Research and Information Needs for Management of Tar Sands Development

Committee on Onshore Energy Minerals Management Research
Board on Mineral and Energy Resources
Commission on Physical Sciences, Mathematics, and Resources
National Research Council
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The purpose of this report is to review the research needed to support the regulatory and managerial role of the agencies in the development of tar sands resources. The material reviewed in preparation for this report was assembled and presented at the Workshop on Research Needs for the Management of Tar Sands Development, which was held on April 14-15, 1983, in Salt Lake City, Utah. The workshop was organized by the Committee’s Tar Sands Subcommittee to provide a forum for experts from academia, industry, state and federal agencies, as well as environmental, native, and user groups, to exchange views on the wide range of research issues central to the development of these resources. (See Appendices A and B for the workshop agenda and list of participants.) Copies of the transcripts of the workshop presentations are available at cost from the Archivist of the National Academy of Sciences.

The Committee on Onshore Energy Minerals Management Research was organized by the National Research Council in response to a request from the U.S. Geological Survey's (USGS) Conservation Division of the U.S. Department of the Interior. In early 1982, the Minerals Management Service (MMS) was formed largely from the Conservation Division. In late 1982, the responsibility for onshore minerals management was transferred to the Bureau of Land Management (BLM). These agencies have been responsible for managing and coordinating mineral activities on public lands. These responsibilities include resource evaluation, approval of mineral development plans and regulatory duties during mineral operations, and postoperational plans for reclamation and monitoring. The primary objectives of the regulatory program are resource conservation, protecting life and property, and minimizing the risks of environmental and ecological damage or degradation. The Committee, at the request of these agencies, has conducted a series of four workshops to elicit technical guidance on research needs in support of their regulatory responsibilities for onshore mineral activities involving oil shale, arctic oil and gas, uranium, and tar sands. Socioeconomic research lies beyond the purview of this Committee.
It is expected that the information and analysis presented herein will make a contribution toward that research needed to manage these valuable public resources.

Donald A. Dahlstrom and Joe B. Rosenbaum, Co-Chairmen
Tar Sands Subcommittee

John W. Roll, Chairman
Committee on Onshore Energy Minerals Management Research
## Contents

1 Introduction and Overview 1
2 Utah Tar Sands Distribution, Geology, and Characterization 7
   Water Supply 9
   Research and Information Needs 9
3 Technologies for Oil Recovery 11
   Mining Tar Sands 12
   Solvent Extraction Processes 12
   Water (with Additives) Processes 13
   Thermal Recovery Process 15
   Bitumen Upgrading 16
   Research and Information Needs 16
4 Environmental Aspects of Tar Sands Mining and Processing 18
   Mining 18
   Processing 18
   Synthetic Crude Oil Transportation 19
   Water Use 19
   Land Reclamation and Wildlife 19
   Development of Regulations and Guidelines for Tar Sands Mining and Processing 20
   Research and Information Needs 21
5 Summary 23
   References 24
   Appendixes
   A. Agenda for the Workshop on Research Needs for the Management of Tar Sands Development 26
   B. Participants in the Workshop on Research Needs for the Management of Tar Sands Development 28
1

Introduction and Overview

Tar sands were defined in 1980 by the U.S. Department of Energy (DOE) as any consolidated or unconsolidated rock (other than coal, oil shale, or lignite) that contains hydrocarbons (bitumen) with a gas-free viscosity greater than 10 pascal seconds, or 10,000 centipoise, at original reservoir temperature (Marchant and Terry, 1982). Basically this means that the bitumen viscosity is so high that it cannot be produced by ordinary primary oil field methods. Following passage of the 1981 Federal Combined Hydrocarbon Leasing Act, the Bureau of Land Management (BLM), for royalty purposes, added the phrase "or is produced by mining or quarrying" to DOE's definition.

The new leasing mechanism authorized by the 1981 Act provides for combined hydrocarbon leases applicable only to 11 specified areas in eastern Utah that contain the bulk of the known federally owned tar sands resource. New leases, for a maximum of 2,073 hectares (5,120 acres), and a 10-year primary term, will be by competitive bids. About 80 percent of the federal tar sands resource in the 11 Special Tar Sands Areas (STSAs) are already held under mining claims (from before 1920), or under existing oil and gas leases (Figure 1). The Act provides for voluntary conversion of the claims and existing leases to the new combined hydrocarbon lease. Few of the unencumbered federal parcels would be logical mining units (LMU) on their own. Hence, the near-term demand for competitively leased tar sands is expected to be limited to small parcels that round out mining claims, private lands, state leases, or holdings obtained under the conversion program to a LMU.

Applicants seeking conversion must file within 2 years of the November 16, 1981, enactment date, or by the expiration date of their lease, whichever comes first. The law requires that an operating plan that ensures diligent development of the tar sands and reasonable protection of the environment must be submitted and must obtain federal approval as a condition for lease conversion. Because of the short deadline and the general paucity of exploration data, the plans submitted may need to provide for appreciable flexibility.
FIGURE 1 Utah special tar sands areas.
SOURCE: Cherry, 1983.
Unitization is permitted by the Act for resource conservation and efficient production from intermingled federal and state leases, Indian lands, and private holdings.

Utah Geological and Mineral Survey (UGMS) Map 47 (Ritzma, 1979) portrays and describes Utah's tar sands deposits. The 51 named deposits and other unnamed occurrences of mineable tar sands, almost all of which are included in the 11 SPEA's, were estimated to contain about 25 billion (25 x 10^9) barrels equivalent of bitumen in place. Sporadic core drilling has been done on several of the larger deposits. Asphalt had been mined from several deposits for use as paving material (and is still being mined from Asphalt Ridge for such use). Experiments in recovering oil from the sands showed that mining and processing recovered about 96 percent of the bitumen, whereas only 10 to 20 percent recovery was obtained by in-situ experiments using steam or organic solvents.

A large and growing literature on government, academic, and private research into oil recovery from Utah tar sands over the past 10 years (Laramie Energy Technology Center, 1983) has not appreciably altered the preliminary findings reported in UGMS Map 47. Underground mining of tar sands appears uneconomical. Surface mining, though more economical, seems applicable to only 10 to 15 percent of the Utah tar sands resource. Government and industry supported in-situ research has continued both in Utah and in Canada.

The history of Canadian heavy oil or tar sands resources, from their mention in 1719 to their geology, distribution, characterization, development, production, and impacts, is succinctly described in an Alberta, Canada, government report by McRory (1982). Bitumen in place is estimated as 1.3 trillion (1.3 x 10^{12}) barrels. Modern-day commercial production of oil from the Athabasca deposits started in 1967. Suncor, Inc., and Syncrude Canada, Ltd., now produce about 185,000 barrels of synthetic crude oil daily. Both firms surface mine and process the tar sands from deposits with less than 80 m (250 ft) of overburden and with a favorable strip-to-tar-sands ratio of about 1:1.

Most of the Canadian oil or tar sands occurs at great depth. About 7 percent of the resource is believed to be surface mineable. This accounts for the continued high rate of Canadian government support for in-situ research and development. Canada and the United States signed a $1.2 million cooperative agreement in late 1982 to coordinate a laboratory effort aimed at assessing various additives for in-situ steam stripping of heavy oils and tar sands.

Utah's tar sands resource of approximately 25 billion barrels oil equivalent is only a small fraction compared to the Canadian 1.3 trillion barrel resource. Furthermore, over half of the Utah bitumen is in lean deposits containing 8 to 9 percent bitumen. The remaining
deposits contain 9 to 13 percent bitumen. H.R. Ritzma (Consultant, Salt Lake City, UT, personal communication, 1983) estimates that no more than 15 to 20 percent of the Utah tar sands are accessible to surface mining because of their typical occurrence in cliffs and the attendant problems of coping with excessive overburden. Underground mining of tar sands may therefore become economically feasible in the future.

The technology base for a Utah tar sands industry has been laid by the Canadian developments, by the private sector's persistent laboratory and field studies, by the Utah Geological and Mineral Survey, and by research and development at government and university laboratories, particularly the DOE Laramie Energy Technology Center and the University of Utah. Of the 63 pilot and commercial projects completed, current, and planned, that were tabulated by Marchant and Terry (1982), 20 were in Utah. Of those, 14 were mining and processing projects and 6 were in-situ projects.

Unlike the Canadian megaprojects (55,000 and 125,000 barrels (bbls.) daily), initial U.S. tar sands mining and processing plants are seen as following a minimodular development mode with initial module capacities of 2,000 to 5,000 barrels/day. This approach avoids the commitment of huge capital outlays for many years before revenue production begins, and makes startup problems and delays more tractable. It also appears to be a prudent strategy in view of the many unknowns about the tar sands resource, its processing, and the environmental consequence.

A tar sands regional environmental impact statement (EIS) and separate EISs on the Sunnyside and Tar Sand Triangle ISAs are being prepared by BLM. These are expected to recognize that tar sands development in Utah must compete for air quality increments and water quality and quantity increments with oil shale projects, coal-fired power plants, possible coal gasification projects, oil and gas fields, and other industries. The Tar Sand Triangle EIS is being prepared jointly with the National Park Service as the land involved is within or adjacent to the Glen Canyon National Recreation Area and immediately west of Canyonlands National Park.

State government interest in orderly development of Utah's tar sands resource was expressed and defined by the Utah Energy Office (Bradley, 1983). The governor's liaison and assistance in coordinating actions by state agencies in matters relating to permits and approvals promise to expedite the clearances for a tar sands operation during the current administration.

Resource, technology, and environmental data needs of federal tar sands resource managers are sizeable, but less detailed than those recently defined for the Canadian Commercial tar sands operations. Part of the research and data
acquisition in the pertinent areas has traditionally been done and supported by federal and sometimes state agencies that have the requisite statutory authority. To the extent feasible, the federal lease managers should seek to obtain research assistance and information from such agencies and the private sector.

Relatively short time limits are allowed the federal agencies and lessees for mandated actions under the Combined Hydrocarbon Leasing Act. Therefore, in the interest of timeliness, we attempted to identify research needs for short-term decisions separately from the longer-term needs for later decisions.

Both short- and long-term needs for federal lease management of tar sands mining and processing are summarized here. These research and information needs appear in greater detail in the individual chapters.

Short-term needs include the following:

- Develop more complete definition and characterization of the potentially mineable deposits, including the location, depth, shape, structure, grade, and mineralogy for each unit, and its related overburden.
- Determine the hydrology of potentially leaseable tracts with reference to the quantity and quality of surface waters and groundwaters, water problems in mining, availability of water for plant use, and the susceptibility of groundwater and surface water to pollution from tar sands operations on both a regional and a site-specific scale.
- Develop models for assessing the potential economic value of lease tracts and for delineation of tracts into logical mining units (LMUs).
- Continued close monitoring of environmental aspects of Canada's oil or tar sands operations, and develop guidelines for environmental monitoring of U.S. operations.

Long-term needs include the following:

- Fill the most critical need for one or more demonstration-scale operations, federally supported if necessary, to reveal and resolve operational problems and provide opportunities for measuring, analyzing, and tracking wastes and emissions.
- Determine the long-term potential accumulation and migration of organic and inorganic pollutants in mine and process wastes.
- Devise soil and overburden management, waste disposal, and revegetation methods for developing and maintaining stable ecosystems on disturbed lands.
• Study and maintain revised estimates of both sequential and concurrent tar sands and other mineral developments as a means of developing optimum scheduling to fulfill both economic and environmental protection needs, as well as minimum inconvenience to the populace.
Other terms that are generally synonymous with tar sands include oil-impregnated rock, oil sands, rock asphalt, and bituminous sandstone. Some of the world's major resources of in-place bitumen are listed in Table 1. The data are adapted from Walters (1974). Utah's major tar sands resources are shown, in round numbers, in Table 2 (Ritzma, 1979). Eleven areas in Utah, designated as Special Tar Sands Areas (STAs) in the 1981 Combined Hydrocarbon Leasing Act, are shown in Figure 1. The bitumen content of the Asphalt Ridge and P.R. Spring tar sands is estimated as 13 and 12 percent, respectively—about the same as in the tar sands being processed in Canada. Bitumen in the Sunnyside and Tar Sand Triangle deposits is estimated at 5 to 9 percent.

Eight of the 11 STAs occur within, or on the periphery of, the Uinta Basin in northeast Utah. The other three are in southeastern Utah, north and west of the Colorado River. Most of the major deposits occur in structurally simple, gently dipping beds. However, the varied and often extensive topographic relief associated with many of the deposits and excessive overburden may preclude surface mining of much of the resource. It has been estimated that in the aggregate only 10 to 15 percent would be amenable to surface mining, but this could be much higher for favorably situated deposits (Marchant and Terry, 1982).

The Uinta Basin has an asymmetric oval shape and an areal extent of about 210 km (130 mi) east–west and 130 km (80 mi) north–south. The Asphalt Ridge, White Rocks, and Raven Ridge deposits occur along the northern rim of the basin in moderately dipping and sometimes complexly faulted strata. Around the southern rim of the basin, the P.R. Spring and Sunnyside deposits occur on the eroded edges of strata that dip gently to the north. Bitumen in the northern flank deposits may have originated deep within the basin, probably from the Green River Formation. Oil may have ascended along faults, fractures, and unconformities, emerging in giant seeps (≥50 million bbls, Ritzma, 1979) at or near the outcropping edges of the tar sands reservoir.
TABLE 1 Some Major World Resources of In-Place Bitumen

<table>
<thead>
<tr>
<th></th>
<th>In-place Bitumen (billion (10^9) barrels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>1,300</td>
</tr>
<tr>
<td>Venezuela</td>
<td>700</td>
</tr>
<tr>
<td>Utah</td>
<td>25</td>
</tr>
<tr>
<td>Other U.S. (mostly CA, KY, NM)</td>
<td>3</td>
</tr>
<tr>
<td>Europe</td>
<td>3</td>
</tr>
<tr>
<td>Africa</td>
<td>2</td>
</tr>
</tbody>
</table>


Beds. These beds include the Duchesne River, Uinta, and Green River Formations (Eocene); Mesaverde Formation sandstones (Upper Cretaceous); and, for the White Rocks deposit, the Jurassic Navajo Sandstones. Oil may yet be migrating into and becoming entrapped in the bitumen seeps.

Along the southern rim of the Uinta Basin, the F.R. Spring and Sunnyside deposits may have originated from giant, stratigraphically entrapped oil fields. These probably formed in the deltaic and fluvial sands of the Douglas Creek Member of the Eocene Green River Formation and the underlying Wasatch Formation, and have since been exposed by erosion. Because most of the major Uinta Basin deposits occur in fluvial, lagoonal, and deltaic environments, the areal extent and thickness of individual tar sands reservoirs are difficult to predict. Individual deposits exhibit rapid changes in shape, porosity, and clay content that would complicate tar sands mining and processing.

In southeastern Utah, formation of the major tar sands deposits is attributed to oil reservoirs stratigraphically entrapped in the White Rim and Cedar Mesa Permian sandstones, and the Triassic Moenkopi Formation. Minor tar sands occurrences are in the Triassic Chinle and Wingate Formations, the Permian Kaibab Limestone, and the Permian Coconino Sandstone. Erosion by the Colorado River and its tributaries uncovered the oil fields allowing the gases and volatile fractions to escape, leaving the tarry residues.
<table>
<thead>
<tr>
<th>Tar Sand Deposits</th>
<th>In-place Bitumen (billion (\times 10^9) barrels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tar Sand Triangle</td>
<td>13</td>
</tr>
<tr>
<td>P.R. Spring</td>
<td>4</td>
</tr>
<tr>
<td>Sunnyside</td>
<td>4</td>
</tr>
<tr>
<td>Circle Cliffs</td>
<td>1</td>
</tr>
<tr>
<td>Hill Creek</td>
<td>1</td>
</tr>
<tr>
<td>Asphalt Ridge</td>
<td>1</td>
</tr>
<tr>
<td>San Rafael Swell</td>
<td>0.5</td>
</tr>
<tr>
<td>Argyle Canyon</td>
<td>0.2</td>
</tr>
<tr>
<td>Raven Ridge</td>
<td>0.2</td>
</tr>
<tr>
<td>White Rocks</td>
<td>0.1</td>
</tr>
<tr>
<td>Pariette</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**SOURCE:** Ritzma, 1979.

**WATER SUPPLY**

Annual precipitation in eastern Utah varies markedly with the terrain and altitude. It is 210 to 280 mm (8 to 10 in.) in desert areas with cold winters and hot summers; 310 to 420 mm (12 to 16 in.) at middle elevations; and 390 to 650 mm (15 to 25 in.) on high plateaus with long, cold winters and mild summers. There are only a few streams in the area. Surface water in these streams is fully allocated. Hence, surface water rights would have to be purchased, if needed, for tar sands operations. Groundwater supplies may be available locally. For instance, the Midasnest aquifer underlying parts of the Uinta Basin has been estimated to contain 18 million acre feet of water.

An environmental impact statement, in preparation by BLM, will include an assessment of water availability and the effects of synfuels development (tar sands and oil shale) in the Uinta Basin on water supplies. Estimates of water consumption for processing mined tar sands range from 2 to 6 volumes per volume of oil product.

**RESEARCH AND INFORMATION NEEDS**

The more important research and information needs related to tar sands resource definition and characterization, and water resource, include the following:
- Gather more definitive data on the size and distribution of the bitumen resource for the deposits that are potentially mineable by surface methods. Determine the vertical and horizontal distribution of bitumen beds. Obtain data on the thickness, structure, and overburden depths for each bed, as well as the way in which individual beds thicken, thin, and pinch out. Additional geological mapping, core drilling, and subsurface sampling are required to obtain the needed data. Drill-core holes for resource definition should be logged to obtain geotechnical data on the overburden and interbedded mining wastes. Such information as mineral composition, grain size, water content, and plasticity would help guide waste-dump design and determine possible suitability of waste material for building tailing dikes.

- Determine the mineralogy of the bitumen-bearing beds, including water content and grain size distribution. Note particularly the percentage and type of clays, as these markedly influence the bitumen recovery process and tailing disposal. Also determine the presence of heavy metals and trace elements that may have an economic potential or that may adversely affect the environment or separation process.

- Determine the bitumen characteristics and range of variability in separate beds and within individual beds. Include analyses for sulfur and nitrogen.

- Assess the hydrology in the areas of mineable deposits. Determine the presence and amount of and depth to groundwater and the water quality, its direction and rate of movement, and its probable entry into the mine. This would provide essential information for mine planning and for evaluating the effects of mining and waste disposal on the hydrologic system. It also would provide valuable information on water resources.

- Develop models for assessing the economic value of lease tracts under varying demand scenarios and for delineation of tracts into logical mining units.
Intensive field studies for recovering oil from deeply buried bitumen beds by assorted in-situ methods have been, and are being, conducted in Canada and in the United States. Commercial production has not resulted to date from such in-situ experiments, but 180,000 barrels daily of synthetic crude oil is being produced in Canada by surface mining and processing of relatively shallow tar sands. With the Canadian experience in mind, this report addresses only the research and information needs for oil production by surface mining and processing of tar sands from federal leases. Under special access and economic conditions an initial underground mine may be appropriate.

Methods for processing the mined tar sands have been summarized by Marchant and Terr (1982) as "solvent, water with various additives, and thermal retort." In most instances the proposed projects use various elements of proven technologies that are assembled into processes that are unique or unproven. Conversion of the recovered bitumen to synthetic crude oil suitable for conventional transport and refining is performed by an "upgrading" process. In Canada, upgrading is done by removing excess carbon in the form of coke.

On the basis of still fragmentary data about the Utah tar sands, these appear to differ from the Canadian tar sands in several important ways that could affect mining and processing. The Utah deposits are less massive and extensive; also, the bitumen often occurs in a consolidated rock. The Canadian sands being mined are unconsolidated, except when frozen. In some instances, the Utah sands appear to contain substantially less clay than the Canadian sands. A low clay content may be an important advantage during processing and in spent sands disposal. The sand particles in Canadian deposits are "water wet" rather than "bitumen wet" as in most of the Utah sands. "Water wet" sands, having a film of water between the bitumen and sand surface, are more readily separated from bitumen. Also, the bitumen in the Canadian sands is of lower viscosity and more readily floated than the Utah bitumen, and this facilitates separation from water and sand.
Bunger et al. (1979) showed P.R. Spring and Asphalt Ridge bitumen samples that were low in sulfur (0.79 percent and 0.69 percent) and were also very low in vanadium (25 ppm). Bitumen from Tar Sand Triangle samples contained 4.38 percent sulfur and 180 ppm vanadium, whereas Athabasca bitumen contained 4.86 percent sulfur and 280 ppm vanadium. Low sulfur and low vanadium are desirable in refinery feed. Hunger and his associates also showed that tar sands bitumens differed significantly from one another in the amounts and kinds of heteroatomic compound types present. Those compounds have important effects on recovery and refining processes. Utah tar sands generally contain more nitrogen, which is less desirable for refining.

Utah tar sands containing less than about 10 percent bitumen would require crushing and grinding before treatment for bitumen recovery. Tar sands of higher bitumen content ordinarily are too sticky for crushing and grinding at ambient temperature.

MINING TAR SANDS

In Canada, the practice is to remove several meters of muskeg from the surface, strip up to 80 m (250 ft) of overburden, and then mine the tar sands to a similar depth. Combinations of draglines and bucket-wheel excavators, that feed belt conveyors, are used for stripping and mining. Because of Utah's much rougher tar sands terrain, and the much smaller scale of the contemplated operations, stripping and mining are likely to be done by shovel and truck. Large stockpiles of mined tar sands may be necessary at the plant site to provide uniform feed to the recovery process.

SOLVENT EXTRACTION PROCESSES

Dissolution of bitumen from tar sands by organic or halogenated hydrocarbons is readily accomplished in cyclic processes that recover most of the solvent for reuse. A preliminary water treatment may be desirable, as wetting the sand surface with water before introducing the organic solvent facilitates recovery of the solvent from the spent sands. Essentially complete recovery of solvent from the spent sand is required to reduce operating cost. In Canadian practice, naphtha is used as a displacing agent in cleaning up the initial crude bitumen concentrate produced by hot water extraction.

Characteristics and limitations of various solvents and procedures for their use were reviewed at the Committee's Tar Sands Workshop by Aiford (1983). Processes that have advanced to the pilot-plant stage are reported to use toluene, naphtha, kerosene, or a halogenated hydrocarbon as solvents, in anhydrous or water-solvent systems.
Anhydrous solvent systems appear to be the most straightforward. Several extraction stages are required to obtain high-recovery bitumen with minimum solvent. Depending on the solvent, it is recovered from the extract by atmospheric pressure distillation, vacuum distillation, or steam stripping. Generally, the recovered bitumen is expected to be sufficiently free of entrained sand or clays that it can be upgraded directly. The pilot-plant operation that uses a halogenated hydrocarbon solvent does not upgrade its recovered bitumen but sells it to nearby refineries. In most process variations the solvent is recovered from the spent sands by direct or indirect heating with steam. Bitumen recoveries of over 90 percent and almost complete recovery of solvent are commonly reported. Such recoveries may be difficult to sustain in practice.

Water-solvent processes in which either the solvent or the water is applied first also have been tested. The addition of water first appears to present fewer operational difficulties and minimizes loss of solvent with the spent sands. A pH of 8 to 9, by addition of soda ash (Na₂CO₃), is required to avoid formation of troublesome emulsions and to "wet" the sand. Both bitumen-wet and water-wet tar sands appeared to be amenable to the water-solvent process. Bitumen recovery of 99 percent and low solvent loss in the spent sand are claimed. The recovered bitumen concentrate is reported to be low enough in entrained water and solids for direct retorting.

Marchant and Terry (1962) show pilot-plant studies based on solvent extraction of bitumen that have been completed or were in progress by Amoco on Asphalt Ridge tar sands, and by Big Horn Oil Company on P.R. Spring tar sands. Aminoil used an anhydrous solvent; Big Horn used cold water and solvent.

**WATER (WITH ADDITIVES) PROCESSES**

Commercial Practice in Canada is based on use of alkaline hot water for initial stripping of bitumen from the tar sands. The mined tar sands are mixed in revolving drums with alkaline hot water at 80°C. Screening of the thick slurry follows to remove rocks, and lumps of clay and oil sand, which are discarded. Then the slurry enters separation tanks, where most of the bitumen rises as a froth. Spent sands sink and are pumped to tailing storage along with excess water. In between the floating bitumen froth and the spent sands at the bottom of the separation tanks is a "middling" sludge composed of clay, bitumen, and water. This is drawn off and treated by "froth" flotation (aeration of the slurry) to recover the bitumen and discard the clay and water.
Bitumen from the primary separators and froth flotation is combined, heated, diluted with naphtha, then centrifuged in two stages: first to remove coarse solids, and next to remove clay and water. Clean bitumen from the centrifuges is distilled to recover the naphtha for recycling, then "upgraded" by coking to make synthetic crude oil. The coke formed is burned to generate power and steam for plant and local use, or stockpiled. Liquid and gaseous products from coking are treated with hydrogen (made by reforming natural gas) for removal of nitrogen and sulfur. Solids and water from flotation and centrifugation join the sands and water from the primary separators (both with remaining entrained bitumen) for tailing storage and water recovery in diked ponds.

Mira and Miller (1980) of the University of Utah, have reported that the Canadian hot water extraction practice, with some significant changes, was applicable to the high-grade Asphalt Ridge and P.R. Spring tar sands, but was unsuited for the Sunnyside and Tar Band Triangle tar sands. A water film ordinarily is present between the bitumen and the sand surface in Canadian tar sands, but the Utah tar sands are generally dry—the bitumen is bonded directly to the sand. Also, the viscosity of the bitumen is much higher in the Utah sands. These adverse factors necessitate the use of a high shear, stirred tank reactor with substantial detention time for digestion of the tar sands, a 900°C digestion temperature, use of wetting agents, and modified flotation for phase disengagement.

For the relatively lower grade Sunnyside material that contains bitumen of still higher viscosity, an ambient temperature water extraction process was developed (Miller, 1983). The tar sands are ground in a conventional ball mill to liberate the bitumen from the sand, and the bitumen recovered by froth flotation with the addition of necessary flotation reagents. Grinding the Sunnyside tar sands to 60 percent minus 100 microns enabled recovery of over 90 percent of the bitumen in a low-grade concentrate of 20 percent bitumen. In laboratory experiments the process energy required per ton of Utah tar sands for the preparation of an initial concentrate containing 90 percent of the bitumen in the feed was about 15 kwh for the ambient temperature and about 40 kwh for the hot water process. Further beneficiation of the 20 percent bitumen concentrate by solvent extraction or thermal processes may be feasible. Application of the hot water process to the 20 percent concentrate improved the concentrate grade only to 45 percent bitumen.

An alternative water-based process for coping with extremely viscous bitumen is the modified hot-water process in which a bitumen diluent, such as kerosene, is added before water treatment to reduce the bitumen viscosity (Miller, 1983). A certain conditioning time is required, dependent on the initial viscosity and size of individual
tar sand particles. Required time for adequate penetration was 30 minutes for Asphalt Ridge tar sands and 3 hours for Sunnyside tar sands. In general, the use of kerosene diluent gave somewhat improved results over the hot water process without kerosene and enabled operation at milder conditions of alkalinity and temperature. However, appreciable fine sand continued to be entrained in the bitumen concentrate.

Pilot-plant studies of water extraction processes completed or then in progress were reported by Marchant and Tery (1982). These included use of cold water and diluent by the Major Oil Company on Asphalt Ridge tar sands; hot water and diluent by the AI Rack firm and the Major Oil Company on White Rocks tar sands; and hot water and caustic by Enercor on P.R. Springs tar sands.

**THERMAL RECOVERY PROCESS**

Thermal processes generally resemble oil shale retorting methods. Possible advantages of thermal processing are lower water requirement, ease of product handling and waste disposal, and applicability to lean tar sands. Direct or indirect heating may be employed in recovering oil from the tar sands. The high energy requirement is a major disadvantage.

In the direct recovery method, a portion of the bitumen in tar sands charged to a retort vessel is burned, and the heat partially decomposes and vaporizes the remaining bitumen. Bitumen vapors and combustion products leave the retort together. The vapors are condensed and separated from the combustion gases. In the indirect thermal method, the tar sands are heated in the absence of oxygen to vaporize most of the bitumen. The remainder is coked and burned to provide heat for the carbonization step.

Bench-scale testing of an indirect thermal process at the University of Utah was reported by Weeks (1977). Despite operating difficulties, oil was recovered from Tar Sand Triangle lean tar sands in several tests. Current work on the indirect thermal process at the University of Utah showed that solid retention time (measured in seconds) was the most critical variable, and that 450°C was the minimum retorting temperature (Frank Hanson, University of Utah, personal communication, 1983). When retorting for a suitable time at 330°C to 550°C, recovery of 80 percent of the bitumen in liquid form was possible.
BITUMEN UPGRADEING

Upgrading converts the bitumen concentrate into a refineable product by removing excess carbon, by adding hydrogen, or both. Canadian practice is to remove appreciable carbon in the form of coke, and mildly hydrotreat the liquids to improve their stability and remove nitrogen and sulfur. Considerable natural gas is used in manufacturing the needed hydrogen.

Syncor, Inc., uses conventional delayed coke units in a batchwise operation. Resultant lump coke is used as process fuel or stored for sale. Vapors from the coking operation are separated by distillation into light process gas, naphtha, kerosene, and gas oil. The three liquid products are separately treated with hydrogen in "Unifiers" to remove nitrogen and sulfur. Then the purified liquids are blended for shipment to refineries as synthetic crude oil. Unifier gases are scrubbed to remove the nitrogen and sulfur compounds. The \( \text{H}_2\text{S} \) removed from the scrub liquor is converted to elemental sulfur for sale.

Syncrude Canada, Ltd., uses fluid coking, a continuous operation, conducted in an interlocked fluidized bed retort and a fluidized bed burner. Coke, the size of fine sand, produced in the retort flows to the burner, and in turn the heated coke from the burner flows to the retort where it forms a fluidized bed at a temperature of \( 500^\circ\text{C} \). Preheated bitumen is sprayed into the hot coke with production of hydrocarbon vapors and more coke. About 40 percent of the coke produced is consumed in the burner. The remainder is withdrawn from the burner and stockpiled for future disposition. Only two liquids—naphtha and gas oil—are made at Syncrude. The Syncrude oil blend is of slightly lower quality than that sent to the refinery by Syncor.

RESEARCH AND INFORMATION NEEDS

Differences in important process response characteristics between Utah's and Canada's tar sands preclude the direct application of Canadian technology to mined Utah tar sands. Paramount is the need for one or more demonstration-scale operations to reveal and resolve operational problems in mining and processing and provide opportunities for observation, measurement, and assessment to mining and processing wastes and emissions. Continued laboratory testing and research and development on tar sands, such as that currently conducted by the University of Utah and the Laramie Energy Technology Center, would provide valuable support to an expanded exploration program and the demonstration-scale operations. Particular attention should be directed at reduction in water requirements, and improvement
in the storage and reclamation characteristics of the spent sands. Plausible innovative approaches that offer significant cost advantages should be supported.
Environmental Aspects of Tar Sands Mining and Processing

Utah's tar sands terrain, climate, hydrology, and geology differ substantially from Canada's, but environmental impacts requiring mitigation, which depend on the interaction of emissions with the environment, nevertheless are expected to be generally similar. These include disruption of terrain, and changes in the plant community, in hydrology, and in the fish and wildlife community caused by liquid, solid, and gaseous emissions.

MINING

Removal of oil sands by open-pit mining is common to both commercial operations in Canada. The immediate consequences of mining operations include disruption or alteration of vegetation, soil, overburden, and the hydrologic regime with attendant disruption of wildlife and fish habitat. Suitable disposition and reclamation are required for overburden and mine rejects.

PROCESSING

Reclaimed water from the hot water process used for bitumen recovery in Canada is heavily contaminated with clay and bitumen. However, zero discharge of contaminated process water is achieved in large settling ponds, which provide for water reuse. It is not known whether Utah's tar sands will be processed using this technique. If so, sludges of clay, organics, and spent sands will require disposal. There are marked variations in the Utah tar sands deposits. Deposits that were formed as river deltas may contain appreciable clay, which would lead to significant sludge disposal problems.

Water quality may be affected by an extraction method, because spent sand sludges contain sulfur, metal compounds, and hydrocarbons. The latter may include polynuclear aromatic compounds. The volume of
spent sand may be greater than the volume of an equivalent amount of tar sands in the deposit. Hydrocarbon and metal concentrations are generally calculated on the basis of the total volume or weight of a specific waste stream, but are often part of the water-soluble or colloidal fraction of the waste, and hence have enhanced mobility.

Most of the methods for production of marketable crude oil from recovered bitumen require an upgrading step to remove the undesirable constituents. Extra high-molecular-weight organics, sand and clay, metals, sulfur, and mineral waters. Coking, to remove excess carbon and the various contaminants, is employed in the Canadian oil sands operations to yield a low-sulfur, mineral-free, high-grade synthetic crude oil that is transported to refineries through a pipeline. The coking operation has an air and water pollution potential from gaseous emissions and from the carbonized solid waste.

SYNTHETIC CRUDE OIL TRANSPORTATION

Environmental problems from pipeline construction and from spills of product must be addressed. It is expected, however, that these problems will not be unique to tar sands operations, and that strategies for dealing with them are generally available in the petroleum industry.

WATER USE

Diversion of relatively fresh water from streams of the area, in a zero-discharge mode of operation, to industrial developments in the Uinta Basin could result in an increase of total dissolved solids in the Colorado River. On the other hand, diversion of water for plant use from the more saline streams of the area could improve the quality of the Colorado River.

LAND RECLAMATION AND WILDLIFE

Utah tar sands development might affect several climatic types, natural plant communities, and their attendant fish and wildlife. The most extensive of these include cold deserts with cold winters and hot dry summers (210 to 286 mm (8 to 10 in.) precipitation), open pinyon pine/juniper shrub lands (310 to 420 mm (12 to 16 in.) precipitation), Douglas fir forests on moist sites and Ponderosa pine forests on drier sites among the higher plateaus with long, cold winters and mild summers (390 to 650 mm (15 to 25 in.) precipitation). These climatic
and vegetation differences greatly influence the reclamation procedures that will be successful. Plateau areas are relatively easily reclaimed to productive status, while the cold desert landscapes are more difficult to revegetate. Reestablishment of wildlife populations depends upon the success of revegetation goals.

The design of successful reclamation procedures is dependent upon the following:

- Knowledge of the chemical and physical properties of the seed bed quality materials (including tailings spoil) to be used.
- Weathering rates of these substrates; their nutrient status including salinity levels, and possible amendments and treatments.
- Regional climate as it relates to precipitation (amount and seasonality) and temperature regime. Some modification of effective precipitation is possible through irrigation, snow fences, and contour manipulations.
- Native species most appropriate for establishing and maintaining a plant cover including planting procedures (seeding and/or container plantings). This would include accepted forestry and agronomic practices.
- Plant-plant and plant-animal interactions that will be central to establishing and maintaining a vegetation that is self-maintaining and one that will support appropriate wildlife species at desired levels.
- Determination of type and a model of the successional sequence of plants and animals that will achieve an open and innovative approach to revegetation and wildlife management.

DEVELOPMENT OF REGULATIONS AND GUIDELINES FOR TAR SANDS MINING AND PROCESSING

Regulations specifically designed for tar sands operations are still to be formulated by ELM. The USDA-Forest Service Surface Environment and Mining Program (SEAM), designed for reclamation of coal-mined lands, might well serve as a model for developing the needed regulations. That program has benefited from integration of industry/federal/state needs into a workable program. SEAM also has served as a mechanism for the transfer of technological information and design to the field situation. Both the ELM and the U.S. Forest Service will need information on new technologies for reclamation.

Standards for revegetation and wildlife maintenance should emphasize performance rather than design standards. The regulation should provide sufficient flexibility to encourage innovative
approaches to achieve the final land-use objectives. Regulations should recognize the need for flexibility as it relates to future land-use practices. The original vegetation of an area might have been managed for production of big game. However, it may be necessary for ecosystem stability to manage the modified lands primarily for control of erosion. The species used for this may not be as palatable to the desired wildlife as the predevelopment vegetation.

The variability in spent sands (tailings), off-grade stockpiles, and overburden may create problems for revegetation that require test-plot studies, including their long-term monitoring. As both water quantity and water quality potentially will be affected by tar sands mining and associated processing, effective management of the resource on federal lands requires the assessment of the effects of specific operations on the hydrologic environment, formulation of guidelines covering hydrologic aspects of leasing, operations, and abandonment phases of tar sands extraction, and development of effective monitoring systems.

RESEARCH AND INFORMATION NEEDS

The more important research and information needs associated with mitigation of adverse environmental impacts from tar sands operations include several that are best met by focusing on realistic disturbances, emissions, and wastes from a demonstration-scale tar sands mine and processing operation. Continued monitoring of the environmental aspects of Canada's oil sands operations may aid in developing strategies to mitigate their adverse consequences in U.S. operations.

Specific examples include the following:

- Determine whether mine and process wastes can be used effectively in diking and sealing waste storage impoundments.
- Determine the leachability of metals and hydrocarbons from the wastes, particularly as these may change with residual time in the environment. Are toxic or carcinogenic materials being released to the hydrosphere or biosphere?
- Adapt hydrologic and chemical models to sludges, wet sands, and coking wastes to assess water and solute movement through wastes, interaction with substrata, and possible impact on groundwater and surface waters. Would more effective dewatering improve disposal of sludge and tailing slurry?
- Achieve the desired stability of vegetation and wildlife through continued innovative research that will include the role of fungi in establishing plants, the use of
containerized plants versus seeding, the native species best adapted climatically and biologically to the substrates available, and the desired structure and nutrition of plants appropriate for wildlife. Scenarios are needed that address plant-plant and plant-animal interactions on landscapes that include cold desert shrub lands, pinyon pine-juniper scrub forest, and ponderosa pine-Douglas fir forest lands. The research should consider species desired for initial erosion control as well as long-term vegetation-wildlife stability that can be maintained at low cost.
Most of the known federal tar sands resource is within 11 specified areas in eastern Utah, which is estimated to contain about 25 billion barrels of bitumen. Recent federal legislation provides that existing mining claims, and oil and gas leases, which embrace about 80 percent of the resource, may be converted to combined hydrocarbon leases that would include tar sands. Applications for conversion must be submitted by November 16, 1983, and federal approval of an operating plan for tar sands must be obtained as a condition for conversion.

Exploratory drilling has been scanty, and the bulk of the resource is ill defined. About half of the bitumen occurs in deposits of 9 to 13 percent bitumen, somewhat lower grade than the feed to commercial Canadian oil sands operations. The remainder is in lean deposits of 8 to 9 percent bitumen. Terrain is rugged, and access is sometimes difficult. A variety of climate, wildlife, and plant communities are represented. Only 10 to 15 percent of the resource appears to be surface mineable.

Treatment of mined sand from the richer deposits, in the laboratory and in pilot plants, recovered about 90 percent of the bitumens by a variety of processes. However, the Utah sands are sufficiently different from the Canadian deposits that direct transfer of technology is probably not feasible.

A tar sands regional environmental impact statement and separate environmental impact statements for two proposed tar sands projects are being prepared by federal agencies. These are expected to take into account prospective developments for oil shale, oil and gas, and other industries in the vicinity.

Important short-term research and information needs for federal lease management include more complete definition and characterization of the tar sands deposits, the hydrology, and the regions downwind from the tar sands areas. Most critical of the longer-term needs is for one or more demonstration-scale operations to resolve production, waste management, and reclamation problems and provide opportunities for measurement, analysis, and assessment of mining and processing wastes and emissions.
References


Appendix A

Agenda for the Workshop on Research
Needs for the Management of Tar Sands Development

April 14, 1983

Morning Session - Moderator: Donald A. Dahlstrom

Welcome and Introductions
John W. Rold, Committee Chairman
Donald A. Dahlstrom
Subcommittee Chairman

Managerial and Regulatory Responsibilities of the BLM in Supervision of Tar Sands Operations and Research Needs
Francis E. Cherry
Bureau of Land Management

Tar Sands Resource Assessments and Definition
Howard R. Ritzma
Consulting Geologist

Tar Sands Resource Development Concerns and Probable Involvement of State Government
James Bradley
Utah Energy Office

Afternoon Session - Moderator: Joe B. Rosenbaum

Tar Sands Mining Production Methodologies
Kent Hatfield
KBI Engineers-Constructors, SLC, UT

Tar Sands Production Methodologies Using Water Processing
Jan D. Miller
University of Utah

Tar Sands Production Methodologies Using Solvent Technology
Harvey E. Alford
Ex-SCHIO, Cleveland

New and Other Processing Methods for Tar Sands and Bitumen Upgrading
Alex G. Obled
University of Utah
Waste Management and Spent Sands Disposal
Ed C. McRoberts
Hardy Associates (1978) Ltd.

26
Evening Session – Moderator: John W. Reid

Concerns of the Environmental Community in Tar Sands Development

Concerns of Indian Tribes in Tar Sands Development

April 15, 1981

Morning Session – Moderator: Lawrence C. Bliss

Air Pollution Control in Tar Sands Operations

Water Pollution Control in Tar Sands Operations

Revegetation and Land Restoration in Tar Sands Operations

Water Quality and Quantity Needs in Tar Sands Operations

Afternoon Session – Moderator: Sullivan S. Marden, Jr.

Plant-Animal Interaction and Wildlife Management Related to Tar Sands Reclamation

Government Management Concerns in Canadian Tar Sands Development

Operational and Environmental Concerns and Solutions in the Development of Canadian Tar Sands

Future Development Scenario as Seen by Industry

Summary Discussion of Workshop Activities

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R. Steven Chambers & Associates Law Offices

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Ute Indian Tribe

David C. Sheesley & Thomas E. Owen
U.S. Department of Energy

William F. McFerran & L.C. Marchant
U.S. Department of Energy

Mohan K. Wali
State Univ. of New York

Kenneth L. Lindskov
U.S. Geological Survey

James A. MacMahon
Utah State University

Michael J. Day
Alberta Energy & Natural Resources

Frederick W. Camp
Sunoco Energy Development Co.

David S. Mitchell
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Donald A. Dahlstrom & John W. Reid
Appendix B

Participants in the Workshop on Research Needs for the Management of Tar Sands Development

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28
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William L. Petrie, National Research Council, Washington, DC, Staff Officer