Oil & Natural Gas Technology

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Quarterly Progress Report
With Summaries of Center-sponsored Research
(January – March 2008)

UTAH HEAVY OIL PROGRAM

Submitted by:
University OF Utah
Salt Lake City, UT

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National Energy Technology Laboratory

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Office of Fossil Energy

Quarterly Progress Report

Utah Heavy Oil Program

University of Utah

DE-FC26-06NT15569

Quarter Ended March 31, 2008

Philip J. Smith, Principal Investigator

Project Period June 21, 2006 through October 21, 2008

EXECUTIVE SUMMARY

The mission of the Utah Heavy Oil Program (UHOP) is to provide research support to federal and state constituents for addressing the wide-ranging issues surrounding the creation of an industry for unconventional oil production in the United States. UHOP held a project review meeting at the University of Utah on March 12, 2008 with three personnel from DOE /NETL (Olayinka Ogunsola, Robert Vagnetti, Tom Mroz). The purpose of the meeting was to provide an opportunity to review midterm progress on the projects being funded by UHOP. The meeting included updates by the principal investigators or graduate students from each of the five UHOP-funded research projects. In addition, overviews were given of other UHOP activities, including the update report on North American unconventional oil resources, the on-line repository, and the map server. Industrial connections that have arisen from various UHOP research activities were also highlighted.

Work continued in this quarter with the five UHOP-sponsored research projects and with the on-line repository for information, data, and software relating to unconventional oil resources in North America. Updates of those projects are provided below.

PROJECT MILESTONES/PROGRESS PERFORMANCE

A. Progress in Program-Sponsored Projects

UHOP selected five Program-sponsored research projects in the previous quarter. Brief summaries of the ongoing work in each project are provided below.

1. Detailed Study of Shale Pyrolysis for Oil Production

Milind Deo, Eric Eddings, Terry Ring

Shale Oil Pyrolysis Experiments: Thermogravimetric analyses (TGA) of the shale samples were performed in order to obtain pyrolysis kinetics. Both isothermal and non-isothermal studies were conducted. Isothermal analyses are presented in this report. Kinetics from the non-isothermal runs are being compiled.

Experimental conditions are tabulated in Table 1. The sample size was 25 mg of 100 mesh particles. The purge gas flow rate was about 60 ml/min. Experiments were performed in an inert (nitrogen) atmosphere and in combustion mode (with nitrogen and air).

Table 1: Experimental matrix for isothermal TGA.

Purge Gas	**N2**	**Air**
Temperature (^{o}C)	**Time (min)**	
300	720	240
350	240	240
400	240	240
450	240	180
500	240	
550	180	
600	30	

The first few experiments were performed to check reproducibility. The weight loss and derivative curves shown in Figure 1 indicate that the experiments were reproducible.

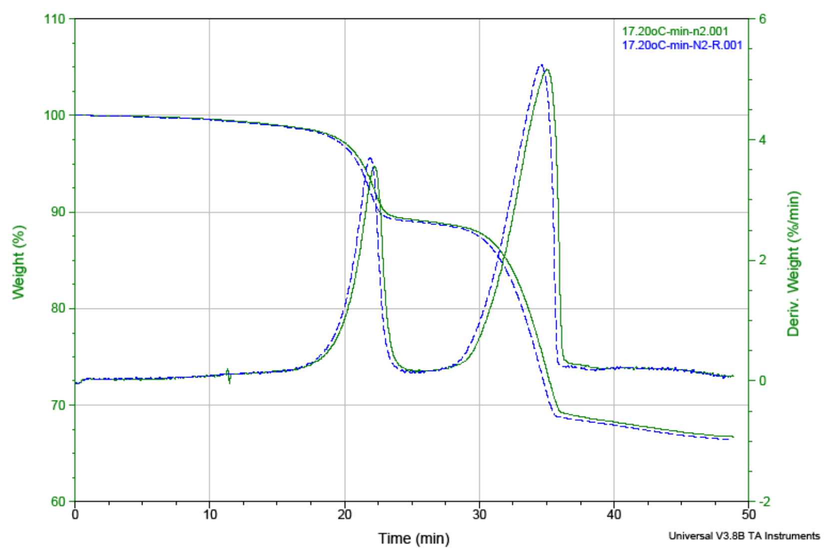


Figure 1: Weight loss and derivative curves from two TGA experiments conducted in a nitrogen atmosphere. The signatures are almost identical.

Weight loss curves for temperatures ranging from 300-600^{0}C are shown in Figure 2. A 10-12% weight loss (with respect to total organic carbon) is observed between 400-450^{0}C and weight loss increases as the temperature increases. Weight loss curves for the isothermal runs shown in Figure 3 reveal greater weight losses than those observed for the non-isothermal runs.

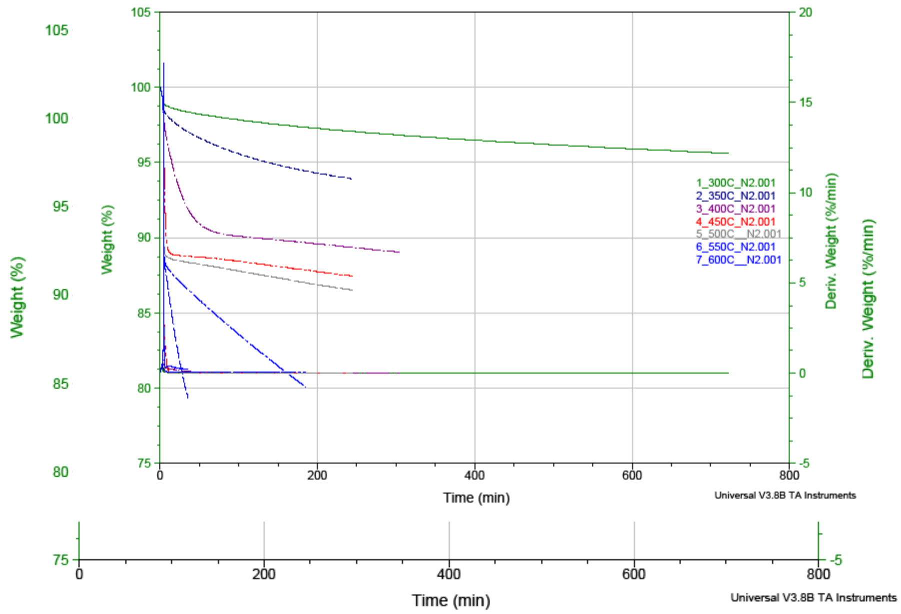


Figure 2: Weight loss curves in a nitrogen atmosphere for temperatures ranging from 300-600^{0}C.

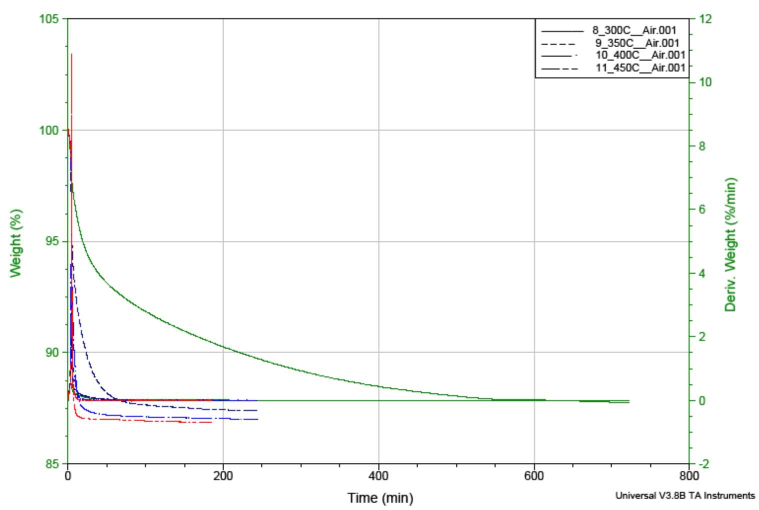


Figure 3: Isothermal weight loss curves in the presence of air.

Kinetic parameters from the isothermal analyses can be obtained using the intial weight of the sample, the weight of the sample at time t, and the weight of the sample at the end of pyrolysis. Assuming first-order kinetics, rate constants can be calculated at different temperatures as seen in Figure 4 and Table 2.

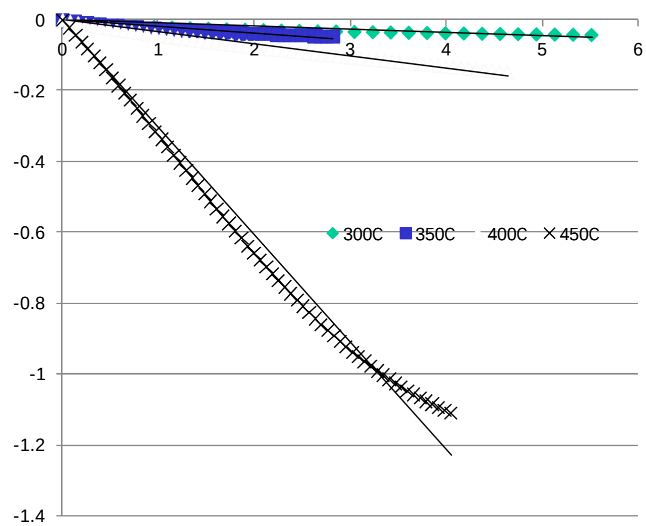


Figure 4: Isothermal data fit to a first-order kerogen decomposition equation.

Table 2: Rate constants temperatures for kerogen decomposition at various temperatures.

K,/min	T, °C	T, K	1000/T,K	ln(K)	R^2
0.009	300	573.5	1.743679	-4.71053	0.623
0.019	350	623.5	1.603849	-4.13517	0.972
0.034	400	673.5	1.484781	-3.38139	0.984
0.303	450	723.5	1.38217	-1.19402	0.719

These rate constants can be used to calculate the activation energy and pre-exponential factor for the assumed pyrolysis reaction. These calculated kinetic parameters are shown in Table 3. An activation energy of 76 kJ/mole is consistent with literature values between 70-85 kJ/mole for the pyrolysis of Greenriver shale.

Table 3: Kinetic parameters of Greenriver shale pyrolysis.

Ea/1000R	9.144	
ln(A)	10.85	
A	51534.15	min-1
R	8.314	J/molK
Ea	**76.02322**	KJ/mol

2. New Approaches to Treat Produced Water and to Perform Water Availability Impact Assessments for Oil Shale Development

Steve Burian, Ramesh Goel, Andy Hong

Project Objectives:

- Create a digital geospatial database of water, geology, energy, natural resources, and other pertinent data for the Uinta and Piceance Basins
- Quantify past, current, and future water use requirements for oil shale development in the Uinta and Piceance Basins
- Develop a methodology to assess water availability using a water budget analysis approach
- Advance and develop new technologies for bitumen extraction and process water treatment to limit future impacts on water availability and quality
- Develop an integrated treatment scheme for produced water.

Water Resources Sustainability: We are continuing our conceptual model development of the energy-water interdependent system in the Uintah Basin. We have chosen a geographic information system (GIS) approach to take advantage of the spatial analysis capabilities of existing software. We are writing new code to execute the necessary spatial analysis functions to facilitate the study of energy-water interdependencies and to quantify energy and water needs associated with oil shale industry growth, urban growth, and energy production in the Uintah Basin.

We have also spent time improving the input datasets for the conceptual model. A planning-level urban growth scenario was produced based on observations of Fort McMurray's growth, current trends in Vernal, and discussions with planners in the Vernal area. Data were gathered from water conservancy districts providing water to Vernal and to surrounding areas to provide better input information to the water requirements estimates. Finally, we updated estimates of producible oil using GIS software and data available from the Utah Geological Survey.

Water Treatment and Reuse: During this quarter, we tested the hypothesis that formation of oil sheen from produced water can be prevented by brief consecutive treatment steps that involve brief ozonation - rapid sand filtration - additional ozonation.

The 3-step process quickly eliminated the potential of oil sheen from the produced water. From the analysis of our 3-step process resuilts, we are preparing a technical paper to be submitted to an archived journal. In addiont, we are conceptualizing a new technique for enhanced extraction of bitumen from oil sands. Preliminary results are being gathered on the separation and recovery of bitumen from Asphalt Ridge oil sands under different pressure, temperature, and solid loading conditions and will be reported next quarter.

Integrated Treatment Approach: Based on our analysis on real produced water received from Conoco Philips, two refractory organic compounds, i.e. naphthalene and MTBE, were selected as model pollutants. For naphthalene, three different gas chromaograph-based analytical methods (liquid-liquid extraction, direct aqueous injection
and solid micro-extraction) were tested to get better recovery. Degradation of naphthalene was tested using direct electrolytic and biological degradation. Bacteria capable of degrading naphthalene were enriched in our lab and then we conducted molecular analysis on these bacteria.

Similar experiments are now underway for MTBE. Research in the next quarter will focus on identifying different degradation intermediates of naphthalene and MTBE and testing degradation of these two compounds in simulated synthetic produced water.

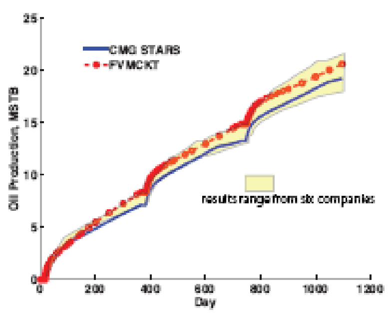
3. In Situ Production of Utah Oil Sands

Pete Rose, Royhan Gani, Jack Hamilton and Milind Deo

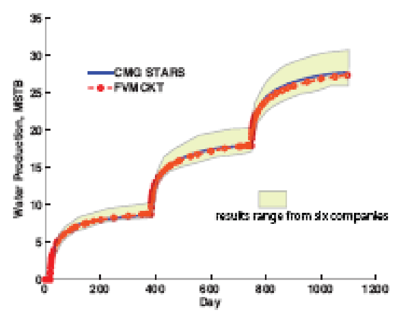
Numerical Simulation Modeling of the Steam Assisted Gravity Drainage (SAGD) and Cyclic Steam Processes: In the previous project period, simulations of SAGD and cyclic steam were performed using STARS, a commercial reservoir simulator. The next step in this process was to see how reservoir heterogeneities like fractures and faults impacted production of oil. The reservoir simulator developed at the University of Utah was used for this purpose. A modularization concept divides the development of the simulator into two major modules: the physical method module (PM) and the discretization module (DM). The PM provides the property data required in the reservoir model and performs the solution of the governing equations which describe the nature of the reservoir performance. The DM provides the spatial information related to the chosen discretization method. For thermal recovery modeling, a PM called CKT (compositional K-value thermal model) was developed. This PM can be combined with the DMs already available in the simulator suite (e.g. SFD, simple finite difference; CVFEMF2, control-volume finite element method for type I and II reservoir; FVM, finite volume method). In the CKT model, the primary equations (the conservation equations for species and the energy) and the secondary equations (the constraint equations for volume, phase and thermal equilibrium) are solved using the natural variable (pressure, temperature, saturations and molar fractions) formulations. For maximum numerical stability, a fully implicit scheme and a novel equation alignment procedure are used. An equation decoupling technique is adapted to reduce the size of the Jacobian matrix to be solved in the linear solver.

We performed a validation study using data from the fourth SPE comparative solution project [1]. We used the FVM-CKT approach to simulate cyclic steam injection in a cylindrical domain. Since the problem is symmetric in the azimuthal direction, the three-dimensional domain was reduced to two dimensions (r, z). The transmissibilities and well indices were obtained from STARS. Four layers were defined in the domain with each layer assigned different properties. Properties of a black oil were used in the PM; the viscosity of this non-volatile oil strongly depends on temperature. Three year-long cycles were simulated. Each 365-day cycle began with a 10-day steam injection period (0.7 steam quality) followed by 7-day soak period and concluded with 348 days of production. All four layers were open for both injection and production. Detailed model parameters were taken from [1].

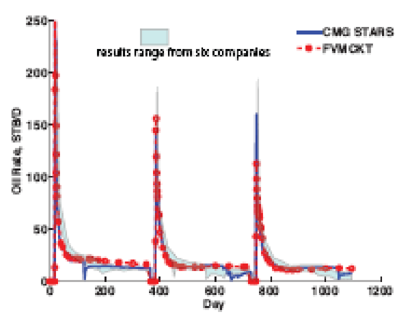
In Figure 5, simulation results for cumulative oil production, water production and oil production rate are compared with results of other six other commercial simulators whose creators participated in the SPE comparative project. Also shown in the figure are results from the latest version of STARS. As there is no known analytical solution to this problem, the purpose of this exercise is to show the range of results obtained from the different simulators. Pressure changes in the cyclic process make it a difficult process to simulate. Figure 5 shows that results from the University of Utah simulator are well within the range of other commercial simulators. The simulator will be used to study the impact of fractures in Utah oil sand reservoirs.



(a) cumulative oil production



(b) cumulative water production



(c) oil production rate

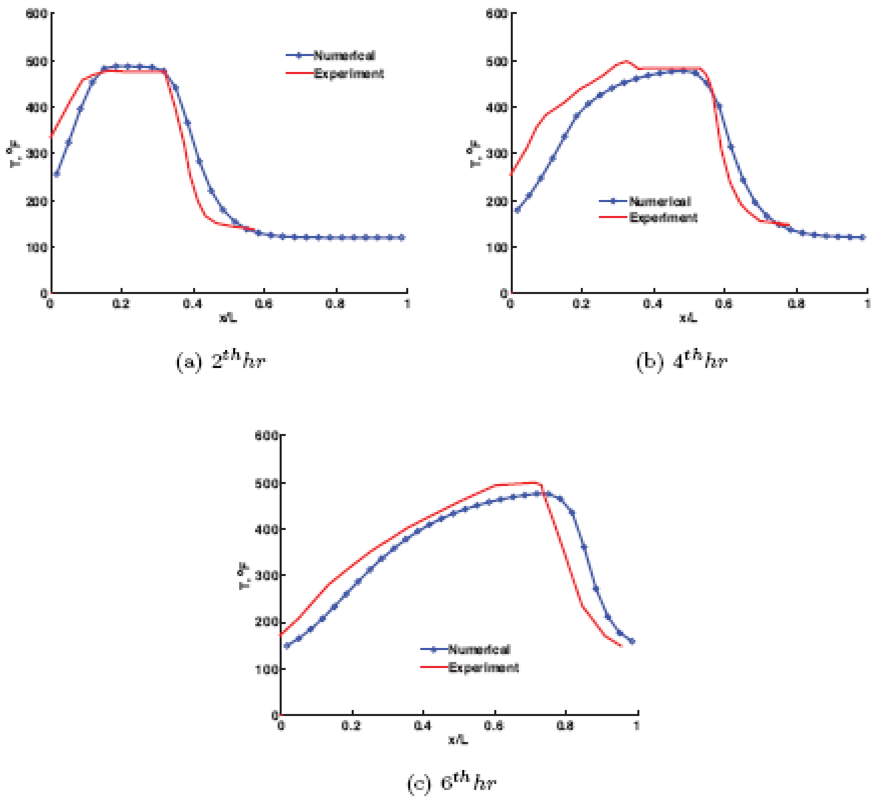
Figure 5: Results of a cyclic simulation in a heavy oil reservoir from the 4th SPE comparative solution project [1].

4. Depositional heterogeneity and fluid flow modeling of the oil shale interval of the upper Green River Formation, eastern Uinta Basin, Utah

Royhan Gani and Milind Deo

Subsurface Geology: The core in the Utah Geological Survey core library was completely analyzed. It was determined that the level of heterogeneity was much greater than originally anticipated. It was also determined that the inter-bedding consists of carbonates rather than sandstones in several intervals. These results are being compiled into a core report, which will be presented in the next quarterly report.

Reservoir Modeling: We have moved to the next stage of using the University of Utah thermal simulator because of its capability for handling fractures and other large-scale heterogeneities. Details of the development of the simulator are provided elsewhere [2]. Our validation study was performed on the in-situ combustion experimental data set of Smith and Perkins [3]. The authors conducted a forward, wet combustion process in a vertical adiabatic combustion tube. The crude studied in this experiment was very light (API gravity of 36.) The initial temperature was 120° F and the tube head was preheated prior to air injection. During the initial period of injection, dry air was injected until vigorous combustion was visible and no oxygen was measured in the flue gas. Water was then added to perform forward, wet combustion. The steam/water mixture was injected from the top of the tube, and the water/air ratio was maintained at 0.18lbm/scf.
We simulated the low pressure experiment. Parameters reported in [3] were used in the simulation. The comparisons of temperature profiles between experimental data and the numerical simulations at 2 hours, 4 hours and 6 hours are shown in Figure 6. While the agreement between the numerical and analytical results is acceptable, at the far end of the tube (tail), the numerical simulation predicts lower temperatures than those measured experimentally. Smith and Perkins stated that the insulation for the combustion tube was unusually permeable, and the heat loss in the burning front was picked up by the tailing edge section through external convection [3]. We are now in the process of adapting the simulator to model oil recovery from the Greenriver formation with an emphasis on the impact of fractures.



(a) $2^{th} hr$ (b) $4^{th} hr$

(c) $6^{th} hr$

Figure 6: Comparison of the experimental and simulated results of an in-situ combustion process

5. **Analysis of Environmental, Legal, Socioeconomic and Policy Issues Critical to the Development of Commercial Oil Shale Leasing on the Public Lands in Colorado, Utah, and Wyoming under the Mandates of the Energy Policy Act of 2005; Economic Evaluation of Bitumen Upgrading**

Robert Keiter, Kirsten Uchitel, Alan Isaacson

Legal and Economic Analysis: We continued our analysis of the Bureau of Land Management's Programmatic Environmental Impact Statement on oil shale leasing. We also augmented our report outline and time frame, formalized assignments for writing various sections of the final report, and commenced legal research and analysis on a variety of legal policy issues relevant to the final report.

The economic analysis portion of this project has been temporarily suspended due to the unexpected death of Alan Isaacson last month.

B. On-line Repository

We have created a new text-based interface for the UHOP on-line repository for information, data, and software relating to unconventional oil resources in North

America. Figure 7 shows a snapshot of the new repository interface. Please note that the map interface is also available at map.heavyoil.utah.edu.

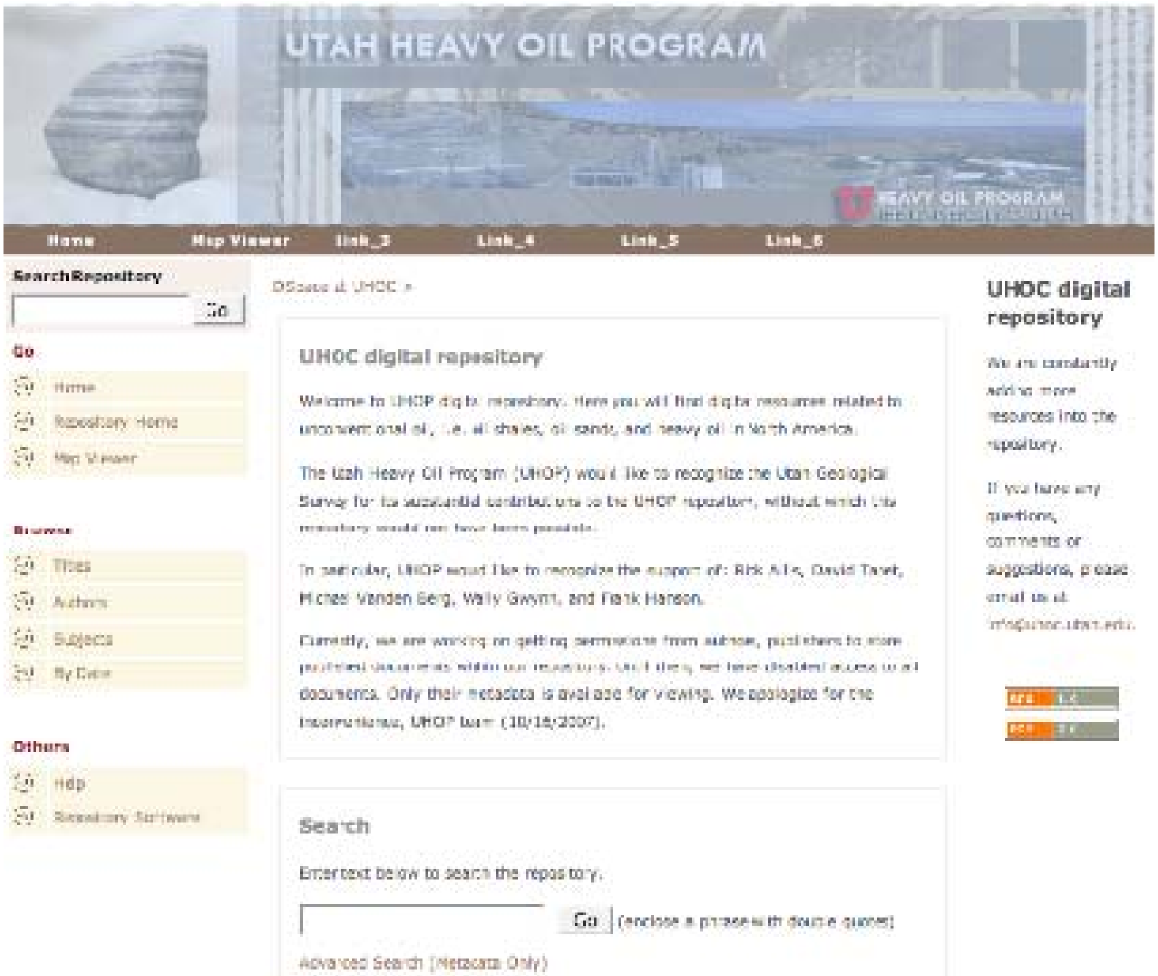


Figure 7: Text-based interface for UHOP on-line repository for unconventional oil resources.

We have begun the task of providing more accurate metadata for all documents currently available in the repository, including copyright information. Once the metadata is updated for a document, the full text of that document will once again be available for download from the repository. We will hire a student to help with metadata input during the next quarter and will have the repository populated with over 1200 documents by the end of August 2008.

REFERENCES

1. K. Aziz, A. B. Ramesh, and R. T. Woo, “Fourth SPE Comparative Solution Project: Comparison of Steam injection Simulators”, JPT, vol. 39, no. 12, pp. 1576–1584, 1987.

2. Chung-Kan Huang, Yi-kun Yang and Deo, M.D., “A New Thermal Compositional Simulator with a Novel “Equation Lineup” Method”, SPE 110219, archived at the Society of Petroleum Engineers, Dallas, Texas.

3. F. W. Smith and T. K. Perkins, “Experimental and Numerical Simulation Studies of the Wet Combustion Recovery Process”, J. Can. Pet. Tech., pp. 44–54, 1973.

CONCLUSIONS

The UHOP project review meeting on March 12, 2008, provided opportunities for some fruitful exchanges between UHOP and DOE/NETL. All research projects have made progress in this quarter, and the on-line repository has a more user-friendly interface.

COST PLAN/STATUS

REVISED Baseline Reporting Quarter	**Year 1**	**Start: 06/21/2006**	**End: 06/30/2007**	
	Q1	Q2	Q3	Q4
Baseline Cost Plan (from SF-424A)				
Federal Share	$126,295	$239,349	$41,357	$147,911
Non-Federal Share	$31,574	$34,342	$25,969	$38,387
Total Planned (Federal and Non-Federal)	$157,869	$273,691	$67,326	$186,298
Cumulative Baseline Costs	$157,869	$431,560	$498,866	$685,184
Actual Incurred Costs				
Federal Share	$126,295	$239,349	$41,357	$164,491
Non-Federal Share	$31,574	$34,342	$25,969	$30,841
Total Planned (Federal and Non-Federal)	$157,869	$273,691	$67,326	$195,332
Cumulative Baseline Costs	$157,869	$431,560	$498,866	$694,218
Variance				
Federal Share	0	0	0	$16,580
Non-Federal Share	0	0	0	$ (7,546)
Total Planned (Federal and Non-Federal)	0	0	0	$9,034
Cumulative Baseline Costs	0	0	0	$9,034

REVISED Baseline Reporting Quarter	**Year 2**	**Start: 07/01/2007**	**End: 06/30/2008**	
	Q5	Q6	Q7	Q8
<u>Baseline Cost Plan (from SF-424A)</u>				
Federal Share	$147,911	$147,911	$147,911	$147,911
Non-Federal Share	$38,620	$38,620	$38,620	$38,620
Total Planned (Federal and Non-Federal)	$186,531	$186,531	$186,531	$186,531
Cumulative Baseline Costs	$871,715	$1,058,246	$1,244,777	$1,431,308
<u>Actual Incurred Costs</u>				
Federal Share	161,343	178,570	165,243	
Non-Federal Share	29,299	10,038	36,285	
Total Planned (Federal and Non-Federal)	190,642	188,608	201,528	
Cumulative Baseline Costs	884,860	1,073,468	1,274,996	
<u>Variance</u>				
Federal Share	$13,432	$30,659	17,332	
Non-Federal Share	(9,321)	(28,582)	(2,335)	
Total Planned (Federal and Non-Federal)	$4,111	$2,077	14,997	
Cumulative Baseline Costs	$13,145	$15,222	30,219	

REVISED Baseline Reporting Quarter	**Year 3**	**Start: 07/01/2008**	**End: 10/20/2008**	
	Q9	Q10		
<u>Baseline Cost Plan (from SF-424A)</u>				
Federal Share	$147,911	$147,909		
Non-Federal Share	$38,620	$37,222		
Total Planned (Federal and Non-Federal)	$186,531	$185,131		
Cumulative Baseline Costs	$1,619,839	$1,802,970		
<u>Actual Incurred Costs</u>				
Federal Share				
Non-Federal Share				
Total Planned (Federal and Non-Federal)				
Cumulative Baseline Costs				
<u>Variance</u>				
Federal Share				
Non-Federal Share				
Total Planned (Federal and Non-Federal)				
Cumulative Baseline Costs				

MILESTONE COMPLETION CHART

Task	Critical Path Project Milestone Description	Project Duration Start: End: Project Year 1 Q1	Q2	Q3	Q4	Project Year 2 Q5	Q6	Q7	Q8	Project Year 3 Q9	Q10	Planned Start Date	Planned End Date	Actual Start Date	Actual End Date	Comments (notes, explanation of deviation from baseline)
1.1	Identify resources on unconvention-al oil in North America	X										June, 2006	Sept., 2006	June, 2006	Sept., 2006	
1.2	Prepare draft update report on domestic unconvention-al oil resources	X	X									June, 2006	Sept., 2006	June, 2006	Feb. 2007	Identifying personnel & surveying available sources took longer than expected. Added value from the report will be from analysis, which also takes more time.
1.3	Release draft update to public & request input from unconvention-al oil community		X									Sept., 2006	Sept., 2006	Oct., 2006	March 2007	Preliminary draft was released on March 21, 2007 Release delayed by Task 1.2 delay and by problems with report quality from company hired to do page layout.

1.4	Attend the CERI Oil Shale Symposium & provide a summary		X				X					Oct., 2006	Oct., 2006	Oct., 2006	Oct., 2006	
1.5	Develop on-line repository for all types of material pertaining to unconvention-al oil resources in North America	X	X	X								June, 2006	June, 2008	June, 2006		Documents, data continue to be added to repository.
1.6	Update and release enhanced version of report developed under 1.3, integrating comments received			X								Jan., 2007	Aug., 2007	April, 2007	Sept., 2007	
1.7	Release on-line repository to unconvention-al oil community			X								Jan., 2007	Jan., 2007	Jan., 2007	Feb, 2007	Release date was Feb. 15, 2007.
1.8	Refine repository, incorporating information provided by user community			X	X	X	X			X	X	Jan., 2007	Oct., 2008	Jan., 2007		

2.1	Identify Center-sponsored research projects areas in consultation with DOE	X				X						Sept., 2006	Sept., 2006	Sept., 2006	Oct., 2006	
2.2	Issue internal RFP to support project areas identified in 2.1		X			X						Sept., 2006	Sept., 2006	Oct., 2006	Nov., 2006	RFP was released on Nov. 20, 2006. Proposals were due Dec. 15, 2006.
2.3	Select 2-3 Center-sponsored research projects		X			X						Oct., 2006	April, 2007	Jan., 2007	April, 2007	Selection of research projects completed in March 2007. Researchers were not notified of project selection before end of quarter three.
2.4	Complete technical reports for Center-based research projects					X						Oct., 2008	Oct., 2008			
2.5	Provide priority listing of research & demonstration needs for domestic production from unconventional oil resources				X	X						June, 2007	Sept., 2007	Nov. 2007		Will address this milestone in the first quarter of 2008

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