10 ppm Sulfur Gasoline Opportunity Analysis

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A comprehensive analysis was necessary to identify the best scenario required to meet ULSG regulations: Severe FCC feed pre-treatment alone or milder pre-treatment combined with FCC gasoline post-treatment. CFHT cycle length requirements, with and without post-treatment, were also under scrutiny to determine their impact.

An existing refinery reconfigured to process Heavy Canadian Crudes while maintaining its FCC Unit was assumed. The VGO feedstock consists of a 55,000 BPD blend of straight run VGO and Heavy Coker Gas-Oil with 4.2 wt% sulfur. Due to the refractory nature of this feed, it has to be hydrotreated in a high pressure unit prior to feeding the FCCU and the resulting gasoline constitutes about one third of the total gasoline pool and all of the pool sulfur.

The following three cases were considered:

- **Case 1:** A high HDS CFHT unit and FCC capable to produce a 10-wppm Gasoline pool sulfur without the need of a FCC Post-treatment unit with a CFHT cycle length of 4 years to match the FCC.
- **Case 2:** A moderate HDS CFHT designed for a 4-year cycle length with a FCC Post-treatment unit (Prime-G+) designed for a 4-year cycle length to meet ULSG pool specifications.
- **Case 3:** Similar to Case 2 but with a 2-year cycle length target for the CFHT unit combined with a Prime-G+ unit designed for a 4-year cycle length. During the CFHT catalyst change-out, the Prime-G+ unit will operate at a higher severity to meet pool sulfur requirements.

For all cases, a relatively high pressure was selected for the CFHT to ensure good hydrogen addition during the whole run. Reactor residence time was adjusted to meet the CFHT HDS and cycle length requirement - Figure 1. The very severe level of HDS and 4-year cycle length in Case 1 naturally leads to a much larger CFHT than the other cases. High purity hydrogen is supplied from a SMR plant.

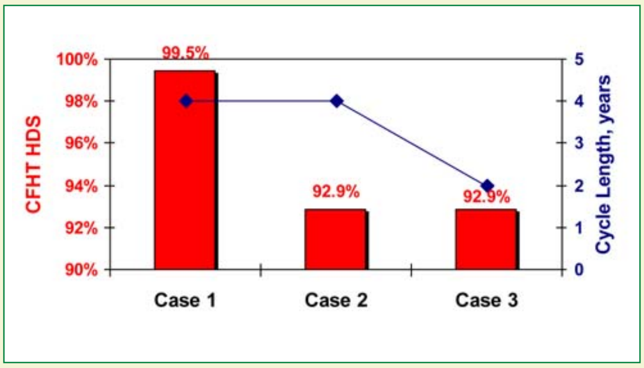


Figure 1 CFHT HDS & Cycle Length

A block flow diagram illustrating the three different cases with the various configurations along with the corresponding products considered for the economics is shown in Figure 2.

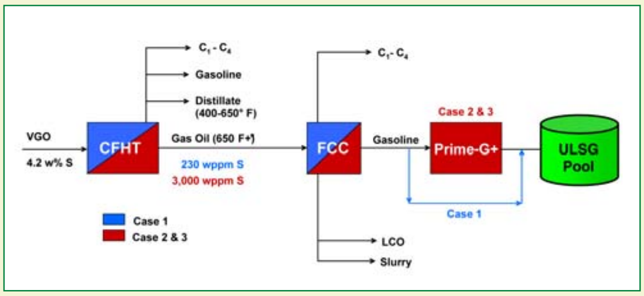


Figure 2 Case Studies Block Flow Diagram

The economic evaluation was based on a Discounted Cash Flow (DCF) analysis assuming a depreciation period and a project duration of 10 years. In addition, a profitability index comparison in terms of Net Present Values (NPV) and Internal Rate of Return (IRR) was conducted. The prices for investment, catalysts, utilities, feedstock and finished products were based on 2011 averaged values assuming the plant to be located in the USA serving a domestic market. Prices are presented in Table 1.

Table 1 Price Considerations

Feedstock	96 US $/bbl
Natural Gas	4.0 US $/MMBtu
Hydrogen	3.300 US $/MSCF
LPG	69 US $/bbl
Propylene	140 US $/bbl
Butenes	112 US $/bbl
Gasoline Premium	127 US $/bbl
Diesel/LCO	131 US $/bbl
Fuel Oil	104 US $/bbl

For all three cases considered, projections on CFHT and FCC operations were conducted leading to expected product yields and hydrogen requirement. As one could have expected, the implementation of a high severity CHFT (Case 1) leads to better product yields in the FCC but has a major drawback of driving hydrogen consumption up. Results in terms of main product yields and hydrogen cost for each case are presented in Table 2. The evaluation was based on a Natural Gas price of $4/MMBTU resulting in a hydrogen cost of $3.300/MSCF.

Table 2 Study Results - Product Yields & Hydrogen Requirement

Case **New Units** **Cycle Length**	**Case 1** **CFHT** **4 yr**	**Case 2** **CFHT+** **Post-treat** **4 yr + 4 yr**	**Case 3** **CFHT+** **Post-treat** **2yr+4yr**
Gasoline Yield, Vol.% / VGO Feed	61.9	56.3	55.0
Diesel + LCO Yield, Vol.% / VGO Feed	27.2	27.6	28.0
Propylene Yield, Vol.% / VGO Feed	7.8	7.5	7.3
Butenes Yield, Vol.% / VGO Feed	8.8	8.3	8.1
Hydrogen Cost, $/bbl Feed	4.71	3.73	3.66

The hydrogen cost for Case 1 is almost 25% higher than that of Case 2 or Case 3; however, the yield improvement is quite significant over the lower severity CFHT cases. Between the lower severity CFHT cases, the yields and hydrogen consumption are rather similar with the more severe and longer cycle Case 2 providing a slight improvement in terms of yields over Case 3 commensurate with the small increase in hydrogen consumption.

With regards to the operating cost (OPEX) of the different cases, the study took into consideration the hydrogen, octane and utility costs. Compared to the other factors, the hydrogen cost was by far the major contributor to the OPEX. In addition to the operating cost, a detailed Total Capital Investment (TCI) was developed to estimate the CAPEX for each case.

The TCI trend illustrated in Figure 3 clearly shows that Case 1 has a much higher capital requirement than the other two cases due to the significantly higher desulfurization and cycle length requirements for the CFHT.

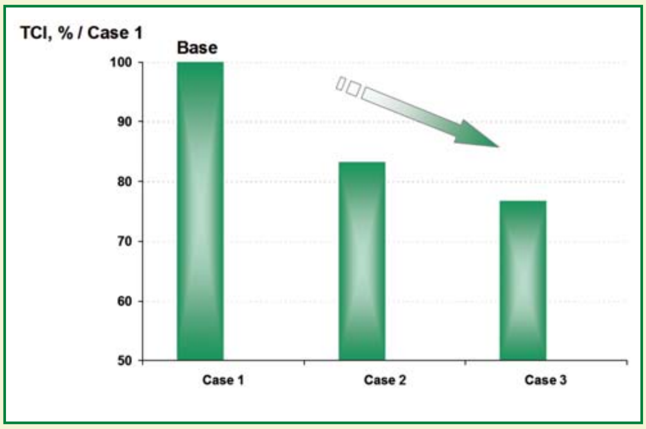


Figure 3 Total Capital Investment (TCI) Impact

Both Net Present Value (NPV) and Internal Rate of Return (IRR) comparisons are shown in Figures 4 and 5. The high severity CFHT without post-treatment, Case 1, was considered as the basis and the IRR and NPV of the other cases were compared to Case 1.

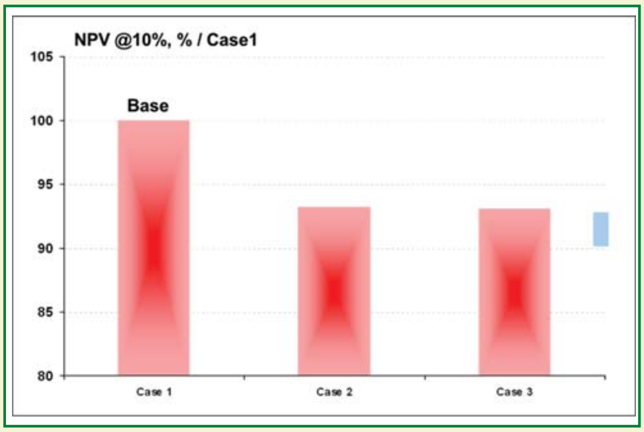


Figure 4 NPV Results

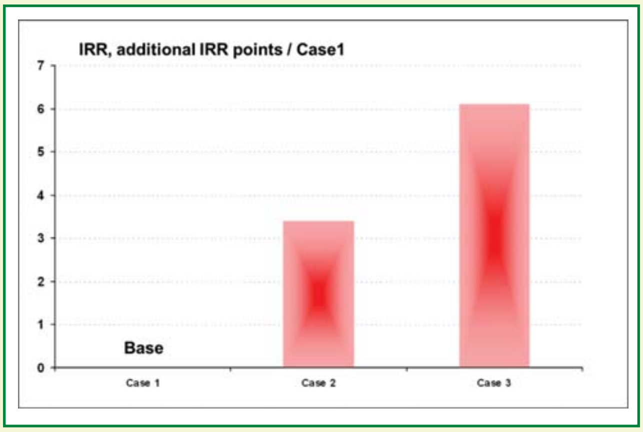


Figure 5 IRR Results

The NPV results favor Case 1 with a high HDS/long cycle length CFHT and no post-treatment over more moderate HDS CFHT cases coupled with a post-treatment unit. On the other hand, the IRR is most favorable for Case 3 with the lowest cost CFHT option (moderate and 2-year cycle) coupled with a 4-year cycle post-treatment Prime-G+ unit.

A sensitivity case was examined to determine the impact of Natural Gas (NG) cost on the NPV results. The findings are highlighted in Table 3 where pricing is contrasted to the 2011 basis above. Assuming a higher NG price (6 vs. 4 \$/MMBTU), the cost of hydrogen increases and the difference in NPV between the three cases diminishes somewhat.

Table 3 Study Results - Hydrogen Cost Sensitivity Study

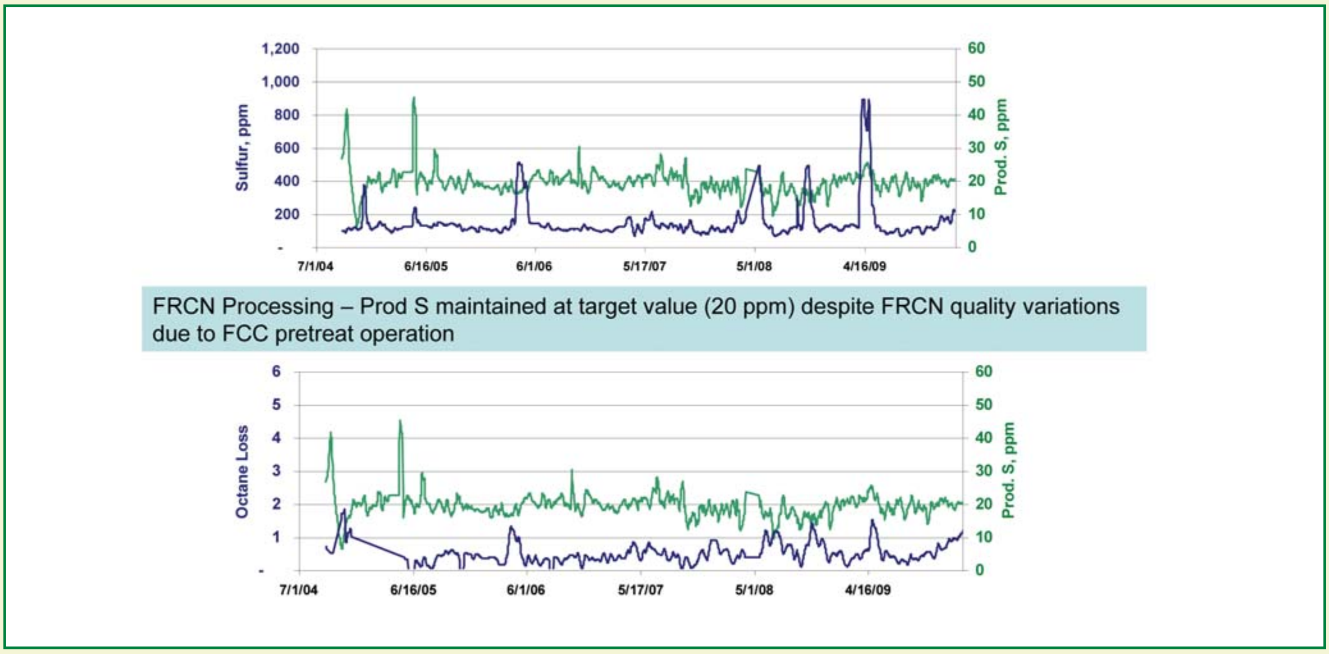
Case Study	Case 1	Case 2	Case 3
NPV @10% : Nat. Gas = 4 \$/MMBTU (case 2011)	Base	Base x 0.93	Base x 0.93
NPV @10% : Nat. Gas = 6 \$/MMBTU	Base	Base x 0.94	Base x 0.94

From and IRR perspective, the advantage of Case 3 increases when hydrogen cost increases and the gap in NPV between Case 1 and 3 decreases.

Surprisingly, Case 2 with a 4-year CFHT cycle in sync with the FCC cycle does not show an NPV or IRR advantage over the shorter cycle Case 3 for either NG pricing scenario. One could have assumed that designing a CFHT in sync with the downstream units compared to limiting the CFHT cycle length to only 2 years would be an advantage. However, the 4-year cycle post-treatment unit brings the additional flexibility to continuously operate during a CFHT catalyst change-out. Despite higher feed sulfur (that could be partially limited with a change in crude diet during the CFHT catalyst change-out) the design of the post-treatment unit with the Prime-G+ technology is robust enough to handle this higher severity requirement during the catalyst change-out.

This flexibility is clearly illustrated in Figure 6 which shows operating data on a Prime-G+ unit in a refinery processing heavy crudes and equipped with a FCC CFHT pre-treater. When the CFHT is in operation the normal feed sulfur to the Prime-G+ unit is typically below 200 wppm. Despite turnarounds or operation upsets on the CFHT unit, which can lead to feed sulfur as high as 900 wppm, the product sulfur from the Prime-G+ unit can be maintained to the target value of 20 wppm at all times.

When processing Full Range Cut Naphtha (FRCN), the sulfur content in the product is maintained at the target value (20 ppm), as shown in Figure 6, despite variations in FCRN quality thanks to the FCC pretreatment option.



FRCN Processing – Prod S maintained at target value (20 ppm) despite FRCN quality variations due to FCC pretreat operation

Figure 6: Prime-G+ Operation Flexibility

The flexibility brought by adding a post-treatment to the compulsory FCC pretreater when processing heavy crudes should be underlined and is a major advantage over the pre-treatment alone solution. In order to produce a gasoline pool with less than 10-wppm, the refinery becomes a chemical plant with no margin for error; relying on the CFHT alone leaves little flexibility.

In summary, coupling a CFHT with a FCC Naphtha post-treatment unit brings the following advantages:

- The CFHT severity is lowered which offers the possibility to revamp an existing CFHT.
- It is possible to design the CFHT unit for a cycle length of 2 years instead of 4 years.
- The Prime-G+ post-treatment design is simplified to typically a single-stage unit.
- The refinery reliability and flexibility is improved:
- CFHT upset may be compensated by the Prime-G+ post-treatment unit.
- CFHT severity may be decreased if needed/ permitted.
- FCCU operation is more flexible in terms of fractionation quality.
- FCC gasoline end-point may be increased when margins favor gasoline production while still controlling FCC naphtha sulfur through post-treatment.

The issue of SOx and NOx control in FCC flue gas is not addressed in the above analysis. The high severity CFHT (Case 1) may allow the typical 50 and 40 ppmv targets for SOx and NOx to be achieved directly while a flue gas scrubber would be necessary to meet such constraints with Cases 2 and 3. The addition of the scrubber for Cases 2 and 3 decreases the IRR differential to Case 1 by one point while conversely the NPV advantage over Case 1 is increased by approximately 1%.

It is important to note that in spite of a trend in favor of Case 3, the conclusion drawn from this particular study is case specific and cannot be generalized to other cases that may have different configurations and project premise.

Conclusion

A large number of countries are working towards a 10 wppm limit in transportation fuels sulfur levels. After reviewing commercial best practices and specific refinery challenges, meeting new ULSG regulations with existing FCC post-treatment assets can be achieved. Low refinery margins combined with capital constraints will likely favor the revamping of existing FCC post-treatment units.

Although each situation is unique, the combination of pre-treat and post-treat solutions around the FCC Unit will often result in increased flexibility and benefits. As a licensor of CFHT, FCC and FCC post-treatment technologies, Axens is tailored to provide the service that will fit each specific case.

> *“If you love life, don't waste time, for time is what life is made up of.”*
>
> *~Bruce Lee*

> *“Everyone suffers some injustice in life, and what better motivation than to help others not suffer in the same way.”*
>
> *~Bella Thorne*