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CHANGES IN GLOBAL REFINING AND ITS IMPACT ON ANODE QUALITY PETROLEUM COKE

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Abstract

The global refining industry has undergone a dramatic upheaval over the past decade. From the mid-2000s when a "Golden Age" was underway, through several years of earnings losses, concerns about 'peak oil' to today's unique crude supply situation in the mid-Continent United States, refiners have never been more challenged in their feedstock supply strategy.

Introduction

Petroleum refiners are in the business of producing liquid transport and heating fuels from crude oil. The economics of refining are complex as refineries are flexible manufacturing facilities able to broadly swing feedstock volume and quality, and thus product volume and quality.

The refining industry is a small piece of the larger hydrocarbon supply chain on the way to gasoline and diesel for use in our cars and trucks. In many ways it is similar to the petroleum coke calcining business (which sits between two larger groups – refining and aluminum). Refiners act as a wide spot in the pipeline of unconverted crude oil and finished transport fuel or petrochemicals.

This paper reviews the main economic drivers for refining, including the impact on petroleum coke production. How the markets (and decisions) have changed over the past decade will be examined, and scenarios of what's ahead will be covered.

Probably the biggest change taking place in the U.S. refining sector is the rapid development of shale oil crude supply. Shale oil, along with changes in global refining and coking capacity – additions and closures – will make a profound impact on the quality and quantity of calcinable anode grade petroleum coke.

Politics and Oil

Oil industry fundamentals are like any other commodity industry – at its core is dependent upon supply and demand. What makes oil different, however, is how minor events create ripples on a global scale that impact every industry that depends on energy, including anode grade petroleum coke supply.

For many years the price of oil was set by international oil companies posting a given price – typically light sweet crude oil (West Texas Intermediate) in Cushing, Oklahoma. Prices (on an adjusted 2010 real dollar basis) were in the \$15-\$18 per barrel range. Figure 1 gives a broad perspective of some of the world events that have changed the price of crude oil [1], starting with the upheaval in the Middle East in the 1970s. Most of these geopolitical events have been centered on that region of the world. From the formation of OPEC (Organization of the Petroleum Exporting Countries), to the Saudis adding and removing production from the world markets, the Middle East is the source for most of the swings in pricing seen once market control moved from the oil companies to OPEC and to a large extent, the financial markets with the introduction of oil futures in 1983.

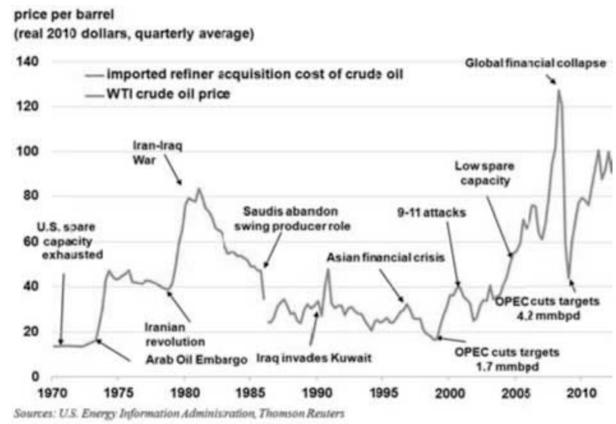

Figure 1: Economic or Political Events and the Price of Oil

Focusing on the last decade (Figure 2), we see that not just political events impact the price of oil [2, 3]. The financial crisis in 2009 resulted in the largest drop of crude oil prices since the mid 1980s. Other events such as the US Gulf Coast hurricanes (2004-2005) had their own impacts on availability (and quality) of crude oil for the U.S. markets. As seen recently, turmoil again in the Middle East (Libya, Iran) resulted in another run-up in prices, primarily for Brent price-related crude oils.

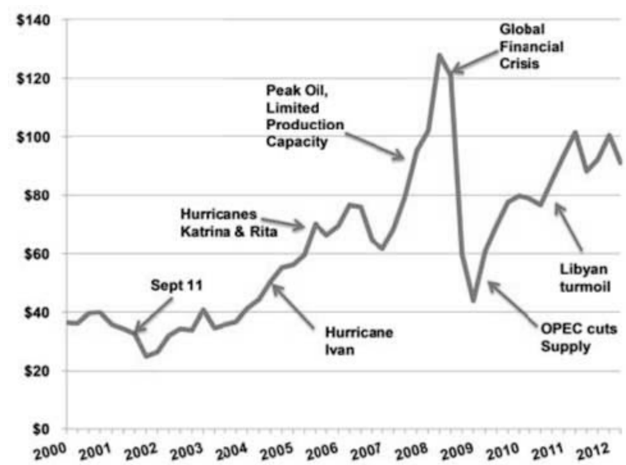

Figure 2: Events of the Past Decade

One conclusion that should be taken from an examination of oil market pricing is that exogenous events have, and will continue to, impact market supply, demand and pricing.

Crude Oil Production and Quality

Although crude oil is produced, transported, and consumed on a global basis, to a large extent it is a regional commodity, subject to pricing, logistics, and availability of processing facilities able to refine it to make products to regional specifications. Figure 3 gives a perspective of what volumes come from the major producing regions [2]. As one would expect, the Middle East is the world's largest producer of oil.

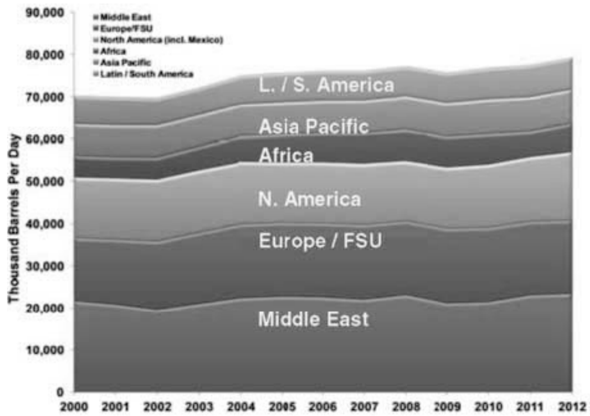

Figure 3: Global Oil Production by Region

Surprisingly, the Middle East has been extremely short of refining capacity to process its own crude oil [2]. That is one reason why Middle East crude oil has been the swing source of feed for refiners around the world. Most people would think North America would have the most refining capacity, but it is actually Asia Pacific first, then Europe (including Eastern Europe, FSU, and Russia), then North America.

What this demonstrates is the mismatch of processing in a given region versus regional production of crude oil supply. The particular availability of crude oil combined with the type of processing capability sets the type of product that can be supplied.

Over time the assumption has been made that the supply of crude oil is getting heavier (lower API gravity). To an extent this has been true over the longer-term. However, as shown in Figure 4, there has actually been an increase in the global production of lighter grades of crude oil (crudes categorized by sulfur content - "Sweet", "Med Sour", and "Sour")[4].

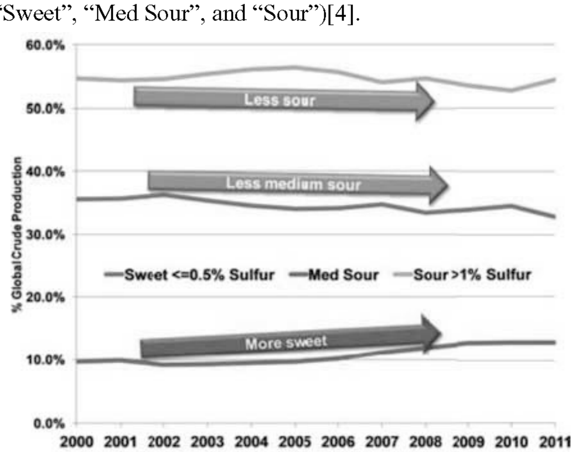

Figure 4: Global Crude Mix by Type

Figure 5 provides an insight into quality and quantity produced by major crude oil field [4]. The sizes of the bubbles represent the volume of each crude oil produced. The vertical axis shows °API gravity – the lower the API gravity, the thicker and heavier the crude oil. The horizontal axis shows sulfur content.

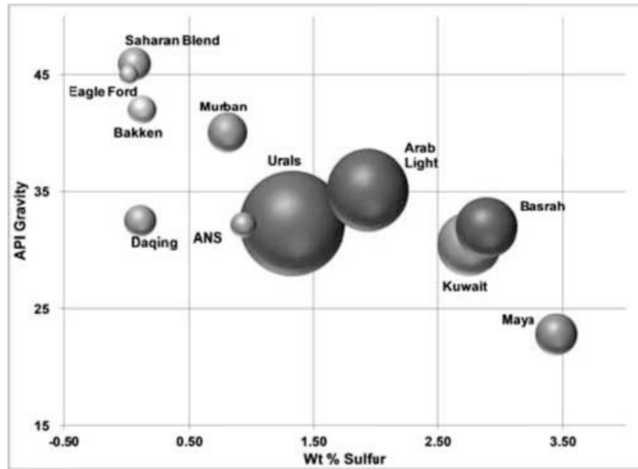

Figure 5: Crude Production by Volume and Quality

Russian Urals crude oil is the largest single volume crude oil produced in the world. The Middle East as a region dominates global production - Arab Light (Saudi), Basrah (Iraq), Kuwait, and Murban (UAE) are the next ME largest fields shown.

For the U.S., The Energy Information Administration (EIA) is the definitive national source of data on crude oils processed by U.S. refiners. Since the U.S. has such a key role in the production of fuel and anode petroleum coke, analysis of EIA data can provide a snapshot into regional and global refining dynamics.

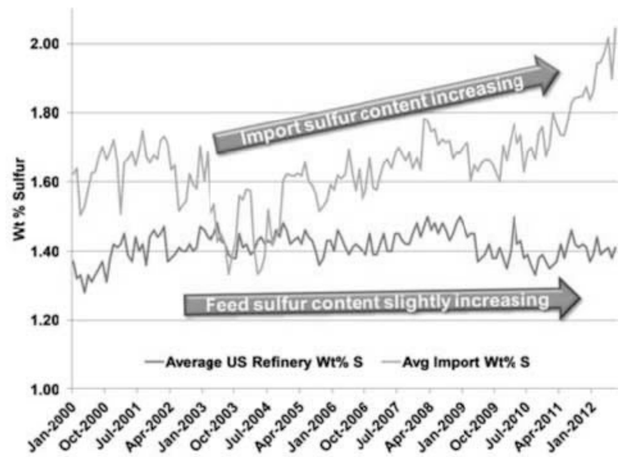

Figure 6: U.S Average Crude Quality and Import Crude Quality

The average quality (by sulfur content) of crude oils processed [5] by U.S. refiners is presented in Figure 6. The average feed sulfur input has remained almost unchanged over the past decade. What has been changing is the quality of imported crude oils [6]. The average sulfur content has been steadily increasing particularly over the past year and a half as additional heavy sour Canadian crude oil is processed by northern U.S. refiners. By difference this indicates that the average quality of domestic crude oil has been improving, which will be covered later in this paper as shale oil is discussed. Additional information on imported crude oil quality since 2000 is shown in Figure 7, which shows °API gravity and sulfur.

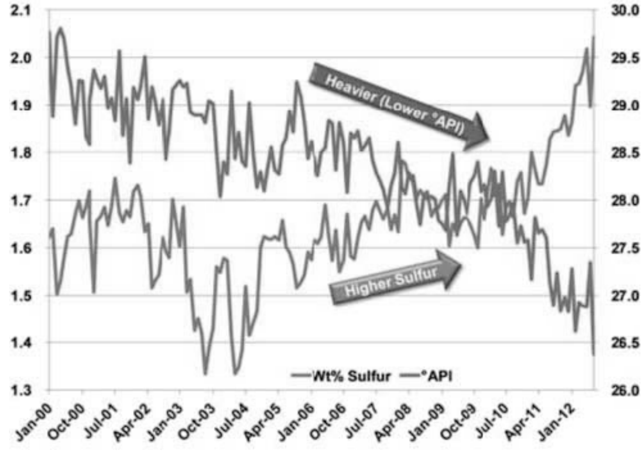

Figure 7: U.S. Imported Crude Quality

Coking Economics

Critical to the topic of anode grade petroleum coke is the processing of crude oil into refined products and petroleum coke. Every refinery is unique, based on the type of crude oil it was designed for and the type of products it was intended to produce. A refinery's configuration is not fixed – refineries continually add or upgrade processing capability depending on market economics, government regulation (such as changing product specifications), and feedstock availability.

North America – specifically the United States – is the world's largest coking region. In 2000 the U.S. represented over 50% of the world's capacity, as the capacities show in Figure 8 [2]. Today, the U.S. represents 38%. Other regions have caught up with the U.S. in processing heavy oils. Asia Pacific – China and India – have increased coking capacity from approximately 20% of world coking in 2000 to just under 37% share of global coking capacity

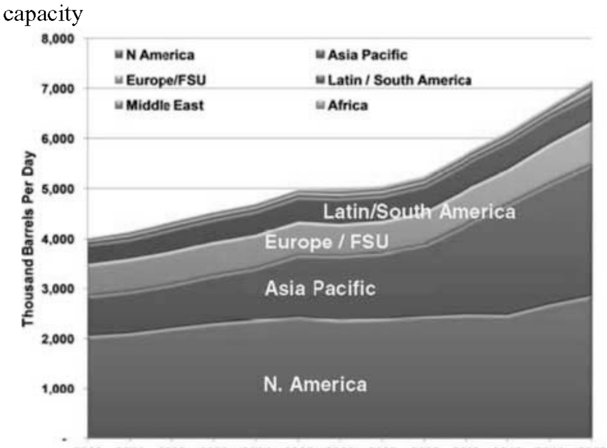

Figure 8: Coking Capacity by Region

Every refiner has a different way of determining their economics for processing different feedstocks for their hardware configuration. Different benchmarks also exist for evaluating coking – whether to run the unit at full capacity, or switch to different crude oil mixes. For many years the typical metric for coking economics was the spread between West Texas Intermediate (light sweet) and Maya (heavy sour) crude oils. As the spread (also known as the Heavy Oil Discount) widened, refiners looked to take advantage of processing lower quality and lower priced crude oils. Sometimes the changes in HOD led to switching between fuel and anode quality petroleum coke production; if sustained refiners looked at adding additional coking capacity. The graphic below (Figure 9) gives a perspective of coking economics over the past 10 years [2].

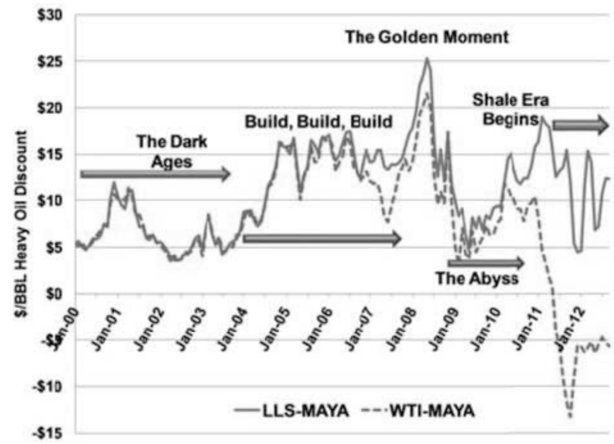

Figure 9: Coking Economic Indicators

On the left axis are two HODs – WTI-Maya (red dashed line) and Louisiana Light Sweet (LLS)-Maya (blue solid line). The reason why the two indicators are shown is a direct result of shale oil production, as the price for WTI has become depressed compared to global crude markets. LLS has now become the marker of choice as it is priced against global crudes such as North Sea Brent.

What is labeled "The Dark Ages" is the period before the increase in oil prices in 2005. It represents the refining industry during a period of meager earnings, and balanced demand and refining capacity. Starting in 2004 however, oil price and coking economics underwent a step change due to various forces. These include the impact of Hurricane Ivan to the US Gulf Coast, increasing demand from China, and the perceived lack of oil production and refining capacity.

From 2004 until 2008 (the "Build, Build, Build" period), prices and coking margins rose and new capacity was planned. For a brief period in 2008 ("the Golden Moment" instead of the "Golden Age" as some term it), WTI crude oil went over $140 per barrel, and the coking HOD averaged over $20 per barrel, reflecting the new wisdom that the world had finally seen "peak oil" and that until alternate energy technologies developed, oil would become a scarce global commodity.

Figure 10 shows new coking capacity added since 2000 by refining region [2]. Planning, permitting and building a new coker (or new refinery) does not happen in a short time period. Often it takes between 4-5 years – assuming the project gets financed, obtains necessary environmental permits – from the time an investment decision is approved to startup.

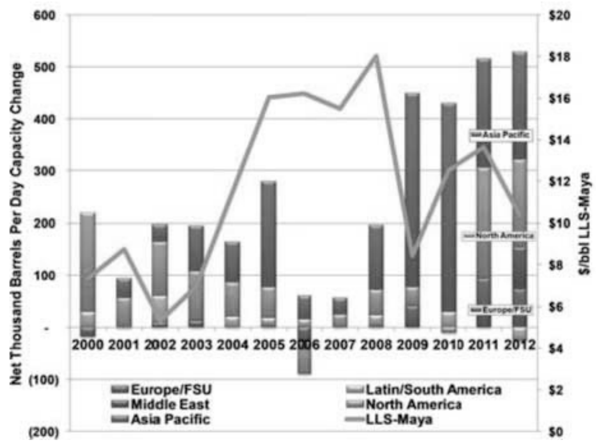

Figure 10: Coking Additions by Region

Figure 10 also shows the connection between the HOD and coking additions. While the HOD was in a range of \$4-\$8 per barrel in the early part of the decade, very few new cokers were planned and built. The low point (2006), when some capacity was actually shutdown, occurred 4 years from the low point of the HOD.

The old saying "what goes up must come down" ended up being true. The global financial crisis caused a severe drawback in oil demand, resulting in a large drop in oil price and coking economics ("the Abyss"). From 2009 until demand picked up in 2010, coking economics did not support new coking investment.

Many projects however were already well underway, and resulted in a large amount of new capacity starting up during the past four years. This new capacity, much of it in China, has not helped provide new volumes of anode quality coke, as most of it was designed to process heavy Middle East crude oils that do not produce anode quality.

How has petroleum coke quality changed during this same time period of new capacity and changing crude oil slates?

The following set of figures below provides a historical snapshot that mirrors the changes previously shown (Figures 4, 6, 7) in quality of crude oil processed. As noted in those figures, the average qualities of crude oils processed have become slightly heavier, slightly higher in sulfur and contaminants. Looking at the qualities on a macro-basis, however, can lead to erroneous conclusions.

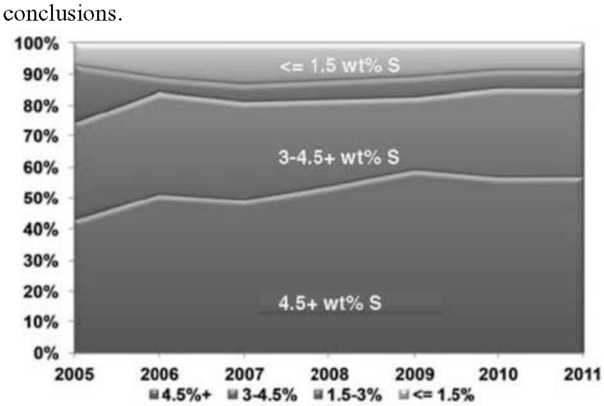

Figure 11: Average U.S. Coke Sulfur Content

Figure 11 above shows the relative percentage of coke by sulfur content produced in the U.S. since 2005. As the slate of crude oils processed worsened in quality, so too did the resulting quality of cokes produced. From 2006 forward, the change does not appear to be that great.

Looking at the qualities of cokes produced that have gone into the calcining market, however, tells a different story. Figure 12 shows the quality range of cokes in the same sulfur levels as Figure 11. Vanadium is shown in Figure 13.

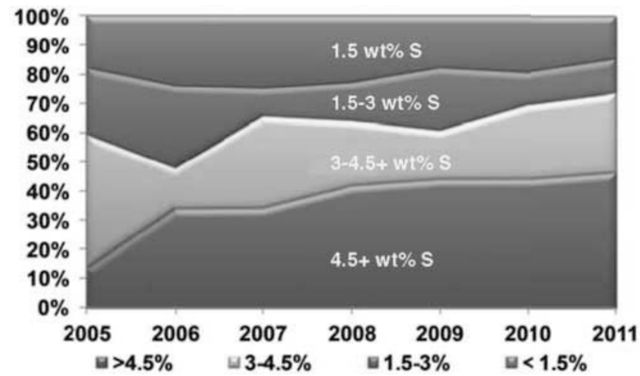

Figure 12 Average U.S. Calcineable Coke Sulfur

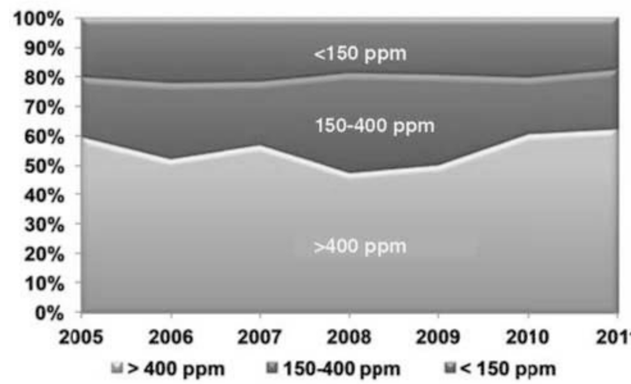

Figure 13 Average U.S. Calcineable Coke Vanadium

On an average basis, since so much of the base production is already high sulfur fuel grade, it appears that coke qualities have not changed much. But when the smaller part of U.S. production that is calcined is examined, the worsening quality shift is clearer to see.

The Shale Oil Revolution

Within the backdrop of the past decade of concerns of peak oil, a new technology was being tested that has revolutionized the oil industry. Mitchell Energy of Houston, Texas combined fracturing – a technology in use for over 40 years – with horizontal drilling in oil and gas formations previously thought to be uneconomic to produce due to its geological structure [8]. The production from these previously untapped reservoirs – termed "shale" due to the type of rock structure – has sparked a renewal of oil and gas production in the U.S. and elsewhere in the world, and is reversing long-held perceptions of oil supply (and quality) [9]. The shale oil & gas plays currently in production are of mostly light sweet quality - very low sulfur and contaminant content. The

United States is in furthest along in its development of shale oil and gas.

One of the most prolific areas is the Bakken in North Dakota, shown as the northern most shale area in Figure 14. It is considered to be the largest single oil resource in the US. In 2005 production was below 100,000 barrels per day. Production of the Bakken topped 600,000 barrels per day in July 2012 [10]. Numerous announcements come out almost weekly on rail projects to transport Bakken to the West Coast and to the Northeast US refining sector.

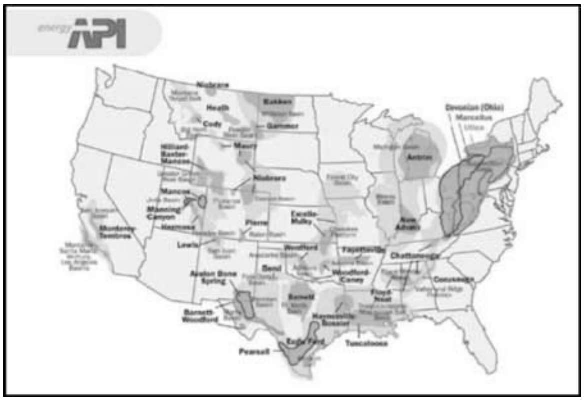

Figure 14: U.S. Shale Oil & Gas Plays

The introduction of shale oil to refining is having a large effect on coking economics and petroleum coke production and is already creating fundamental changes to refining economics. Refineries in the mid US once considered prime targets for shutdown are now seeing economic boom times as more and more shale oil is produced. Distressed crude oil is selling at a massive discount to products and refineries are using as much of this light sweet crude as they can.

The EIA and US Geological Survey have recently increased the volume of potential reserves in the shale oil reservoirs [11]. One shale reserve – the Utica, located underneath the Marcellus field in the eastern U.S., has now been estimated to contain almost 950 million barrels of light very sweet crude oil.

The latest annual review by the EIA [12] has forecasted different scenarios of future crude production from US shale ("tight oil") as presented in Figure 15. In the most optimistic case, oil production could rise from approximately 0.7 million barrels per day up to over 2.5 million barrels per day. That will have a great impact on quality of crude processed and anode petroleum coke made.

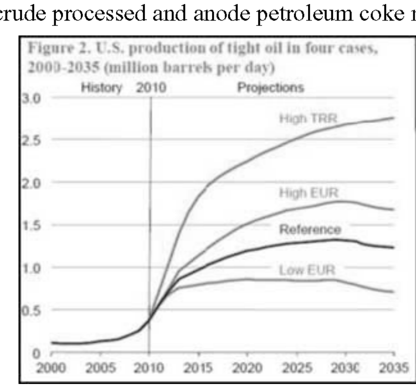

Figure 15: U.S. Shale Oil Production Forecasts

The Future for Anode Petroleum Coke Production

At a recent industry conference on petroleum coke, the chart in Figure 16 was presented by an industry participant on the change in quantity and quality of petroleum cokes calcined [13]. It reflects the changing quality of cokes produced and available for calcining.

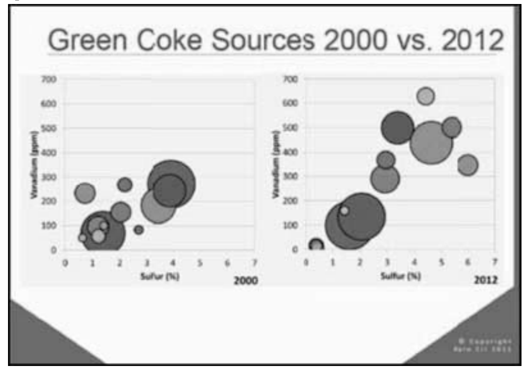

Figure 16: Coker Relative Coke Quality over Time

This mirrors the developments in the refining industry with new cokers built over the past decade, processing a wider range of crude oils of lower quality. The challenge facing the anode producers is how to obtain better quality anode cokes, as refiners' primary goal is to make transport fuel, not coke. The U.S. refining industry serves as a good proxy to demonstrate this.

Part of the answer for quantity and quality of future anode coke production is already set. Going back to the previous discussion on coking economics, most new cokers that will be starting in the next five years were designed at least four to five years ago. Figure 17 shows the short term forecast for new coking additions by global region [2].

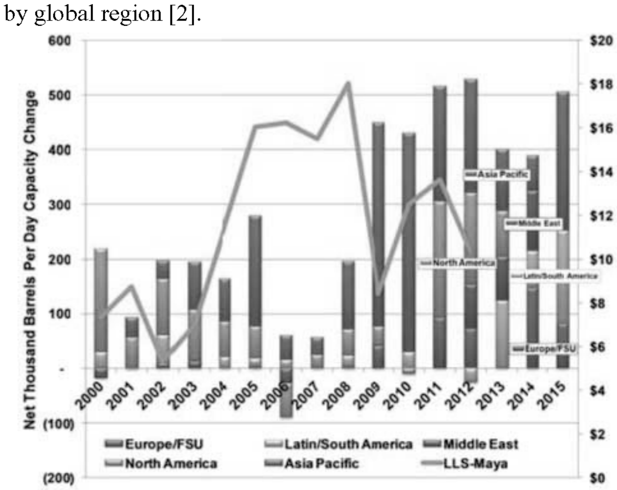

Figure 17: Forecasted Coker Additions

Many of the cokers that began operation from 2008 to 2012 were based on the strong HOD seen in the market from 2005 through 2008. On a regional basis, most of these new cokers are fuel grade cokers in Asia-Pacific – China and India. The mega refineries in India are processing heavy sour Middle East crude oils and many of the coastal Chinese refineries will import and process similar quality crude oils.

So how does shale oil factor into coking and what does that mean for anode coke production and quality? The conclusion has both positive and negative implications for the calcining and aluminum industries.

Figure 18 [2] provides illustrative crude oil yields and coker yields for four representative crude oils. From left to right are crude oil yields for Bakken shale oil, West Texas Intermediate, Western Canadian Select, and Maya crude oil.

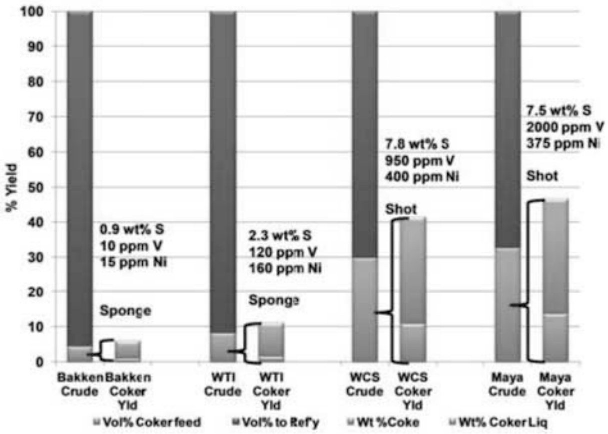

Figure 18: Relative Coking Yields

The feed to a coker is the 'vacuum resid' portion of the crude oil barrel – nominally the 1050 °F + portion of the crude oil. It is called vacuum resid as the material is distilled out of crude under a vacuum. The volume of Bakken vacuum resid is approximately 4.5% of the total crude barrel. In other words, a refinery charges 100 barrels of Bakken and has 4.5 barrels available for the coker.

Contrast this with Maya crude oil, which was the principal feedstock for many of the cokers built in the US Gulf Coast in the early 2000s. Almost one third (33%) of the crude barrel is coker feed, or almost 38% by weight. (Remember that US refiners typically deal in barrels, while refiners in other world regions deal in weight such as metric tons).

The second bar beside each crude oil represents the yield of gas & liquid and coke from the coker as weight percent of the crude oil barrel. Heavy sour crude such as Maya will yield almost 14 wt% of crude oil feed as petroleum coke. A shale oil such as the Bakken will yield only 1 wt% of the crude oil barrel as coke. So while a refiner processing Bakken shale will produce very good quality petcoke for calcining, it won't produce very much.

Conclusions

The future challenge then for anode volume and quality is that vast new reserves of high quality crude oils (shale) are being discovered and produced. That's a positive factor for anode quality as the cokes produced from these light sweet shale oils are very low in sulfur and metal contaminants. The negative aspect of coking these shale oils is that the total production of coke is substantially less than traditional heavy crude oils will produce. Blending clearly has a role to play and the value of coke qualities are likely to compress with the advent of petroleum coke made from high quality shale crude oils.

Many in the refining industry have termed this future combination of very light sweet crude oil and heavy sour crude oil processing as "refining a dumbbell crude oil slate". On average, the quality of the feed to the coker will look not that changed from the quality processed over the past decade. But it will not be from an 'average' crude oil of reasonable quality – it will be from a blend of very clean crude oil and very dirty crude oil. A challenge for anode coke quality will be that refiners may very well produce good quality sponge coke of low metals along with shot coke of high metal content. This situation will likely persist for the foreseeable future, particularly for calciners and smelters getting their anode coke sources from US refiners.

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