ECONOMIC PLANT PRODUCING TRANSPORTATION FUELS & FEED FOR CARBON PRODUCTS FROM COAL

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INTRODUCTION

The U.S. needs a stable supply of environmentally clean, affordable fuels. After the oil embargo and gasolene shortage of the early 1970's when oil reached a price of $35/bbl, the U.S. Dept of Energy (DOE) intensified its work on making transportation fuels by the direct liquefaction of coal, which is the most abundant energy source in the U.S. Continuing improvement in this technology has resulted in confidence in the advanced technology developed on a small scale (to 3TPD.) This evolutionary development ran from bench scale and the Cresap, PA, donor solvent pilot plant in the '70's to the Ft. Lewis, WA, Solvent Refined Coal pilot plant and the Wilsonville, AL, 3TPD process demonstration unit (PDU) in the late 1970's to the demonstration plant program (approximately 200 TPD) in the early 1980's. Thereafter, Exxon offered commercial licenses without any takers, and the program slowed down to further bench-scale and PDU tests at Wilsonville and its successor, Hydrocarbon Technologies, Inc (NJ.)

Further scale-up remains needed, however, to establish commercial readiness. But, partly as a result of improved techniques for exploration for petroleum, world reserves have expanded, mostly in developing nations whose economic needs have pushed marketing and driven oil prices down to about $14/bbl. Nonetheless, Table 1[a] shows that projections are that not only will oil prices increase, but also supply will start to decline starting at about the year 2020 while demand will steadily increase. This would lead in the absence of new factors to an inevitable rapid increase in price. If a partial solution is found in the conversion of coal, Table 1 shows that an expected decline in the cost of coal should be a mitigating factor.

APPROACH

The present price of about $14/bbl is a much more difficult target for liquids from coal. This has led DOE to look for profitable co-products to improve the economics of the liquefaction process. A particularly attractive one of these is a heavy, clean hydrocarbon pitch suitable as feed to make carbon products. In addition to such million-tons/yr markets for carbon products as anode coke for the aluminum industry and graphite anodes, there is the rapidly growing need for feed for manufacturing Carbon Fibers for use in composite materials. These carbon fibers and composites thereof have an unusual combination of superior strength and light weight. As a consequence this is likely to lead to their becoming commodity materials used for structural members and bodies for high mileage cars. This in turn could result in a dramatic reduction in emissions from vehicles as well as a significant decrease in the cost of their fabrication. Another desirable outcome is that the carbon products produced tie up carbon for an extended period and reduce the emissions of the Greenhouse Gas, CO2, that would result if the product were fuel.

This paper describes a proposed giant step in process development/demonstration based on data developed in the 1980's by DOE with the 3 TPD Wilsonville, AL, coal liquefaction PDU (b.) Liquefying coal requires its dissolution, liquefaction at ~ 825F and 2000 psi hydrogen pressure, plus deashing either by filtration or critical solvent deashing, and further selective hydrotreating to produce light hydrocarbons without over cracking them. With the carbon-product pitch as a valuable co-product obtained as a bottom of the barrel product of the first of the two stages, further selective hydrocracking of this co-product is no longer required so that the complexity of the process and its severity and hydrogen requirement are significantly decreased. Figure 1 compares the two process variants. Instead of two expensive slurry bed catalytic stages and ash separation as presently specified to produce an all distillate product, a thermal reaction stage, ash separation and a fixed catalytic stage suffice. Fixed bed catalysis has been estimated to cost one-fifth of the cost of ebullated bed catalytic reactors. With removal of the first stage heavy fraction as a source of the Carbon Product feed, the cost of the second stage fixed bed catalytic reactor will be smaller and cheaper. As a result the process economics are estimated to be significantly improved.

DATA

Table 2 compares the conditions selected for the 1982 one product configuration vs. the proposed co-product plant. As stated the primary source of cost reduction is reduction in the amount and hence cost of hydrogen. In the present one product, "all distillate" plant, the hydrogen cost has been estimated to be one-half of the total cost of the conversion of coal to distillate hydrocarbon fuels or

$15/bbl of product. Table 3 lists the ways in which hydrogen requirement is reduced. The lower severity (temperature, pressure, residence time) results in a drop in C1-C4 gaseous hydrocarbons which require much hydrogen but have little more than fuel value. The decrease is estimated to be from 7% to 3% on feed coal with an average composition of CH_3 giving a 1.65% drop in total H_2 needed. Moreover, for a process requiring a total residence time of one hour or more, its reduction to reduce severity would help. This should work since the PDU testing included a successful short contact time thermal stage of a few minutes. A more significant decrease in hydrogen requirement results from the conversion of the feed coal with its average composition of $CH_{0.7}$ to essentially pure carbon at about 800C which otherwise would need an added 1.2 atoms of H to convert them to liquids. This 1.9 H/C savings cuts the hydrogen cost by $10.50 and the product cost to $20/bbl of fuel plus carbon product carbon equal to that in one bbl of fuel which assumes that the carbon has the same value as the oil. Therefore, it was assumed that Carbon products will be 40% of the product slate. The hydrogen formerly found in the coal is recovered when it reports upon the conversion to Carbon Products largely as aromatic distillates that are suitable as part of the fuels product or as chemical products.

DISCUSSION

A reasonable approximation is that the revenue requirements of a co-products plant is the same as the one-product plant. For the one-product plant the revenue requirement equals the typical 4 Bbl/Ton of feed coal at the above reduced price of $20/Bbl made possible by making 0.4 Tons of C-Products/Ton of feed coal giving $80/Ton of feed coal as the required revenue per ton of feed coal. Table 4 gives possible options for pricing of the two co-products that each generate the needed revenue. This shows that the oil product can be priced competitively even with the existing world petroleum prices of $10-14/bbl with the last set of co-product prices shown. The Carbon Product feed price is also realistic since Table 4 shows that with the oil product priced at $10/bbl the required price of C-Product feed is $140/ton of Carbon Product ($0.07/lb.) vs. a carbon fiber manufacturer's estimate that his feed cost is $1.80/lb. for carbon fibers. Table 4 also shows the ability to exercise pricing flexibility, i.e. the capability of the processor to follow the ups and downs in world petroleum prices in order to maximize profitability even as is the case in the pricing of gasolene by the petroleum industry. This compares with $30/bbl oil needed for a single product plant at a 20% ROI. No credit has been taken for the simpler process and reduction in process severity.

CONCLUSIONS

Added R&D will be needed (1) to redefine the conditions required for the two product plant though no dramatic changes are indicated, (2) to demonstrate the integrated process for valuable co-products, (3) to confirm the economics, and (4) to confirm marketing estimates. Ongoing tests by a DOE contractor (CCP) will continue in order to confirm the suitability of the carbon product feeds and carbon products produced. Carbon fiber composites are already common for tennis rackets, for golf clubs, and for aircraft parts. Work on production and marketing of carbon products for automobile and structural applications will be needed. A life cycle study has been reported[c] of the use of carbon product composites for automobile manufacture taking into account ease of fabrication, fuel economy, etc to determine the price of carbon fibers at which their use for this application is justified. The study concludes that this price is $5 to $7.50/lb. A major manufacturer has indicated that it already prices carbon fibers at $8/lb. to large users and expects to achieve $5/lb. in the year 2000.

If the proposed added work confirms the above conclusions as to supply-demand for fuels, competitive position of carbon fiber composites for high volume markets, and capability of direct coal liquefaction to supply low cost carbon product feed, a number of important, significant improvements should result. In transportation, use of light weight vehicles manufactured from carbon fiber composites having reduced emissions and lower operating cost will grow. In the fuels area, the coal liquefaction co-product plants will add to domestic fuel resources and create domestic jobs that otherwise would continue their decline. With respect to the future of U.S. coal such co-product plants will speed up utilization of this large domestic energy resource in an environmentally safe manner.

REFERENCES

(a) U.S. D.O.E. and/or contractor estimates, 1997,1998.
(b) U.S.D.O.E. Report DOE/PC/50041-55, Sept, 1985,
(c) A.E.Mascarin & M.M.Brylawski, http://www.rmi.org/hypercars/b_i_w/T95_35.html, 1998

Table 1:PROJECTED RESOURCE BASE CONSUMPTION AND PRICE OF ENERGY THROUGH 2020[1] AND BEYOND[2]

	1996	2000	2005	2010	2015	2020	2040	2060
U.S. Consumption, B/D	18.44	19.62	21.15	22.70	23.65	24.39	----	----
Oil Price, $/B	20.48	19.11	20.19	20.81	21.48	22.32	----	----
Coal Price, $/Ton	27.52	25.80	24.40	23.12	21.76	20.56	----	----
World Product Capability, B/D	75.0	81.0	87.0	93.0	98.0	100.0	55.0	12.0

(1) DOE Energy Information Agency (1998)
(2) DOE Energy Information Agency, as supported by Mitretek (1998)

TABLE 2: CURRENT AND 1982 SINGLE PRODUCT PLANTS VS 1982 CO-PRODUCT PLANTS
(All %'s based on feed coal)

Type Plant:		**1982 Single Prod.344b-g**	**1982 Single Prod., Short Contact,242**	**Calc'd 1982 Co-prod, Short Contact Time**	**Current Single Dist. Prod.**
	Proc Stage 1				
	Reactor Size	**8**	**2**	**2**	**8**
	Space Rate, lb/hr,sq ft	**40**	**95**	**95**	**40**
	Pressure, psi	**2400**	**2400**	**2400**	**2400**
	Temperature, F	**825**	**825**	**810**	**825**
	Hydrogen Used, %	**1.5**	**0.7**	**0.7**	**3.**
	C1/C3 Gas Make,%	**4.2**	**3.3**	**2.0**	**4.5**
	% C-Prod. Feed or % Resid	**5 resid**	**5 resid**	**55**	**5 resid**
	Distillables, %	**55**	**28**	**20**	**58**
	Entire Process				
	Hydrogen Used, %	**5**	**5**	**2.3**	**7**
	C1/C4 Gas Make, %	**7**	**5**	**3**	**7**

TABLE 3: WAYS IN WHICH HYDROGEN REQUIREMENT IS REDUCED
(All %'s are % of Feed Coal)

Means of Reducing H2 Requirement	H2 Requirement, Current Single Product Plant	H2 Requirement, Proposed Two Product Plant	Estimated Savings: % H2 on Coal & $/Bbl Equiv.
Reduced "CH3" Gas Make	7.0%	3.0%	0.8% & $1.65/Bbl
H2 Released by "CH.7" Coal Converted to C-Products	0	1.9%	1.9% & $3.20/Bbl
Avoid 1.2 H/C Needed to Convert Above Coal to "CH2" Distillates	0	2.8%	2.8% & $6.00/Bbl
TOTAL SAVINGS			**$10.60/Bbl**

Basis:
(1) Upon the high temperature version of C-Products feed to carbon products essentially all the hydrogen reports as volatized hydro aromatic distillate product.
(2) Estimated 40% of Feed Coal to C-Product Feed

TABLE 4: RESULTANT CO-PRODUCT COSTS

CASE I: MAKE 0.4T. C-PRODUCT+ (0.6)(4 BBL/T) OIL PER TON OF FEED COAL ASSUME TOTAL PROCESS COST = ($30 - $10 SAVINGS)(4 BBL/T COAL)

Assumed Price of Heavy Oil for C-Product, $/T. C-Product	Resultant Product Oil Cost $/Bbl
100	16.7
50	25.0
75	21.0
140	10.0

Basis: $\frac{\text{0.4 T. C-Prod + 2.4 Bbl Oil}}{\text{T. Coal Feed}}$

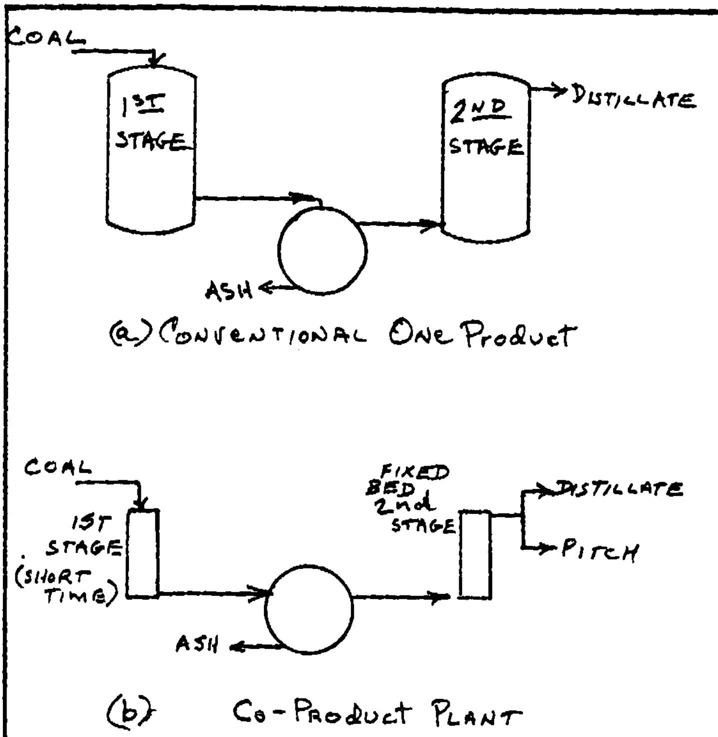

FIG. 1: ALL DISTILLATE VS CARBON CO-PRODUCT PLANT -- UNITS SCALED TO ACTUAL SIZE