Shale Oil Value Enhancement Research

**Quarterly Report
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Summary Management Report

A review of the marketing, compositional analysis, and process data has pointed to a simplification of the process scheme envisaged for the phase-II continuous process work. This translates into a higher probability of success, both for the R&D and the likelihood of securing an industrial partner for future commercialization..

The phase-II PDU construction work is well-along and will be completed in the next quarter. The high efficiency distillation unit is complete and the liquid-liquid extraction unit is operable at ambient temperature and pressure conditions.

In the last quarter, JWBA experienced a personnel change. Dr. Prasad Devineni who was handling most of the information gathering including market research took a job with a chemical marketing consulting firm. In his place we hired Dr. Chung-Hsi (Jesse) Tsai who has extensive experience in process development. His services will greatly enhance the productivity in phase-II. We also commissioned the consulting services of Dr. Geoff Dolbear to assist in the industrial liaison. We also employed two chemistry students for work over the summer and possibly into the school year. The current team is well-suited for the forthcoming tasks of running the PDU's and preparing samples for introduction to potential buyers and partners.

Technical Progress Report

Objectives for the Quarter were:

- Conduct THD experiments to complete the conversions exploration task;
- Complete process modeling task and conduct preliminary economics;
- Conduct process design for phase-II separations development;
- Explore product and process integration strategies.

Discussion

Tasks 1 (NEPA compliance), 2 (separations characterization), 3 (analytical), 5 (separations exploration), and 6 (conversions exploration) have been completed. A final summary report of all seven Phase-I tasks is in preparation.

Task 4. Marketing

The marketing task was perhaps the most complex task because a match needed to be made between shale oil and the markets. This task involved the following considerations.

- A. What compound types are present in shale oil that resemble **current commodity and specialty products**.
- B. What compound types are present in shale oil for which **new markets** may be developed in a long range program.
- C. **How extensively can one afford to process shale oil** before the process costs and the increased market complexity reach a point of diminishing returns.
- D. What type of **industrial buyers** should be sought, eg. brokers, product manufacturers, intermediates manufacturers, end users, etc.
- E. What type of **industrial investment partners** should be sought, eg. technology-based companies, natural resource based companies, chemical manufacturers, strategic partnerships, etc.

The answers to these questions depend on the technical and economic results as well as the market opportunities. Fully integrated (task-7) the answers form the basis for phase-II strategy and phase-III implementation.

In phase-I we have answered these questions as follows.

Current Markets - Current markets exist for pure compounds of the pyridine, quinoline, pyrrole, indole, phenol and aromatic hydrocarbon types. Larger molecular weight benzologs and homologs of these types will need to be converted to lower molecular weight species before they can enter the pure compound markets. Buyers exist for both pure compounds and concentrates of these types. We have aimed at converting 10% of the barrel into a rich concentrate of these types.

Markets exist for the hydrocarbon portion of shale oil in the petroleum and refining industries. The principal high value product in these markets are waxes. About 5-7% of the barrel may be produced as high value waxes.

Future Markets - Near term markets exist for asphalt additives, resins, agrochemicals and solvents. In each of these cases the transition to shale oil-based products may be relatively easy, especially if the phase-III effort is funded. From 10-30% of the barrel fits this market category.

Longer term markets exist for higher molecular weight pure compounds, monomers and shale oil derived polymers. Any desirable property of shale oil which is unique to shale oil is a candidate for enhanced value but will probably require both product and market development. In designing our phase-II and phase-III strategy we have taken into account discussions with industry that have shown that **an investment partner will need to be convinced that the venture can be profitably based on current markets**. Any evidence that can be supplied to show the potential in future markets would be viewed as an investment up-side but could not be used to base the initial investment decision. Therefore, **the process emphasis in phase-II is appropriately placed on current commodities and specialty products to ensure that economic viability is achieved on that basis**.

Extent of Processing - A quantitative cost-benefit analysis is being completed in task-7. From a marketing point of view, it is most desirable to sell products to the fewest number of buyers so as to reduce the uncertainty that all products will find a buyer. This is consistent with the desirability to reduce the number of process steps, as well.

The concept of this project is to thermodynamically efficiently separate components by type. The mere act of performing this separation efficiently upgrades both sides of the separation. But, one wants to perform these separations in the fewest number of steps to keep the overall efficiency high. This strategy makes sense from a market and economic point of view as well. Thus, the preferred scheme is to do the least amount of processing possible and still find a buyer who values the concentrate provided. A discussion of current refinements to this concept is included in task-7 activities, below.

Buyers

By definition, commodity products are those which are interchangeable from various manufacturers but which meet accepted specifications. Therefore, any commodity product

that meets the specifications should be readily sold for prevailing manufacturer's prices. The principal commodity products from shale oil are the hydrocarbon streams which could be sold to the hydrocarbon industries. Our current expectation is that a nitrogen content of less than 0.3% can be achieved making shale oil quite acceptable to most refineries.

Specialty products are those in which the number of suppliers is limited. Specialty products from shale oil are the nitrogen concentrates and pure compounds. We have contacted a number of industries in these areas including coal-tar extractors, chemical importers, chemical synthesis, adhesives, dyes, flavors and fragrance companies. All we have spoken to have expressed an interest and are willing to examine samples as they come available in phase-II.

The importance of establishing dialog with buyers is two-fold. From a program viewpoint we need to know that the process output is salable and for how much. From an investment viewpoint the investor needs the confidence that the revenue potential is realistic. Once expressions of interest from buyers is gained, the job of attracting an investment partner becomes easier.

Investment Partners

An investment partner will necessarily be a relatively large corporation. In addition to the normal risks of a first generation facility the partner will need to provide assurances to a shale oil producer that the producer's market is secure. Current strategy calls for the value enhancement partner to let a take-or-pay contract for raw shale oil. A base-case price of \$30/bbl has been used for economic evaluation purposes. It is believed that this price is sufficiently high and with the security of the shale oil purchase contract will be attractive enough that a qualified producer (such as Geokinetics) could obtain the financing necessary to produce the raw shale oil feedstock for the Value Enhancement Venture.

An investment partner will need to see how a Shale Oil Value Enhancement Venture would fit into their long-range strategic plans. There are several economic motivators that have been used to categorize the approach to these companies. From this categorization a meaningful business-plan scenario is being developed for each. Investment partners fall into the following general categories:

Natural Resource Companies - These include mining, energy and minerals companies who are in business to add value to raw materials and are lacking for new domestic opportunities (which are dwindling with time).

Process and Technology Based Companies - These include process and technology development companies that see a profit potential in new, innovative technologies for full-scale development and licensing. Large engineering firms such as M. W. Kellog, UOP, Fluor-Daniel and others fit this category. Process development companies will need to know if the technology has a sound theoretical basis and that the process may be expanded or replicated. Development of an entire shale oil based industry through new product developments is of long-term interest to such companies. Earning money through

replication of the original design is not likely, however, so our approach requires that we emphasize the growth of a new industry based on a new source of raw materials.

Chemical Manufacturing - The most diverse category is chemical manufacturing. Companies in this category can range from commodities manufactures, eg. Huntsman Chemical, to specialty companies, eg. Eastman Kodak. Keeping in mind that a large company is required, we are focusing on the major companies that have some line of business in products expected from shale oil. The economic incentives for chemical manufacturers to become involved vary considerably but can generally be broken down into two categories:

Shale oil products as a unique or alternative source material - These companies include coal tar products manufacturers, resins and dyes manufacturers and end users which today are paying high prices for synthesized chemicals and desire to lock in a competitive advantage from lower-priced shale-oil derived products. Clearly the nitrogen heterocyclics fit this category.

Shale oil products as a unique opportunity for new product development - These companies include companies manufacturing products from traditional, synthetic sources who see new product opportunities in the expanded structural types from shale oil. An example of this is the alkylpyridines which are generally not available synthetically, at least at a reasonable cost. These types could provide unique oil/water solubility properties if used as a synthesis starting point in agrochemicals, pharmaceuticals and other medicinal products. For this category of partner we will need to factor into the business plan an intermediate product exploration and research phase.

While this type of partner is not likely to take on the entire responsibility of a Shale Oil Value-Enhancement Venture the number of integrated chemical companies that may desire to have a lock on unique, new product opportunities, as a co-partner, is large. These include Dow, DuPont, Monsanto, 3M and Eastman Kodak, to name a few.

In phase-II the marketing strategy has shifted to contacts with buyers and potential partners. Until now it has only been possible to advise companies of our program and to seek expressions of interest. Now that we are nearing the point of generating samples and analytical data from continuous units we can talk more specifically about each companies' interest. We have contracted with Dr. Geoff Dolbear to take the lead in this effort. The initial list of contacts are:

Amoco Chemical Company
Chicago, IL

Calgon Carbon Corp.
Pittsburgh, PA

CSX Corporation
Richmond, VA

Ashland Chemical Company
Columbus, OH

Chevron Chemical Company
San Ramon, CA

GE Petrochemicals
Parkersburg, WV

Marathon Petroleum Center
Littleton, CO

Neville Chemical Company
Pittsburgh, PA

Occidental Chemical Corporation
Dallas, TX

Sun Company, Inc.
Philadelphia, PA

W. R. Grace & Co.
Boca Raton, FL

Nepera, Inc. a Unit of Cambrex Co.
Hariman, NY

PPG Industries, Inc.
Pittsburgh, PA

Reilly Industries, Inc.
Indianapolis, IN

Unocal Science and Technology Div.
Brea, CA

Westates Carbon
Los Angeles, CA

Task 7. Economics and Integration

The integration task is the final task needed to assure that our phase-II work will give us the best chance of finding the industrial partner. In October, 1994 (cf. Sixth Quarterly Report) we proposed two alternative process schemes. Based on our recent marketing work and industry contacts, we now believe that these schemes warrant simplification for reasons cited above and in our recent monthly reports.

Figure-1 shows the preferred alternative, which is the simplest scheme prepared to date and is designed to maximize upgrading while minimizing cost. The preferred scheme possesses a simplicity that promises attractive economics. It involves only one extraction, one distillation and one THDA step and all of these have been proven in other applications. Most importantly, if the preferred scheme can be demonstrated it may be possible to dispose of the products to only two buyers, one for the hydrocarbon stream and one for the heteroatom compound stream.

To complete phase-II of this scheme we only need extraction, distillation, and THDA (see discussion of tasks-8 and -9 below). The preferred alternative, if it is proven, would require only three major field units. This would greatly simplify the on-site commercial system and would reduce the demonstration-phase costs currently proposed to be under a government/industry cooperative agreement.

If a single buyer for the heterocycle concentrate cannot be found, we may need to subdivide the concentrates into its component types and sell these types separately. This scheme is illustrated in Figure-2. Adsorption process separation by acids, bases and neutrals has been shown by small scale experiments to be chemically efficient. The economics of larger scale processing is being estimated, but even if the costs are relatively high, the product values, which typically exceed \$1000/bbl could make this approach highly profitable. It is believed that alternative-2 will need to be demonstrated in phase-II on semi-continuous unit even if alternative-1 proves success in that the buyer of the total concentrate will need to know the economic potential of this concentrate.

It is currently anticipated that the acid, base and neutrals fractions will be simple enough in composition (having been dealkylated, distilled and separated by gross type) that high efficiency distillation could isolate many, if not all, of the pure compounds present. Demonstrating this is a goal of phase-II.

Task 8. Separations Development

The continuous separation units needed are counter-current, liquid-liquid extraction and distillation. While pilot plant data is not needed for distillation we still need a unit to prepare samples in the preferred and alternative schemes.

Correspondingly in this quarter we have upgraded our packed column to include computer controlled reflux ratios and heat fluxes. This allows us to run the distillation at a variety of efficiencies (up to about 15 theoretical stages) to produce the required samples. Referring to scheme-2, different efficiencies are needed for the 290°C unit, the 400°C unit and the high efficiency fractionation. The system as configured will accomodate all three.

The liquid-liquid extraction unit is essentially complete. A recent planned upgrade of this unit was the aquisition of a constant temperature bath with a wide range of heating and cooling control. It is hoped that we will not need a pressurized system to operate at elevated temperatures with low molecular weight solvents, eg. methanol. When doing the temperature variable part of the work we will model the coefficient of separation behavior to see if elevated temperatures provide a significant advantage. Theoretical considerations and laboratory experiments to date show an advantage at elevated temperatures. If the system needs to be modified for higher pressure, this can be done for up to 100 psig with the pumps currently available.

Task 9. Conversion Development

A decision has been made to use thermal hydrodealkylation for reducing high molecular weight heterocyclic components to lower molecular weight components. THDA is not a simple process, particularly on a continuous scale where H₂ recycle is provided. Fortunately, a unit now exists at the University of Utah which can be modified for this purpose. (The original unit under control of Dr. Bunger as part of his University program was taken out of commission during a consolidation of departments.) The unit we will use in phase-II was built by James W. Bunger and Associates, Inc. under contract to the University of Utah and so we have first hand experience in the design and operation of this unit. A subcontract to the University of Utah is provided for in the subject work and terms are being negotiated.

Task 10. Product and Process Integration

Our industrial liason activities will be continued in phase-II under this task and full reports will begin in the coming quarter.

Figure 1 Flow Diagram - Preferred Process

Figure 2 Flow Diagram - High Product Value Process