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Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

Research and Development

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Project Summary

A Compendium of Synfuel End-Use Testing Programs

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This document summarizes "A Compendium of Synfuel End-Use Testing Programs," which provides information on major recently completed, current, and planned synfuel end-use testing projects. The compendium is intended to promote flow of information among various synfuel testing programs, thereby reducing the chances for duplication of effort and enabling design and implementation of cost-effective and systematic approaches to the collection of appropriate environmental data in conjunction with on-going and planned performance testing projects. EPA intends to update this compendium to include results from current and future testing programs.

Projects described in the compendium involve testing of shale-derived fuels, SRC-II middle distillates, EDS fuel oils, H-coal liquids, and methanol/indolene mixtures in various equipment such as utility boilers, steam generators, diesel engines (laboratory- and full-scale), auto engines, and various other combustors. Published reports on various testing efforts and discussions with test sponsors/contractors are the sources of data for the compendium.

Based on the data presented in this compendium, the thrust of the synfuel testing program which has been carried out to date has been to assess equipment performance and fuel handling characteristics. Where some emissions have been monitored, such efforts have been limited in scope and have primarily emphasized measurement of criteria pollutants (NO_x, SO_x, particulates, etc.). Essentially no data have been collected on emissions of non-criteria/non-regulated pollutants.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction to and Objectives of the Compendium

A recent synfuel utilization background study* identified a great need for better coordination among various agencies involved in synfuel end-use testing so as to promote more systematic approaches to the collection of environmental data in connection with such testing and to reduce the duplication of effort. As recommended by the background study, a compendium of synfuel end-use testing programs has been developed as an information source on major recently completed, ongoing, and planned synfuel end-use testing programs. Availability of the document to agencies/organizations engaged in various aspects of synfuel production, testing, utilization, and regulation, coupled with regular symposia/workshops on synfuel utilization and end-use testing, should greatly enhance coordination and flow of information among various programs and, in the long run, contribute to the goal of more rapid establishment of an environmentally acceptable commercial synfuel industry in the U.S.

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*M. Ghassemi and R. Iyer, "Environmental Aspects of Synfuel Utilization," Report No. EPA-600/7-81-025 (NTIS PB81-175937), March 1981.

Data Base Used and Data Presentation

Information on the synfuel testing programs has been obtained from published documents and by telephone calls and/or interviews with organizations involved in the testing programs. The key individuals/agencies providing most of the reports and data used in the compendium are listed in Table 1.

A separate data sheet is devoted to each project covered in this compendium to permit periodic updating of the document to include additional projects and incorporation of further results from ongoing studies. The data sheets are grouped into four categories, covering projects for which the key sponsors/participants are Electric Power Research Institute (EPRI), Department of Defense (DOD), Department of Energy (DOE), and miscellaneous agencies (e.g., EPA). Data sheets cover 45 projects: 7 are in the EPRI-sponsored category, 16 in the DOD category, 13 in the DOE category, and 9 in the miscellaneous category.

Where data are available, each data sheet provides the following information on a test project: type of fuel tested (both synfuel and the reference petrofuel, where indicated), test equipment used, test site, test objectives, sponsoring agency, contractor, test conditions, environmental monitoring, project status, summary of results, and references (where a report or reports have been published on a project).

Table 2 summarizes the data contained in the data sheets. Tables 3 and 4 briefly describe some of the recently initiated and tentatively planned synfuel testing programs. Two sample data sheets are shown.

Table 1. *List of Organizations/Individuals Providing Information Used in the Development of the Compendium*

Electric Power Research Institute
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Air Force Wright Aeronautical
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David W. Taylor Naval Ship R&D Center
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Gene Ecklund

DOE, Office of Coal Utilization
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Washington, DC 20454
John Fairbanks

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John A. Russell

U.S. Department of Transportation
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Cambridge, MA 02142
Joe Sturm

U.S. Department of Energy and
Coordinating Research Council
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Al Zingle

Carson Associates for
Bank of America
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Alexandria, VA 22309
Gavin McGurdy

Energy and Environmental Research
Corporation
8001 Irvine Boulevard
Santa Ana, CA 92705
Dave Pershing

Ford Motor Company
Scientific Research Laboratory
Dearborn, MI 48121
W.D. Tallent

Vulcan Cincinnati, Inc.
2900 Vernon Place
Cincinnati, OH 45219
R.W. Duhl

Table 2. *Synfuels-Combustion System Combinations Tested and Emissions Monitored*

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
1	EPRI	SRC-II fuel oil	No. 6 fuel oil	Tangentially fired utility boiler	NO_x, CO, THC, SO_3, POM, particulates, particle size, particulate composition	• No adverse boiler performance effects with SRC-II fuel. • NO_x emissions nominally 70% higher than No. 6 fuel.
2	EPRI	SRC-II fuel oil H-Coal EDS oil	No. 6 and No. 2 fuel oils	Scaled-down utility boiler	NO, CO_2, CO, SO_2, SO_3, THC, smoke, particulates, particle size	• Higher fuel nitrogen content of SRC-II fuels produced higher NO emissions than reference fuels. • NO emissions from H-Coal and EDS liquids were lower than SRC-II. • No unique differences in combustion or emission characteristics of SRC-II fuel blends.
3	EPRI	SRC-II fuel oil	No. 2 and No. 5 fuel oils	Babcock & Wilcox package boiler	NO_x, CO, CO_2, SO_2, hydrocarbons, O_2, and dust	• NO_x emissions consistent with fuel nitrogen content. • Combustion performance of SRC-II fuel oil was similar to No. 2 and No. 5 fuel oils.
4	EPRI	SRC-II fuel oil H-Coal	No. 2 diesel fuel	Three catalytic reactors	NO_x and CO	• Coal-derived liquids can be burned catalytically but SRC-II, and to a lesser degree H-Coal, appeared to degrade reactor performance significantly as evidenced by higher CO emission. • NO_x emissions were consistent with fuel nitrogen content.
5	EPRI	Hydrogenated shale oil and various liquid fuels for SRC-I, H-Coal, EDS, and SRC-II	No. 2 distillate fuel	Full-scale and subscale turbine combustors	NO_x, CO, UHC, particulates, and smoke	• A selected number of coal liquids and shale oil fuels can be used in current turbines. • Emission levels of CO, UHC, and particulates for synfuels were about the same as for No. 2 fuel—not significant. • Significant quantities of fuel-bound nitrogen are converted to NO_x, causing emissions higher than EPA limits.
6	EPRI	Solvent refined coal	Bituminous coal	Utility boiler	NO_x, SO_2, CO_2, particulates, particulate composition	• The boiler stayed much cleaner with SRC than with coal, producing an equivalent boiler efficiency as coal at full load. • The quantity of SRC flyash was 10 to 15% of that of coal flyash with no bottom ash accumulation from SRC. • Particulates, SO_2 and NO_x emissions from SRC were all under EPA limits.
7	EPRI	*	Jet-A fuel, natural gas, methanol	Two utility gas turbines	NO_x, CO, SO_2, THC, POM, sulfates, particulates, aldehydes, opacity	• Methanol is a suitable fuel for gas turbines; turbine performance and NO_x and particulate emissions are improved over the other fuels.

Table 2. *(Continued)*

Test No.	*Agency*	*Synfuel*	*Reference Fuel*	*Combustion System*	*Emissions Monitored*	*General Conclusions*
8	*DOD*	*Shale-derived JP-5 and blends with petroleum JP-5*	*Petroleum JP-5*	*DOD helicopter engine: Allison T63-A-5A turbo-shaft*	*NO$_x$, CO, CO$_2$, and THC*	- *NO$_x$ emissions increased with increasing fuel nitrogen content; conversion efficiency was about 45%.* - *No significant effects were noted on engine performance or CO, CO$_2$, and THC emissions due to the presence of high levels of fuel bound nitrogen.*
9	*DOD*	*Shale-derived diesel fuel marine (DFM)*	*Petroleum diesel fuel (MIL-F-16884G)*	*U.S. Navy LM2500 turbine engine*	*NO$_x$, CO, THC, and smoke*	- *Combustor and engine operating characteristics were identical when using marine diesel or DFM shale oil; thus, DFM shale oil would be suitable for use in LM2500 engines.* - *NO$_x$ emissions followed fuel nitrogen content; CO and THC levels were essentially the same for both fuels.*
10	*DOD*	*JP-5 from oil shale, coal, and tar sands*	*Jet-A, JP-5, DFM, leaded gasoline, and blends of the above*	*Two high temperature/pressure research combustors*	*NO$_x$, CO, UHC, and smoke*	- *In all performance areas, the synfuels correlated in the same manner as petroleum-derived fuels except for NO$_x$ emissions from the shale oil fuel.* - *Smoke formation was dependent on hydrogen content; combustion efficiency, CO, and UHC depend more on higher boiling point components than fuel viscosity.*
11	*DOD*	*Shale fuel oil*	*Petroleum DFM*	*Steam generator diesel engine*	*Particulates and particulate composition*	- *No significant differences between particulate emission products measured in the study from the combustion of DFM or shale fuel oil.*
12	*DOD*	*Shale-derived diesel fuel*	*Petroleum distillate*	*Lab-scale diesel engine*	*NO$_x$, THC, and smoke*	- *There was no significant difference in performance or emissions with the shale-derived fuel.*
13-15	*DOD*	*Shale-derived DFM*	*Petroleum DFM*	*3 different types of prototype steam generators*	*NO$_x$, SO$_2$, CO, CO$_2$, THC, O$_2$, and smoke*	- *There were no significant differences in measured pollutant emissions resulting from the combustion of petroleum DFM or shale-derived DFM on the CVA-60, DDG-15, and the FF-1040 boilers. In each case, SO$_2$, NO$_x$, and smoke were below levels set by EPA.*
16	*DOD*	*Oil shale-derived JP-5*	*Petroleum-derived JP-5*	*DOD helicopter engine: Allison T62-A-5A turbo-shaft*	*NO$_x$, CO, and THC*	- *Performance, CO, and THC emissions were equivalent for both fuels.* - *NO$_x$ emissions followed fuel nitrogen content.*
17	*DOD*	*Unifined kerosene derived from tar sands*	*Petroleum-derived JP-5 fuel*	*DOD helicopter engine: Allison T63-A-5A turbo-shaft*	*NO$_x$, CO, and UHC*	- *Unifined kerosene was a satisfactory substitute for petroleum JP-5 fuel.* - *NO$_x$ emissions were slightly higher when using unifined kerosene than with JP-5.*

Table 2. *(Continued)*

Test No.	*Agency*	*Synfuel*	*Reference Fuel*	*Combustion System*	*Emissions Monitored*	*General Conclusions*
18	*DOD*	*Distillate, aviation, turbine, and diesel fuels derived from coal, tar sands, and oil shale*	*Various petroleum-derived fuels*	*Wide variety of Army power-plant systems*	*Various pollutants*	• *Product quality of many synfuels tested and other results are described in individual abstracts.*
19	*DOD*	*Shale-derived JP-5, JP-8, and DFM*	*JP-5, diesel fuel No. 2, and Jet A*	*DOD helicopter engines: Allison T-63 gas turbine, Detroit Diesel 6V-53T, LDT-465-1C diesel engine, Teledyne-Continental AVDS-1790 diesel engine, and Detroit Diesel 3-53*	*CO, NO_x, UHC, and smoke*	• *The CO emissions followed the same trend as combustion efficiency. At the lower power points, DFM showed slightly higher CO than JP-5 and Jet A. There were no fuel property effects on the emissions of UHC and NO_x. The flame radiation and exhaust smoke levels for the synfuels were higher than those of Jet A and are attributed to differences in hydrogen content.* • *The shale JP-5 in the DD6V-53T engine showed a 6% average loss in maximum power output when compared to the reference diesel fuel which approximates the 6.5% power loss observed in the same engine with petroleum-derived JP-5. The shale-derived JP-5 and DFM performed in the CUE-1790 engine like similar petroleum-derived fuels. Evaluation of DFM from shale in the LDT-465-1C engine resulted in no difference between the maximum power produced by this fuel and that of a petroleum No. 2 diesel fuel.* • *The results from the 210-hour test in the DD 3-53 engine are indistinguishable from those that may result from tests with conventional petroleum-derived diesel fuel with similar properties.* • *Shale-derived fuels met virtually every military specification with the exception of the failure of JP-5 to meet copper corrosion requirement and DFM to meet maximum pour point limit.*
20-22	*DOD*	*	*13 petroleum derived fuels: JP-4, JP-8 diesel No. 2, & various blends*	*General Electric F101 turbofan, J79-17C turbojet, and J79 turbojet engines*	*NO_x, CO, UHC, and smoke*	• *In all three engines, fuel hydrogen content strongly affected smoke and NO_x emissions. NO_x emissions were also highly dependent upon combustor operating conditions.*
23	*DOE*	*	*12 petroleum-derived fuels: JP-4, JP-8, and various blends*	*TF41 turbofan combustor*	*NO_x, CO, UHC, and smoke*	• *All pollutant emissions measured were highly dependent upon operating conditions. CO and smoke levels were also strongly affected by hydrogen and aromatic content of fuels.*

Table 2. (Continued)

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
24	DOE	SRC-II middle distillate	Low quality residual oil, and petroleum reference distillate fuel	Combustor sized for use with industrial gas turbine	NO_x, CO, CO_2, THC, and smoke	• The combustor was able to achieve low NO_x with all fuels. • CO and smoke varied directly with rich zone equivalence ratio and inversely with lean zone equivalence ratio.
25	DOE	SRC-II middle distillate	Petroleum distillate	Various combustor concepts	NO_x smoke	• Values of NO_x were reduced for the smaller diameter quench zone and increased for larger diameter quench zone. • Rich-lean burn stage combustion system can meet EPA emission standards.
26	DOE	SRC-II middle distillate	Low quality residual oil and distillate fuel	Seven combustors of varying designs for use in utility gas turbine engines	NO_x, smoke, CO, UHC	• A lean-lean combustor has potential for achieving ultra-low NO_x emissions with distillate, residual, or other fuels containing up to 0.25% (wt.) fuel nitrogen. CO and smoke met program goals from this combustor also.
27	DOE	SRC-II middle distillate	Low quality residual oil, petroleum oil, petroleum reference distillate oil, and natural gas	Combustors for use in utility gas turbine engines	NO_x, CO, THC, smoke	• Lean-lean combustor NO_x emission levels were higher than emission goals using SRC-II fuel. CO emissions remained low using SRC-II fuel, while no smoke was detectable and UHC levels were negligible throughout these tests. • Rich-lean combustor NO_x emissions appeared to reach a minimum below the NO_x emission goal for rich primary zone condition.
28	DOE	SRC-II middle distillate	Low quality residual oil, petroleum reference distillate oil	Experimental combustor for use with utility gas turbine engines	NO_x, CO, UHC, smoke	• Five combustors have been found adequate for further development: rich-lean diffusion-flame venturi quench burner, ceramic-lined piped lean burner, multiannular swirl burner, Rolls-Royce combustor, and lean catalytic combustor. These meet NO_x emission limits set by EPA with petroleum distillate and/or residual oils. • SRC-II fuel NO_x emissions were close to meeting EPA limits in only two combustors: rich-lean diffusion and ceramic-lined pipe lean burners.
29	DOE	SRC-II middle and heavy distillate, fuel oils & three blends of the above	No. 2 and No. 6 petroleum based fuel oils	A 20-hp Johnston, fire-tube boiler	NO_x, SO_2, CO, HC, and PAHs	• The levels of NO_x and SO_2 produced were proportional to the amount of nitrogen and sulfur in the fuel. • There appear to be two sources of trace organics in the exhaust gases: small amounts of the fuel itself not burned during combustion, and the products of combustion. For the petroleum fuels, n-alkanes and PAHs are seen in the exhaust gas; for the SRC-II fuels, the alkanes are absent or present at very low levels, and PAHs not seen in the petroleum exhaust gases are present.

Table 2. *(Continued)*

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
30	DOE	*	Indolene and 10% methanol/ 90% indolene	Two light duty vehicles	Evaporative emissions (hydrocarbons and methanol)	• Using methanol 10% blend increased evaporative emissions by 130% for short term use and 220% for long term use.
31	DOE	*	Unleaded gasoline and methanol/indolene mixtures	Auto engines (10)	NO_x, CO, THC, aldehydes, and methanol	• Aldehyde, methanol, and HC emissions increased with higher concentration of methanol in the fuel. • CO was reduced by the addition of methanol to the base fuel
32	DOE	*	10% methanol/ 90% gasoline blends	Auto engines (7)	NO_x, CO, and evaporative emissions (HC and methanol)	• Data show consistent reduction in CO emissions with use of methanol blends. • Significant increases in evaporative emissions with methanol blends.
33-35	DOE	*	Ethanol, methanol, and gasoline blends	Fleet vehicles	Evaporative and tailpipe HC emissions	• 75% increase in evaporative emissions with methanol blends over a straight gasoline. • Emissions were lower for vehicles fueled with gasohol but data was inadequate to conclude a significant difference.
36	DOE	*	Indolene, indolene/methanol blends, and ethanol/indolene blends	Pontiac 4-cylinder modified engine	Total aldehydes and specific organics	• Total aldehydes increased 25% in going from indolene to ethanol/indolene and methanol/ indolene blends. • Formaldehyde is the largest component of the total aldehydes (up to 90 mole % of the total).
37	Vulcan Cincinnati	*	No. 6 residual oil, natural gas, and methanol	Small scale boiler test stand and a 49 MW utility boiler	NO_x, CO, and aldehydes	• In the utility boiler, methanol NO_x levels were 7-14% of those measured during residual oil combustion. • CO emission levels of methanol were less than 100 ppm and generally less than those observed for the residual oil. • Aldehyde emissions during methanol combustion were generally less than 1 ppm.
38	Ford Motor Co.	*	Methanol, indolene, and blends	Ford 400 CID engine and 1975 Ford LTD with 400 CID engine	THC and specific organics	• Methanol/indolene blends gave significantly higher HC and aromatic emissions than indolene without a catalyst, but only slightly higher emissions with a catalyst.
39	DOT	Shale-derived DFM	No. 2 diesel fuel	VW Rabbit engine	NO_x, CO, THC, particulates, Ames test on particulates	• HC and CO emissions were found to be lower and NO_x levels higher for the shale-derived fuel as compared to the petroleum-derived fuel. Particulate emissions were similar for both fuels. • Mutagenic activity of the organics from the particulate matter was similar for the two fuels.

Table 2. *(Continued)*

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
40	Bank of America	*	Methanol/gasoline blends	Fleet vehicles	NO, CO, UHC	• Blends of 2 to 18% methanol decrease emissions of CO and UHC and result in improved mileage in new cars. • Certain blends result in operating cost decreases of 1¢/mile.
41	EPA	Shale-derived DFM	No. 2 fuel, and No. 2 fuel with 0.5% nitrogen	Two configurations of a full-scale prototype (25-MW engine-size) gas turbine combustor utilizing a rich-burn/quick-quench combustor	NO_x, CO, UHC	• Both combustor configurations met program emissions goals using both reference fuels and synfuel. • UHC emissions from one combustor ranged from 0.9 to 7.3 ppmv for No. 2 fuel; 1.1 to 21.8 ppm for No. 2 fuel with 0.5% nitrogen; and 1.3 to 15.3 ppmv for shale-derived DFM at 15% O_2.
42	EPA	SRC-II middle distillate fuel oil and shale-derived residual oil	No. 2 fuel oil and Indonesian/Malaysian residual oil	Prototype full-scale (25-MW engine-size) rich-burn/quick-quench gas turbine with two gas combustor configurations	NO_x, CO, UHC, and smoke	• All emissions exhaust goals met. • Relationship demonstrated between primary zone residence time and attainable NO_x emission concentrations.
43	EPA	*	Residual and distillate oils, natural gas, propane, isopropanol, methanol	Experimental wall furnace and prototype industrial boiler	NO_x, NO, CO, HC, and aldehydes	• NO emission levels for the five fuels were as follows: distillate oil > propane > isopropanol > alcohol mixture > methanol. • Although there was considerable scatter in the data, aldehyde concentrations were around 10 ppm for methanol. • NO emissions for all fuels decreased with increasing fraction of flue gas recirculation. • CO and HC emissions were always below 50 ppm and smoke was not observed for any fuel.
44	EPA	*	No. 5 residual oil, natural gas, and methanol	Industrial water-tube and fire-tube boilers	NO_x	• Flue gas recirculation was capable of reducing NO_x emissions during methanol combustion. • Methanol NO_x emissions were significantly lower than during residual oil combustion and were also less than during natural gas combustion.
45	EPA	*	Indolene and ethanol blends	Two light duty vehicles	NO_x, CO, THC, ethanol, and evaporative emissions	• The addition of ethanol to indolene reduced tailpipe emissions of THC and CO, but increased NO_x. • Use of gasohol increased evaporative emissions substantially.

**Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.*

Table 3. *On-Going Synfuel Testing Programs*

Sponsoring Agency	*Test Fuels*	*Schedule**	*Project Description**
EPA, Motor Vehicle Emission Laboratory	*Shale-derived diesel fuel and SRC-II fuel versus National Average Baseline Diesel Fuel, and Mobil-M gasoline*	*1981—late 1982*	*Volkswagen Rabbit diesel engine testing. Emissions monitored to include particulates, NO_x, CO/CO_2, HC, and aldehydes.*
	EDS and H-coal liquids	*Late 1981—September 1982*	*Large standing diesel engines and a GE research engine. Emissions monitoring includes collection of particulates.*
	SRC-II fuel	*1982*	*Electronically controlled internal combustion engine at Southwest Research Institute, San Antonio, TX.*
EPA, Industrial Environmental Research Laboratory (RTP)	*SRC-II middle and heavy distillates, EDS middle distillates, and shale-derived No. 2 fuels*	*November 1981—April 1982*	*North American package boiler and Caterpillar Model D334 stationary diesel engine testing. Package boiler represents small-to-medium sized fire-tube boiler for industrial and commercial applications; boiler can be equipped with low NO_x burner which may be tested with synfuels. The stationary diesel represents medium-sized industrial and commercial engine used for backup power generation, pumping, and other applications. Emissions monitored include particulates, NO_x, CO/CO_2, SO_2, and HC.*
DOE, Bartlesville Energy Technology Center; Contractor/test site:			
A. General Electric, Erie, PA	*SRC-II middle distillate and oil shale distillate*	*1981—early 1982*	*Testing of GE EDI-8, 8-cylinder "V" configuration, 5344 cu. in. standing diesel engine for electric power, rail and marine applications. Parameters evaluated include: starting ability, injection timing, fuel rate variation effects, and internal engine temperatures. Emissions monitored include O_2, CO/CO_2, NO_x, SO_2, HC, H_2SO_4, and particulates.*
	H-coal liquids	*January—April 1982*	*Limited testing with single cylinder diesel engine. Emissions monitored include O_2, CO/CO_2, NO_x, SO_2, and HC.*
B. Transamerica Delaval, Oakland, CA	*SRC-II middle distillate*	*1981—early 1982*	*Testing of Delaval DSR 46, 6-cylinder in-line configuration, 28,600 cu. in. standing diesel engine for electric power, compressor, and marine applications. Performance parameters being evaluated include starting ability, precombustion chamber effects, and ignition delay. The engine has been operated at full load using a pre-mixed blend of 60% SRC-II liquid and 40% diesel oil which had been injected into the combustion chamber with no modification of the engine, followed by increasing proportions of SRC-II liquid up to 100%. Emissions monitored include O_2, CO/CO_2, NO_x, SO_2, THC, and smoke.*

Table 3. (Continued)

Sponsoring Agency	Test Fuels	Schedule*	Project Description*
C. A.D. Little, Beloit, WI	SRC-II middle distillate	1981-1982	Fairbanks-Morse 38 to 8⅛, 6-cylinder opposed piston design, 3108 cu. in. standing diesel engine for electric power and marine applications, compressors and pumps being tested. Parameters evaluated include effects of load variations, combustion pressure vs. time, and engine delay. Emissions monitored include CO/CO_2, NO, NO_2, SO_2, SO_4, HC, PAH, particulates, and oxidants.
	Various H-coal and EDS liquids	March—November 1982	Testing of Fairbanks piston engine at NAVSSES test facility, Philadelphia, PA. Emissions monitoring to include gaseous pollutants and collection of sizable (i.e., 5 g) quantities of particulate matter.
D. Energy and Environmental Research, Springfield, OH	Shale-derived distillate oil	1981—early 1982	Testing of Superior 6-cylinder in-line configuration turbo-charged 4120 cu. in. standing diesel engine for use in compressors, pumping, and electrical power generation. The purpose of the tests is to compare engine performance parameters during synfuel and conventional fuel combustion. Tests with shale-derived distillate oil and a baseline No. 2 diesel fuel include SASS train sampling for PAH and particulates. Other emissions monitored include CO, HC, NO_x, and smoke†.
E. Acurex, Shoreham-by-the-Sea, England	Shale oil residuals	1981—early 1982	Testing of A.P.E. Allen BSC 128 6-cylinder, in-line configuration, 5101 cu. in. standing diesel engine for marine, pumping, compressor, and electric power applications. Tests include injection, starting, combustion duration, and steadiness. Emissions monitored include CO/CO_2, NO_x, NO_2, THC, and smoke‡.
DOE, Conservation and Solar Energy Division	Various shale- and coal-derived fuels	1978-1984	Auto engine dynamometer testing being conducted at SWRI. Particulates, NO_x, CO/CO_2, HC, and aldehydes being monitored.
	SRC-II distillates and shale-derived JP-5 and DFM mixed with powdered carbon, sawdust, or other cellulosic material	1981 to ---	Slurry/fuel project involving diesel engine testing. Particulates, NO_x, and other emissions being monitored.
	Coal-derived methanol and gasohol	1981 to ---	Testing in 1,000 fleet vehicles; program currently constrained for lack of fuel samples.
DOE, Office of Coal Utilization	SRC-II and shale-derived fuels	1980 to ---	Medium speed diesel engine testing conducted by SEMT-Pielstich, Paris; Baumester Wain, Copenhagen; Grandi Motori Trieste, Trieste; and Selzer, Switzerland.

Table 3. (Continued)

Sponsoring Agency	*Test Fuels*	*Schedule**	*Project Description**
DOE, Office of Coal Utilization (Continued)	*SRC-II middle distillates, a 2.9 to 1 blend of SRC-II middle and heavy distillate, and shale-derived fuels*	*1980 to ---*	*Program conducted at Norwegian Technical Institute in various ships.*
	SRC-II middle distillate	*1981 to ---*	*Continuation of low NO_x fuel combustor concept program (see Tests 24-28). Several combustors to be tested by Westinghouse; staged combustor to be tested at several operating loads at Detroit Diesel Allison; testing of 5 combustors planned at GE.*
DOE, Pittsburgh Energy Technology Center	*Biomass fuel, H-coal, Exxon Donor Solvent, and shale fuel oils*	*1981 — October 1982*	*Continuation of small scale combustion of synthetic fuels program (see Test 29). A 20-hp firetube boiler is to be tested with the above synfuels using No. 2 and No. 6 fuel oils as a baseline. The purpose of the program is to assess the possible environmental impact of substituting synfuels for petroleum in utility and industrial boilers.*
Air Force/Navy/FAA (under the direction of H. Cewell, USAF Civil Engineering and Services Center, Tyndall AFB)	*Shale-derived JP-4 and JP-8*	*1982-1984*	*Testing of CF-6 and CFM-56 turbine engines. Emissions monitoring to include NO_x, SO_x, CO/CO_2, HC, and particulates. Limited Ames mutagenicity testing to be performed on particulate samples, as well as photochemical reactivity testing on exhaust gases.*
Department of Transportation and Rutgers University	*Coal- and shale-derived diesel fuel*	*1981-1982*	*Testing of a recently designed and constructed one cylinder diesel engine, including collection of particulates and other combustion products.*
Sandia Laboratories	*Petroleum-derived synfuel simulation fuels, with higher hydrocarbon/aromatic content than conventional fuels*	*1981 to ---*	*Testing being conducted in single-cylinder diesel systems and auto/truck engines from Cummins Engine Co. Emphasis on measurement of flame fronts and other engine/burn parameters. Limited emissions monitoring performed.*
Bank of America	*Methanol/gasoline blends*	*1980 to ---*	*Testing being conducted in blends ranging from 2 to 18% methanol in fleet vehicles, with emphasis on blends of 2 and 4%. CO, NO, and UHC being monitored.*

* *The schedules and some of the activities listed under Project Description are tentative and subject to modification.*

† *Test results to date indicate that the performance of the shale-derived fuel was comparable to the No. 2 diesel fuel, although easier atomization and lower fuel consumption were observed with the shale-derived fuel.*

‡ *The test engine satisfactorily burned residual shale oil when heated above the wax melting point and with agitation; emissions were comparable to a No. 2 diesel fuel except for an increase of cylinder deposits of fine carbon.*

Overview of Synfuel Testing Programs

Based on the data in the test program data sheets and summarized in Table 2, and on the discussions with a number of synfuel developers, trade associations, and potential major users of synfuels, general observations on the status, nature, and thrust of the synfuel testing programs include:

- Since synfuel products are expected to be used primarily as combustion fuels, nearly all synfuel end-use testing programs have involved evaluation of fuel suitability for use in combustion systems (auto engines, industrial/utility boilers, turbines, etc.).
- Reflecting the developmental status of the synfuel technologies, the thrust of the synfuel testing programs which have been carried out to date has been to assess equipment performance and fuel handling characteristics. Where some emissions have been monitored, such efforts have been limited in scope and have primarily emphasized measurements of gross parameters such as particulates, NO_x, and SO_x emissions. The limited scope of the monitoring programs has also been due

Table 4. *Tentative Synfuel Testing Programs*

Sponsoring Agency	*Fuels to be Tested*	*Time Period*	*Project Description**
Army, MERADCOM, Ft. Belvoir, VA	*Diesel fuels and other synfuels (high aromatic content fuels, low lubricity fuels)*	*1982 to ---*	*Development of accelerated fuel qualification test procedures, including matrix of specific Army equipment components and candidate fuels; project is part of Army Alternative Fuels Program.*
Navy Air Propulsion Test Center, Trenton, NJ	*Various shale-derived fuels*	*1982 to ---*	*Testing of synfuels in various test burners and aviation equipment.*
AF Wright Aeronautical Lab, Aero Propulsion Laboratory, Wright-Patterson AFB, Cincinnati, OH	*Various shale-derived fuels*	*1982-1983*	*Engine augmenter tests and whole engine tests on 3 engines; emissions monitoring for* NO_x*,* CO/CO_2*, and hydrocarbons.*
EPRI	*Various liquid and solid synfuels, including shale-derived heavy and middle residuals, and methanol*	*Fall 1982—1986*	*Testing of synfuels in various diesel engines, turbines, and boilers; limited emissions monitoring for* SO_x*,* NO_x*,* CO/CO_2*,* O_2*, and/or particulates.*

**Tests pending receipt of synfuel samples.*

in part to: (a) no clear definition of the specific environmental data which would be required on synfuel products by regulatory agencies (e.g., by EPA's Office of Pesticides and Toxic Substances in connection with the Premanufacturing Notification Section of the Toxic Substances Control Act); and (b) no standard protocol for testing for environmental data acquisition.

- Most synfuel end-use testing programs have been, or are being, conducted/funded by DOD, EPRI, and DOE. The programs of these agencies have, respectively, emphasized the use of shale oil products in military aviation and ship equipment; use of coal liquids in boilers; and testing of methanol and methanol/gasoline blends in auto engines and use of coal and shale-derived fuels in stationary diesel engines.
- Many synfuel developers appear to have in-house synfuel testing programs; the emphasis of these programs is primarily on synfuel characterization and not on end-use testing. The data generated in these programs are generally considered company proprietary and are not published.
- Nearly all the refined shale oil products which have been used in combustion testing to date have been from the refining of the 100,000 barrels of Paraho shale oil at Sohio's Toledo (OH) refinery. Since this refining operation apparently did not involve the use of typical unit operations which would be employed in commercial refining of shale oil, the refined products from this operation are not considered to be representative of products from any future commercial refining of the shale oil.
- To date the synfuel testing effort has been severely curtailed by lack of adequate quantities of fuel for testing. Some of the planned testing programs will utilize shale oil products from the forthcoming refining of 50,000 barrels of shale oil by Union Oil for the Defense Fuel Supply Center.
- Synfuel products (especially the shale-derived materials) which will be marketed in the future will most likely be blends and not 100% pure products. The use of 100% pure products in the initial synfuel testing programs has been justified on grounds that it would simulate a possible extreme/worst case condition (at least from the standpoint of emissions and their environmental implications).
- Although performance testing is continuing, the limited data which have been gathered to date indicate that the tested synfuels are generally comparable to petrofuels and do not present any unique problems from the standpoint of fuel handling and combustion characteristics. Potential problems with long-term fuel storage stability (observed with certain shale- and petroleum-derived middle distillates) and durability and material compatibility problems (e.g., possible increase in the engine wear with methanol use) are under investigation.
- The very limited data which have been collected on the emission of criteria pollutants (particulates, NO_x, SO_x, etc.) indicate that, except for a higher emission of NO_x with synfuels having a higher content of fuel-bound nitrogen, the emissions of such criteria pollutants are similar to both synfuels and their petrofuel counterparts. For most synfuels, however, no data have been collected on emissions of noncriteria pollutants such as polycyclic organic matter (POMs), primary aromatic amines, nitropyrenes, and other organics. There is also very limited data on overall trace element composition of emissions.

Combustion and Emission Characteristics of Coal-Derived Liquid Fuels

1. FUELS TESTED

   Synfuels: SRC-II fuel (5 ratios of medium and heavy boiling range components); H-Coal (syncrude mode of operation, full-range distillate); EDS (full-range distillate). Reference fuel: No. 6 and No. 2 petroleum-derived fuels.

2. TEST EQUIPMENT
An 80-HP firetube boiler system extensively modified to simulate a utility boiler including an indirectly fired air preheater, a scaled-down utility boiler burner, radiation shields to increase the thermal environment in the combustion chamber, and capabilities to implement staged combustion.
3. TEST SITE
KVB Combustion Research Laboratory, Tustin, CA.
4. TEST OBJECTIVES
    - Develop an understanding of the effect of compositional variations of a particular coal liquid and the resulting effects on the implementation of combustion modifications for pollutant emission reductions;
    - Establish an understanding of the difference in the combustion and emission characteristics of coal liquids produced from various processes—specifically the SRC-II Process, the Exxon Donor Solvent Process, and the H-Coal Process;
    - Establish a standard test method, using a small-scale facility, to predict the response to changes in operation of smoking tendency, CO, and NO_x. This will be used to differentiate various fuel properties and the performance of each fuel in a large variety of commercial boilers.
5. SPONSORING AGENCY
Electric Power Research Institute (EPRI)
Power Generation Program
Advanced Power Systems Division
Palo Alto, CA
EPRI Project Manager: W.C. Rovesti
Telephone No: 415-855-2519
6. CONTRACTOR
KVB Inc.
Irvine, CA
Principal investigators: L.J. Muzio, J.K. Arand
Telephone No. 714-641-6200
7. TEST CONDITIONS
A systematic set of experiments was conducted which investigated the following variables: excess air with single stage combustion, burner stoichiometry with two-staged combustion, firing rate, air preheat temperature, fuel temperature (viscosity), and atomizer (mechanical, steam).
8. ENVIRONMENTAL MONITORING
O_2, CO_2, CO, NO, SO_2, SO_3, UHC, smoke number, particulate size distribution.
9. PROJECT STATUS
Completed.
10. RESULTS
Emissions from the various synfuels combustion tests in this program are summarized in Table A. A brief description of other emission test results is shown below.

SRC II

Particle size data indicate that SRC-II fuel blends produced finer-size-distribution particulate than No. 6 oil, the exception being SRC-II heavy distillate component under single-stage combustion. Measured SO_2 emissions were consistent with the fuel sulfur content, with nearly all fuel sulfur emitted as SO_2. An SO_3 concentration of 2 ppm for heavy distillate component was the only SRC-II test detecting this pollutant. Reference fuel No. 6 oil burn test also emitted 2 ppm SO_3. UHC concentrations measured for SRC-II combustion tests were 1-14 ppm.

H-Coal

Average particle size of particulate matter proved to be less than 0.4 μm. Measured SO_2 emissions were consistent with fuel sulfur content in that the SO_2 emissions were the lowest of all synfuels tested. SO_3 was not detected. UHC emissions were from 1-4 ppm.

EDS

Two particle sizing tests showed the average particle size to be less than 0.4 μm. Measured SO_2 emissions were consistent with the fuel sulfur content. EDS flue gas samples showed no detectable levels of SO_3. Measured UHC emissions were 1 and 2 ppm.

Table A. *Summary of Emissions*

		Single-Stage			*Two-Stage (Low O_2)*			*Two-Stage (High O_2)*		
Fuel Type	*Fuel Ash Content lb/10^6 Btu*	*O_2 %*	*Part. lb/10^6 Btu*	*NO ppm @ 3% O_2*	*O_2 %*	*Part. lb/10^6 Btu*	*NO ppm @ 3% O_2*	*O_2 %*	*Part. lb/10^6 Btu*	*NO ppm @ 3% O_2*
No. 6 oil	*0.0045*	*3.7*	*0.024*	*270*	*3.6*	*0.037*	*199*	–	–	–
SRC-II 5.75/I	*0.0017*	*3.8*	*0.014*	*400*	*3.2*	*0.022*	*303*	*4.9*	*0.020*	*382*
SRC-II Medium Distillate	*0.0012*	*4.0*	*0.011*	*476*	*3.1*	*0.017*	*307*	*4.2*	*0.012*	*342*
SRC-II 2.9/I	*0.0041*	*3.3*	*0.012*	*361*	*2.9*	*0.015*	*308*	*4.5*	*0.017*	*371*
SRC-II 0.4/I	*0.018*	*3.4*	*0.031*	*509*	*3.3*	*0.039*	*279*	*4.7*	*0.039*	*375*
SRC-II Heavy Distillate	*0.034*	*3.3* *3.8*	*0.029* *0.037*	*381* *392*	*3.5*	*0.184*	*249*	*4.6*	*0.090*	*269*
SRC-II Heavy Distillate (210°F fuel temperature)	*0.034*	–	–	–	*3.2*	*0.065*	*339*	–	–	–
H-Coal	*0.0095*	*2.8*	*0.022*	*247*	*3.1*	*0.037*	*226*	*4.95*	*0.034*	*202*
EDS fuel	*0.0045*	*2.8*	*0.022*	*259*	*3.2*	*0.0184*	*270*	*5.15*	*0.0154*	*216*

11. REFERENCE
Muzio, L.J. and J.K. Arand. Combustion and Emission Characteristics of Coal-Derived Liquid Fuels. EPRI AP-1878, Electric Power Research Institute, Palo Alto, CA, 1981.

Effect of Fuel Bound Nitrogen on Oxides of Nitrogen Emissions from a Gas Turbine Engine

1. FUELS TESTED
Synfuel: JP-5 type fuel derived from crude shale oil.
Reference fuel: JP-5 derived from petroleum.
2. TEST EQUIPMENT
Allison T63-A-5A turboshaft engine (free turbine type used in Army OH-58A and Navy TF-57A helicopters).
3. TEST SITE
Naval Air Propulsion Test Center
Trenton, NJ
4. TEST OBJECTIVES
    - Confirm the presence of high levels of NO_x in engine exhaust;
    - Obtain information on conversion efficiency of fuel bound nitrogen into NO_x;
    - Assess the impacts of high nitrogen fuel on meeting pollution control regulations.
5. SPONSORING AGENCY
Deputy Chief of Naval Material (Development)
Department of the Navy
Washington, DC 20361
Project Manager: L. Maggitti
Telephone No: 202-545-6700
6. CONTRACTOR
Naval Air Propulsion Center
Fuels and Fluid Systems Division, PE71
Trenton, NJ 08628
Authors: A.F. Klarman, A.J. Rollo
Telephone No. 609-896-5841
7. TEST CONDITIONS
The T63-A-5A engine was installed in a sea level test cell using a three-point mounting system. A flywheel and an Industrial Engineering Water Brake, Type 400, were connected to the engine gearbox assembly at the forward power output pad to absorb the engine power. The brake reaction was measured by a Baldwin load cell. All parameters to determine the engine starting and steady-state performance with the fuels were measured using standard test cell instrumentation. Engine performance data is contained in the reference report.
Fuels of varying nitrogen content were tested in a T63-A-5A engine to measure their effects on exhaust gas emissions. Five test fuels varying in fuel bound nitrogen content from 3 μg (nitrogen)/g (fuel) to 902 μg (nitrogen)/g (fuel) were evaluated. The nitrogen content in the fuel was adjusted by mixing a JP-5 type fuel derived from shale oil (902 μg (nitrogen)/g (fuel)) and regular petroleum JP-5 (3 μg (nitrogen)/g (fuel)).
8. ENVIRONMENTAL MONITORING
HC, CO_2, CO, and NO_x.
9. PROJECT STATUS
Project report completed November 1977. This is part of an ongoing Naval program to evaluate fuel products derived from alternate sources.
10. RESULTS
Table B shows the results of the exhaust gas measurements performed during the test program. Additional results include:
    - NO_x emissions for the same engine power rating increased with increasing fuel nitrogen content.
    - The conversion efficiency of fuel bound nitrogen to NO and NO_x was approximately 45 percent for the test data in which the NO and NO_x values could be accurately measured.
    - No significant effects were noted on engine performance or CO and UHC emissions due to the presence of high levels of fuel bound nitrogen.
    - The use of shale-derived JP-5 fuel with a high nitrogen content will make it more difficult to meet the EPA NO_x standards for aircraft gas turbine engines.
11. REFERENCE
Klarman, A.F. and A.J. Rollo. "Effect of Fuel Bound Nitrogen on Oxides of Nitrogen Emission From a Gas Turbine Engine," Naval Air Propulsion Center, Trenton, NJ, NAPC-PE-1, November 1977, 32 pp.

Table B. *Emission Data Summary*

Fuel Nitrogen μg/g fuel	Engine Power Rate	CO_2 %	CO			NO			NO_x (as NO_2)			NC			F/A (calculated)
			ppm	g/s	g/kg fuel	ppm	g/s	g/kg fuel	ppm	g/s	g/kg fuel	ppm	g/s	g/kg fuel	
3	IDLE	1.98	1035	0.714	99.2	6.7	0.00495	0.688	6.7	0.00690	1.06	157	0.0503	6.99	0.00979
	60% MR	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	MIL	3.03	140	0.227	9.25	21.9	0.0416	1.69	23.9	0.0637	2.59	5.6	0.00422	0.172	0.0146
47	IDLE	2.08	985	0.692	90.5	7.7	0.00579	0.758	7.3	0.00887	1.16	131	0.0427	5.59	0.0105
	60% MR	2.43	430	0.482	35.0	12.7	0.0152	1.11	13.1	0.0241	1.75	18.3	0.00952	0.692	0.0119
	MIL	3.03	130	0.207	8.60	24.3	0.0415	1.72	24.3	0.0635	2.64	8.4	0.00621	0.258	0.0146
267	IDLE	2.08	1005	0.698	92.3	9.1	0.00677	0.895	9.4	0.0108	1.42	134	0.0432	5.71	0.0105
	60% MR	2.43	3.80	0.438	31.0	16.5	0.0204	1.44	16.7	0.0315	2.24	14.5	0.00775	0.549	0.0119
	MIL	3.03	140	0.224	9.26	27.6	0.0473	1.96	27.6	0.0726	3.00	11.1	0.00825	0.341	0.0146
515	IDLE	2.10	950	0.688	86.7	11.6	0.00900	1.11	12.3	0.0146	1.85	109.6	0.0368	4.65	0.0106
	60% MR	2.43	445	0.482	36.2	17.8	0.0206	1.55	18.4	0.0327	2.47	18.6	0.00935	0.702	0.0119
	MIL	3.03	130	0.210	8.60	31.6	0.0547	2.24	31.6	0.0838	3.44	8.7	0.00652	0.267	0.0146
902	IDLE	2.10	992	0.710	90.4	14.9	0.0114	1.45	16.0	0.0188	2.39	116	0.0385	4.91	0.0106
	60% MR	2.43	460	0.500	37.4	22.1	0.0257	1.92	22.5	0.0401	3.01	18.2	0.00918	0.687	0.0119
	MIL	3.03	135	0.218	8.93	35.9	0.0621	2.55	36.3	0.0962	3.95	8.4	0.00629	0.258	0.0146

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***Joseph A. McSorley** is the EPA Project Officer (see below).*

The complete report, entitled "A Compendium of Synfuel End-Use Testing Programs," (Order No. PB 82-236 936; Cost: $19.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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