Title: Integration Opportunities for Coal/Oil Coprocessing with Existing Petroleum Refineries

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Introduction:

In the future, petroleum refineries will require modification if they are to efficiently process the lower quality crudes and heavy oils that are expected to become more prevalent in world crude markets. As crude quality declines and final product fuel specifications become more demanding to meet environmental regulations, many refineries will find it necessary to make expensive additions to their capital facilities. These additions will allow refiners to increase processing severity to meet future product specifications, and to take advantage of the diverging price differential between light sweet crudes and more abundant heavier crudes. With the price of crude oil and the value of refined fuels increasing relative to the value of residual and other bottom-of-the-barrel products, a strong incentive exists for a refiner to maximize output of higher value products. Increasing coking capacity to process vacuum residual has been the refiner's preference to date, but excess petroleum coke product will exacerbate the glut of coke on the market, depressing its price even further. As the quality of the resid feedstock declines with respect to sulfur and heavy metals content, the resulting coke quality is poor and consequently has little economic value.

An alternative to simply coking the vacuum resid is to utilize resid hydrocracking followed by coking of the unconverted hydrotreated resid. This combination results in more distillate of higher quality. The resulting coke quality is improved as a result of the hydrotreatment and could be suitable for anode coke production and should command a high value. Introduction of resid hydrocracking technology into a refinery paves the way for the coprocessing of this resid with coal. There has been considerable research and development work sponsored by the U.S. Department of Energy to improve technical performance and the resulting economics. The results of work performed at Hydrocarbon Research Inc. (HRI) and more recently at Hydrocarbon Technologies Inc. (HTI) have been extremely promising. The concept of coprocessing allows two low-value feedstocks like resid and coal to be used to produce high-value distillate.

The configurations for direct coal liquefaction and coprocessing currently being developed utilize supported or dispersed catalysts in ebullated or back-mixed hydrocracker reactors similar to those designed to process petroleum refinery bottoms. Such units are slowly coming into wider use in refineries and in bitumen upgrading as bottoms processing and bitumen upgrading become more important. The promising technical performance of coal/resid coprocessing demonstrated in small-scale continuous units at HTI represents an opportunity for the introduction of domestic coal into existing refineries and, therefore, for an early application of coal liquefaction technology. Coprocessing units once added to a refinery could also be used to hydrocrack petroleum resid. This flexibility substantially reduces the technical and financial risks to a refiner interested in deploying coprocessing; a technology having no full-scale industrial precedent.

The analysis reported in this paper uses data from the operations at HTI to develop conceptual coprocessing plant designs that can be integrated into existing petroleum refineries. The objective of this integration is to allow the refiner to use lower cost feedstocks and still produce essentially the same final product slate. This is accomplished with minimal changes to the downstream refinery operations to minimize refinery disruptions. By reducing refinery feedstock costs, overall profitability will be enhanced if the increased margins counteract the capital investment necessary for the coprocessing facility.

The HTI COPRO Process

The schematic of the HTI COPRO process is shown in Figure1. The feed consisting of different compositions of coal, heavy oil, dispersed catalyst, and recycle oil is mixed with hydrogen and sent to the slurry preheater. Here the coal/oil mixture is heated and coal dissolution begins. The mixture is then sent to the bottom of the first stage back-mixed reactor. The effluent from the top of the first stage reactor flows into an interstage high-pressure separator where gases and light distillate formed in the first stage are separated from the heavier slurry products. These are mixed with additional hydrogen and pumped into the second stage back-mixed reactor. The products from the second stage reactor are fractionated in a high pressure separator into heavy slurry product that enters a flash vessel for further separation and light products and gases. These light products are combined with the light products and gases from the interstage separator and those from the overhead stream of the flash vessel, containing about 85 percent hydrogen, and sent to an in-line fixed-bed hydrotreater. The effluent from the in-line hydrotreater passes to a low-pressure fractionator that separates gases and light hydrocarbons from the product distillate. This light gaseous product is sent to hydrogen purification where hydrogen is separated and purified for recycle and LPG and acid gases are recovered. The flash vessel bottoms are sent to a solids separation unit, for example a Critical Solvent Deasher (CSD), where heavy distillate and unconverted and product resid are recovered for recycle. The underflow stream containing used dispersed catalyst, unrecovered resid, unconverted coal and mineral matter is sent to gasification for hydrogen production.

Test data from HTI run PB-01 material balance period 25 was used in this analysis to develop a conceptual commercial design of the coal/oil coprocessing unit. In run PB-01, the feeds were 50 weight percent Black Thunder coal and 50 percent by weight Hondo resid. These were processed together using a dispersed catalyst system consisting of 50 ppm molybdenum and 5,000 ppm iron.

Integration of Coprocessing and the Refinery:

A generic refinery has been used to illustrate how coprocessing can be integrated into an existing refinery to provide distillate products that are compatible with the downstream refinery operations. This generic refinery uses coking to process the bottom products from the vacuum still. A simplified schematic of this generic refinery is shown in Figure 2. The feedstock consists of 65,000 BPD of an average crude containing 20 volume percent 950°F+ that is sent to an atmospheric still where it is topped and the atmospheric bottoms are sent to a vacuum still. Vacuum gas oil (VGO) is recovered and the vacuum bottoms are sent to a delayed coker for processing. Coker distillate is recovered and the resulting coke is the final solid product. This coke is of low quality, containing heavy metals and high sulfur. It has a low value, probably about $3-5 per ton. This generic refinery produces 59,680 BPD of C5-950°F distillate material consisting of atmospheric overhead, vacuum overhead, and coker distillate. LPG is also produced. This distillate material is then processed in the refinery downstream units to produce gasoline, diesel fuel, and 760 tons per day of low value petroleum coke.

The bottom of Figure 2 shows the coprocessing unit integrated into this generic refinery. This conceptual unit consists of two full-scale commercial trains of HTI COPRO and coal gasification for hydrogen production. The coprocessing unit processes 38,670 BPD of low value Hondo resid and 6,500 tons per day of coal. An additional 3,800 TPD of coal is sent to gasification for hydrogen production. This coprocessing unit produces 45,850 BPD of C5-850°F distillate and 6,200 BPD of LPG. All of this material is sent to the refinery to be upgraded in the refinery's downstream units. In this coprocessing case, the refinery uses the coprocessing distillate in place of the 65,000 BPD of purchased crude. An additional quantity of 13,535 BPD of 850°F+ material is also sent to the refinery from the coprocessing unit. This is sent to the delayed coker where 8,120 BPD of coker distillate is recovered and 770 tons per day of high quality coke is produced. The insert table in Figure 2 shows the resulting quantities of distillate in the baseline generic refinery case and in the coprocessing case. As can be seen, the total quantities of distillate in the two cases is very similar, therefore downstream refining operations are not changed.

The quality of the distillate produced in the coprocessing unit is assumed to be compatible with the existing generic refinery's downstream processing capabilities. This is a reasonable assumption considering the reported high quality of products from the HTI COPRO process. The resulting quality of the coke product from the coprocessing case is assumed to be superior to the baseline coke. Since this material has undergone extensive hydrotreating prior to coking, it is assumed that the coke will be anode quality and thus worth $200 per ton. Because of this potential high value, the coke was not gasified to produce hydrogen for the coprocessing unit. Additional low value coal was used for hydrogen production.

The capital cost for the two-train coprocessing facility including hydrogen production is estimated to be $837 million. In the generic refinery, feedstock cost for crude oil at $20 per barrel is $429 million per year. Feedstock costs in the coprocessing refinery are only $128 million for the Hondo resid per year and $82 million for coal for a total of $210 million. Thus, feedstock savings of $219 million per year are achieved by using the coprocessing feed to the refinery in place of crude oil. Also, if the coprocessing petroleum coke is worth $200 per ton, an additional $51 million per year in revenue can be realized through sales of anode quality coke.

The return on equity (ROE) for this two-train coprocessing unit has been calculated as a function of crude oil price. For a 33 percent equity financial assumption case, a 15 percent ROE can be obtained for this facility at an oil price of $20 per barrel. Thus in the current oil price range, a coprocessing facility integrated with the appropriate existing refinery could realize acceptable rates of return for investors. This observation is contingent upon on the assumed capital cost of the coprocessing facility, the level of technical performance shown, the relative feedstock costs, and the premium value obtained for the coprocessing coke.

Conclusions:

Modification of existing refineries so that they are able to use a combination of coal and low value residual materials in full scale coprocessing facilities is potentially profitable at today's oil prices. Returns on equity of about 15 percent could be realized with conventional 33 percent equity financing if the resid feed to the coprocessor was half the cost of crude oil and coal was $1 per million Btu. However, because of the high capital investment required, around $600-850 million, the uncertainties about future oil price and supply, and the technical uncertainties inherent in technology not previously proven in a commercial scale, the required modifications would not be bankable propositions for most potential investors.

Smaller scale coprocessing modifications utilizing a single, half-scale coprocessing train can reduce the capital requirement to about $370 million for a project supplying hydrogen for both the refinery and the coprocessing unit. These smaller units suffer from inefficiencies of scale and are thus less profitable than the full scale units giving returns on equity in the range of 5 to 10 percent. Investors would thus require incentives in the way of investment tax credits, State and/or Federal Sales tax exemptions, or some form of product price guarantee in order to find the risks acceptable. However, the required incentives would generally be less costly than those that have already been provided to stimulate the production and use of other alternatives to imported oil. The successful completion of an incentivised **pioneer** plant would pave the way for full-scale follow on facilities that would be profitable without incentives. These facilities have the potential of making a substantial contribution to the production of transportation fuel from domestic sources.

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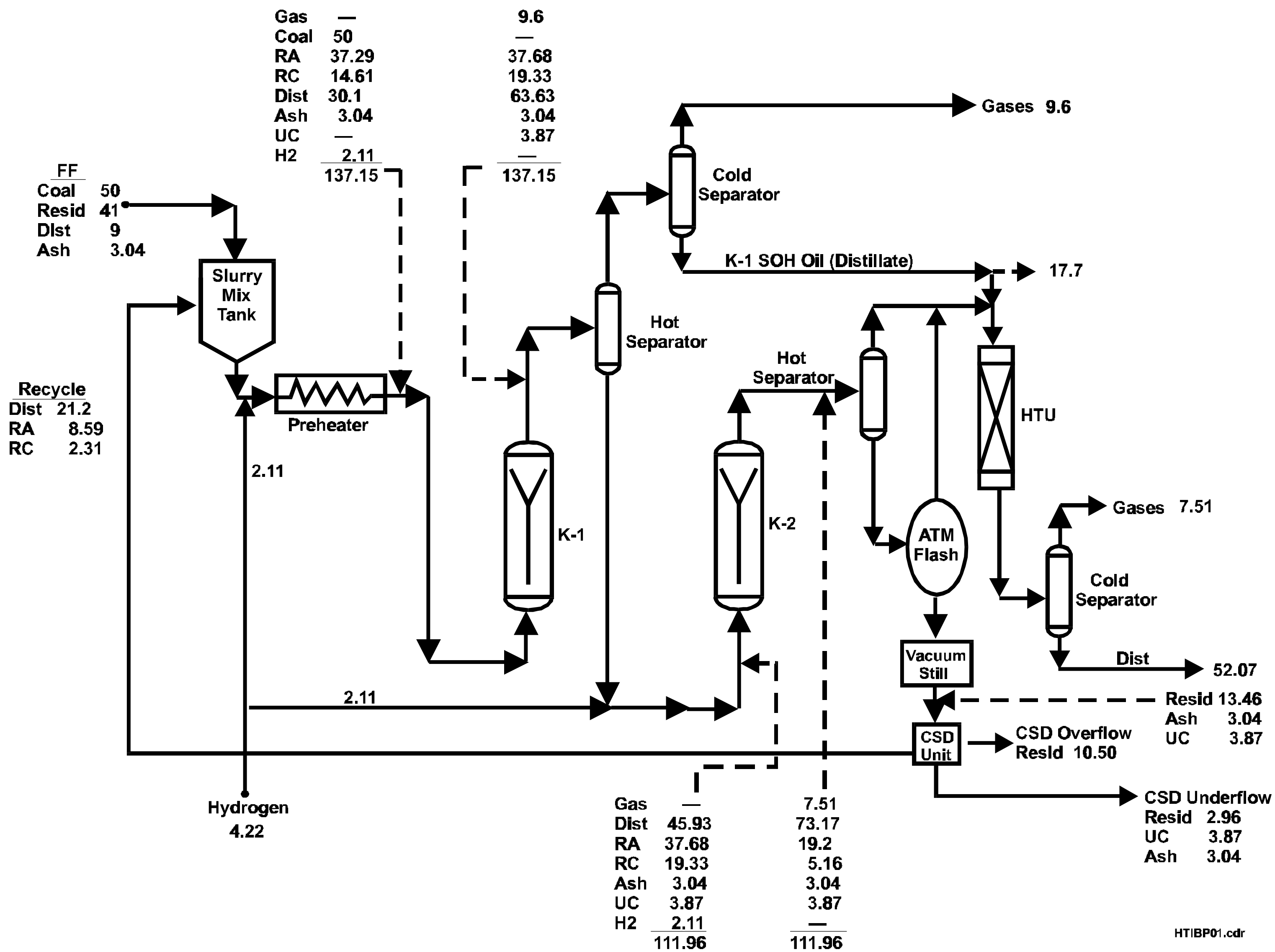

Figure 1. HTI COPRO Process Schematic

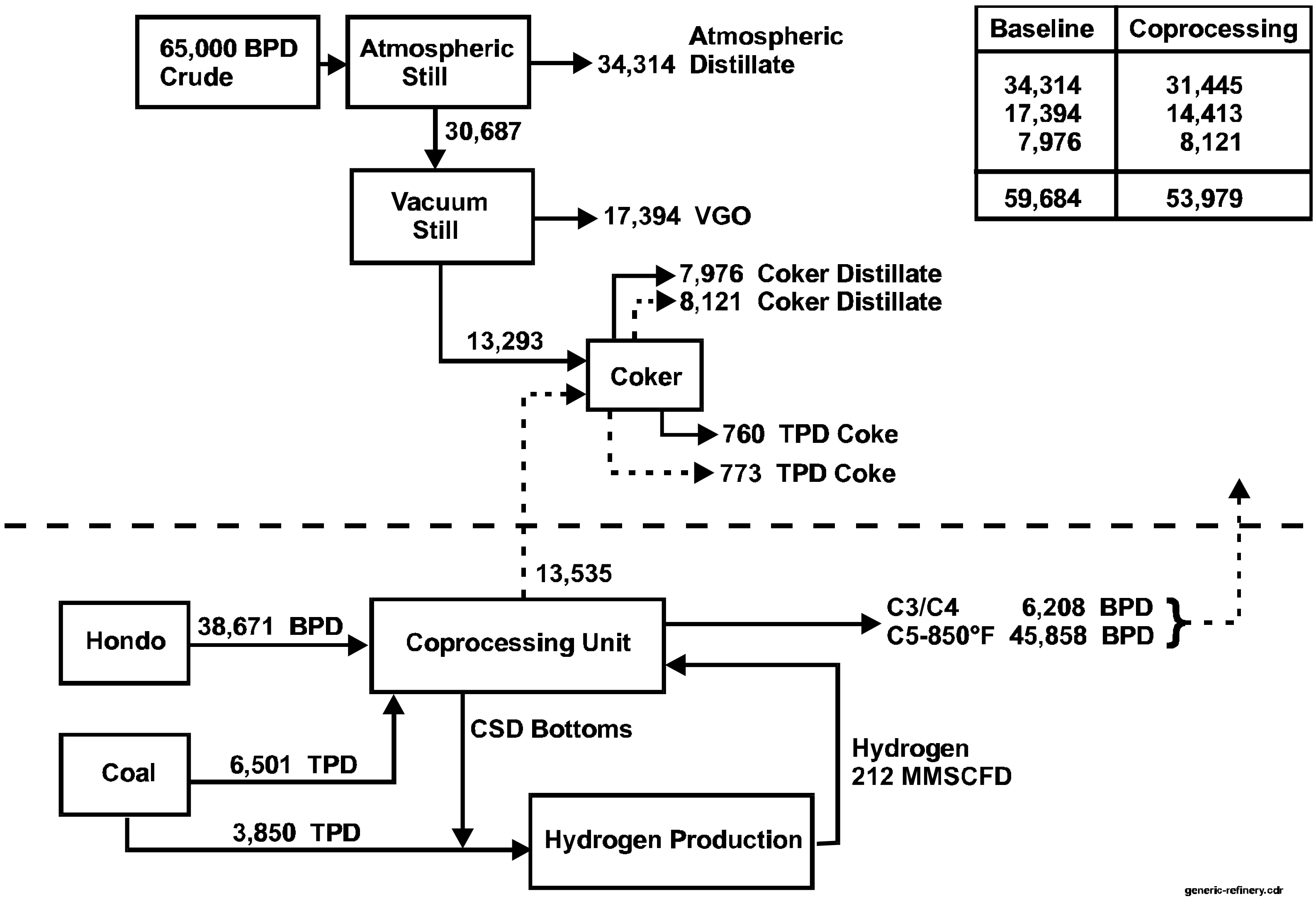

Figure 2. Generic Refinery/Coprocessing Integration