The power option

With the market for high sulphur fuel oil under pressure, refiners with delayed cokers can instead opt for higher value power and steam generation

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The vacuum residuum produced by vacuum distillation comprises long carbon chains that are cracked by a delayed coker, increasing refinery yields of short chain molecular weight hydrocarbon gases, naphtha, and light oils products by 30%, while producing a residual solid product known as petroleum coke. Refineries configured with a delayed coking system can generally produce from 20-30% by weight of entering residual oil as solid petroleum coke. There is a global market for petcoke used for steam and power generation.

Refineries also blend the products of vacuum distillation with lighter petroleum liquids (kerosene, diesel, gasoil) to produce a high sulphur fuel oil (HSFO), with sulphur content typically 1-4% by weight, for the maritime and power generation industries 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.

The International Maritime Organization (IMO), responsible for prevention of marine pollution by ships, is in the process of reducing allowable fuel sulphur content and increasing engine efficiency standards for ships (MARPOL 73/76, Annex VI Amendments). In 2020, the allowable fuel sulphur 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 about 75% of the world's production of HSFO today 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 required to produce HSFO, refiners' higher margin from the crude can be greatly increased. Refiners with delayed coking capability will have an added market opportunity.

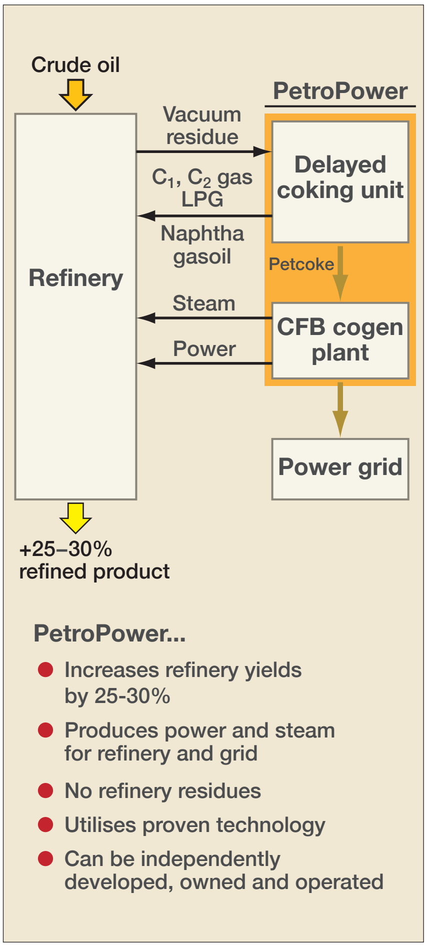

Figure 1 PetroPower extracts value from crude oil by closely coupling refining to power and steam production

According to IHS Markit, in 2015, delayed coking technology was used in 41% of the world's refineries, with Asia, Latin American, and the US having the greatest percentage of coking capacity. There are many refiners with existing delayed coking capability that have already moved away from the volatile HSFO market by producing petroleum coke instead of HSFO. PetroPower couples delayed coking technology with circulating fluidised bed combustion (CFB) technology to convert the petroleum coke into power and steam, completely eliminating refinery residues. PetroPower eliminates the value-losing vacuum residue blend step common in many refineries that currently produce HSFO for maritime use (see **Figure 1**).

The petcoke produced by delayed cokers is an attractive source of energy due to its very high heating value (over 8500 kcal/kg) that stems from its high carbon (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 sulphur (over 5%) and high metal content (2000-3000 ppm total for vanadium, nickel, sodium and iron).

CFB power plants are ideally suited to burn the petcoke byproduct to produce power and steam. There are many PetroPower configuration options. For example, the CFB power plant can be close coupled with the refinery where the refinery uses all of the steam and power, or it can take an open market approach where the refinery and power plant are located apart from one another and the petcoke is transported by barge or rail.

power producers a low risk investment opportunity with an attractive economic return.

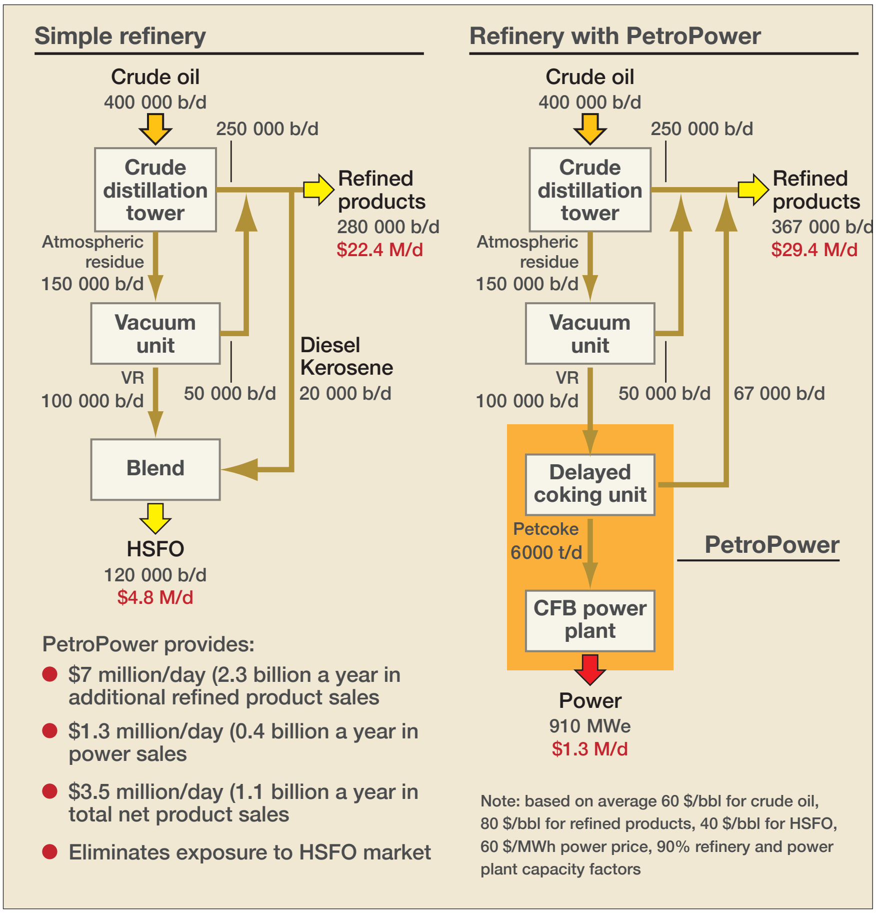

Figure 2 Mass and financial balance of a 400 000 b/d refinery The PetroPower option on the right increases net product sales by $3.5 million/day

Because petcoke is traded globally, the CFB power plant can be located closer to large power consumers to reduce power transmission losses.

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 multiple 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 significant market power when establishing regional petcoke pricing hubs. The technology offers both refiners and independent

Economic analysis of the addition of a PetroPower plant at a 400 000 b/d simple refinery

Financial parameters (revenue/ investment)	Simple refinery	Refinery with PetroPower	PetroPower Value
Refined product sales, K$/yr	7.4	9.6	2.3
HSFO sales, K$/yr	1.6	0.0	-1.6
Power sales, K$/yr)	0.0	0.4	0.4
O&M of PetroPower plant, K$/yr	NA	-0.2	-0.2
Net income increase, K$/yr		0.9	
Delayed coker investment, K$/yr	NA	1.0	
Power plant investment, K$/yr	NA	1.9	
Total investment, K$/yr	NA	2.9	
Simple payback, years		3.1	
NPV, K$/yr		11.0	
IRR, %		32.0	

The analysis is based on a $1800/kWe CFB plant installed cost, 90% refinery and power plant capacity factor, 30-year term, and 5% discount rate. The $2.9 billion investment in the delayed coker and PetroPower installation will have an approximate 3.1-year simple payback.

Table 1

Powerful pro forma

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

The refiner now decides to add PetroPower and shifts production away from HSFO to producing petcoke fuel. Now, instead of losing 20 000 b/d of light product to the HSFO blend step, the delayed cokers yield an additional 67 000 b/d. This would boost the output of refined products by 87 000 b/d, producing an additional $7 million/day of revenue, offset by the loss of $4.8 million/day for the HSFO produced by the refinery.

Further, the plant will produce 910 MWe of electricity that 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 $60/MWh, the PetroPower plant would generate $1.3 million/day in power sales for the refinery, a net increase of $3.5 million/day in revenue.

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

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.

The economics of the PetroPower plant surpass other generation alternatives. For example, if a simple refinery installed a conventional power plant to burn the HSFO to produce power and steam based on $40/bbl HSFO and $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 $77/MWh. The LCOE for a $1000/kWe natural gas-fired combined cycle plant using $7/million Btu natural gas under the same assumptions is approximately $60/MWh. The PetroPower option at 1800 $/kWe, under the same operating assumptions and $50/tonne for petcoke, would produce the lowest LCOE of $43/MWh.

Specially designed arch-fired pulverised fuel boilers have been used to burn low volatile solid fuels like petcoke and anthracite coals for many years. A thermograph of an arch-fired pulverised coal furnace is viewed on the left of **Figure 3**. The burners are pointed downward to form a high temperature refractory lined combustion zone below the boiler so that the slow burning petcoke reaches a temperature and burning time high enough to crack and burn out the high level of fixed carbon in the petcoke. However, these types of boilers achieve only mediocre 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 NOx and SOx emissions due to the high combustion temperature and sulphur levels in the petcoke. For example, the arch-fired boiler design produces increased boiler corrosion and fouling due to the

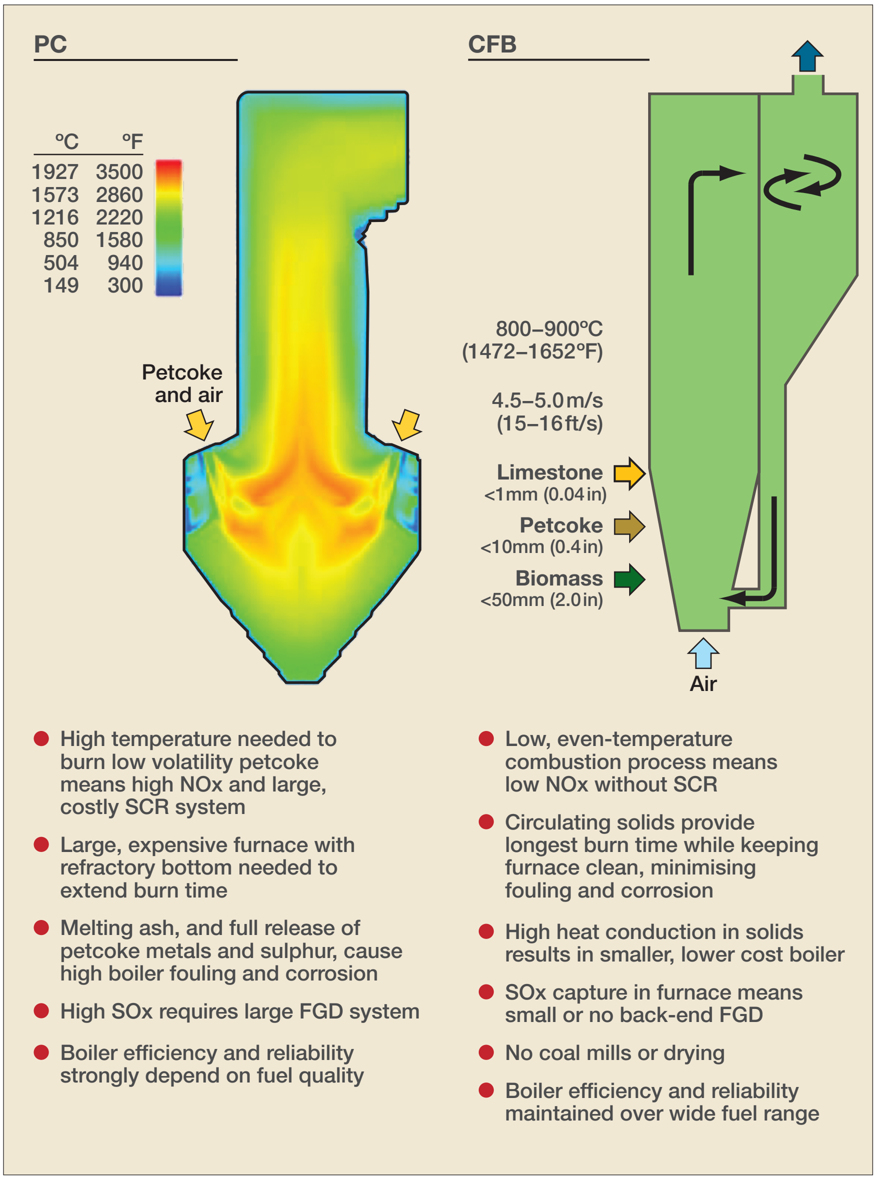

Figure 3 Thermal graph comparisons of arch-fired pulverised fuel furnace burning petcoke (left) is compared to the CFB combustion process (right) when burning the same fuel. The lower combustion and gas temperature produce fewer flue gas emissions and significantly less furnace and steam generator corrosion

high sulphur 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 desulphurisation (FGD) system to clean the flue gas. Each of these issues contributes to higher operating costs and lower reliability for the arch-fired PC boiler when burning petcoke.

PetroPower eliminates the value-losing vacuum residue blend step common in many refineries that currently produce HSFO for maritime use

The thermograph on the right 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 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

Figure 4 Sumitomo SHI FW's longest running PetroPower Plant is located in Talcahuano, Chile. The plant entered service in 1998

Figure 5 JEA's 600 MWe CFB power plant firing petcoke and coal at the Northside generating station in Jacksonville, Florida

can remain in the hot loop (furnace, separator, return leg) for as long as 30 minutes, compared to four to five second furnace resident time in the arch-fired design boiler.

The combustion temperature can be lowered well below the ash softening temperature of the fuel since the combustion time is so greatly increased in the CFB. This eliminates the ash slagging and fouling problems found in all open flame boiler types. Instead of causing fouling, the ash particles, along with 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's metals into the flue gas, avoiding the serious corrosion problems experienced in arch-fired boilers.

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

There are several other significant benefits with the low temperature CFB process. First, limestone may be injected directly into the furnace to capture most of the petcoke's sulphur at its point of release. This minimises corrosion and fouling throughout the entire gas pass including the boiler, air heater, ducting, ESP. Second, the lower SO_2 concentration in the flue gas allows the use of a lower cost semi-dry 'polishing' FGD system. Next, since the CFB sulphur capture process is completely dry, water cost and supply issues are minimal compared to the arch-fired PC option. Finally, low combustion temperatures result

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in low thermal NOx formation so the CFB can accommodate ammonia injection into the solids separator for effective NOx reduction without the need for an expensive SCR system.

CFB boilers have been in service around the world 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.

Figure 4 shows Sumitomo SHI FW's longest running PetroPower plant. This plant is located in Talcahuano, Chile, where the company built a 12 000 bbl/day delayed coking facility that is coupled with a 74 MWe CFB cogeneration plant. The plant provides both steam and power to a refinery owned by Chile's national oil company, Empresa Nacional del Petróleo (ENAP). Sumitomo SHI FW operates and maintains the cogeneration facility. For many years, the cogeneration plant was jointly owned by Sumitomo SHI FW (85%) and ENAP (15%); recently, ENAP has acquired 100% ownership.

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

Jacksonville Electric Authority's (JEA) Northside Generating Station is an example of an open market PetroPower plant (**Figure 5**). The 600 MWe petcoke and coal-fired CFB plant is located in Jacksonville, Florida, USA. The plant consists of two 300 MWe Sumitomo SHI FW CFBs with SDA polishing scrubbers. The plant began commercial operation in 2001 and has achieved forced outage rates 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. JEA procures petcoke and coals both on spot cargo and short- to mid-term fixed price basis, taking advantage of market arbitrage to reduce operating costs.

Cleco Power's Brame Energy Center's Madison Unit 3, located in Boyce, Louisiana, USA, is another example of an open market PetroPower plant (see **Figure 6**). The 660 MWe plant consists of two 330 MWe Sumitomo SHI FW CFBs coupled to a single 660 MWe steam turbine generator that 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 burns primarily petcoke (80%), but also has the capability to fire bituminous and sub-bituminous coals, lignite, wood waste, and paper sludge, which demonstrates the 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.

Figure 6 Cleco's 660-MWe Madison Unit 3 is a multi-fuel CFB power plant that typically burns a 80% petcoke/20% coal mix. The unit is located at the utility's Brame Energy Center, Boyce, Louisiana

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