DOE/ET/10532-T20
(DE85001932)

Energy

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REFINING AND UPGRADING OF SYNFUELS FROM COAL AND OIL SHALES BY ADVANCED CATALYTIC PROCESSES

Quarterly Report for the Period April–June 1984

By
R. F. Sullivan

August 1984
Date Published

Work Performed Under Contract No. AC22-76ET10532

Chevron Research Company
Richmond, California

Technical Information Center
Office of Scientific and Technical Information
United States Department of Energy

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DOE/ET/10532-T20
(FE-2315-106)
(DE85001932)
Distribution Category UC-90d

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I. Abstract

This report gives results of our current studies on refining of integrated two-stage liquefaction (ITSL) process product to distillate fuels. The experimental program on ITSL Syncrude derived from Illinois No. 6 Coal is now complete.

We studied the effect of ITSL syncrude end point on the severity necessary for hydrotreating to distillate products. Lummus provided Chevron with an additional barrel of ITSL process product (Illinois No. 6, Burning Star Mine) with an end point of about 800°F to serve as feed. A 1080-hr pilot plant test was made with this feed and ICR 106 catalyst at 0.5 LHSV and 2300 psia hydrogen partial pressure. The new feed was harder to upgrade than the lower end point feed previously tested, but we were able to make 20 mm smoke point jet fuel at these conditions and 720°F catalyst temperature.

We made a 2385-hr second-stage hydrocracking pilot plant run in which hydrotreated ITSL oil was cracked to extinction over ICR 202 catalyst. It included series of tests to determine the quantity and quality of products produced at a variety recycle cut points (350°F, 400°F, 450°F, 500°F, 525°F, and 550°F). At 350°F, the entire liquid product was naphtha. At higher cut points, products included a combination of naphtha and jet fuel. The smoke point of the jet fuel fraction met the specification of 20 mm at a cut point of 550°F. At lower cut points, it exceeded 20 mm.

II. Contract Objective and Status

The object of this program is to determine the feasibility and to estimate the costs of hydroprocessing synthetic crude feedstocks to distillate fuels using modern commercial petroleum processing technology. Tests are conducted only to the extent needed to make reasonable estimates of commercial plant performance and only to the extent that a commercial plant is feasible using presently existing technology. Tests are made for each whole synthetic oil and, if appropriate, for the fractions derived therefrom. Tests are not made for processes which can be reliably estimated.

The experimental work on all of the feedstocks is now complete except that Task 12 is being modified to include additional experimental and engineering studies on ITSL oil derived from a subbituminous coal (Wyodak). The Interim Report describing the experimental studies on ITSL from bituminous coal (Illinois No. 6) is now being prepared. The Interim Report describing the study of EDS oil was issued in draft form in June. Interim Reports to date are as follows:

Interim Report No.	DOE Report No.	Subject	Date of Issue
1	FE-2315-25	Paraho Shale Oil	April 1978
2	FE-2315-45	SRC-I	November 1979
3	FE-2315-47	SRC-II	March 1980
3 (Reissued)	DOE/ET/10532-T10	SRC-II	November 1982
4	FE-2315-50	Paraho Shale Oil (Update)	June 1980
5	DOE/ET/10532-T3	H-Coal	September 1981
5 (Addendum)	FE-2315-77	H-Coal	May 1982
6	DOE/ET/10532-T5	SRC-II (For Health-Related Studies)	April 1982
7	DOE/ET/10532-T11	H-Coal, EDS (for Health-Related Studies)	January 1983
8	DOE/ET/10532-T15 (FE-2315-93)	H-Coal (for Health-Related Studies)	September 1983
9	DOE/ET-10532-T19	EDS	June 1984 (Draft)

III. Task 12: Upgrading of ITSL Product

A. Feeds

The object of Task 12 is to upgrade ITSL process product to distillate fuels using modern petroleum processing technology. The experimental work to date has been done with two ITSL oils derived from Illinois No. 6 coal (Burning Star Mine).

A. Hydrotreating of 800°F End Point ITSL Oil With ICR 106 Catalyst; Pilot Plant Run 90-171

We made a 1080-hr pilot plant test (Run 90-171) in which 800°F end point ITSL oil was hydrotreated with ICR 106 catalyst. The purpose was to find out how well ICR 106 performs compared to its performance when hydrotreating 750°F end point ITSL oil. Table I gives the properties of these feeds, as well as those of other syncrudes studied.

The catalyst for the run had been used for 1250 hr in a proprietary test (paid for by Chevron) in which we hydrotreated petroleum vacuum gas oil. The catalyst had essentially fresh activity, though--it was stable and had not fouled. The feed was switched to ITSL oil (WOW 5338) and the test for DOE started without interruption.

Initial test conditions for ITSL oil were:

Liquid Hourly Space Velocity (LHSV), Vol Feed/Vol Catalyst/Hr	0.5
Hydrogen Partial Pressure, psia	2300
Total Pressure, psig	2500
Recycle Gas Rate, SCF/Bbl	8000

Figure 1 is a plot summarizing average catalyst temperature, product nitrogen, and product aromatics versus run hours. Catalyst temperatures were adjusted to make products with varying amounts of nitrogen.

At 720°F average catalyst temperature, the product nitrogen was about 0.35 ppm. The product contained about 17 LV % aromatics. The catalyst was stable for both nitrogen removal and aromatics saturation during the 400-hr test. In previously reported work, the 750°F end point feed made product with only 10% aromatics and less than 0.2 ppm nitrogen at a catalyst temperature of 710°F, 10°F lower. Clearly, the higher boiling feed is harder to hydrotreat.

The catalyst temperature was further increased to 750°F. The product nitrogen dropped to 0.1-0.2 ppm, about the limit of our ability to measure. The catalyst was stable for nitrogen removal during the 500-hr test at 750°F. However, increasing the temperature did not improve the aromatics saturation. Rather, it caused some catalyst deactivation for aromatics saturation. During the first 300 hr at 750°F, the product aromatics content rose from less than 20 LV % to over 30 LV %. Then it appeared to stabilize.

Yield periods for the run are given in Tables II and III. Product inspections are given in Tables IV, V, and VI.

At 720°F, the 250-500°F product contains 16-18% aromatics and just meets the smoke point specification of 20 mm. The 250-550°F contains 15-16% aromatics and has a smoke point of 19-20 (two analyses--one meets the specification, the other just misses it).

B. Hydrocracking of Hydrotreated ITSL Oil; Pilot Plant Run 62-281

We made a second-stage hydrocracking pilot plant test (Run 62-281) using Chevron's commercial ICR 202 catalyst. The feeds were hydrotreated ITSL oils, derived from the first (lower end point) sample from Lummus. Tests were designed: (1) to make naphtha as the sole liquid product and (2) to make both naphtha and jet fuel products.

Feeds of two different boiling ranges were tested: (1) 350°F+ hydrotreated oil, WOW 5251 and (2) full-boiling-range (whole) hydrotreated oil, WOW 5329 and WOW 5380. Inspections of these feeds are given in Table VII.

The run was described in detail in the January-March 1984 Quarterly and details will not be repeated here.

During the April-June quarter, we completed distillations and analyses of product fractions from the portion of the run feeding full-boiling range hydrotreated feed. Tests were made at various recycle cut points (RCPs) ranging from 350°F to 550°F. Yields at 350°F RCP, 400°F RCP, and 450°F RCP are given in Tables VIII and IX. Product inspections at the latter RCPs are given in Tables XIX-XVI.

The smoke points and yields of the jet fuel fractions are of particular interest:

Effect of Cut Point on Jet Yield and Smoke Point

Cut Point, °F	Jet Boiling Range, °F	Jet Yield, LV %		Smoke Point, mm
		Based on Feed to First Stage	Based on Feed to Second Stage	
400	250-400	59	55	26
450	250-450	67	63	24
500	250-500	72	68	24
525	250-525	79	74	23
550	250-550	84	79	20

Figure 2 summarizes the jet yields and smoke points versus recycle cut points. At a 550°F cut point, the jet fuel meets the ASTM specification of 20 mm. The yield is 84 LV %, based on fresh feed to the first stage. (It is lower than that, 79 LV %, based on feed to the second stage because of the volume expansion in the first stage.) At lower cut points, the smoke points exceed the specification, but the yields are lower.

The jet gravity specification of 37°API is met at cut points up to 525°F. At 550°F RCP, the jet gravity is 34.4°API, well below the current specification. However, this very dense jet fuel has a high volumetric energy content and could be of particular interest as a military fuel.

Figure 3 shows the smoke points of narrow boiling fractions as a function of midboiling points.

It is concluded that hydrocracking is an excellent way to maximize jet fuel from ITSL oil.

The recycle stream compositions at different cut points are of interest. Figure 4 shows the different boiling ranges of the recycle streams as the cut point is varied. In general, the heavier material is cracked first, leaving most of the recycle stream boiling just above the cut point.

The recycle streams were colorless at all the cut points tested, indicating that almost all of the aromatics were hydrogenated. At 550°F, white crystals began to form in the recycle stream when it was cooled to room temperature. These crystals were identified by mass spectrometry as perhydropyrene (hexadecahydropyrene).

Table XXVII gives group type analyses of the recycle streams at several cut points. Although this analytical method may not be completely reliable for these unusual materials, it does show the

high concentrations of polycyclic naphthenes in the recycle streams.

C. Program

The experimental work on Illinois ITSL oil is complete and we are preparing an Interim Report describing the results. DOE has asked that we add a brief experimental program on upgrading ITSL derived from Wyodak coal to Task 12 of the contract and also include Wyodak engineering studies as part of the final ITSL report. Therefore, we will defer the engineering studies on Illinois ITSL until the Wyodak experimental work is complete. Then the entire ITSL engineering study can be done at one time.

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TABLE I

DOE CONTRACT DE-AC22-76ET10532
COMPARISON OF PROPERTIES OF ITSL OILS
TO OTHER COAL-DERIVED PILOT PLANT FEEDS

Liquefaction Process	ITSL*	ITSL*	ITSL**	H-Coal	H-Coal	SRC-II	EDS
Type of Coal	Illinois No. 6	Illinois No. 6	Illinois No. 6	Illinois No. 6	Wyodak	Pittsburgh Seam	Texas Lignite
Chevron Identification	WOW 4998	WOW 5104	WOW 5338	WOW 3919	WOW 4137	WOW 3666	WOW 4536
Inspections							
Gravity, °API	17.6	17.4	14.0	25.8	35.1	18.6	29.0
Sulfur, ppm	700	730	1,500	2,000	4,100	2,900	1,180
Nitrogen, ppm	730	835	1,739	4,600	1,700	8,500	3,000
Basic Nitrogen, ppm	443	532	1,050	3,000	1,300	7,000	1,500
Oxygen, ppm	1,800	1,450	8,600	18,000	8,500	37,900	19,200
Hydrogen, Wt %	10.68	10.46	9.79	11.29	12.74	10.46	11.25
Carbon, Wt %	88.99	89.24	89.03	86.25	86.20	84.61	86.41
Chlorine, ppm	2.4	0.7	4	32	3	50	10
Iron, ppm	1.3	1.7	12.6	20	3	3	6
Water, ppm	456	436	1,100	2,200	<500	6,000	1,580
Hot Heptane Insolubles, ppm	290	260	2,000	3,500	680	469	1,300
Ramsbottom Carbon, Wt %	0.30	NA	0.60	0.29	0.23	0.70	0.57
ASTM D 2887 Distillation, °F (TBP by GC)							
St/5	97/214	104/213	267/362	56/177	53/156	56/189	53/164
10/30	314/471	320/474	380/455	213/333	173/261	241/379	203/317
50	560	563	579	404	354	424	370
70/90	609/676	616/684	645/715	476/588	429/535	473/562	452/662
95/99	703/763	714/780	747/811	654/765	602/785	642/820	799/(950+)

*End point about 750°F; water washed to remove chloride; WOW 4998 and WOW 5104 are "duplicate" blends.

**End point about 800°F; not water washed. Produced near end of LC-Fining run.

NA = Not Analyzed

TABLE II

DOE CONTRACT DE-AC22-76ET10532
YIELDS FROM HYDROTREATING 800°F EP ITSL OIL, WOW 5338, WITH ICR 106 CATALYST AT 0.5 LHSV
PILOT PLANT RUN 90-171

Run Hours	1633-1657	
Average Catalyst Temp., °F	720	
LHSV	0.50	
Total Pressure, psig	2499	
H_2 Mean Pressure, psia	2308	
Total Gas, SCF/B	9979	
Recycle Gas, SCF/B	7847	
No Loss Product Yields	**Wt %**	**LV %**
C_1	0.04	
C_2	0.10	
C_3	0.10	
iC_4	0.01	0.01
nC_4	0.05	0.09
C_5-250°F	2.58	3.28
250-500°F	40.10	45.88
500°F+	58.87	60.73
Total C_5+	101.54	109.89
Actual/No Loss Recovery	100.9/103.2	
H_2 Consumption (Gross), SCF/B	2131	
H_2 Consumption (Chemical), SCF/B	2033	
Whole Liquid Product Properties*		
Gravity, °API	26.1	
Aniline Point, °F	119.9	
Nitrogen, ppm	0.38	
ASTM D 2887 Distillation, °F (TBP by GC)		
St/5	99/293	
10/30	336/395	
50	518	
70/90	584/652	
95/99	683/748	

*Product sample is actually a blend from 1573 to 1681 hr.

TABLE III

DOE CONTRACT DE-AC22-76ET10532
YIELDS FROM HYDROTREATING 800°F EP ITSL OIL,
WOW 5338, WITH ICR 106 CATALYST AT 0.5 LHSV

Pilot Plant Run 90-171

Run Hours	1454-1478		1681-1705		1921-1945		2113-2137	
Average Catalyst Temperature, °F	720		720		750		750	
LHSV	0.51		0.50		0.49		0.51	
Total Pressure, psig	2,493		2,505		2,500		2,449	
H_2 Mean Pressure, psia	2,320		2,317		2,290		2,272	
Total Gas, SCF/B	9,963		10,033		10,232		9,836	
Recycle Gas, SCF/B	7,806		7,980		8,044		7,843	
No Loss Product Yields	Wt %	LV %	Wt %	LV %	Wt %	LV %	Wt %	LV %
C_1	0.04		0.04		0.09		0.08	
C_2	0.07		0.09		0.18		0.17	
C_3	0.08		0.08		0.21		0.18	
iC_4	0.01	0.02	0.01	0.01	0.03	0.06	0.03	0.04
nC_4	0.04	0.07	0.05	0.08	0.14	0.23	0.13	0.21
C_5-150°F	0.02	0.02	0.02	0.02	0.03	0.04	0.03	0.04
150-180°F	0.61	0.82	0.81	1.08	1.55	2.05	1.88	2.49
180-250°F	2.57	3.27	1.93	2.42	13.26	16.19	3.36	4.21
250-350°F	7.72	9.30	7.91	9.56			8.50	10.18
350-450°F	44.91	50.37	44.76	49.71	86.45	93.23	27.62	31.21
450-550°F							19.91	21.33
550°F+	45.83	46.84	46.02	47.07			39.75	40.73
Total C_5^+	101.66	110.63	101.46	109.86	101.29	111.51	101.05	110.19
Actual/No Loss Recovery	102.0/103.2		101.4/103.1		100.0/103.3		101.0/103.0	
H_2 Consumption (Gross), SCF/Bbl	2,156		2,053		2,188		1,993	
H_2 Consumption (Chemical), SCF/Bbl	2,073		1,956		2,090		1,902	
Whole Liquid Product Properties								
Gravity, °API	26.2		26.0		28.4		27.2	
Aniline Point, °F	119.7		119.0		114.3		107.5	
Sulfur, ppm	4.0		2.9				2.8	
Nitrogen, ppm	0.55		0.35		0.17		0.14/0.21	
Oxygen, ppm	100		100				100	
Hydrogen, Wt %	87.30		87.32				87.48	
Carbon, Wt %	12.70		12.68				12.52	
Group Type, LV % (22-Component)								
Paraffins	0.0		0.0		0.0		0.2	
Naphthenes	80.2		79.0		75.7		68.5	
Aromatics	19.7		21.0		24.0		31.1	
Hydrogen Wt % (Calc From Mass Spectrum)	13.1		13.1		12.9		12.7	
Group Type, LV % (Average of Fractions)								
Paraffins	1.1		0.9		1.4		3.6	
Naphthenes	81.6		81.5		79.6		66.3	
Aromatics	17.2		17.6		19.0		30.2	
ASTM D 2887 Distillation, °F (TBP by GC)								
ST/5	81/292		109/295		58/222		59/237	
10/30	335/395		337/395		312/381		318/386	
50	517		517		490		496	
70/90	584/653		584/653		565/635		571/641	
95/99	683/749		683/749		664/733		670/740	

TABLE IV

DOE CONTRACT DE-AC22-76ET10532
HYDROTREATING OF 800°F EP ITSL OIL, WOW 5338, AT 0.5 LHSV
WITH ICR 106 CATALYST; PROPERTIES OF 180-250°F, 180-350°F,
AND 250-350°F PRODUCT FRACTIONS

Pilot Plant Run 90-171

Run Hours	1454-1478	1681-1705	2113-2137	1921-1945	1454-1478	1681-1705	2113-2137
Average Catalyst Temperature, °F	720	720	750	750	720	720	750
Boiling Range, °F	180-250	180-250	180-250	180-350	250-350	250-350	250-350
Product Inspections							
Gravity, °API	53.5	51.4	50.8	46.2	43.9	44.2	42.7
Aniline Point, °F	95.3	94.5	90.2	103.7	116.8	118.8	103.1
Octane No., F-1 Clear							60.2
Smoke Point, mm							23
Group Type (Low Mass), LV %							
Paraffins	6.5	6.3	6.9	8.0	6.8	7.0	8.6
Naphthenes	88.5	87.8	84.0	83.1	87.4	86.5	79.7
Aromatics	5.0	5.8	9.1	8.9	5.8	6.5	11.7
Naphthene Distribution							
Mononaphthenes	88.5	87.8	84.0	70.7	-	-	61.0
Dinaphthenes	0.0	0.0	0.0	12.4	-	-	18.7
Aromatics Distribution							
Alkylbenzenes	5.0	5.8	9.1	8.9	-	-	11.5
Benzonaphthenes	0.0	0.0	0.0	0.0	-	-	0.3
Hydrogen, Wt %							
Analysis	14.15	14.08	13.60	13.67	13.91	13.94	13.52
Calculated From Mass Spectrum	14.1	14.1	13.9	13.8	13.9	13.9	13.6
Carbon, Wt % (Analysis)	85.85	85.92	86.40	86.33	86.09	86.06	86.48
Group Type, LV % (FIAM)							
Paraffins + Naphthenes	94	94	91	90	92	91	85
Aromatics	6	6	9	10	8	9	15
ASTM D 2887 Distillation, °F (TBP by GC)							
St/5	58/171	93/181	57/178	59/180	173/255	163/254	181/251
10/30	182/191	183/214	184/214	192/241	269/310	269/309	267/303
50	220	222	222	294	327	327	328
70/90	227/258	229/254	232/254	324/345	340/354	340/353	339/355
95/99	270/286	266/278	267/281	354/364	360/368	359/367	362/367

TABLE V

DOE CONTRACT DE-AC22-76ET10532: HYDROTREATING OF 800°F EP ITSL OIL, WOW 5338, AT 0.5 LHSV WITH ICR 106 CATALYST; PROPERTIES OF 250-500°F, 250-550°F, 350-450°F, 450-550°F, AND 350-550°F PRODUCT FRACTIONS

Pilot Plant Run 90-171

Run Hours	1573-1681	1454-1478	1681-1705	2113-2137	2113-2137	1454-1478	1681-1705
Average Catalyst Temperature, °F	720	720	720	750	750	720	720
Boiling Range, °F	250-500	250-550	250-550	350-450	450-550	350-550	350-550
Product Inspections							
Gravity, °API	35.0	33.5	31.9	32.9	24.4	31.7	30.1
Aniline Point, °F	105.8	NA	110.5	84.1	116.8	111.5	109.5
Smoke Point, mm	20	20	19	17	15	18	18
Freeze Point, °F	NA	NA	NA	Below -94	Below -94	Below -94	Below -94
Group Type, LV %	High Mass/ 22-Component	* Calculated	* Calculated	Low Mass	22-Component	22-Component	22-Component
Paraffins	1.5/5.0	1.4	1.0	8.0	0.0	0.4	0.1
Naphthenes	82.3/76.4	83.2	82.8	67.9	75.7	82.4	81.9
Aromatics	16.2/18.5	15.4	16.2	24.0	24.3	17.7	18.0
Naphthene Distribution							
Monocycloparaffins	42.3/48.6			26.0	22.5	33.9	34.2
Dicycloparaffins	31.5/22.1			41.9	29.2	33.0	34.0
Tricycloparaffins	8.6/5.8			NA	24.1	15.0	13.8
Aromatics Distribution							
Monoaromatics							
Alkylbenzenes	12.5/15.7			16.4	13.3	13.5	14.2
Benzocycloparaffins	3.7/2.4			7.4	5.6	2.8	2.9
Benzodicyloparaffins	0.0/0.3			NA	2.6	0.2	0.2
Diaromatics							
Naphthalenes	0.0/0.3			0.2	2.8	0.7	0.6
Group Type (FIAM), LV %							
Paraffins and Naphthenes	83	NA	94	67	81	81	80
Aromatics	17		6	33	19	21	20
Hydrogen, Wt %							
Analysis (Combustion)	13.40	NA	NA	12.54	12.62	13.01	12.97
Calculated From Mass Spectrum	13.5	13.2	13.2	12.8	12.9	13.2	13.2
Carbon, Wt % (by Combustion)	86.60	NA	NA	87.46	87.38	86.99	87.03
ASTM D 2887 Distillation, °F (TBP by GC)							
St/5	214/296	218/310	217/313	314/348	422/454	316/353	318/354
10/30	320/362	330/366	334/368	358/369	467/474	360/381	361/382
50	378	395	397	386	511	415	413
70/90	401/469	474/524	477/524	401/427	525/542	492/528	491/527
95/99	485/500	536/554	535/553	449/459	549/559	540/559	537/554
ASTM D 86 Distillation, °F	NA	NA	NA	NA	NA		
St/5						376/385	377/384
10/30						390/407	391/406
50						428	428
70/90						474/515	474/515
90/EP						523/536	522/534
% Overhead						99	98.5

NA = Not Analyzed.

* Calculated = Weighted Average of Components.

TABLE VI

DOE CONTRACT DE-AC22-76ET10532 HYDROTREATING OF
800°F ITSL OIL, WOW 5338, AT 0.5 LHSV WITH ICR 106
CATALYST PROPERTIES OF 350°F+ AND 550°F+, PRODUCT FRACTION

Pilot Plant Run 90-171

Run Hours	1454-1478	1681-1705	2113-2137	1921-1945
Average Catalyst Temperature, °F	720	720	750	750
Boiling Range, °F	550+	550+	550+	350+
Product Inspections				
Gravity, °API	17.2	17.3	17.6	25.4
Aniline Point, °F	137.2	135.2	129.8	118.4
Pour Point, °F	-25	-15	-45	<-80
Cloud Point, °F	No Cloud	No Cloud	NA	<-80
Freeze Point, °F	14	14	NA	<-94
Group Type (22-Component), LV %				
Paraffins	0.0	0.0	0.0	0.0
Naphthenes	79.0	79.7	53.8	78.9
Aromatics	21.0	20.3	46.2	21.1
Naphthene Distribution				
Cycloparaffins	9.9	10.5	13.3	27.7
Dicycloparaffins	27.1	26.0	19.6	27.4
Tricycloparaffins	27.7	28.5	21.1	23.8
Tetracycloparaffins	14.4	14.7	0.0	0.0
Aromatics Distribution				
Monoaromatics				
Alkylbenzenes	7.7	8.0	20.3	13.8
Benzocycloparaffins	1.9	2.2	4.5	4.0
Benzodicycloparaffins	2.6	2.5	4.2	0.8
Diaromatics				
C(N)H(2N-12) Naphthalenes	3.6	3.1	6.6	1.2
C(N)H(2N-14)	0.9	0.9	1.8	0.0
C(N)H(2N-16)	2.9	2.6	5.9	0.4
Triaromatics				
C(N)H(2N-18)	0.6	0.4	1.0	0.0
C(N)H(2N-22)	0.6	0.5	1.7	0.8
Group Type (FIAM), LV %				
Paraffins and Naphthenes	80	75	NA	79
Aromatics	20	25		21
Hydrogen, Wt %				
Analysis	12.19	12.18	12.01	12.51
Calculated from Mass Spectrum	12.7	12.7	12.2	13.0
Carbon, Wt % (Analysis)	87.81	87.82	87.99	87.49
ASTM D 2887 Distillation, °F				
(TBP by GC)				
St/5	522/559	526/559	533/550	323/357
10/30	565/591	565/590	563/588	365/429
50	619	618	617	519
70/90	645/692	644/692	642/687	578/642
95/99	720/792	720/795	717/803	671/742
ASTM D 1160 Distillation, °F				
St/5	579/599	590/599	593/598	NA
10/30	604/614	604/612	602/609	
50	624	624	622	
70/90	645/684	643/685	642/685	
90/EP	709/809	713/795	716/837	
% Overhead	99	99	99	

NA = Not Analyzed

TABLE VII

DOE CONTRACT DE-AC22-76ET10532
PROPERTIES OF HYDROTREATED ITSL OIL HYDROCRACKER FEEDS

Description	350°F+	Full Boiling Range	Full Boiling Range
Blend Identification	WOW 5251	WOW 5329	WOW 5380
Inspections			
Gravity, °API	21.7	25.0	25.1
Aniline Point, °F	105.3	100.0	110.4
Sulfur, ppm	0.58	2.4	0.94
Nitrogen, ppm	0.25	0.26	0.25
Oxygen, ppm	80	100	100
Hydrogen, Wt %	12.11	12.33	12.63
Carbon, Wt %	87.89	87.67	87.37
Group Type, LV % (22 Component)			
Paraffins	0.0	0.0*	0.0*
Naphthenes	67.8	64.5	75.6
Aromatics	32.2	35.5	24.0
ASTM D 2887 Distillation, °F			
(TBP by GC)			
St/5	298/359	95/215	103/241
10/30	384/483	298/437	322/445
50	543	514	516
70/90	591/654	574/639	575/639
95/99	683/747	667/724	668/732
LV % Below 350°F	4.0	14.3	12.8
LV % Below 400°F	13.5	24.1	21.8
LV % Below 450°F	22.5	32.8	31.0
LV % Below 500°F	34.7	44.5	43.4
LV % Below 525°F	44.6	52.7	53.2
LV % Below 550°F	52.9	60.9	60.0
ASTM D 86 Distillation, °F			
St/5	368/401	217/289	N/A
10/30	425/496	338/456	
50	550	521	
70/90	590/637	567/616	
95/EP	664/667	644/687	
% Overhead	97	99	
First-Stage Conditions for Feed Preparation			
Pilot Plant Run No.	36-75	90-167	90-167
Run Hours	261-505	2527-3163	1887-2333
		3365-3401	
Average Catalyst Temperature, °F	721	740	730
LHSV	1.0	1.0	1.0
H_2 Partial Pressure, psia	2300	2300	2300
H_2 Consumption, SCF/Bbl, Approx.	1200	1200	1400

N/A = Not analyzed.

*The small amount of light paraffins in the naphtha fraction of the full-boiling-range feed were not detected by this analytical method.

TABLE VIII

YIELDS FROM HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OIL, WOW 5329, AT 350°F, 400°F, AND 450°F RCP, PILOT PLANT 62-281

Recycle Cut Point, °F	350		350		350		400		450		450	
Run Hours	1278-1302		1302-1326		1374-1398		1494-1518		1614-1638		1686-1710	
Average Catalyst Temperature, °F	590		590		592		591		583		583	
LHSV	1.07		1.10		1.09		1.09		1.11		1.09	
Per Pass Conversion, LV %	68.3		65.0		68.6		80.4		83.35		82.51	
Total Pressure, psig	2299		2298		2299		2300		2304		2299	
Hydrogen Partial Pressure, psig	2008		2004		2011		2009		2034		2012	
Total Gas In, SCF/Bbl	7044		6883		6955		6812		6854		6788	
Recycle Gas, SCF/Bbl	5734		5627		5639		5425		5537		5489	
No Loss Product Yields	Wt %	LV %	Wt %	LV %	Wt %	LV %	Wt %	LV %	Wt %	LV %	Wt %	LV %
C_1	0.01		0.01		0.01		0.00		0.00		0.00	
C_2	0.05		0.06		0.10		0.06		0.04		0.05	
C_3	1.42		1.49		1.48		1.20		0.99		0.99	
iC_4	10.01	16.08	10.23	16.43	10.68	17.14	7.77	12.48	5.64	9.06	5.77	9.26
nC_4	1.49	2.31	1.56	2.42	1.56	2.41	1.32	2.04	0.67	1.04	0.71	1.09
C_5-150°F	11.39	15.98	11.89	16.65	11.73	16.52	9.28	13.02	8.25	11.55	7.99	11.21
150-180°F	8.66	10.53			8.58	10.49	7.82	9.56	6.92	8.42	6.81	8.26
180-250°F	24.96	35.82	77.76	90.88	31.16	37.25	26.15	31.20	23.46	27.98	22.96	27.39
250-300°F	17.07	19.89			16.91	19.67	16.17	18.79	13.56	15.74		
300-350°F	22.93	25.46			20.79	23.11	15.64	17.43	15.15	16.83	57.19	62.97
350-400°F	-	-	-	-	-	-	17.27	18.54	13.76	14.77		
400-450°F	-	-	-	-	-	-	-	-	14.03	14.71		
Total C_5^+	90.01	107.68	89.65	107.53	89.16	107.04	92.35	108.54	95.12	110.01	94.95	109.82
Actual/No Loss Recovery	101.5/103.0		101.8/103.0		100.8/103.0		102.0/102.7		101.6/102.5		102.0/102.5	
H_2 Consumption (Gross), SCF/Bbl	1917		1931		1918		1726		1580		1575	
H_2 Consumption (Chemical), SCF/Bbl	1780		1788		1778		1607		1470		1465	
Whole Liquid Product Properties												
Gravity, °API	53.7		54.1		54.5		51.1		48.6		48.5	
ASTM D 2887 Distillation, °F (TBP by GC)												
St/5	72/122		72/126		81/133		81/115		55/131		55/131	
10/30	159/201		160/201		163/203		163/213		166/218		166/218	
50	241		233		235		249		273		272	
70/90	274/331		275/328		275/329		307/366		339/405		338/405	
95/99	342/354		388/351		340/351		384/398		429/451		429/451	

TABLE IX

DOE CONTRACT DE-AC22-76ET10532
YIELDS FROM HYDROCRACKING HYDROTREATED FULL-BOILING-RANGE ITSL OIL, WOW 5380, AT 350°F RCP
PILOT PLANT RUN 62-281

Run Hours	2310-2334		2358-2382	
Average Catalyst Temperature, °F	606		606	
LHSV	1.09		1.11	
Per Pass Conversion, LV %	64.8		63.9	
Total Pressure, psig	2304		2304	
Hydrogen Partial Pressure, psia	1997		1995	
Total Gas In, SCF/Bbl	6717		6681	
Recycle Gas, SCF/Bbl	5566		5537	
No Loss Product Yields	Wt %	LV %	Wt %	LV %
C_1	0.01		0.01	
C_2	0.07		0.05	
C_3	1.67		1.56	
iC_4	10.70	17.17	10.08	16.18
nC_4	1.76	2.73	1.67	2.59
C_5-150°F	9.73	14.03	10.08	14.27
150-180			9.14	11.31
180-250	78.79	92.02	30.44	36.37
250-300			16.70	19.42
300°F+			23.03	25.56
Total C_5+	88.52	106.05	89.39	106.94
Actual/No Loss Recovery	100.2/102.7		100.6/102.8	
H_2 Consumption (Gross), SCF/Bbl	1779		1789	
H_2 Consumption (Chemical), SCF/Bbl	1627		1643	
Whole Liquid Product Properties				
Gravity, °API	52.1		51.9	
ASTM D 2887 Distillation, °F				
St/5	130/161		130/161	
10/30	169/208		169/211	
50	243		245	
70/90	279/330		283/334	
95/99	340/351		344/355	

TABLE X

DOE CONTRACT DE-AC22-76ET10532; C_5-150°F PRODUCT PROPERTIES
FROM HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OIL
WITH ICR 202 CATALYST AT 350°F, 400°F, AND 450°F RCP

	Pilot Plant Run 62-281							
Recycle Cut Point, °F	350	350	350	350	350	400	450	450
Feed No.	WOW 5329	WOW 5329	WOW 5329	WOW 5380	WOW 5380	WOW 5329	WOW 5329	WOW 5329
Run Hours	1278-1302	1302-1326	1374-1398	2358-2382	2310-2334	1494-1518	1614-1638	1686-1710
Average Catalyst Temperature, °F	590	590	592	606	606	591	583	583
Inspections of C_5-150°F								
Gravity, °API	87.9	87.5	88.8	90.1	94.2	87.9	87.5	87.9
Group Type, LV % (By GC)								
Paraffins								
Isobutane	0.0		0.0	0.0	0.0	0.0	1.7	1.2
n-Butane	0.0		0.0	0.0	0.0	0.0	4.0	3.7
Isopentane	61.4		64.5	68.9	66.9	61.5	54.4	55.5
n-Pentane	5.1		5.2	6.0	5.3	5.6	5.1	5.3
2,2-Dimethylbutane	0.1		0.1	0.0	0.0	0.1	0.1	0.1
2,3-Dimethylbutane	4.1		4.1	2.3	2.5	4.7	4.4	4.5
2-Methylpentane	14.2		13.4	10.6	12.4	14.3	13.9	14.4
3-Methylpentane	7.5		6.7	5.8	7.2	6.5	6.3	6.9
n-Hexane	0.8		0.6	0.7	0.8	0.7	0.7	0.9
Isoheptanes	0.0		0.0	0.01	0.02	0.0	0.3	0.0
Total Paraffins	93.2	93.2	94.6	94.3	95.1	93.4	90.9	92.5
Naphthenes								
Cyclopentane	1.6		1.6	0.01	0.01	2.0	2.0	2.0
Methylcyclopentane	5.9		3.6	5.5	4.7	4.3	4.6	5.1
Cyclohexane	0.2		0.0	0.1	0.03	0.1	0.4	0.1
C_7 Naphthenes	0.0		0.0	0.01	0.01	0.0	1.9	
Total Naphthenes	7.7	6.8	5.2	5.6	4.7	6.4	8.9	7.2
Aromatics								
Benzene	0.0		0.1	0.07	0.08	0.1	0.2	0.2
Total Aromatics	0.0	0.0	0.1	0.07	0.08	0.1	0.2	0.2
Iso-to-Normal Ratios								
Isopentane/n-Pentane	12		12	11	13	11	11	10
Isohexanes/n-Hexane	32		40	27	28	37	30	30

TABLE XI

DOE CONTRACT DE-AC22-76ET10532
150-180°F PRODUCT PROPERTIES FROM
HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OIL
WITH ICR 202 CATALYST AT 350°F, 400°F, AND 450°F RCP
PILOT PLANT RUN 62-281

Recycle Cut Point, °F	350	350	350	400	450	450
Feed No.	WOW 5329	WOW 5329	WOW 5380	WOW 5329	WOW 5329	WOW 5329
Run Hours	1278-1302	1374-1398	2358-2382	1494-1518	1614-1638	1686-1710
Average Catalyst Temperature, °F	590	592	606	591	583	583
Inspections of 150-180°F Product						
Gravity, °API	58.9	59.9	62.3	59.7	59.1	58.3
Aniline Point, °F	102.6	104.0	N/A	104.5	101.5	102.1
Octane Number, F-1 Clear	87.7	87.7	86.8	87.1	87.1	87.4
Group Type, LV % (Low Mass)						
Paraffins	20.1	22.2	21.4	22.8	13.1	20.8
Naphthenes	79.3	77.8	78.6	77.1	86.4	78.8
Aromatics (Benzene)	0.6	0.0	0.0	0.2	0.5	0.4
Hydrogen, Wt % (Calc. from Mass Spec.)	14.6	14.7	14.6	14.7	14.5	14.7
Group Type, LV % (By GC)						
Butanes	0.00	0.00	0.00	0.00	0.04	0.04
Isopentane	0.4	0.3	0.00	0.2	0.3	0.4
n-Pentane	0.07	0.07	0.00	0.04	0.04	0.3
2,2-Dimethylbutane	0.0	0.01	0.0	0.00	0.00	0.0
2,3-Dimethylbutane	1.2	1.3	2.2	1.3	1.0	1.0
2-Methylpentane	5.9	6.3	12.1	7.2	5.3	5.5
3-Methylpentane	5.9	6.5	10.1	7.1	5.6	5.4
n-Hexane	3.2	2.9	3.3	3.3	3.2	3.1
Isoheptanes	5.9	4.6	3.2	3.5	3.8	3.9
n-Heptane	0.0	0.0	0.01	0.01	0.02	0.02
Total Paraffins	22.6	22.3	30.9	22.8	19.4	19.6
Cyclopentane	0.2	0.2	0.0	0.1	0.1	0.2
Methylcyclopentane	56.9	60.6	55.8	57.7	57.0	56.1
Cyclohexane	18.9	13.3	9.0	14.1	17.6	17.8
C7 Naphthenes	1.2	3.1	3.9	4.5	5.1	5.3
Total Naphthenes	77.0	77.2	68.7	76.4	79.6	79.4
Benzene	0.3	0.5	0.4	0.8	1.0	1.0
Total Aromatics	0.3	0.5	0.4	0.8	1.0	1.0
Isohexane/n-Hexane	4.1	4.9	7.4	4.7	3.7	3.8
TBP Distillation, °F (Calc. from Detailed GC)						
St/5	82/140	82/140	136/140	82/140	11/140	11/140
10/30	146/161	146/161	140/161	146/161	146/161	146/161
50	161	161	161	161	161	161
70/90	161/168	161/177	161/177	161/177	161/177	161/177
95/99	194/214	194/218	194/214	194/-	195/248	195/248
ASTM D 2887 Distillation, °F (TBP by GC)						
St/5	85/138	82/136	126/136	88/138	83/138	85/138
10/30	145/170	142/169	139/164	143/170	145/171	145/170
50	175	174	172	176	176	176
70/90	183/193	180/192	176/187	182/194	184/193	184/195
95/99	196/202	196/205	194/201	199/206	200/205	199/206

N/A = Not Analyzed

TABLE XII

DOE CONTRACT DE-AC22-76ET10532; 180-250°F PRODUCT PROPERTIES FROM HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OIL WITH ICR 202 CATALYST AT 350°F, 400°F, AND 450°F RCP

	Pilot Plant Run 62-281					
Recycle Cut Point, °F	350	350	350	400	450	450
Feed No.	WOW 5329	WOW 5329	WOW 5380	WOW 5329	WOW 5329	WOW 5329
Run Hours	1278-1302	1374-1398	2358-2382	1494-1518	1614-1638	1686-1710
Average Catalyst Temperature, °F	590	592	606	591	583	583
180-250°F Product Inspections						
Gravity, °API	55.6	55.6	55.6	55.2	55.2	55.2
Aniline, Point, °F	118.8	119.3	120.0	119.1	118.6	118.5
Octane Number, F-1 Clear	76.4	75.9	76.0	75.9	75.1	75.8
Group Type (Low Mass), LV %						
Paraffins	9.8	9.8	8.2	9.8	9.6	8.6
Naphthenes	90.2	90.2	91.4	90.2	90.4	91.4
Aromatics	0.0	0.0	0.4	0.0	0.0	0.0
Hydrogen, Wt % (from MS)	14.5	14.5	14.5	14.5	14.5	14.5
Group Type (by GC), LV %						
Isohexanes	0.06	0.1	0.4	0.1	0.06	0.1
n-Hexane	0.04	0.05	0.05	0.5	0.04	0.05
Isoheptanes	5.2	5.2	5.6	5.4	4.8	7.5
n-Heptane	0.7	0.8	0.8	0.8	0.8	0.8
Isooctanes	5.0	4.9	4.9	4.8	5.1	4.4
n-Octane	0.05	0.1	0.1	0.1	0.1	0.1
Isononanes	0.08	0.1	0.2	0.2	0.2	0.2
Total Paraffins	11.2	11.2	12.2	10.0	11.2	13.5
Methylcyclopentane	1.8	2.3	2.6	2.2	1.9	2.2
Cyclohexane	5.7	3.5	2.8	4.1	4.3	4.6
C_7-Cyclopentanes	31.8	30.2	30.8	29.0	27.2	25.5
Methylcyclohexane	24.9	24.8	24.3	25.6	26.7	27.2
C_8-Cyclopentanes	14.3	15.0	14.7	14.8	14.6	14.1
C_8-Cyclohexanes	6.6	8.0	7.8	3.7	9.4	8.5
C_9-Cyclopentanes	3.6	3.9	3.9	5.1	4.5	4.2
C_9-Cyclohexanes	0.0	0.01	0.0	0.02	0.03	0.0
Total Naphthenes	88.7	88.7	86.8	84.6	88.6	86.3
Benzene	0.00	0.01	0.05	0.02	0.02	0.03
Toluene	0.07	0.07	0.3	0.1	0.2	0.2
C_8 Aromatics	0.0	0.0	0.3	0.0	0.0	0.0
C_9 Aromatics	0.0	0.0	0.3	0.0	0.0	0.0
Total Aromatics	0.1	0.1	1.0	0.1	0.2	0.2
ASTM D 2887 Distillation, °F						
(TPB by GC), St/5	161/183	157/185	145/163	161/185	162/184	154/182
10/30	194/205	195/204	196/205	196/206	195/205	195/206
50	220	220	218	222	221	221
70/90	228/249	228/248	226/248	230/250	230/251	229/250
95/99	253/259	253/260	252/295	254/261	254/261	254/261

TABLE XIII

DOE CONTRACT DE-AC22-76ET10532
PROPERTIES OF 250-300°F PRODUCT FRACTIONS
HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OIL,
OVER ICR 202 CATALYST AT 350°F, 400°F, AND 450°F RCP
PILOT PLANT RUN 62-281

Recycle Cut Point, °F	350	350	350	400	450
Feed No.	WOW 5329	WOW 5329	WOW 5380	WOW 5329	WOW 5329
Run Hours	1278-1302	1374-1398	2358-2382	1494-1518	1614-1638
Average Catalyst Temperature, °F	590	592	606	591	583
250-300°F Product Inspections					
Gravity, °API	50.8	50.5	50.6	50.3	50.1
Aniline Point, °F	128.8	127.9	127.8	126.1	127.4
Octane Number, F-1 Clear	65.0	60.4	65.1	60.4	63.2
Smoke Point, mm	NA	NA	NA	30+	31
Group Type (Low Mass), LV %					
Paraffins	6.9	6.5	6.9	6.3	5.9
Naphthenes	93.1	93.5	93.1	93.7	94.1
Aromatics	0.1	0.0	0.1	0.0	0.0
Naphthene Distribution					
Cycloparaffins	87.7	87.9	88.0	88.1	87.7
Dicycloparaffins	5.4	5.6	5.6	5.6	6.9
Hydrogen, Wt % (Calc. from Mass Spec.)	14.4	14.4	14.4	14.4	14.4
ASTM D 2887 Distillation, °F (TBP by GC)					
St/5	214/245	214/243	211/242	215/244	213/244
10/30	248/259	246/258	246/258	247/260	247/260
50	273	273	272	275	276
70/90	283/297	282/297	282/297	284/300	285/300
95/99	302/310	303/312	301/311	304/313	305/314

NA = Not Analyzed

TABLE XIV

DOE CONTRACT DE-AC22-76ET10532
PROPERTIES OF 300-350°F PRODUCT FRACTIONS
HYDROCRACKING OF FULL-BOILING-RANGE ITSL OIL,
OVER ICR 202 CATALYST AT 350°F, 400°F, AND 450°F RCP
PILOT PLANT RUN 62-281

Recycle Cut Point, °F	350	350	350	400	450
Feed No.	WOW 5329	WOW 5329	WOW 5380	WOW 5329	WOW 5329
Run Hours	1278-1302	1374-1398	2358-2382	1494-1518	1614-1638
Average Catalyst Temperature, °F	590	592	606	591	583
300-350°F Product Properties					
Gravity, °API	42.3	42.5	42.3	42.9	42.4
Aniline Point, °F	128.1	132.0	127.5	125.7	125.4
Octane Number, F-1 Clear	49.4	49.8	50.7	50.8	51.0
Smoke Point, mm	NA	NA	NA	25	28
Group Type, LV % (High Mass)					
Paraffins	8.7	9.1	9.2	8.0	7.1
Naphthenes	89.6	89.2	89.5	90.2	91.2
Aromatics	1.7	1.7	1.3	1.7	1.7
Naphthene Distribution					
Cycloparaffins	49.4	50.1	51.4	53.3	52.4
Dicycloparaffins	40.2	39.2	38.1	36.9	38.7
Alkylbenzene Distribution					
C_6	1.3	1.2	1.3	0.9	0.9
C_7	0.4	0.5	0.0	0.3	0.3
C_8	0.0	0.0	0.0	0.0	0.0
C_9	0.0	0.0	0.0	0.5	0.5
C_{10}	0.0	0.0	0.0	0.0	0.0
Hydrogen, Wt % (Calc. from Mass Spec.)	13.7	13.8	13.8	13.8	13.7
ASTM D 2887 Distillation, °F					
St/5	266/293	265/293	264/290	264/291	262/292
10/30	299/319	299/319	296/318	297/315	297/317
50	332	331	331	327	328
70/90	343/354	341/352	342/353	338/348	339/350
95/99	358/364	358/-	357/361	353/362	354/363

NA = Not Analyzed

TABLE XV

DOE CONTRACT DE-AC22-76ET10532
PROPERTIES OF 350-400°F AND 400-450°F PRODUCT FRACTIONS
HYDROCRACKING OF FULL-BOILING-RANGE ITSL OIL WOW 5329,
OVER ICR 202 CATALYST AT 400°F AND 450°F RCP
PILOT PLANT RUN 62-281

Recycle Cut Point, °F	400	450	450
Run Hours	1494-1518	1614-1638	1614-1638
Average Catalyst Temperature, °F	591	583	583
Boiling Range, °F	350-400	350-400	400-450
Gravity, °API	36.5	36.5	32.6
Aniline Point, °F	126.2	124.9	135.0
Octane Number, F-1 Clear	33.1	NA	NA
Smoke Point, mm	21	23	19
Freezing Point, °F	NA	NA	Below -94
Group Type, LV %	Low Mass	Low Mass/ 22-Component	22-Component
Paraffins	8.2	5.9/3.8	2.9
Naphthenes	88.0	90.9/91.4	92.7
Aromatics	3.8	3.1/4.8	4.4
Naphthene Distribution			
Cycloparaffins	39.4	38.4/47.5	23.8
Dicycloparaffins	48.5	52.6/34.4	20.4
Tricycloparaffins	NA	NA/9.6	48.6
Hydrogen, Wt % (Calc. from Mass Spec.)	13.4	13.4/13.7	13.1
ASTM D 2887 Distillation, °F			
St/5	317/341	312/340	367/385
10/30	349/367	347/365	392/413
50	378	372	428
70/90	391/402	383/394	441/456
95/99	406/412	399/407	460/468

NA = Not Analyzed

TABLE XVI

DOE CONTRACT DE-AC22-76ET10532
PROPERTIES OF 150-350°F PRODUCT FRACTION
HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED
ITSL OIL OVER ICR 202 CATALYST AT 350°F RCP
PILOT PLANT RUN 62-281

Feed No.	WOW 5329	WOW 5380
Run Hours	1302-1326	2310-2334
Average Catalyst Temperature, °F	590	606
150-350°F Product Properties		
Gravity, °API	51.4	51.4
Aniline Point, °F	122.6	121.6
Octane Number		
F-1 Clear	69.6	69.4
F-2 Clear	70.4	69.9
Group Type, LV %		
Paraffins	9.2	10.3
Naphthenes	90.8	89.7
Aromatics	0.0	0.0
Naphthene Distribution		
Cycloparaffins	80.5	80.3
Dicycloparaffins	10.3	9.4
Hydrogen, Wt % (Calc. from Mass Spec.)	14.3	14.4
ASTM D 2887 Distillation, °F		
St/5	135/162	132/166
10/30	184/216	178/214
50	247	246
70/90	285/332	286/332
95/99	341/352	342/358
ASTM D 86 Distillation, °F		
St/5	202/216	195/211
10/30	220/233	216/230
50	253	250
70/90	281/316	279/312
95/EP	324/345	321/346
% Overhead	99.5	99.0

TABLE XVII

DOE CONTRACT DE-AC22-76ET10532; 250°F-450°F PRODUCT PROPERTIES FROM HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OIL, WOW 5329, WITH ICR 202 CATALYST AT 450°F RCP

Pilot Plant Run 62-281

Run Hours	1686-1710	
Average Catalyst Temperature, °F	583	
250-450°F Product Properties		
Gravity, °API	40.8	
Aniline Point, °F	127.8	
Octane Number, F-1 Clear	50.0	
Smoke Point, mm	24	
Group Type, LV %	Low Mass	High Mass
Paraffins	9.0	0.0
Naphthenes	88.2	99.8
Aromatics	2.9	0.2
Napththene Distribution		
Monocycloparaffins	53.6	50.8
Dicycloparaffins	34.5	26.9
Tricycloparaffins	NA	22.0
Aromatics Distribution		
Alkylbenzenes	2.9	0.1
Benzonaphthenes	0.0	0.1
ASTM D 2887 Distillation, °F (TPB by GC)		
St/5	224/251	
10/30	266/308	
50	343	
70/90	379/426	
95/99	439/454	

NA = Not Analyzed

TABLE XVIII

DOE CONTRACT DE-AC22-76ET10532
YIELDS FROM HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OILS, WOW 5329 AND WOW 5380, AT 500°F, 525°F, AND 550°F RCP, PILOT PLANT 62-281

Feed No.	WOW 5329		WOW 5329		WOW 5329		WOW 5380		WOW 5380		WOW 5380	
Recycle Cut Point, °F	500		500		525		525		550		550	
Run Hours	1734-1758		1758-1782		1866-1878		1938-1962		2142-2166		2166-2190	
Average Catalyst Temperature, °F	578		579		577		576		567		568	
LHSV	1.09		1.10		1.10		1.11		1.11		1.09	
Per Pass Conversion, LV %	84.2		83.0		85.1		80.8		77.0		77.9	
Total Pressure, psig	2302		2304		2304		2304		2306		2304	
Hydrogen Partial Pressure, psig	2018		2025		2043		2044		2064		2068	
Total Gas In, SCF/Bbl	6843		6681		6786		6326		6276		6417	
Recycle Gas, SCF/Bbl	5575		5501		5641		5363		5467		5657	
No Loss Product Yields	Wt %	LV %	Wt %	LV %	Wt %	LV %	Wt %	LV %	Wt %	LV %	Wt %	LV %
C_1	0.00		0.00		0.00		0.00		0.00		0.00	
C_2	0.04		0.03		0.04		0.02		0.03		0.03	
C_3	0.83		0.79		0.77		0.70		0.58		0.62	
iC_4	4.83	7.76	4.31	6.92	4.28	6.87	3.83	6.14	3.09	4.95	3.33	5.34
nC_4	0.55	0.85	0.49	0.76	0.48	0.74	0.44	0.68	0.34	0.52	0.39	0.60
C_5-150°F	7.05	9.91	7.18	9.99	6.52	9.00	5.35	7.57	4.75	6.52	4.36	6.11
150-180°F	6.08	7.38	5.74	6.96	5.42	6.53	5.01	6.09	3.87	4.75	4.24	5.15
180-250°F	21.12	25.17	20.92	24.91	19.01	22.58	18.03	21.55	14.81	17.64	15.29	18.20
250-300°F			12.06	13.97			10.54	12.24			9.36	10.86
300-350°F			13.58	15.05			12.78	14.21			11.52	12.81
350-400°F	61.87	67.16	17.02	18.21	65.57	70.56	17.55	18.83	74.15	78.56	14.87	15.92
400-450°F			9.09	9.54			7.85	8.28			12.88	13.50
450-500°F			11.01	11.22			-	-			10.55	10.87
450-525°F	-	-	-	-			19.75	20.17			-	-
500-550°F	-	-	-	-	-	-	-	-			14.19	14.24
Total C_5+	96.12	109.62	96.60	109.85	96.52	108.67	96.60	109.85	97.6	107.5	97.27	107.67
Actual/No Loss Recovery	102.8/102.4		101.7/102.2		101.2/102.1		101.7/102.2		99.2/101.6		100.2/101.6	
H_2 Consumption (Gross), SCF/Bbl	1506		1422		1346		1422		1051		1070	
H_2 Consumption (Chemical), SCF/Bbl	1412		1323		1247		1323		957		976	
Whole Liquid Product Properties												
Gravity, °API	46.2		46.3		44.3		43.6		40.0		41.0	
ASTM D 2887 Distillation, °F (TBP by GC)												
St/5	52/154		54/137		62/143		60/149		55/160		55/160	
10/30	167/223		169/226		170/241		180/249		184/265		183/259	
50	297		300		315		331		352		350	
70/90	363/447		365/448		379/469		392/486		420/509		416/507	
95/99	473/494		474/496		495/519		507/527		529/548		528/551	

TABLE XIX

DOE CONTRACT DE-AC22-76ET10532; C_5-150°F PRODUCT PROPERTIES
FROM HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED
ITSL OIL, WITH ICR 202 CATALYST AT 500°F, 525°F, AND 550°F RCP

Pilot Plant Run 62-281

Feed Number	WOW 5329	WOW 5329	WOW 5329	WOW 5380	WOW 5380	WOW 5380
Recycle Cut Point, °F	500	500	525	525	550	550
Run Hours	1734-1758	1758-1782	1866-1878	1938-1962	2142-2166	2166-2190
Average Catalyst Temperature, °F	578	579	577	576	567	568
Inspections of C_5-150°F Product						
Gravity, °API	88.4	86.3	84.4	89.7	83.3	87.4
Group Type, LV % (by GC)	NA		NA		NA	
Paraffins						
Isobutane		3.9		1.5		0.2
n-Butane		4.2		3.8		1.2
Isopentane		46.9		50.4		47.6
n-Pentane		4.4		5.1		5.8
2,2,-Dimethylbutane		0.1		0.1		0.1
2,3,-Dimethylbutane		4.3		5.1		5.2
2-Methylpentane		14.5		16.6		17.2
3-Methylpentane		7.4		7.9		8.3
n-Hexane		1.4		0.9		1.4
Total Paraffins		87.0		91.4		87.0
Naphthenes						
Cyclopentane		2.0		2.4		2.6
Methylcyclopentane		10.2		5.7		9.8
Cyclohexane		0.3		0.1		0.2
Total Naphthenes		12.5		8.2		12.6
Aromatics						
Benzene		0.5		0.3		0.4
Total Aromatics		0.5		0.3		0.4
Iso-to-Normal Ratios						
Isopentane/n-Pentane		11		10		8
Isohexane/n-Hexane		19		31		23

NA = Not Analyzed

TABLE XX

DOE CONTRACT DE-AC22-76ET10532; 150-180°F PRODUCT PROPERTIES FROM HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OIL WITH ICR 202 CATALYST AT 500°F, 525°F, AND 550°F RCP

Pilot Plant Run 62-281

Feed Number	WOW 5329	WOW 5329	WOW 5329	WOW 5380	WOW 5380	WOW 5380
Recycle Cut Point, °F	500	500	525	525	550	550
Run Hours	1734-1758	1758-1782	1866-1878	1938-1962	2142-2166	2166-2190
Average Catalyst Temperature, °F	578	579	577	576	567	568
Inspections of 150-180°F Product						
Gravity, °API	58.4	58.3	57.2	58.9	60.6	59.0
Aniline Point, °F	99.5	100.0	98.7	NA	103.2	100.3
Octane Number, F-1 Clear	87.3	NA	NA	NA	NA	NA
Group Type, LV % (Low Mass)						
Paraffins	12.9	NA	15.3	NA	23.6	NA
Naphthenes	86.4		83.5		75.8	
Aromatics (Benzene)	0.6		1.2		0.6	
Hydrogen, Wt % (Calculated From Mass Spectrum)	14.5	NA	14.5	NA		NA
Group Type, LV % (By GC)						
Butane		0.1		0.1		0.1
Isopentane		0.5		0.5		0.6
n-Pentane		0.1		0.1		0.1
2,2-Dimethylbutane		0.0		0.0		0.0
2,3-Dimethylbutane		1.0		1.0		1.1
2-Methylpentane		4.4		4.7		5.2
3-Methylpentane		3.9		4.5		4.7
n-Hexane		2.6		2.6		2.8
Isoheptanes		4.4		4.6		3.6
n-Heptane		0.02		0.02		0.02
Total Paraffins		17.0		18.1		18.2
Cyclopentane		1.7		0.2		0.2
Methylcyclopentane		52.5		55.7		55.8
Cyclohexane		22.1		17.7		19.2
C_7-Cyclopentane		6.4		6.8		5.0
Methylcyclohexane		0.3		0.3		0.3
Total Naphthenes		80.7		80.7		80.5
Benzene		0.0		1.2		1.3
Total Aromatics		0.0		1.2		1.3
Isohexane/n-Hexane		4		4		4
TBP Distillation, °F (Calculated from Detailed GC)						
St/5		11/140		11/140		11/140
10/30		161/161		161/161		146/161
50		161		161		161
70/90		177/177		176/190		161/177
95/99		195/218		195/218		195/218
ASTM D 2887 Distillation, °F (TBP by GC)						
St/5	79/138	84/140	60/138	85/140	54/131	NA
10/30	150/171	150/172	154/171	148/172	138/169	
50	176	179	177	178	175	
70/90	186/197	187/197	187/198	184/192	184/192	
95/99	199/204	203/208	201/204	203/208	199/204	

NA = Not Analyzed

TABLE XXI

DOE CONTRACT DE-AC22-76ET10532; 180-250°F PRODUCT PROPERTIES FROM HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OIL, WITH ICR 202 CATALYST AT 500°F, 525°F, AND 550°F RCP

Pilot Plant Run 62-281

Feed Number	WOW 5329	WOW 5329	WOW 5329	WOW 5380	WOW 5380	WOW 5380
Recycle Cut Point	500	500	525	525	550	550
Run Hours	1734-1758	1758-1782	1866-1878	1938-1962	2142-2166	2166-2190
Average Catalyst Temperature, °F	578	579	577	576	567	568
180-250°F Product Inspections						
Gravity, °API	55.0	54.8	54.4	55.7	55.1	54.9
Aniline Point, °F	116.9	117.5	117.3	116.5	114.5	116.1
Octane Number, F-1 Clear	75.0	NA	NA	NA	NA	NA
Group Type (Low Mass), LV %						
Paraffins	8.4	8.6	7.7	7.7	9.7/13.6	12.8
Naphthenes	91.6	91.4	92.3	92.3	90.3/86.3	85.2
Aromatics	0.0	0.0	0.0	0.0	0.0/0.1	2.0
Hydrogen, Wt % (Calculated from Mass Spectrum)	14.5	14.5	14.5	14.5	14.5	
Hydrogen, Wt % (by Combustion)	NA	NA	NA	NA	NA	14.4
Group Type (by GC), LV %	NA		NA		NA	
Isohexanes		0.08		0.10		0.08
n-Hexane		0.04		0.04		0.04
Isoheptanes		6.5		6.1		6.3
N-Heptane		0.8		0.7		0.8
Isooctanes		4.7		4.9		4.4
n-Octane		0.2		0.2		0.2
Isononanes		0.2		0.3		0.2
Total Paraffins		12.6		12.4		12.0
Methylcyclopentane		1.8		1.9		1.9
Cyclohexane		4.5		3.2		4.9
C_7-Cyclopentanes		23.9		22.7		23.3
Methylcyclohexanes		27.9		27.6		30.6
C_8-Cyclopentanes		14.1		14.7		13.0
C_8-Cyclohexanes		10.3		12.0		9.6
C_9-Cyclopentanes		4.7		5.2		4.5
C_9-Cyclohexanes		0.01		0.06		0.02
Total Naphthenes		87.2		87.3		87.8
Benzene		0.03		0.03		0.03
Toluene		0.24		0.24		0.25
Xylenes		0.01		0.02		0.01
Total Aromatics		0.3		0.3		0.3
ASTM D 2887 Distillation, °F (TPB by GC)						
St/5	160/183	159/186	160/184	158/188	136/183	160/185
10/30	194/205	197/207	196/206	198/209	194/204	197/208
50	221	222	221	223	221	223
70/90	229/251	232/253	229/251	235/253	229/250	232/252
95/99	255/262	258/264	255/262	257/265	254/260	257/263

NA = Not Analyzed

TABLE XXII

DOE CONTRACT DE-AC22-76ET10532;
PROPERTIES OF 250-300°F PRODUCT FRACTIONS FROM
HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED
ITSL OIL OVER ICR 202 CATALYST AT 500°F, 525°F, AND 550°F RCP

Pilot Plant Run 62-281

Feed Number	WOW 5329	WOW 5380	WOW 5380
Recycle Cut Point, °F	500	525	550
Run Hours	1758-1782	1938-1962	2166-2190
Average Catalyst Temperature, °F	579	576	568
250-300°F Product Inspections			
Gravity, °API	49.8	50.5	50.1
Aniline Point, °F	126.5	126.7	126.0
Smoke Point, mm	32	32	32
Group Type (Low Mass), LV %			
Paraffins	5.4	5.1	4.9
Naphthenes	94.6	94.9	95.0
Aromatics	0.0	0.0	0.1
Naphthene Distribution			
Cycloparaffins	86.9	86.5	88.5
Dicycloparaffins	7.7	8.4	6.5
Hydrogen, Wt % (Calculated from Mass Spectrum)	14.3	14.3	14.3
Hydrogen, Wt % (by Combustion)	NA	NA	14.44
ASTM D 2887 Distillation, °F (TBP by GC)			
St/5	211/244	210/243	211/244
10/30	249/265	248/267	249/262
50	279	279	277
70/90	288/304	290/304	286/301
95/99	308/317	309/318	306/313

NA = Not Analyzed

TABLE XXIII

DOE CONTRACT DE-AC22-76ET10532; PROPERTIES OF 300-350°F PRODUCT FRACTIONS FROM HYDROCRACKING OF FULL-BOILING-RANGE ITSL OIL OVER ICR 202 CATALYST AT 500°F, 525°F, AND 550°F RCP

Pilot Plant Run 62-281

Feed Number	WOW 5329	WOW 5380	WOW 5380
Recycle Cut Point, °F	500	525	550
Average Catalyst Temperature, °F	1758-1782	1938-1962	2166-2190
300-350°F Product Properties			
Gravity, °API	41.9	42.6	42.6
Aniline Point, °F	124.3	124.0	123.0
Smoke Point, mm	29	26	25
Group Type, LV % (Low Mass)			
Paraffins	7.0	6.7	6.6
Naphthenes	91.2	91.4	91.7
Aromatics	1.8	1.9	1.8
Naphthene Distribution			
Cycloparaffins	50.8	51.1	52.9
Dicycloparaffins	40.4	40.3	38.7
Alkylbenzene Distribution			
C_6	0.9	0.8	0.8
C_7	0.4	0.4	0.2
C_8	0.0	0.1	0.0
C_9	0.5	0.6	0.7
C_{10}	0.0	0.0	0.0
Hydrogen, Wt % (Calculated from Mass Spectrum)	13.7	13.6	13.7
Hydrogen, Wt % (by Combustion)	NA	NA	13.89
ASTM D 2887 Distillation, °F			
St/5	265/294	254/292	250/291
10/30	301/320	300/320	298/317
50	331	331	329
70/90	341/352	341/353	340/351
95/99	357/365	358/368	356/364

NA = Not Analyzed

TABLE XXIV

DOE CONTRACT DE-AC22-76ET10532; PROPERTIES OF 350-400°F, 400-450°F PRODUCT FRACTIONS FROM HYDROCRACKING OF FULL-BOILING-RANGE ITSL OIL OVER ICR 202 CATALYST AT 500°F, 525°F, AND 550°F RCP

Pilot Plant Run 62-281

Boiling Range, °F	350-400	350-400	350-400	400-450	400-450	400-450
Feed Number	WOW 5329	WOW 5380	WOW 5380	WOW 5329	WOW 5380	WOW 5380
Recycle Cut Point, °F	500	525	550	500	525	550
Run Hours	1758-1782	1938-1962	2166-2190	1758-1782	1938-1962	2166-2190
Average Catalyst Temperature, °F	579	576	568	579	576	568
Gravity, °API	36.6	36.6	36.2	32.6	33.6	32.7
Aniline Point, °F	123.6	123.3	122.0	133.7	131.6	130.8
Smoke Point, mm	24	24	23	22	20	20
Group Type, LV % (22-Component)						
Paraffins	0.3	0.0	0.7	0.8	0.0	0.0/0.2
Naphthenes	96.8	95.7	96.6	96.2	96.4	96.9/97.6
Aromatics	2.8	4.2	2.6	3.0	3.6	3.0/2.2
Napththene Distribution						
Cycloparaffins	40.6	43.0	48.0	23.4	25.7	24.5/23.2
Dicycloparaffins	42.4	43.4	42.3	32.6	36.8	39.0/33.6
Tricycloparaffins	13.9	9.4	6.3	40.1	33.9	33.4/40.9
Aromatics Distribution						
Alkylbenzenes	2.8	4.2	2.6	3.0	3.6	3.0/2.2
Hydrogen, Wt % (Calculated from Mass Spectrum)	13.2	13.6	13.7	13.2	13.2	13.2/13.1
Hydrogen, Wt % (by Combustion)	NA	NA	13.45	NA	NA	13.42
ASTM D 2887 Distillation, °F						
St/5	316/344	313/343	307/340	356/385	356/392	359/385
10/30	352/367	352/368	348/366	394/416	402/417	391/412
50	377	378	374	429	427	425
70/90	390/404	391/403	385/397	440/455	437/448	437/450
95/99	411/422	409/419	402/410	462/473	452/461	455/461

NA = Not Analyzed

TABLE XXV

DOE CONTRACT DE-AC-76ET10532; PROPERTIES OF 450-500°F, 450-525°F, AND 500-550°F FRACTIONS FROM HYDROCRACKING OF FULL-BOILING-RANGE HYDROTREATED ITSL OIL OVER ICR 202 CATALYST AT 500°F, 525°F, AND 550°F RCP

Pilot Plant Run 62-281

Boiling Range	450-500	450-500	450-525	500-550
Feed	WOW 5329	WOW 5380	WOW 5380	WOW 5380
Recycle Cut Point, °F	500	550	525	550
Run Hours	1758-1782	2166-2190	1938-1962	2166-2190
Average Catalyst Temperature, °F	579	568	576	568
Properties				
Gravity, °API	28.0	29.2	28.4	25.6
Aniline Point, °F	140.5	137.2	139.5	146.1
Smoke Point, mm	20	20	18	21
Freezing Point, °F	Below -94	NA	Below -94	Below -94
Group Type, LV % (22-Component)				
Paraffins	0.8	0.0	0.0	0.9
Naphthenes	95.4	95.9	94.9	96.7
Aromatics	3.8	4.1	5.1	2.3
Naphthene Distribution				
Monocycloparaffins	15.5	21.0	16.4	14.5
Dicycloparafins	29.8	30.7	32.8	20.4
Tricycloparaffins	50.1	44.2	44.3	30.6
Tetracycloparaffins	0.0	0.0	0.0	31.2
Aromatics Distribution				
Alkylbenzenes	3.8	4.1	5.0	1.9
Benzocycloparaffins	0.0	0.0	0.1	0.3
Naphthalenes	0.0	0.0	0.0	0.1
Hydrogen, Wt % (Calculated From Mass Spectrum)	13.1	13.2	13.1	12.8
Hydrogen, Wt % (by Combustion)	NA	13.18	NA	13.12/13.24
ASTM D 2887 Distillation, °F (TBP by GC)				
St/5	404/434	429/448	412/438	479/501
10/30	445/468	455/471	448/473	507/521
50	480	480	493	543
70/90	493/504	491/502	510/526	545/558
95/99	507/515	506/511	533/543	562/570

NA = Not Analyzed

TABLE XXVI

DOE CONTRACT DE-AC22-76ET10532; PROPERTIES OF 250-500°F, 250-525°F, AND 250-550°F JET FUEL PRODUCTS FROM HYDROCRACKING OF FULL-BOILING-RANGE ITSL OIL OVER ICR 202 CATALYST AT 500°F, 525°F, AND 550°F RCP

Pilot Plant Run 62-281

Jet Product Boiling Range	250-500		250-500	250-525			250-525	250-550		250-550
Feed	WOW 5329		WOW 5329	WOW 5329			WOW 5380	WOW 5380		WOW 5380
Recycle Cut Point	500		500	525			525	550		550
Run Hours	1734-1758		1758-1782	1866-1878			1938-1962	2142-2166		2166-2190
Average Catalyst Temperature, °F	578		579	577			576	567		
Properties										
Gravity, °API	38.4		NA	36.9			NA	34.4		NA
Aniline Point, °F	128.3		NA	128.4			NA	129.3		NA
Smoke Point, mm	24		NA	23			NA	20		NA
Freezing Point, °F	Below -94		NA	Below -94			NA	Below -94		NA
Group Type, LV %	High Mass	22-Component	Average*	Low Mass	High Mass	22-Component	Average*	High Mass	22-Component	Average*
Paraffins	0.8	1.3	3.0	6.3	0.2	0.2	2.1	0.4	6.5	1.9
Naphthenes	99.0	95.9	94.8	89.9	99.7	97.2	94.5	99.3	90.6	95.8
Aromatics	0.2	2.7	2.2	3.8	0.1	2.6	3.3	0.3	2.9	2.3
Naphthene Distribution										
Monocycloparaffins	41.0	46.9	45.8	53.0	38.8	45.3	42.7	30.1	36.6	40.6
Dicycloparaffins	26.3	21.8	31.4	36.9	27.3	24.4	33.4	27.4	29.9	30.7
Tricycloparaffins	31.7	27.3	17.6	NA	33.6	27.5	18.4	41.8	21.5	18.8
Tetracycloparaffins	NA	0.0	0.0	NA	NA	0.0		NA	2.7	5.7
Aromatics Distribution										
Alkylbenzenes	0.0	2.7	2.2	3.8	0.0	2.6	3.3	0.0	2.9	2.2
Benzocycloparaffins	0.2	0.0	0.0	0.0	0.1	0.0	0.02	0.3	0.0	0.1
Hydrogen, Wt % (Calculated from Mass Spectrum)		13.5	13.5	13.6		13.5	13.5		13.6	13.5
ASTM D 2887 Distillation, °F (TBP by GC)										
St/5	223/255		NA	228/256			NA	234/267		NA
10/30	271/321			272/327				286/349		
50	361			368				393		
70/90	403/467			418/488				461/521		
95/99	482/496			505/526				535/551		

NA = Not Analyzed

* = Weighted Average of Components

TABLE XXVII

DOE CONTRACT DE AC-22-76ET10532
HYDROCRACKING OF HYDROTREATED ITSL OIL
WITH ICR 202 CATALYST; VARIATION OF
RECYCLE STREAM COMPOSITION WITH RCP;
PILOT PLANT RUN 62-281

Recycle Cut Point, °F	350	400	450	500	525	550	350
Run Hours	870	1518	1710	1758	1902	2190	2382
Group Type, LV % (22-Component)							
Total Paraffins	5.2	4.3	3.7	2.1	2.1	1.3	6.5
Monocycloparaffins	15.6	13.1	12.1	10.5	9.8	8.8	21.1
Dicycloparaffins	2.9 (?)	4.9 (?)	11.9	13.4	11.3	9.7	8.3 (?)
Tricycloparaffins	71.8	70.7	50.5	29.6	33.7	29.7	59.3
Tetracycloparaffins	0.0	3.3	16.9	38.8	34.3	36.3	0.0
Pentacycloparaffins	0.0	0.0	0.0		1.2	6.2	0.0
Total Naphthenes	90.3	91.9	91.4	92.3	903	90.7	88.6
Alkylbenzenes	4.4	3.7	4.5	4.9	6.5	7.6	4.8
Benzocycloparaffins	0.0	0.1	0.3	0.6	0.8	0.3	0.0
Naphthalenes	0.0	0.0	0.0	0.0	0.3	0.1	0.0
Total Aromatics	4.4	3.8	4.8	5.5	7.5	8.0	4.8
Calculated Hydrogen, Wt %	12.8	12.8	12.9	12.7	12.7	12.7	13.0

DOE/ET/10532-T20

REFINING AND UPGRADING OF SYNFUELS FROM COAL AND OIL SHALES BY ADVANCED CATALYTIC PROCESSES

DOE