Comparative Economics of Two-Stage Liquefaction Processes

David Gray, Glen Tomlinson, Abdel El Sawy and Abu Talib

The MITRE Corporation, 1820 Dolley Madison Blvd. McLean, Va. 22102

Background

It has been recognized in research and development carried out by Lummus-Crest (1), that two stage liquefaction provides an attractive route to coal liquefaction by optimizing the discrete stages in conversion of solid coal to distillate. While improvements in process efficiency, product yield and quality have been demonstrated, the current limited kowledge of coal structure and liquefaction chemistry still necessitates empirical testing of process alternatives.

A number of promising process alternatives have been developed and are under current investigation at a bench or process development unit (PDU) scale by a number of contractors under DOE sponsorship. The contractors include Lummus-Crest, Southern Services (Wilsonville) (2), Hydrocarbon Research Inc., (3) and Amoco (4). The process variations under current investigation are as follows:

- Production of a major part of the distillate product in Stage 1 versus Stage 2.
- Catalytic first and second stage versus thermal first stage and catalytic second stage.
- Critical Solvent Deashing versus Anti-Solvent Deashing.
- Direct coupling of Stages 1 and 2 without intermediate deashing.

DOE requested that MITRE undertake a comprehensive technical and economic analysis of all the two-stage coal liquefaction configurations currently under development in order to quantify the improvements made in the production of high quality distillates from coal. Table 1 lists the processes that were analyzed in this task.

The methodology used to perform this analysis was as follows:

- Review test data. Select most representative run for each process using both Illinois #6 and Wyoming coals.
- Scale test data to develop material balances for conceptual commercial plants processing 30,000 tons per day of moisture free coal to the liquefaction units.
- Identify unit operations for commercial plants.
- Compute coal and energy requirements for plant balance.
- Estimate capital and operating costs for commercial plants.

- Compute annual revenue requirements based on consistent economic assumptions.
- Compute product costs required to satisfy revenue required.

Results and Discussion

Table 2 shows the characteristics of the commercial-scale plants for both Illinois No. 6 and Wyoming coals. Plants with high yields and/or high hydrogen consumption require large quantities of additional coal for steam and hydrogen production.

The construction costs of the conceptual commercial plants were estimated using an 1981 UOP/SDC (5) commercial design of the Lummus Integrated Two-Stage Liquefaction (ITSL) plant as a basis for costs of unit operations, where possible. Costs of unit operations not addressed in this report were obtained from other sources. Operating and maintenance costs were estimated using a standard procedure developed by UOP/SDC. The annual revenue requirements for these plants were then calculated based on the capital recovery and operating costs developed from use of consistent economic assumptions.

Since each process configuration produces a syncrude having a different quality, it was decided to account for this product quality difference. In order to do this, MITRE has calculated the hydrogen requirements and volume gain which occur when the C_4-850°F raw output of each plant is hydrotreated to produce a heteroatom-free, 35°API, 13-percent hydrogen product. The cost of this hydrotreatment is calculated based on the assumption that the cost of hydrogen production and addition is $1.00/pound.

Product costs were then computed to satisfy the annual revenue requirements based on the following assumptions. It was assumed that heavy products (i.e., 850°F+ products) were valued at one-half of the value of a barrel of C_4-850°F liquid product. For the hydrocarbon gases (C_1-C_3), it was assumed that 12×10^6 Btus were equivalent in value to one barrel of C_4-850°F product.

Figure 1 shows comparisons of the annual revenue requirement, equivalent product yield, and required selling price of products from the conceptual commercial plants when operated with Illinois No. 6 coal. All values are shown as percentages of the Lummus Integrated Two-Stage Liquefaction (ITSL) base case. For comparative purposes two conceptual plants based on single-stage processes (H-Coal (6) and EDS (7)) are included.

The bars depicting annual revenue requirements are divided into four sections, to illustrate the relative contribution of capital recovery, coal, operating and hydrotreating costs. The capital recovery costs for the two-stage plants vary by about 2 percent, indicating a similarly small variation in the capital costs of the plants. Capital costs of the single-stage plants are 5.4- and 9.5-percent lower than the Integrated Two-Stage Liquefaction (ITSL) base case for H-Coal and EDS, respectively.

The variation in hydrotreating costs reflects variation in both the quality of the raw product and the quantity of the C_4-850°F fraction. Hydrotreating costs of EDS are lower than the other systems, because of the relatively low yield and high API quality of the raw EDS product. The total annual revenue requirements vary from a low of 89.7 percent of base for EDS, to a high of 107.5 percent of base for CTSL.

The equivalent barrels of yield show a much wider variation than the annual revenue requirements. EDS yield is lowest at 84.6 percent of base, while CTSL is highest at 115.7 percent.

The lower portion of Figure 1 compares the required selling price of hydrotreated products from the conceptual plants. The prices vary from 105.9 percent of base for EDS to a low of 92.9 percent of base for CTSL, a spread of 13 percent. The most advanced systems, e.g., modified Lummus, Wilsonville RITSL, and CTSL, offer the lowest product prices. All these systems catalytically treat an ash-containing extract. It is doubtful that the one-percent difference between CTSL and RITSL is significant. However, the slight superiority of these systems relative to the modified Lummus is believed to be significant and is traceable to the higher rejection of soluble material which is inherent in the deashing system employed at Lummus. Lummus has suggested that the additional liquids in the deashed overflow could be recovered by coking.

Figure 2 shows economic comparisons for plants operated with Wyoming coal. Capital recovery cost variations between the plants are very similar to those observed in the Illinois No. 6 plants. The total revenue requirements vary from 93.8 to 100 percent of base for the two-stage plants, but are much lower at 89 and 83.3 percent of base for the single-stage H-Coal and EDS plants, respectively.

Plant yields show a much greater variation than was observed in the plants processing Illinois No. 6 coal. Yields vary from a low of 91.6 percent of base for EDS to a high of 141.5 percent of base for CTSL.

The required selling prices also show a wide variation. The Lummus ITSL shows the highest selling price at 100 percent of base, while CTSL offers the lowest price at 68.9 percent of base. The single-stage H-Coal and Wilsonville DITSL processes offer similar prices of 80.3 and 80.7 percent of base, respectively.

The results with both Illinois No. 6 and Wyoming coals indicate that the additional cost and complexity of two-stage processing is justified by the increases in yield and product quality which can be obtained.

REFERENCES

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FIGURE 1: COMPARISONS OF ILLINOIS NO. 6 COAL PLANTS

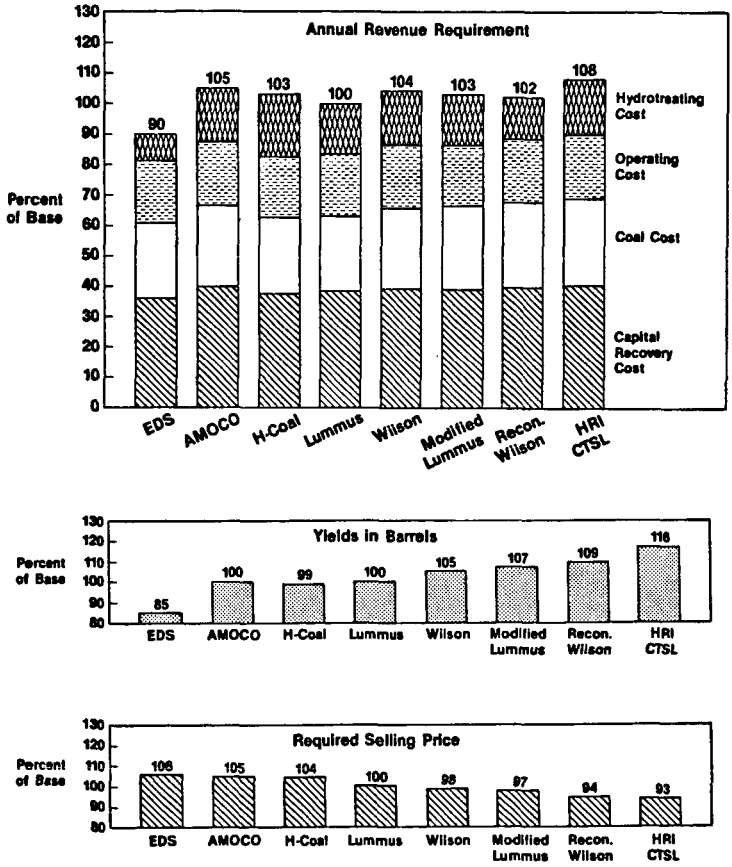

FIGURE 2: ECONOMIC COMPARISONS OF WYOMING COAL PLANTS

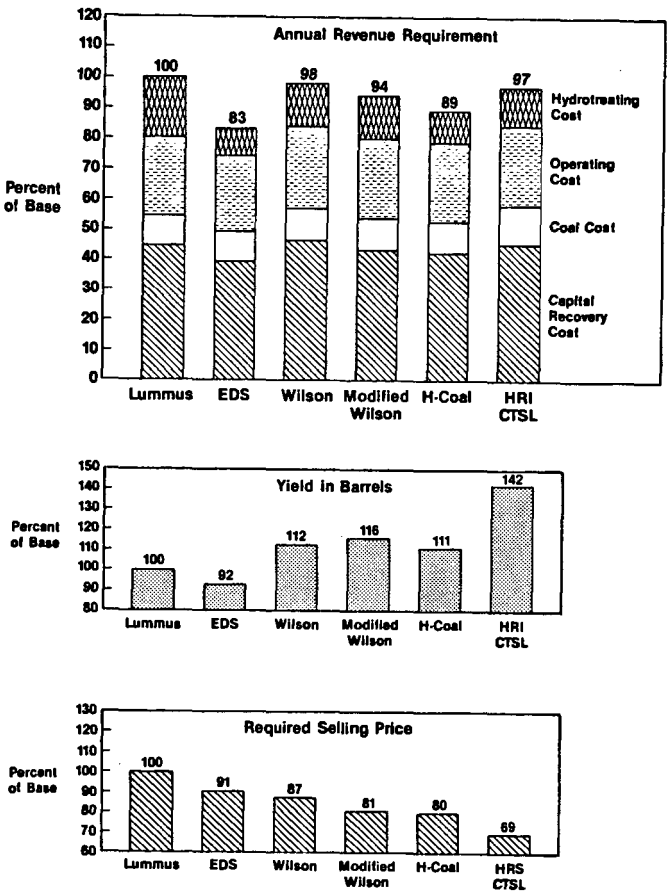

TABLE 1: TWO-STAGE PROCESSES

Process	Scale	Stage I	Deashing	Stage II
Lummus-Crest Integrated Two-Stage Liquefaction (ITSL)	600 Lb/Day	Thermal	Anti-Solvent	Catalytic
Wilsonville Two-Stage Liquefaction	3 T/Day	Thermal*	Critical Solvent Deashing	Catalytic
Hydrocarbon Research, Inc. Catalytic Two-Stage Liquefaction (CTSL)	50-100 Lb/Day	Catalytic	No Deashing Between Stages	Catalytic
AMOCO Thermal/Catalytic Two-Stage Liquefaction	50-100 Lb/Day	Thermal	No Deashing Between Stages	Catalytic

*Sometimes Slurry Catalyst Used

TABLE 2: CONCEPTUAL COMMERCIAL PLANT SUMMARIES

ILLINOIS NO. 6 COAL FEED

Process:	Lummus ITSL	Wilsonville ITSL	Wilsonville RITSL	Modified Lummus ITSL	AMOCO	CTSL
Input						
Steam Coal, TPD (MF)	2,000	2,000	2,000	3,000	3,000	3,000
Gasifier Coal, TPD (MF)	0	3,000	4,000	2,000	2,000	4,000
Total Plant Coal, TPD (MF)	32,000	34,000	37,000	35,000	35,000	37,000
Output						
SNG, MMSCFD	0	0	12	11	50	25
Raw C_4 + Liquid, BPSD	90,000	105,000	105,000	95,000	94,000	108,000
Total Liquid Yield after Hydrotreatment, BPSD	101,000	114,000	113,000	106,000	100,000	117,000

WYOMING COAL FEED

Process:	Lummus ITSL	Wilsonville ITSL	Wilsonville DITSL	CTSL
Input				
Steam Coal, TPD (MF)	3,000	2,000	2,000	4,000
Gasifier Coal, TPD (MF)	0	3,000	4,000	9,000
Total Plant Coal, TPD (MF)	33,000	36,000	36,000	43,000
Output				
SNG, MMSCFD	33	28	6	3
Raw C_4 + Liquid, BPSD	70,000	90,000	97,000	114,000
Total Liquid Yield after Hydrotreatment, BPSD	80,000	94,000	98,000	119,000