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U.S. TAR SAND OIL RECOVERY PROJECTS

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SYNTHETIC FUELS FROM OIL SHALE AND TAR SANDS

Louisville, Kentucky

May 17-19, 1983

Institute of Gas Technology

U. S. TAR SAND OIL RECOVERY PROJECTS

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ABSTRACT

The increasing U. S. energy demands, decreasing conventional crude oil reserves, and decontrol of crude oil prices have resulted in significant numbers of projects in U. S. tar sands. Data are reported for 62 projects involving in situ, mining and plant extraction, modified in situ and upgrading technologies. The data include operator name, project location, project status (completed, current, or planned), project type (commercial or pilot), reservoir and oil characteristics, and estimated product costs. The cost estimates per unit of produced oil provide encouragement for the commercialization of the U. S. tar sand resource.

INTRODUCTION

As the demand for energy in the United States increases and the reserves of conventional petroleum decrease, the interest in development of less conventional energy sources is increasing dramatically. This interest, plus the recent decontrol of crude oil prices, has resulted in widespread activities aimed at commercialization of the U.S. tar sand resource.

Although the U.S. currently has little commercial oil production from tar sand, considerable hope exists that in situ steam and combustion technologies, proven successful for heavy oils in California, and various mining and plant extraction and modified in situ processes will enable significant production from tar sand. Continued research and the field testing in 62 reported oil recovery projects (a majority, but not all field projects in U.S. tar sands) are providing the base of knowledge and experience for the economic exploitation of this energy resource. Three projects in reservoirs containing oils with less than 10 Pa.s viscosity are included because the unique oil recovery methods, if successful, are expected to be applicable to tar sands.

Cost data from several of the field projects indicate costs per cubic meter of produced crude oil from tar sands in the \$100 to \$125 range. These data, primarily capital investments and operating costs, are still incomplete but do provide encouragement for commercial development.

The status of the reported projects include time (completed, current or planned) and type (commercial or pilot). Planned pilot and planned commercial status are nearly synonymous because nearly all commercial projects are preceded by successful pilots.

TAR SAND DEFINITION

Tar sand was defined in 1980 by the U.S. Department of Energy as any consolidated or unconsolidated rock (other than coal, oil shale, or gilsonite) that contains a hydrocarbonaceous material with a gas-free viscosity greater than 10 Pa.s at reservoir temperature. Additional terms synonymous with tar sand are bituminous sandstone, oil-impregnated rock, oil sand, and rock asphalt. Tar sand deposits are distinguishable from heavy oil deposits by differences in viscosity between the contained bitumens or oils. The tar sand bitumen viscosity is so great that commercial production is impossible by ordinary primary methods. On the other hand, heavy oil viscosity is sufficiently low to permit production but probably not at economic rates. The United Nations Institute for Training and Research (UNITAR), the Interstate Oil Compact Commission (IOCC), and the American Petroleum Institute (API) have all recommended adoption of similar tar sand definitions.

U. S. TAR SAND RESOURCE

About 550 tar sand occurrences are known to exist in 22 of the United States (Figure 1)(Ball Assoc., 1965). Information on the majority of these deposits is very limited and therefore the resource estimate is for only five states. The estimated resource in California, Kentucky, New Mexico, Texas, and Utah is 4 to 6 billion m^3 of oil-in-place in 43 evaluated deposits (Marchant, 1980). There are eleven known deposits that contain a resource of 15.9 million m^3 or more, leaving 500+ occurrences in the small deposit category. An estimated 15 per cent of the U. S. tar sand resource is at shallow enough depths to enable surface or strip mining. Recently published data from California (Hallmark, 1979), Kentucky (McGrain, 1976), Missouri (Well, 1979) and Utah (Campbell and Ritzma, 1979) contributed to these estimates. However, these resource estimates predate the 1980 quantitative definition of tar sand and exclude those deposits, in California and other states, containing crude oils in the lower viscosity range of 10 to about 100 Pa.s. A current cooperative resource assessment project by the U.S. Geological Survey and the Interstate Oil Compact Commission is expected to significantly increase the total U.S. resource base.

The tar sand deposits involved in the reported projects possess a wide range of reservoir characteristics. Porosities are generally about 30 percent, but range from 17.5 to 37 percent. Permeabilities are also generally high, but range from 0.012 to 5.92 m^2. Oil saturations range up to 82 percent of pore space. Water saturations are reported as high as 65% in California reservoirs and generally less than 10% in the major Utah deposits. Reported oil gravities and viscosities range from 0.96 Mg/m^3 to about 1.09 Mg/m^3 and from 10 (less than 10 for three projects) to over 2,000 Pa·s, respectively. Depths of overburden range to 1097 m.

PROJECTS

Figure 2 and Tables 1, 2, 3 and 4 contain data for 62 reported field projects related to U.S. tar sands. Included are 37 in situ projects, 20 mining and plant extraction projects, 3 modified in situ projects, and 2 upgrading projects in 9 states. Over two-thirds of the projects are in California and Utah and about one-sixth are in Kentucky and Texas.

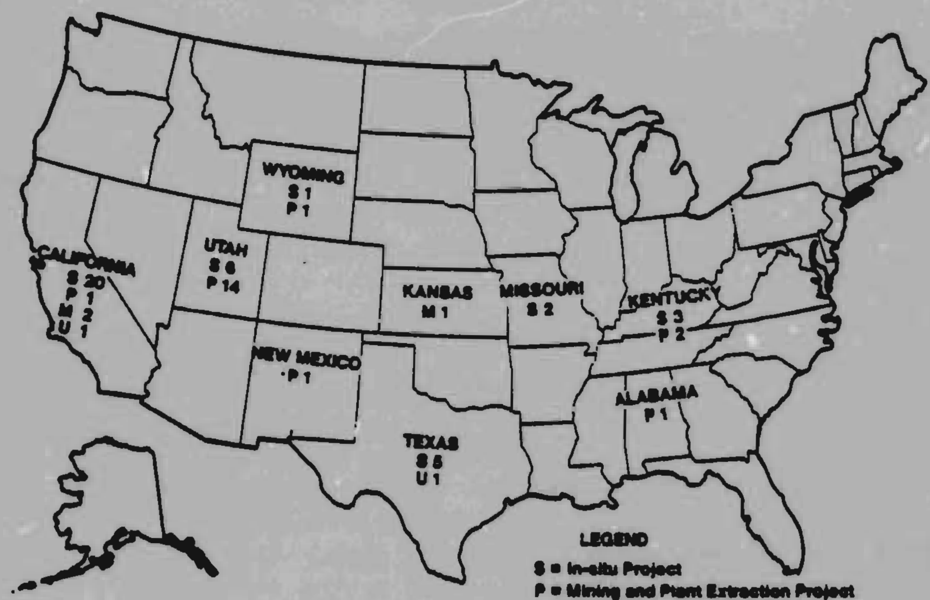
In Situ Processes

The primary technical deterent to production of oil from tar sand by in situ processes is the oil's high viscosity and resultant immobility. In most (35 of 37) reported in situ oil recovery projects, the viscosity reduction is accomplished by thermal processes - either steam or combustion. The other two projects have utilized electrical energy. Ten of the eleven current commercial in situ projects in California are in reservoirs containing oils with viscosities of 10 Pa·s to 25 Pa·s - relatively low for tar sands.

Steam - Most of the 28 steam projects utilize a steamdrive preceded by or in conjunction with cyclic steam injection. Several projects in California are classified as unconventional because they are, or will be, applied to reservoirs at depths greater than 760 m. Unique steam applications include combinations of steam and combustion, co-injection with sodium hydroxide and carbon dioxide (SCOT), and coal fired fluidized

Figure 1. Tar Sand Occurrences in the U.S.

Figure 2. U.S. Tar Sand Projects



bed combustors for steam generation. The Conoco (#27) and Enpex (#28) projects in the Saner Ranch field in Texas include current and planned use of coal fired fluidized bed combustors to generate steam. The Conoco projects include a patented "Fracture Assisted Steam Technology (FAST)". At the Kirkwood project (#37) in Wyoming's Burnt Hollow deposit the addition of sodium hydroxide will enhance the steam drive process. The Signal Oil and Gas Co. tests (#34) in Utah's Sunnyside deposit were conducted in horizontal wells drilled into a quarry face.

Combustion - The majority of the five in situ combustion projects utilize variations of the forward combustion process. The only reverse combustion applications were by Phillips Petroleum Co. (#25) in a completed pilot project in Missouri (Trantham, 1966) and by the U. S. Department of Energy's Laramie Energy Technology Center (LETC) (#32) in Utah. The LETC series of experiments has included reverse combustion (Land, 1977); combination reverse and forward combustion (Johnson, 1981); steamdrive (Johnson, 1981); and (planned but aborted in 1982) combination reverse combustion and steamdrive.

Other - The Illinois Institute of Technology Research Institute (#31), under contract to the U. S. Department of Energy, has conducted a small scale field experiment in Utah to test the feasibility of in situ heating of tar sand with radio frequency (RF) electrical waves. As the RF heating is accomplished, production of the mobilized oil to a collection chamber is by gravity drainage. In their completed combustion pilot in Kentucky, Gulf Oil Co. (#21) employed a propped induced fracture. The specific thermal processess to be employed in two planned projects by Altex and Kirkwood, in Utah's Tar Sand Triangle Deposit (#35 & #36), are not identified at this time.

Mining and Plant Extraction Processes

The commerical potential of tar sand oil production by mining is a function of the ratio of overburden thickness to tar sand thickness. Experience in the Canadian tar sands, (the only current significant commercial tar sand surface mining operations) indicates this ratio should not exceed one. It is estimated that not more than 15% of the U.S resource has a ratio of one or less. Conventional underground mining is not considered feasible for tar sands, but various combinations of mining and in situ processes are being tested. The mining and plant extraction processes utilized in the reported projects involve three primary oil extraction processes: solvent, water with various additives, and thermal retort. Each project, although it can be included in one of these broad process categories, is unique with the process details tailored to the operator's preferences and patents and the resource characteristics. The mining phases of the reported projects are all similar conventional strip-mining operations.

Solvent - Eight of the 20 reported mining and plant extraction projects utilize solvent processes for extraction of the oil from the tar sand. Most of these are unique patented or proprietary processes. The Western Tar Sands, Inc. (#50) project in Utah's Raven Ridge deposit utilizes an anhydrous solvent process enhanced by ultrasonics.

Water - The nine reported water based oil extraction processes all involve additives to enhance the oil-from-rock separation. The additives include caustic, surfactant, solvents, and various diluents.

TABLE 1a. U. S. TAR SAND FIELD PROJECTS - IN SITU

PROJECT NUMBER	STATE LOCATION	OPERATOR	PROJECT STATUS	RECOVERY METHOD	OIL PROPERTIES Gravity Mg/m^3	Viscosity Pa.s
	CALIFORNIA					
1	Cat Canyon F.[1/]	Conoco	cu. comm.	steam drive	1.00	1.6-10
2[2/]	Cat Canyon F.	Getty	cu. comm.	steam drive	1.01	25
3	Cat Canyon F.	Husky	cu. pilot	steam drive	1.00-1.01	4-20
4	E. Cat Canyon F.	Texaco	cu. comm.	steam drive	1.00	13.3-15.5
5	Coalinga F.	Shell	pl. pilot	steam drive	0.99	>10
6	Cymric F.	Gulf	pl. comm.	steam drive	0.99	28
7[3/]	Cymric F.	Sun	cu. pilot	steam drive	-	>10
8	Kern Front F.	Chevron	cu. comm	steam drive	0.98	23
9	Kern River F.	Stanford-DOE	cu. pilot	steam with foam	0.98	10
10	McKittrick	Shell	pl. pilot	cylic steam	1.00	>10
11	McKittrick	Union	cu. comm.	steam drive	0.99	10
12	Marport Area	Ogle	cu. pilot	steam drive	1.04-1.06	1,000
13	Midway-Sunset F.	Arco	cu. comm.	steam drive	0.99	24.5
14[3/]	Midway-Sunset F.	Shell	cu. comm.	steam drive	0.99	17
15	Midway Sunset F.	Tenneco	cu. comm.	steam drive	0.99	20
16	Midway-Sunset F.	Union	cu. comm.	steam drive	0.99	10
17	Oxnard F.	Exeter	cu. comm.	steam drive	1.03	500
18	Oxnard F.	Husky	pl. pilot	cyclic steam	1.03	500
19	Paris Valley F.	Husky	co. pilot	wet comb.	0.99-1.01	50-400
20	Yorba Linda F.	Tenneco	cu. comm.	cyclic steam	0.97-0.99	22.5
21	Edmonson C.	Gulf[4/]	co. pilot	comb. with frac.	1.00	150
22	Edmonson C.	Rio Verde	pl. comm.	wet comb.	1.00	100
23	Edmonson C.	Westken	cu. pilot	steam drive & comb.	0.97-0.99	15
	MISSOURI					
24	Vernon C.	Mapco	cu. pilot	steam with CO_2	0.97	11
25	Vernon C.	Phillips[5/]	co. pilot	rev. comb.	1.00	500

Table 1a. (Continued)

PROJECT NUMBER	STATE LOCATION	OPERATOR	PROJECT STATUS	RECOVERY METHOD	OIL PROPERTIES Gravity Mg/m^3	Viscosity Pa.s
	TEXAS					
26	Little Tom F.	Electro Thermic	co. pilot	electric heater	-	10
27[3]	Saner Ranch F.	Conoco	cu. pilot	steam drive[6]	1.09	2,000
28	Saner Ranch F.	Enpex	pl. pilot	steam drive	1.09	2,000
29	Saner Ranch F.	Exxon	cu. pilot	steam drive	1.09	2,000
30	Saner Ranch F.	Mobil	co. pilot	combustion	1.02	10
	UTAH					
31	NW Asphalt Ridge D.	DOE-IITRI	co. pilot	RF heating	0.97	1,000
32[2]	NW Asphalt Ridge D.	DOE-LETC	co. pilot	comb. & steam drive	0.97	1,000
33[3]	Sunnyside D.	Shell[7]	co. pilot	steam soak & drive	1.01	100
34	Sunnyside D.	Signal	co. pilot	steam soak	1.00-1.01	100
35	Tar Sand Triangle D.	Altex	pl. pilot	thermal	1.00	10
36	Tar Sand Triangle D.	Kirkwood	pl. pilot	thermal	0.99-1.01	113
	WYOMING					
37	Burnt Hollow D.	Kirkwood	cu. pilot	steam drive w/caustic	1.01	1,000

1/ All abbreviations defined in appendix
2/ Three projects in same reservoir
3/ Two projects in same reservoir
4/ Terwilliger, 1976
5/ Trantham and Marx, 1966; Harvey and Arnold, 1974
6/ Patented Fracture Assisted Steam Technology (FAST)
7/ Thurbert and Welbourn, 1977

Most California steam drive projects preceded by cyclic steam.

TABLE 1b. U. S. TAR SAND FIELD PROJECTS - MINING & PLANT EXTRACTION

PROJECT NUMBER	STATE LOCATION	OPERATOR	PROJECT STATUS	RECOVERY METHOD	OIL PROPERTIES Gravity Mg/m^3	Viscosity Pa.s
	ALABAMA					
38	Colbert C.	Solv-Ex	pl. pilot	hot water & solvent	1.01	10
	CALIFORNIA					
39	McKittrick D.	Getty	cu. pilot	Dravo & Lurgi[1/]	0.97-0.98	10
	KENTUCKY					
40	Edmonson C.	Green Coal & Texas Gas Tran.	pl. pilot	Dravo solvent	-	-
41	Logan C.	Tarco	pl. comm.	solvent	0.96	10
	NEW MEXICO					
42	Santa Rosa D.	Solv-Ex	pl. pilot	hot water & solvent	0.99	30
	UTAH					
43	Asphalt Ridge D.	Aminoil	co. pilot	solvent	0.99-1.00	1,000
44	Asphalt Ridge D.	Major Oil	co. pilot	cold water & diluent	0.99-1.00	1,000
45	Asphalt Ridge D.	Sohio	pl. pilot	solvent	0.99-1.00	1,000
46	PR Spring D.	Big Horn Oil Co.	cu. pilot	cold water & solvent	1.00	1,000
47	PR Spring D.	C&A Companies	pl. pilot	solvent	1.00	1,000
48	PR Spring D.	Enercor	cu. pilot	hot water & caustic	0.99-1.00	1,000

Table 1b. (continued)

PROJECT NUMBER	STATE LOCATION	OPERATOR	PROJECT STATUS	RECOVERY METHOD	OIL PROPERTIES Gravity Mg/m^3	Viscosity Pa.s
49	PR Spring D.	International Hydrocarbons	pl. comm.	retort	1.01	100
50	Raven Ridge D.	Western Tar Sands	pl. pilot	anhydrous solvent & ultrasonics	-	1,000
51	Sunnyside D.	Great National	pl. comm.	ambient water & thermal or anhydrous solvent	1.0	100
52	Sunnyside D.	Sabine	pl. comm.	TBD	1.0	100
53	Sunnyside D.	Standard of Indiana	pl. comm.	TBD	1.01	100
54	Whiterocks D.	Al Hack	co. pilot	hot water & diluent	-	>10
55	Whiterocks D.	Major Oil	co. pilot	hot water & diluent	-	>10
56	TBD	Natomas	pl. pilot	solvent	-	-
	WYOMING					
57	Trapper Canyon D.	Big Horn Oil Co.	co. pilot	cold water & diluent	-	>10

1/ Two pilots, Dravo solvent and Lurgi retort.

Table 1c. U.S. Tar Sand Field Projects - Modified In Situ

PROJECT NUMBER	STATE LOCATION	OPERATOR	PROJECT STATUS	RECOVERY METHOD	OIL PROPERTIES Gravity Mg/m^3	Viscosity Pa.s
	CALIFORNIA					
58	Kern River F.	Cornell	pl. comm.	HOPCO	0.97	0.08
59	Midway-Sunset F.	California Tar Sand Development Corporation	pl. pilot	Downhole hydraulic mining & water with solvents	0.97	<10
	KANSAS					
60	Labette C.	EOR Petroleum	pl. pilot	Tetra "flip-flop"	0.96	>10

Table 2a. U.S. Tar Sand Field Projects - In Situ

PROJECT NUMBER	STATE LOCATION	GEOLOGIC FORMATION-AGE	WELL PATTERN SHAPE	SIZE hectares	DEPTH meters	THICKNESS meters	OIL-IN-PLACE m^3/m^3 or % porosity
	CALIFORNIA						
1	Cat Canyon F.	Sisquoc (Plio.)-Ter.	5-spot[1/]	1.0	1097	30	35-60% (por)
2	Cat Canyon F.	Sisquoc (Plio.)-Ter.	5-spot	2.3	762	21	0.197
3	Cat Canyon F.	Brooks (Plio.)-Ter.	7-spot	1.0	945	68	0.286
4	E. Cat Canyon F.	Sisquoc (Plio.)-Ter.	5-spot	4.0	796	26	75% (por)
5	Coalinga F.	Etchegoin(Plei.)-Ter.	5-spot	2.0	244	11	0.244
6	Cymric F.	Tulare (Plei.)-Ter.	5-spot	3.2	213	37	63% (por)
7	Cymric G.	Tulare (Plei.)-Ter.	9-spot	0.9	183	61	---
8	Kern Front. F.	Chanac (Mio.)-Ter.	5-spot	1.9	794	40	49% (por)
9	Kern River F.	---	5-spot	1.0	91	18	50% (por)
10	McKittrick F.	Tulare (Plei.)-Ter.	-	-	183	21	50-85% (por)
11	McKittrick F.	Tulare (Plei.)-Ter.	5-spot	0.8	381	15	57% (por)
12	Marport Area	Monterey (Mio.)-Ter.	5-spot	0.6	457	27	0.215
13	Midway-Sunset F.	Tulare (Plei.)-Ter.	5-spot	0.5	293	13	42% (por)
14	Midway-Sunset F.	Reef Ridge(Mio.)-Ter.	9-spot	2.0	305	92	65-80% (por)
15	Midway-Sunset F.	Potter (Mio.)-Ter.	-	-	610	91	50% (por)
16	Midway-Sunset F.	Reef Ridge(Mio.)-Ter.	linear	-	305	137	64% (por)
17	Oxnard F.	Vaca (Plio.)-Ter.	-	-	610	31	0.232
18	Oxnard F.	Vaca (Plio.)-Ter.	3 wells	-	610	71	-
19	Paris Valley F.	Ansberry (Mio.)-Ter.	-	-	256	15	-
20	Yorba Linda F.	LaHabra (Plei.)-Ter.	47 wells	0.5	152	38	70% (por)
	KENTUCKY						
21	Edmonson C.	Caseyville-Penn.	5-spot	0.1	30	6	0.142
22	Edmonson C.	Golconda-Miss.	7-spot	2.0	91	13	0.116
23	Edmonson C.	Golconda-Miss.	7-spot	1.4	76	9	70% (por)

Table 2a. (Continued)

PROJECT NUMBER	STATE LOCATION	GEOLOGIC FORMATION-AGE	WELL PATTERN SHAPE	SIZE hectares	DEPTH meters	THICKNESS meter	OIL-IN-PLACE m^3/m^3 or % porosity
	MISSOURI						
24	Vernon C.	-	-	-	79	11	0.100
25	Vernon C.	-	linear	-	15	4	0.129
	TEXAS						
26	Little Tom F.	Anacacho-Cret.	-	-	914	15	-
27	Saner Ranch F.	San Miguel-Cret.	5-spot	2.0	463	12	0.130
28	Saner Ranch F.	San Miguel-Cret.	5-spot	2.8	610	15	0.155
29	Saner Ranch F.	San Miguel-Cret.	5-spot	2.0	518	15	0.109
30	Saner Ranch F.	San Miguel-Cret.	8-spot	4.7	-	10	-
	UTAH						
31	NW Asphalt Ridge D.	Mesaverde-Cret.	none	-	5	15	0.240
32	NW Asphalt Ridge D.	Mesaverde-Cret.	linear & 5-spot	0.4-0.2	183	3-15	0.240
33	Sunnyside D.	Waatch-Ter.	1 well & 4-spot	0.5	198-335	12-76	0.178
34	Sunnyside D.	Wasatch-Ter.	3 wells 2/	-	-	-	-
35	Tar Sand Triangle D.	White Rim-Perm.	-	-	457	43	0.123
36	Tar Sand Triangle D.	White Rim-Perm.	5-spot	0.1	396	11	0.180
	WYOMING						
37	Burnt Hollow D.	Minnelusa-Penn.	5-spot	1.0	274	8	0.120

1/ All 4, 5, 7, and 9 spot patterns are inverted, i.e., 1 injection well with 3, 4, 6, or 8 production wells.

2/ Horizontal wells in quarry face.

Table 2b. U.S. Tar Sand Field Projects - Mining & Plant Extraction

PROJECT NUMBER	STATE LOCATION	GEOLOGIC FORMATION-AGE	DEPTH meters	THICKNESS meters	OIL-IN-PLACE m^3/m^3 or % porosity (por.) or % weight (wt.)
	ALABAMA				
38	Colbert C.	Hartselle-Miss.	0-20	11	0.170
	CALIFORNIA				
39	McKittrick D.	Diatomaceous Earth (Mio.) - Ter.	0-122	107-274	12% (wt)
	KENTUCKY				
40	Edmonson C.	-	-	-	-
41	Logan C.	Caseyville-Penn.	1-3	12	6% (wt)
	NEW MEXICO				
42	Santa Rosa D.	Santa Rosa-Tri.	0-15	-	5% (wt)
	UTAH				
43	Asphalt Ridge D.	Mesaverde-Cret.	-	-	-
44	Asphalt Ridge D.	Mesaverde-Cret.	0-91	-	0.129-0.258
45	Asphalt Ridge D.	Mesaverde-Cret.	0-91	-	0.129-0.258
46	PR Spring D.	Green River & Wasatch-Ter.	-	-	-
47	PR Spring D.	Green River & Wasatch-Ter.	0-91	7.6	0.206
48	PR Spring D.	Mesaverde-Cret.	-	-	-
49	PR Spring D.	Green River & Wasatch-Ter.	18	5	-
50	Raven Ridge D.	Green River-Ter.	-	-	-

Table 2b. (continued)

PROJECT NUMBER	STATE LOCATION	GEOLOGIC FORMATION-AGE	DEPTH meters	THICKNESS meters	OIL-IN-PLACE m^3/m^3 or % porosity (por.) or % weight (wt.)
	UTAH (continued)				
51	Sunnyside D.	Wasath & Green River-Ter.	0-61	122-152	8% (wt)
52	Sunnyside D.	Wasatcch & Green River Ter.	-	-	-
53	Sunnyside D.	Wasatch & Green River Ter.	-	-	-
54	Whiterocks D.	Navajo-Jur.	-	-	-
55	Whiterocks D.	Navajo-Jur.	-	-	-
	WYOMING				
57	Trapper Canyon D.	Tensleep-Penn.	-	5	0.192

Table 2c. U.S. Tar Sand Field Projects - Modified In Situ

PROJECT NUMBER	STATE LOCATION	GEOLOGIC FORMATION-AGE	WELL PATTERN SHAPE	WELL PATTERN SIZE hectares	DEPTH meters	THICKNESS meters	OIL-IN-PLACE m^3/m^3 or % porosity
	CALIFORNIA						
58	Kern River F.	Kern River (Plio.)-Ter.	-	-	213	18	0.215
[illegible]	Midway-Sunset F.	Tulare	-	-	46	100	0.129
	KANSAS						
60	Labette C.	Bartlesville-Penn.	-	-	30	4.4	40% (por)

TABLE 3a. COST DATA - SELECTED IN SITU PROJECTS[1/]

PROJECT NUMBER	STATE LOCATION	OPERATOR	RECOVERY METHOD	ESTIMATED RECOVERY $10^3 m^3$	TOTAL PROJECT COST $10^6	COST $/m^3
	CALIFORNIA					
1	Cat Canyon F.	Conoco	steam drive	118	11	93
2	Cat Canyon F.	Getty	steam drive	TBD	TBD	116[2/]
3	Cat Canyon F.	Husky	steam drive	176	28	160
4	E. Cat Canyon	Texaco	steam drive	295	17	63
5	Coalinga F.	Shell	steam drive	-	-	50
6	Cymric F.	Gulf	steam drive	143	17	119
8	Kern Front F.	Chevron	steam drive	2115	162	77
12	Marport Area	Ogle	steam drive	68	7.1	103
	MISSOURI					
24	Vernon C.	Mapco	steam with CO_2	TBD	7.6	TBD
	TEXAS					
27	Saner Ranch F.	Conoco	steam drive	27	TBD	TBD
28	Saner Ranch F.	Enpex	steam drive	53	9.6	157
	UTAH					
31	NW Asphalt Ridge D.	DOE-IITRI	RF heating	TBD	TBD	107
32	NW Asphalt Ridge D.	DOE-LETC	comb.& steam	TBD	TBD	159
	WYOMING					
37	Burnt Hollow D.	Kirkwood	steam drive	26	6.7	258

1/ Cost data excludes royalty interest and leasing costs.
2/ Operating costs only.
3/ m^3 oil per day.

TABLE 3b. COST DATA - SELECTED MINING AND PLANT EXTRACTION PROJECTS[1/]

PROJECT NUMBER	STATE LOCATION	OPERATOR	RECOVERY METHOD	ESTIMATED RECOVERY $10^3 m^3$	TOTAL PROJECT COST $\$10^6$	COST $\$/m^3$
	ALABAMA					
38	Colbert C.	Solv-Ex	hot water & solvent	32[2/]	TBD	110
	KENTUCKY					
41	Logan C.	Tarco	solvent	0.795[2/]	7.5[3/]	10[4/]
	UTAH					
51	Sunnyside D.	Great National	hot water	--	--	113-132

1/ Cost data excludes royalty interest and leasing costs
2/ m^3 oil per day
3/ Capitol costs only
4/ Operating costs only

Table 3c. Cost Data - Selected Modified In Situ Projects[1/]

PROJECT NUMBER	STATE LOCATION	OPERATOR	RECOVERY METHOD	ESTIMATED RECOVERY $10^3 m^3$	TOTAL PROJECT COST $\$10^6$	COST $\$/m^3$
	CALIFORNIA					
58	Kern River F.	Cornell	HOPCO	302	14	46
59	Midway-Sunset F.	California Tar Sand Development Corp.	Downhole hydraulic mining & water with solvents	-	10	189

Table 3c. (continued)

PROJECT NUMBER	STATE LOCATION	OPERATOR	RECOVERY METHOD	ESTIMATED RECOVERY $10^3 m^3$	TOTAL PROJECT COST $\$10^6$	COST $\$/m^3$
	KANSAS					
60	Labette C.	EOR Petroleum	Tetra "flip-	461	28	61

1/ Cost data excludes royalty interest and leasing costs

Table 4. U.S. Tar Sand Field Projects - Upgrading

PROJECT NUMBER	STATE LOCATION	OPERATOR	PROJECT STATUS	UPGRADING PROCESS	PLANNED FEED RATE m^3/day	CAPITOL COST $\$10^6$
	CALIFORNIA					
61	Torrance	Cal Syn	pl. comm.	HRI Dyna-cracking	795	35
	TEXAS					
62	SW Texas	Enpex	pl. comm.	Lummus LC Fining	1590	--

Three Utah projects - Major Oil Co. (#44), Big Horn Oil Co. (#46) and Great National Corp. (#51) utilize cold water processes. The Major Oil and Big Horn Oil projects both involve versions of the patented Brimhall process. The Great National project will use a two stage process: 1. concentration of the oil content by a U.S. Bureau of Mines ambient temperature flotation process which includes soda ash and phosphate dispersants and a fuel oil collector: and; 2. final separation of the oil from the concentrate by either a fluidized bed reactor or an anhydrous solvent. The other water-based processes utilize hot water.

Thermal retort - The Getty Oil Co. (#39) pilot project in the McKittrick area of California is testing two oil extraction technologies simultaneously: a Dravo solvent process and a Lurgi retort. The oil mined for this project has a viscosity of less than 10 Pa.s but the project is included here because both tested processes are expected to be applicable to tar sand oils. The planned International Hydrocarbons (#49) project at Green River, Utah, will retort oil from nearby deposits utilizing waste heat from a planned coal gasification plant.

Modified In Situ Processes

Three projects involving combinations of in situ and mining techniques are planned. The Cornell Heavy Oil Process Inc. (HOPCO) (#58) utilizes a 1.5 m diamter (ID) cased well terminating in a 7.62 m diameter cavern near the bottom of the reservoir from which horizontal production wells are drilled. The production wells also serve as steam injection wells during a reservoir preheating phase. After preheating, vertical wells drilled from the surface serve as steam injection wells and the horizontal wells serve as producing wells. The California Tar Sand Development Corporation (#59) project will produce oil saturated sand through a well-bore by down-hole hydraulic mining. The oil will then be extracted from the ore in an extraction plant. These two projects, involving crude oil with viscosities less than 10 Pa.s, are included here because the unconventional technologies (if successful) are expected to be applicable to tar sand. The EOR Petroleum Co. (#60) project in Labette County, Kansas, will employ a combination mining-in situ technique developed by Tetra Systems, Inc. and referred to as the "flip-flop" process. In the "flip-flop" process, the top of the oil reservoir is accessed by mine shaft and tunnels; a heated surfactant solution is pumped to the exposed top of the reservoir and imbibes (aided by gravity) into the reservoir displacing the oil upward; and the displaced oil is "skimmed" off the top of the reservoir and pumped to the surface.

Upgrading Processes

Tar sand oils exceed 10 Pa.s in viscosity (some known cases exceed 2,000 Pa.s) at reservoir temperatures and, in some cases, contain high concentrations of sulfur and heavy metals. These characteristics dictate some form of upgrading of the produced crude oils before refining. In some areas, the upgrading may be accomplished by merely diluting the produced tar sand oil with more conventional crude oils produced in the same area.

Two upgrading-plant projects are planned (Table 4). The Calsyn (#61) project in California will utilize the Hydrocarbon Research, Inc. "dynacracking" process to upgrade 5,000 barrels per day of any of several feedstocks, including tar sand oil. It will produce 74% liquids (naptha and heavy petroleum distillate) and 16% fuel gas. The Enpex (#62) project will process 20,000 barrels per day of southwest Texas tar sand oil (viscosity 2,000 Pa.s, gravity 1.08, sulfur 10%) with the Lummus "LC Fining" process.

Operators of eleven of the tar sand oil recovery projects report upgrading of their produced oil. The upgrading is being or will be accomplished by the oil recovery process, by dilution, or by separate upgrading plants. Rio Verde Energy Co. (#22) expects its in situ combustion process in Kentucky to partially upgrade its produced oil; and Great National Corporation (#51) expects the thermal portion of its oil extraction process to significantly upgrade its product oil. The oil produced from eight projects (#2, 4, 5, 17, 27, 29, 37, 46) is upgraded by dilution with lighter crude oils or various distillates. Conoco (#27) and Exxon (#29) in southwest Texas, Kirkwood (#37) in Wyoming and Getty (#39) in California (if the Lurgi retort is used) expect that commercial production will require upgrading facilities utilizing coking or hydrogenation processes.

COSTS

The economics involved in determining the cost of producing oil from U.S. Tar sand deposits are dependent on a number of factors, including: recovery method, geographic location, depth and thickness of sand, proximity to pipeline or refinery, and labor market. The cost data listed in Table 3 are general cost data received from companies operating the projects and for the most part are reported in mid-1981 dollars. The data in Table 3 reflect, in most cases, direct capital investment, engineering costs, drilling costs, fluid injection costs, and annual operating costs. Costs related to royalty interest, all taxes, lease costs, transportation, and exploration are not included in the cost-per-cubic meter rate shown. In some cases, the cost-per-cubic meter data were calculated by the authors from data supplied by the operator. The reader should be aware that the total project cost divided by the estimated recovery will not always result in the cost-per-cubic meter shown.

Cost data are listed in Table 3 for projects in a number of states and for different recovery methods. The cost per cubic meter varies from a low of $46 per cubic meter for the Cornell-HOPCO (#58) project in the Kern River Field, California, to a high of $258 per cubic meter for the Kirkwood (#37) project in Wyoming. It is again stressed that many of these cost-per-cubic meter prices are estimates and others are based on a pilot test. Only one of the projects has a very high per cubic meter cost estimate of over $250, but this value could be lowered as the project increases in magnitude and better process control is achieved. The average of the 16 projects (11 in situ, 2 mining and extraction, and 3 modified in situ) for which there are per-cubic meter costs, is $117. Should upgrading and other costs be as high as $70 per cubic meter, the net average cost would be $187 per cubic meter. This compares very well with predicted costs for oil from enhanced recovery techniques which are in the range of $132-$289 per cubic meter (Lewin and Associates, 1981). Since the recent selling price of oil is near $220 per cubic meter, if the prices shown in the table become firm prices, they are well within the range of a commercial tar sand operation.

Most of the reported projects are primarily pilot projects but some have the status of commercial projects. The success of these pilot projects is essential for future technology. Results of these tests will help dictate the final design and equipment selection of future commercial operations.

SUMMARY

The 62 projects reported here represent a recent significant increase in activity related to the U. S. tar sand resource. These reported projects, summarized in Table 4, are a majority, not all, of those planned or underway.

TABLE 5. Status of Reported Projects

Status	In Situ	Mining and Plant Extraction	Modified In Situ	Upgrading Plant	Totals
Current Commercial	11	0	0	0	11
Current Pilot	9	3	0	0	12
Planned Commercial	2	5	1	2	10
Planned Pilot	6	7	2	0	15
Completed Pilot	9	5	0	0	14
Totals	37	20	3	2	62

That most of the U. S. tar sand resource is too deep for economic development by mining is reflected in the ratio of planned and current in situ to mining and plant extraction projects - nearly 2 to 1. The reported in situ projects utilize, primarily, proven enhanced oil recovery technologies as applied to the related "heavy crude oil" resource. In most cases, the reported mining and plant extraction projects also utilize various elements of proven technologies which are assembled into processes that are unique and unproven. It is generally recognized that the production of significant commercial quantities of tar sand oil will necessitate large scale upgrading facilities.

The incomplete reported cost data, and the number of projects reported as "planned or current commercial" provide encouragement that the commercial feasibility of the U. S. tar sand resource will be proven.

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APPENDIX

Unit Conversions

From	To	Multiply by
hectare	acre	2.471
meter (m)	foot	3.281
cubic meter (m^3)	barrel	6.290
Pascal·second (Pa·s)	centipoise	1,000
dollars per cubic meter	dollars per barrel	0.159
m^2	millidarcies	1.013×10^3
cubic meter per cubic meter (m^3/m^3)	barrels per acre foot	7758
Specific gravity	°API	$°API = \frac{141.5}{\text{specific gravity}} - 131.5$

Abbreviations

C. - county
co. - completed
comb. - combustion
comm. - commercial
Cret. - Cretaceous
cu. - current
D. - deposit
Dev. - development
DOE - U.S. Department of Energy
DHSG - downhole steam generator
E. - east
F. - field
frac. - fracture
HOPCO - Heavy Oil Process Company
IITRI - Illinois Institute of Technology Research Institute
Jur. - Jurassic
LETC - Laramie (Wyoming) Energy Technology Center
m - meter
m^3 - cubic meter
Mg - megagram
Mio. - Miocene
Miss. - Mississippian
NG - Natural Gas
NW - northwest
Pa·s - Paschal seconds
Penn. - Pennsylvanian
Perm. - Permian
Pet. - Petroleum
pl. - planned
Plei. - Pleistoscene
Plio - Pliocene
por. - porosity
Rec. - Recovery
res. - research
rev. - reverse
SNL - Sandia (New Mexico) National Laboratory
SW - southwest
TBD - to be determined
Ter. - Tertiary
Tri. - Triassic

END

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