Sumitomo SHI FW built the 74 MWe cogeneration facility at the PetroPower Plant in Talcahuano, Chile, which has been successfully operating since 1998.

A STRATEGIC SOLUTION

As the industry prepares for the impending IMO sulfur regulations, **Robert Giglio, Sumitomo SHI FW, USA,** explains how refiners can find opportunity in a disrupted heavy sulfur fuel oil market.

Refining is the process of separating crude oil into different hydrocarbon groups through distillation. Atmospheric distillation is used to produce fuels such as propane, gasoline, and diesel, based on market demand. The heavy crude residual or 'bottoms' produced by atmospheric distillation are further separated into light fractions using vacuum (low pressure) distillation.

The vacuum residual produced by vacuum distillation is long carbon chain residual oil that is thermally heated or 'cracked' to produce short chain molecular weight hydrocarbon gases, naphtha, light oil products, as well as a residual solid product known as petroleum coke (petcoke). Refineries configured with a 'delayed coking' system can generally produce from 20% to 30% by weight of entering residual oil as solid petcoke. There is a global market for petcoke for use in steam and power generation.

Refineries also blend the products of vacuum distillation with lighter petroleum liquids (e.g. kerosene, diesel and gasoil) to produce a high sulfur fuel oil (HSFO), with typical sulfur content of 1 – 4% by weight, for the maritime industry and power generation in developing countries and the Middle East. This blending step decreases the value yield from the crude feed since it uses higher value liquids to produce a lower value product.

Why is this important? The International Maritime Organization (IMO), responsible for prevention of marine pollution by ships, is in the process of reducing allowable fuel sulfur content and increasing engine efficiency standards for ships (MARPOL 73/76, Annex VI Amendments). In 2020, the allowable fuel sulfur content limit will drop from 3.5% to 0.5%. The new regulations are expected to reduce demand for HSFO maritime fuels.

The shipping industry consumes approximately 75% of global HSFO production, so refiners must soon respond to an imminent global drop in demand for HSFO as ships move to gasoil, diesel or LNG. Perceptive refiners will find opportunity in a disruption in the HSFO market. By eliminating the blending step, which is required to produce HSFO, the refiners' higher margin yield from the crude can be greatly increased. Refiners with delayed coking capability will have an added market opportunity.

Table 1. An economic analysis of the addition of a PetroPower plant at a simple refinery

Financial Parameters	Simple refinery	PetroPower (revenue/ investment)	PetroPower value
Refined product sales (US$ billion/yr)	7.4	9.6	2.3
HSFO sales (US$ billion/yr)	1.6	0	-1.6
Power sales (US$ billion/yr)	0	0.4	0.4
O&M of PetroPower plant (US$ billion/yr)	N/A	-0.2	-0.2
Net income increase (US$ billion/yr)			0.9
Delayed coker investment (US$ billion)	N/A	1	
Power plant investment (US$ billion)	N/A	1.9	
Total investment (US$ billion)	N/A	2.9	
Simple payback (years)	3.1		
NPV (US$ billion)	11		
IRR (%)	32		

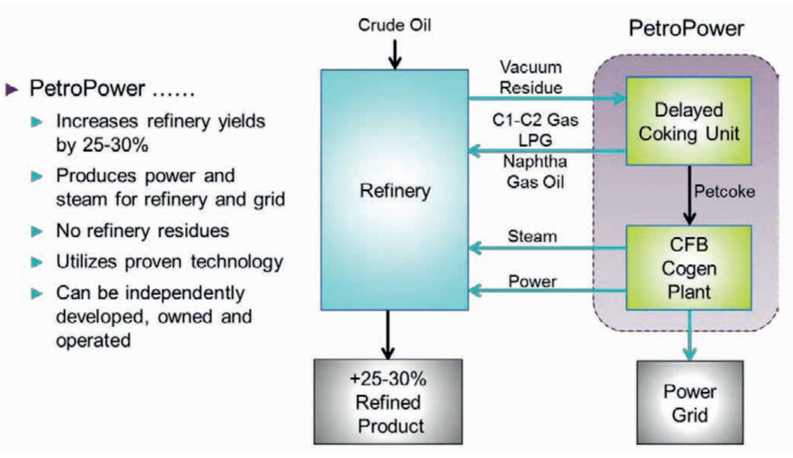

Figure 1. PetroPower extracts the maximum value from crude oil by closely coupling refining to power and steam production.

A plan

There are many refiners with existing delayed coking capabilities that are in the position to move away from the volatile HSFO market, into the more stable power and steam markets.

PetroPower, the process of producing power from petcoke, couples delayed coking technology with circulating fluidised bed combustion (CFB) technology to fully convert heavy refinery residues into valuable light products, power and steam. It eliminates the value-losing vacuum residue blend step, which is common in many refineries that currently produce HSFO for maritime use (Figure 1).

The petcoke that is produced by the delayed cokers is an attractive source of energy due to its very high heating value (over 8500 kcal/kg), which stems from its high carbon content (75 – 80% by weight) and low ash content (under 1%). However, extracting its energy is no simple task because of its low volatile matter (under 15%), high sulfur (over 5%) and high metal content (2000 – 3000 ppm total for vanadium, nickel, sodium and iron).

CFB power plants are suited to burning the petcoke byproduct to produce power and steam. There are many PetroPower configuration options. For example, a CFB power plant can be close-coupled with a refinery, where the refinery can either use all of the steam and power or can take an open-market approach where the refinery and power plant are located apart and the petcoke is transported by barge or rail. As petcoke is traded globally, the CFB power plant can be located closer to large power consumers to reduce power transmission loss.

In some locations, excess power and steam can be exported to adjacent industrial facilities and local power grids. The open market concept could be expanded, with several refineries selling petcoke to multiple power plants, perhaps establishing regional petcoke pricing hubs, as is common with coal-fired power plants. First adopters will have market power when establishing regional petcoke pricing hubs.

Powerful pro forma

The economic benefit of the process is site specific but a simple case study will serve to illustrate the value proposition. Consider a large refinery that processes a medium to heavy sour crude (Figure 2). The simple refinery (left) produces 400 000 bpd from the atmospheric and vacuum towers, but loses 20 000 bpd to blend its VR to produce HSFO. Assuming the average market value for its suite of light products and gases (gasoline, diesel, gasoil, kerosene, LPG, etc.) is US$80/bbl and the HSFO is US$40/bbl, then the simple refinery total product sales would be US$27.2 million/d.

The refiner now decides to add PetroPower and shifts production away from HSFO to producing petcoke fuel, as shown on the right side of Figure 2. Instead of losing 20 000 bpd of light product to the HSFO blend step, the delay cokers yield an additional 67 000 bpd. This would boost the output of refined products by 87 000 bpd, producing an additional US$7 million/d of revenue, offset by the loss of US$4.8 million/d for the HSFO produced by the refinery.

Furthermore, the PetroPower plant will produce 910 MWe of electricity, which may be sold to the local electricity market or, perhaps, used to reduce the power purchased by a nearby refinery. If the price paid for power by the local electricity market is a conservative US$60/MWh, the plant would generate US$1.3 million/d in power sales for the refinery – a net increase of US$3.5 million/d in revenue.

A reasonable estimate of the construction cost of the delay coking process and CFB power plant is US$2.9 billion. Therefore, the investment in PetroPower produces a 3.1 year payback, US$11 billion net present value, and an internal rate of return (IRR) of 32% (Table 1). The economics would be further improved if refinery electricity purchases were offset by PetroPower generation (net metering) rather than sold directly to the local utility grid. For this example, a US$60/bbl crude price was assumed, and for every US$10/bbl increase above this, the IRR would increase by approximately 4%.

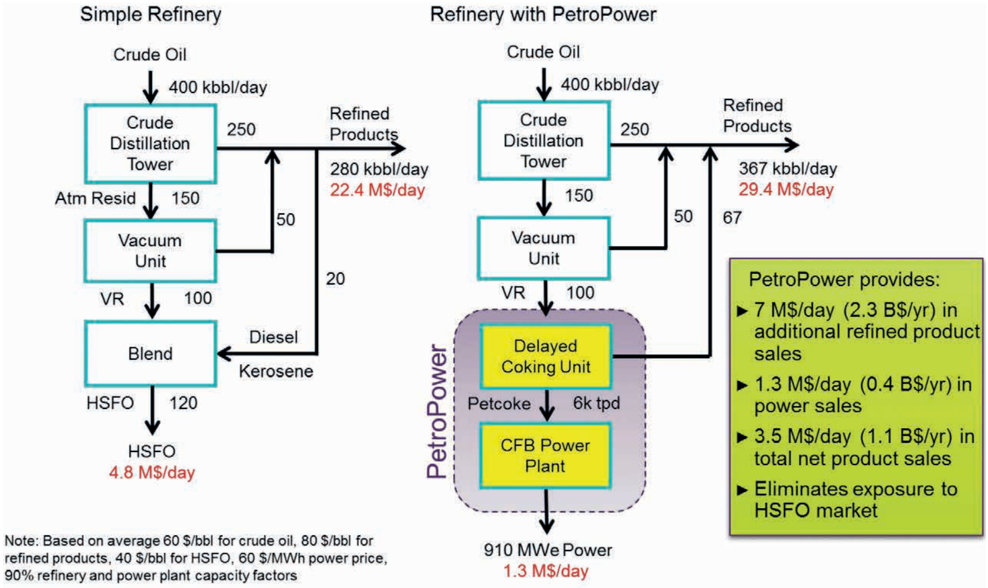

Figure 2. Mass and financial balance of a 400 000 bpd refinery, with and without PetroPower. Using the process increased net product sales by US$3.5 million/d.

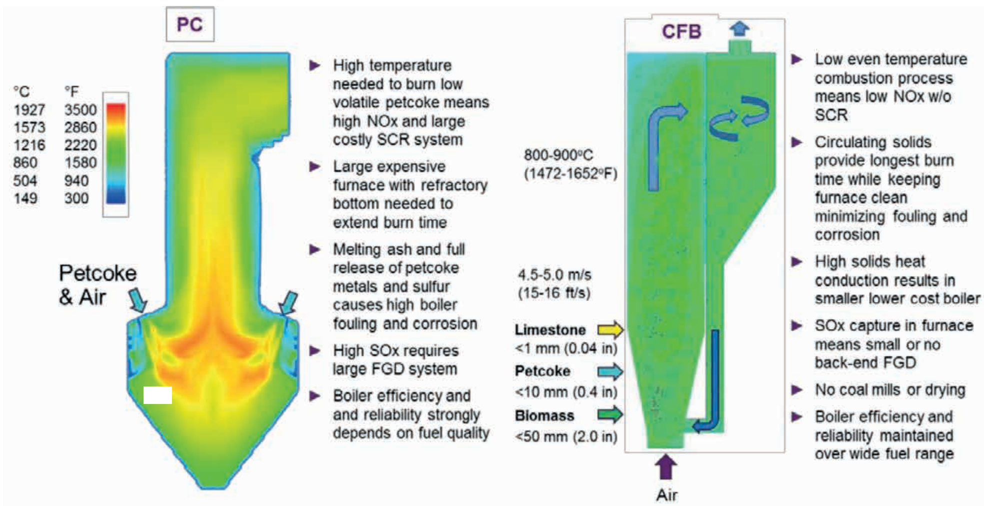

Figure 3. Thermal graph comparisons of arch-fired pulverised fuel furnace burning petcoke (left), to the CFB combustion process (right) when burning the same fuel.

There is one further intangible factor to consider: the PetroPower plant has traded its current HSFO market volatility risk for the low-risk and predictable power market while also diversifying its product portfolio. Commodity prices have a strong influence on the project economics. For this case study, US$60/bbl was assumed as the average crude oil price, US$80/bbl for the refined products, US$40/bbl for the HSFO, US$50/t of petcoke, and US$60/MWh for the power sale revenue.

As a comparison, if a simple refinery installed a conventional power plant to burn the HSFO to produce power and steam based on US$40/bbl HSFO and US$1500/kWe plant, first cost then the levelised cost of electricity (LCOE) over 30 years (including fixed and variable O&M, 80%/20% debt-equity investment, and 90% capacity factor) would be approximately US$77/MWh. The LCOE for a US$1000/kWe natural gas-fired combined cycle plant using US$7/million Btu natural gas under the same assumptions is approximately US$60/MWh. The PetroPower option at US$1800/kWe, under the same operating assumptions and US$50/t for petcoke, would produce the lowest LCOE of US$43/MWh.

CFB and petcoke: a perfect match

Specially designed arch-fired pulverised fuel boilers have been used to burn low volatile solid fuels, such as petcoke, for many years. A thermograph of an arch-fired pulverised coal (PC) furnace is presented on the left of Figure 3. The burners point downwards to form a high temperature refractory lined combustion zone below the boiler so that the slow burning petcoke reaches a temperature and burning

Figure 4. Cleco's 660 MWe Madison Unit 3 is a multi-fuel CFB power plant that typically burns a 80% petcoke/20% coal mix.

time that is high enough to crack and burn out the high level of fixed carbon in the petcoke. However, these types of boilers achieve only average combustion efficiency and struggle with ash disposal issues due to high levels of unburned carbon remaining in the boiler ash.

There are several other drawbacks to these open flame boilers, such as high NO_X and SO_X emissions due to the high combustion temperature and sulfur levels in the petcoke. For example, the arch-fired boiler design produces increased boiler corrosion and fouling due to the high sulfur and metal content in the fuel, requiring costly fuel additives to control to reasonable levels. Also, the conventional design requires a large selective catalytic reduction (SCR) system and flue gas desulfurisation (FGD) system to clean the flue gas. Each of these issues contribute to higher operating cost and lower reliability for the arch-fired PC boiler when burning petcoke.

The thermograph on the right hand side of Figure 3 illustrates the radically different combustion process that is characteristic of the CFB. There is no open flame in the CFB furnace and the gas temperature is both low and uniform throughout the combustion process. The CFB repeatedly recycles the fuel particles, greatly increasing the time available to completely combust the low volatile petcoke. Some petcoke particles can remain in the hot loop (furnace, separator, return leg) for as long as 30 min., compared to 4 – 5 second furnace resident time in the arch-fired design boiler.

The combustion temperature can be lowered to below the ash softening temperature of the fuel as the combustion time is greatly increased in the CFB. This eliminates the ash slagging and fouling problems found in open flame boiler types. Instead of causing fouling, the ash and limestone particles keep the boiler heat transfer surfaces clean, while evenly and efficiently conducting heat. The low temperatures also minimise the release of the petcoke metals into the flue gas, avoiding the serious corrosion problems experienced in arch-fired boilers.

The large volume of solids also adds thermal inertia to the CFB's combustion process, making it even-tempered. The temperature of the solids is stable (+/- 25°C) within the hot loop and with changing fuel properties. This means that the petcoke can be fed to the CFB without drying or milling, which eliminates the first and ongoing operations and maintenance (O&M) costs required with fuel pulverising and drying equipment.

There are several other significant benefits of the low temperature CFB process. First, limestone may be injected directly into the furnace to capture most of the petcoke's sulfur at its point of release. This minimises corrosion and fouling throughout the gas pass, including the boiler, air heater, ducting and electrostatic precipitator (ESP). Second, the lower SO_2 concentration in the flue gas allows the use of a lower cost semi-dry 'polishing' flue gas desulfurisation (FGD) system. Next, becuase the CFB sulfur capture processes is completely dry, water cost and supply issues are minimal compared to the arch-fired PC option. Finally, low combustion temperatures result in low thermal NO_X formation so the CFB can accommodate ammonia injection into the solids separator for effective NO_X reduction without the need of an expensive SCR system.

PetroPower in action

CFB boilers have been in service globally for over 40 years, starting out as a solution for industrial facilities with a need for steam and power, combined with sources of waste byproducts, such as petcoke, waste coal, bark, waste wood, plastics, cardboard, paper, and sludges. In fact, the use of CFBs in large central station power generation has grown rapidly over the past 10 years. Sumitomo SHI FW now has 482 CFBs, representing 37.4 GW of equivalent power capacity operating around the world, many with long years of experience burning petcoke.

The PetroPower plant has been in operation since November 1998 with an average availability exceeding 95%. In 2011 and 2012, the co-generation plant set a plant record for continuously running of 467 days.

Jacksonville Electric Authority's (JEA) Northside generating station is an example of an open-market PetroPower plant. The 600 MWe petcoke and coal-fired CFB plant is located in Jacksonville, Florida, US. The plant consists of two 300 MWe CFBs with spray dryer absorber (SDA) polishing scrubbers. The plant began commercial operation in 2001 and has achieved forced outage rates of below 1% over the past five years.

JEA buys petcoke primarily from nearby refineries located along the US Gulf Coast and coal from both US and international suppliers. It procures petcoke and coals both on spot cargo and short- to mid-term fixed price basis, taking full advantage of market arbitrage to reduce operating costs. This is a good example of the value that the fuel flexibility of CFBs can bring to power producers.

Cleco Power's Brame Energy Center's Madison Unit 3, located in Boyce, Louisiana, US, is another example of an open-market PetroPower plant (Figure 4). This 660 MWe plant consists of two 330 MWe CFBs, coupled to a single 660 MWe steam turbine generator, which is connected to the Entergy power grid. Behind each CFB boiler is a CFB polishing scrubber that produces very low acid gas and metal stack emissions.

This multi-fuel plant primarily burns petcoke (80%), but also has the ability to fire bituminous and sub-bituminous coals, lignite, wood waste, and paper sludge, which demonstrates the flue flexibility of CFB technology. Madison Unit 3 entered commercial service in 2010 and remains Cleco's most dispatched unit because of its low operating cost.