Section 6

EXXON DONOR SOLVENT COAL LIQUEFACTION PROCESS: DEVELOPMENT PROGRAM STATUS III

by

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ABSTRACT

The status of the Exxon Donor Solvent Coal Liquefaction Process Development Program will be reviewed. Included in the overview of this government-industry cost-shared development is a description of Exxon's integrated approach to the project. The status of the laboratory and engineering research and development studies along with an up-to-date status of the 250 T/D large pilot plant operation, Test Program and a 70 T/D FLEXICOKING prototype program will be presented. The process description will include discussions of coal feed flexibility and product flexibility. Potential product utilization schemes, including direct utilization and various conventional upgrading routes, will be surveyed. The project environmental program philosophy and studies will be described. The economic outlook for the EDS process and the effects of various bases will be presented, concluding with consideration of the prospects for commercialization.

INTRODUCTION

This paper describes the status of the Exxon Donor Solvent (EDS) Coal Liquefaction Project. Included is an overview of this government-industry cost shared development, along with a description of Exxon's integrated approach to the development. The status of the laboratory and engineering research and development studies and the status of the 250 T/D large pilot plant operation, Test Program and a 70 T/D FLEXICOKING* prototype program which was approved this summer will be presented. The process description will include discussions of coal feed flexibility and product flexibility. Potential product utilization schemes will be surveyed. The literature contains past status reports of the development program,(1-12) and discussions of the potential for commercialization,(13) as well as the organizational structure of the EDS Project.(14)

Figure 1 lists the project participants. The U.S. Department of Energy is providing 50% of the funding through a unique government/industry cost sharing arrangement, the Cooperative Agreement. The remaining funding for the liquefaction program is provided by Exxon Company, U.S.A., Electric Power Research Institute, Japan Coal Liquefaction Development Company, Phillips Coal Company, ARCO Coal Company and Ruhrkohle AG. Private sector support of the FLEXICOKING prototype construction and operation is provided by Exxon Company U.S.A., Japan Coal Liquefaction Development Company, ARCO Coal Company and Ruhrkohle AG. Additional participants are possible in the future.

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* "Service Mark"

The overall objective of the project is to bring the technology to a stage of commercial readiness so that commercial plants can be designed with an acceptable level of risk. The EDS project includes the process blocks of liquefaction, solvent hydrogenation, and bottoms processing; the program includes work on hydrogen generation, fuel gas generation, and environmental controls as well.

INTEGRATED DEVELOPMENT

To achieve the objective of commercial readiness, the EDS program integrates all phases of process development. Bench scale research, small pilot unit operation, and engineering design and technology studies support operation of a 250 T/D coal liquefaction pilot plant and a 70 T/D FLEXICOKING prototype program. Work is also in progress to evaluate the use of a bottoms partial oxidation process for generation of hydrogen or fuel gas.

As shown in Figure 2, the integrated approach involves optimum use of the laboratory and engineering R&D programs, and the 250 T/D liquefaction pilot plant and 70 T/D FLEXICOKING prototype with their associated test programs to obtain the data for a commercial design. The design data for the key development areas, e.g., slurry drying, liquefaction, distillation, solvent hydrogenation, FLEXICOKING, product quality, and environmental control, will be obtained in the most appropriate project area at the minimum development cost. For example, the roles of the ECLP (250 T/D) pilot plant and FLEXICOKING prototype unit in the EDS Project are to provide operability and design data in the slurry drying, liquefaction, distillation and bottoms processing areas.

Design data from the large pilot plants will be collected through extensive engineering technology tests. ECLP was planned to include facilities for 115 individual tests whose results are expected to provide a comprehensive basis for a commercial plant design. Included in this program are test activities such as materials evaluation, erosion and corrosion, coal slurry preheat furnaces, slurry pumping, high pressure letdown valves and environmental monitoring and control. While the details of a similar effort for the FLEXICOKING prototype operation are not finalized, planning has already begun. Critical engineering design areas for FLEXICOKING include fluid bed operation, product quality effects and environmental control. The planned test program will include these areas plus materials evaluation, high pressure vacuum bottoms pumping, and coke particle integrity and gasification activity.

EDS PROCESS BLOCK DIAGRAM

One configuration of the EDS process is shown in Figure 3. Feed coal is crushed and dried by mixing with hot recycle donor solvent. The coal-solvent slurry is fed along with gaseous hydrogen to the liquefaction process block. The liquefaction reactor design is relatively simple, consisting of an upward plug flow reactor with design conditions of 800-900°F and about 2000-2500 psi total pressure. The reactor product is separated via conventional separation and fractionation steps into chemical and light hydrocarbon gases, C_3-1000°F distillate, and vacuum bottoms containing 1000°F+ liquids, unconverted coal, and coal mineral matter.

Part of the 400-800°F fraction of the C_3-1000°F distillate is taken as the recycle hydrogen donor solvent. This spent (dehydrogenated) solvent stream is hydrogenated in a conventional fixed bed catalytic hydrotreater using commercially-available hydrotreating catalysts.

The light hydrocarbon gases can be fed to a steam reformer to produce process hydrogen. The vacuum bottoms stream can be fed to a FLEXICOKING unit to produce additional liquid products and low BTU fuel gas while concentrating the coal mineral matter for disposal. FLEXICOKING is a commercial petroleum(15) process that employs integrated coking and gasification reactions in circulating fluidized beds. The process is a low pressure (<50 psi) and intermediate temperature operation (900-1200°F in the coker, 1500-1800°F in the gasifier). FLEXICOKING recovers essentially all of the feed carbon as product liquid or fuel gas. A small amount of carbon is purged from the unit with the coal mineral matter.

Partial oxidation of the vacuum bottoms (not shown) can produce either process hydrogen or intermediate BTU fuel gas.(16) This configuration frees the light gas stream for sales or furnace fuel.(17) In high conversion coal liquefaction operating modes, process hydrogen can be generated by partial oxidation of coal.(18) Partial oxidation units typically operate in the 2500-2800°F range and at 400-1000 psi. Partial oxidation is a commercial process employing oxygen to gasify petroleum fractions. The process does not recover additional liquid product but has the potential to consume effectively all of the feed carbon in the production of hydrogen or fuel gas.

COAL FEED FLEXIBILITY

Coal is located in many places in the U.S. as well as other countries. Differences in deposits can be very important in coal liquefaction. As shown in Figure 4, bituminous coals are found in Appalachia, the mid-west, and the Southern Rocky Mountain regions. Subbituminous coals are found primarily in the west. Lignites are found in the west and the Gulf Coast. One of the technical challenges is to be able to convert this wide variety of different quality coals into liquids. To do this, we need to learn more about the chemical structure of coal and how it reacts to form liquids.(19)

The EDS process is suitable for a wide range of coals. Figure 5 shows that bituminous, subbituminous and lignite rank coals can be liquefied using the EDS process. The liquid yields on a dry ash free basis resulting from once-through and bottoms recycle liquefaction are shown on this slide. Bituminous coals studied produce 39-46% liquids, subbituminous coals about 38% liquids, and the lignite about 36% liquids. The liquefaction yield can be increased substantially by recycling vacuum bottoms back to liquefaction. The slide shows that yields for bituminous coals are increased to 55-60% liquids, subbituminous coals 44-50% liquids and 47% for the lignite. Although not shown, additional liquids can be recovered by FLEXICOKING the vacuum bottoms stream. FLEXICOKING yields range from 5 to 10 weight percent additional liquids on coal for the coals shown. The FLEXICOKING yield corresponds to about 25 percent of the ash free vacuum bottoms yield.

In addition to increasing conversion to liquid products, the bottoms recycle process improvement results in improved pilot unit operability. Figure 6 shows the improvement in service factor for lower rank coals observed in our 50 and 100 pound per day recycle coal liquefaction units (RCLU). The improvement in service factor is felt to result from the reduction in bottoms viscosity which accompanies bottoms recycle operation. The bottoms recycle improvement reduces the viscosity of Wyodak and Big Brown bottoms to a level comparable with Illinois once-through and bottoms recycle bottoms.

PRODUCT FLEXIBILITY, UTILIZATION

Figure 7 shows the range of product flexibility which can be obtained from EDS liquefaction of Illinois No. 6 coal. The ranges shown represent the variation in yield expressed as a percentage of the total liquid product between a plant operating without vacuum bottoms recycle (once-through) using steam reforming of the C_1 and C_2 hydrocarbon gases to produce process hydrogen with bottoms FLEXICOKING for plant fuel, and a plant operating with vacuum bottoms recycle using partial oxidation of coal to produce process hydrogen and bottoms FLEXICOKING for plant fuel.

The ranges in product yield indicated on Figure 6 result from differing process variable combinations and differing process configurations. The arrows indicate the yield fractions for two specific configurations. The first, is a plant operating without bottoms recycle (OT) using Texaco Partial Oxidation of vacuum bottoms to produce process hydrogen and bottoms FLEXICOKING to produce plant fuel. The second is a plant operating with bottoms recycle (BR) using partial oxidation of coal to produce process hydrogen and FLEXICOKING of vacuum bottoms to produce plant fuel.

In addition Figure 7 shows the end uses of the hydrotreated streams. The C_1/C_2 stream can be used as synthetic natural gas, C_3/C_4 as a premium fuel or refinery feed, naphtha as a gasoline blending component, middle distillate as a stationary turbine fuel, and heavy distillate as low sulfur fuel oil. C_3 and C_4 liquefied petroleum gas, naphtha and mid-distillate yields are all maximized when operating with bottoms recycle while heavy distillate yield is minimized. Conversely, heavy distillate production is maximized with once-through operation.

All of the raw (unhydrotreated) EDS liquids contain significant levels of sulfur and nitrogen. They also contain compounds, e.g. nitrogen compounds, which cause degradation during storage. The heteroatom concentration increases with increasing boiling range.

The EDS project includes an effort to define suitable product uses, but does not include a major upgrading program. Limited hydrotreating studies are included in the project, to define the treatment required to stabilize the products for storage and shipment and to make them suitable for limited direct utilization. Major upgrading studies to make all clean products and/or transportation fuels are specifically excluded from the project, however, others under DOE and EPRI funding are conducting upgrading studies.(20-25)

Figure 8 shows some of the results that UOP(25) has obtained on reforming the hydrotreated naphtha to a gasoline-blending component. It also shows results from an ER&E funded program evaluating reforming of EDS naphtha. What is plotted for catalytic reforming is the yield, as percent of C_5+ liquid reformate produced per barrel of feed versus the research octane--clear or unleaded--of the product. By comparison, the yield on naphtha from a Saudi Arabian feed is much lower for any given octane. Hence, the EDS-derived naphtha would be an excellent reformer feed when compared with a major current source of crude in the world market.

ENVIRONMENTAL PROGRAM

The first step in formulating an environmental program was defining those areas expected to be different from petroleum experience.(22) As shown on Figure 9, three general areas were identified. The coal feed is expected to impact the following environmental areas: Air as fugitive dust emissions generated during coal handling and crushing, and coal fines disposal; noise generated during coal crushing; and worker health in light of potential dust emissions and noise levels. The products are anticipated to pose a potential health hazard to workers due to their high aromatics content.(27) Plant discharges are expected to impact due to fugitive dust and hydrocarbon emissions to the air, aromatic hydrocarbons and phenols in process and runoff water, and solid waste leaching in landfills.

Figure 10 shows the planned development strategy for addressing these concerns. The general approach is to define the problem using large pilot plant data and engineer solutions based on existing control technology. For example, air quality control measures based on existing petroleum refining and electric power industry control technology are being used in ELCP and the FLEXICOKING prototype unit. Also, all wastewater streams analyzed thus far appear to be treatable using existing refinery technology. (This will be verified in bench scale tests). Programs to protect workers from both coal and product-based emissions are based on Exxon experience in coal liquefaction in more than 10 years of research and the experience of others.(28)

EDS PROJECT STATUS

The schedule of the EDS Project is shown on Figure 11. In addition to the continuing laboratory and engineering programs, the schedules for detailed engineering, procurement, construction and operation of the 250 T/D Exxon Coal Liquefaction Pilot Plant (ECLP) and the 70 T/D FLEXICOKING prototype unit are shown. Construction and operation of the two large pilot plants are under the direction of Exxon Company, U.S.A.

The detailed engineering, procurement, and construction phase of ECLP which was begun in mid-1977 was completed in March of this year. The schedule has slipped about three months from the original schedule due to job scope changes. The cost of the unit was 118M$ compared with the original estimate of 110M$. The planned ECLP operating schedule spans a 24-month period beginning with a 12 1/2-month run on Illinois No. 6 coal followed by a 6 1/2-month run on a subbituminous rank coal and a 5-month run on a third coal. The plant started integrated operation on June 24, 1980. The first run continued 5 days when coal feed was halted to make modifications to alleviate several minor mechanical problems. The longest run to date has been 21 days. The coal-in factor has been 47% versus a target of 50%, and the unit has logged over 1000 hours of coal in operation as of the end of September.

Figure 12 is a detailed depiction of the ECLP operating plan. The plant is currently in the shakedown phase of the operation which is expected to last until the end of this month. Several of the key shakedown objectives are shown in the figure. The goal is to not only get all of the ECLP systems in operation during shakedown, but to achieve key operational objectives as well. Several key objectives have been achieved already. For example, the unit has operated on -8 mesh coal at 4% coal moisture content, and the slurry and vacuum tower furnaces and atmospheric and vacuum towers have been operated at their design heat fluxes and flash zone temperatures. The goal of testing the limits of operability in these sections has yet to be attempted. No process problems have been identified, but experience thus far has identified four mechanical areas which have posed some operating difficulty.

Erosion has proven to be a problem in the transfer line between the vacuum tower and vacuum preheat furnace. A 90° elbow in the line eroded through July 31 and resulted in termination of Run 2 after a total of 26 days of coal-in operation. X-rays of the "Flooded "T" replacement indicate that it is subject to unexceptably high rates of metal loss.

The eroded "T" and downstream portion of the transfer line is slated for replacement by refractory lined piping. The metal fiber reinforced refractory system is the same as that successfully tested in a pipe spool already installed in a high velocity segment of the transfer line as part of the equipment, component test program.

Reciprocating pump packing life is a continuing concern. Proper choice of packing materials and careful installation are required. Plans are being made to spare the two most troublesome pumps that are in atmospheric bottoms service with a centrifugal pumping system.

The lack of Dowtherm heater capacity has plagued the entire operation. The existing Dowtherm furnace output is about five times smaller than is needed for startup. As a result, the vacuum separation section is difficult to startup and relatively intolerant to upset. To alleviate this problem, a new Dowtherm furnace was installed and commissioned on September 19. It is expected that this furnace will provide the necessary Dowtherm capacity to handle startup needs and permit flexibility in responding to upsets.

The final area experiencing difficulties is the coal preparation unit. Problems with the prepared coal feeder belt on the gas-swept mill system have hampered operations. While aggravating, this problem is not felt to be critical. Separately, the coal slurry drier heat exchanger is experiencing severe plugging and fouling. After two trial fixes, it has been concluded that the existing multipass horizontal exchanger should be replaced with four singlepass vertical exchangers. The exchangers themselves are expected to be delivered late this month. Procurement of the necessary block valves may delay installation until 1981.

The detailed engineering, procurement, and construction phase of the FLEXICOKING prototype revamp began in July. This phase is estimated to last 22 months leading to an August 1982 mechanical completion target. Eighteen months of FLEXICOKING prototype unit operations are planned on bottoms produced in ECLP from operations on two different coals. The first, from Illinois No. 6 coal, will last 12 months while the second will last 6 months. Current projections based on this schedule indicate that a basis for a commercial plant design could be available in the first quarter of 1983, about midway through the FLEXICOKING run on Illinois No. 6 coal bottoms, assuming successful continuation of the program.

PICTURES OF ECLP/PROTOTYPE FLEXICOKING UNIT

Figure 13 shows an overview of the pilot plant. The relative positions of the administration building, the coal storage and preparation facilities, the process area and the product tankage areas are shown.

Figure 14 is a view of the Prototype FLEXICOKING Unit. The large cylinder is the coke storage silo. The coking reactor is behind the silo and the gasifier is in the structure to the left.

EDS ECONOMIC OUTLOOK

Figure 15 is a summary of the product cost outlook based on an EDS study design. All financial figures shown here are expressed in 1985 dollars A study design is an in-depth examination of the EDS process. It involves designing a conceptual, pioneer commercial plant and then estimating its investment and operating costs. This outlook is for a plant using FLEXI-COKING to produce process fuel and bottoms partial oxidation to produce hydrogen. It would process 28,000 tons/calendar day of coal and produce about 62,000 fuel oil equivalent barrels/calendar day of product. The investment required is 3.7 billion dollars including a contingency of 35%. The required initial selling price (RISP) for the C_3^+ product required to provide a 15% discounted cash flow return from this type of plant operating on Illinois No. 6 coal would be 48 $/B. A definition of RISP and example calculation can be found in a report on the EDS Commercial Plant Study Design.(29)

To calculate the cost of the liquids produced in such a plant various economic parameters must be specified. In total, there are about 90 parameters which must be specified to calculate the cost of liquids from a synthetic fuels plant. Figure 15 shows the impact of six of the more significant economic parameters which must be chosen. The values shown as base are those used to arrive at the 48 $/B figure above. The impact on RISP of these six areas are shown in $/B along with the change from the base. For example, changing from 100% equity financing to 75%/25% debt/equity financing would reduce RISP by 12 $/B to 36 $/B.

Of the other basis items, one of the most important parameters is the rate at which the selling price of petroleum and coal liquids will escalate during the plant life, as compared with the escalation rate of coal and other plant operation costs. The greater the differential escalation between hydrocarbon liquids and plant operating costs, the greater is the future flow of revenues to the synthetic fuels producer; this results in a lower RISP for the product when the plant starts up to achieve a desired rate of return over the life of the plant. As a base case, it was assumed that product price escalates at 6% per year, the same as operating expenses.

As a sensitivity, it was assumed based on published information(30) that plant revenues will escalate at 9% per year for the first 15 years of plant life and at 7-1/2% per year thereafter (equivalent to 8.7% per year on average), while plant operating costs escalate at 6%. On this basis a RISP of 37 $/B was calculated.

The effect of the other economic parameters on the RISP is generally smaller. For example, an investment tax credit of 10%, rather than 20%, would increase RISP by 3 $/B. Writing off equipment more quickly, such as through 3-year straight line depreciation or by treating capital costs as expense costs, would further reduce the RISP by 9 $/B. Lastly, a tax credit for coal liquids would lower RISP by 5 $/B.

It is clear that the assumed values of these economic parameters can strongly affect the calculated cost of synthetic fuels. The depth of detail present in a study design and the assumptions made during the study can also affect the calculated plant investment. These variations make it very difficult to compare the costs of products reported by different organi-zations on a consistent basis.

SUMMARY

The prospects for successfully developing coal liquids technology are good with the programs presently in place, but the prospects and timing for an economically attractive coal liquids industry are uncertain.

Project activities are directed toward achieving commercial readiness for EDS. Successful operation of ECLP is a high priority activity this year, and a continuing effort on process improvements will be made in an effort to reduce the cost of synthetic liquids. The project will also continue to focus attention on bottoms processing, a critical step in the development.

EXXON DONOR SOLVENT PROCESS

PROJECT
SPONSORED BY

U.S. Department of Energy
Exxon Company, U.S.A.
Electric Power Research Institute
Japan Coal
Liquefaction Development Co., Ltd.
Phillips Coal Company
ARCO Coal Company
Ruhrkohle AG

Exxon Research
and Engineering Company
Project Manager

Figure 1

INTEGRATED EDS
COAL LIQUEFACTION PROJECT

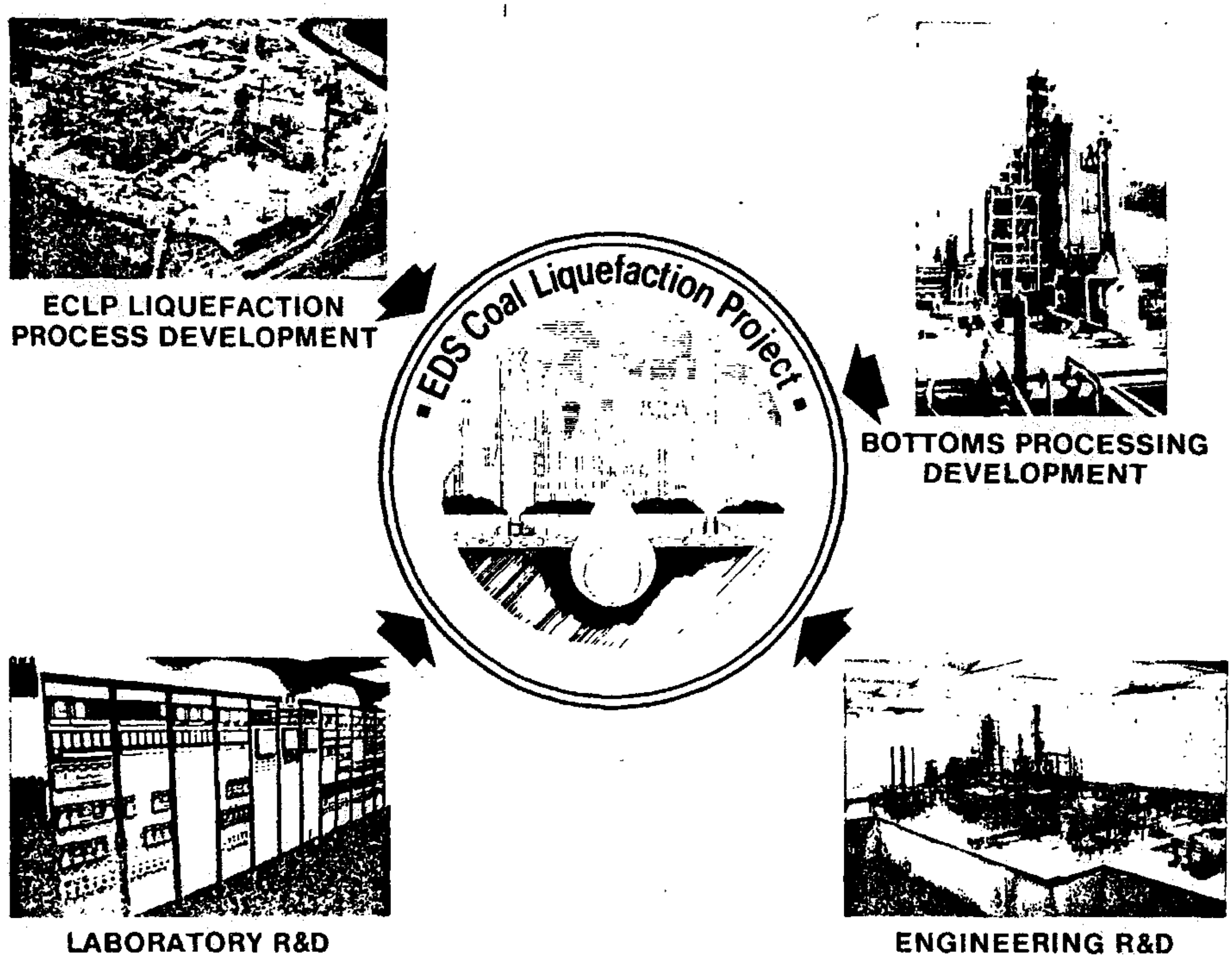


Figure 2

EXXON DONOR SOLVENT COAL LIQUEFACTION

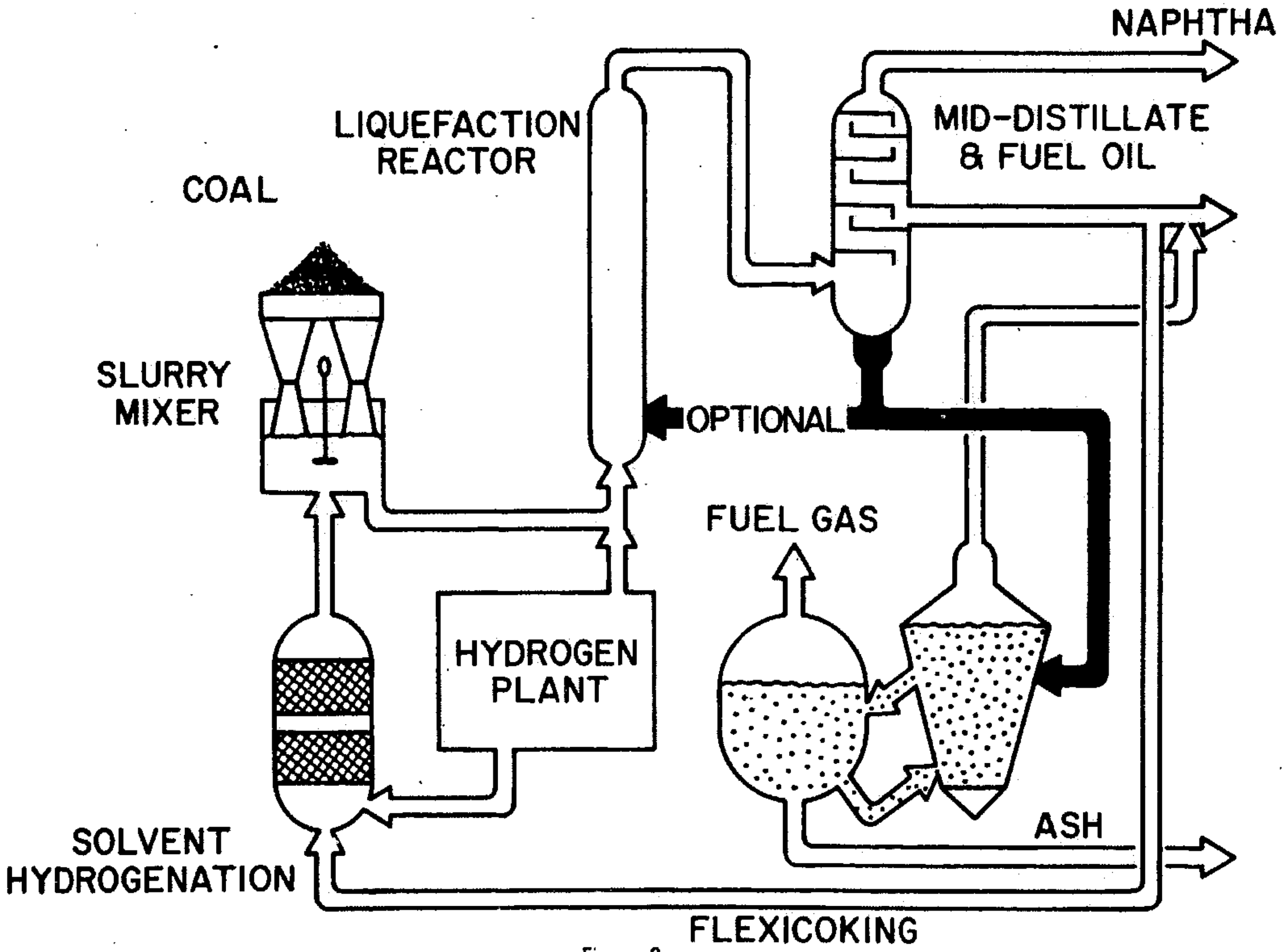


Figure 3

LOCATION OF U.S. COALS

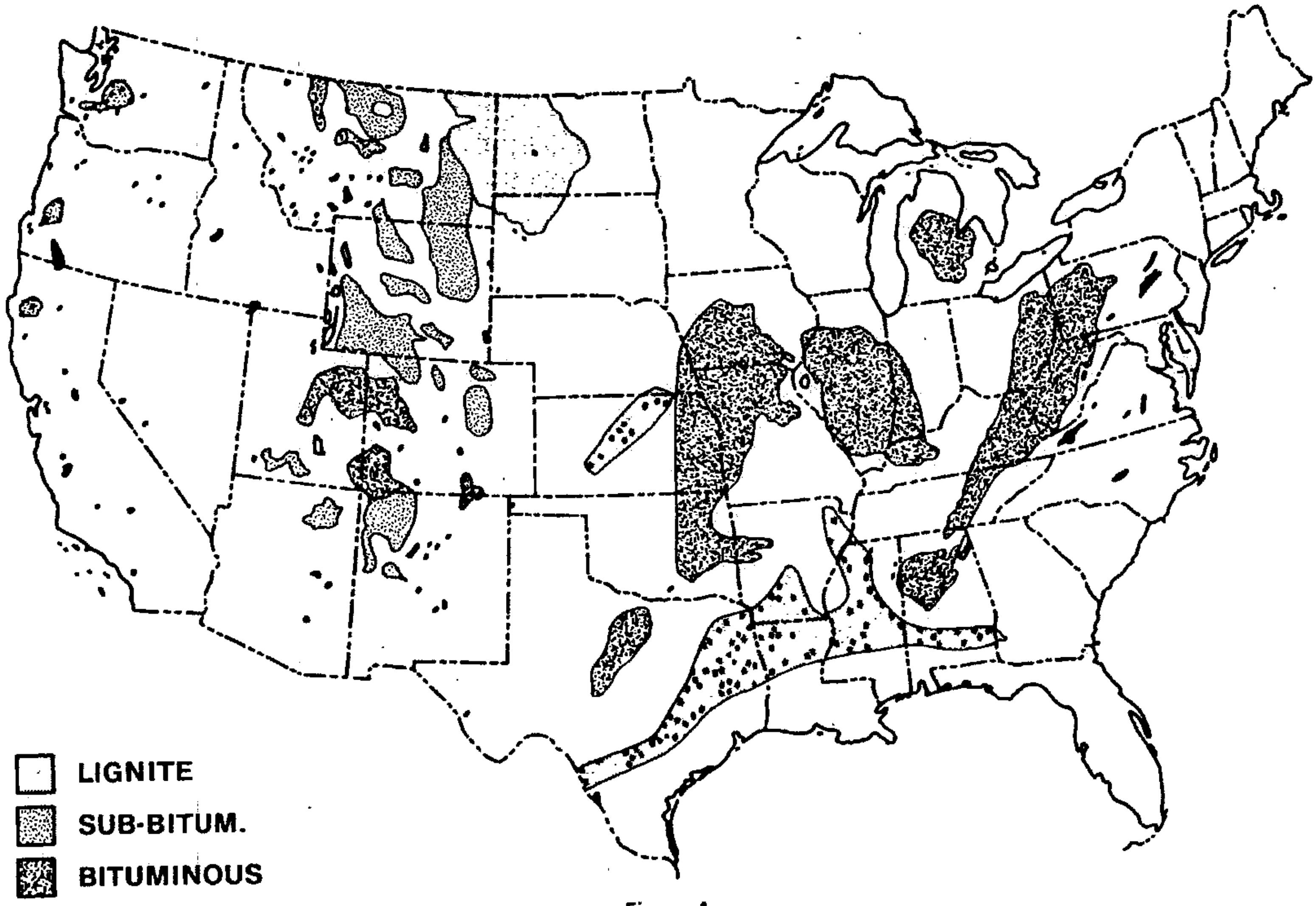


Figure 4

INCREASED LIQUID YIELDS OBTAINED WITH BOTTOMS RECYCLE COMPARED TO ONCE THRU OPERATION

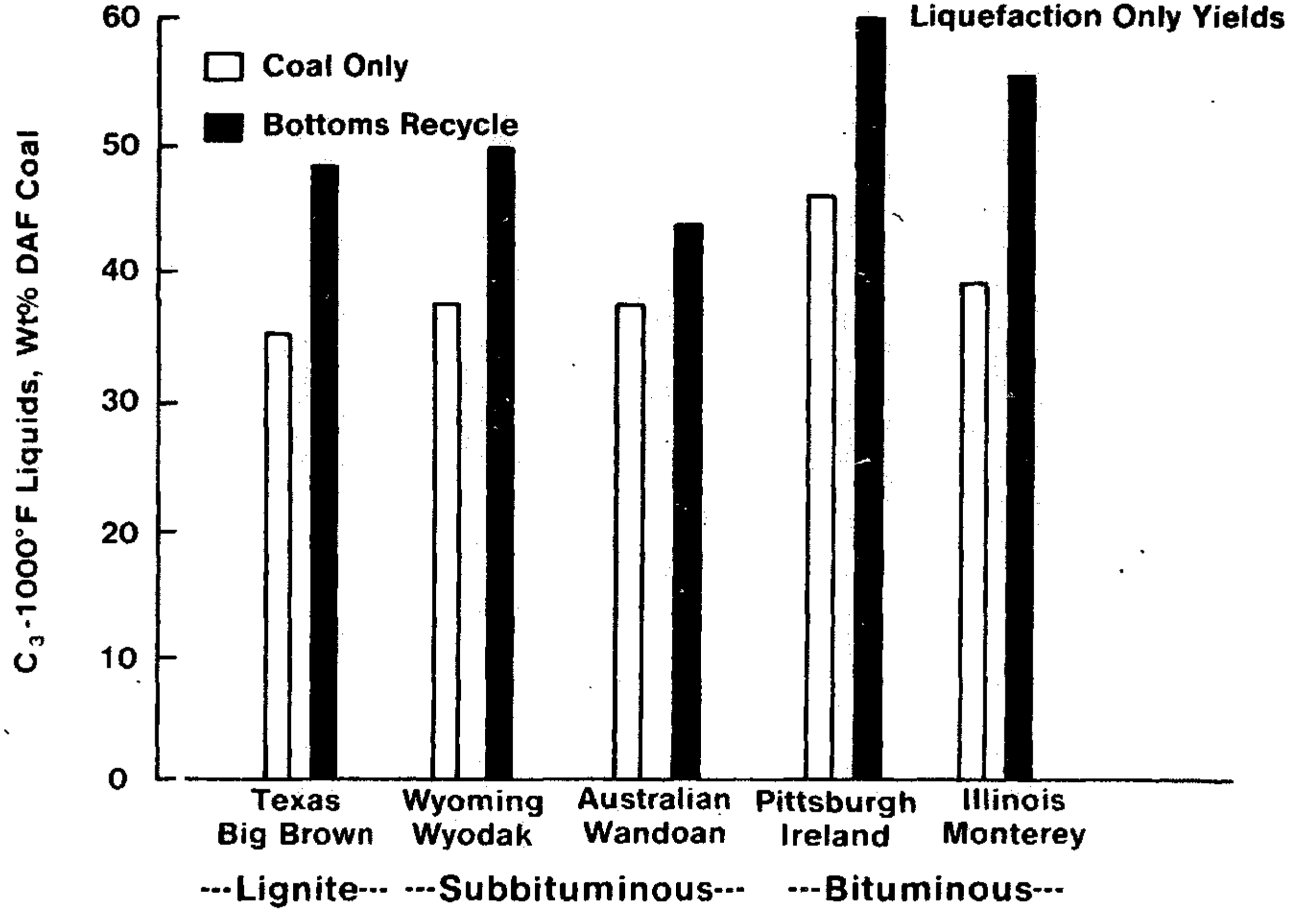


Figure 5

OPERABILITY SUBSTANTIALLY IMPROVED BY BOTTOMS RECYCLE

	RCLU Service Factor	
	Once Through	Bottoms Recycle
Illinois	76	73
Wyodak	58	68
Big Brown	44	64

Figure 6

RANGE OF PRODUCT FLEXIBILITY/PRODUCT INSPECTIONS

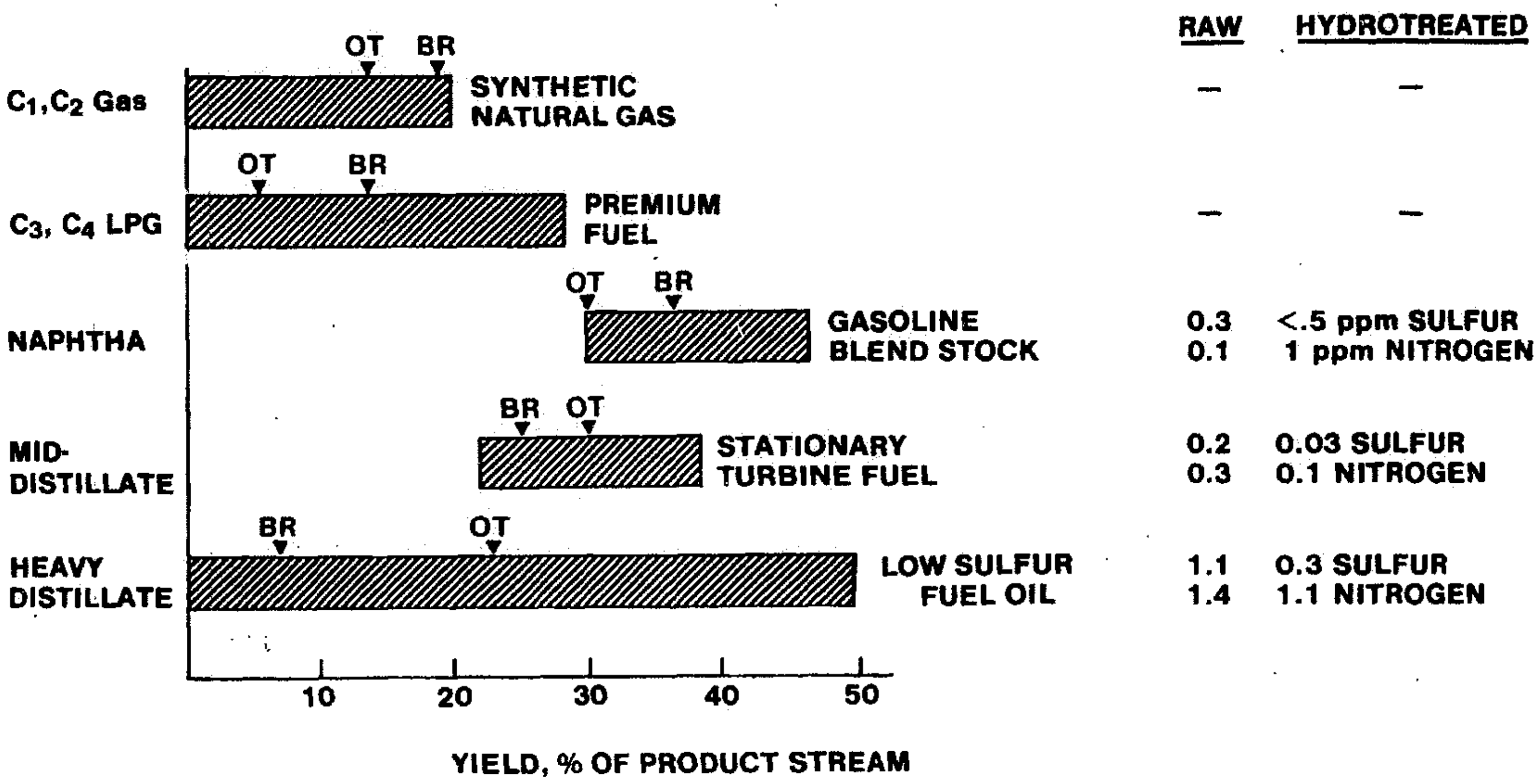


Figure 7

EDS NAPHTHA
IS EXCELLENT REFORMER FEED

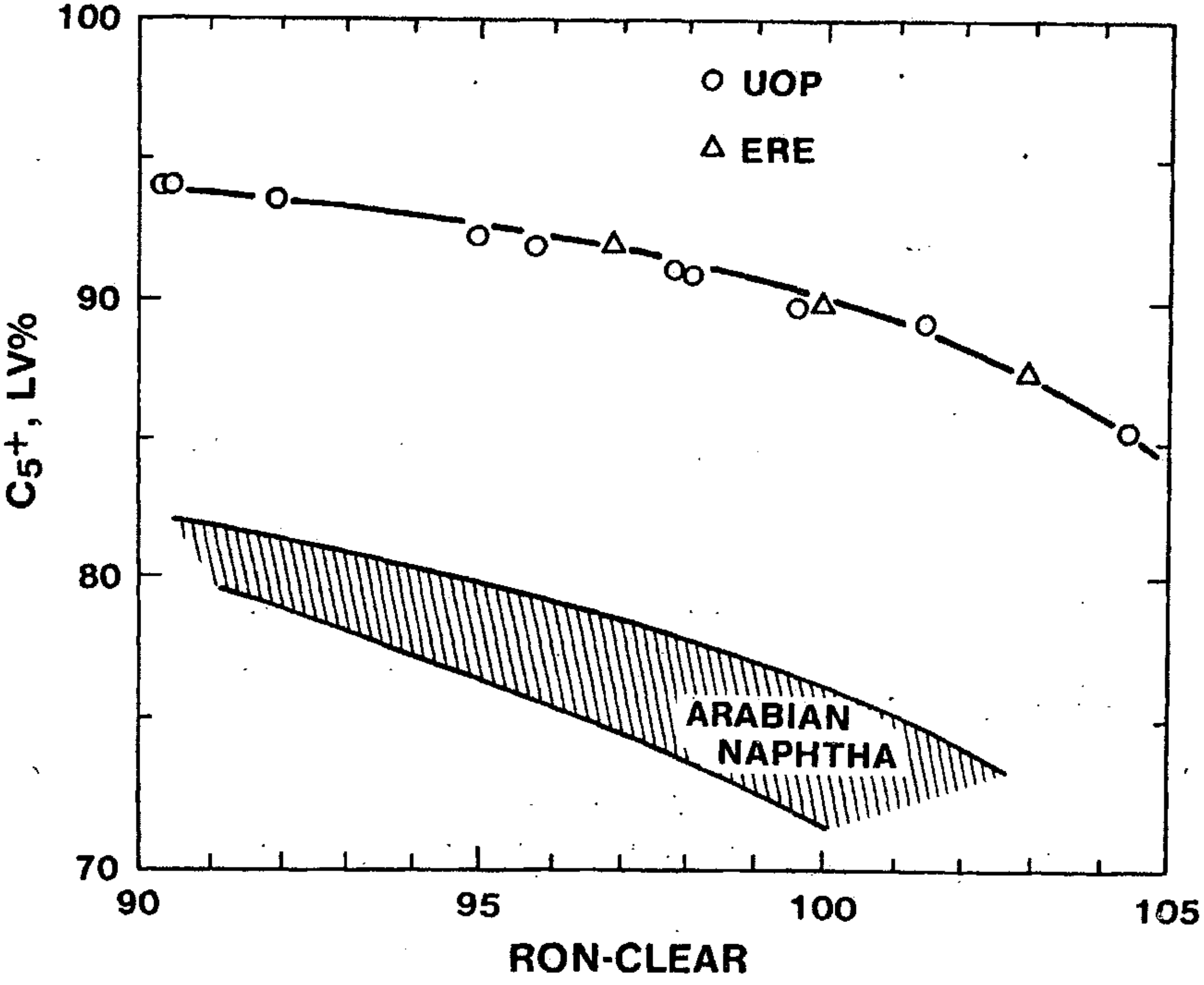


Figure 8

ANTICIPATED ENVIRONMENTAL IMPACT AREAS

SOURCE	AIR	WATER	SOLIDS DISPOSAL	NOISE	OCCUPATIONAL HEALTH
COAL FEED	X		X	X	X
PRODUCTS					X
PLANT DISCHARGES	X	X	X		

Figure 9

ENVIRONMENTAL CONTROLS DEVELOPMENT STRATEGY

- **AIR**
  - — QUANTIFY ECLP/FLEXICOKING PROTOTYPE EMISSIONS
  - — ADAPT CONTROL TECHNOLOGY FROM ELECTRIC POWER/ PETROLEUM REFINING INDUSTRY
- **WATER**
  - — CHARACTERIZE WATER FROM LARGE PILOT PLANTS
  - — SIMULATE TREATING SCHEME USING EXISTING TECHNIQUES
- **SOLIDS**
  - — PERFORM LEACHING/CHARACTERIZATION ON FLEXICOKING SOLIDS
- **NOISE**
  - — IDENTIFY/QUANTIFY SOURCES IN LARGE PILOT PLANTS
  - — ADAPT CONTROLS FROM ELECTRIC POWER/PETROLEUM REFINING
- **OCCUPATIONAL HEALTH**
  - — MONITOR WORKPLACE
  - — ASSESS ADEQUACY OF HEALTH PROGRAMS

Figure 10

EDS PROJECT SCHEDULE

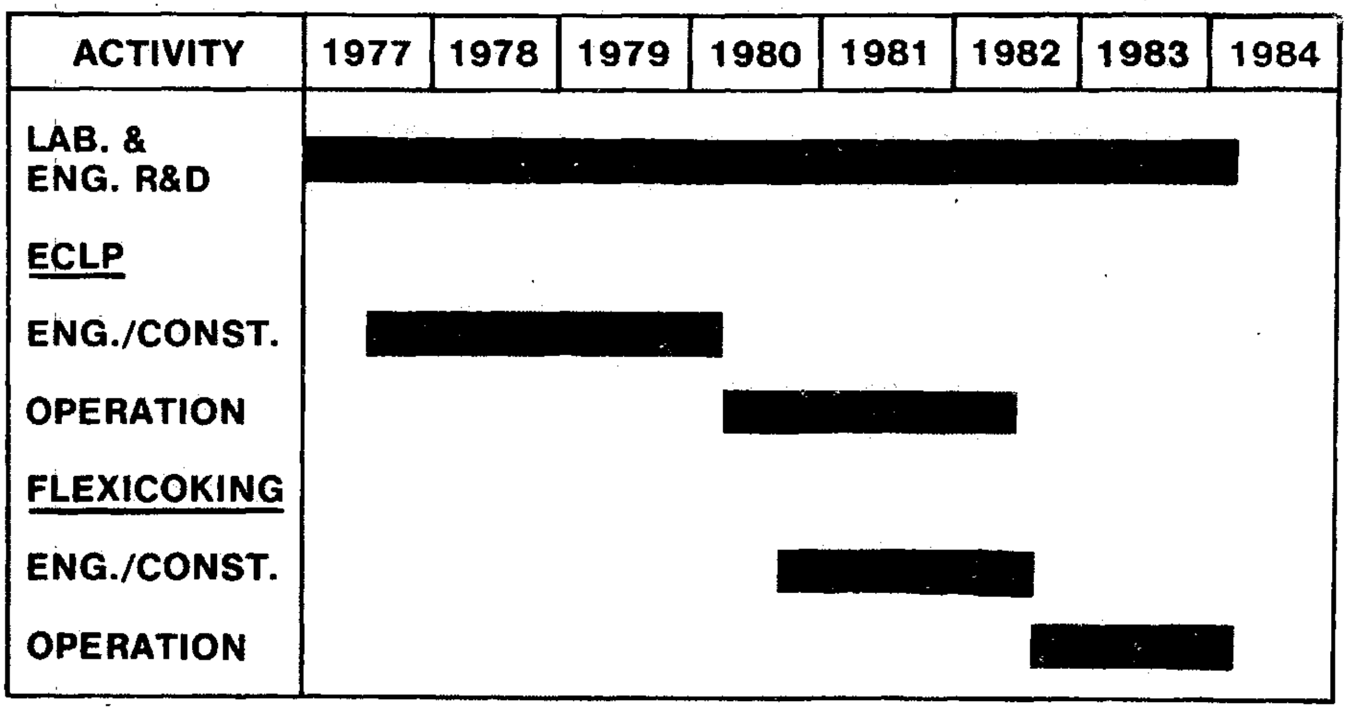


Figure 11

ECLP DETAILED OPERATING SCHEDULE

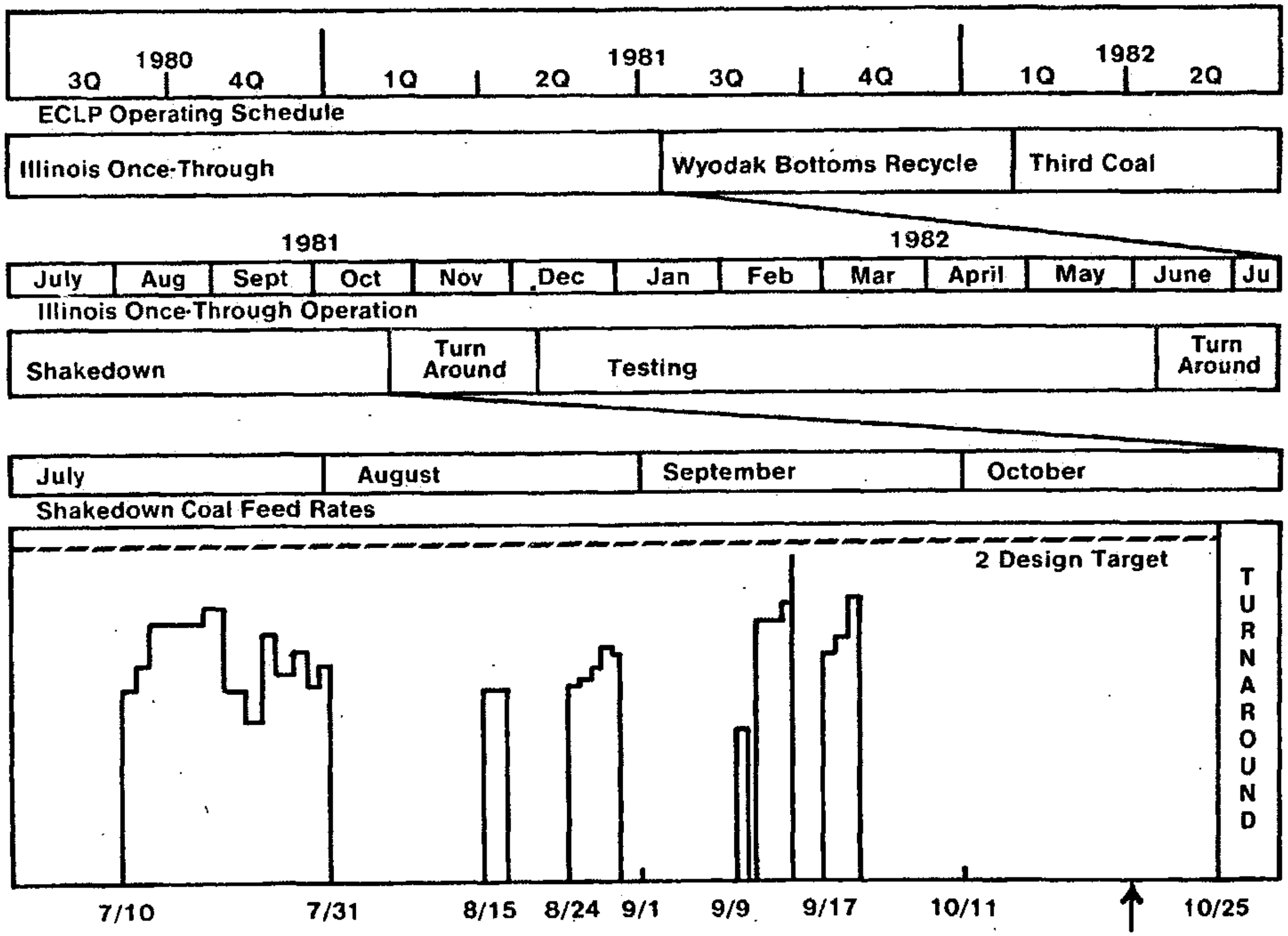
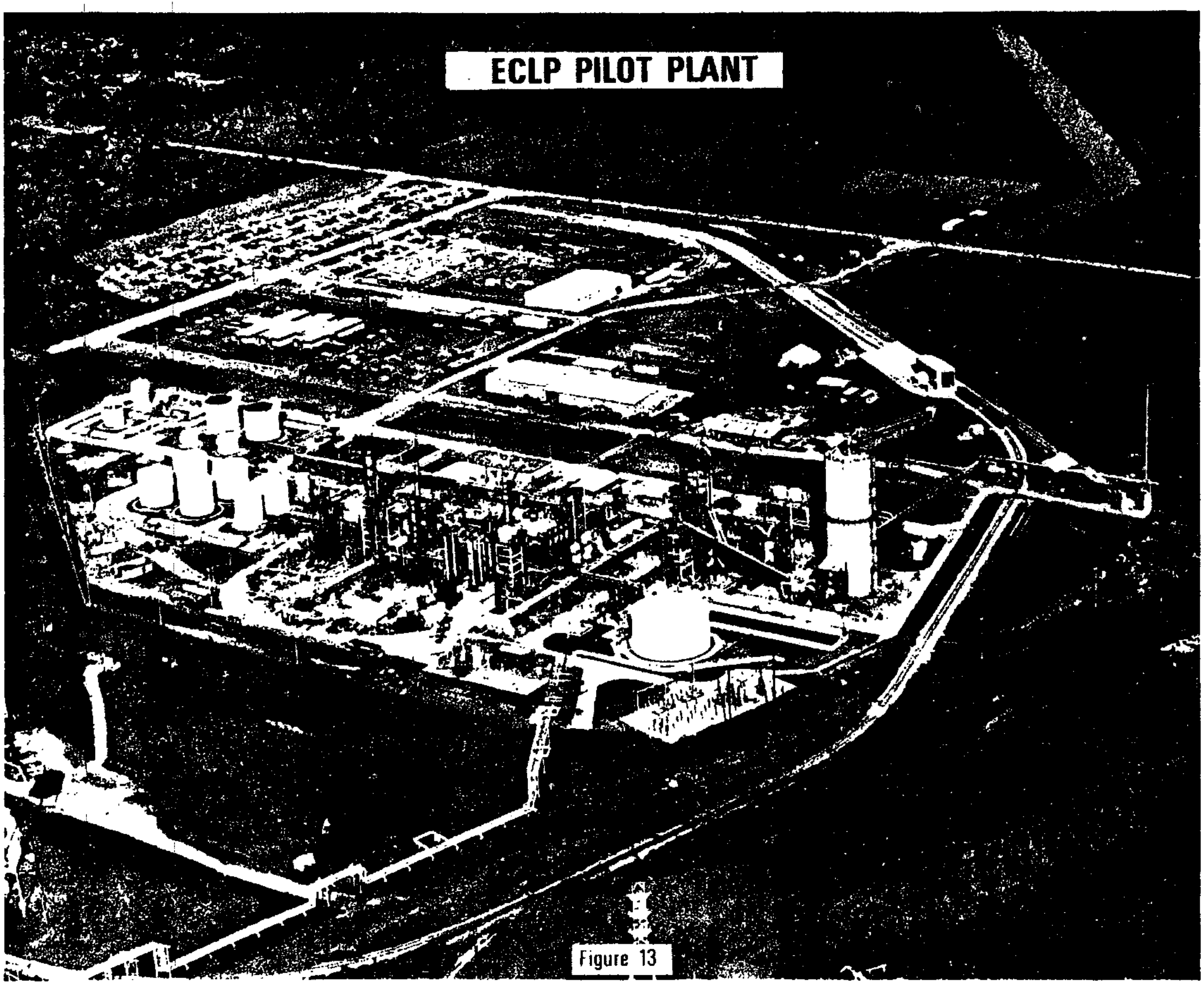


Figure 12



ECLP PILOT PLANT

Figure 13

FLEXICOKING PROTOTYPE

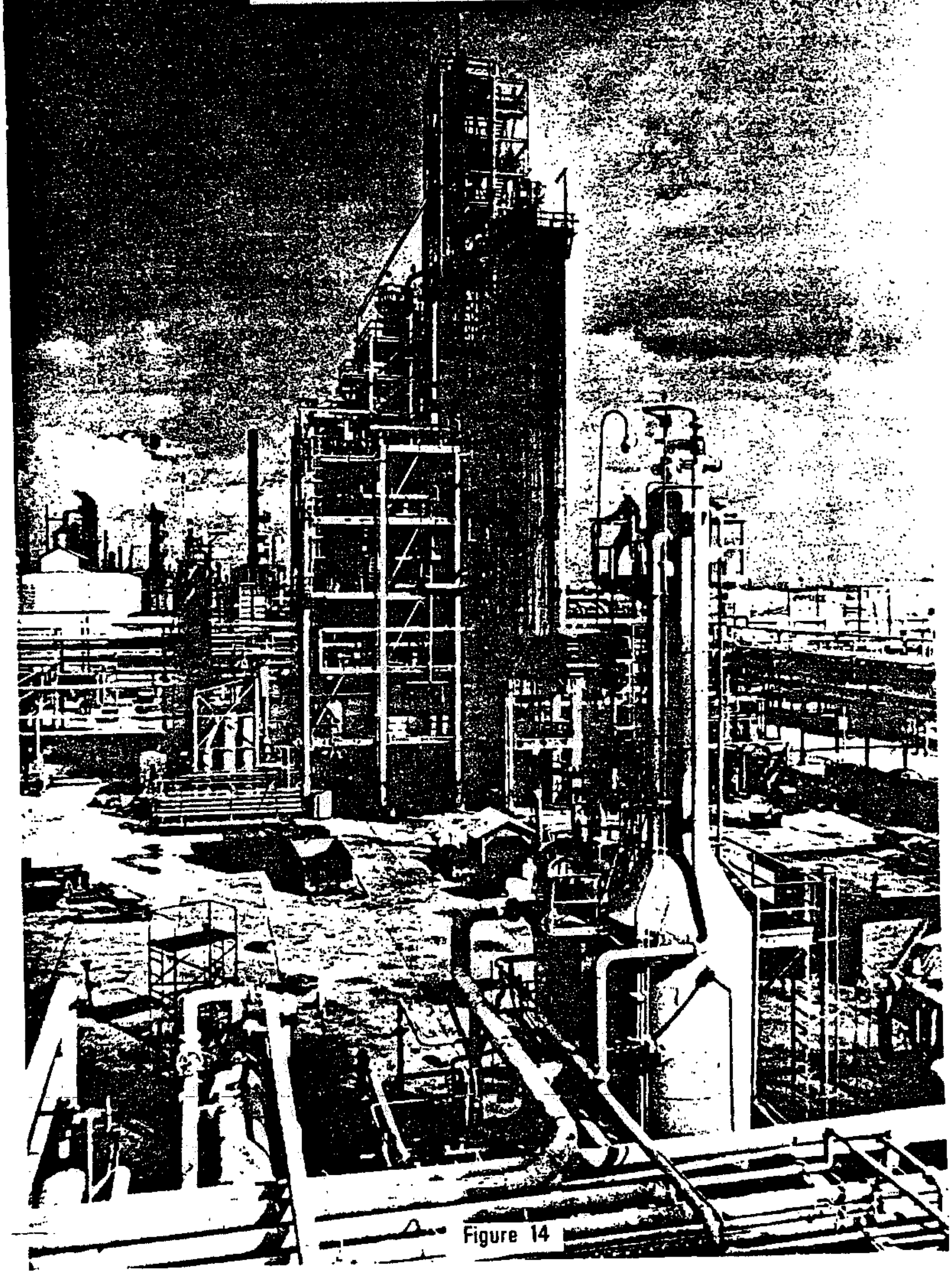


Figure 14

IMPACT OF SELECTED BASES ON REQUIRED INITIAL SELLLING PRICE (RISP)

(1985 $)

- ILLINOIS NO. 6 COAL
- 28,000 T/CD PLANT
- 3.7 BILLION $ INVESTMENT
- CURRENT $ DCF RETURN 15%
- 48 $/B RISP ($C_3^+$ PRODUCT)

BASIS ITEM	BASE	SENSITIVITY	RISP IMPACT, $/B
● DEBT/EQUITY FINANCING	100% EQUITY	75%/25%	−12
● ITC	20%	10%	+3
● DEPRECIATION	13 YR. SYD	3 YR. STR. LINE	−2
● CAPITAL COSTS TREATED AS EXPENSE			−9
● COAL LIQUIDS TAX CREDIT	NONE	6 $/B	−5
● OPERATING COST/PRODUCTS ESCALATION	6%/6%	6%/8.7%	−11

Figure 15

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