the actual heater used for the AMSO heating tests and set up a simulation that captures both fluid and solid time scales simultaneously. Additionally, this work was presented at the 33rd Oil Shale Symposium in Golden, Colorado in October of 2013.

In simulations discussed in previous quarterly reports, researchers were able to resolve the heat dissipation results throughout the simulation domain, which represents the AMSO solid shale retorting region. They were also able to capture heat reflux occurring inside the lower lateral well, which contains the heater, the steel shroud which protects the heater, and the fuel mixture. However, these two simulations were not coupled. Heat transfer in the solid shale is several orders of magnitude slower than heat transfer occurring inside the fluid in the lower lateral. Very small time steps would be required to capture both effects simultaneously in a single simulation, which would prove prohibitively expensive in capturing months of heating.

Therefore, researchers have employed a new simulation technique available in STAR-CCM+ called co-simulation. Using this technique, they can resolve the small, convective fluid time scales occurring inside the lower lateral and still compute heat transfer inside the solid shale formation at larger, conductive time scales (order of months). For co-simulation, the computational domain is divided into two regions: the first region contains only the lower lateral geometry, including heater, fuel, and the shroud, and the second region contains only the solid shale. Two simulations are performed simultaneously, one for each region. The two simulations exchange information on the selected boundaries. With this methodology, they are able to use time steps of differing magnitudes to resolve the necessary physics in both regions.

In the past quarter, the project team has subdivided the simulation. Figure 9 contains the geometry of the updated representation of the heater used by AMSO in both heater tests, while Figure 10 shows only the solid portion of the shale formation. Simulations with these two regions will be performed next quarter.

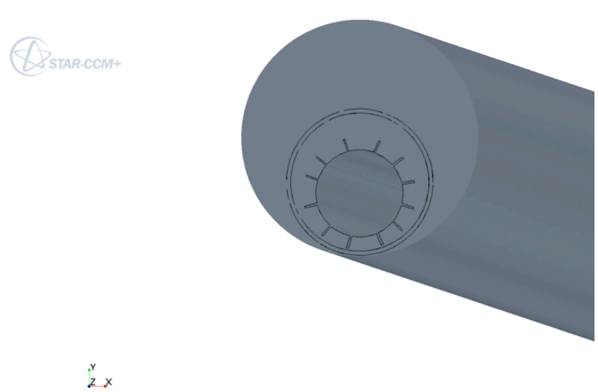

Figure 9. Geometry of the lower lateral well showing the updated geometry of the heater, as well as the steel shroud surrounded by fuel used for the co-simulation.

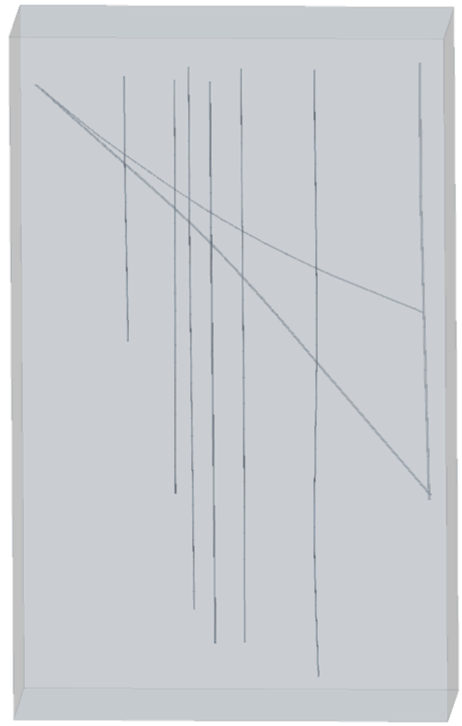

Figure 10. Geometry of the solid shale region used in the co-simulation.

CONCLUSIONS

Subtask 4.9 was completed this quarter with the submission of a second paper to Energy & Fuels. The completion of Subtasks 4.1 and 4.8 was delayed by the availability of personnel but are expected to wrap up next quarter. A draft version of the Subtask 5.3 topical report will submitted to Mr. Robert Vagnetti in February of 2014. Researchers from Subtasks 4.3, 4.9, and 6.3 presented papers at the 33rd Oil Shale Symposium in October of 2013.

COST PLAN/STATUS

Baseline Reporting Quarter - PHASE II	Yr. 4								Yr. 5			
	Q13		Q14		Q15		Q16 - REVISED		**Q17**		Q18	
	10/01/12 - 12/31/12		01/01/13 - 03/31/13		04/01/13 - 06/30/13		07/01/13 - 09/30/13		**10/01/13 - 12/31/13**		01/01/14 - 03/31/14	
	Q13	**Total**	Q14	**Total**	Q15	**Total**	Q16	**Total**	Q17	**Total**	Q18	**Total**
Baseline Cost Plan												
Federal Share	146,824	**5,235,073**	146,824	**5,381,897**	146,824	**5,528,721**	-471,238	**5,057,483**	157,250	**5,214,733**	157,250	**5,371,983**
Non-Federal Share	36,705	**1,306,563**	36,705	**1,343,268**	36,705	**1,379,973**	-211,982	**1,167,991**	53,484	**1,221,475**	53,484	**1,274,959**
Total Planned	183,529	**6,541,636**	183,529	**6,725,165**	183,529	**6,908,694**	-683,220	**6,225,474**	210,734	**6,436,208**	210,734	**6,646,942**
Actual Incurred Cost												
Federal Share	128,349	**4,485,377**	180,613	**4,665,990**	233,732	**4,899,722**	157,761	**5,057,483**	113,187	**5,170,670**		**5,170,670**
Non-Federal Share	79,871	**1,051,976**	62,354	**1,114,330**	51,708	**1,166,038**	1,953	**1,167,991**	66,131	**1,234,122**		**1,234,122**
Total Incurred Costs	208,220	**5,537,353**	242,967	**5,780,320**	285,440	**6,065,760**	159,714	**6,225,474**	179,318	**6,404,792**		**6,404,792**
Variance												
Federal Share	18,475	**749,696**	-33,789	**715,907**	-86,908	**628,999**	-628,999	**0**	44,063	**44,063**		
Non-Federal Share	-43,166	**254,587**	-25,649	**228,938**	-15,003	**213,935**	-213,935	**0**	-12,647	**-12,647**		
Total Variance	-24,691	**1,004,283**	-59,438	**944,845**	-101,911	**842,934**	-842,934	**0**	31,416	**31,416**		

Note: Baseline Cost Plan adjusted in Q16 to reflect NCE projections.

Baseline Reporting Quarter - PHASE II	Yr. 5			
	Q19		Q20	
	04/01/14 - 06/30/14		07/01/14 - 09/30/14	
	Q19	**Total**	Q20	**Total**
Baseline Cost Plan				
Federal Share	157,250	**5,529,233**	133,282	**5,662,515**
Non-Federal Share	53,484	**1,328,443**	87,436	**1,415,879**
Total Planned	210,734	**6,857,676**	220,718	**7,078,394**
Actual Incurred Cost				
Federal Share		**5,170,670**		**5,170,670**
Non-Federal Share		**1,234,122**		**1,234,122**
Total Incurred Costs	0	**6,404,792**	0	**6,404,792**
Variance				
Federal Share	157,250	**358,563**	133,282	**491,845**
Non-Federal Share	53,484	**94,321**	87,436	**181,757**
Total Variance	210,734	**452,884**	220,718	**673,602**

MILESTONE STATUS

ID	Title/Description	Planned Completion Date	Actual Completion Date	Milestone Status
1.0	Project Management			
2.0	Technology Transfer and Outreach			
	Advisory board meeting	Jun-13	N/A	Decision has been made to disband EAB
	Hold final project review meeting	Jun-13		NCE will delay this meeting until 2014
3.0	Clean Oil Shale & Oil Sands Utilization with CO2 Management			
3.1	Lifecycle greenhouse gas analysis of conventional oil & gas development in the Uinta Basin			
	Complete modules in CLEAR CO2 emissions from conventional oil & gas development in the Uinta Basin	Mar-14		Milestone date has been changed to reflect new project timelines
3.2	Flameless oxy-gas process heaters for efficient CO2 capture			
	Preliminary report detailing results of skeletal validation/uncertainty quantification analysis of oxy-gas combustion system	Sep-12	Oct-12	Report attached as appendix to Oct. 2012 quarterly report
3.3	Development of oil & gas production modules for CLEAR			
	Develop preliminary modules in CLEAR for conventional oil & gas development & produced water management in Uinta Basin	Oct-11	Dec-11	Discussed in Jan. 2012 quarterly report
3.4	V/UQ analysis of basin scale CLEAR assessment tool			
	Develop a first generation methodology for doing V/UQ analysis	Oct-11	Nov-11	Discussed in Jan. 2012 quarterly report
	Demonstrate full functionality of V/UQ methodology for conventional oil development in Uinta Basin	Nov-13		Demonstration delayed until first quarter of 2014
	Demonstrate full functionality for conventional & unconventional oil development in Uinta Basin	Mar-14		
4.0	Liquid Fuel Production by In-Situ Thermal Processing of Oil Shale/Sands			
4.1	Development of CFD-based simulation tool for in-situ thermal processing of oil shale/ sands			

ID	Title/Description	Planned Completion Date	Actual Completion Date	Milestone Status
	Expand modeling to include reaction chemistry & study product yield as a function of operating conditions	Feb-12	Mar-12	Discussed in April 2012 quarterly report
4.2	Reservoir simulation of reactive transport processes			
	Incorporate kinetic & composition models into both commercial & new reactive transport models	Dec-11	Dec-11	Discussed in Jan. & July 2012 quarterly reports
	Complete examination of pore-level change models & their impact on production processes in both commercial & new reactive transport models	Jun-12	Jun-12	Discussed in July 2012 quarterly report
4.3	Multiscale thermal processes			
	Complete thermogravimetric analyses experiments of oil shale utilizing fresh “standard” core	Sep-11	Sep-11	Discussed in Oct. 2011 quarterly report
	Complete core sample pyrolysis at various pressures & analyze product bulk properties & composition	Dec-11	Sep-12	Discussed in Oct. 2012 quarterly report
	Collection & chemical analysis of condensable pyrolysis products from demineralized kerogen	May-12	Sep-12	Discussed in Oct. 2012 quarterly report
	Complete model to account for heat & mass transfer effects in predicting product yields & compositions	Jun-12	Jun-12	Discussed in July 2012 quarterly report
4.5	In situ pore physics			
	Complete pore network structures & permeability calculations of Skyline 16 core (directional/anisotropic, mineral zones) for various loading conditions, pyrolysis temperatures, & heating rates	Mar-12	Mar-12	Discussed in April 2012 quarterly report; PI dropped loading condition as variable
4.6	Atomistic modeling of oil shale kerogens & oil sand asphaltenes			
	Complete web-based repository of 3D models of Uinta Basin kerogens, asphaltenes, & complete systems (organic & inorganic materials)	Dec-11	Dec-11	Discussed in Jan. 2012 quarterly report
4.7	Geomechanical reservoir state			
	Complete high-pressure, high-temperature vessel & ancillary flow system design & fabrication	Sep-11	Sep-11	Discussed in Oct. 2011 quarterly report
	Complete experimental matrix	Mar-14		Due date revised to reflect status of expts.
	Complete thermophysical & geomechanical property data analysis & validation	Apr-14		Due date has been revised to reflect status of expts.

ID	Title/Description	Planned Completion Date	Actual Completion Date	Milestone Status
4.8	Developing a predictive geologic model of the Green River oil shale, Uinta Basin			
	Detailed sedimentologic & stratigraphic analysis of three cores &, if time permits, a fourth core	Dec-12	Dec-12	Discussed Jan. 2013 quarterly report
	Detailed mineralogic & geochemical analysis of same cores	Dec-12	Dec-12	Discussed Jan. 2013 quarterly report
4.9	Experimental characterization of oil shales & kerogens			
	Characterization of bitumen and kerogen samples from standard core	Jan-12	Feb-12	Email sent to R. Vagnetti on Feb. 6, 2012 & discussed in April 2012 quarterly report
	Development of a structural model of kerogen & bitumen	Jun-12	Jun-12	Discussed in July 2012 quarterly report
5	Environmental, legal, economic, & policy framework			
5.1	Models for addressing cross-jurisdictional resource management			
	Identify case studies for assessment of multi-jurisdictional resource management models & evaluation of utility of models in context of oil shale & sands development	Jun-11	Jul-11	Discussed in Oct. 2011 quarterly report
5.2	Conjunctive management of surface & groundwater resources			
	Complete research on conjunctive surface water & groundwater management in Utah, gaps in its regulation, & lessons that can be learned from existing conjunctive water management programs in other states	Aug-11	Aug-11	Discussed in Oct. 2011 quarterly report
5.3	Policy & economic issues associated with using simulation to assess environmental impacts			
	White paper describing existing judicial & agency approaches for estimating error in simulation methodologies used in context of environmental risk assessment and impacts analysis	Dec-12	Dec-12	Submitted with Jan. 2103 quarterly report
6	Economic & policy assessment of domestic unconventional fuels industry			
6.1	Engineering process models for economic impact analysis			
	Upload all models used & data collected to repository	Oct-12	Aug-13	All models/data have been uploaded to the ICSE website

ID	Title/Description	Planned Completion Date	Actual Completion Date	Milestone Status
7	Strategic Alliance Reserve			
	Conduct initial screening of proposed Strategic Alliance applications	Mar-11	Mar-11	
	Complete review and selection of Strategic Alliance applications	Jun-11	Jul-11	Discussed in Oct. 2011 quarterly report
	Implement new Strategic Alliance research tasks	Sep-11	Sep-11	Discussed in Oct. 2011 quarterly report
7.1	Geomechanical model			
	Make experimental recommendations	Aug-13	Aug-13	Discussed in this quarterly report
	Infer permeability-porosity-temperature relationships, develop model that can be used by other subtasks	Jan-14		Due date has been revised to reflect status of expts.
	Basic reservoir simulations to account for thermal front propagation	Aug-14		Due date has been revised to reflect status of expts.
	Evaluation of flow mechanics	Aug-14		Due date has been revised to reflect status of expts.
7.2	Kinetic compositional models & thermal reservoir simulators			Project has been terminated
	Incorporate chemical kinetics into thermal reservoir simulators	Jun-12	Jun-12	Discussed in July 2012 quarterly report
7.3	Rubblized bed HPC simulations			
	Collect background knowledge from AMSO about characteristics & operation of heated wells	Jun-12	Jun-12	Discussed in July 2102 quarterly report
	Perform generation 1 simulation - DEM, CFD & thermal analysis of characteristic section of AMSO rubblized bed	Sep-12	Sep-12	Discussed in Oct. 2012 quarterly report
	Perform generation 2 simulation that incorporates kinetic compositional models from subtask 7.2 and/or AMSO	Jun-13	Jan-14	Delayed due to priorities of AMSO

NOTEWORTHY ACCOMPLISHMENTS

Subtask 4.7 and 7.1 researchers are particularly excited about testing out new permeability measurement capabilities and the development of the material response curve enfranchising temperature, confining pressure and grade.

PROBLEMS OR DELAYS

A milestone for Subtask 3.4 was delayed due to the sharing of a graduate student between Subtasks 3.3 and 3.4. The student is making good progress & should have both remaining milestones complete in the next quarter. The Subtask 4.1 Topical Report has been delayed one quarter because the primary researcher on the project, Dr. Hradisky, spent most of last quarter working with AMSO on Subtask 7.3. After several delays in receiving the final deliverable for Subtask 5.3, it now appears that a draft of the report will be sent to Mr. Robert Vagnetti by the end of February of 2014.

RECENT AND UPCOMING PRESENTATIONS/PUBLICATIONS

Hsieh, C. H. (2012, March). Procedure and analysis of mineral samples using high resolution X-ray micro tomography. M.S. thesis, Department of Metallurgical Engineering, The University of Utah. (NOTE: This reference was added after Q3 report was sent in; include in Q4 report. Also add in any other theses like Jake & Pankaj).

Bauman. J. H. & Deo, M. D. (2012). Simulation of a conceptualized combined pyrolysis, in situ combustion, and CO_2 storage strategy for fuel production from Green River oil shale. *Energy and Fuels*, *26*, 1731-1739.

Vanden Berg, M. D., Birgenheier, L. P. & Rosenberg M. J. (2012, September). Core-based sedimentologic, stratigraphic, and geochemical analysis of the lacustrine upper Green River Formation, Uinta Basin, Utah: Implications for conventional and unconventional petroleum development. Paper presented at the 2012 American Association of Petroleum Geologists - Rocky Mountain Section Meeting, Grand Junction, CO.

Rosenberg, M.J., Birgenheier, L.P, & Vanden Berg, M.D. (2012, October). Sedimentology and sequence stratigraphy of the Green River Formation, eastern Uinta Basin, Utah. Paper presented at the 32nd Oil Shale Symposium, Golden, CO, October 15-19, 2013.

Burnham, A., Day, R., Switzer, L., McConaghy, J., Hradisky, M., Coates, D., Smith, P., Foulkes, J., La Brecque, D., Allix, P., Wallman, H. (2012, October). Initial results of the AMSO RD&D pilot test program. Paper presented at the 32nd Oil Shale Symposium, Golden, CO, October 15-19, 2013.

Deo, M. (2012, October). *Oil shale liquefaction: Modeling and reservoir simulation*. Short course presentation to Statoil, Trondheim, Norway.

Deo, M. (2012, October). *Oil shale conversion to liquids: Experimental aspect*. Short course presentation to Statoil, Trondheim, Norway.

Fletcher, T. H. (2012, October). *Oil shale 1: Chemical structure and pyrolysis*. Short course presentation to Statoil, Trondheim, Norway.

McLennan, J. (2012, October). *Legacy and new geomechanical measurements of oil shale*. Short course presentation to Statoil, Trondheim, Norway.

Smith, P. J. (2012, October). *Multiscale simulation*. Short course presentation to Statoil, Trondheim, Norway.

Smith, P. J. (2012, October). *A description of a UQ-predictive validation framework for application to difficult engineering problems*. Short course presentation to Statoil, Trondheim, Norway.

Tiwari, P., Deo, M., Lin C. L. & Miller, J.D. (2012, October). Characterization of the oil shale core pore structure before and after pyrolysis. Paper presented at the 2012 AICHE Annual Meeting, Pittsburgh, PA, October 28-November 2, 2012.

Orendt, A. , Pimienta, I. S. O., Badu, S., Solum, M., Pugmire, R. J., Facelli, J. C., Locke, D. R., Winans, R. E., Chapman, K. W. & Chupas, P. J. (2012). Three-dimensional structure of the Siskin Green River oil shale kerogen model: A comparison between calculated and observed properties. *Energy and Fuels, 27*, 702-710.

Spinti, J. (2013, January 10). Presenter/panelist - *The real impact of oil shale and oil sands development in Utah.* 2013 Governor's Energy Development Summit, Salt Lake City, UT.

Hradisky, M., Smith, P. J. & Burnham, A. (2013, March). *STAR-CCM+ simulations of in-situ thermal treatment of oil shale*. Paper presented at the STAR Global Conference, Orlando, FL, March 18-20, 2013.

Orendt, A. M., Solum, M. S., Facelli, J. C., Pugmire, R. J., Chapman, K. W., Winans, R. E. & Chupas, P. (2013, April). Characterization of shale and kerogen from a Green River oil shale core, ENFL-535. Paper presented at the 245th American Chemical Society National Meeting, New Orleans, LA, April 7-11, 2013.

Birgenheier, L. P. (2013, May 7). Presenter/panelist - *Constructing a basin-wide geologic model*. University of Utah Unconventional Fuels Conference, Salt Lake City, UT.

Smith, P. J. (2013, May 7). Presenter/panelist - *Simulation of in situ production process using computational fluid dynamics*. University of Utah Unconventional Fuels Conference, Salt Lake City, UT.

Spinti, J. P. (2013, May 7). Presenter/panelist - *Assessment of unconventional fuels development costs*. University of Utah Unconventional Fuels Conference, Salt Lake City, UT.

Birgenheier, L.P., Plink-Bjorklund, P., Vanden Berg, M.D., Rosenberg, M., Toms, L. & Golab, J. (2013). *A genetic stratigraphic framework of the Green River Formation, Uinta Basin, Utah: The impact of climatic controls on lake evolution*. Paper presented at the American Association of Petroleum Geologists Annual Meeting, Pittsburgh, PA, May 22-25, 2013.

Vanden Berg, M. D., Eby, D. E., Chidsey, T. C. & Laine, M.D. (2013). *Microbial carbonates in cores from the Tertiary (Eocene) Green River Formation, Uinta Basin, Utah, U.S.A.: Analogues for non-marine microbialite oil reservoirs worldwide*. Paper presented at Microbial Carbonates in Space and Time: Implications for Global Exploration and Production, The Geological Society, London, United Kingdom, June 19-20, 2013.

Rosenberg, M. J. (2013). Facies, stratigraphic architecture, and lake evolution of the oil shale bearing Green River Formations, eastern Uinta Basin, Utah. M.S. thesis, Department of Geology and Geophysics, University of Utah.

Tiwari, P., Deo, M., Lin, C. L. & Miller, J.D. (2013, May). Characterization of oil shale pore structure before and after pyrolysis by using X-ray micro CT. *Fuel*, *107*, 547–554.

Pugmire, R. J., Fletcher, T. H., Hillier, J., Solum, M., Mayne, C. & Orendt, A. (2013, October). Detailed characterization and pyrolysis of shale, kerogen, kerogen chars, bitumen, and light gases from a Green River oil shale core. Paper presented at the 33rd Oil Shale Symposium, Golden, CO, October 14-16, 2013.

Fletcher, T. H., Gillis, R., Adams, J., Hall, T., Mayne, C. L., Solum, M.S. & Pugmire, R. J. (2013, October). Characterization of pyrolysis products from a Utah Green River oil shale by ^{13}C NMR, GC/MS, and FTIR. Paper presented at the 33rd Oil Shale Symposium, Golden, CO, October 14-16, 2013.

Wilkey, J., Spinti, J., Ring, T., Hogue, M. & Kelly, K. (2013, October). Economic assessment of oil shale development scenarios in the Uinta Basin. Paper presented at the 33rd Oil Shale Symposium, Golden, CO, October 14-16, 2013.

Hillier, J. L., Fletcher, T. H., Solum, M. S. & Pugmire, R. J. (2013, October). Characterization of macromolecular structure of pyrolysis products from a Colorado Green River oil shale. Accepted, *Industrial and Engineering Chemistry Research*. dx.doi.org/10.1021/ie402070s

Birgenheier, L. & Vanden Berg, M. (n.d.). Facies, stratigraphic architecture, and lake evolution of the oil shale bearing Green River Formation, eastern Uinta Basin, Utah. To be published in Smith, M. and Gierlowski-Kordesch, E. (Eds.). *Stratigraphy and limnogeology of the Eocene Green River Formation*, Springer.

Solum, M. S., Mayne, C. L., Orendt, A. M., Pugmire, R. J., Hall, T., Fletcher, T. H. (2014). Characterization of macromolecular structure elements from a Green River oil shale-(I. Extracts). Submitted to *Energy and Fuels, 28*, 453-465. dx.doi.org/10.1021/ef401918u,

Kelly, K.E., Wilkey, J. E. Spinti, J. P., Ring, T. A. & Pershing, D. W. (2014). Oxyfiring with CO_2 capture to meet low-carbon fuel standards for unconventional fuels from Utah. *International Journal of Greenhouse Gas Control*. In press.

Fletcher, T. H., Gillis, R., Adams, J., Hall, T., Mayne, C. L., Solum, M.S., and Pugmire, R. J. (2013, January). Characterization of pyrolysis products from a Utah Green River oil shale by ^{13}C NMR, GC/MS, and FTIR. Submitted to *Energy and Fuels*.

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