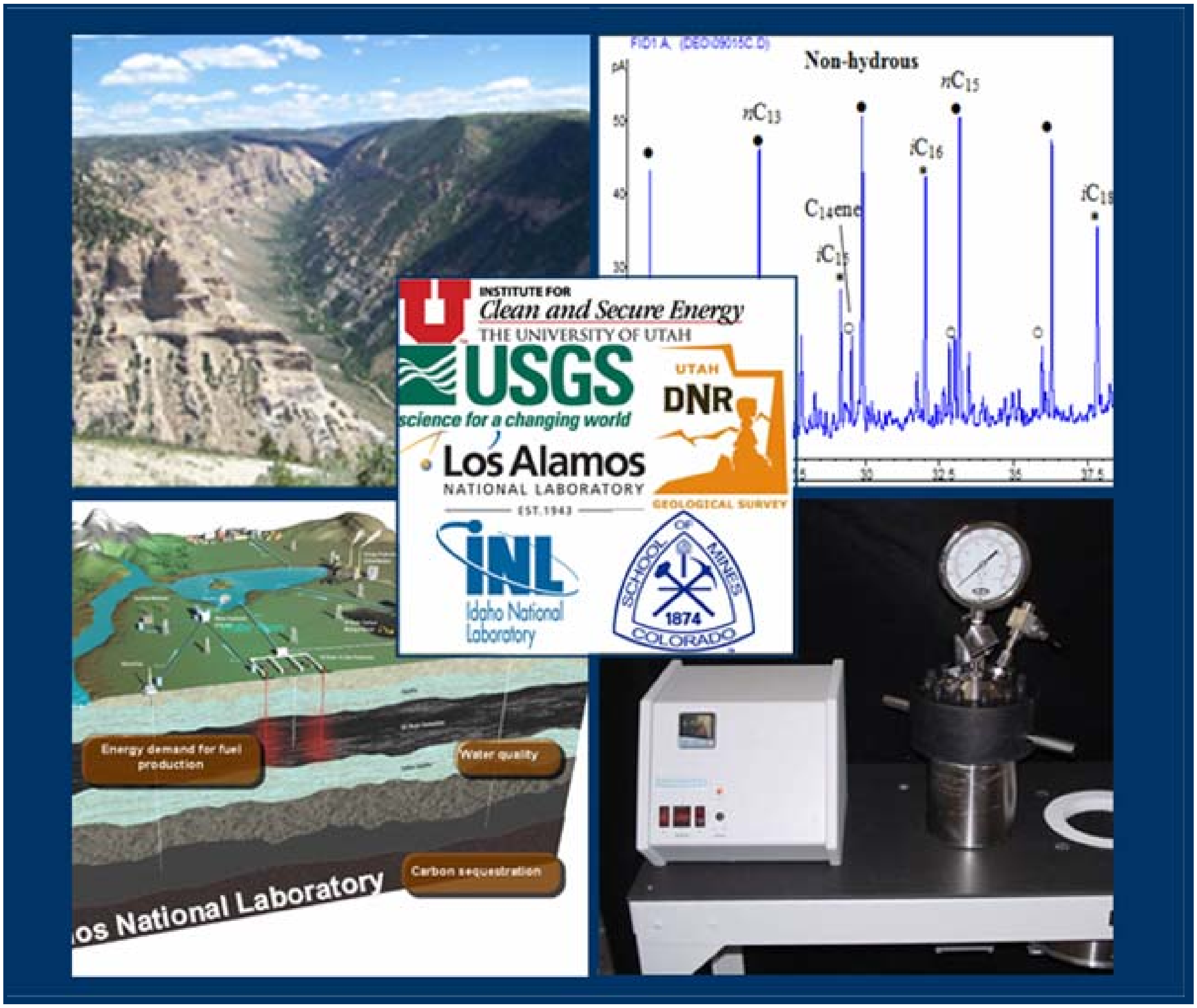
2nd Edition



Oil Shale Research in the United States

Profiles of Oil Shale Research and Development Activities In Universities, National Laboratories, and Public Agencies

Prepared by INTEK, Inc. for

U.S. Department of Energy • Office of Petroleum Reserves
Office of Reserve Lands Management

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FOREWORD

Significant research efforts are underway in the United States to address some of the technical, economic, and policy uncertainties that constrain the development of America's enormous oil shale resource.

The purpose of this report is to document research and analytical work that is ongoing and planned in the nation's universities, national laboratories, and government agencies related to U.S. oil shale resources and technologies for their potential development.

The information contained in each of the profiles found in this report was prepared by the host institution, in response to a format provided by the authors. Information on each project includes:

- Project purpose and goals
- Period of performance
- Sponsors and funding
- Principal investigator(s), and
- Activities and deliverables.

Contact information is provided to help readers obtain additional information about institutions, projects, and emerging results, and to facilitate the sharing of information among research community participants and with the industry and the public at large. As new research projects are initiated, the profiles will be updated subject to the availability of funding.

Additional technology and project development work that is being carried out in the private sector has been documented by a separate Department of Energy-sponsored report titled: *"Secure Fuels from Domestic Resources: Profiles of Companies Engaged in Domestic Oil Shale and Tar Sands Resource and Technology Development"*. This report was originally published in June 2007 and has been updated annually therafter. The fourth edition will be completed in September 2010.

Together, the Secure Fuels Report and this new report on institutional research provide insight into the scope and direction of ongoing oil shale related research activities in the United States.

OIL SHALE RESEARCH IN THE UNITED STATES

I. BACKGROUND

Higher oil prices, economic and security issues associated with oil imports, and other factors have renewed interest in oil shale in the United States.

U.S. Oil Shale Resources

The United States has the largest and most concentrated oil shale resources in the world: the equivalent of six trillion barrels of oil.

A small area of Colorado, Utah, and Wyoming contains at least four trillion barrels of resource in deposits with richness greater than 10 gallons per ton (g/t). Some 1.2 trillion barrels are contained in the rich of the Green River Formation deposits with richness greater than 25 g/t.

If technologies to extract oil from shale can be proven, as much as 600 to 800 billion barrels of shale oil could be booked as reserves, depending on the price of oil (this is 2 to 3 times the proved reserves in Saudi Arabia).

Prior Oil Shale Development Efforts

Prior development efforts have yielded a wealth of knowledge regarding U.S. oil shale resources and characteristics, as well as potential technology options for developing those resources. None, however, have been demonstrated in the United States at commercially-representative scale.

The renewed interest in oil shale has stimulated a wide variety of research efforts intended to advance oil shale technology and to assess and respond to resource, economic, environmental, socio-economic, market, and other challenges associated with the development of a domestic oil shale industry.

These efforts are ongoing within private industry, the federal government, and the nation's research community, including universities, national laboratories, and federal and state geological surveys.

Federal R&D Efforts

Department of the Interior: As early as the 1940s, the U.S. Department of the Interior (DOI), through its Bureau of Mines, was engaged in oil shale research, sponsoring the development and testing of three gas combustion retorts.

In the early 1970s, DOI implemented a Prototype Oil Shale Leasing Program and conducted a comprehensive environmental impact assessment relating to oil shale development in Colorado, Utah, and Wyoming. This effort resulted in four leases being issued for research, development, and demonstration (RD&D) projects.

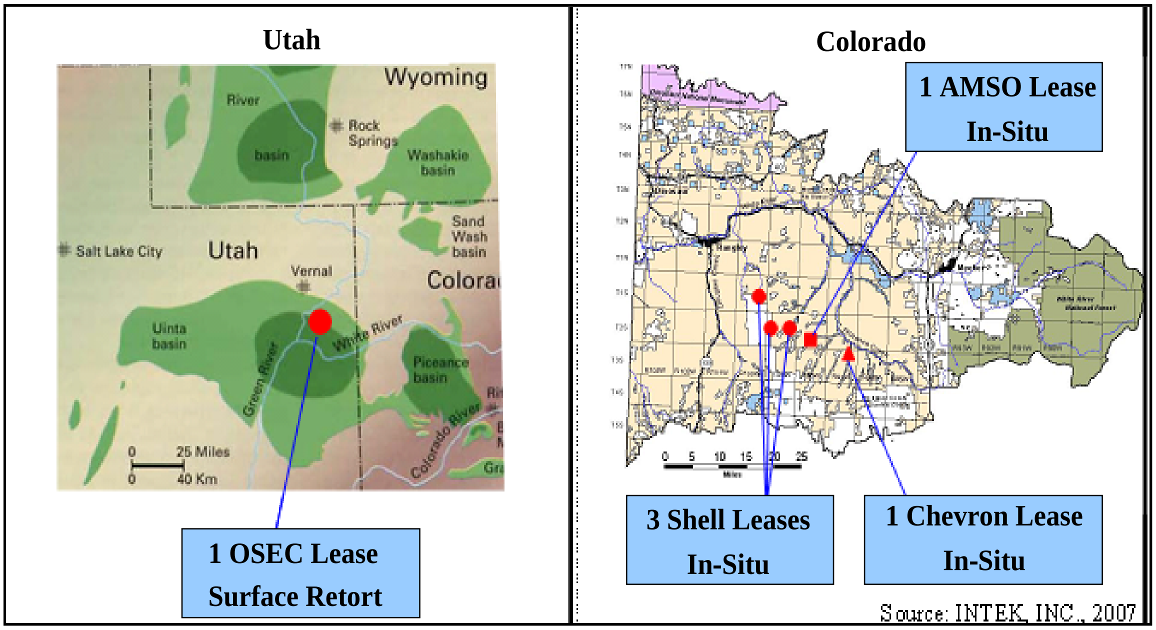
More recently, DOI's Bureau of Land Management (BLM) has developed a new oil shale RD&D leasing program to make land and resources available for demonstration of advanced technologies that have high potential for commercial success.

Six RD&D leases were issued by BLM to four companies in 2006 and 2007 (Figure 1). DOI recently offered additional RD&D leases, and is currently reviewing the lease applications.

Department of Energy: The Department of Energy (DOE) has had an active oil shale program since the 1970s, when an aggressive synthetic fuels research program was initiated to pursue the economic and environmentally acceptable development of fuels from domestic energy resources including oil shale. DOE has supported public and private basic and applied research and development, and cost-shared several large scale demonstration projects.

More recently, DOE has engaged in a variety of oil shale activities to assess the benefits and challenges of oil shale development, including the development of economically viable technologies that are environmentally and socially acceptable and sustainable.

Figure 1. DOI Oil Shale RD&D Leases Issued in 2006 and 2007



Energy Policy Act of 2005

The Energy Policy Act of 2005 directed both DOI and DOE to take significant steps to address the development of oil shale resources:

Department of the Interior: The Energy Policy Act directed DOI to proceed with RD&D leasing efforts, to prepare a Programmatic Environmental Impact Statement (PEIS) for commercial leasing, and to develop and implement oil shale commercial leasing regulations, facilitating access to the 75+ percent of the nation's oil shale resources that reside on federal lands.

DOI has completed a PEIS to amend Colorado, Utah, and Wyoming Resource Management Plans (RMP) to include commercial oil shale leasing, and the associated Record of Decision to amend the RMPs was released in November 2008, together with final commercial leasing regulations. Specifically, access to federal lands for oil shale leasing will include approximately 2 million acres in Colorado, Wyoming and Utah.

In doing so, DOI, with the assistance of Argonne National Laboratory, identified a host of potential environmental impacts that must be considered in oil shale development, including carbon emissions, requirements for and availability of water, potential impacts on surface and groundwater quality, degradation of air quality, and socio-economic impacts.

Department of Energy: The Energy Policy Act directed the Secretary of Energy to convene a Task Force on Strategic Unconventional Fuels, comprised of the Secretaries of the Departments of Energy, Interior and Defense, the Governors of affected states, and representatives of impacted communities, to provide input on how best to create and implement a program to promote and advance the commercial development of fuels from unconventional fuels resources, including oil shale.

The Task Force's initial findings and recommendations were documented in a September 2006 report that was provided to Congress and the President. A more comprehensive report was completed in September 2007.

The Task Force determined that oil shale development in the United States could produce as much as 2.5 million barrels per day by 2030, if a number of significant constraints can be overcome.

These constraints include the readiness of oil shale technology for commercial demonstration, and potential environmental impacts of industry development and operations, including:

- Surface and wildlife impacts
- Groundwater protection

- Air emissions and quality
- Carbon emissions
- Energy use and sources
- Demand for limited water resources
- Socio-economic impacts, and
- Infrastructure and market issues.

The Task Force recommended public and private efforts to address all of these issues and uncertainties as they apply not only to oil shale but to other unconventional fuels, as well.

Ad hoc Working Group

The Task Force's findings, recommendations, and plans have been given careful review by the Department of Energy.

Subsequent to the Task Force's recommendations, an ad hoc group of representatives from industry, government, academia, and U.S. national laboratories was convened to help determine how best to implement the Task Force's recommendations.

As a result of the work of the ad hoc group, a Strategic Plan was developed and released in November 2008 for developing unconventional resources, including oil shale, in an area extending from Alberta, Canada to the state of New Mexico. This area has been dubbed the Western Energy Corridor; Implementation of the Plan is referred to as the Western Energy Corridor Initiative.

The Strategic Plan for the Western Energy Corridor Initiative provides a framework for assessing the potential environmental and socio-economic impacts associated with unconventional fuels development, based on the application of sound science and engineering principles by recognized experts at western universities and national laboratories.

The next step in the implementation process is to develop implementation plans for each of five unconventional fuels: coal-to-liquids, oil shale, tar sands, heavy oil and CO_2 enhanced oil recovery, with oil shale being the highest priority.

Initial Research Activities

Using available funds, including a congressionally directed appropriation, DOE initiated a limited set of activities aimed at estimating carbon emissions and water resource requirements for oil shale development in the Piceance Basin in Colorado, using existing data and information. These efforts were scheduled to be completed in 2010, but have not been fully funded

Modeling and Analysis

To support the efforts of the Task Force, and internal decision making, DOE developed an analytical model, initially focused on oil shale, to assess the costs, economics, and other potential benefits of oil shale development under various development, fiscal, oil price, and public policy scenarios. The model, referred to as the National Strategic Unconventional Resources Model (NSURM), was later expanded to address all five unconventional fuels resources. NSURM was originally documented in a 2006 report and later updated in the 2009 report.

International Collaboration

Oil shale is found not only in the U.S., but in more than 100 major deposits in 27 countries around the globe. In an effort to share information and support technology advancement, the U.S. has collaborated with researchers in other countries.

An extensive three-phase collaborative effort with Estonia was conducted by DOE between 2000 and 2006 to research and develop advanced process approaches and improve the production economics of U.S. and Estonian oil shale resources. Four reports were completed between September 2001 and November 2004.

A follow-on project is currently envisioned, pending the execution of a new agreement between the two nations.

II. PRIVATE INDUSTRY RD&D ACTIVITIES

Extensive technology research, development, and demonstration work is being conducted by private companies in the U.S. and elsewhere to improve understanding of oil shale resources and to advance technologies for producing hydrocarbon gases and liquids that can be refined to create cleaner fuels.

Between 2007 and 2010, the DOE Office of Petroleum Reserves identified more than 39 U.S. companies engaged in oil shale and tar sands research, technology development, or project development. Twenty-nine are focused specifically on U.S. oil shale resources, including the recipients of the oil shale RD&D leases issued by BLM.

These private efforts address both surface and in-situ processes, new heating and retorting approaches, reduction and management of emissions, minimization and re-use of process water, surface and ground water protection, and other critical challenges posed by the current economic and policy environment.

Table 1 shows the distribution of these private oil shale industry efforts, according to the resource and process type, and the technology development status.

Many of these private companies are also drawing on the immense resources and scientific and technical capabilities of U.S. research universities, state geological surveys, and national laboratories to assist them in their research, analysis, technology development, testing and demonstration efforts.

A broad group of industry associations and other interested organizations is also actively assisting in addressing oil shale development uncertainties and public concerns. These include the National Oil Shale Association (NOSA), the Oil Shale Committee of the

American Petroleum Institute (API), and the Center for North American Energy Security (CNAES), among others.

III. OIL SHALE R&D IN THE U.S. RESEARCH COMMUNITY

The following compendium of profiles describes 29 known oil shale-related research projects being performed at several research institutions, including universities, national laboratories, and federal and state agencies.

This compendium does not include all of the research that is currently ongoing related to oil shale. Nor does it document the many previous research projects that were completed throughout the nation's oil shale history. Rather, it is intended to provide a foundation for understanding the activities that are ongoing and also to help identify and assess the areas of research that are still required.

This report contains 29 profiles received from six research institutions that have chosen to participate on a voluntary basis. The institutions that have directly participated in this initiative are:

- Colorado School of Mines
- Idaho National Laboratory
- Los Alamos National Laboratory
- U.S. Geological Survey
- University of Utah, and
- Utah Geological Survey.

Indirectly, 15 research projects being sponsored, or co-sponsored, by the Department of Energy's National Energy Technology Laboratory, as well as a number of private sponsors, are included in this report and described in the profiles by those performing the work. Some profiles describe multiple projects that are managed under one program.

The areas of study being addressed by each of the institutions are summarized in Table 2, above.

Table 3 provides a quick-reference guide to the profiles included in this report, including the performing institution, project title, research category, and page number.

Table 1. Summary of Private Industry Oil Shale RD&D Efforts

	Stage of Development (Number of Projects)				
Process Type	**Concept**	**Laboratory**	**Pilot**	**Commercial Demonstration**	**Total**
In-Situ Extraction	2	7	5	0	14
Surface Retort	2	4	6	0	12
Hybrid Extraction	0	0	1	0	1
Upgrading	0	0	1	1	2
Total	4	11	13	1	29

Source: Secure Fuels from Domestic Resources, 2010.

Table 2. Summary of Research Community RD&D Efforts

	Research Institution						
Research Area	**Colorado School of Mines**	**University of Utah**	**Idaho National Lab**	**Los Alamos National Lab**	**Utah Geological Survey**	**U.S. Geological Survey**	**National Energy Technology Lab**
Resource Characterization	•	•	•	•	•	•	•
Technology	•	•	•	•			•
Environmental Impacts	•	•	•	•	•		•
Source Water	•	•	•	•	•	•	•
Economics		•		•			•
Regulations / Permitting		•	•				•

Table 3. Quick Reference Guide to Oil Shale Research Project Profiles

Institution	Research Project Description	Research Category	Page
Colorado School of Mines (CSM)	**1. Center for Oil Shale Technology and Research (COSTAR)**	Outreach	13
	-Geomechanical Behavior of Oil Shale	Resource	14
	-Geologic Controls on Oil Shale Properties	Resource	14
	-Oil Shale Information Office	Outreach	14
	2. GIS-based Water Resource Geospatial Infrastructure	Water	15
	-Web Portal Development	Outreach	16
	-Dynamic Systems Models: A Framework for Decision Support	Water	16
	-Surface Water and Groundwater Modeling	Water	16
	-Transfer Technology	Outreach	16
Idaho National Laboratory (INL)	3. Development of Thermally Generated in situ Precipitation Barriers due to Subsurface Heat Injection	In-Situ Retorting Water Protection	17
	4. Dynamic System Modeling of Regional Influences from Energy Resource Development	Water	19
	5. Generation and Expulsion of Hydrocarbons from Oil Shale	Geochemistry	21
	6. Industrial Support for Basic and Applied Research	In-Situ Retorting	23
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LANL	10. Water, Energy and Carbon Management Issues and Assessment Models	Overview	31
	11. Integrated Assessment Model for Basin-Scale In Situ Oil Shale Production: CLEARuff Model	Development Impact Modeling	33
	12. Hydrologic Analysis of the Upper Colorado River Basin for Oil Shale Development and Potential Future Climate Change: WARMF Model	Water & Carbon Management	35
	13. CO_2 Management for Oil Shale Development: CO_2-PENS and SimCCS	Carbon Mgmt	37
USGS	14. Common Data Repository and Water Resource Assessment for the Piceance Basin	Water	39
	15. Oil Shale Assessment	Resource	41
University of Utah	16. Analysis of CO_2 Emissions from Unconventional Fossil Fuel Resources	Carbon Mgmt	43
	17. Basin-wide Characterization of Oil Shale Resource in Utah and Examination of In-situ Production Models	Resource, In-Situ Simulation	45
	18. Development of CFD-Based Simulation Tools for In-Situ Thermal Processing of Oil Shale/Sands	In-Situ Retorting	47
	19. Econometric Analysis Methods for Heavy Oil Production and Upgrading	Economics	49
	20. Effect of Oil Shale Processing on Water Compositions	Water	51
	21. Kerogen/Asphaltenes Atomistic Modeling	Research	53
	22. Land and Resource Issues Relevant to Deploying In-Situ Thermal Technologies	Policy Analysis	55
	23. Market Assessment of Heavy Oil, Oil Sands, and Oil Shale Resources	Market	57
	24. Multiscale Thermal Processing (Pyrolysis) of Oil Shale	Retorting	59
	25. Oxy-gas Process Heaters for Efficient CO_2 Capture	CO_2 Capture	61
	26. Policy Analysis of Water Availability and Produced Water Issues Associated with In-Situ Thermal Production	Water	63
	27. Pore Scale Analysis of Oil Sands/Shale Pyrolysis by X-ray Micro CT and LB Simulation	Retorting	65
UGS	28. Evaluation of the Birds Nest aquifer and relationship to Utah's oil-shale resource	Water	67
	29. Geologic Characterization of Utah's Oil Shale Resource	Resource	69
	30. Utah Oil Shale Resource Evaluation	Resource	71

Center for Oil Shale Technology and Research

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PROJECT PURPOSE/GOALS

The Center for Oil Shale Technology and Research (COSTAR) was created to integrate efforts in scientific and engineering research, as well as information management, technical review, education, and communication related to development and production of hydrocarbons from oil shale.

- The primary function of COSTAR is to conduct research on oil shale deposits, properties of oil shale, and technical approaches to measurement of oil shale productivity.
- COSTAR plans and executes the annual Oil Shale Symposium, which is intended to serve as the leading venue for the exchange of ideas and information on the global oil shale enterprise.
- Additionally, COSTAR includes an oil shale information office, located in the Colorado School of Mines (CSM) library, which is preparing a Web-based digital database of oil shale technical materials.

PROJECT START DATE/DURATION

The current research program runs from May 31, 2008 to October 31, 2010. A second phase is planned.

PROJECT SPONSOR(S)

▪ TOTAL Exploration & Production	$300,000 per year
▪ Shell Exploration & Production	$300,000 per year
▪ ExxonMobil Upstream Research Company	$300,000 per year

PROJECT DESCRIPTION

COSTAR's program is subdivided into four projects:

- Geomechanics (Rock Physics and Rock Mechanics)
- Geology and Paleoclimatology
- Geochemistry
- The Oil Shale Information Office

The work in these projects is summarized in Table 1.1. Most tasks are expected to last two to three years, although the larger projects are expected to continue longer. This research program uses a broad, consistent geologic framework (Project 2) as the *integrating tool* to understand spatial distribution and heterogeneity of oil shale properties.

Table 1.1: Oil Shale Research Projects

Project 1: Geomechanical Behavior of Oil Shale		
1.1	*Rock physics of oil shale* Evaluate the rock properties of oil shale and the variation of those parameters with composition, temperature and pressure to define potential remote geophysical signatures for either resource characterization or *in-situ* process monitoring. Evaluate physical parameters controlling fracture behavior as input to rock mechanics models.	M. Batzle, M. Prasad, CSM
1.2	*Rock mechanics of oil shale* Develop modeling tools to model fracturing in oil shale. Evaluate the fracture properties of oil shale to define modeling parameters for *in-situ* production processes. Model fracture mechanics of natural fracturing and of *in-situ* production processes for shale oil.	G. Mustoe, J. Berger, CSM
Project 2: Geologic Controls on Oil Shale Properties		
2.1	*Unified stratigraphic framework and sedimentology of the Green River Formation* Develop improved geologic understanding of the Green River Formation through integration of shale richness data with a modern interpretive framework for lake deposits. Compare the properties of the three Green River Formation basins and stratigraphic units to define the controls on oil shale properties. Understand the composition, depositional environments and diagenetic paragenesis of lacustrine sediments, including evaporitic sediment, and interpret the paleoclimatic implications of the stratigraphic and paragentic succession. Ongoing work involves comprehensive analysis of selected reference cores from Colorado and Wyoming, examining stratigraphic, sedimentologic, mineralogic, and organic and isotopic geochemical characteristics to provide the integrating framework for all related projects, and to serve as a model for comparison to other oil shale deposits in the world.	J. Sarg, K. Tanavsuu-Milkeviciene, J. Boak, CSM; A. Carroll, U. Wisconsin; T. Lowenstein, Binghamton U.
2.3	*Global controls on oil shale properties* Evaluate the sequence stratigraphic framework of oil shale deposits to determine principles controlling richness distribution as a basis for resource estimation. Develop principles within both lacustrine and marine oil shale basins.	R. Sarg, J. Boak, CSM; A. Carroll, U. Wisconsin
Project 3: Oil Shale Information Office		
4.1	*Digitization, analysis and publication of relevant oil shale research* Catalog and digitize existing technical data from CSM collections. Analyze data and report on developments surrounding global development of oil shale. Conduct Oil Shale Symposia.	J. Carmen, J. Boak, CSM
4.2	*Geographically referenced digital database of oil shale data* Prepare a comprehensive geographically referenced digital database of oil shale data, reports, maps, etc., from multiple sources and support research on oil shale using this resource.	M. Spann, J. Boak, CSM

GIS and Web-Based Water Resource Geospatial Infrastructure for Oil Shale Development

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PROJECT PURPOSE/GOALS

The goal of this project is to develop a water resource geospatial infrastructure that provides water management solutions to facilitate decision making for potential oil shale resource development in the western U.S., environmental impact studies (EIS), and scenario analyses.

PROJECT START DATE/DURATION

The current research program runs from October 1, 2008 to September 30, 2011.

PROJECT SPONSOR(S)

- DOE National Energy Technology Laboratory $883,971
- American Shale Oil (AMSO) ~$100,000 (in kind contribution)
- Colorado School of Mines ~$48,000 (in kind contribution)

PROJECT DESCRIPTION

The project will develop a Geographic Information Systems (GIS)-based regional/basin water resource geospatial infrastructure, and a web-based data warehouse for storing, managing, analyzing, visualizing, and disseminating oil shale related data. Customized analytical toolsets and analytical models will also be developed to address water availability (quality and quantity) and environmental issues surrounding potential development of oil shale resources in the western U.S. The task structure follows.

1. GIS-based Water Resource Geospatial Infrastructure

The team will develop the infrastructure of a GIS- and Web-Based Water Resources geospatial infrastructure for storing, managing, analyzing and displaying the data, and build a web-based GIS and a web-based data warehouse for storing and disseminating data. Regional surface water and groundwater data will be collected from various available sources. Customized analytical tools and analytical models will be developed to facilitate data analysis, visualization, and decision making.

Subtask: Regional "baseline" data collection and compiling

Collect and compile regional "baseline" data, such as surface water and groundwater data (on quality and quantity), geological, topographic and climatic data from a variety of sources, such as National Hydrography Dataset Plus (NHD Plus), USGS National Water Information System (NWIS), U.S. Environmental Protection Agency Storage, the Tell Ertl Oil Shale Repository (TESOR) at the Colorado School of Mines and from DAYMET.org via the Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. (CUAHSI) web services. New hydrological data will be collected from American Shale Oil (AMSO) from its proposed characterization well on land within its Research, Development and Demonstration lease working in the Piceance Basin as available.

Subtask: Regional "baseline" data integration, storing, and managing

Integrate the collected data into relational geodatabases for the Piceance Basin. Collect and compile relevant geologic maps (e.g., of the Green River Formation), surficial material maps, land use/land status maps and transportation network. Create a 3-D geological model using data collected in the geodatabases to facilitate the development of surface water, groundwater and dynamic system models, such as hydrological boundaries creation, ground water table creation from well data, performing volume calculation , and 3-D visualization.

Subtask: Regional "baseline" data processing and customized GIS analytical tool development

Analyze and Visualize geodatabase using ArcGIS, and MVS (Mining Visualization System) by C-Tech. Develop data processing tools by using Matlab scripts and data mining techniques. Develop customized analytical tools using VBA macros and ArcObjects. Prepare GIS analytical models built using ArcGIS ModelBuilder.

Subtask: Web-based GIS development and data dissemination

A GIS server is purchased and has set up within the CSM network system . The initial prototype of the web-based GIS store on this GIS server shall be internet ready by the end the second year of the project. The web-based GIS is supported by ArcServer Enterprise.

2. Web Portal Development

A web-site is used to allow developments to be controlled, organized, tracked, and distributed throughout the duration of the project and beyond. The web portal shall be maintained and available to the general public.

3. Dynamic Systems Models: A Framework for Decision Support

Team members from Idaho National Laboratory will develop and exercise simplified decision aiding models of various oil shale production technology options, of the hydrologic response function of such options, including potential impact mitigating technology, and of basin wide performance against selected performance models.

4. Surface Water and Groundwater Modeling

The Watershed Analysis Risk Management Framework (WARMF) is selected for surface water modeling. The model is capable of simulating surface water hydrology including the impact of water use on stream flow and pollutant transport and reactions. MODFLOW will be used for groundwater modeling. The combination of surface water and ground water modeling will help to understand and predict the environmental impacts and water availability under different oil shale development scenarios.

5. Technology Transfer

Results of the project will be disseminated through technical papers presented at symposia, and a minimum of two presentations shall be given at meetings of the Association of Environmental and Engineering Geologists (AEG), the Society of Economic Geologists, the Society of Petroleum Engineers (SPE) or American Geophysical Union (AGU). Quarterly, Annual, and Final technical reports will be made available to the general public on the internet via a designated website to be developed for this project. The website will be linked to pertinent webpages at NETL and CSM for wider publicity. (http://www.netl.doe.gov/technologies/oil-gas/Petroleum/projects/Environmental/Produced_Water/06554_GreenRiverGIS.html)

Performers
Colorado School of Mines, Golden, CO
University of Texas at San Antonio, San Antonio, TX
Idaho National Laboratory, Idaho Falls, ID

Development of Thermally Generated in situ Precipitation Barriers due to Subsurface Heat Injection

Organization: Energy Resource Recovery & Management Department
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PROJECT PURPOSE/GOALS

The objective of this project is to understand how a chemical precipitation barrier may develop in fractured and porous media where groundwater is converted to steam by anthropogenic heating. This project focuses on in situ oil-shale retorting, where development of a chemical precipitation barrier could effectively limit water ingress into an oil-shale retort. To evaluate *in situ* thermally induced precipitation, we will evaluate conditions necessary to create mineral deposition events through numerical simulations from modified multiphase transport models that are supported by laboratory validation experiments. If creation of a barrier is feasible, we can compare the energy and time required to develop it with alternative means of excluding groundwater from the retort to help identify the feasibility of creating a mineral deposition barrier for groundwater control.

PROJECT START DATE/DURATION

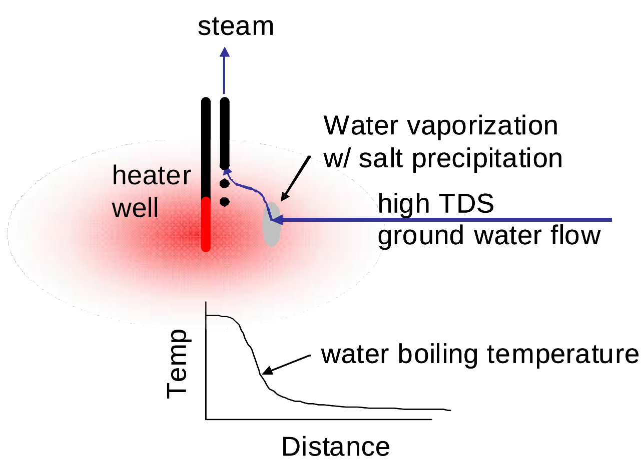
The current research program runs from May, 2010 to September, 2012.

PROJECT SPONSOR(S)

- Laboratory Directed Research and Development ~$275,000 per year

PROJECT DESCRIPTION

In situ oil shale resource development involves large-scale heating of the subsurface in order to convert kerogen contained in the oil shale to extractable hydrocarbon gases and liquids. From an engineering standpoint, it is desirable to use the energy injected into the subsurface to pyrolyze kerogen to a useable product and not waste it heating and vaporizing groundwater. Most in situ pilot scale test plans thus incorporate a groundwater exclusion zone around the retort to keep the groundwater out and retain the oil-shale gas/liquid products. The primary goal of this project is to determine if a vaporization-induced precipitation barrier can be developed and used to advantage in an in situ oil-shale retort, where groundwater migration into the retort is undesirable. This project is addressing this question with a combination of numerical modeling of subsurface chemistry and fluid flow, laboratory validation experiments and scaling calculations of cost.



Conceptual model of ground water evaporation with salt deposition to form a barrier around an in situ oil shale retort.

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Dynamic System Modeling of Regional Influences from Energy Resource Development

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PROJECT PURPOSE/GOALS

The principal objective of this joint Colorado School of Mines, University of Texas San Antonio, and Idaho National Laboratory project is to develop a water resource geospatial infrastructure (including data, toolsets, analytical models and graphical user interfaces (GUIs)), to provide water management solutions to facilitate decision making for potential oil shale resource development in the western United States, and to facilitate environmental impact studies (EIS), and cost estimation under different scenarios.

PROJECT START DATE/DURATION

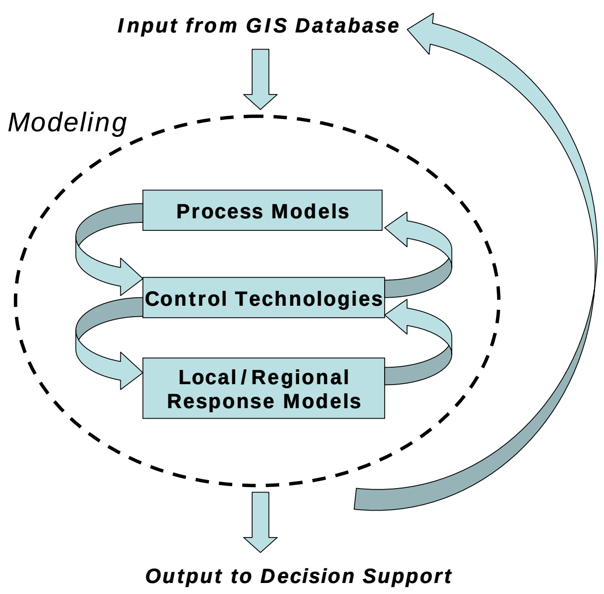
The current research program runs from March, 2009 to September, 2011.

PROJECT SPONSOR(S)

- National Energy Technology Laboratory ~$85,000 per year

PROJECT DESCRIPTION

INL project specific goals are to develop and exercise simplified decision support models of (1) various oil shale production technology options and (2) the hydrologic response function of such options, including potential impact mitigating technology, and (3) basin wide performance against selected performance models.



Relationship of modeling activity to the geospatial infrastructure and decision support.

INL will develop system dynamic models to evaluate the potential impact of proposed oil shale development processes and various control technologies on regional water resources. The focus of this effort is on water resources, although the decision support framework envisioned could be broadened to evaluate other elements of the baseline such as increased electrical power production for oil shale development and the development of other resources (e.g., natural gas, nahcolite). These analyses will be directed first at defining limitations and gaps in the GIS baseline data, based on likely development scenarios.

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Generation and Expulsion of Hydrocarbons from Oil Shale

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PROJECT PURPOSE/GOALS

This project focuses on understanding key geochemical factors that affect the rate of pyrolysis of oil shale, the quality of the generated shale oil, identifying geochemical signatures that will provide information about the performance of in-situ retorting processes, and on the physical mechanisms governing the expulsion of product from the oil shale rock and the transport of that product to an extraction well.

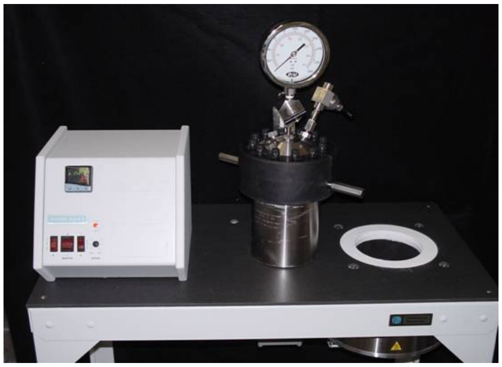
PROJECT START DATE/DURATION

The current research program runs from October, 2007 to September, 2010.

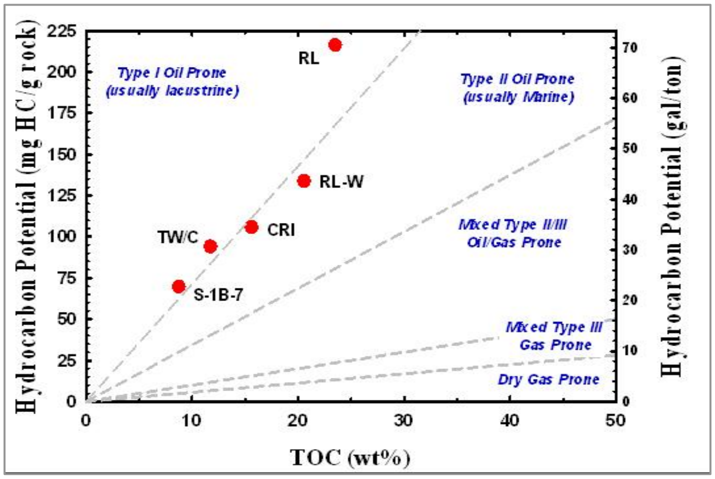
PROJECT SPONSOR(S)

- Laboratory Directed Research and Development $350,000 per year

PROJECT DESCRIPTION



This work will develop a fundamental understanding of how physical and chemical conditions affect the quality and quantity of oil derived during in-situ pyrolysis of kerogen in oil shale. The primary objectives of the project are to 1) develop an expression for the rate of pyrolysis that accounts for the effects of temperature and the role of water, 2) develop a better understanding of how confining stresses affects the expulsion of oil from the porous shale matrix, 3) identify “performance signatures” that will permit one to determine the temperature and pressure regimes present in the subsurface, 4) incorporate thermogeomechanical effects of the oil shale during heating to understand the stability of fractures and the recovery of the product, and 5) develop a one-dimensional numerical model that incorporates the functional relationships between the distribution of pyrolysis conditions in a shale matrix and oil generation and test it against a one-dimensional physical model.



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Industrial Support for Basic and Applied Research

Organization: Energy Resource Recovery & Management Department
Contact: Varies – General POC Tom Wood
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PROJECT PURPOSE/GOALS

The Idaho National Laboratory (INL) provides support services for industry sponsors on projects where these services are not available in the private sector. For instance, on projects where the laboratory has unique capabilities or where problem solutions are derived as a part of the project (basic research). The INL has specialized capabilities in physics-based numerical simulators for modeling coupled flow, heat transport and geomechanic problems associated with recovery of oil and gas from unconventional fossil resources, such as, oil shale and shale gas. Laboratory and intermediate scale experiments are typically performed for model validation. Projects include modeling generation and expulsion of oil from oil shale, hydraulic fracturing, proppant-shale mechanical interactions in hydraulic fractures etc. These projects are protected by confidentiality and intellectual property agreements.

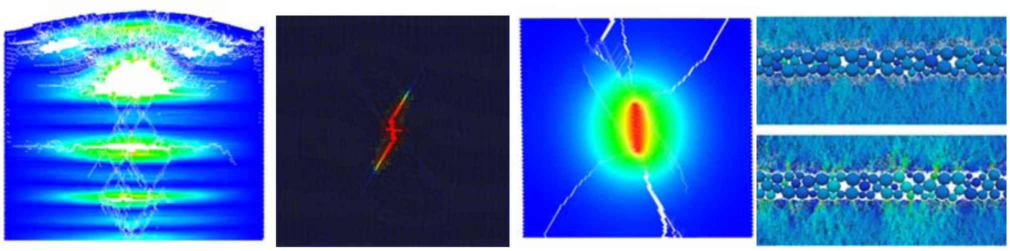
PROJECT START DATE/DURATION

Several projects are underway and the duration varies for a few months to several years.

PROJECT SPONSOR(S)

- Various Sponsoring Companies

PROJECT DESCRIPTION



Example simulations (from left to right): thermal expasion and spallation of oil shale due to heating and oil expulsion; propagation of hydraulic fracture-hydrofracturing; fracturing of shale rock due to heating and proppant-shale mechanical interaction under large fracture closing stress.

New petroleum extraction methods are being designed and tested that will alter the physical characteristics of the subsurface so that useful energy products can be extracted from unconventional energy resource. These processes are often multiphase, multi-component flow and transport problems involving non-linear mechanical deformation and fracturing of the subsurface media. In order to find solutions to these difficult problems, the INL has developed capabilities to perform high resolution laboratory experiments and mutli-scale multi-physics simulation techniques that incorporate physics-based representation of the tightly coupled processes occurring at various scales.

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Integration of Next Generation Nuclear Plant and Oil Shale Development Options

Organization: Energy Resource Recovery & Management Department
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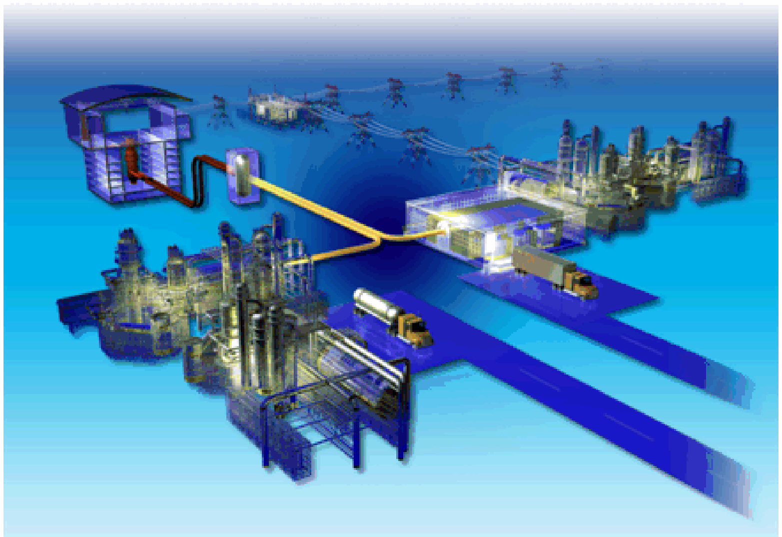
PROJECT PURPOSE/GOALS

The objective of this project is to determine the technical and economic feasibility of integrating oil shale development with power and process heat derived from a high temperature gas reactor (HTGR), which is part of the Next Generation Nuclear Plant (NGNP) program led by Idaho National Laboratory. Specific goals of the work include identification and matching of power and heat requirements of the oil shale needs and the HTGR, as well as end products and emissions of both processes. Cost savings resulting from the nuclear integration will be identified along with reduction in CO_2 emissions. By identifying any economic and environmental benefits of integrating an HTGR with oil shale development at this early stage, decision makers at all levels (regulatory, business, R&D, etc.) will be aware of the potential benefits and have time to plan for an integrated project.

PROJECT START DATE/DURATION

The current research program runs from Feb 2010 to June 2011.



PROJECT SPONSOR(S)

- Next Generation Nuclear Plant, Department of Energy, Office of Nuclear Energy.

PROJECT DESCRIPTION

Production of oil from oil shale deposits requires significant energy inputs and depending on the type of energy used, it can also emit a significant amount of greenhouse gases. An HTGR nuclear plant can produce high temperature fluids suitable for use in retorting oil shale, high efficiency hydrogen, as well as electricity. The HTGR may be ideally suited for integration with oil shale development due to the matching of input needs and output capabilities.

The work will focus on three methods of oil shale production: an ex situ retorting process, an ex-situ/in-situ hybrid process, and a true in situ process. A process model will be developed that incorporates input and output requirements for the energy supplier (HTGR) and the shale oil producer. A user-friendly model will be developed that incorporates process and economic variables for an integrated project based on an output of 50,000 barrels per day. The three nuclear-assisted oil shale production scenarios will be evaluated by discounted cash flow analyses and compared to unassisted projects. Variables that have the greatest impact on project economics will be identified for potential R&D efforts.

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Near Field Impacts of In-Situ Oil Shale Development on Water Quality

Organization: Energy Resource Recovery & Management Department
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PROJECT PURPOSE/GOALS

The objectives of this research are to understand the oil products, the potential mobile contaminants, and determine the near field permeability during and after in-situ retorting. Experimental results will be used to develop representative modeling and simulation tools to predict impacts to groundwater. Laboratory testing of oil shale is defining the relationships between leachable contaminants and the applied heat and pressure. Additionally, quantitative relationships among permeability, retort heating history, and effective stress are being developed. These relationships will be incorporated into heat-flow models that will allow characterization of the permeability field immediately surrounding the in-situ oil shale retort zone.

PROJECT START DATE/DURATION

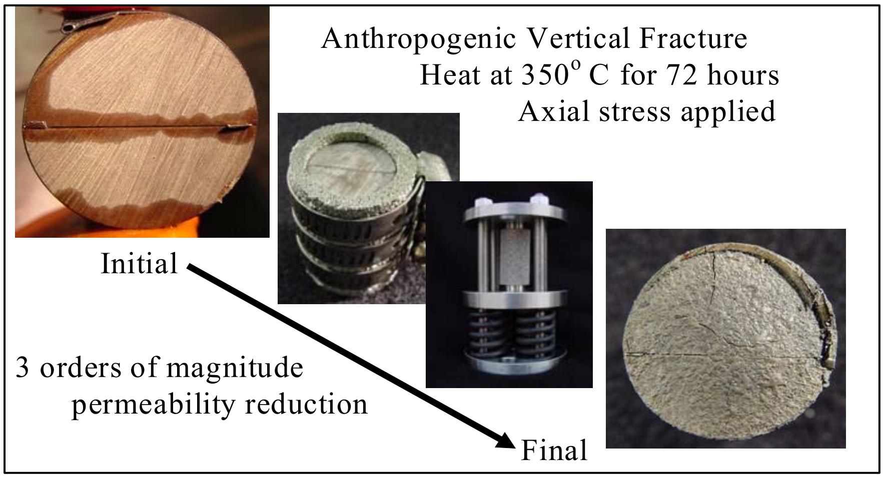
The current research program runs from March, 2008 to September, 2010.

PROJECT SPONSOR(S)

- Laboratory Directed Research and Development ~$245,000 per year

PROJECT DESCRIPTION

The project examines controls on the mass flux of contaminants from oil shale retorts to groundwater by conducting retorting experiments under a range of temperatures similar to those currently being proposed by energy development companies. Potential contaminant concentrations of water in contact with the spent shale will be measured. Permeability is measured under various conditions of temperature and total stress to obtain the appropriate constitutive relationships. Numerical simulations of temperature distributions in a hypothetical retort will be conducted and the results related to the water quality and permeability studies to improve the understanding of the potential distribution of water quality and permeability within a retort zone. The results of the proposed work will provide basic information needed for the development of larger-scale simulations of the impact of oil shale retorting on regional water quality.



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Idaho National Laboratory

Nuclear Pathways to Energy Security

Organization: Energy Resource Recovery & Management Department
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PROJECT PURPOSE/GOALS

This project will identify ways in which nuclear power can provide secure, affordable energy systems by developing a better understanding of how to build energy systems that operate within the carbon and water constraints imposed by the regional and global environment. This project will quantify the water impacts of energy systems in a rigorous manner, and use this quantification as a basis for contrasting the carbon and water impacts of various strategies, which will lead to improvements in the design and expansion of new energy developments. It is anticipated that this work will demonstrate that nuclear-hybrid energy systems can cost effectively provide a secure, low-carbon, water-smart source of energy in many market sectors.

PROJECT START DATE/DURATION

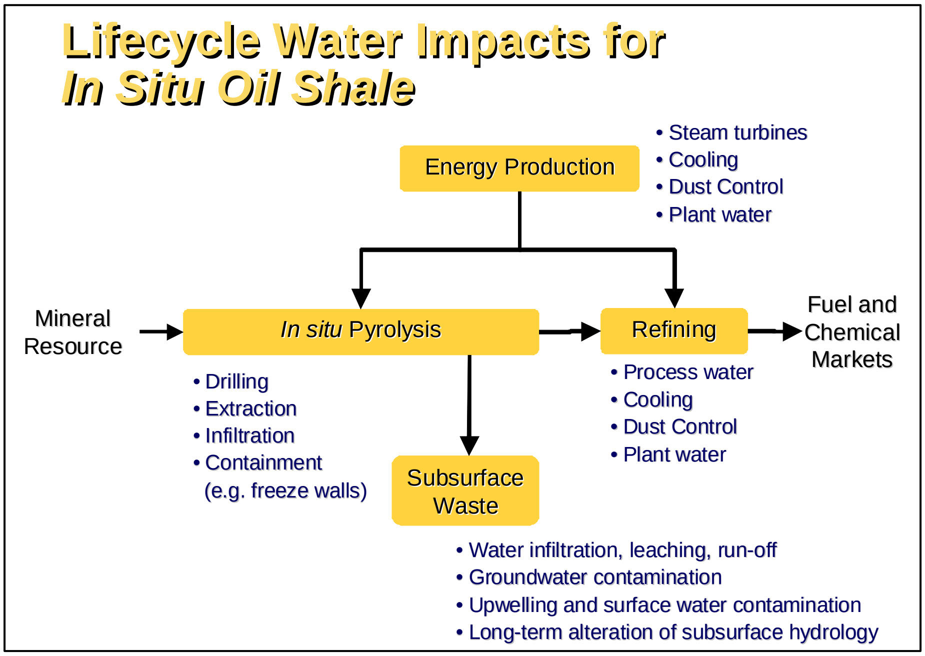
The current research program runs from October, 2007 to September, 2010.

PROJECT SPONSOR(S)

- Laboratory Directed Research and Development   ~$200,000 per year

PROJECT DESCRIPTION

This project uses systems modeling techniques to address two nested problems. First, this project seeks to improve the understanding of the complex linkages between energy and environmental systems by demonstrating how innovative new "sustainable energy systems" can be designed, based on environmental constraints on greenhouse gas emissions and water availability. Second, within the context of this overarching goal, the project will determine whether hybrid nuclear energy systems can provide cost-effective options for producing secure, "green" transportation fuels from North American feedstocks.



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Water, Energy and Carbon Management Issues and Assessment Models for Oil Shale Development: Overview

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PROJECT PURPOSE/GOALS

This project utilizes an integrated modeling process to facilitate scenario analyses to evaluate water, carbon, energy, social and economic requirements and impacts as related to in situ oil shale development. The multi-scale modeling approach involves an integrated assessment (IA) modeling framework in addition to (a) a detailed model of basin-scale hydrology investigating the spatial relationships of river flow, water diversions and requirements, reservoir locations, and climate change impacts and (b) a CO_2 sequestration model to analyze storage capacity and infrastructure requirements and costs for alternative carbon management options. The IA model simulates the dynamic development of a basin-scale oil shale industry, including interdependencies of financial investment, labor needs, energy and water requirements, and CO_2 generation. The hydrologic model investigates flows, diversions, and water storage in the Upper Colorado and White River basins, investigating consequences of alternative oil shale production rates and potential future climate change. Carbon transport infrastructure and geologic sequestration optimization software address the CO_2 generated by alternative power plant types providing energy for in situ oil shale extraction.

PROJECT START DATE/DURATION

This project started on July 1, 2008 and ended in July, 2010. Final Report in Press

PROJECT SPONSOR(S)

- DOE-FE; Office of Naval Petroleum and Oil Shale Reserves $1.9 Million

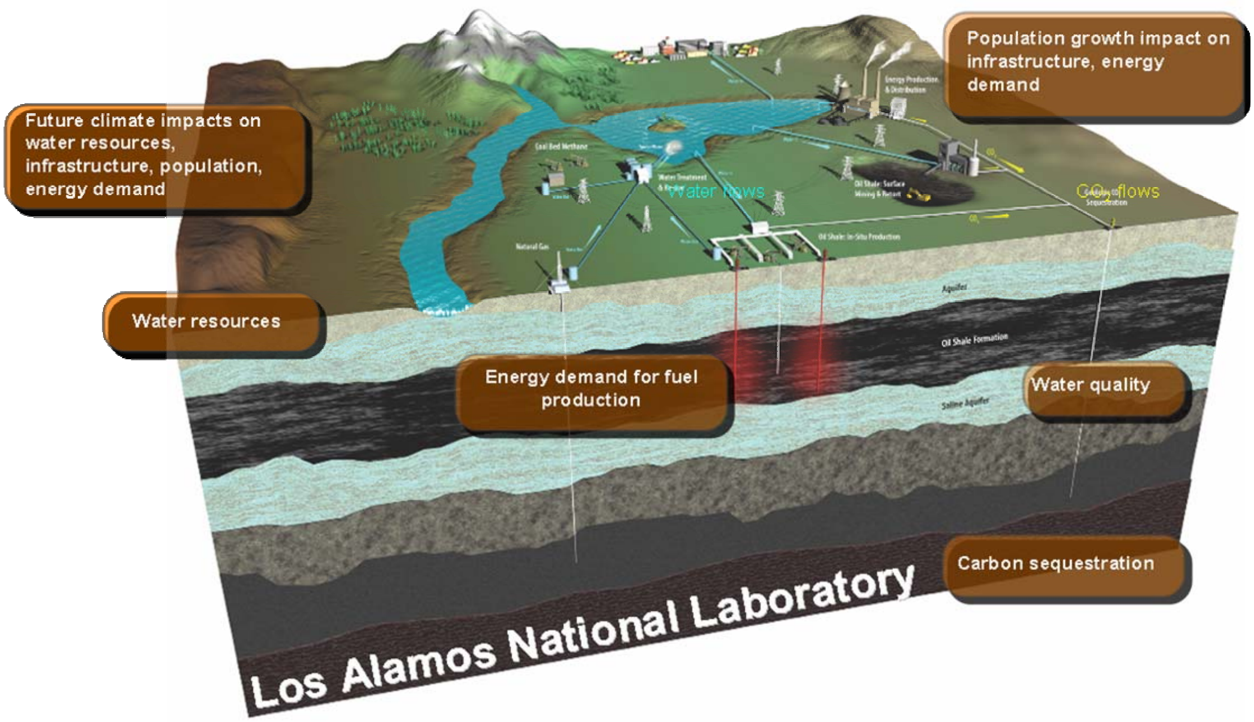
PROJECT DESCRIPTION

LANL has developed and applied computer models to assess the dynamic growth of an oil shale production industry, the carbon footprint and management alternatives, and water requirements and impacts associated with shale oil production in the Piceance Basin of Colorado. This is done in the context of multiple variables that include climate changes, population changes, land use changes, alternative energy supply scenarios, and alternative carbon management options.

- The integrated assessment model $CLEAR_{uff}$ (CLimate Energy Assessment for Resiliency for Unconventional Fossil Fuel) has been developed and utilized oil shale development assessment in a System Dynamics framework with 13 modules implemented, including water requirements, land use, population growth, CO_2 emissions, electricity generation, climate and economic impacts. The model simulates basin-wide in-situ development with drilling, heating, producing, and remediating phases occurring simultaneously in different locations, constrained by resource availability, such as drill rigs and labor. For each phase, energy requirements, water demands, CO_2 emissions, labor requirements, and other factors vary.

- WARMF (Watershed Analysis Risk Management Framework) models for the White and Upper Colorado Rivers have been calibrated and utilized to assess flow impacts, storage requirements, and reliability of water resources for different levels of oil shale development. These analyses have been conducted for current and future climate change scenarios. The climate change scenarios show the potential for substantial impact on storage requirements due to longer droughts, less storage as snow pack, more evapotranspiration, and a shift in the timing of runoff.

- CO_2 generated during power production as simulated with CLEARuff is managed with CO_2-PENS (Predicting Engineerd Natural Systems) and SimCCS. These two modules enable consideration and optimization of alternative geologic storage sites for the captured CO_2. CO_2-PENS enables comparison of different target sequestration reservoirs, optimizing the number of wells and injections rates and SimCCS enables optimization of pipeline locations and sizes and choice of target reservoirs. This study demonstrates that choice of location and operation of sequestration sites varies depending on the rate of quantity of CO_2 production at the power plant, which in turn depends on the power required for different oil shale development scenarios and the type of power plant (e.g. natural gas or different coal plant designs).



Conceptual schematic showing multiple processes considered in the LANL modeling framework for in-situ shale oil production scenarios. Integrated and interdependent processes include fuel production, energy production and demand, water requirements and impacts, climate impacts, agriculture and land-use, and economic and infrastructure factors.

Integrated Assessment Model for Basin-Scale In Situ Oil Shale Production: CLEAR$_{uff}$ Model

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PROJECT PURPOSE/GOALS

The goal of the *CLEAR$_{uff}$* model (Climate Energy Analysis for Resiliency applied to Unconventional Fossil Fuel) is to investigate both sectoral and broader implications of unconventional fossil fuel production; it is a dynamical integrated assessment model developed to evaluate potential production capacity of unconventional fossil fuels within the constraints of environmental quality, land use, and socioeconomics. *CLEAR$_{uff}$* integrates the technical, environmental, economic, regulatory, and social processes involved with information flow and feedbacks among all of the modules (see figure). The *CLEAR$_{uff}$* model simulates oil shale production approximating the Shell In Situ Conversion Process, considering the dynamic phases of drilling, freezing, heating, producing, and reclamation. For basin-scale fuel production, sub-basin sized cells are developed and reclaimed sequentially in the model, but, due to the timing of the different phases, activities can occur asynchronously in different cells. In each of the phases, energy and water requirements are computed as basin-wide production ramps up to a targeted rate. As the simulated industry grows throughout the region, economic and resource (e.g. water, energy, carbon, labor) requirements and limitations are tracked. Simulations demonstrate interdependencies among the multiple systems and resources as an industry ramps up, achieves steady state, and then ramps down.

PROJECT START DATE/DURATION

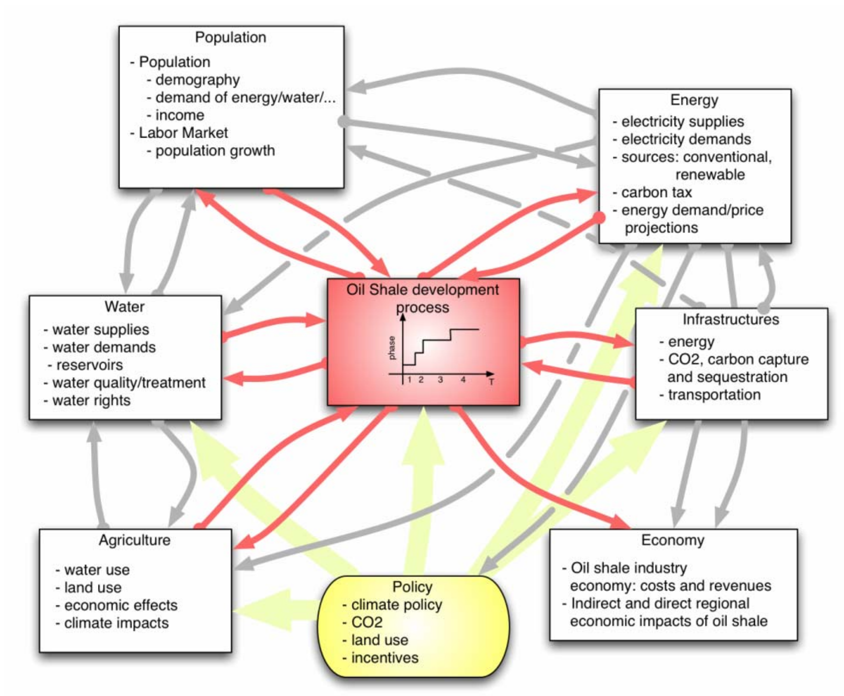
This project started on July 1, 2008 and ended in July, 2010. Final Report in Press.

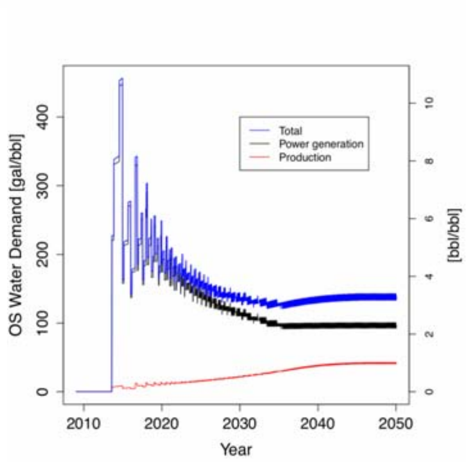
PROJECT SPONSOR(S)

- DOE-FE; Office of Naval Petroleum and Oil Shale Reserves

PROJECT DESCRIPTION

Development and application of *CLEAR$_{uff}$* is one of the three components of the recently completed LANL project to develop and test a simulation framework for assessing water and carbon issues and impacts related to basin-scale oil shale production. The *CLEAR$_{uff}$* capability represents a new assessment tool ready for application to address a variety of stakeholder questions and concepts for basin-scale fuel development. The scenarios analyzed focus on an approximation of a single in situ fuel production concept – the Shell In Situ Conversion Process (Shell ICP) and four alternative methods to provide the energy demand for large-scale development of oil shale-based transportation fuel. The power production concepts include a range from all natural gas to a combination of natural gas, coal, and renewable energy supplies. Each of these methods has different water demands for power production and different CO_2 generation rates per unit of energy. The *CLEAR$_{uff}$* results demonstrate how resource demands and production outputs track through time during the staged development of basin-wide oil shale production. In addition to tracking the timing of water demands for the different phases and the CO_2 generation, *CLEAR$_{uff}$* tracks the investments necessary for capital to produce at a targeted rate and the timing for profitability as basin-wide development proceeds. This requires, also, modeling the labor for construction, management and operations and the associated regional impact on the GDP. Finally, carbon capture requirements, as might be imposed by pending legislation, are considered with regard to their impact on the operating results (revenues minus costs) and compared with the Business as Usual case (BAU). The analysis shows that the oil shale development case depicts the synergies and tradeoffs between economic, environmental, national and energy security goals. The *CLEAR$_{uff}$* simulations show the ramp up to steady state in energy requirements, water demand and CO_2 generation. Thus, whereas many assessments to date assume steady-state rates of fuel production, water demand, and CO_2 generation, this simulation capability enables stakeholders to track the growth in demand, production, and potential impact.





Some key modules in *CLEAR$_{uff}$* and one scenario run looking at water demand during basin-wide development

Hydrologic Analysis of the Upper Colorado River Basin for Oil Shale Development and Potential Future Climate Change: WARMF Model

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PROJECT PURPOSE/GOALS

We use *WARMF* (Watershed Analysis Risk Management Framework), a dynamic basin hydrology model, to examine impacts of water demand growth, climate change, and climate variability on surface water flows in the Upper Colorado, Gunnison, and White River Basins. This model is used because streamflows on these rivers fluctuate significantly on daily, monthly and annual timescales, responding to weather and natural inter-annual climate variability. While water demand for oil shale production will also fluctuate through time, it will not be possible to shut down production during periods of drought (though some water intensive operations such as reclamation may be delayed under conditions of water shortage). Thus, this component of the LANL project seeks to examine the relationship between oil shale development water demand and natural variability in stream flows, with an emphasis on quantifying new storage capacity needs. We use the *WARMF* model to examine how much additional reservoir capacity will be required to meet water demand from commercial oil shale production rates of between 100,000 and 1.5 million bpd without significantly impacting current water use for humans and the environment. Our simulations include the effects of natural climate variability for scenarios that include both current and future climate conditions.

PROJECT START DATE/DURATION

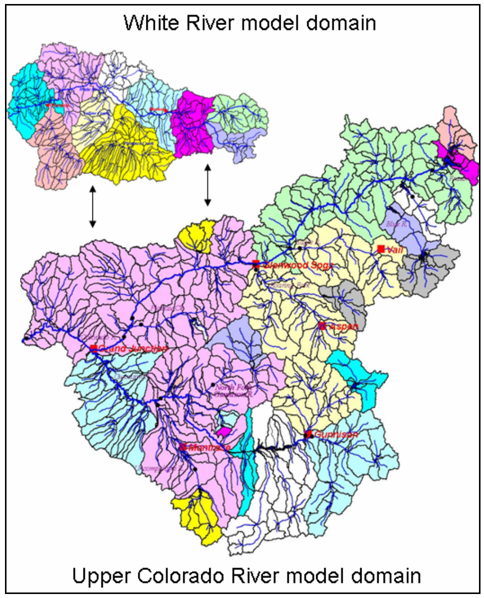
This project started on July 1, 2008 and ended in July, 2010. Final Report in Press

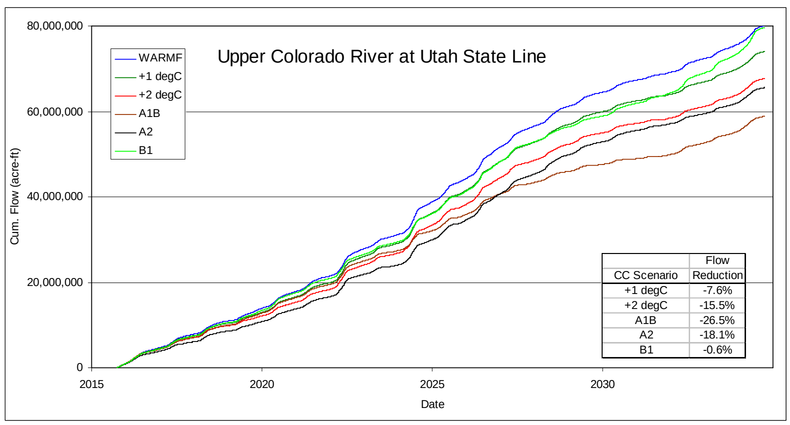
PROJECT SPONSOR(S)

- DOE-FE; Office of Naval Petroleum and Oil Shale Reserves

PROJECT DESCRIPTION

On average, there is a surplus of 600,000 af/year in the Colorado River. Even with a water demand ratio of 8:1 (barrels of water needed to barrels of oil produced), the annual demand for an oil shale production rate of 1.5 M bbl/yr would only be 564,000 af/yr. At first glance, it would seem that there is sufficient water available under these conditions. However, temporal fluctuations in river flow, particularly long periods of drought, require storage to shift water availability in time in order to provide continuous and reliable flows. This study examines flow rates that can be achieved for different sizes of additional storage capacity and puts them in the context of oil shale production rates that can be supported, based on water demand ratios. With potential climate change, periods of draught are longer and evapotranspiration is larger, so, for the same size reservoir, lower continuous flows can be provided. Conversely, this means that more storage capacity would be required to address the impacts of climate change in order to provide the same supply rate of water to the oil shale industry, as compared with current climate conditions.





OS Production Rate (bpd)	Water usage (af/year) for each ratio of water:oil							
	1:1	2:1	3:1	4:1	5:1	6:1	7:1	8:1
100,000	4,708	9,416	14,123	18,831	23,539	28,247	32,955	37,662
200,000	9,416	18,831	28,247	37,662	47,078	56,494	65,909	75,325
300,000	14,123	28,247	42,370	56,494	70,617	84,740	98,864	112,987
400,000	18,831	37,662	56,494	75,325	94,156	112,987	131,818	150,649
500,000	23,539	47,078	70,617	94,156	117,695	141,234	164,773	188,312
600,000	28,247	56,494	84,740	112,987	141,234	169,481	197,727	225,974
700,000	32,955	65,909	98,864	131,818	164,773	197,727	230,682	263,636
800,000	37,662	75,325	112,987	150,649	188,312	225,974	263,636	301,299
900,000	42,370	84,740	127,110	169,481	211,851	254,221	296,591	338,961
1,000,000	47,078	94,156	141,234	188,312	235,390	282,468	329,546	376,623
1,100,000	51,786	103,571	155,357	207,143	258,929	310,714	362,500	414,286
1,200,000	56,494	112,987	169,481	225,974	282,468	338,961	395,455	451,948
1,300,000	61,201	122,403	183,604	244,805	306,007	367,208	428,409	489,610
1,400,000	65,909	131,818	197,727	263,636	329,546	395,455	461,364	527,273
1,500,000	70,617	141,234	211,851	282,468	353,084	423,701	494,318	564,935

WARMF basins (top), simulated cumulative flow for some alternative climate change scenarios with no additional storage in the basin (middle), and simulated capacity needed for various fuel production rates and efficiencies under conditions of no climate change (bottom)

CO_2 Management for Oil Shale Development: *CO_2-PENS* and *SimCCS*

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PROJECT PURPOSE/GOALS

Two carbon management simulations tools, *CO_2-PENS* and *SimCCS*, are integrated together with $CLEAR_{uff}$ in this study to evaluate transport and sequestration options for CO_2 produced primarily from the power generation (natural gas and/or coal) infrastructure that may be necessary for basin-scale oil shale production. The tools are brought together to evaluate the potential for managing CO_2 for a range of oil shale production targets and alternative mixes of power generation. Taking the CO_2 rates simulated by $CLEAR_{uff}$, the sequestration capacity ($MtCO_2$/yr) for each of a set of target reservoirs is calculated in *CO_2-PENS,* along with the on-site injection costs (dollars per metric tonne of CO_2, \$/tCO_2) that include drilling, distribution piping, and maintenance. The set of reservoir capacities and on-site costs is provided to *SimCCS*, which calculates the optimal combination of reservoirs (sinks) and pipelines to store a given source rate of CO_2 from the oil shale industry

PROJECT START DATE/DURATION

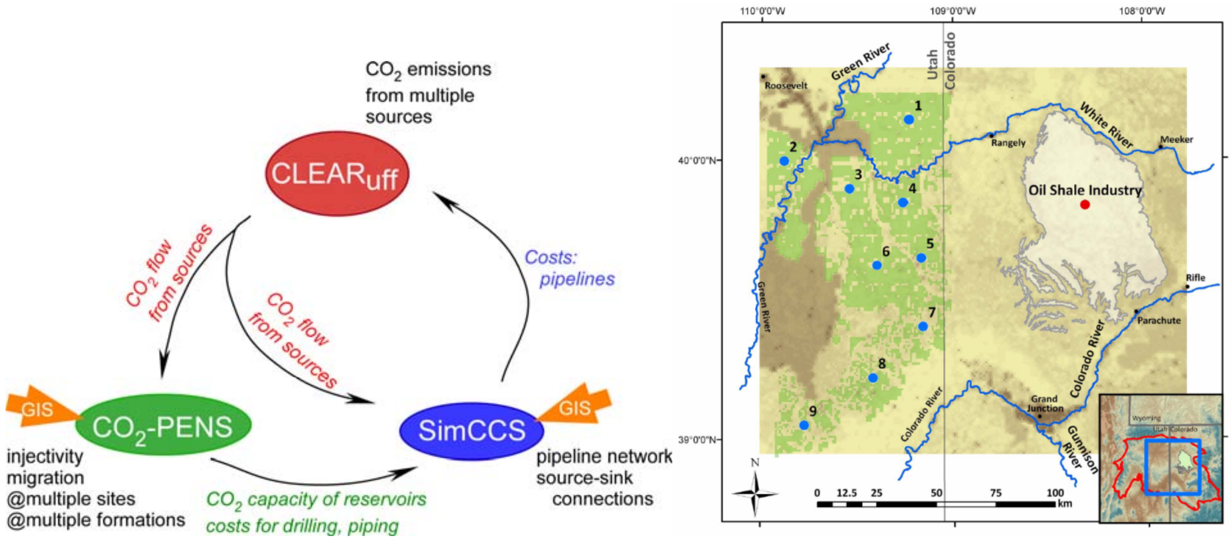
This project started on July 1, 2008 and ended in July, 2010. Final Report in Press

PROJECT SPONSOR(S)

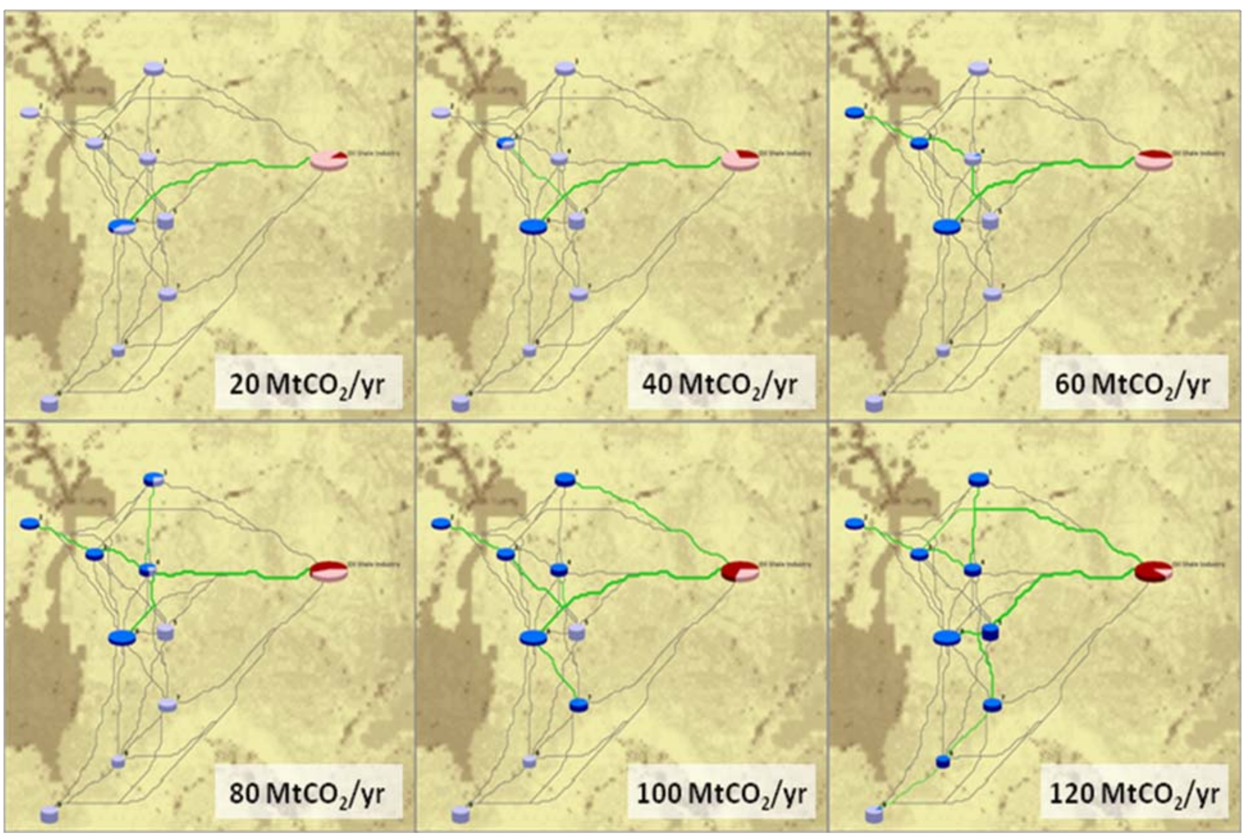
- DOE-FE; Office of Naval Petroleum and Oil Shale Reserves

PROJECT DESCRIPTION

For a range of oil shale production rates in the Piceance Basin, a range of costs for carbon transport and storage is calculated. The selection of the locations for the example sequestration reservoirs in this study emphasizes, among other criteria, proximity to the oil shale resource in the Piceance Basin. The abundance of accessible pore space in saline formations beneath the Green River Formation of the Piceance and Uinta Basins makes this kind of sequestration target a good choice for this proof-of-concept site-level study. A review of the available data favors sequestration reservoirs in the eastern Uinta Basin in Utah over potential sites in the Piceance Basin because the strata tend to be thicker in the eastern Uinta Basin than their equivalents in the Piceance. This not unexpected geospatial constraint enables appropriate demonstration of both the target reservoir characterization process and the infrastructure optimization process, both of which operate jointly to minimize costs of carbon management once it is captured at the power plant. The *CO_2-PENS* runs provide values of capacity and cost for each of nine potential target reservoirs. Then *SimCCS* optimizes the pipelines and usage of those reservoirs for different CO_2 management targets.



Framework relationships between CO_2 Management Modules and *CLEAR$_{uff}$* (left), CO_2 source and sequestration targets (right)



Carbon management simulations for a range of CO_2 production rates. Figure shows source at hypothetical power plant in Piceance Basin and optimized sequestration at targets in the Uinta Basin

Common Data Repository and Water Resource Assessment for the Piceance Basin, Western Colorado

Organization: U.S. Geological Survey
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Grand Junction, Colorado 81506
Phone: 970-245-5257x17 Fax: 970-245-1026

PROJECT PURPOSE/GOALS

- Develop a web-accessible common data repository that provides energy operators, researchers, consultants, agencies, and interested stakeholders equal access to the latest information.
- Evaluate existing water-resources data for uniformity.
- Perform and publish a baseline assessment of available water-resources data.
- Develop regional monitoring strategies to more economically fill identified data gaps by reducing duplication of effort while still meeting regulatory requirements.

PROJECT START DATE/DURATION

Funding for the project started June, 2008. The project was scheduled to run for 2 years with the first year focusing on compilation of water quality data and construction of the data repository, the second year would focus on data analysis and report writing. In May of 2010, USGS met with the project cooperators and discussed a no-cost extension owing to the extra time needed for data compilation as well as a 2 report approach for the study area, a groundwater report and a surface-water report.

PROJECT SPONSOR(S)

Currently this project has the following funding partners:

- U.S. Geological Survey
- Two Colorado Department of Local Affairs (DOLA) Energy and Mineral Impact Assistance Grants
- Bureau of Land Management (BLM)
- Garfield County
- Delta County
- Rio Blanco County
- Colorado River Water Conservation District
- City of Grand Junction
- City of Rifle
- Town of Carbondale
- Town of Silt
- Town of Rangely
- Town of Palisade
- Town of Parachute
- Town of De Beque
- EnCana Oil & Gas (USA) Inc.
- Chevron
- Shell Oil Company
- Petroleum Development Corporation
- Berry Petroleum Company
- Williams Exploration & Production

FUNDING

Currently, total project funding is $1,245,190.

PROJECT DESCRIPTION

Data Repository and Website

A common data repository has been assembled that combines surface- and groundwater data from numerous public and private sources. Data have been screened and merged from widely variable formats into a single reporting format. Routines to streamline future data updates will be developed and shared with the various data sources to simplify updates to the common data repository on a semi-annual or annual basis as needed. Data will be evaluated to identify data gaps and redundancies that will inform future monitoring planning. Each entity contributing data may provide some level of quality assurance; however, a data-quality-ranking scheme will also be used to assess the relative quality of data (e.g. Litke, 2001). Where applicable, the ranking scheme will take into account sampling procedure, field quality assurance, and laboratory/analytical method. Additional simple data-verification checks will be made on selected data to check for outliers or inconsistent values. Geographic checks will be made to compare, for example, well locations or reported well-screen depth to available aquifer information. The data repository assembly process will be documented and published in a USGS report.

Hydrologic Database: The hydrologic database will contain historical water data collected at monitoring sites near or in the Piceance Basin. The database will include surface-water data (streamflow measurements, stream water-quality data, reservoir water-quality data), groundwater data (water levels, groundwater-quality data, spring-flow measurements and spring water-quality data), and precipitation data (precipitation chemistry if available). The hydrologic database will be updated every 6-12 months during the life of the project.

Website: The website will provide access to data in the Repository. Users will be able to select information of interest through a combination of choices on interactive maps and interactive forms. Users will have the option of downloading custom retrievals of water-quality data of interest in spreadsheet format compatible for import to commonly-used spreadsheet, database, GIS, and statistical software packages.

Data Analysis

Because the common data repository will yield a vastly more complete and comprehensive base of information that lends itself to broad scale resource assessment, a detailed description of baseline conditions in the Piceance Basin will be conducted that will describe natural and human factors related to surface-water and groundwater systems. Data evaluation and resource assessment tasks will be completed in a manner that identifies opportunities to streamline and economize required regulatory-driven monitoring. The baseline assessment results will be published in 2 USGS reports, one covering groundwater and the other surface water.

Regional Monitoring Planning

Based on results of the groundwater and surface-water baseline assessments and the evaluation of existing data and data collection programs for uniformity and utility for tracking water-resource conditions, 2 regional monitoring plans will be developed, a groundwater plan and a surface-water plan. These monitoring plans will be developed in collaboration with energy operators and their representatives in addition to the various agencies and stakeholders. The goal of the regional monitoring plan and development of consistent and coordinated monitoring strategies is to streamline existing monitoring such that the resultant datasets minimize duplication of effort and maximize utility for spatial and temporal assessment of local and regional scale water resource conditions.

Oil Shale Assessment

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PROJECT PURPOSE/GOALS

Assess the oil shale resources of the Eocene Green River Formation, Colorado, Utah, and Wyoming, and of the Mississippian-Devonian strata in the eastern United States.

PROJECT START DATE/DURATION

Funding for the project started April, 2007. The project is scheduled to run four years with the first two years focusing on oil shale of the Green River Formation and the second two years focusing on eastern oil shales.

PROJECT SPONSOR(S)

- USGS Energy Resources Program; Line item funding under the Energy Policy Act of 2005
- The project is funded at $500,000 per year

PROJECT DESCRIPTION

This project consists of putting together the most complete inventory ever attempted of the in-place oil shale resources of the Green River Formation in the Piceance Basin of western Colorado, the Uinta Basin of eastern Utah and western Colorado, and the Greater Green River Basin of southwest Wyoming and northwest Colorado. The oil shale interval in the Piceance Basin is subdivided into seventeen "rich" and "lean" zones that were assessed separately. These zones are roughly time-stratigraphic units consisting of distinctive, laterally continuous sequences of rich and lean oil shale beds that can be traced throughout much of the Piceance and Uinta Basins. The oil shale resources of the Greater Green River Basin will be subdivided into four or five stratigraphic intervals with each zone assessed separately.

All of the Fischer Assay data, corehole location data, and oil shale zone tops files have been assembled into one Access database. Due to the number of data records (approximately half a million) and the complexity of the spatial data involved in the assessment, Microsoft Access database management software and ESRI's ArcGIS software were used to combine, store and analyze the raw data. The ability to create custom forms in Access was a crucial element in the assessment methodology as it allowed staff to write Visual Basic scripts and SQL statements to filter subsets of the data and perform the necessary calculations using Access form controls. The public benefits from this process as the original forms used to calculate resources also serve as the end-user interface to view the raw data in a more simplified and meaningful manner. After resources were calculated for each corehole, the resultant Access tables were linked seamlessly with ESRI's ArcGIS software to model, extrapolate and quantify the data spatially. The end product is a large database of tables (spreadsheets), forms to view the data and a series of maps quantifying the results of those calculations.

In this assessment, a spatial interpolation and extrapolation method for generating resource maps and computing resource volumes was used--the Radial Basis Function (RBF) in ArcGIS GeoStatistical

Analyst (Environmental Systems Research Institute, Inc. (ESRI), Redlands, Calif., 2006, version 9.2). Four maps are generated for each interval: 1) isopach map, 2) variation in gallons per ton, 3) variation in barrels per acre, and 4) total in-place resource in each 36-square mile township. In addition, structure contour maps on the tops of several key oil shale zones have been constructed.

At this time, recoverable shale oil will not be estimated as there are currently no proven, economically viable extraction methods. The intent is to calculate recoverable shale oil once these extraction technologies are perfected. Dividing the resource into a large number of individual zones should aid greatly in this future effort. In addition, volumes of overburden have been calculated on key oil shale horizons by overlaying the structure contour maps on land surface grids.

In addition to oil shale resources, the in-place nahcolite resources that occur with the oil shale in the Piceance Basin have been calculated. Nahcolite is a leasable sodium bicarbonate mineral that has been solution mined in the Piceance Basin. It has many uses, including being used in scrubbers that remove pollutants from stack gases in coal-fired power plants. It is, however, a potential problem for the in-situ oil shale extraction methods that are currently being developed, as any nahcolite present in the oil shale interval will break down during the heating required to extract oil in these in-situ methods generating large quantities of carbon dioxide, a major greenhouse gas.

Analysis of CO_2 Emissions from Unconventional Fossil Fuel Resources

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PROJECT PURPOSE/GOALS

- Evaluate life-cycle greenhouse gas emissions from several oil sands and shale processes and compare these to conventional liquid-fuel production processes
- Evaluate opportunities to reduce life-cycle CO_2 emissions from these unconventional resources such as the use of oxygen firing in upgrading and refining processes for CO_2 capture
- Develop a tool for predicting life-cycle CO_2 emissions for these opportunities

PROJECT START DATE/DURATION

October 1, 2009 to March 31, 2011

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $160,000

PROJECT DESCRIPTION

In the future, one important selection criterion for the nation's energy supply will likely be the life-cycle carbon footprint of the resource. The state of California has already adopted a carbon-based fuel standard, and similar standards are currently being discussed in several states. Consequently, we are evaluating life-cycle greenhouse gas emissions (GHG) from several oil sands and shale processes and opportunities for reducing GHG emissions.

As a first step, we are gathering and summarizing available data on life-cycle GHG emissions from a variety of oil sands and shale liquid-fuel production processes. It can be challenging to compare life-cycle estimates of GHG emissions from the production of transportation fuels because of differences in the functional unit (i.e., barrel of raw bitumen, barrel of synthetic crude, energy content), which processes are included in the assessment, (i.e., construction of the upgrading plant, transportation between the upgrading and refining facility, reclamation processes, etc.), and lack of detail on assumptions, conversion factors, and fuel quality. Figure1 provides a comparison of life-cycle, well-to-pump GHG emissions from gasoline, oil sands, and oil shale processes. A summary of published ranges is listed above each column. For oil shale in general, estimates vary more widely (38 - 180 g CO_2 equiv/MJ) than for liquid fuels produced from petroleum or from oil sands because oil shale is not produced commercially in the U.S. and because of uncertainty over the amount of CO_2 released from minerals in the oil shale during processing.

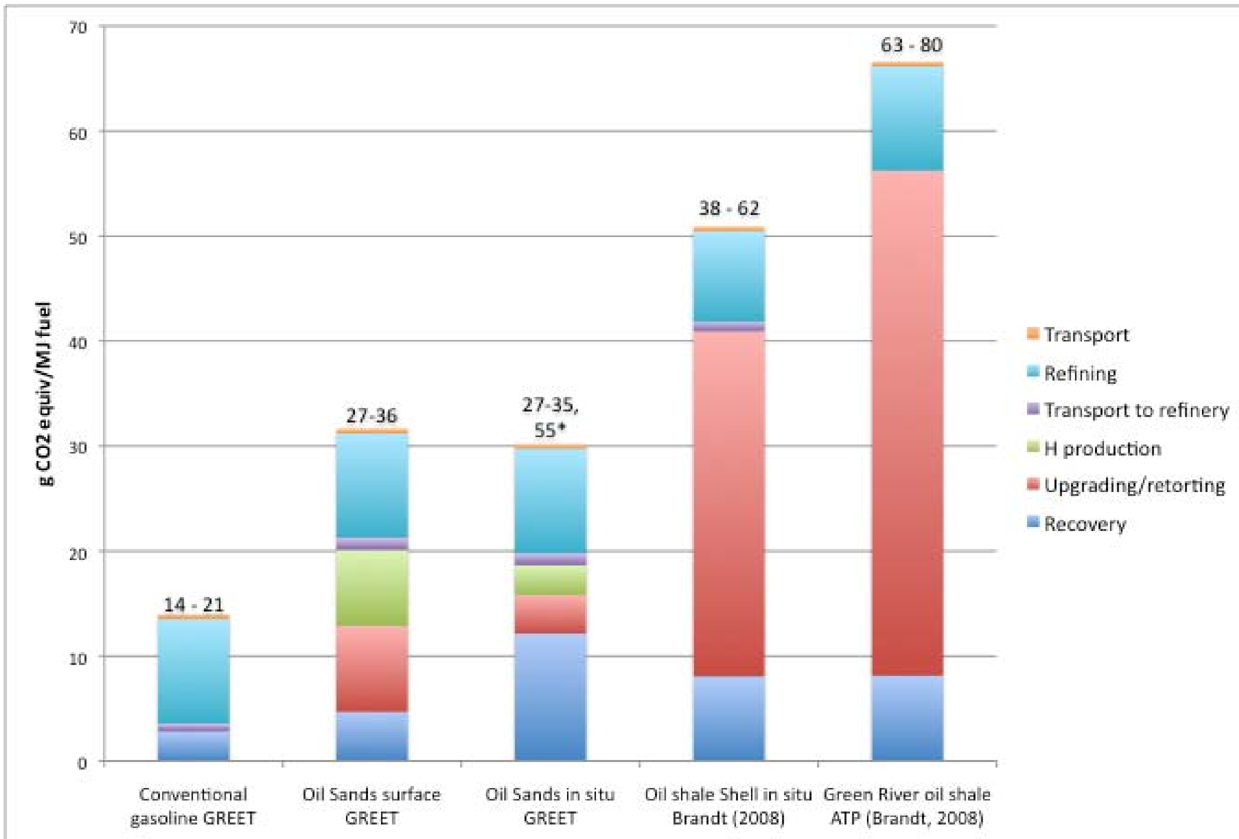

Figure 1: Life-cycle, well-to-pump GHG emissions from gasoline, oil sands, and oil shale processes.

Because of concern over GHG emissions, carbon-based fuel standards and the larger GHG life-cycle emissions of unconventional fossil fuels when compared to conventional fuels, there is significant interest in reducing GHG emissions from unconventional fuel sources through efficiency improvements and carbon capture and sequestration (CCS). The refining industry, as the third largest stationary source of GHG emissions globally, is evaluating technologies such as oxyfiring for GHG reduction. Oxyfiring is a promising technology for reducing the CO_2 footprint from this industrial sector, but it requires a significant amount of energy to generate oxygen in an air separation unit. We are currently evaluating the potential for reducing life-cycle GHG emissions from a refinery employing oxy-fuel combustion for CO_2 capture in its boilers and process heaters. This evaluation includes the additional GHG emissions associated with the power required for air separation and CO_2 handling; the fuel savings from oxyfiring compared to air firing; and the upstream GHG emissions associated with the additional fuel requirements.

INSTITUTE FOR Clean and Secure Energy
THE UNIVERSITY OF UTAH

Basin-wide Characterization of Oil Shale Resource in Utah and Examination of In-situ Production Models

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PROJECT PURPOSE/GOALS

- Analyze how geologic heterogeneity impacts production from Utah oil shale resource.
- Build a more effective reservoir simulation tool capable of managing physics unique to oil shale production processes.
- Incorporate reaction kinetics, pore property information, and reservoir characterization into simulation.

PROJECT START DATE/DURATION

October 1, 2009 to March 31, 2011

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $230,000

PROJECT DESCRIPTION

In-situ oil shale processing has the potential to minimize surface disturbance and process water requirements and to access deep, un-mineable resources. Modeling the thermally-induced transformation of oil shale kerogen to liquid and gaseous fuels requires solving mass and energy conservation equations, which in turn requires physical understanding and models for reaction kinetics, multiphase fluid flow, geomechanics, and heat transfer. At reservoir scales, each of these submodels has continuously changing parameters that may affect model predictivity. Sparse geological data is an additional challenge as mineral and organic heterogeneity between and within resources may be important.

Various commercial reservoir simulators, including the STARS simulator developed by Computer Modeling Group (CMG), have capabilities to represent thermal in-situ processes. We are using STARS to evaluate the sensitivity of production rates from oil shale to various parameters involved in in-situ processes. For example, we are performing an analysis of heterogeneity impacts on production from Utah oil shale resources and comparing that sensitivity to those of reaction, heat transfer, and geomechanical, and flow parameters. This sensitivity comparison will give insight into the complexity required of each submodel used in the simulator.

Geological characterization of cross sections (Figure 1) in the Uinta Basin is providing a better picture of the organic and inorganic content of the reservoirs of interest and of their heterogeneity. Organic content information from this characterization has been incorporated into process simulations. Various sensitivity studies have been conducted to expose the interplay between physical parameters in STARS. Early results show that activation energies in a multi-step reaction scheme and relative permeability representations affect oil production results more than heat of reaction.

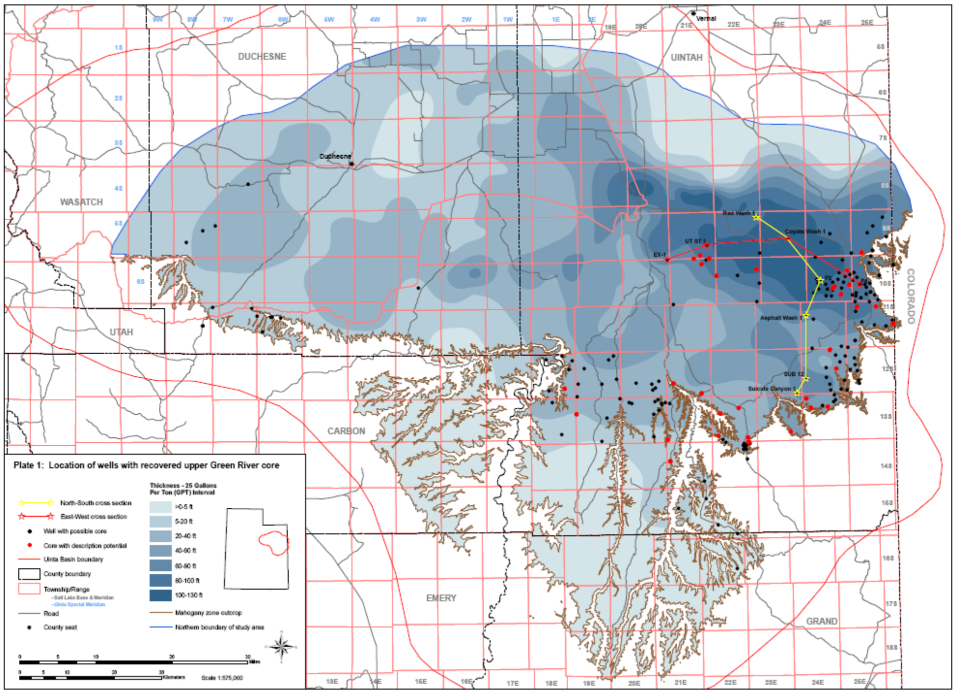

Figure 1: Green River oil shale core analysis work with current, E-W (red line), and proposed, N-S (yellow line), cross section locations. Darker blue areas indicate higher yield regions. From M. VandenBerg, “Basin-wide evaluation of the uppermost Green River Formation's oil-shale resource, Uinta Basin, Utah and Colorado.” Presented at 29th Oil Shale Symposium, October 19-21, 2009, Golden, CO.

To achieve better predictivity, simulation tools will need to account for physics occurring at vastly different spatial and temporal. In addition, more detailed geological information, more complex geomechanical models, and more representative kinetic parameters need to be included in the simulator and in the sensitivity studies. Sensitivity to permeability could be a crucial parameter to understand and to accurately represent in the simulator. The limitations of commercial simulators in modeling oil shale pyrolysis will then be evaluated and more effective modeling tools developed.

Development of CFD-Based Simulation Tools for In-Situ Thermal Processing of Oil Shale/Sands

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PROJECT PURPOSE/GOALS

- Assess the capability of Computational Fluid Dynamics (CFD)-based simulation tools to quantitatively predict performance of a modified in-situ oil shale treatment process
- Use simulation data and available test data from the ECOSHALE capsule to perform a validation/uncertainty quantification (V/UQ) of the modified in-situ process
- Demonstrate how the V/UQ approach can provide quantified understanding of the ECOSHALE capsule performance and can be used to predict performance of other in-situ processes

PROJECT START DATE/DURATION

October 1, 2009 to December 31, 2010

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $233,000

PROJECT DESCRIPTION

In-situ technologies are currently being explored because of their potential for reducing the environmental footprint of oil shale development. However, the first generation technologies have proven to be energy-intensive, and many unknowns remain relative to optimal heating strategies, potential groundwater contamination, and achievable production rates.

Reservoir simulation tools are typically applied to in-situ production processes. However, in the case of a modified in-situ process, there is a distribution of rock size and orientation (important due to directional permeability of the rock) in the production bed and those rocks are packed in such a way that large convective currents heat the bed. Preliminary simulations using a reservoir simulation-type approach (e.g. fluid flow through porous media) showed that such an approach is insufficient to resolve key physics affecting production rates, particularly convective heat flow patterns.

We are taking the novel approach of applying CFD-based tools simulation tools to a modified in-situ process. Rigorous validation/uncertainty quantification (V/UQ) requires both a simulation tool that captures the relevant physical processes and data from a large-scale system. Initially, we are focusing on pilot-scale heat transfer data obtained from Red Leaf Resources' ECOSHALE capsule. As data sets from other processes become available, the tools being developed can be applied to those processes as well.

To simulate the ECOSHALE capsule, which consists of a clay-lined volume filled with rubblized oil shale and heated by pipes fired with natural gas burners, we are using a suite of commercial software tools, including EDEM, Matlab, Gambit, and Star-CCM+. EDEM, a discrete element method, allows the user to pack particles randomly based on an input distribution of particles sizes and on particle physics. Figure 1 shows the particle packing output from EDEM in a slice of the ECOSHALE capsule. This particle packingis then meshed using Gambit; channels between the particles where fluid flow can occur are included in the computational mesh. This computational mesh becomes an input to Star-CCM+, with which we simulate the channel physics (using Large Eddy Simulation) of the modified in-situ system and potentially the particle (porous) physics as well. By incorporating an appropriate kerogen pyrolysis model, we can also compute production rates of gaseous and liquid fuels for a given gas burner firing rate.

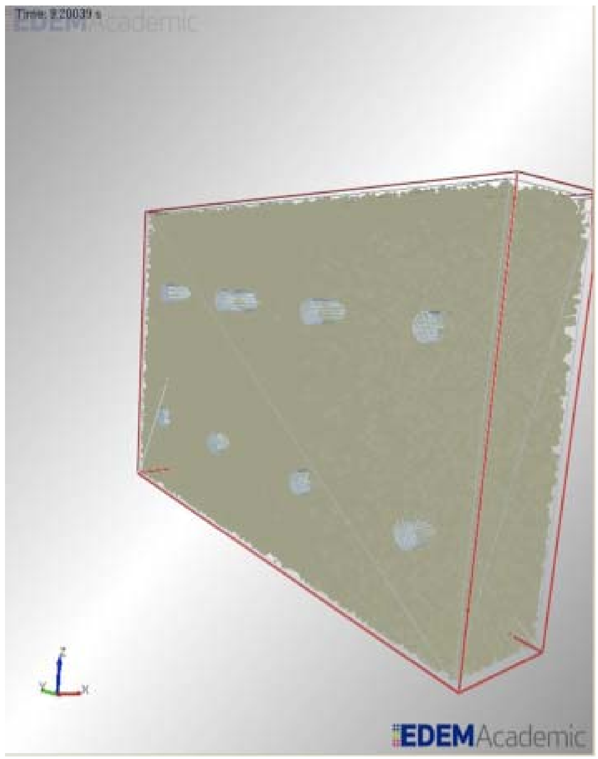

Figure 1: Slice of ECOSHALE capsule showing heating tubes in grey and particle packing in taupe.

Once this set of tools has shown its efficacy with a demonstration simulation of the ECOSHALE capsule, a V/UQ analysis will be performed involving experimental uncertainty, model uncertainty, operating condition uncertainty and numerical uncertainty with the goal of better understanding the processes that drive production in a modified in-situ process.

INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

Econometric Analysis Methods for Heavy Oil Production and Upgrading

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PROJECT PURPOSE/GOALS

- Develop scenarios for economic evaluation of methods to produce various heavy oils. The scenarios include:
  - Uinta Basin oil shale extraction
    Surface mining
    In situ extraction
  - Uinta Basin oil sands extraction
    Surface mining
    In situ extraction
  - North Slope heavy oil extraction
    Steam injection and oil well extraction

PROJECT START DATE/DURATION

October 1, 2009 to December 31, 2010

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $80,000

PROJECT DESCRIPTION

Supply costs have been performed by various industries interested unconventional fuels extraction, but these costs are not shared with policy makers. This study will perform supply cost predictions on a consistent basis for three unconventional fuels production (oil shale, oil sands, and heavy oil), allowing direct comparisons between these resources.

Each scenario will be developed at a production capacity of 50,000 bbl/d and will include one or more types of extraction with the subsequent primary and secondary upgrading of the crude oil to produce pipeline-quality oil ready for transport from the point of upgrading to a refinery capable of refining it.

Supply costs will be developed for the various scenarios using industrial standard methods for the estimation of capital and operating costs for each year over the life of the project. These supply cost analyses will include sensitivity analyses for various utilities and raw materials and the impacts of either CO_2 sequestration or CO_2 tax at various levels. Standard accounting methods are used to establish discounted cash flow predictions for the project allowing various measures of profitability to be established. Operating costs are determined by accounting for 1) the direct manufacturing costs including feed stocks, utilities including electricity, water (steam, cooling and process), refrigeration, fuels, solid waste treatment, waste water treatment and air-pollution abatement as well as labor and maintenance, 2) operating overhead, and 3) fixed costs including: property taxes and insurance, depreciation, as well as general expenses including selling (or transfer) expenses, research (direct or allocated) expenses, administrative expenses and management incentives. Well drilling costs are estimated from recent industrial data available from collaboration with industry.

We will perform simulations of the various processes used to produce and refine these unconventional fuels using Aspen or ProMax process simulation software. In all cases, the final product is pipeline-quality crude oil that can be sold to a refinery. The process simulation gives information on the oil production rate, use of utilities and raw materials, and the size of major pieces of equipment; capital and operating cost per unit of oil production can thus be determined. The process simulations to be performed include extraction by various means described in the scenarios, primary upgrading, secondary upgrading including hydrogen generation (see Figure 1), and pipeline transportation to a refinery. The process simulations will be rerun for the various cases in the sensitivity analysis to determine the effect on supply costs of differences in raw material costs and utility costs.

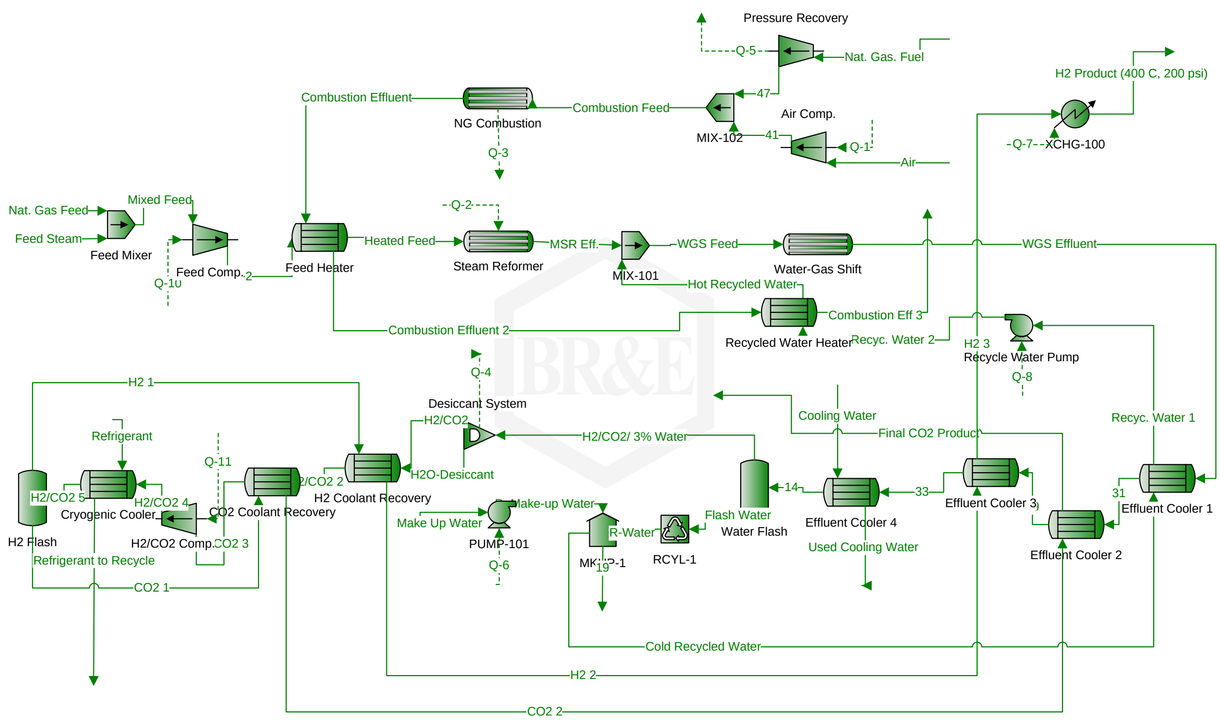

Figure 1: Process flow sheet of the process to convert natural gas to hydrogen for heavy oil upgrading.

These supply costs will then be used in a profitability analysis calculating return on investment, pay-back period, and investor rate of return as well as annual cash flows for 20 years. Commodity prices will be predicted in out years using an extrapolation of historical price volatility data. A sensitivity analysis will be performed with respect to commodity prices for the oil produced and will be coupled with the supply cost sensitivity analysis to determine what effect these variations have on profitability measures. Finally, the impact on the environment will be determined for each of these scenarios including greenhouse gas emissions, water use, waste water produced and solid waste produced.

INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

Effect of Oil Shale Processing on Water Compositions

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PROJECT PURPOSE/GOALS

This project is part of a larger water management effort in the Uinta Basin being performed at the Utah Geological Survey with the following objectives:

- Evaluation of saline water disposal problems impacting oil and natural gas development
- Examination of how saline water disposal from conventional petroleum development might create technical and economic hurdles for a prospective oil shale industry
- Collection of baseline surface- and ground-water information which could be used by oil shale development companies
- Analysis of water produced from different *in-situ* oil shale extraction technologies

PROJECT START DATE/DURATION

October 1, 2009 to December 31, 2010

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $84,000

PROJECT DESCRIPTION

All of the significant oil shale deposits in Utah are located in the Uinta Basin, a petroleum-rich basin that is home to significant conventional oil and gas production activities as seen in Figure 1. In the last few years, the basin has seen a large increase in unconventional gas production activity. In these operations, natural gas is produced from reservoirs of very low inherent permeability. One of the significant technical and environmental issues in these operations is the disposal of produced water. One method of disposing this water is to inject it into aquifers of sufficient capacity. Eastern Uinta Basin gas producers dispose of produced water in the Bird's-nest aquifer located in the Parachute Creek Member of the Green River Formation because of its suitability for large volume disposal. Utah's oil shale deposits are also located within the Parachute Creek Member. The Bird's-nest aquifer is typically several hundred feet above the richest oil shale interval, the Mahogany zone. In-situ operations for the production of oil shale, which would require heating the deposits in place, could impact the dynamics of water movement and water composition in the aquifer and ongoing water injection activities. This project specifically addresses the water composition question by studying the possible implications of an in-situ pyrolysis process on water quality.

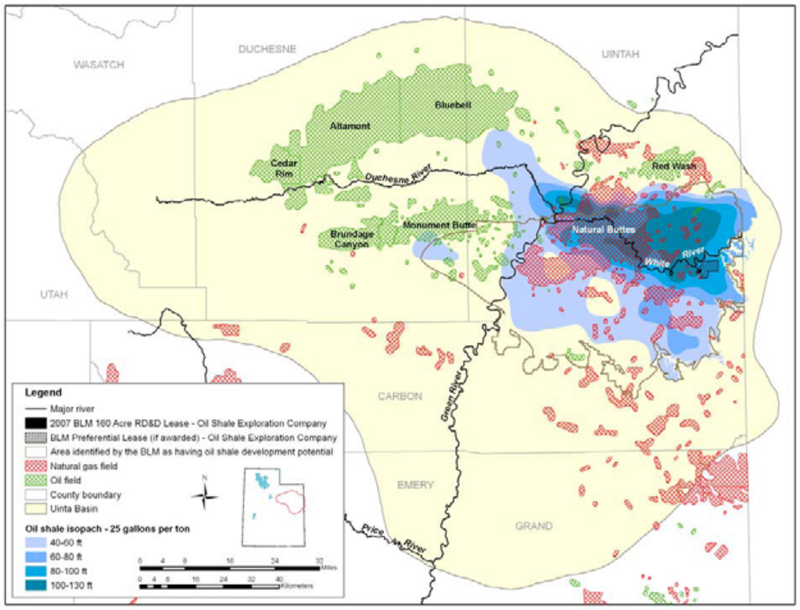

Figure 1: Map showing proposed study area, Uinta Basin, Utah. Note that the prime oil shale area overlaps with several natural gas fields.

We are utilizing the same experimental system that was constructed to study multi-scale kerogen pyrolysis. We determined the types of organic constituents that would characterize the samples by obtaining the detailed composition of an oil sample produced using hydrous pyrolysis at 400^0C for 24 hours. Some of the identified compounds are tabulated in Table 1.

Table 1: Organic compounds identified in the oil produced. The double-bonded compounds and aromatics have higher water solubilities.

Library/ID	Library/ID
1-Heptene	1H-Pyrrole, 2,3,5-trimethyl-
Heptane	Decane
Toluene	**Benzene, 1,3,5-trimethyl-**
Heptane, 2-methyl-	1-Decene, 4-methyl-
1-Octene	Decane, 4-methyl-
Octane	2-Decene, 4-methyl-, (Z)-
Cyclohexane, 1,1,3-trimethyl-	**Benzene, 1-methyl-4-(1-methylethyl)-**
1-Heptene, 2,6-dimethyl-	2-Nonanone
6,6-Dimethylhepta-2,4-diene	1-Undecene
Benzene, 1,3-dimethyl-	Undecane
1-Nonene	1H-Pyrrole, 3-ethyl-2,4,5-trimethyl-
Nonane	2-Decanone
Octane, 2,6-dimethyl-	1-Dodecene
Heptane, 3-ethyl-2-methyl-	Dodecane
Benzene, 1-ethyl-2-methyl-	Undecane, 2,6-dimethyl-
Benzene, 1-ethyl-2-methyl-	Cyclohexane, 2-butyl-1,1,3-trimethyl-
2-Octene, 2,6-dimethyl-	Octane, 2,3,7-trimethyl-
Benzene, 1,2,3-trimethyl-	1-Tridecene
Nonane, 4-methyl-	1-Octene, 3,7-dimethyl-
Cyclohexane, 1,2,3-trimethyl-	Tridecane
Benzene, 1,3,5-trimethyl-	1H-Indene, 2,3-dihydro-1,1,3-trimethyl-
Cyclopentene, 1,2,3,4,5-pentamethyl-	Naphthalene, 1,2,3,4-tetrahydro-1,1,6-trimethyl-
1-Decene	Decane, 2-methyl-

Kerogen/Asphaltenes Atomistic Modeling

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PROJECT PURPOSE/GOALS

- Establish a representative three-dimensional model of the Green River oil shale kerogen
- Develop a protocol for model validation with respect to available experimental data
- Model interaction of kerogen with the inorganic matrix

PROJECT START DATE/DURATION

October 1, 2009 to December 31, 2010

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $169,000

PROJECT DESCRIPTION

Atomistic modeling is routinely used in many industries (pharmaceutical, polymers, coatings, explosives, membrane proteins, etc.) to gain insight into material properties, biological properties and behavior. The three-dimensional models of kerogen are obtained by performing a molecular mechanics minimization of a two-dimensional model followed by a simulated annealing procedure to generate new structures.

The three-dimensional characteristics of kerogen not only define the manner in which the kerogen folds and interacts with the extractable bitumen, but also provide a new structural view that shows which portions of the structure are exposed on the surface, which are accessible through channels, or which may be isolated in the interior of the structure.

The computational results can be correlated with experimental data obtained from solid and liquid state ^{13}C NMR spectroscopy, magnetic resonance imaging, TGA data on pyrolysis kinetics, small angle X-ray scattering, and ICR-mass spectroscopy via atom pair distribution function analysis. Figure 1 shows the three-dimensional structure of a 12-unit kerogen model.

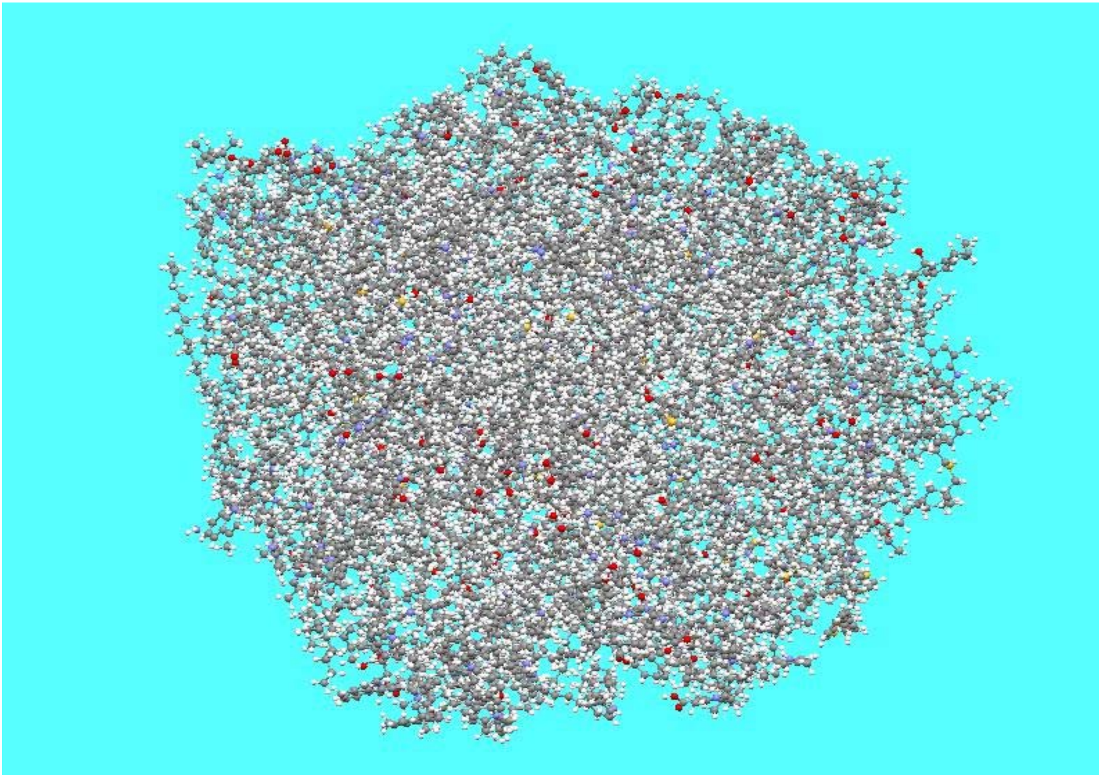

Figure 1: Structural model with 12 kerogen units (20402 atoms). The atom colors are as follows: C - gray, O - red, N - blue, S - yellow, H - white. The tubes represent the molecule's backbone and the spheres represent the atoms.

The interaction of the kerogen structure with the inorganic matrix will be modeled using molecular mechanics minimization of the established three-dimensional kerogen sandwiched between slabs of illite. Our goal of understanding the nature of these interactions is critical to design new approaches that can more readily facilitate the extraction of kerogen from oil shales without resorting to costly thermal processes.

INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

Land and Resource Issues Relevant to Deploying In-Situ Thermal Technologies

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PROJECT PURPOSE/GOALS

- Investigate land ownership, resource ownership, and associated jurisdictional issues that present challenges to unconventional fuel utilization
- Research consolidation of isolated state sections
- Analyze opportunities for coordinated leasing and regulation across multiple jurisdictions
- Analyze legal and policy solutions to these challenges for in-situ thermal oil shale/sands development

PROJECT START DATE/DURATION

October 1, 2009 to December 31, 2010

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $143,000

PROJECT DESCRIPTION

When Utah became a state, it received title to four sections in every township plus more than 1.5 million acres of additional land, which was granted to the state in support of public schools and institutions. The sections granted to the state are scattered across the landscape and, except where consolidated, reflect a checkerboard pattern of ownership. Under the 1872 Mining Act, thousands of acres of mining claims on federal land were "patented" and reduced to private ownership. Patented lands are also scattered across the landscape. Additionally, creation of the Uintah and Ouray Reservation set aside a large block of land in eastern Utah as the permanent home for the Northern Ute Tribe of Indians. The checkerboard of ownership of Uinta Basin oil shale resources is shown in Figure 1. By comparison, almost all oil shale resources within the most prospective portion of Colorado are under federal or private control and jurisdiction is much less fragmented.

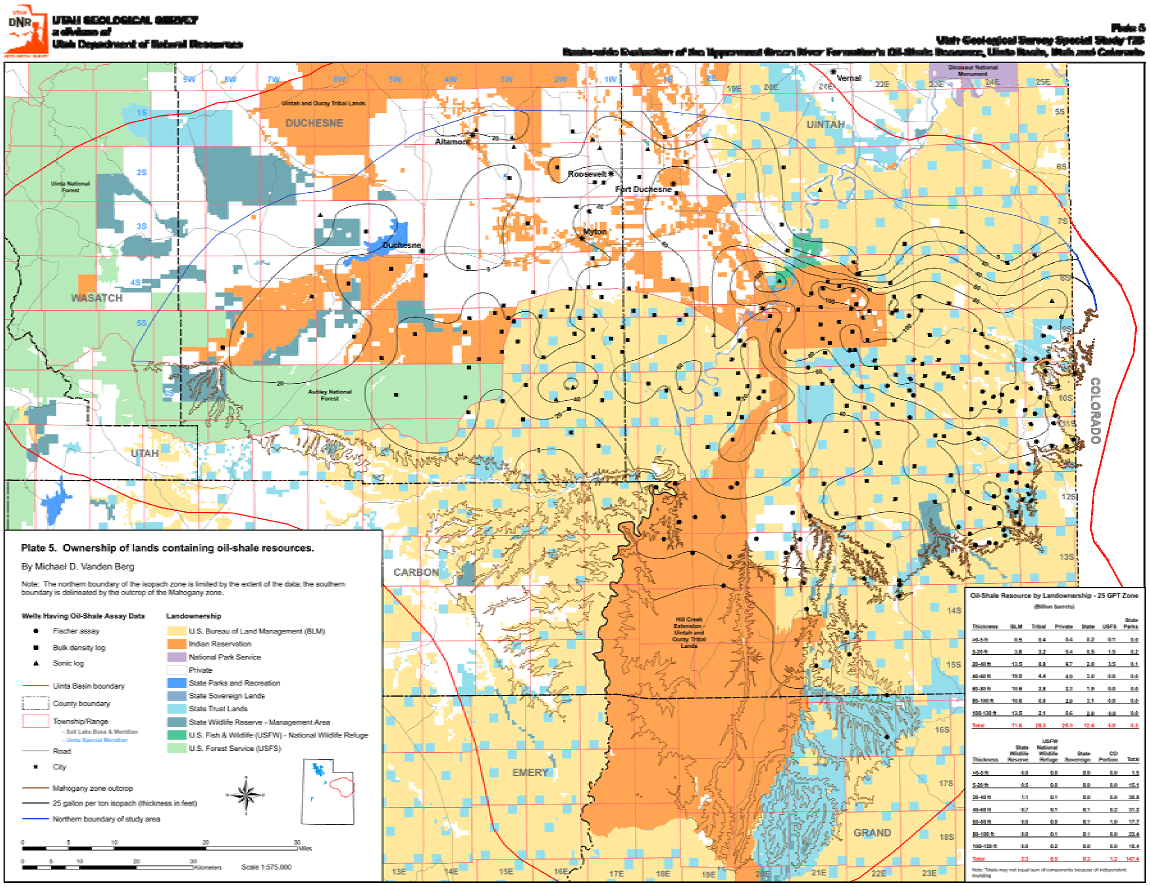

Figure 1: Map showing ownership of lands with oil-shale resources in the Uinta Basin. From M. Vanden Berg, Utah Geological Survey Special Study 128, 2008.

The various land owners and management agencies have disparate management objectives and management requirements. For instance, the Bureau of Land Management (BLM), which manages the majority of federal land within the Uinta Basin, operates under a multiple use, sustained yield mandate. The Utah School and Institutional Trust Lands Administration (SITLA), which manages state trust lands, is charged with maximizing returns for trust beneficiaries. BLM lands are subject to comprehensive planning requirements that include extensive public involvement; this obligation does not fall on SITLA. Management requirements therefore vary significantly across the jurisdictional patchwork.

Attempts to coordinate or improve management fall into two general categories: (1) cooperative management and (2) land exchanges. Pooling of oil and gas resources is an example of the former and dealt with in accordance with requirements set forth in state law. The State of Utah and the federal government have engaged in a number of land exchanges in an attempt to consolidate ownership. These exchanges and selection of in-lieu lands have proven highly controversial, resulting in protracted litigation. Both categories of management action have proven cumbersome because of disparate mandates and development philosophies.

For this project, land and resource research will focus on clarifying resource ownership, management objectives, and areas of likely conflict. Research will also look at methods for exchanging lands, the requirements applicable to exchanges, and means of improving exchange efficiency. The research will include an example of collaborative cross-jurisdictional management and will seek opportunities to increase management efficiency. The project will culminate with a topical report submitted to the Department of Energy.

INSTITUTE FOR Clean and Secure Energy
THE UNIVERSITY OF UTAH

Market Assessment of Heavy Oil, Oil Sands, and Oil Shale Resources

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PROJECT PURPOSE/GOALS

- Review current energy climate and the potential role of unconventional fuels (specifically heavy oil, oil sands, and oil shale)
- Examine policy and regulatory issues that will affect unconventional liquid fuels development
- Identify and examine the externalities that will not be included in the supply cost analysis and how those externalities may influence unconventional fuels development
- Identify a range of plausible production scenarios for domestic heavy oil, oil sands, and oil shale
- Establish the supply cost for each of these scenarios, identify revenue streams, and use the approach of an economic impact analysis to show likely regional effects from one or two of the production scenarios.
- Prepare an assessment report for distribution to policy makers and the public

PROJECT START DATE/DURATION

October 1, 2009 to December 31, 2010

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $239,000

PROJECT DESCRIPTION

Despite decades of research (both academic and industrial) and a relatively favorable oil price, development of unconventional fuels (specifically oil sands, oil shale, and heavy oil in Alaska) has been limited. At the request of the DOE Office of Oil and Gas per the recommendation of the Federal Advisory Committee on Unconventional Oil and Gas (Sect. 999), we are conducting an assessment that examines limiting factors to the development of domestic heavy oil, oil sands, and oil shale resources and identifies policy, technology, and economic gaps that could be advanced through increased research activities.

While numerous studies have been conducted that estimate supply costs, environmental footprints, and economic impact for various types of unconventional fuels development, our approach is somewhat different. First, we have identified six scenarios that span the range of oil shale, oil sands, and heavy oil development. Second, we are using a microeconomic impact (e.g. supply cost) analysis to determine commercial viability of given production scenarios due to induced effects such as economic constraints/uncertainties (market for refinery outputs, the price of natural gas, the potential price of CO_2, etc). As part of the analysis, supply costs associated with bringing sources of unconventional liquid fuels to market, including upstream production, down stream processing, & transportation are computed. Third, the overall view of commercial viability incorporates findings on producers' revenue and on costs.

Fourth, for a couple of plausible oil shale/sands production scenarios in Utah, an economic impact analysis will be conducted that estimates the total addition to regional levels of employment, personal income, and government revenue from those scenarios. Fifth, we have chosen scenarios for which there industrial support/collaboration.

For each resource type (oil shale, oil sands, heavy oil), we have established criteria to allow filtering of production scenarios for further study. For example, the induced effects on the commercial viability of a given production scenario due to economic constraints and uncertainties such as the market for refinery outputs, the price of natural gas, and the potential price of CO_2 must be considered. The likelihood and magnitude of these microeconomic impacts has guided the choice of scenarios because the scenarios get their plausibility from their commercial viability.

Next, we are establishing the supply cost for each of these scenarios. Note that the supply cost can be partitioned among construction (amortized), operations, and contingent costs, where contingent costs are those coming from shocks such as such as rising natural gas, oil, or carbon-emission prices. It is these contingent costs that are most pivotal to viability among the uncertain costs. For each production stage within each scenario, we are creating lists of construction inputs and of operations inputs. These lists are the feedstock for the economic impact analysis (i.e. the macroeconomic model), which is meant to show the likely regional effects (on employment, income, tax revenue, etc.) from such an operation.

Multiscale Thermal Processing (Pyrolysis) of Oil Shale

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PROJECT PURPOSE/GOALS

- Perform thermal gravimetric analysis (TGA) and bench scale experiments on cores of different sizes to create mechanistic pathways for the conversion of kerogen to oil.
- Conduct pyrolysis of oil shale at high temperature and pressure, as would exist under in-situ conditions, for a range of heating rates
- Measure compositions of raw material and of products at different stages of conversion
- Develop a comprehensive kerogen pyrolysis model that combines heat and mass transport mechanisms along with reaction kinetics

PROJECT START DATE/DURATION

October 1, 2009 to March 31, 2011

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $174,000

PROJECT DESCRIPTION

When oil shale is heated in an oxygen-free environment either on the surface or in-situ (e.g. pyrolysis), oil is produced. The rate at which oil is produced and composition(s) of the product(s) depend on raw material composition, temperature, heating rate, pressure, and a host of other factors. Model accuracy in predicting product amounts and compositions depends on accurate kinetic data. *Intrinsic* kinetic data is measured in a thermal gravimetric analyzer (TGA) using shale that is finely ground. Understanding how this data is related to processes occurring at larger scales allows accurate submodels to be moved upscale.

The decomposition kinetics of complex materials such as oil shale are not easily described. It is also difficult to establish the proportions and compositions of the primary products of pyrolysis, e.g. oil, gas and coke, because the industrial processes are occurring at different scales. In this regard, one must consider how the material is heated (heat transfer) and how the products come into production pathways on their way to production manifolds or wells (mass transfer). A concept called distribution of activation energies with conversion can be used to unify what is observed in the laboratory with what transpires on the geologic time-scale.

While the framework for creating distribution of activation energies-based kinetic models exists in the literature, the generalized methodology for scaling up data from the laboratory to industrial scales does not. The purpose of this project is to generate oil shale-specific kinetics using the distribution of activation energy methodology, to understand the compositional aspects of pyrolysis, and to create generalized scale-up procedures.

Our research plan is to start with grain-scale TGA experiments coupled with sophisticated instrumentation for doing compositional analysis of the products to better understand kinetics. We will also perform experiments at pressures more realistic of those observed for in-situ processes. Additional experiments will be performed on cores of different diameters to understand scale effects and methods of incorporating heat and mass transfer. The experimental system that has been built to perform these studies is shown in Figure 1.

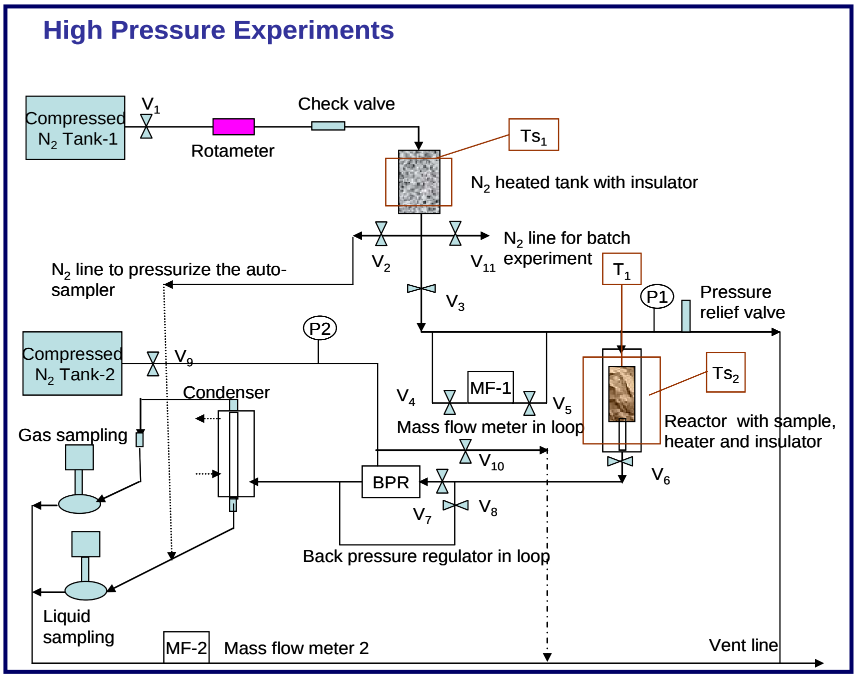

Figure 1: Experimental system designed and built to study multi-scale pyrolysis at high pressures.

An example of how we have applied the distribution of activation energy methodology is seen in Figure 2. In these "model-free" kerogen-to-oil kinetic models, the activation energies are represented as a distribution that is a function of conversion. Figure 2 shows the distribution with uncertainty bands from the pyrolysis of Green River oil shale. This kinetic model applies to all heating rates and at all temperatures. Our understanding of kerogen conversion to oil, gas and coke has improved by looking at compositions obtained under different operating conditions.

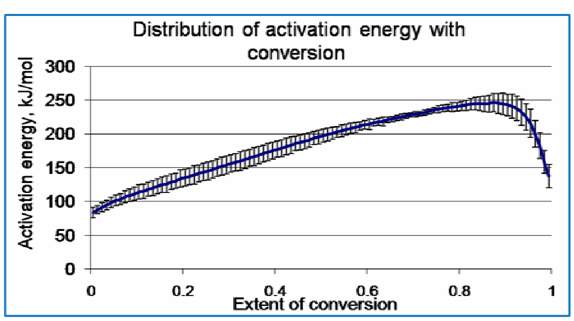

Figure 2: Distribution of activation energy on overall oil shale pyrolysis with TGA

INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

Oxy-gas Process Heaters for Efficient CO_2 Capture

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PROJECT PURPOSE/GOALS

- Create a Large Eddy Simulation (LES) tool for demonstrating oxy-gas combustion in a process heater
- Identify an oxy-gas experimental dataset that can be used for validation/uncertainty quantification (V/UQ)
- Perform a V/UQ analysis on the identified oxy-gas system using the LES tool, a simulation test matrix, and Data Collaboration methods
- Using results from the V/UQ analysis, quantify predictive capability for oxy-gas burner simulations for CO_2 capture technology

PROJECT START DATE/DURATION

October 1, 2009 to March 31, 2011

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $122,000

PROJECT DESCRIPTION

Implementation of oil shale and oil sands technologies in the U.S. will require methods for mitigating greenhouse gases, including CO_2. CO_2 emissions in these emerging industries will originate primarily from the combustion of gaseous hydrocarbons for thermal heating in upstream production, the bitumen/kerogen upgrading process, and downstream refining. Oxy-fuel combustion has the potential of providing inexpensive CO_2 capture technology for implementation on a global scale if its effects on the operation and design of the furnace, heater, or thermal processor can be reliably predicated through computer simulation with quantifiable uncertainty.

To achieve the necessary reductions in CO_2 emissions, all existing process heaters in the upgrading and refining industries will need to be retrofitted for oxy-gas operation. Operators of such facilities want assurance that proposed changes will not adversely affect the throughput of the process, the production of pollutants, nor the heat transfer. It will be prohibitively expensive to test various oxy-gas operating modes on all process heater equipment due to the down time that such a plan would require. To allow transition from air-fired furnace and heater operations to oxy-gas fired applications, the creation of enabling simulation technology is needed.

Oxy-gas combustion presents a number of challenges from the simulation and modeling points of view. For example, this problem has a range of spatial and temporal scales that extends from very small (fast combustion time scales, small turbulent eddies) to large (slower NO reactions, large turbulent eddies). For this project, we will use the LES modeling approach to resolve, directly on the mesh, the important large scales that are necessary to describe more of the sub-grid phenomena. Because LES applies a spatial filter rather than a temporal filter,the temporal term is treated directly, resulting in a time dependent simulation. With LES, we hope to produce a degree of fidelity in oxy-fuel simulation that has been heretofore unavailable.

The application of robust V/UQ techniques to oxy-gas processes has not been previously attempted. Our proposed outcome, the creation of enabling simulation technology to allow the transition from air-fired furnace and heater operation to oxy-gas fired applications, requires robust V/UQ analysis and the integration of terabyte data sets from massively parallel simulations with data from key experiments. We have selected the International Flame Research Foundation's (IFRF) oxy-gas experiments (2009) as the foundation for our V/UQ analysis.

The V/UQ analysis will be conducted by first evaluating numerical, scenario, and model parameters that most influence the response quantities of interest, including gas phase temperature and species concentrations. Next, a simulation test matrix will be designed and executed. For a Face-Centered Composite Design (FCC), which samples the design space at the extrema, a minimum of 36 simulations is required for a 5-parameter design. Once the simulations have been run and the response quantity of interest has been extracted, a response surface is created that correlates the parameter space to the response quantity. This response surface together with the IFRF data and its estimated error bounds are provided as inputs to the Data Collaboration package developed by Michael Frenklach, Andrew Packard, and coworkers ("Consistency of a Reaction Dataset," *J. Phys. Chem. A* 2004, *108*, pp 9573-9583). Output from Data Collaboration includes a numerical estimate of the consistency of the simulation and experimental datasets as well new bounds on the parameter space imposed by the requirement of consistency. New uncertainty bounds can then placed on data that identify the region where all data, both experimental and simulation, are consistent. Thus, by bringing together simulation and experiment, we gain new insight into the oxy-gas combustion system.

Policy Analysis of Water Availability and Produced Water Issues Associated with In-Situ Thermal Production

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PROJECT PURPOSE/GOALS

- Identify water requirements associated with oil shale and oil sands development
- Identify water sources and the extent to which water is available from those sources
- Explain the process for obtaining and reallocating water rights
- Identify and discuss barriers to water resource acquisition and reallocation
- Address regulation of water produced as a byproduct of energy development and the potential reuse of this water
- Address indirect constraints on water use and availability such as requirements imposed by the Endangered Species Act, Clean Water Act, and Safe Drinking Water Act

PROJECT START DATE/DURATION

October 1, 2009 to December 31, 2010

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $118,000

PROJECT DESCRIPTION

Oil shale and oil sands production require water, which is in short supply throughout the intermountain west. Demand for water resources will increase over the coming decades as population, recognition of instream water uses, energy production, and climate change place new demands on water resources. New fuel development will require acquisition of existing water rights and conversion of these water rights to new uses. While market reallocation of water resources is a well-established process, its success depends on knowledge of the attributes of competing water rights. Colorado and Utah can make competing claims to the White River. Likewise, the Northern Ute Tribe of Indians claim extensive "reserved rights" to water resources throughout the Uinta Basin. While these claims are known, their uncertain terms pose a challenge for prospective water users.

Oil, natural gas, and coalbed methane development all produce water as a byproduct. Traditionally, produced water was treated as a disposal issue because it was much deeper than, isolated from, and of a lower quality than potable water supplies. This distinction between waste products and valuable resources is crumbling as coalbed methane produces higher quality water from shallower aquifers, as the search for potable water goes deeper, and as the cost of treatment falls. Colorado recently issued regulations requiring water producers to obtain a water right unless they produce from a "non-tributary" aquifer. Wyoming also requires a water right to appropriate produced water and New Mexico is grappling with strategies to address permitting for production from deep aquifers. These challenges may be harbingers of issues ahead for oil shale producers as in situ production well depths are much shallower than most conventional oil or gas wells. Resolving these challenges raises complex questions regarding both water quality management and permitting to reuse produced water.

Resolving Colorado and Utah's competing claims to waters from the White River is difficult because the body of law that developed to apportion water between Colorado River Basin states only rarely addresses how much water must pass downstream at specific interstate rivers. Colorado makes water availability determinations regarding the White River without regard to Utah's downstream requirements. This process has worked because of limited water development in Utah's portion of the White River Basin. As holders of approved water right applications perfect their rights through application to beneficial use, conflicts will increase.

Resolution of Northern Ute reserved rights claims is problematic because of the complex issues that must be negotiated, the potential to impact water right holders who are not party to the negotiations, and historic relationships between the State of Utah and the Tribe. These reserved rights have yet to be put to beneficial use, so conflicts have yet to occur. Conflict will increase as the Tribe seeks to develop its legal rights and others seek more and more water.

In Utah, produced water treated as a waste product and the State Division of Oil, Gas, and Mining permits its disposal. The State Engineer is likely to require a water right for produced water that is subsequently put to a beneficial use, but the issue has not reached the level of concern experienced in neighboring states because Utah has very little coalbed methane development. In-situ production or growth of the coalbed methane industry is likely to engender conflict.

Our research will occur in two phases. Phase I was focused on identification of water resource requirements associated with oil shale and oil sands development, description of water resources within the development area, identification of potential sources of supply, discussion of competing claims for water, and recommendations for resolution. Phase I concluded on March 31, 2010 with the submittal of a topical report to the Department of Energy. Phase II will build on Phase I, focusing on produced water as both a waste product and as a potential source of supply for unconventional fuel development. Phase II will conclude with a topical report submission to the Department of Energy.

Pore Scale Analysis of Oil Sands/Shale Pyrolysis by X-ray Micro CT and LB Simulation

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PROJECT PURPOSE/GOALS

- Characterize the pore network structure for selected oil sand/oil shale resources using Computer Tomography (CT)
- Perform Lattice Boltzmann simulations of flow through pore network structures to predict transport properties such as permeability
- Conduct CT analysis of pore network structures during pyrolysis reactions over a range of temperatures using drill cores (1.8 cm in diameter and 5 cm in length) from a Mahogany oil shale sample and oil sand samples from the U.S. and Canada

PROJECT START DATE/DURATION

October 1, 2009 to March 31, 2011

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $93,000

PROJECT DESCRIPTION

The most significant oil shale deposits in the U.S. are in the Green River Formation of Colorado, Utah, and Wyoming with an estimated resource size of 1.5-1.8 trillion barrels. Oil shale resources will be used primarily for producing transportation fuels. In a carbon-constrained world, transportation fuel production from these resources will require an understanding of processes that occur over a wide range of length and time scales from the structure of kerogen and how it binds to an inorganic matrix to the fluid flow resulting from in-situ processing of an oil shale interval that covers hundreds of acres. In this regard, parameters which are important for the analysis of in-situ oil shale pyrolysis include:

1. Kerogen conversion to oil, gas and coke
2. Nature of the pore space before and after pyrolysis
3. Porous media characteristics after pyrolysis
4. Permeabilities and relative permeabilities.

This project addresses the challenging characterization problems presented by items 2 to 4. First, we will characterize and digitize the pore space of the oil shale samples before and after pyrolysis using the multi-scale, non-invasive, non-destructive 3D imaging technique known as x-ray micro/nano CT (XMT/XNT) and specialized software. With these tools, the 3D network of the pores, kerogen/mineral phases, crack network and flow channels of oil shale samples can be imaged before and after pyrolysis. Figure 1a shows the 3D volume rendered images from the reconstructed multi-scale x-ray CT data for Mahogany oil shale drill core sample before pyrolysis. Lamellar structures (kerogen-rich and silicates-rich) are observed. The middle column shows the distribution of the kerogen phase, further validating results obtained from optical microscopy. At a 60 nm voxel resolution, individual grains can be identified. Figure 1b shows the same set of 3D images for a Mahogany oil shale drill core sample after pyrolysis. Crack networks, developed during pyrolysis, are evident and well defined within two distinct regions. Inside region A (silicates-rich lamellar structure), cracks and voids as small as 100 nm are observed. Inside region B (kerogen-rich lamellar structure from HRXMT images), larger, anisotropic cracks and voids have developed.

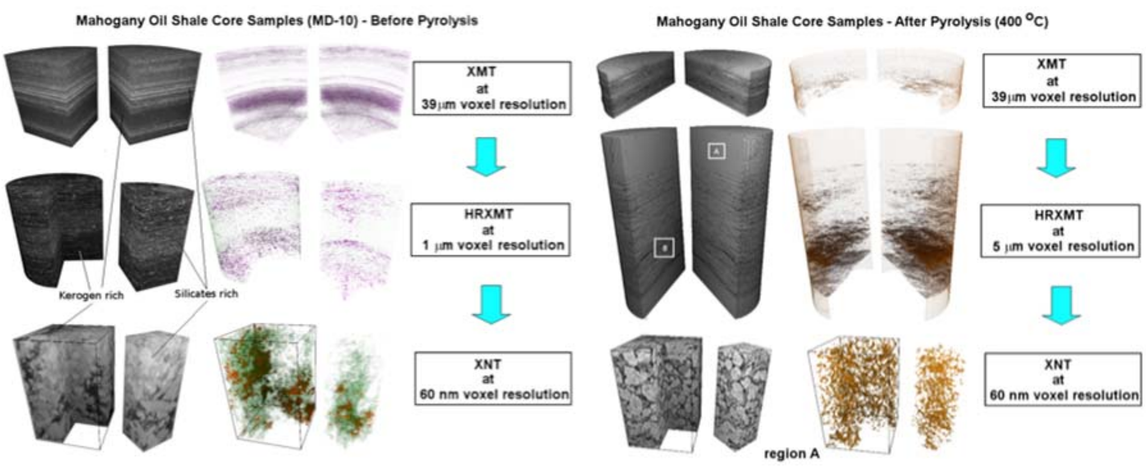

Figure 1a (left): Volume rendered images of Mahogany oil shale drill core sample MD-10 from reconstructions of multi-scale x-ray CT data. Gray scale indicates variations in density and atomic number of material. Middle column shows kerogen phase distribution (in purple and brown colors for XMT, HRXMT and XNT, respectively). Figure 1b (right): Volume rendered images of Mahogany oil shale drill core sample after pyrolysis (400°C, N_2 flow) from reconstructions of multi-scale x-ray CT data.

Once the digital representation of the pore space is established, the Lattice Boltzmann method (LBM) is used to calculate flow properties such as absolute and relative permeabilies. For example, the cracks and voids inside region A are small and are created due to thermal expansion of grain boundaries. For region A, the estimated permeability from LB simulation of oil shale after pyrolysis was found to be about 0.00363 μm^2 or 0.363 mD (millidarcy). Because the absolute permeability is highly anisotropic, the estimated permeability in region B is $3.87 x 10^{-8}$ cm^2 or 3.87 darcy, which is four orders of magnitude higher than that in region A. Anisotropic features of oil shale permeability are being quantified and may be the first 3D imaging of pyrolysed oil shale by high resolution X-ray micro CT (HRXMT) and Nano-CT.

Evaluation of the Birds Nest Aquifer and its Relationship to Utah's Oil Shale Resource

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PROJECT PURPOSE/GOALS

- Study the spatial and stratigraphic extent of the Birds Nest aquifer to determine the possible impacts of saline water disposal on future oil shale development in Utah's Uinta Basin.

PROJECT START DATE/DURATION

The current research program runs from October 2008 to September 2011.

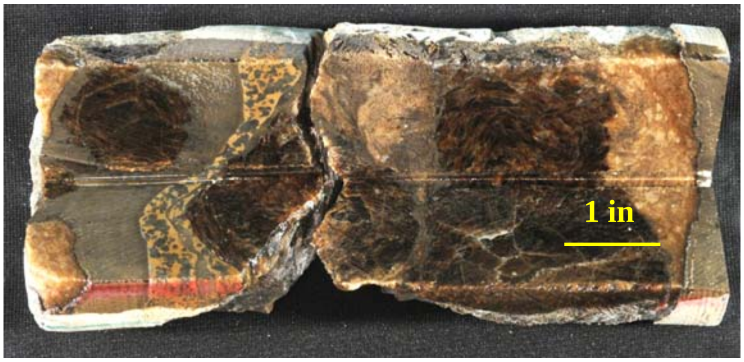
PROJECT SPONSOR(S)

- National Energy Technology Laboratory – part of an $800,000 grant looking at water-disposal issues in the Uinta Basin, Utah

PROJECT DESCRIPTION

The Birds Nest aquifer is one potential disposal zone for the large volumes of saline water produced by Utah natural gas companies. This poorly understood aquifer, with water ranging from fresh to briny, was formed from the dissolution of saline minerals within the upper Green River Formation's Parachute Creek Member, roughly 300 feet above the oil-shale-rich Mahogany zone and only about 80 feet above significant oil shale resources within the R-8 zone. In many areas containing rich oil shale deposits, the Birds Nest contains fresh to slightly saline water. A significant concern is that saline water disposal into the Birds Nest by conventional gas producers may further degrade water quality, creating unforeseen economic and technical water-management hurdles for oil shale development companies.

The Utah Geological Survey is researching the overall characteristics of the Birds Nest aquifer including its areal extent, thickness, host rock type, and zonation of saline dissolution. In addition, the project will examine the aquifer's relationship to regional fracture patterns and cross-cutting gilsonite veins. Determining the relationship of the Birds Nest aquifer to Utah's oil shale deposits will provide the scientific base needed for development of sound water-disposal plans that will protect potential future oil shale development.



Nahcolite nodules within the Bird Nest aquifer. Dissolution of these saline mineral deposits creates the aquifer's porosity.

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Geologic Characterization of Utah's Oil Shale Resource

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PROJECT PURPOSE/GOALS

- Examine the vertical and lateral variability of oil shale deposits in the upper Green River Formation.

PROJECT START DATE/DURATION

The current research program runs from Spring 2009 to Fall 2011.

PROJECT SPONSOR(S)

- University of Utah – Institute for Clean and Secure Energy
- University of Utah – Energy and Geoscience Institute

PROJECT DESCRIPTION

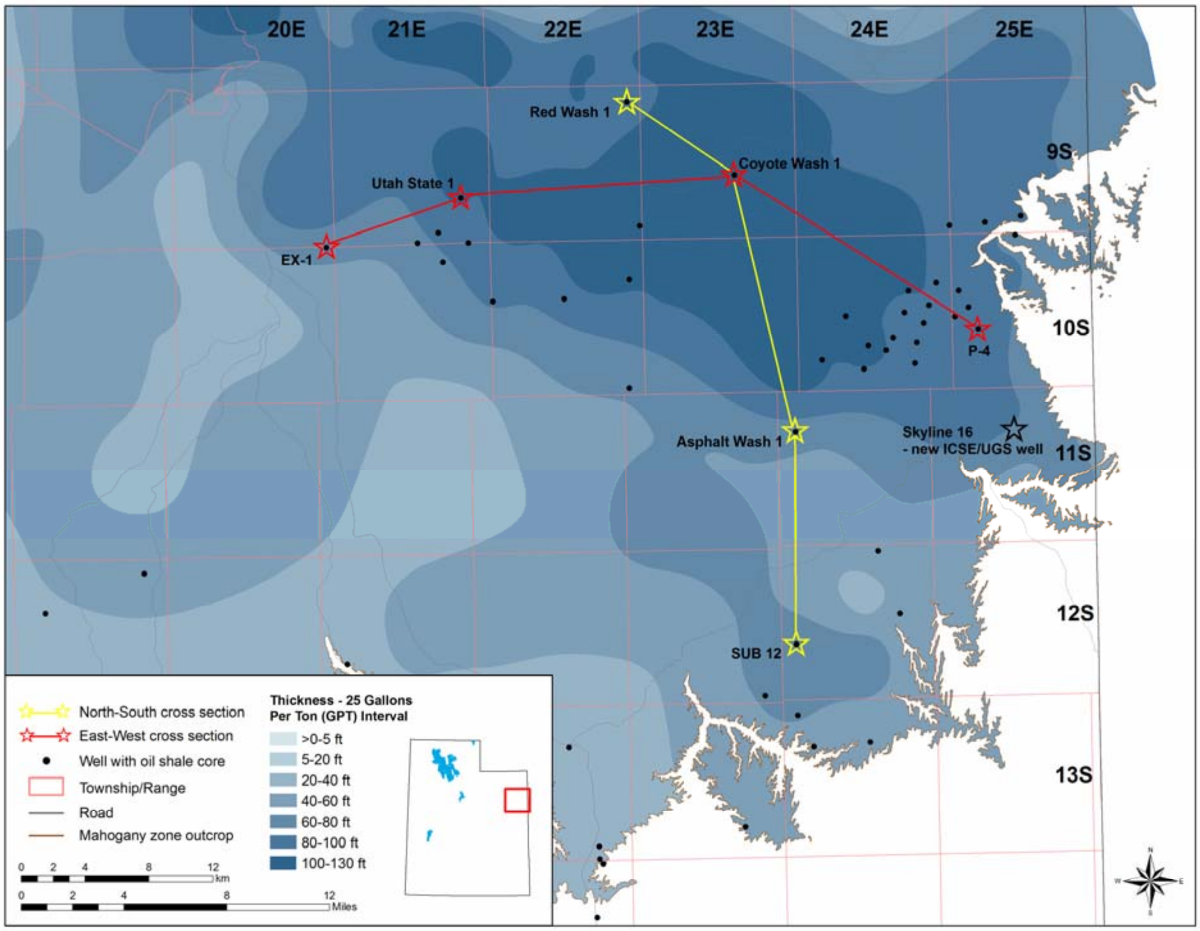
This core-based geologic analysis of the middle and upper Green River Formation oil shale deposits will examine vertical and lateral variability in oil shale properties across a 30 mile N-S and 30 mile E-W transect in the eastern Uinta Basin. Emphasis will be placed on identifying changes in oil shale richness and inorganic mineralogy in order to build a predictive model of behavior across a wide area of the basin. Understanding the vertical and lateral trends in oil shale characteristics will be useful in modeling both in-situ and ex-situ retorting technologies.

Heterogeneity of oil shale units

Initial examination of two oil shale cores, one from the basin edge and one from a more central location, has confirmed that significant sedimentary and geochemical heterogeneity exists, but further analysis of core from other locations and outcrop are needed to develop a predictive model of heterogeneity that can be used to extrapolate between available datasets. From an engineering perspective, lateral and vertical changes in oil shale mineralogy and geochemistry may result in varying preferred production methods and recovered hydrocarbon products, as well as differences in spent shale composition by region or oil shale zone (stratigraphic depth). The lateral and vertical lithologic changes in the nonorganic material may also affect the geomechanical behavior of the oil shales, with implications for mining and in-situ extraction technologies. This geologic investigation will specifically address the questions: 1) What are the different rock types and how might they react differently during pyrolosis?; 2) How might non-oil shale layers impact an in-situ operation (where are sand layers and could shale oil migrate along these pathways)?; and 3) What areas are most prospective for in-situ operations?

The Big Picture

The thickness, distribution, and regional variations in oil shale resource in the Uinta Basin can be attributed directly to the evolution of ancient Lake Uinta, which was, at times in its history, connected to or disconnected from the adjacent Piceance, Washakie, and Green River Basins. A detailed sedimentologic, stratigraphic, and geochemical study of the middle and upper Green River Formation will allow us to accurately reconstruct the evolution of ancient Lake Uinta and assess the relative roles of tectonics (uplift and subsidence) and climate (regional wet/dry variations and global climate change) on deposition. Furthermore, this history can be tied to adjacent lake and basin evolution as documented by existing or ongoing research efforts in order to develop a robust understanding of interbasin oil shale resource similarities and differences, which can be correlated to production strategies.



Map showing the location of N-S and E-W cross sections through the richest and thickest oil shale deposits in the Uinta Basin, Utah.

Utah Oil Shale Resource Evaluation

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PROJECT PURPOSE/GOALS

Develop a comprehensive oil shale resource evaluation for the state of Utah.

- Develop techniques to quantify the oil shale resource in the Uinta Basin, Utah.
- Create basin-wide oil shale resource maps displaying thickness, richness, and depth of oil shale.

PROJECT START DATE/DURATION

The current research program runs from 2006 to late 2010.

PROJECT SPONSOR(S)

- U.S. Bureau of Land Management
- Utah School and Institutional Trust Lands Administration
- U.S. Geological Survey
- University of Utah – Institute for Clean and Secure Energy

PROJECT DESCRIPTION

The Utah Geological Survey (UGS) is conducting a comprehensive oil shale resource assessment for the Uinta Basin, Utah. Past assessments, the first conducted in 1964 and subsequent studies continuing through the early 1980s, concentrated on the Eocene Green River Formation's Mahogany zone in the southeastern part of the Uinta Basin, and were limited in the amount of available drill-hole data. We have broadened the investigation to include the entire Uinta Basin, taking advantage of the hundreds of geophysical logs from oil and gas wells drilled over the past two decades. We created conversion equations by correlating available Fischer assays with corresponding density and sonic measurements as a way to predict oil yield from geophysical logs. In addition to the core-based Fischer assays obtained from 107 wells drilled specifically for oil shale, 186 oil and gas wells with oil yields calculated from digitized bulk density or sonic logs were used to create a basin-wide picture of Utah's oil shale resource.

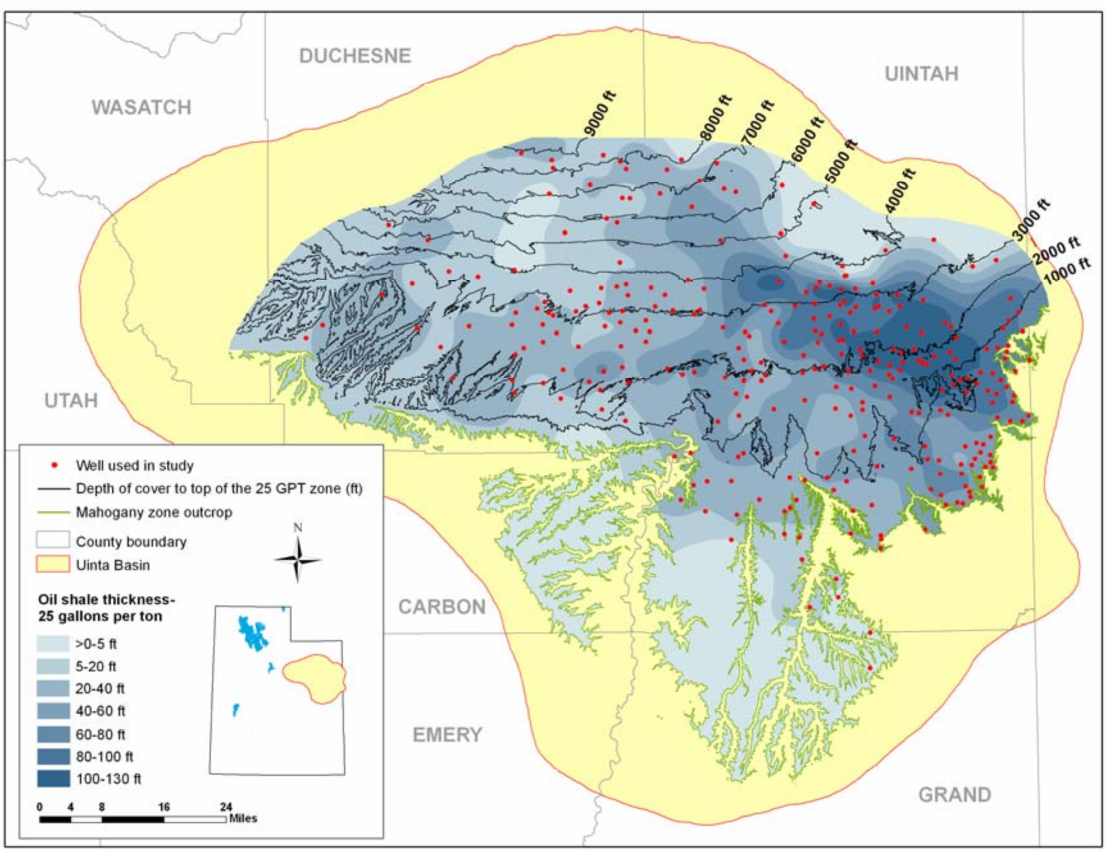
This resource assessment is being conducted in two phases: the first phase defined the oil shale resource by richness interval (i.e., 50 gallon per ton [GPT] zone, 25 GPT zone, etc.), whereas the second phase will delineate the resource by previously recognized oil shale horizon (i.e., Mahogany zone, R-6, etc.). To date, phase one of this project has been completed and is available as UGS Special Study 128, while phase two is currently in progress.

Results of Phase 1:

The thickest and richest oil shale zones are located in central Uintah County in Townships 8-12 South and Ranges 20-25 East. Overburden in these areas ranges from zero at the outcrop in the east to almost 4000 feet in the northwest. A continuous interval of oil shale averaging 50 GPT contains an in-place oil resource of 31 billion barrels in a zone ranging up to 20 feet thick. Where the 50 GPT interval is at least 5 feet thick and less than 3000 feet deep, the in-place resource drops to 26 billion barrels. An interval averaging 35 GPT, with a maximum thickness of 55 feet, contains an in-place oil resource of 76 billion barrels. Where this interval is at least 5 feet thick and less than 3000 feet deep, the total in-place resource drops to 61 billion barrels. The 25 GPT interval and the 15 GPT interval contain unconstrained resources of 147 billion barrels and 292 billion barrels, respectively. The maximum thickness of 25 GPT rock is about 130 feet, whereas the maximum thickness of 15 GPT rock is about 500 feet. Where these two intervals are at least 5 feet thick and less than 3000 feet deep, the 25 GPT resource drops to 111 billion barrels and the 15 GPT resource drops to 228 billion barrels.

The 25 GPT resource calculated for U.S. Bureau of Land Management (BLM) lands that could be considered for commercial oil shale leasing is approximately 69 billion barrels, roughly 50% of Utah's total 25 GPT oil shale resource. The remaining resource is located on tribal (20%), private (16%), state trust (9%), U.S. Forest Service (3%), and protected land (2%) such as state wildlife reserves, national wildlife refuges, state sovereign lands, and state parks. Furthermore, approximately 25% of Utah's 25 GPT oil shale resource lies within existing oil or gas fields, creating resource conflict issues that will need to be addressed as conventional and unconventional resources are developed.

After placing several constraints on Utah's total in-place oil shale resource, the UGS determined that approximately 77 billion barrels of oil could be considered as a potential economic resource. This estimate is for deposits that are at least 25 GPT; at least 5 feet thick; under less than 3000 feet of cover; not in conflict with current conventional oil and gas resources; and located only on BLM, state, private, and tribal lands.



Map of the Utah's Uinta Basin showing thickness and depth of the 25 GPT oil shale resource.