

LCI CO-PROCESSING: A FAMILY OF TECHNOLOGIES  
FOR UPGRADING LOW GRADE FEEDSTOCKS

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INTRODUCTION

The Western Hemisphere and North Sea oil producers have been experiencing a serious decline in light oil production and light oil "find" rates. In spite of aggressive drilling programs, "finds" over the past fourteen years have been about 60 percent of production (1). In seeking continued production of refined petroleum products, refiners will have to consider processing of bottom-of-the-barrel feedstocks to a much greater extent. When one superimposes the additional issue of the politically-controlled availability of Mid-East petroleum supplies in the Western World, it is clear that there is a need for technology that will afford the refiner greater flexibility in feedstock selection and feedstock processability.

One potentially attractive route to satisfying these needs is the co-processing of petroleum feedstocks with other more plentiful and less costly fossil fuels. Lummus Crest Inc. (LCI) has formulated a concept for co-processing bottom-of-the-barrel oils with coal and other solid carbonaceous feedstocks to produce high quality distillate fuels. The concept is based on a two-stage approach in which the solid carbonaceous feedstocks are converted to liquid hydrocarbonaceous materials in a thermal reaction zone devoid of externally-supplied catalysts followed by catalytic hydroprocessing of the thermal stage products together with petrolea in an expanded-bed hydrotreater. The unconverted solids from the thermal reactor can optionally be removed by known solids separation techniques, such as Anti-Solvent Deashing (ASDA), prior to upgrading in the expanded-bed hydrotreater. A distillate fraction from the hydrotreater can be recycled to serve as the slurry vehicle for the solid carbonaceous feedstock.

Co-processing of heavy petroleum residua and coal has been the subject of a 33-month experimental program currently being carried out at LCI's Engineering Development Center under joint funding with the U.S. Department of Energy. Details of this work have been presented elsewhere (2,3). Currently, we envision a common reaction system that can co-process petroleum residua with other carbonaceous feedstocks, such as oil shale and biomass, in addition to coal.

### LCI CO-PROCESSING FLOWSCHEMES

With current refinery technology, heavy petroleum residua characterized by high metals content and high coking propensity can be processed by either carbon-rejection technology such as delayed or fluid coking; by hydrogen-addition technology such as fixed-bed or expanded-bed hydrogenation; or by combinations thereof. Two co-processing applications based on hydrogen-addition technology are disclosed here.

With current commercial residuum hydroprocessing technologies, conversion is limited to about 50 to 60 percent to IBP-524°C (975°F) distillates. The unconverted resid from the hydrotreater is either processed further in a coker to recover additional distillates and a coke product or blended off with available low sulfur fuels. The unconverted residuum that has been subjected to catalytic hydrogenation has potentially good properties as a solvent for liquefaction of coal, biomass and oil shale.

Figure 1 is a schematic flow diagram of a co-processing scheme for utilizing the unconverted resid from a residuum hydrotreater. The short contact time (SCT) thermal reactor system has been demonstrated at the 300 kg/day (1/3 tpd) scale in LCI's Integrated Two-Stage Liquefaction (ITSL) process development unit (4) as well as at the 5448 kg/day (6 tpd) scale at the Wilsonville pilot plant (5), both on coal products only. The SCT concept is predicated on the fact that the rate of activation of fossil-derived oil precursors is relatively fast with respect to the rate of hydrocracking of these intermediate products to all distillate products. On this basis, the ITSL process "decouples" the primary fossil liquefaction step from the secondary hydrocracking step. Accordingly, we have projected that there will be capital cost savings in a commercial plant in which the primary liquefaction step is carried out in a relatively low-cost, fired-coil reactor system as compared to a larger, high pressure soaker-reactor system. Furthermore, the more capital-intensive catalytic step could then be optimized to hydrocrack the extracts without being constrained by the need to simultaneously solubilize the solid carbonaceous feedstock.

An alternative co-processing application is shown schematically in Figure 2. This application is predicated on the following factors:

- o The feedstock cost of liquid products from the hydroliquefaction of coal, oil shale and biomass is significantly less than that of petroleum as seen from the following table:

Table 1

<u>Feedstock</u>	<u>Typical Liquids Yields</u>		<u>Typical Feedstock Transfer Price</u>			<u>Feedstock Cost of Raw Liquids</u>	
	10 <sup>3</sup> M <sup>3</sup> /Kg	g/t	\$/kg	\$/ton	\$/MM Btu	\$/M <sup>3</sup>	\$/Bbl
Bituminous Coal	0.70	168	0.033	30	1.25	47	7.50
Kentucky Shale	0.10	24	0.004	4	0.68	44	7.00
Wood Chips	0.50	120	0.022	20	1.40	44	7.00
Municipal Solid Wastes	0.25	60	0.009*	8*	0.85*	(35)	(5.60)

\* Denotes tipping fee paid by solid waste collector.

( ): Denotes credit for MSW feedstock against product liquids.

o A raw syncrude can probably be generated in a thermal reaction system, such as an SCT heater, at an incremental cost competitive with that of imported petroleum crude when the conversion units are constructed and operated on an over-the fence basis adjacent to a large petroleum refinery.

o There is good indication that there will be a beneficial synergism during catalytic hydrotreatment when co-processing synfuels products from an SCT reactor with vacuum residua. The synergism may take the form of increased distillate yield and/or improved desulfurization/demetallization at conventional hydrocracking operating severities.

o There should be no significant deterioration of the hydrogen content-molecular weight relationship (Stangeland surface) of the distillate products when the syncrude content of the combined feed to the hydrocracker is less than about 20 percent (6).

#### DEVONIAN SHALE RESOURCES

The Devonian oil shale resource of the Kentucky-Ohio-Tennessee region of the U.S. has the potential of providing a significant percentage of our refinery feedstock needs. Until recently, U.S. oil shales were considered unsatisfactory resources because of their relatively low oil yields in the Fischer Assay test and in conventional retorting. Fischer Assay oil yields per unit weight of organic carbon obtained with the Devonian marine shales have been less than half of those obtained from the Eocene lacustrine shales (Green River formation) of Colorado, Utah and Wyoming. The shale resources recoverable by surface mining in the Lewis and Fleming County, Kentucky region alone could generate shale liquids

corresponding to about 12,000 M<sup>3</sup>/day (750,000 bbl/day) for 20 years.

Previous efforts (7,8) have clearly demonstrated that hydrogen addition or hydrotreating technologies can result in significantly higher oil yields from Devonian shales than can be achieved by thermal retorting technologies, on the order of 200 to 250% of that of Fischer assay. These studies also concluded that a commercial-scale application of hydrotreating technologies has potentially favorable economics.

However, without some type of government subsidy, a grass-roots shale conversion facility still cannot compete on the open market with current petroleum prices. The LCI co-processing concept represents a possibly nearer-term economic reality when applied in an over-the-fence relationship with an interested refiner. By way of example, assume an existing hydrocracker is processing a virgin resid priced at \$157/M<sup>3</sup> (\$25/bbl). For the case of a 8584 M<sup>3</sup>/day (54,000 Bbl/day) unit, if we back off 20% feed or 1717 M<sup>3</sup>/day (10,800 Bbl/day) and replace this by 1717 M<sup>3</sup>/day (10,800 Bbl/day) of shale liquids, then there should be no significant deterioration of the distillate product characteristics. In other words, the co-processing liquids should respond in conventional downstream refinery processing units essentially similar to that of the straight run petroleum-derived liquids. With oil shale priced at \$0.004/Kg (\$4/ton) and resid at \$157/M<sup>3</sup> (\$25/bbl), the differential cash flow available for a) amortizing the capital equipment associated with shale preparation, spent shale disposal and the SCT reaction system and b) operating costs is estimated to be about \$64MM per year. Assuming 20% capital charges and operating costs (ex. shale) of \$0.006/Kg (\$5.75/ton) (8), this cash flow would correspond to an installed capital cost for the upstream shale processing equipment of about \$140 MM.

Some preliminary screening tests were made in the batch autoclave reactor system at LCI's Engineering Development Center. The tests simulated the SCT reaction system in which the oil shale samples were first extracted under short-contact-time conditions. This was followed by blending of the SCT products with an Arab Heavy vacuum residua and hydrotreatment in an LC-Fining<sup>(SM)</sup> simulation test unit. The results of these tests will be reviewed at the Symposium.

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(SM) LC-Fining is a service mark of Lummus Crest Inc. for engineering, marketing and technical services related to hydrocracking and hydrosulfurization processes for reduced crude and residual oils.

## BIOMASS RESOURCES

Biomass materials either virgin in nature such as trees, crops and vegetation or as waste such as refuse-derived fuel (RDF) represent an energy source much like conventional fuels. They vary in composition, density, heating value and other properties. Recycling them as industrial fuel has the added advantage of minimizing the severe and continuing problems associated with solid waste disposal. The total estimated quantity of organic wastes generated in 1980 (9) in the U.S. was about 1 trillion kilograms (1150 million tons). Approximately 15 percent is potentially recoverable and assuming a typical heating value of 2780 gcal/gm (5000 Btu/lb), this energy displacement might be equivalent to  $1.2 \times 10^{18}$  Joules per year or 1.1 quads per year (500,000 bbl oil equivalent per day) when converted to useful fuels.

There are two fundamental methods of biomass conversion to clean fuels: thermochemical and biochemical conversion. While the latter route is the most prevalent currently in development, processes that can produce petroleum-like synthetic fuels should be more desirable than alcohol fuels for example, in that they do not require significant modifications to the existing nationwide network of refining, transporting and utilizing liquid hydrocarbon fuels. Furthermore, because of the unique composition of biomass relative to that of petroleum, selective biomass conversion may result in the generation of high valued, specialty fuels such as certain phenolic compounds having high octane values.

The thermochemical route also has the following potential advantages over that of the biochemical route:

- o Higher thermal efficiency;
- o Wider applicability to feeds containing lignins and contaminants (e.g., MSW);
- o Production of completely detoxified products;
- o Access and similarity to the advanced state-of-the-art technologies utilized in the petroleum/petrochemical/coal industries.

The latter feature is the basis for applying the ITSL co-processing flowscheme to the utilization of biomass feedstocks. The economic driving forces delineated previously for the case of Devonian shale co-processing are even more profound for biomass applications, in particular, the organic-rich fraction of municipal solid waste (sometimes referred to as refuse-derived fuel-RDF). In a manner similar to that previously described for the case of Devonian shale co-processing, it can be shown that it may be feasible to justify the economic tradeoff between the differential values of petroleum feedstocks and MSW tipping fees.

However, because of the smaller capacities associated with MSW collection and classification, co-processing of petroleum residua and liquids derived from RDF would probably be limited to refinery hydrotreaters having capacities below about  $3.18E6$  L/day (20,000 bbl/day). Furthermore, lower feedstock ratios of biomass-derived liquids to those of the petroleum liquids would be necessitated because of the availability and current design capacity of typical MSW classification units. This would in turn result in the co-processed liquids being more petroleum-like and thereby posing less potential problems to the refiner. A similar analysis can be performed of the co-processing of petroleum residua with wood chips derived from forest wastes.

Some preliminary screening tests were made in the batch autoclave reactor systems, similar to those made with the Devonian oil shale samples, utilizing two biomass feedstocks: pine wood flour and dust RDF. The results of these tests and the feedstock properties will be discussed at the Symposium.

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FIGURE 1  
ALTERNATIVE CO-PROCESSING FLOWScheme FOR COAL AND HYDROTREATED RESIDUA

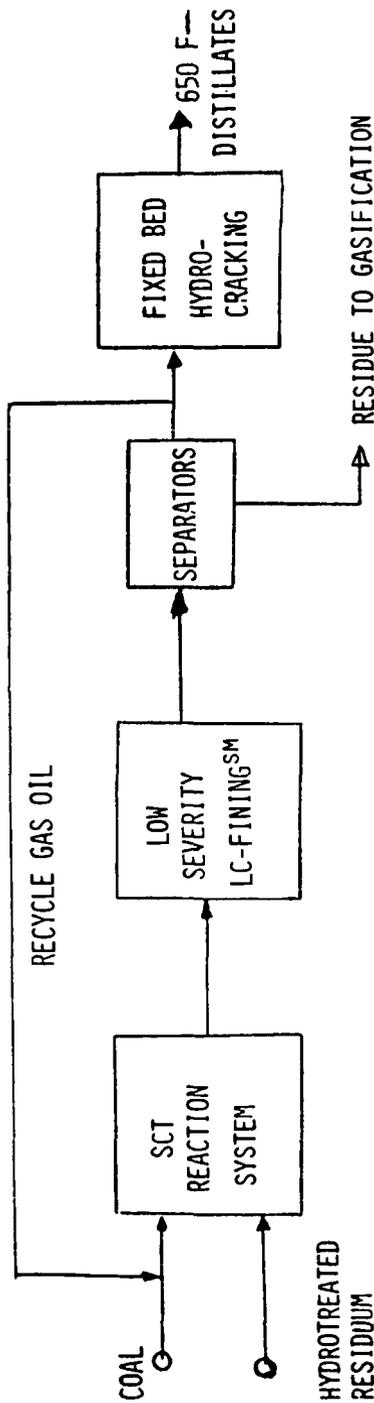
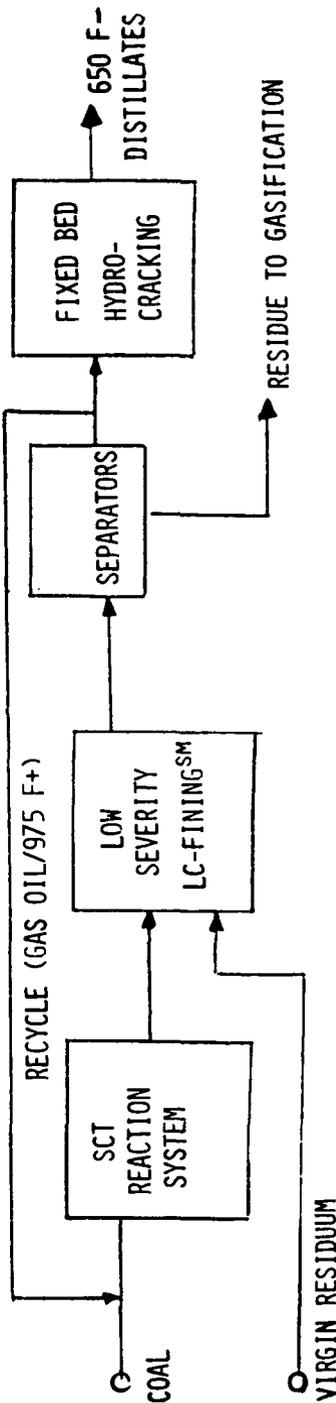


FIGURE 2  
ALTERNATIVE CO-PROCESSING FLOWScheme FOR COAL AND VIRGIN RESIDUA



## COPROCESSING OF HIGHVALE COAL WITH ATHABASCA BITUMEN IN SYNGAS MIXTURES,

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### ABSTRACT

Coprocessing of Alberta subbituminous coal with bitumen is currently under investigation at the Alberta Research Council. The high oxygen content of the coal results in high hydrogen consumption. The present study compares the effectiveness of syngas/water mixtures catalyzed by potassium carbonate for coprocessing Highvale coal with Athabasca bitumen. Single-stage (solubilization) experiments were performed with syngas (5.1 MPa) at 390°C in a stirred autoclave. In simulated two-stage experiments, the second (upgrading) stage employed hydrogen (8.5 MPa) at 440°C with a potassium molybdate/dimethyldisulfide catalyst.

Coal conversion improved from 47 to 78% systematically when the carbon monoxide: hydrogen ratio was varied from 1:3 to 7:1. The additional yield was confined to pyridine extractable material. In simulated two-stage experiments similar coal conversions were observed when using carbon monoxide/water (91%) or hydrogen (88%) in the first stage.

### INTRODUCTION

Within the Province of Alberta there are vast proven reserves of hydrocarbons in the form of coal ( $2780 \cdot 10^9$  tons), heavy oil and bitumen ( $200 \cdot 10^9$  m<sup>3</sup>) and natural gas. The subbituminous coal is mined from shallow deposits and used locally for the thermal generation of power. Bitumen is also surface mined as oil sands; extracted on site and upgraded to a synthetic crude oil ( $20 \cdot 10^3$  m<sup>3</sup>/day) in two commercial operations. Heavy oil is mostly recovered by thermal processes from deeper deposits. It is used in the production of asphalt or blended with light crudes to produce a refinery feedstock.

The low cost of the mined coal (US \$12/ton) has provided the impetus to investigate processes<sup>1,2</sup> to convert the coal into more valuable hydrocarbon products. Recent studies<sup>1,2</sup> at the Alberta Research Council (ARC) have indicated that the coprocessing of Alberta coal with bitumen or heavy oil is technically and economically superior to direct coal liquefaction. Coprocessing eliminates the need for recycle solvents and takes advantage of synergistic effects to improve the liquid yields and product quality from the two feed components.

Laboratory and bench unit studies have shown that two-stage coprocessing has distinct advantages over a single stage operation. Lower temperatures can be employed during the first stage which permit solubilization of the coal while minimizing coke and gas production. The second stage operates at cracking temperatures 430-460°C, conditions which favour upgrading of both the coal and bitumen to liquid products.