Petroleum Coke Refueling of Underutilized Oil-fired Assets Produces Low Cost Power

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Abstract

Air Products and Foster Wheeler have jointly developed a proprietary oxygen-based combustion technology that enables the retrofit and conversion of existing oil-fired utility boilers to allow the use of 100% petroleum coke as fuel for the refueled facility. The basis of the technology is the selective use of oxygen to stably and efficiently burn pulverized petroleum coke, a low-volatile, low-cost fuel, within a furnace that provides a much shorter combustion residence time than would ordinarily be required for this type of fuel. This allows the petcoke to be combusted, for example, in a boiler originally designed for higher-priced oil and/or gas firing. The enabling technology not only allows the combustion of petroleum coke, but also retention of most, if not all, of the original furnace steaming capacity. Additionally, the application of oxygen as developed reduces the amount of NOx produced in the furnace. The economic value of this process is the conversion of the existing units with their high-cost, low-dispatch profile into low-cost, baseload generating units while utilizing best available emission reduction technology. There are additional operating benefits as a result of the technology application that will be discussed below as well.

A Short Historical Perspective

The oil-fired generating fleet which exists in the United States today was constructed primarily in response to the concern of utilities and their regulators over the high exposure to coal as a percentage of generating fuel. Nuclear capacity was also being added during this time period as well. The view forward was one of cheap, readily available oil while natural gas at the time was considered a higher value fuel that needed to be conserved for essential and agricultural uses. Almost as soon as many of these facilities were completed, the formation of OPEC and the Arab Oil Embargo occurred. The result was a group of high cost facilities that, as a consequence of economic dispatch, tended to run at low dispatch.

Air Products, through its previous Pure Air joint venture with Mitsubishi Heavy Industries that was created to develop flue gas desulfurizers, had previously provided estimates for the conversion of many of these oil-fired units to burn Orimulsion®* furnace boilers, a heavy bitumen product from Venezuela. The goal of these potential conversions was to lower the feedstock pricing and thereby lower the cost of power production to a more competitive level.

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In addition to its experience with flue gas desulfurizer design and operation, Air Products is the world's largest on-purpose supplier of hydrogen to oil refiners. In the course of those relationships, the subject of petroleum coke has been brought up numerous times as a concern of the refining community. Air Products burns petroleum coke, along with coal and tire-derived fuel, in its Stockton Cogeneration Company circulating fluidized bed facility in Stockton, CA.

Foster Wheeler is a boiler designer and after-market services and pressure parts supplier that also supplies the majority of delayed cokers to the refining community. Both companies have a long history of combustion experience, with Foster Wheeler's background designing new burner designs for power plants and with Air Products' background in oxygen-enriched combustion which includes some of the earliest patents concerning oxygen enrichment applications for coal combustion.

Petroleum Coke

Petroleum coke is produced through batch thermal coking of residual feeds within the refinery. These bottom of the barrel streams are typically flowable only at temperatures above 325°F and are largely composed of asphaltenes. These feeds are introduced into the coking drum (for delayed coking, which comprises the bulk of world coke production capacity), which is then closed up. Heat is introduced and the drum is "cooked" for between 16 and 24 hours to drive off most of the remaining light ends. The drum is then unheaded and the solid mass is removed via a rotating water lance that cuts the coked residual product out of the drum into a pit below the coker. The solid product is then removed from the pit via clamshell and loaded out. Chemically, Petroleum coke is largely carbon, with some sulfur, hydrogen and nitrogen composing the bulk of the remainder. There is very low ash in petroleum coke and also very low volatiles. Because of the low volatile material in coke, combustion is difficult. In addition, the high sulfur content creates difficulties in meeting air emission limitations for any facility burning coke. Finally, much of the fuel-grade (i.e., sulfur content above 1-2%) coke is hard, with HGI's below 50, limiting the use of coke in existing facilities with fixed pulverizing capacity. Refineries generally have limited storage capacity for coke making the ratable take by marketers and customers of primary importance.

Combustion Process Development

Air Products was interested in the conversion of existing power generating units to take advantage of the low price of coke vis-à-vis other fuels and to provide a steady new application to utilize the ever-increasing amounts of coke produced by refiners. Originally, Air Products was interested in increasing the percentage of coke in a mixed fuel consisting of coke and Orimulsion® furnace boilers, residual fuel oil or natural gas. As the economic propositions were developed, it was apparent that the maximization of petroleum coke to the extent possible was required to provide potentially acceptable economics. Air Products and Foster Wheeler began combustion testing of petroleum coke in Foster Wheeler's Dansville, NY Combustion and Environmental_ Testing Facility in December of 2000. Foster Wheeler's CETF was a flexibly designed facility built to allow simulation and data capture for both wall-fired and for down-fired configurations. The facility was thermally equivalent to approximately 6MWe, utilizing two 30MMBtu/hr burners and was instrumented to provide excellent data for burner scaling and emission prediction of large-scale commercial units. Initial testing and modeling focused on assessing the relative benefit of utilizing oxygen-enriched vs air-fuel combustion of petcoke and estimating the expected de-rate that would occur in an existing unit converted from oil to petcoke

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firing. Initial results showed that while air-fuel firing of petcoke in a Foster Wheeler-designed low-volatile, low-NOx solid fuel burner could generate a marginally-stable flame at rated furnace load, oxygen enrichment was required to produce a flame with robust stability and load-following capability. The level of enrichment required was found to be less than 10% (i.e. equivalent to bulk combustion oxidant concentration of 31% O2) in all cases.

A secondary phase of testing was carried out to optimize oxygen injection technology for maximum combustion efficiency and minimum emissions using a variety of petcoke sources and burner designs. As oxygen co-fueled flames are capable of generating adiabatic flame temperatures approaching 5000 ^{o}F, it was expected that oxygen enriched petcoke firing would improve combustion efficiency and radiant heat transfer from the flame to the boiler water relative to air-fuel firing. While these expectations were indeed fulfilled, a major concern was a potentially large increase in thermal NOx formation. However, through the development and application of proprietary combustion technology, Air Products was able to inject oxygen is such a way as to improve thermal efficiency while also achieving a significant reduction in NOx. Measurements also indicated oxygen enrichment produced lower SO3 emissions than air-fuel firing of petcoke. Based on the results of this second round of testing, both Air Products and Foster Wheeler concluded that the viable application of a conversion of an existing facility would require oxygen based on the value of retaining existing furnace capacity while improving combustion stability/efficiency and reducing emissions. Following analysis and economic modeling of the results, Air Products and Foster Wheeler filed a patent application to protect their joint intellectual property.

Demonstration Unit

Air Products and Foster Wheeler then reviewed the data and results of each company's modeling to determine the next step. Both companies agreed that a small-scale demonstration was appropriate. The scaling factor to take the combustion process from the size of the CETF burners to full commercial scale at 60 to 80MMBtu/h is not particularly daunting, but both parties want to obtain more accurate heat balance data within an operating waterwall boiler. A screening process identified a number of existing coal-fired facilities in order to take advantage of existing pulverizers for the petroleum coke and to limit the amount of oxygen required to allow the use of a temporary liquid storage and vaporization skid as opposed to construction of an oxygen generating unit, which would have represented a prohibitive expense to the demonstration. An operating 25MW facility was located with a management willing to host the demonstration and the necessary modifications were engineered. The modifications for this facility consist of new overfire air ductwork, new burners and new coal conduits. Existing pulverizing capacity was determined to be sufficient for operation with petroleum coke and the size was acceptable for scaling. In addition to the modifications above, thermocouple sections of tubes will be welded into existing tubes to obtain an accurate heat balance profile of operation with the oxygen-enriched coke combustion process. The resulting data will allow robust CFD modeling of actual units to allow Air Products and Foster Wheeler to provide guarantees sufficient to achieve financing and incent potential partners to invest in conversions of existing oil-fired units. Further, the demonstration will provide emissions data under varying conditions to allow the filing of the most acceptable air permit possible. The demonstration is therefore not necessary for proof of concept, but is necessary for appropriate risk analysis for operating guarantees and air permit filing.

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Process Description of Refueling Conversion

A process schematic diagram of a coke refueling conversion is shown in Figure 1. Because the target units were originally designed for oil firing and are either utilizing oil or natural gas, they do not have the requisite solids receiving, storage and handling capability. Most subject units were constructed with water access to allow receipt of oil via barge, which is also the preferred method of receiving the coke. A solids unloader, stacker/reclaim capacity, storage and pulverizers will be added to the existing facility. The ultimate cost of the solids handling and preparation equipment will depend on facility geometry and available real estate. In addition to petroleum coked receipts, capacity for limestone receipts and either gypsum or wallboard delivery will be added. Air separation units (ASU) will be added to provide the oxygen necessary for the combustion process. Inside the furnace, sufficient modifications will be made depending on site specific geometries and metallurgies to take advantage of the combustion process and, more importantly, to provide sufficient life extension to allow a 20-year project life. Modifications will be made, as necessary, to allow for bottom ash removal. Petroleum coke has very little ash, generally 0.5% or less, so the modifications will be fairly minimal, even for a furnace with little clearance above grade. Life extension investments will also be made as necessary in the generating set to provide a 20-year project life. The combustion process also allows consideration of uprate capital via a turbine rotor replacement or via investment in additional generating capacity, but this opportunity has not been included in the base case economics. On the back end of the furnace, selective catalytic reduction will be added to further reduce NOx levels. A dry electrostatic precipitator has been included in the base economic case upstream of the new wet limestone flue gas desulfurizer, which includes a wet electrostatic precipitator for particulate control down below $PM_{2.5}$. The FGD is designed to remove more than 98% of the SO_2 which also represents beyond BACT control. Finally, a new stack designed for the aggressive conditions of a wet gas stream from the FGD is assumed. The need for a new stack is based on height requirements and the requirement of internal diameter to allow a brick lining to withstand the aggressive wet gas stream.

In the event not all the described capital is required to achieve project permits and/or financing, then base case economics are further improved. Air Products experience operating the Pure Air On The Lake wet limestone scrubber at Northern Indiana Public Service's Bailly Station provides the experience necessary to provide guarantees around availability and wallboard-quality gypsum from the facility. PAL has operated at an average availability of 99.84% over the 13 years it has been in operation and has provided wallboard-quality gypsum since initial onstream.

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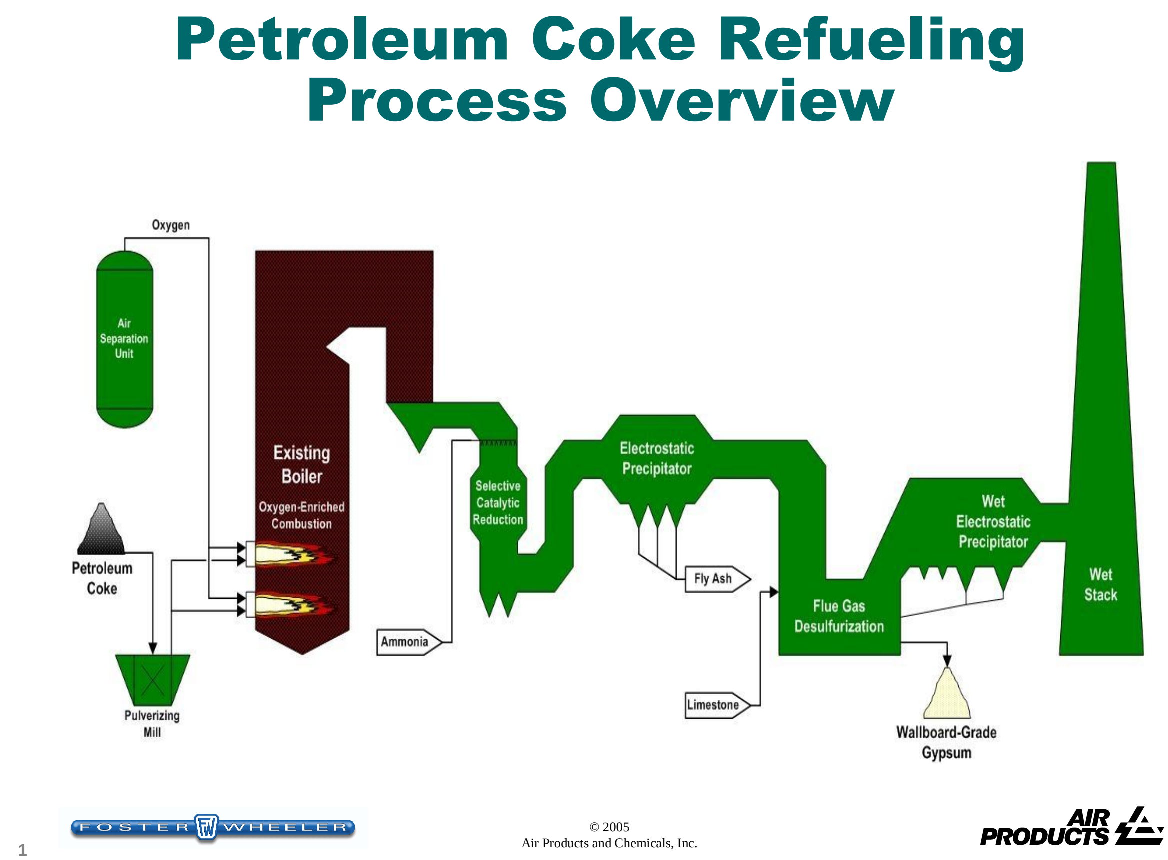
A graphic illustration of the overall base design is shown below:



Economic Outcome

The low cost of petroleum coke relative to other fuels results in a dispatch cost that is lowest other than for nuclear capacity. The majority of fuel-grade petroleum coke demand worldwide comes from cement kilns and from electric power generation. In both instances, coke competes with coal and must be priced as an opportunity fuel vis-à-vis coal in order to stimulate consumption. The base case economic model developed by Air Products in its initial opportunity screening activities assumed a petroleum coke price that was above current market conditions and well above traditional long-term forecasts. In addition, the capital basis assumed allowed use of a petroleum coke feed of 6.5% sulfur, with resulting capital sizing and operating and maintenance expenses. Based on an extremely favorable dispatch cost versus all other forms of generation other than nuclear, the converted unit is expected to dispatch as a baseload unit with an anticipated availability of 90% or greater. This conversion from a low-dispatch, high-cost (and low margin) unit to a baseload, low-cost (and high margin) unit creates exceptional value from the use of an otherwise low value asset. It needs to be noted that economics are site and unit specific based on the amount of life extension necessary and the ease of adding the solid

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and emissions control equipment, but are expected to be attractive in all but the most extreme cases. In addition to providing data necessary to intelligently offer operating and emission expectations from a refueled unit, the demonstration will also provide the opportunity to identify reductions in the amount of oxygen required. Any reduction in oxygen necessary will result in not only capital and operating and maintenance expense, but also in lower parasitic load requirements, thus producing more revenue. Any such reduction in oxygen requirement will further leverage the economic potential of a refueled unit.

The base case economics were developed versus an energy-only revenue model that subtracted the additional parasitic load (i.e., parasitic load is charged at opportunity costs of lost revenue and not at an arbitrarily low energy-only production cost) from the refueled gross capacity. No provision was made for capacity fees or ancillary services. The forecasted energy price was calculated based on an avoided-cost gas fired combined cycle unit with a heat rate of 6,600 Btu/kWh, operating and maintenance expenses of $12/MWh and capital recovery of $11/MWhr. On this basis, acceptable returns are earned on a non-structured basis at natural gas burner tip prices of $2.40/MMBtu for a 20-year term. Further, in comparison to a repowering with petroleum coke fired circulating fluidized bed boilers, the Air Products/Foster Wheeler refueling technology has significantly lower capital costs and much lower operating and maintenance expenses, partially due to the large amounts of ash produced in a CFB burning 6.5% sulfur fuel and the costs of disposal of that ash.

To summarize, Air Products and Foster Wheeler have developed a novel and proprietary oxygen-enhanced combustion technique that allows the conversion of existing electrical generating facilities that were originally designed to utilize fuel oil, residual fuel oil and/or natural gas as their primary fuel to burn 100% petroleum coke. The converted unit allows control of emissions as a point source, which in a macro sense reduces the emissions from the overall use of coke in other facilities around the world. Overall emissions of NOx, SO_2 and particulates as a result of coke destruction will decrease. Finally, coke has little or no mercury. The bulk of any mercury contained in the coke will be removed in the bottom ash in the furnace and any remaining mercury in the fly ash or oxides in the flue gas will be effectively removed in the wet limestone scrubber.

By applying the novel and proprietary combustion technique developed by Air Products and Foster Wheeler, the low cost of petroleum coke in these existing oil-fired facilities provides the economic incentive to convert these facilities and continue operations whereas current economics for those facilities leaves them with uncertain futures with high generating costs which will not attract significant sustaining capital. The application of the petroleum coke refueling concept developed by Air Products and Foster Wheeler thus represents an attractive economic and environmental opportunity for an otherwise distressed asset while utilizing a distressed refinery byproduct and allowing for single point source control of emissions from the use of the coke.

Commercial Status

Commercial development activities continue as initial site screens are made for specific sites with follow-up estimates and more detailed designs as warranted by customer interest and commercial attractiveness of each site. The demonstration is currently anticipated to occur in the late Spring of 2006 and the first commercial unit’s air permit may be filed as early as mid-Summer of 2006 following data analysis and modeling. Additional commercial discussions are proceeding with potential long-term power purchasers and with other potential financial partners.

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