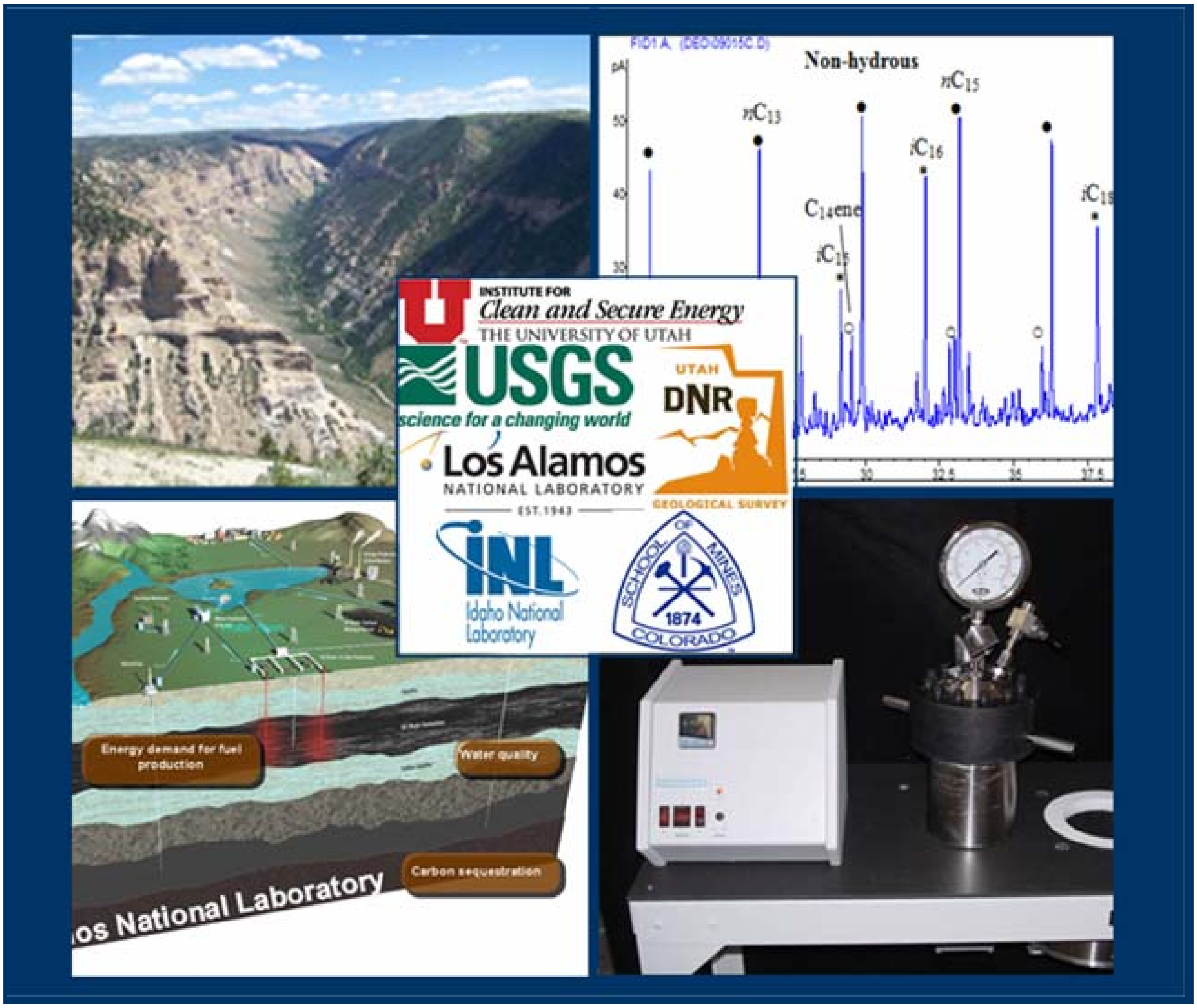
3rd Edition



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 the U.S. Department of Energy • Office of Petroleum Reserves
Naval Petroleum and Oil Shale Reserves

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FOREWORD

Significant research efforts continue 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, planned, and recently completed 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 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 fifth edition will be completed in October 2011.

Together, the Secure Fuels Report and this 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.

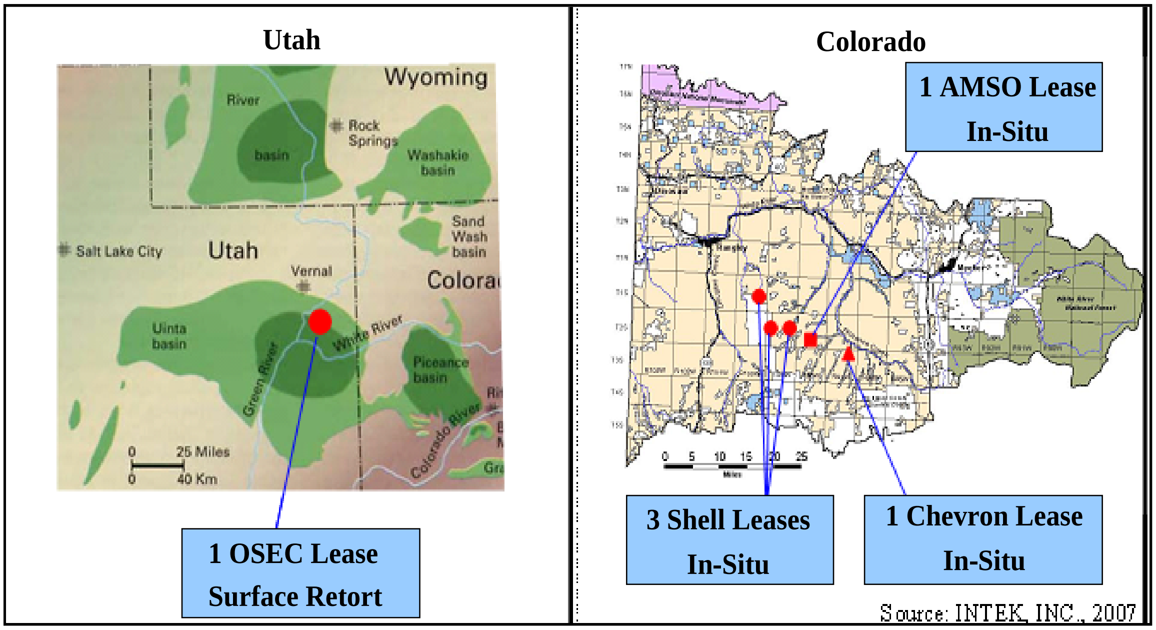
More recently, DOI's Bureau of Land Management (BLM) has developed a new oil shale RD&D leasing program to make land and resources available for demonstration of advanced technologies that have high potential for commercial success.

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. However, as part of a settlement of lawsuits from environmental organizations, these regulations and resource managements plans are currently under review.

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 2011, the DOE Office of Petroleum Reserves identified more than 34 U.S. companies engaged in oil shale and tar sands research, technology development, or project development. Twenty-seven 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 or recently completed 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 6 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, 19 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	5	7	5	0	17
Surface Retort	0	4	4	1	9
Upgrading	0	0	1	0	1
Total	5	11	10	1	27

Source: Secure Fuels from Domestic Resources, 2011.

Table 2. Summary of Ongoing 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. Dynamic System Modeling of Regional Influences from Energy Resource Development	Water	17
	4. Industrial Support for Basic and Applied Research	In-Situ Retorting	19
LANL	5. Water, Energy and Carbon Management Issues and Assessment Models	Overview	21
	6. Integrated Assessment Model for Basin-Scale In Situ Oil Shale Production: CLEARuff Model	Development Impact Modeling	23
	7. Hydrologic Analysis of the Upper Colorado River Basin for Oil Shale Development and Potential Future Climate Change: WARMF Model	Water & Carbon Management	25
	8. CO_2 Management for Oil Shale Development: CO_2-PENS and SimCCS	Carbon Mgmt	27
USGS	9. Common Data Repository and Water Resource Assessment for the Piceance Basin	Water	29
	10. Oil Shale Assessment	Resource	31
University of Utah	11. Atomistic Modeling of Oil Shale Kerogen/Asphaltenes	Modeling	33
	12. Development of CFD-Based Simulation Tools for In-Situ Thermal Processing of Oil Shale/Sands	In-Situ Retorting	35
	13. Development of Conventional Oil and Gas Production Modules for CLEARuff	Resource/ Simulation	37
	14. Developing a Predictive Geologic Model of the Green River Oil Shale	Resource/ Simulation	39
	15. Econometric Analysis Methods for Heavy Oil Production and Upgrading	Economics	41
	16. Effect of Oil Shale Processing on Water Compositions	Water	43
	17. Experimental Characterization of Oil Shales and Kerogens	Resource	45
	18. Geomechanical Reservoir State	In-Situ Retorting	47
	19. In Situ Pore Physics	In-Situ Retorting	49
	20. Land and Resource Issues Relevant to Deploying In-Situ Thermal Technologies	Policy Analysis	51
	21. Life-Cycle Greenhouse Gas Analysis of Conventional Oil and Gas Development in the Uinta Basin	Carbon Mgmt	53
	22. Market Assessment of Heavy Oil, Oil Sands, and Oil Shale Resources	Market	55
	23. Multiscale Thermal Processes	Retorting	57
	24. Policy Analysis of Water Availability and Produced Water Issues Associated with In-Situ Thermal Production	Water	59
	25. Reservoir Simulation of Reactive Processes	Retorting	61
	26. V/UQ Analysis of Basin Scale CLEARuff Assessment Tool	Development Impact Modeling	63
UGS	27. Evaluation of the Birds Nest aquifer and relationship to Utah's oil-shale resource	Water	65
	28. Geologic Characterization of Utah's Oil Shale Resource	Resource	67
	29. Utah Oil Shale Resource Evaluation	Resource	69

Center for Oil Shale Technology and Research

Organization: Colorado School of Mines
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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.
- 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. The Information Office 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.

PROJECT START DATE/DURATION

The current research program runs from November 1, 2010 to October 31, 2012. Additional phases are planned, dependent upon continued interest of the partners.

PROJECT SPONSOR(S)

- TOTAL Exploration & Production — $300,000 per year
- ExxonMobil Upstream Research Company — $300,000 per year

The work of the Oil Shale Information Office has been separated from the main COSTAR project, and is currently funded by sponsorship funds for the Oil Shale Symposium, and by a separate grant from Shell Exploration & Production.

PROJECT DESCRIPTION

COSTAR's program is subdivided into three projects:

- Geomechanics (Rock Physics and Rock Mechanics)
- Geology Stratigraphy and 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

Organization: Colorado School of Mines
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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 publicize the project. The web page shall be maintained and available to the general public. However, the dissemination of project results, including query and download data from the the geodatabase, 3D geologic model, and results from WARMF and MODFLOW models, will be carried out by the web-based GIS.

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

Dynamic System Modeling of Regional Influences from Energy Resource Development

Organization: Energy Resource Recovery & Management Department
Contact: Earl Mattson
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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 anticipated September, 2012.

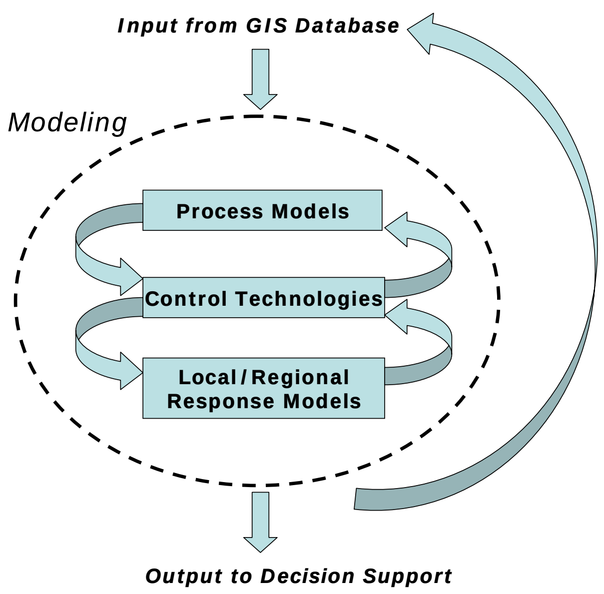
PROJECT SPONSOR(S)

- 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.

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.



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

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Industrial Support for Basic and Applied Research

Organization: Energy Resource Recovery & Management Department
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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.

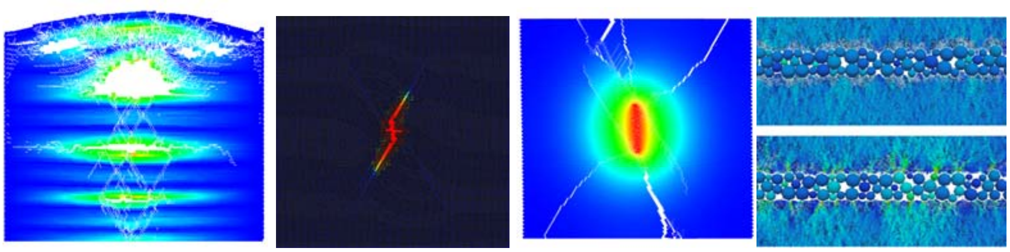
PROJECT START DATE/DURATION

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 stres.

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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Los Alamos NATIONAL LABORATORY EST.1943

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. Draft Report under DOE review.

PROJECT SPONSOR(S)

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

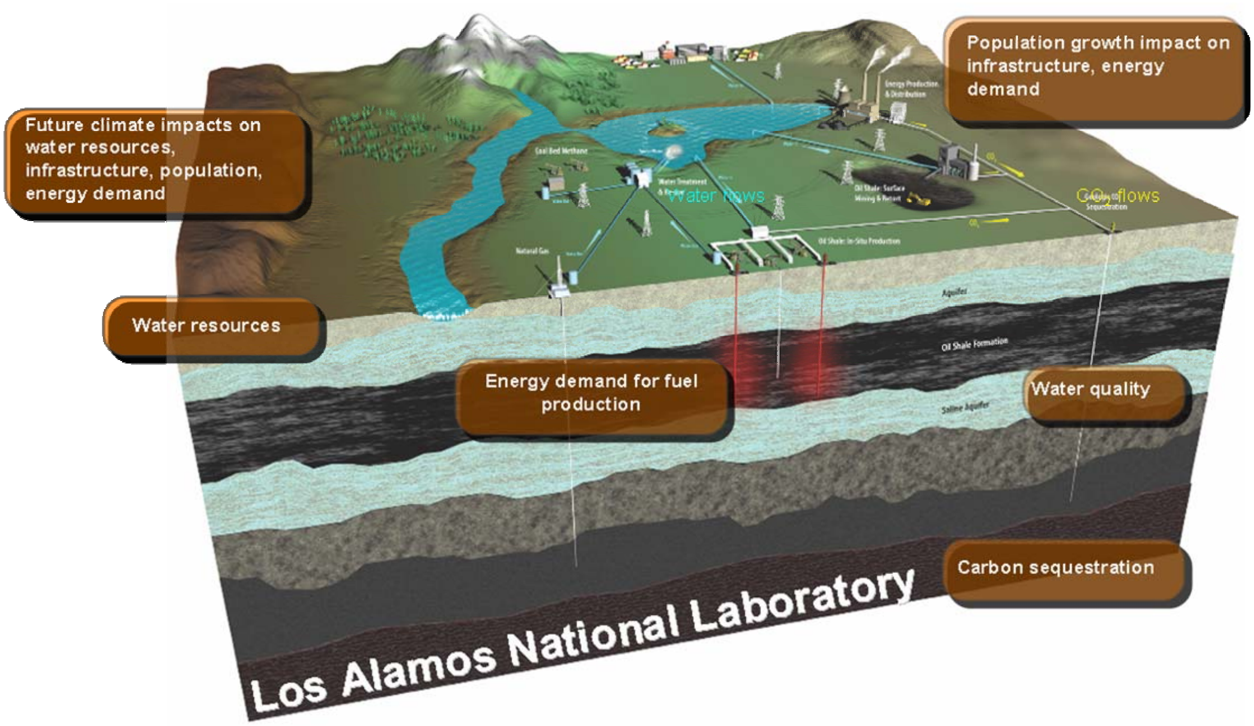
PROJECT DESCRIPTION

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

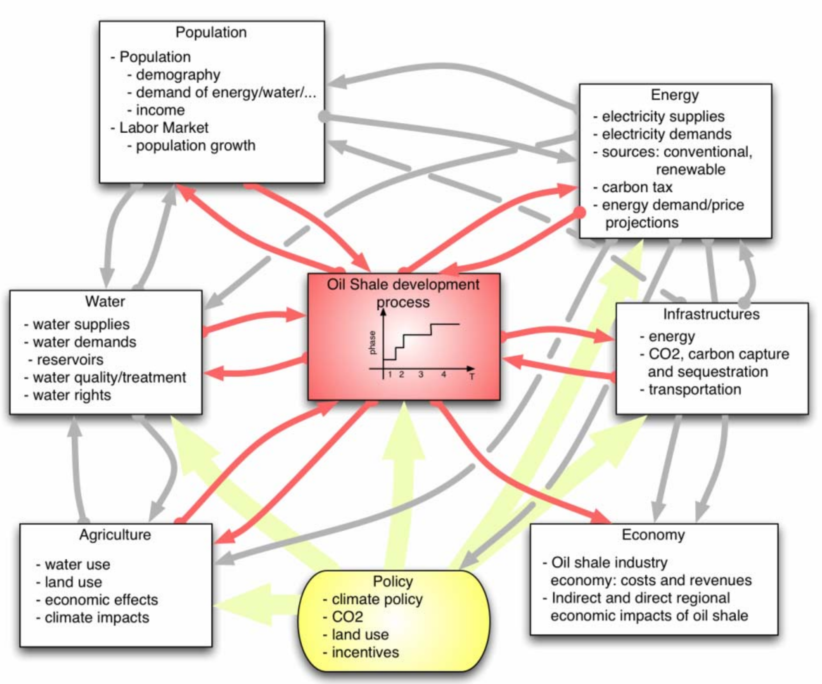
This project started on July 1, 2008 and ended in July, 2010. Draft Report under DOE review.

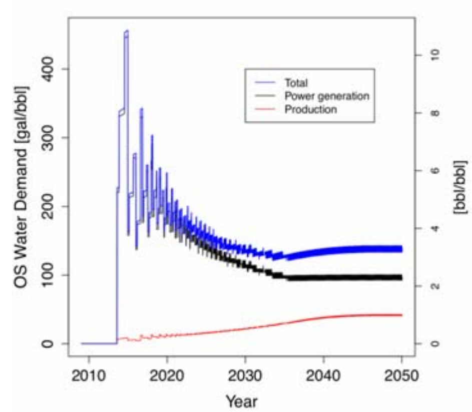
PROJECT SPONSOR(S)

- 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

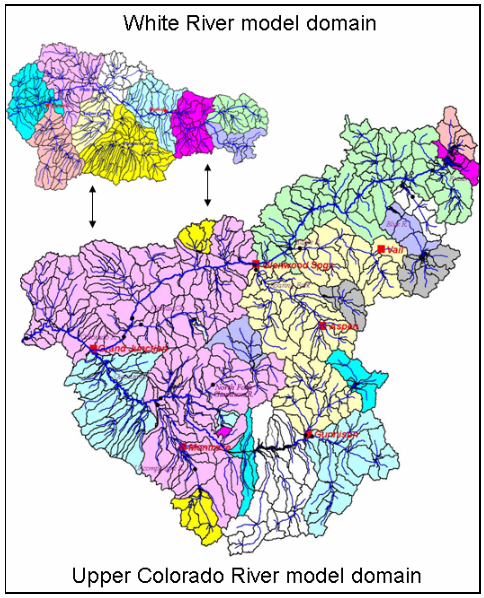
This project started on July 1, 2008 and ended in July, 2010. Draft Report under DOE review.

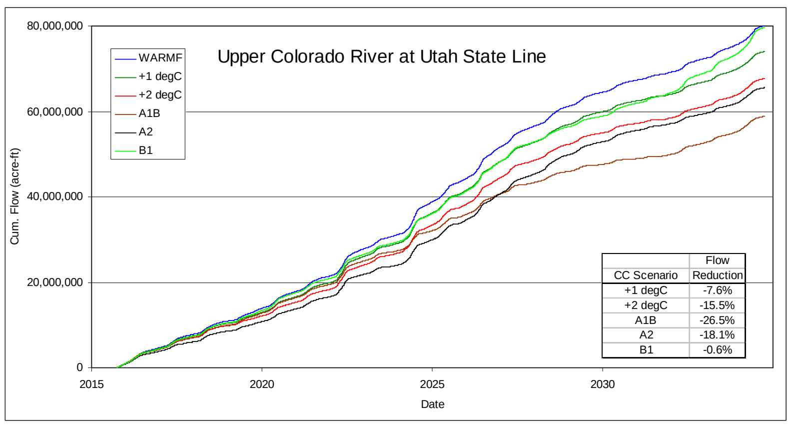
PROJECT SPONSOR(S)

- 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

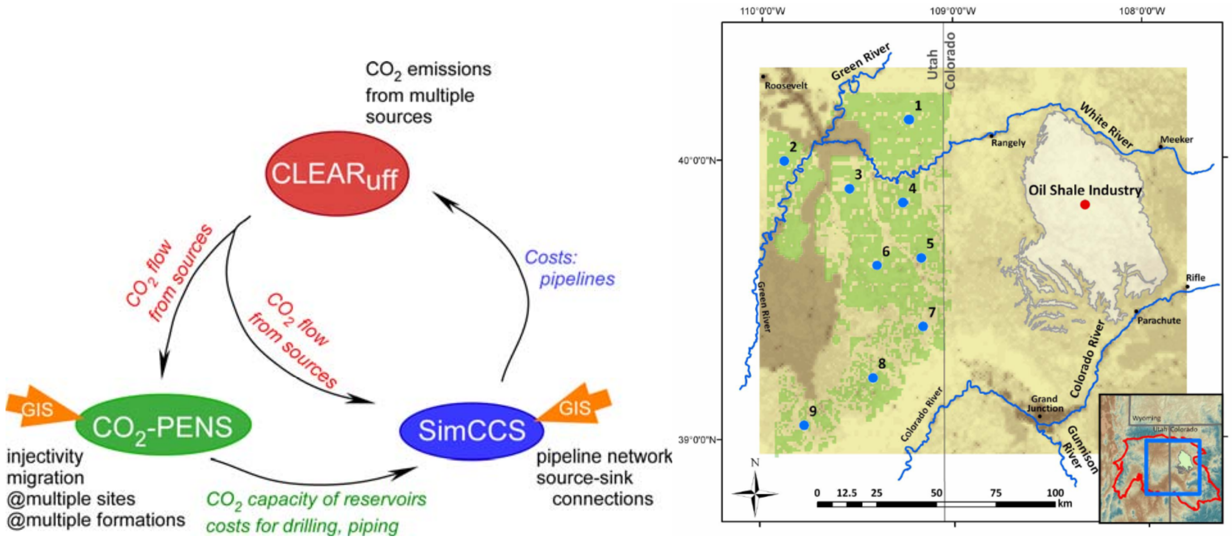
This project started on July 1, 2008 and ended in July, 2010. Draft Report under DOE review.

PROJECT SPONSOR(S)

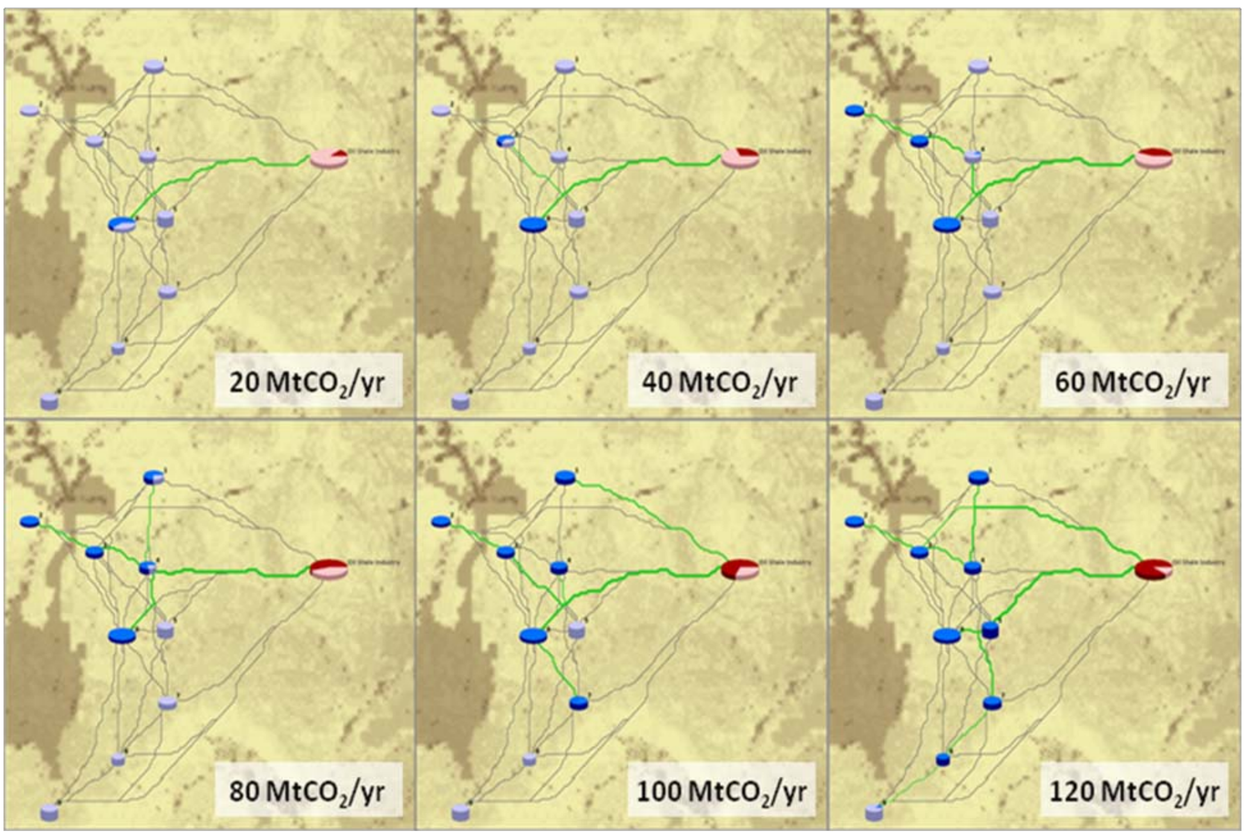
- DOE-FE; Office of Naval Petroleum and Oil Shale Reserves

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

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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. The groundwater and surface water reports will be completed in December 2011.

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.

PROJECT DATA AND REPORTS

Since 2009, the USGS has published more than 20 reports, including digital data sets, resulting from this project. USGS has completed and published five fact sheets summarizing the updated resource assessments:

- Assessment of oil shale resources of the Green River Formation, Piceance Basin, Western Colorado: U.S. Geological Survey National Assessment of Oil Shale Resources Fact Sheet 2009-3011.

- Nahcolite Resources in the Green River Formation, Piceance Basin, Northwest Colorado: U.S. Geological Survey National Assessment of Oil Shale Resources Fact Sheet 2009-3012.

- Assessment of in-place oil shale resources of the Eocene Green River Formation, Uinta Basin, Utah and Colorado: Oil Shale Resources of the Uinta Basin: Utah and Colorado, U.S. Geological Survey National Oil Shale Resources Fact Sheet 2010-3010.

- In-place oil shale resources underlying Federal lands in the Piceance Basin, western Colorado: U.S. Geological Survey National Oil Shale Resources Fact Sheet 2010-3041.

- Assessment of in-place oil shale resources of the Green River Formation, Greater Green River Basin in Wyoming, Colorado, and Utah: U.S. Geological Survey National Oil Shale Resources Fact Sheet 2011-3631.

Publications on the Green River Basin are also scheduled to be released in the fall of 2011. All of these fact sheets, reports, and data resources can be access online from the USGS website http://pubs.er.usgs.gov/.

INSTITUTE FOR Clean and Secure Energy
THE UNIVERSITY OF UTAH

Atomistic Modeling of Oil Shale Kerogens and Oil Sand Asphaltenes

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PROJECT PURPOSE/GOALS

- Establish the validity of 3-D models of kerogen and asphaltenes
- Understand the nature of the kerogen/asphaltene interactions with the inorganic matrix so that new approaches can be designed that more readily facilitate the extraction of kerogen from oil shales and of asphaltenes from oil sands without resorting to costly thermal processes
- Create entirely different models for other oil shale kerogens such as kukersite

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $55,315

PROJECT DESCRIPTION

Building on previous research, this project will establish the validity of 3-D models of kerogen and asphaltenes by performing different molecular mechanics minimizations of 2-D models followed by simulated annealing to generate new structures, thus establishing the sensitivity of the final structure to the methods used in its determination. Experimental data obtained as part of other Institute for Clean and Secure Energy projects, ***Multiscale Thermal Processes*** and ***Experimental Characterization of Oil Shales and Kerogens***, including solid and liquid state ^{13}C NMR spectroscopy, magnetic resonance imaging, TGA data on pyrolysis kinetics, small angle X-ray scattering, and ion cyclotron resonance-mass spectroscopy via atom pair distribution function analysis, will be used to correlate computational results and to validate and verify the various models.

The modeling of the interaction of kerogen and asphalthene structures with the inorganic matrix using molecular mechanics minimization of the established 3-D structures sandwiched between slabs of illite will continue. Validation data will be obtained from the kerogen characterization project.

The project will also initiate the creation of models for other oil shale kerogens. The concept is to create a repository where people working in kerogen-related research activities can easily pull up the structures depending on where the sample was mined. New structures shall be added to this repository once optimal structures have been determined through molecular mechanics.

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INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

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 combined experiments and simulations with the V/UQ approach can provide quantified understanding of in situ processes that are convective heat transfer controlled.

PROJECT START DATE/DURATION

October 1, 2010 to Match 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $106,689

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 many oil shale and oil sands applications, the rate limiting step is not porous media flow but the rate of heat transfer in the thermal treatment process. For example, the rate-controlling step in the modified in-situ process is the combined convective-conductive heat transfer throughout the rubblized bed. In this case, there is a distribution of rock size 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.

This project takes the novel approach of applying massively parrallel CFD-based 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, the focus is 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.

The ECOSHALE capsule, which consists of a clay-lined volume filled with rubblized oil shale and heated by pipes fired with natural gas burners, is simulated using a suite of commercial software tools: Matlab, Gambit, and Star-CCM+. The random shale distribution inside of ECOSHALE capsule is simulated using a discrete element method (DEM) capability in Star-CCM+. Particles are packed randomly based on input particle size distributions and on particle physics. Figure 1 shows the random particle packing obtained from the Star-CCM+ DEM simulation, which is then converted using a Matlab script and Gambit meshing software into a computational domain with convective channels between the particles where fluid flow occurs. With the computational domain as an input, the channel physics are simulated in Star-CCM+ using Direct Numerical Simulation (DNS).

This methodology has been used to produce a CFD simulation of the heat transfer occurring in a simplified computational domain representing the ECOSHALE capsule. Figure 2 shows the thermal distribution of the fluid inside the convective channels as well as pieces of shale. By incorporating an appropriate kerogen pyrolysis model, production rates of gaseous and liquid fuels for a given gas burner firing rate can be computed.

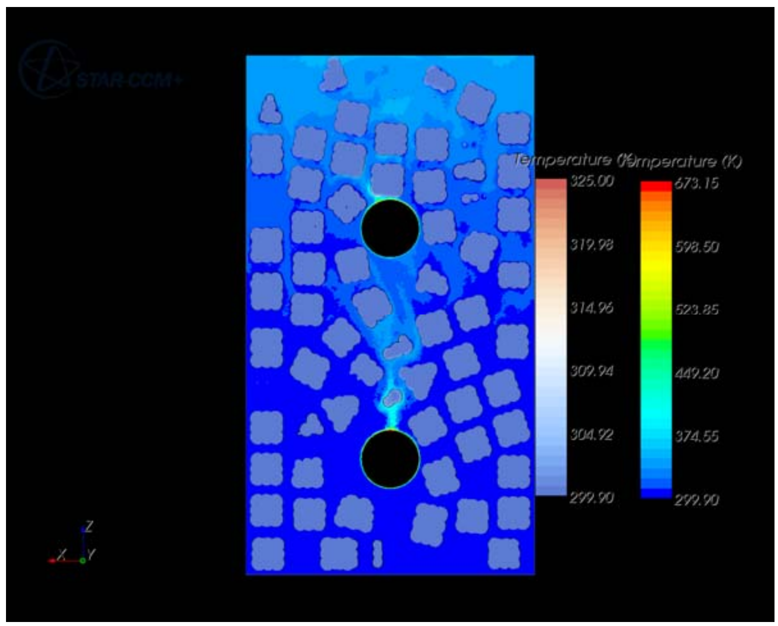

Figure 1 (left): Representative portion of the ECOSHALE geometry including the randomly packed oil shale particles as well as heating tubes.

Figure 2 (right): Thermal distribution of the convective fluid flow as well as the pieces of shale, in a plane of the representative ECOSHALE geometry.

Once this set of tools has shown its efficacy with a demonstration simulation of the representative ECOSHALE capsule geometry, 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.

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INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

Development of Conventional Oil and Gas Production Modules for CLEAR*uff*

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PROJECT PURPOSE/GOALS

- Development of conventional oil and gas production modules for CLEAR*uff*
- Validation and uncertainty quantification of production modules with data from conventional oil and gas production history in Utah's Uinta Basin

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $82,442

PROJECT DESCRIPTION

A basin-scale simulation tool, CLEAR*uff*, has been developed by researchers at Los Alamos National Laboratory (LANL) to assess basin- or regional-scale environmental and economic impacts of unconventional fuel development. This project will interface with two other Institute for Clean and Secure Energy projects, ***Life-cycle Greenhouse Gas Analysis of Conventional Oil and Gas Development in the Uinta Basin*** and ***V/UQ Analysis of Basin Scale CLEARuff Assessment Tool,*** to develop the necessary new modules for conventional oil and gas production to tailor CLEAR*uff* to simulate the Uinta Basin's history of oil and gas development. The details of developmental interdependencies will be maintained for all new modules developed. These interdependencies including air quality, water utilization, power utilization, drilling rates, oil and gas production rates, impacts on labor, and local and state wide economic impacts. The oil and gas production modules will include well drilling, fracking, well completion and production from these new wells at various stages (primary, secondary and tertiary) of production. The model will give time-dependent results as to the use of resources (power, water, drilling and production equipment, labor) and the outputs from this industry (oil and gas produced, taxes paid, spin-off in the state and local economy). These time dependent results will be compared with historical data associated a recent oil and gas industry boom/bust cycle in the Uinta Basin.

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Developing a Predictive Geologic Model of the Green River Oil Shale, Uinta Basin

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PROJECT PURPOSE/GOALS

- Assess geologic heterogeneity of the oil-shale bearing Green River Formation, Uinta Basin, Utah.
- Build a predictive, regional-scale sequence stratigraphic model of oil shale deposits that can be used to predict away from available datasets in the Uinta Basin and addresses geologic drivers of deposition and resulting heterogeneity.

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $110,098

PROJECT COLLABORATOR

- Michael Vanden Berg, Utah Geological Survey

PROJECT DESCRIPTION

The Green River Formation is the record of an Eocene, continental interior, terminal lake basin system that covered a significant area across northeastern Utah (Uinta Basin), western Colorado (Piceance Basin), and southwestern Wyoming (Greater Green River Basin). It is one of the most well-cited examples of an ancient lacustrine system. In Utah, the Green River Formation hosts a vast oil shale resource in the Uinta Basin, estimated at 1.32 trillion barrels in-place (Oil Shale Resources of the Uinta Basin, Utah and Colorado, United States Geological Survey, August 2010). Nevertheless, a solid geologic framework for the Green River Formation in the Uinta Basin is less developed compared to the neighboring Piceance and Greater Green River Basins, and a predictive sequence stratigraphic framework is lacking. In particular, there has been relatively little effort focused on the facies and stacking patterns in the mudstone-dominated basin depocenter as compared to the alluvial and shallow lacustrine facies on the basin margin.

The first steps toward building a predictive, regional-scale sequence stratigraphic model have been achieved with the completion of a systematic, detailed, sedimentologic, stratigraphic, and geochemical study performed on four cores (P-4, Coyote Wash 1, Utah State 1, and EX-1) ranging in length from 960 to 1640 ft, along an east-west transect through the basin's paleo-depocenter (Figure 1). Key features noted in each core include grain size, lamination style, sedimentary structures, mineralogy, bioturbation, biotically influenced features, body fossils, and plant fossils. Nondestructive qualitative X-ray fluorescence (XRF) analysis was performed on whole-rock samples according to key lithologic changes at roughly 10-foot intervals to help determine inorganic mineralogy. The dominant inorganic mineralogy of the mudstones was defined based on XRF criteria. Siltstones and sandstones were identified based on visual inspection. Next, a detailed core log was constructed to graphically represent the data. An east-west cross section was drafted with the core logs plotted next to geophysical log curves and Fischer assay oil yield data (Figure 2). Correlations were made between similar oil shale zones, highlighting how these zones change across the basin.

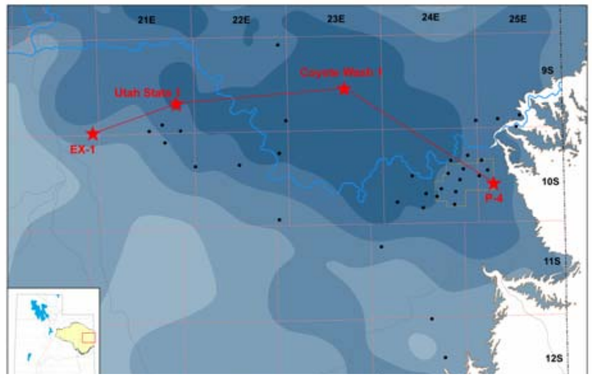

Figure 1: Map showing locations of four cores examined to construct an east-west cross section. Shades of blue indicate thickness of a continuous interval of oil shale averaging 25 gallons per ton, with color shading darkening with increased thickness.

From this work, it has been determined that Lake Uinta evolved in three phases: (1) a freshwater rising lake phase below the Mahogany zone, (2) an anoxic deep lake phase above the base of the Mahogany zone and (3) a hypersaline lake phase within the middle and upper R-8. This long-term lake evolution was driven by tectonic basin development and the balance of sediment and water fill with the neighboring basins. Early Eocene abrupt global-warming events may have had significant control on deposition through the amount of sediment production and deposition rates, such that lean zones below the Mahogany zone record hyperthermal events and rich zones record periods between hyperthermals. This type of climatic control on short-term and long-term lake evolution and deposition has been previously overlooked.

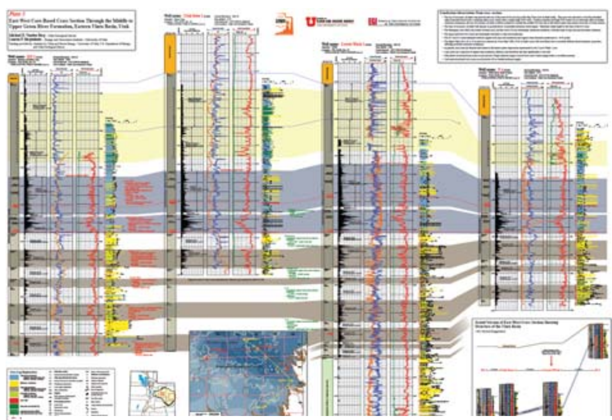

Figure 2: East-west cross section that highlights unit composition, stratigraphy and lake evolution.

This geologic history contains key points relevant to oil shale development and engineering design including:

1) Stratigraphic changes in oil shale quality and composition are systematic and can be related to spatial and temporal changes in the depositional environment and basin dynamics.
2) The inorganic mineral matrix of oil shale units changes significantly from clay mineral/dolomite dominated to calcite above the base of the Mahogany zone. This variation may affect pyrolysis products and geomechanical properties relevant to development and, if so, should be incorporated into engineering experiments.

This study includes a region in the Uinta Basin that would be highly prospective for application of in-situ production techniques. Stratigraphic targets for in-situ recovery techniques should extend above and below the Mahogany zone and include the upper R-6 and lower R-8.

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 production: mining/surface retorting, in situ extraction
  - Uinta Basin oil sands production: mining/surface processing, in situ extraction
  - North Slope heavy oil production: steam injection, oil well extraction

PROJECT START DATE/DURATION

October 1, 2009 to March 31, 2011

PROJECT SPONSOR(S)

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

PROJECT DESCRIPTION

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

Each scenario was developed at a production capacity of 50,000 bbl/d and includes 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 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 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 were used to establish discounted cash flow predictions for the project, allowing various measures of profitability to be established. Operating costs were determined by accounting for: (1) direct manufacturing costs including feed stocks, utilities, water (steam, cooling and process), refrigeration, fuels, solid waste treatment, waste water treatment and air-pollution abatement, labor and maintenance, 2) operating overhead, and 3) fixed costs including property taxes and insurance, depreciation and general expenses (selling or transfer expenses, research expenses, administrative expenses and management incentives). Well drilling costs were estimated from recent industrial data available from collaboration with industry.

The various processes used to produce and refine these unconventional fuels were simulated using ProMax process simulation software. In all cases, the final product was pipeline-quality crude oil. The process simulations gave information on the oil production rate, use of utilities and raw materials, and the size of major pieces of equipment. From this information, capital and operating costs per unit of oil production were determined. The process simulations 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 were rerun for the various cases in the sensitivity analysis to determine the effect on supply costs of differences in raw material and utility costs.

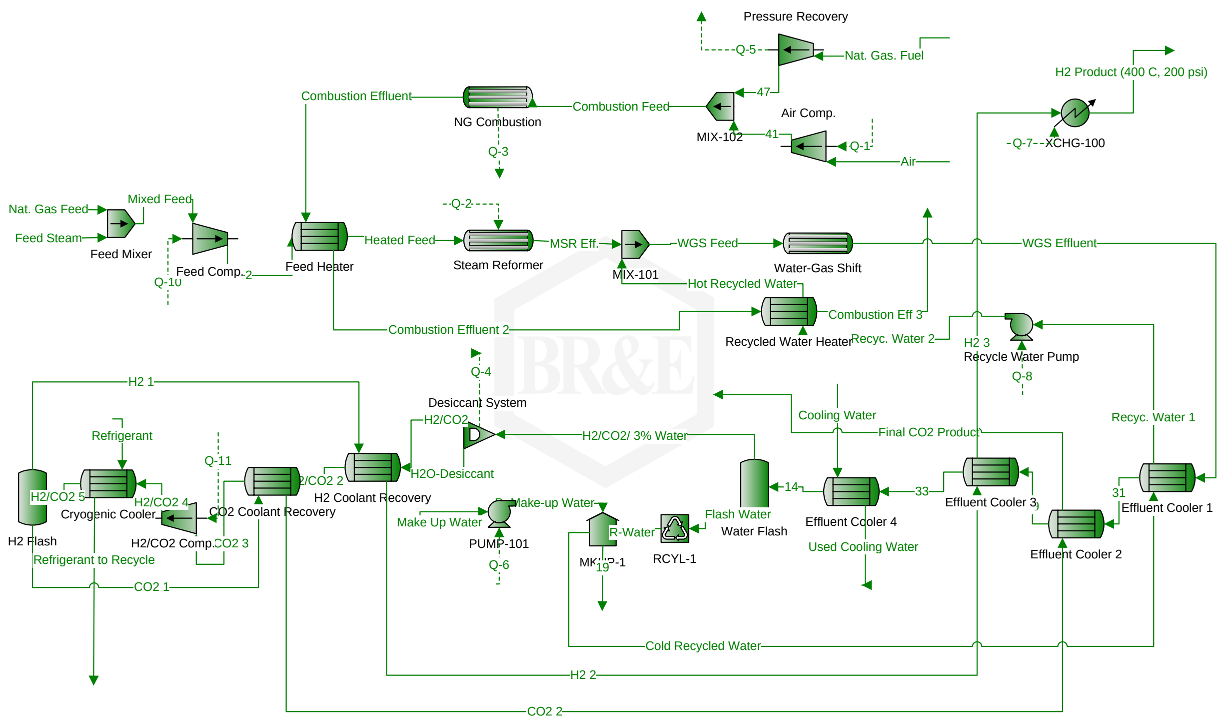

Figure 1: Process flow sheet of the process to convert natural gas to hydrogen for heavy oil upgrading.

These supply costs were then 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 were predicted in out years using an extrapolation of historical price volatility data. A sensitivity analysis was performed with respect to commodity prices for the oil produced, the cost of utilities, the quality of the ore, and other scenario specific parameters.

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 (objective of this project)

PROJECT START DATE/DURATION

October 1, 2009 to March 31, 2011

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.

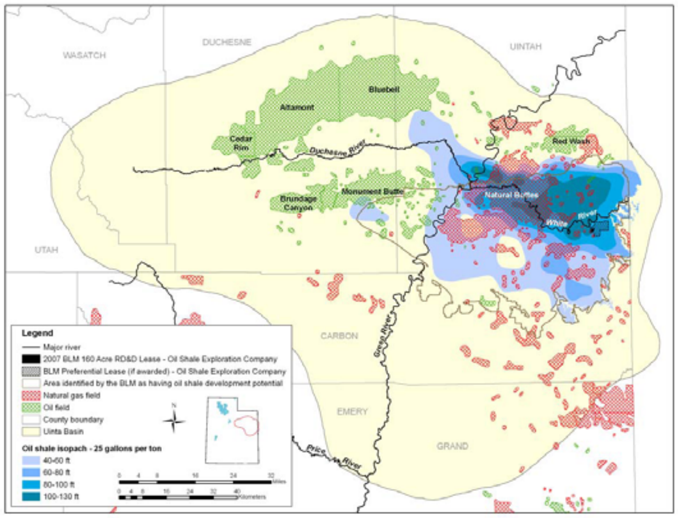

Figure 1: Map showing proposed study area, Uinta Basin, Utah. Note that the prime oil shale area overlaps with several natural gas fields.

Researchers used the same experimental system constructed for another Institute for Clean and Secure Energy project, ***Multiscale Thermal Processes***. Both hydrous and non-hydrous experiments were conducted. The analysis matrix included four water-phase and one oil-phase sample. The gas chromatography/mass spectrometry (GCMS) data obtained for volatile and semi-volatile hydrocarbons are compared in Table 1. Most of the targeted compounds, including the potential aromatics, are not in the detection limit of the instrument used. The C_7-C_{35} aliphatic hydrocarbons were present in all the water-phase samples, and their amount increased with increase in pyrolysis temperature. The oil-phase sample shows a wide range of hydrocarbon species with the potential to be sources of contamination if in contact with water for a long duration. The GCMS analyses also revealed untargeted compounds like acid and alcohol groups.

Table 1: GCMS results for targeted volatile components.

Compounds	Hydrous-300C-water phase (ul L)	Hydrous-350C-water phase (ul L)	Pyrolysis-350C-water phase(ul L	Pyrolysis-500C-500 Psi-water phase (ul L)	Pyrolysis-500C-500Psi-oilr phase (ug Kg)
Benzene	< 200	< 1,000	< 2,000	< 2,000	943,000
Ethylbenzene	< 200	< 1,000	< 2,000	< 2,000	1,730,000
Methyl-tert-butyl ether	< 200	< 1,000	< 2,000	< 2,000	< 50,000
Naphthalene	< 200	< 1,000	< 2,000	< 2,000	766,000
Toluene	< 200	< 1,000	< 2,000	< 2,000	5,030,000
Xylenes,Total	< 200	< 1,000	< 2,000	< 2,000	8,500,000
C6 Apliphatic hydrocarbons	< 200	< 1,000	< 20,000	< 20,000	4,540,000
C7&C8 Aliphatic hydrocarbons	15,700	42,100	< 20,000	< 20,000	34,500,000
C9&C10 Aliphatic hydrocarbons	< 2,000	< 10,000	< 20,000	< 20,000	23,300,000
C9&C10 Alkyl Benzenes	< 2,000	< 10,000	< 20,000	< 20,000	6,540,000

Experimental Characterization of Oil Shales and Kerogens

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PROJECT PURPOSE/GOALS

- Extract kerogen and bitumen from Green River oil shale
- Obtain experimental structural data, including but not limited to ^{13}C solid state NMR, on Green River oil shale, on bitumen and kerogen isolated from the shale, and on products of pyrolysis of these materials

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $112,982

PROJECT DESCRIPTION

The first goal of this project is to isolate the organic matter from the oil shale, which constitutes approximately 10-20% of the total shale. This includes the soluble bitumen as well as the insoluble kerogen. This demineralization is a lengthy process, comprised of a number of acid washes and extractions.

The second goal is to experimentally characterize the structure of the organic material. To achieve this goal, the following experimental techniques are being employed on these samples: ^{13}C nuclear magnetic resonance (NMR) spectroscopy in solution and in the solid state, mass spectrometry (MS) analysis, small angle x-ray scattering (SAXS), and measurement of the atomic pairwise distribution function (PDF) via x-ray scattering. Each of these techniques provides different information on the structure of the materials.

Figure 1 is one example of the data obtained on these samples. The figure shows the ^{13}C solid state NMR data obtained on the shale from three different sections of the Institute for Clean and Secure Energy's (ICSE) Skyline 16 oil shale core. This core was drilled in Utah's Uinta Basin. This data can be analyzed to obtain information such as the percentage of carbons that are aromatic versus aliphatic, the average number of carbons in an aromatic cluster, and the percentage of aromatic carbons that are protonated, substituted or bridgehead carbons

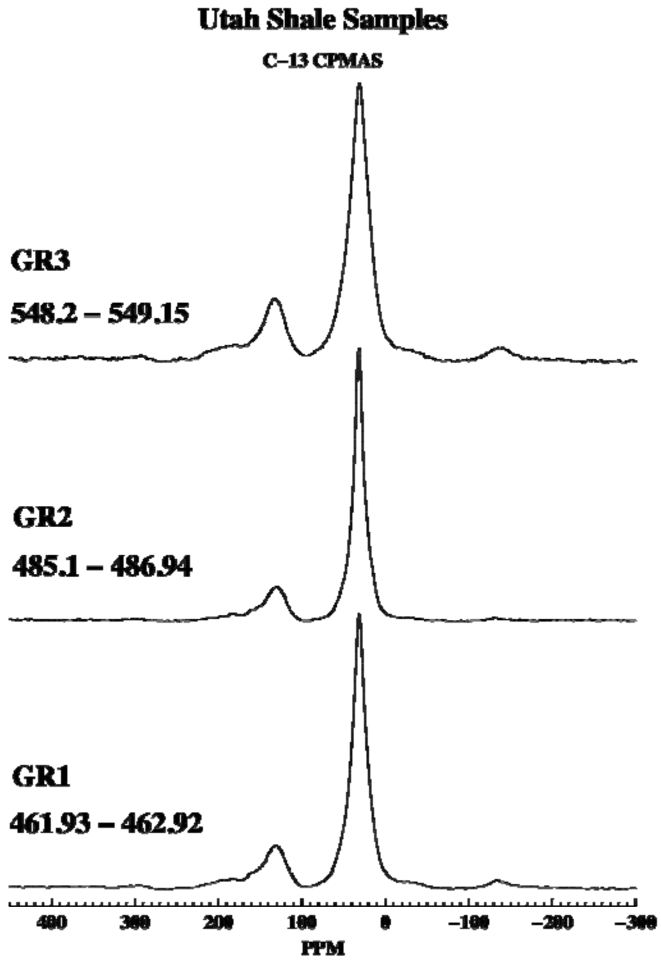

Figure 1: Solid-state ^{13}C NMR data of three different sections (GR-1,-2,-3, numbers indicate depth along core) of the Skyline 16 core from the Uinta Basin, Utah. While the spectra appear to be quite similar, a full NMR analysis of each sample reveals differences.

In addition to the analysis performed as part of this project, the isolated kerogen is also provided to other projects within the Institute for Clean and Secure Energy (e.g. CT microscopy and pyrolysis experiments). All pyrolysis products (tars, chars, etc.) will be returned to this research group to undergo the same characterization as the original material in order to determine the changes in the material.

The experimental data generated by this project will be used by another ICSE project, ***Atomistic Modeling of Oil Shale Kerogens and Oil Sand Asphaltenes***, to assess the quality of an atomic level model of the kerogen and to guide model modification.

INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

Geomechanical Reservoir State

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PROJECT PURPOSE/GOALS

- Measure deformation, porosity and permeability changes on oil shale samples subjected to representative in-situ stresses as well as engineered temperatures required for kerogen conversion and syngas production
- Generate geomechanical, thermophysical and permeability data for use with complimentary ongoing research efforts (***Reservoir Simulation of Reactive Transport Processes***) and for validation efforts (***In Situ Pore Physics***)
- Topical Report assessing subsidence and compaction implications of in situ development of oil shale and oil sands

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $210,093

PROJECT DESCRIPTION

Successful recovery of product from in situ oil shale and oil sands operations requires supplementing existing formation permeability by creating fracture networks and assuring that superjacent lithologies and the surface shall not subside substantially as a consequence of compaction of the pay zone. The fracture networks allow penetration of appropriate carrier media, removal of product, increased surface contact area, and reduced distance for movement of fluids from the matrix to a fracture system intimately connected to a production wellbore. These fracture systems can be newly created, reactivated, healed pre-existing discontinuities, etc. In oil sands, the fracture systems may be more channel-like, depending on the integrity of the native rock. Compaction could occur due to volumetric reduction accompanying kerogen conversion and syngas production. Alternatively, heave could occur during some stages of in-situ heating due to thermal expansion as well as supplementary fracture creation (dilation).

Research for this project shall include experiments to replicate in-situ production processes and determine the potential for creation of supplementary permeability and porosity; to evaluate potential methodologies for increasing contact area in the reservoir; and to determine thermophysical properties for complimentary simulations. A unique high pressure-high temperature vessel and an ancillary flow system has been designed (Figure 1) to carry out measurements representing oil shale response to high-temperature in situ processes under realistic pressure and stress conditions. Measurements will assess strength, fracturing potential, fracture and matrix porosity creation and yield, and temperature-dependent thermophysical properties required for various simulations. This task builds on legacy literature, including a paper by Budd *et al.* (1967)[1] addressing strength parameters in relationship to anisotropic bedding structure and work by Petrofsky (1973)[2] and Tisot (1967)[3]on measurement of mechanical properties.

Examples of tests to be performed include (1) thermal loading measurements to duplicate generic in situ temperature profiles under static but representative in situ stress conditions and to assess the consequences of the stresses and temperatures on generation of fracture and matrix porosity and permeability, (2) temperature-dependent thermophysical properties required for simulations including thermal conductivity and diffusivity, (3) temperature-dependent thermomechanical properties required for simulations as a function of process history including the coefficient of thermal expansion.

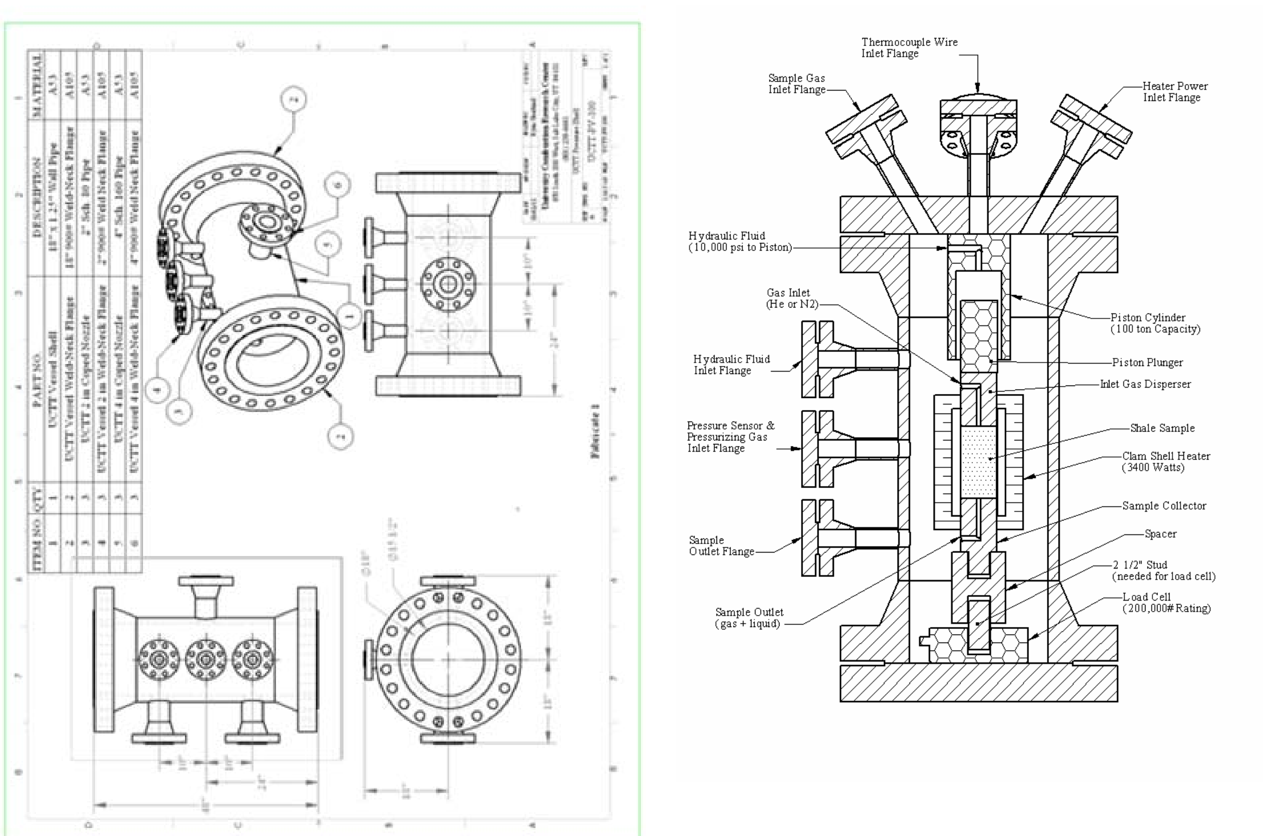

Figure 1: (Left) Preliminary pressure vessel design. (Right) Elevation cross-section through the vessel, designed to accommodate 4-inch diameter oil shale sample and simulate processes with temperatures of 1000°F, 10,000 psi axial stress, and confining pressure of 1500 psi.

[1] Budd, C.H., McLamore, R.T., and Gray, K.E. (1967). "Microscopic examination of mechanically deformed oil shale," SPE 1826, 42nd Annual Fall Meeting SPE, Houston, TX, October 1-4, 1967.
[2] Pelofsky, A. H. (1973). "Composition And Reactions Of Oil Shale: A Review," SPE 4433.
[3] Tisot, P. R. (1967). "Alterations in structure and physical properties of Green River oil shale by thermal treatment," J. Chem. Eng. Data, v. 12, no. 3, p. 405.

INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

In-situ Pore Physics

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PROJECT PURPOSE/GOALS

- Characterize the pore network structure for selected oil sand/oil shale resources using Computed 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 the Mahogany zone of Green River oil shale samples and oil sands samples from the U.S. and Canada

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $50,082

PROJECT DESCRIPTION

Wn a carbon-constrained world, transportation fuel production from oil shale and oil sands 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. Project researchers 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. Figure 1 shows the 3D volume rendered images from the reconstructed multi-scale XMT data for a Mahogany oil shale core sample before pyrolysis. Lamellar structures (kerogen-rich and silicates-rich) are observed. The middle column shows the distribution of the kerogen phase. At a 60 nm voxel resolution, individual grains can be identified. Figure 2 shows the same set of 3D images for a Mahogany oil shale 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 high resolution XMT or HRXMT images), larger, anisotropic cracks and voids have developed.

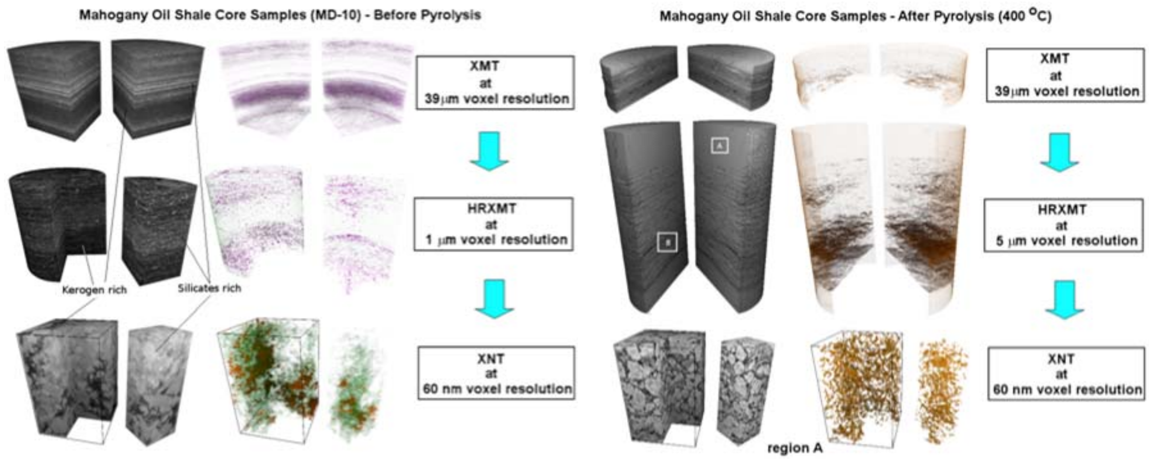

Figure 1 (left): Volume rendered images of Mahogany oil shale drill core sample MD-10 from reconstructions of multi-scale x-ray CT data. Gray scale indicates variations in density and atomic number of material. Middle column shows kerogen phase distribution (in purple and brown colors for XMT, HRXMT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

Figure 2 (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 permeabilities. For region A, the estimated permeability from LB simulation of oil shale after pyrolysis was 0.00363 μm^2 or 0.363 mD (millidarcy). Because the absolute permeability is highly anisotropic, the estimated permeability in region B is 3.87×10^{-8} cm^2 or 3.87 darcy, four orders of magnitude higher than in region A. Anisotropic features of oil shale permeability are being quantified and may be the first 3D imaging of pyrolysed oil shale by HRXMT and nano-CT.

In addition, oil shale core samples after pyrolysis at three reaction temperatures (300°C, 350°C, and 400°C) and heating rates of 1, 10 and 100°C/min have been imaged using HRXMT to establish the pore structure of the core after reaction (~5 micron voxel resolution). The porosity variation with drill core sample height as measured from the CT data clearly correlates with position of the kerogen layers.

Future research includes the analysis of fresh oil shale core and its comparison with the initial oil shale samples, the determination of directional (anisotropic) permeability of the new oil shale samples after pyrolysis reactions at different temperatures and loading conditions using XMT analysis and LB simulation, and calibration for phase identification with results from QEM/SCANA.

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

- Update land ownership and resource ownership in light of the Utah Recreational Land Exchange Act
- Research recent changes in federal policy regarding management of federal lands with wilderness characteristics and likely impacts on access to unconventional fuel resources
- Analyze constraints on development of federal lands contained in BLM Resource Management Plans to identify areas with highest development potential
- Identify models for multi-jurisdictional natural resource management and research their potential to improve management coordination and cooperation

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $111,492

PROJECT DESCRIPTION

When Utah became a state, it received title to approximately 7.5 million acres of federal land scattered across the landscape in support of public schools and institutions. Under other federal laws, other tracts of federal land were granted to settlers and miners. Additionally, the federal government established Indian Reservations, National Forests, National Parks, and other federal reservations. This history led to a fragmentation of ownership overlaying oil shale resources within Utah as shown in Figure 1; similar ownership fragmentation concerns apply to oil sands.

These various land owners and management agencies have disparate management objectives and requirements. For instance, the Bureau of Land Management (BLM), which manages the majority of federal land within Utah's 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.

For this project, research will update surface and oil shale ownership estimates to reflect the volume of oil shale controlled by the four major resource owners within the Uinta Basin (federal, state, tribal, and

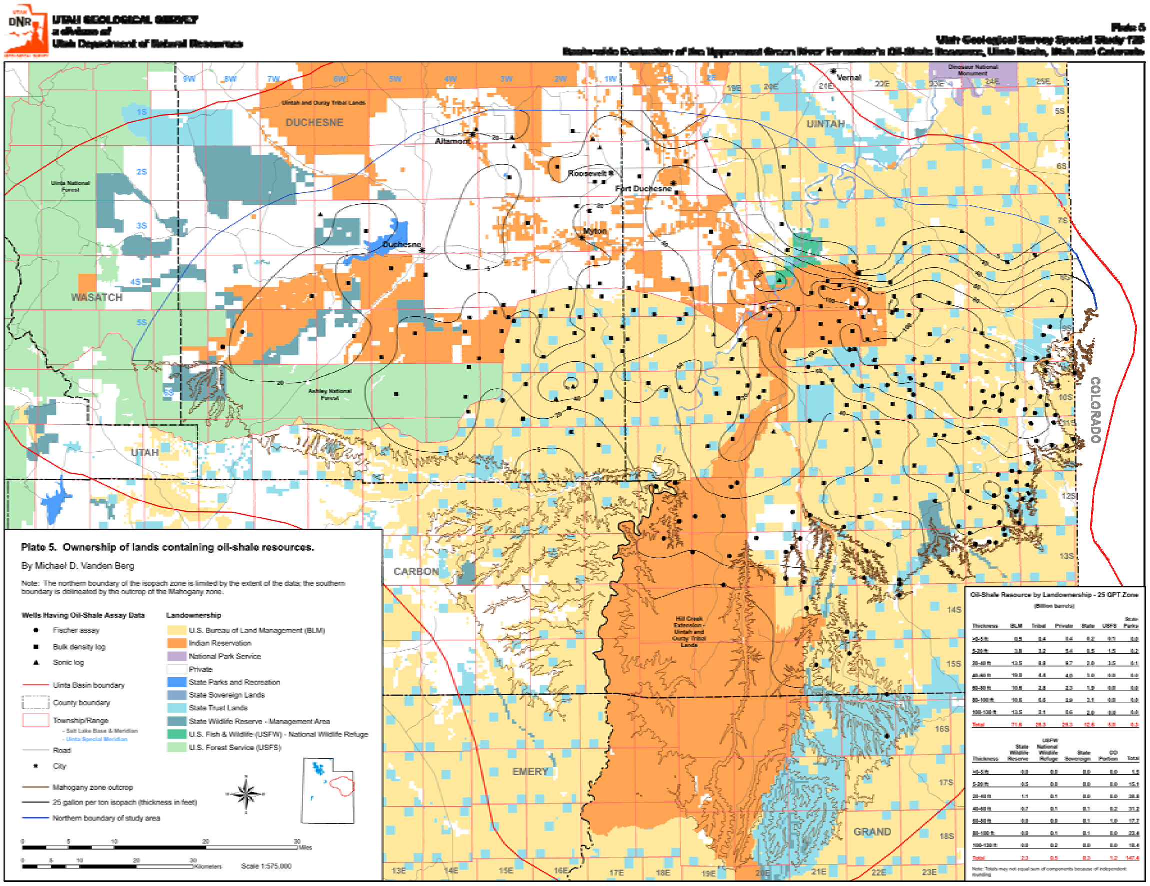

Figure 1: Map showing ownership of lands with oil-shale resources in the Uinta Basin. From M. Vanden Berg, Utah Geological Survey Special Study 128, 2008.

private) given the passage of the Utah Recreational Land Exchange Act in which SITLA is anticipated to obtain from the BLM approximately 19 square miles of oil shale-bearing lands.

Access to oil shale and oil sands resources on federal lands is controlled by a number of laws, requirements contained in several Resource Management Plans, and the 2008 programmatic revision to these plans that designated certain federal lands as available for application for commercial leasing. The impact on access to oil shale and oil sands resources of recently resolved litigation challenging federal oil shale leasing rules and this designation of available lands for commercial leasing will be discussed.

As part of the settlements, the Department of the Interior (DOI) agreed to reconsider management of public lands that possess wilderness characteristics. The DOI also recently issued a Secretarial Order and three BLM Handbook chapters clarifying how the BLM will fulfill its obligations to inventory for lands with wilderness characteristics and to determine the management of lands with wilderness characteristics. This research utilizes BLM wilderness characteristic inventory information to identify, map, and quantify areas with wilderness characteristics and their likely impact on development of Utah oil shale and oil sands resources. Research also evaluates general Resource Management Plan requirements in order to clarify the development potential of different geographic areas.

Lastly, this research discusses prior efforts to designate federal public lands within Utah for dominant uses and to exchange federal and state lands to consolidate ownership and improve management efficiency. Research will identify lessons learned from prior efforts and how these lessons can be applied to improve land and resource management across Utah's fragmented landscape. The project will culminate with a topical report submitted to the Department of Energy.

Life-cycle Greenhouse Gas Analysis of Conventional Oil and Gas Development in the Uinta Basin

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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 modules for predicting life-cycle CO_2 emissions with Los Alamos National Laboratory's CLEAR model from conventional oil and gas development in Utah's Uintah Basin for purposes of model validation and uncertainty quantification

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $146,390

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. This project is evaluating life-cycle greenhouse gas emissions (GHG) from several oil sands and shale processes and opportunities for reducing GHG emissions. This project is also developing modules in Los Alamos National Laboratory's $CLEAR_{uff}$ model for predicting life-cycle CO_2 emissions from conventional oil and gas development in Utah's Uintah Basin in conjunction with two other Institute for Clean and Secure Energy projects***, Development of Conventional Oil and Gas Production Modules for*** $CLEAR_{uff}$ and ***V/UQ Analysis of Basin Scale*** $CLEAR_{uff}$ ***Assessment Tool***.

Available data on life-cycle GHG emissions from a variety of conventional oil and gas, oil sands and shale liquid-fuel production processes are being gathered and summarized. 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. Figure 1 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 there is uncertainty over the amount of CO_2 released from minerals in the oil shale during processing.

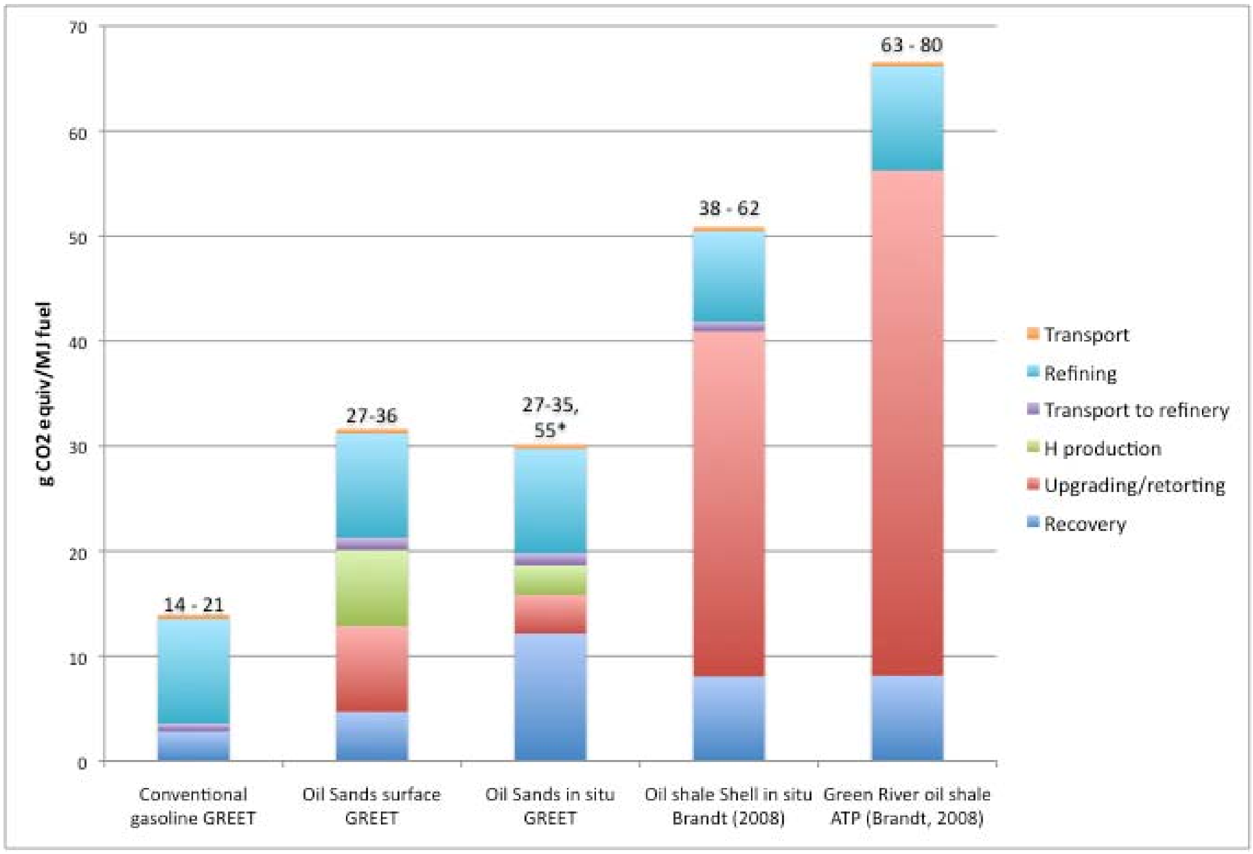

Figure 1: Life-cycle, well-to-pump GHG emissions from gasoline, oil sands, and oil shale processes.

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. The refining industry, as the third largest stationary source of GHG emissions globally, is evaluating technologies such as oxy-firing for GHG reduction. Oxy-firing 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. An evaluation of 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 has recently been completed. This evaluation includes the additional GHG emissions associated with the power required for air separation and CO_2 handling; the fuel savings from oxy-firing compared to air firing; and the upstream GHG emissions associated with the additional fuel requirements.

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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 (oil shale and oil sands)
- Examine policy and regulatory issues as well as externalities that will affect unconventional liquid fuels development
- Identify a range of plausible production scenarios for domestic oil shale and oil sands
- Identify revenue streams and establish a range of supply costs for each of these scenarios using sensitivity analysis to determine the impact of uncertain inputs
- Perform 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, 2011

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $400,000

PROJECT DESCRIPTION

At the request of the Department of Energy (DOE) Office of Oil and Gas per the recommendation of the Federal Advisory Committee on Unconventional Oil and Gas (Sect. 999), the focus of this project is an assessment that examines limiting factors to the development of domestic oil shale and oil sands resources and conducts an evaluation of supply costs for various development scenarios. This assessment utilizes other research performed at the Institute for Clean and Secure Energy as described in the 2010 DOE publication "Oil Shale Research in the United States" (2nd Edition).

Four scenarios are addressed in the assessment: (1) ex situ and (2) in situ development of oil shale and (3) ex situ and (4) in situ development of oil sands. All scenarios are located in oil shale- and oil sands-rich areas of Utah's Uinta Basin. Each scenario is developed at a production capacity of 50,000 bbl/d and includes extraction followed by primary and secondary upgrading of the crude oil to produce pipeline-quality oil for transport to a refinery. Supply costs for each of the scenarios are computed based on process modeling, scaling of industrial data, and the various costs associated with the scenario's location (infrastructure costs, transportation to market, whether federal or state tax laws apply). A sensitivity analysis is conducted to determine a plausible range of supply costs based on uncertainties in various input parameters such as the quality of the ore, the estimated recovery rate of oil, and a potential CO_2

production tax. In addition, an economic impact analysis is performed on 1-2 of the development scenarios to estimate the total addition to regional levels of employment, personal income, and government revenue from those scenarios.

The report has been sent out for review and is currently in the process of revision based on reviewer comments. The report will be released to the public prior to the end of 2011.

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Multiscale Thermal Processes

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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
- Collect an analyze condensable pyrolysis products from demineralized kerogen
- Develop kerogen pyrolysis models that integrate observations at various scales. One model combines heat and mass transport mechanisms along with reaction kinetics. The second model is based on the Chemical Percolation Devolatilization model (CPD)

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $400,000

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. Product composition and rate(s) of production 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 oil shale that is finely ground.

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. 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. In this project, researchers have determined the distribution of kinetic energies of the kerogen decomposition process using advanced isoconversional methods (Figure 1).

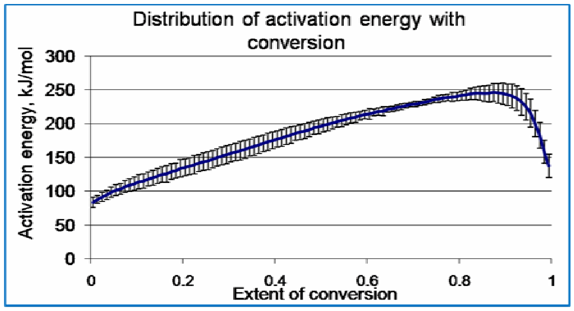

Figure 1: Distribution of activation energy on overall oil shale pyrolysis with TGA.

TGA combined with online mass spectrometry (TGA-MS) affords the opportunity to obtain compositional information while the decomposition is measured quantitatively. In a recently completed TGA-MS analysis of Green River oil shale from Utah, compounds of about 300 atomic mass units were targeted. Alkanes such as hexane and decane were detected at slightly lower temperatures than their equivalent carbon number aromatic compounds, but the differences were not significant. Higher heating rates generated more alkenes compared to the respective alkanes, and as the carbon number increased, this ratio decreased. Kinetics of the formation of naphtha group of compounds (C_5-C_{12}) were derived using the advanced isoconversion method. The activation energies, in the range of 41-206 kJ/mol, were lower than for the entire decomposition process. However, because the compound evolution signals as detected by mass spectrometry are noisier than the overall weight loss data, the uncertainties in these measurements were much greater in certain conversion ranges.

Multiscale pyrolysis of oil shale cores has also been performed. Results of experiments at two different scales at 500°C and 500 psi pressure are shown in Table 1. The significant increase in gas yield in the 2.5” core sample is likely due to secondary reactions that occur before the product is withdrawn. The gas chromatograms and single carbon number distribution show that the composition of oil produced at these two scales is not much different. The peak differences reveal that the ¾” sample has relatively more C10-C14 compounds while the 2.5” sample exhibits a shift in distribution to C24-C26 compounds.

Table 1: Overall mass balance of pyrolysis products.

Results	2.5" core	3/4" core
Wt loss %	24.52%	18.69%
Oil yield %	7.96%	10.63%
Coke %	4.14%	1.03%
Gas%	16.56%	8.06%
Unreacted organic%	0.05%	0.43%

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

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PROJECT PURPOSE/GOALS

- Discuss the current state of conjunctive surface and groundwater management within Utah and neighboring states
- Identify and discuss gaps in Utah's efforts to conjunctively manage surface and groundwater resources
- Analyze and discuss implications of conjunctive surface and groundwater management for oil shale and oil sands developers within Utah

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $192,289

PROJECT DESCRIPTION

Oil shale and oil sands production require water, and water is in short supply throughout the intermountain west. Demand for water resources will continue to increase with population growth, recognition of instream water uses, expanding energy production, and climate disruption. Existing annual and seasonal precipitation variability and associated surface water ebb and flow are likely to intensify if climate change modeling is accurate, exacerbating existing competition for scarce water resources. Because, under Utah law, new water right holders can be served only after all senior water rights have been satisfied, new water rights are susceptible to interruption during times of shortage. Such disruptions would prove problematic for emerging industries that require a stable water supply.

Development of oil shale and oil sands resources may require acquisition of existing water rights and conversion of those water rights to new uses. Where prospective unconventional fuel developers already hold valid water rights, pilot or commercial-scale development may require changes to the point of water diversion or withdrawal. Water right changes frequently involve substituting a groundwater well for a surface water diversion and the permissibility of these changes is dependent, in large part, upon the interaction between surface and groundwater resources.

Western water law developed during a time of less intense demand and when the interaction between surface and groundwater resources was not well understood. Legal developments have not always kept pace with our growing understanding of the hydrologic connection between surface and groundwater resources. This research effort discusses how surface and groundwater resources within Utah are managed conjunctively, addressing the current regulatory regime, gaps therein, and how neighboring states have dealt with similar challenges. The research project also discusses the implications of conjunctive surface and groundwater management challenges for oil shale and oil sands developers, drawing on lessons from domestic, municipal, and irrigation management efforts. The project will culminate with a topical report submitted to the Department of Energy.

INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

Reservoir Simulation of Reactive Processes

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PROJECT PURPOSE/GOALS

- Incorporate reaction kinetics, pore property information, and reservoir characterization into simulation
- Create a reactive-transport reservoir simulation tool capable of modeling the conversion of kerogen to oil and gas and the transport of multiple phases under realistic geologic and reservoir conditions
- Analyze how geologic heterogeneity impacts production from Utah oil shale resource

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $222,395

PROJECT DESCRIPTION

In situ oil shale processing has the potential to minimize surface disturbance and process water requirements and to access deep, unmineable 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.

The STARS simulator developed by Computer Modeling Group has capabilities to represent thermal in situ processes. This project uses STARS to evaluate the sensitivity of production rates from oil shale to various in situ process parameters. Several sensitivity studies have been conducted to expose the interplay among physical parameters in STARS. Early results show that activation energies in a multi-step reaction scheme and relative permeability representations affect oil production more than heat of reaction.

Geological characterization of cores (Figure 1) in the Uinta Basin by another Institute for Clean and Secure Energy project, ***Developing a Predictive Geologic Model of the Green River Oil Shale, Uinta Basin***, is providing a better picture of the organic and inorganic content of the reservoirs of interest and of their heterogeneity. This organic content information is being incorporated into process simulations.

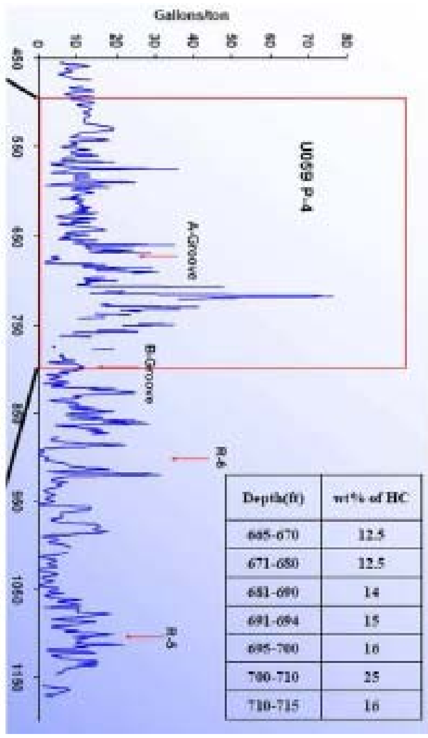

Figure 1: U059 well Fischer Assay log.

Oil shale pyrolysis is an energy intensive process. This project has examined process variations and conceptualized new processes for minimizing energy use. A hybrid process that begins with pyrolysis and later utilizes the energy from coke combustion (produced by air injection) has a reduced energy consumption (Figure 2) compared to the original pyrolysis process. However, CO_2 emissions increase due to coke combustion and carbonate decomposition.

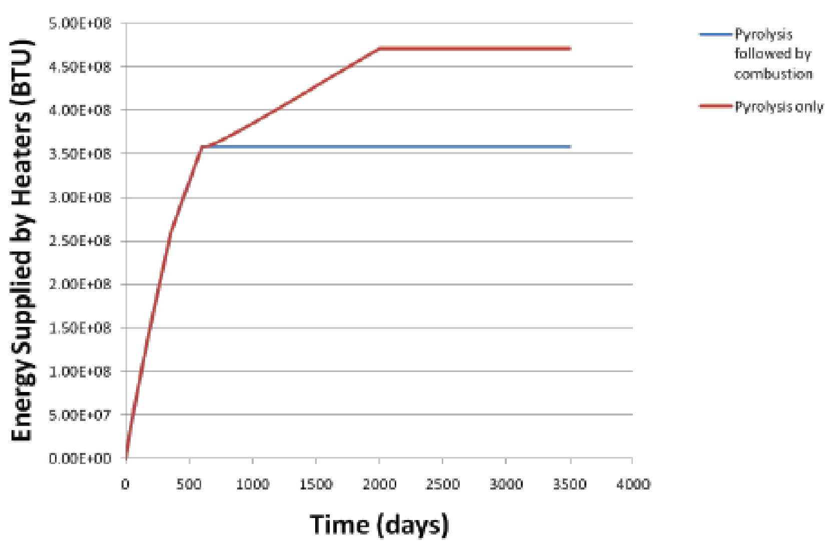

Figure 2: Cumulative energy input for combined and pyrolysis only processes.

INSTITUTE FOR Clean and Secure Energy THE UNIVERSITY OF UTAH

V/UQ Analysis of Basin Scale CLEAR$_{uff}$ Assessment Tool

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PROJECT PURPOSE/GOALS

- Develop a predictive tool for assessing the basin- and regional-scale environmental and economic impacts of unconventional fuel development
- Perform validation/uncertainty quantification (V/UQ) research to establish the predictive capability of the simulation tools that are developed

PROJECT START DATE/DURATION

October 1, 2010 to March 31, 2013

PROJECT SPONSOR(S)

- Department of Energy, National Energy Technology Laboratory
- Funding level: $360,000

PROJECT COLLABORATOR

- Los Alamos National Laboratory

PROJECT DESCRIPTION

The Computational Earth Sciences Group at Los Alamos National Laboratory has recently developed the dynamic, integrated assessment model *CLEAR$_{uff}$* to evaluate the potential for unconventional fuel development given environmental and economic constraints such as water availability, land use regulations, and size of the local labor pool. This project will develop a methodology for doing V/UQ on system models like *CLEAR$_{uff}$*. Issues to be considered include: (1) how to systematically determine which of the hundreds of model parameters have the largest effect on outputs of interest such as energy and water demand, (2) what is the distribution of uncertainty ascribed to the various parameters and how can that choice be justified, and (3) how to perform V/UQ on a dynamical system. Because there is no commercial data which can be used for model validation, this project will demonstrate an application of the methodology for conventional oil & gas development during a recent energy boom in Utah's Uinta Basin, specifically focusing on changes in water and energy demand, population, and tax revenues. Work being performed in other projects supported by the Institute for Clean and Secure Energy, including "***Life-cycle Greenhouse Gas Analysis of Conventional Oil and Gas Development in the Uinta Basin***" and "***Development of Conventional Oil and Gas Production Modules for CLEAR$_{uff}$***," will be utilized for this project.

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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 Summer 2013.

PROJECT SPONSOR(S)

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

PROJECT DESCRIPTION

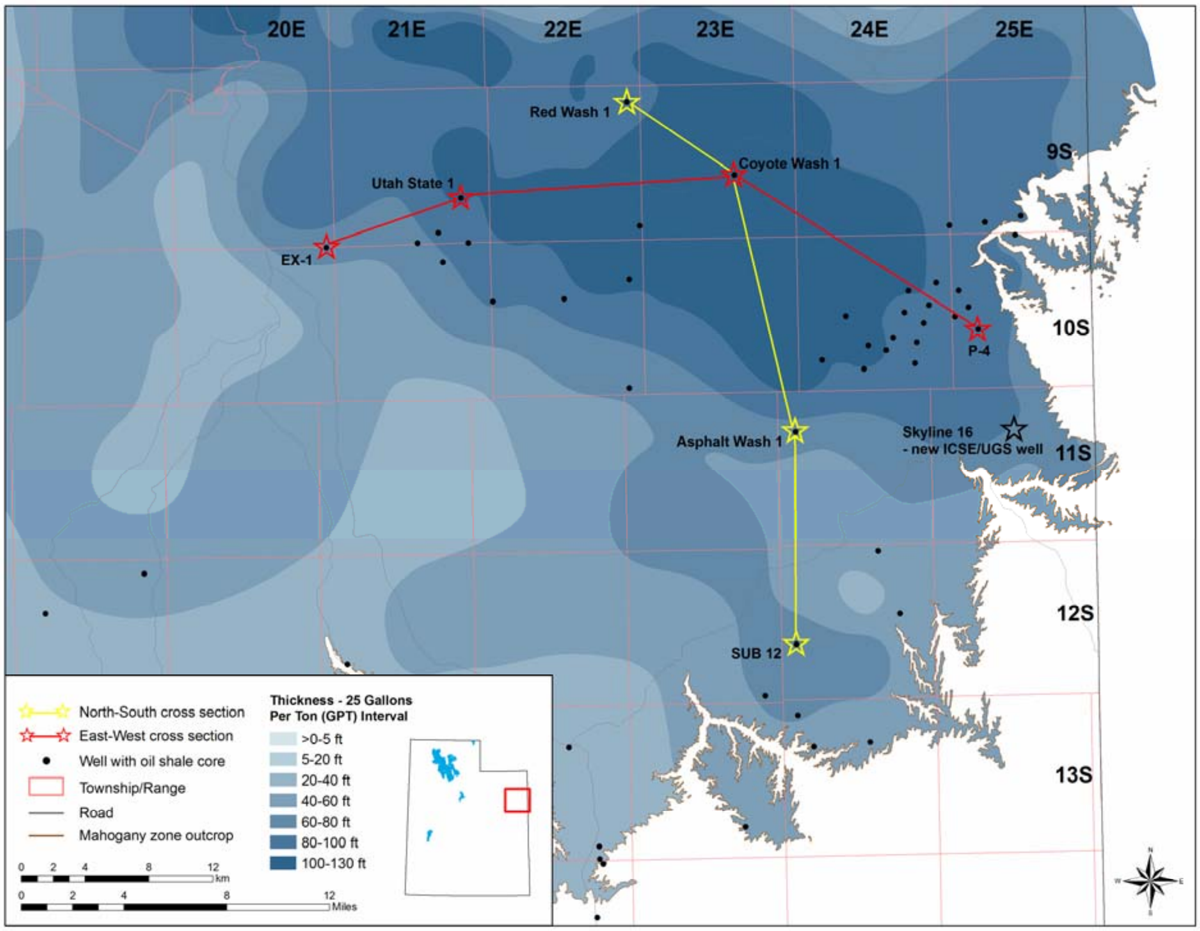
This core-based geologic analysis of the middle and upper Green River Formation oil shale deposits will examine vertical and lateral variability in oil shale properties across a 30 mile N-S and 30 mile E-W transect in the eastern Uinta Basin. Emphasis will be placed on identifying changes in oil shale 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

Completion of the detailed east-west section 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

2006 to 2009

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 conducted 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.

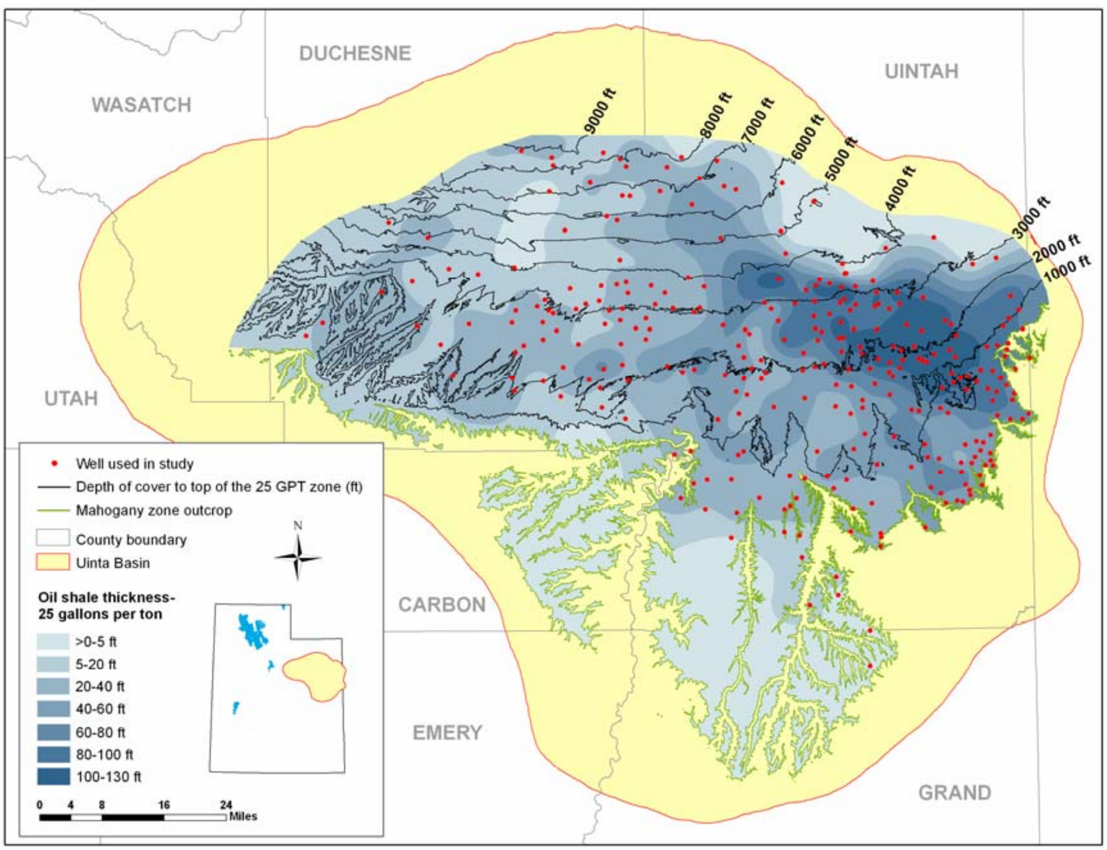
This resource assessment defined the oil shale resource by richness interval (i.e., 50 gallon per ton [GPT] zone, 25 GPT zone, etc.), relevant to land use planning and operator development. The completed assessment is available as UGS Special Study 128.

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.