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# About the Author

**Wang Tao** is a resident scholar in the Energy and Climate Program based at the Carnegie–Tsinghua Center for Global Policy. Linking the work of Carnegie's programs in Beijing and its global centers in Washington, Moscow, Beirut, and Brussels, his research focuses on China's climate and energy policy, with particular attention to unconventional oil and natural gas, transportation, electric vehicles, and international climate negotiation.

Prior to joining Carnegie, Wang was program manager at World Wildlife Fund China, working in the Climate and Energy Program on scenario analysis, energy policy, and climate change adaptation. From 2006 to 2009, he was a core researcher at the UK's Tyndall Centre for Climate Change Research and the Science and Technology Policy Research Department at the University of Sussex.

Wang is author of numerous articles in the journals *Climate Policy*, *Energy Policy*, and *Science of the Total Environment*. He is also a regular contributor to the *Chinese Financial Times*, the *Diplomat*, *People's Daily*, and *China Daily*. Tao contributed to the *State of the World 2009* report by the Worldwatch Institute and the United Nations Development Program's *Human Development Report 2007–2008*. He is a contributing author to *Energy for the Future and Introduction to Low Carbon Economy*.

## Summary

Petroleum coke (petcoke), a by-product of petroleum refining that is high in contaminants, has quietly emerged in China as an inexpensive, but very dirty, alternative to coal. A significant share of the petcoke used in China is imported from the United States, where it is generally considered waste. The Chinese government is committed to reducing coal consumption for environmental reasons, but petcoke is not yet well-known to the country's policymakers. Still, its use and resulting emissions must be addressed if efforts to reduce air pollution and climate change are to be effective.

### Petcoke and Its Use in China

- Petcoke is a bottom-of-the-barrel residue produced from refining heavy oils with varying sulfur contents.
- Low-sulfur petcoke is widely used in metal manufacturing, while high-sulfur petcoke is burned to generate power and heat.
- Increasing amounts of high-sulfur petcoke are being produced by the growing number of complex refineries for extra-heavy oils from Canada and Venezuela. Chinese production is growing as the country imports more heavy and sour crude oil from the Middle East and South America.
- Petcoke has higher greenhouse gas emissions than coal or natural gas that have not historically been accounted for in assessments of the climate impacts of extra-heavy oils.
- About 33 million metric tons of petcoke were consumed in China in 2013. The United States exported 7 million metric tons of petcoke to China that year—20 times the amount exported five years earlier—accounting for nearly 75 percent of Chinese petcoke imports.
- A lack of information about petcoke use and its sulfur dioxide emissions poses a significant hurdle to China's efforts to regulate the substance, and to its broader attempts to reduce air pollution.

### What China Can Do to Control Petcoke and Its Effects

**Monitor the flow and use of petcoke.** Effective regulation requires better data on the amount of petcoke consumed, where it is consumed, and in what

kind of boilers it is combusted. Open, transparent statistics on resulting emissions are also essential.

**Employ economic instruments to internalize environmental costs.** Import tariffs, carbon pricing, and other policies could discourage the use of petcoke. China's carbon trading pilot scheme and its planned national carbon market should include emissions from petcoke.

**Promote cleaner technologies for petcoke combustion.** Technologies such as circulating fluidized bed (CFB) boilers and emissions controls should be mandated to reduce sulfur dioxide and other pollutants.

**Manage petroleum residues.** In the long term, refineries should be required to install low-emitting hydrogenation systems that convert petroleum residues into more valuable liquids and reduce the output of petcoke.

## Introduction

As the world's most populous country, with one of the most rapidly developing economies, China has been the world's largest energy consumer since 2006.

China's economic expansion has been mostly fueled by cheap and abundant coal. But beginning in 2003, coal prices multiplied several times in less than five years, driven by a rapid growth in demand, reaching their peak in 2008.

These higher prices forced many small business owners in heavy industries such as cement, glass, and ceramics, as well as small coal-fired power plants, to search for alternative fuel sources.

Some common options included residual fuel oil and blast furnace gas, as well as more expensive natural gas. But many in these sectors also turned to a less well-known alternative fuel: petroleum coke, or petcoke, a dirty by-product of the petroleum refining process that is largely unregulated.

**China has been the world's largest energy consumer since 2006.**

The majority of the petcoke consumed in China is domestically produced, and about half of the total is of a high enough quality to be used in metal manufacturing processes that do not involve combustion. But another variety of petcoke, with a higher sulfur and heavy-metal content, is increasingly being burned as an alternative to coal, and much of this petcoke is being imported from the United States. When it is combusted, this petcoke releases an array of toxins and greenhouse gas (GHG) emissions, making it even dirtier than coal in several respects.

The United States is the world's top petcoke producer and the dominant exporter of high-sulfur petcoke to China, accounting for nearly 75 percent of China's total imports in 2013.[1] According to the U.S. Energy Information Administration (EIA), U.S. petcoke exports to China jumped from 350,000 metric tons in 2008 to 2.4 million metric tons in 2009, and a staggering 7 million metric tons in 2013.[2] As petcoke use plummeted in the United States for a variety of reasons and U.S. exports to China increased, China became the world's largest consumer of high-sulfur petcoke.[3]

The sheer increase in China's use and imports of petcoke raises concerns about the environmental implications of these trends. But Chinese policymakers are not yet fully aware of petcoke's rapid proliferation, and data on petcoke consumption in China is lacking and far from transparent.

How policymakers approach the management of this by-product in the future will in turn impact China's broader efforts to battle air pollution at home, its commitments to mitigate climate change, and its interactions with global energy markets abroad. With the Chinese government and society pressing for more focused policies that counter environmental degradation and build climate cooperation, now is the time for policymakers to closely consider whether and how China should use petcoke as an energy source.

## What Is Petcoke?

Petroleum coke is a carbon-rich solid that emerges as a by-product of crude oil refining and other "cracking" processes, in which complex organic molecules such as heavy hydrocarbons are broken down into simpler, and more valuable, lighter petroleum products.

Low-sulfur, high-grade petcoke is widely used in metal manufacturing, and high-sulfur, low-grade petcoke—with its many contaminants, which prevent its use in metal manufacturing—is often used as an industrial fuel because of its relatively cheap price and its ability to generate high levels of heat, similar to coal.[4]

Though typically considered inert when it is left unburned and stored, petcoke is in some ways even dirtier than coal when it is burned—with a higher sulfur content, usually higher than 3 percent and typically as high as 6.5 or 7 percent,[5] and various heavy-metal contaminants, including mercury, arsenic, chromium, nickel, and cadmium, as well as dioxins, hydrogen chloride, and hydrogen fluoride that are emitted when it is combusted. If burned in a regular furnace or pulverized-coal-fired power plant, the toxic metal and sulfur dioxide emissions of petcoke are higher than those of coal.

When burned, petcoke also has a greater climate impact than bituminous coal or natural gas. At 104.5 kilograms of carbon dioxide equivalent per million British thermal units (BTUs), petcoke has 11 percent higher GHG emissions than coal, and nearly twice the emissions of natural gas.[6] These additional carbon emissions from petcoke have not historically been figured fully into calculations of the climate impacts of extra-heavy oils, such as those from Canadian oil sands and Venezuela, from which more petcoke is produced.[7]

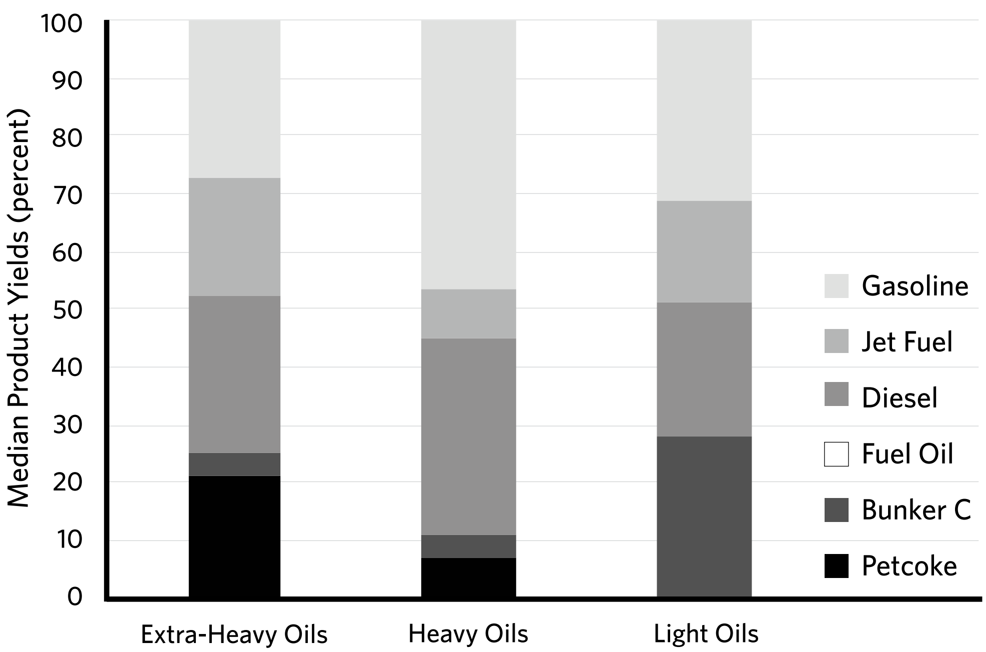
In terms of petcoke's effects on local air quality, common pollutants include carbon monoxide, sulfur dioxide, nitrogen oxides, particulate matter, and heavy metals, depending upon the chemical composition of the petcoke feedstock. These releases can take place through airborne dust particles during storage and through emissions during combustion.[8]

### Production of Petcoke

Crude oil itself is unusable. Instead, it is a feedstock that must be processed into gasoline, diesel fuel, jet fuel, and lubricating oils and waxes, leaving some residual oil that usually undergoes additional processing.

Different oils call for different refining techniques that produce different slates of petroleum products.[9] In general, the heavier the crude oil, the greater the residual that remains after refining. When refined using a coking unit to crack the hydrocarbon molecules, the residuals in heavier crudes are converted into higher shares of petcoke (see figure 1). Based on the sample oils modeled in Carnegie's Oil-Climate Index, the median barrel of refined heavy oil produces

Figure 1. **What's in a Barrel of Crude**




Source: Author's calculations based on Carnegie Oil-Climate Index database and PRELIM model

Note: Estimated shares of petroleum products do not include petrochemical co-products, which are all assumed to be refinery fuel gas in OCI Phase 1.

7 percent petcoke (by volume); the median barrel of extra-heavy oil produces 22 percent. In comparison, a typical refinery that is fed light and extra-light oils yields no petcoke from its total volume output.[10]

Petcoke, referred to as the "bottom of the barrel," is one of the last products manufactured during the oil refining process, with a carbon content of over 90 percent,[11] the highest of any petroleum product. Most of the value in crude oil comes from lighter oil products, such as gasoline, jet fuel, and diesel. As such, heavier oils are increasingly fed into coking refineries that reject excess carbon to yield more light products plus greater volumes of petcoke.

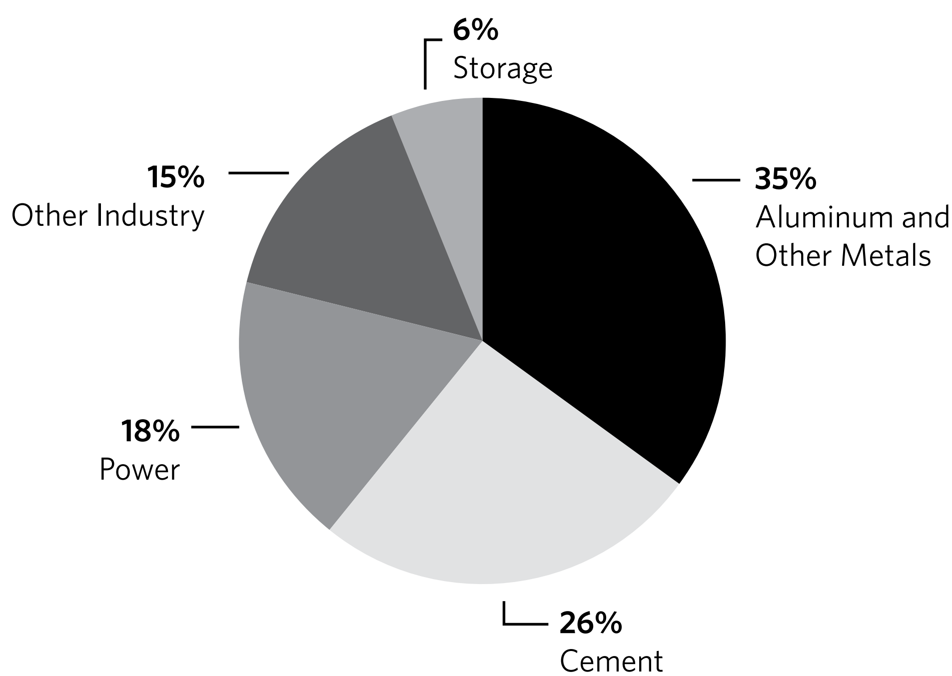
The United States and China have the largest and second-largest petroleum refinery capacities in the world, and they produce large amounts of petcoke. But refinery and coking capacity in the Middle East is expanding rapidly. The region is emerging as another large petcoke producer, and its coking capacity is expected to grow by 25 percent per year, on average, between 2011 and 2016, the highest growth rate in the world.[12]

China is also rapidly adding refinery capacity.[13] And China is contributing to the expansion of capacity in the Middle East through a joint refinery project between the China Petrochemical Corporation (Sinopec) and Saudi Arabia that was projected to handle up to 400,000 barrels per day of Arab heavy crude oil beginning in 2014,[14] of which an estimated 7 percent of the volume of refined products will be petcoke.

### Uses of Petcoke

Depending on its quality, petcoke is used as a fuel, particularly in developing countries, and as a source of carbon in industrial manufacturing processes (see figure 2).

Figure 2. **World Petcoke Use**




Source: American Fuel & Petrochemical Manufacturers

Several metal manufacturing processes rely on anode-grade or "calcined" petcoke, which is the residual by-product of light, low-sulfur, low-metal-content crude oils. This variety of petcoke goes through what is known as a calcination process to remove ash and make it purer. With a relatively low sulfur content (less than 3 percent) and high carbon purity,[15] it is used to provide carbon for the production of aluminum, steel, and titanium dioxide. For example, calcined petcoke is used to make anodes—large blocks that serve as conductors—for smelting alumina into aluminum, and needle coke, a related variety, is used to make the electrodes used in some steel production.

But most petcoke is used as a fuel source. While precise global data are unavailable, U.S. industry officials estimate that some 80 percent of the petcoke produced in the world is high-sulfur, fuel-grade petcoke.[16] The by-product of heavy, high-sulfur, high-metal-content crude oils, this variety is lower in carbon purity and mostly used to generate heat and power in cement kilns, glass furnaces, and power plants.

**North America plays an important part in China's growing use of petcoke.**

However, due to its low cost, fuel-grade, high-sulfur petcoke is also increasingly used in aluminum smelting in China, instead of the lower-sulfur, anode-grade variety. The production of high-sulfur petcoke is likely to increase because crude oil from new unconventional sources is heavier and higher in sulfur. For example, Arab medium-grade crude oil will yield approximately 7 percent carbon by volume as petcoke, whereas extra-heavy crude oils from Venezuela or Canada can yield approximately three times as much petcoke. Some 50,000 metric tons of petcoke was reportedly removed during the upgrading process (used to convert bitumen into synthetic crude oil) for every million barrels of bitumen extracted from Canadian oil sands in 2014.[17]

## Petcoke in North America

North America plays an important part in China's growing use of petcoke.

The region has the world's largest oil refining capacity, which is concentrated along the U.S. Gulf Coast. And, with more high-carbon, extra-heavy oil arriving from Canada's tar sands and from Venezuela, high-sulfur petcoke has been piling up at U.S. refineries. Canada's efforts to sell more crude oil from its extra-heavy bitumen oil sands to the United States—potentially transporting it through trains and an array of pipelines, including the controversial Keystone XL pipeline[18]—could lead to even more petcoke production at U.S. refineries.

At the same time, more onerous U.S. regulations and growing criticism of the open storage of petcoke have made U.S. refineries eager to get rid of their surplus petcoke, boosting exports. Most U.S. exports have gone to developing countries, with China the single largest destination of U.S. petcoke in 2013.[19]

## U.S. Petcoke Regulation

U.S. laws regarding the storage and handling of petcoke have not changed dramatically in recent years. But there has been new regulation of some of the harmful airborne by-products of burning petcoke. Most significantly, in 2013 the U.S. Environmental Protection Agency stopped issuing new licenses for the domestic burning of petcoke.

When stored, petcoke has historically been considered harmless in the U.S. regulatory system, as it does not biodegrade, chemically react with water or light, or bioaccumulate toxic chemicals to its structure. It has also been believed to pose less of a respiratory threat than other waste products when it is stored, despite the fact that it can be an irritant when it is dispersed by wind or floats into waterways.

It has generally been left up to local jurisdictions to decide how to regulate the storage of petcoke. Except for a few cases in the states of Delaware and California, petcoke storage is not specifically regulated by local-, state-, or federal-level codes. Federal law exempts petcoke from classification as a solid or hazardous waste and its movement is not routinely tracked. These laws predate the increased production of dirtier petcoke varieties.

But public pressure has increasingly been a factor for the U.S. petcoke industry. In 2013, the shores of the Detroit River and Chicago's Calumet River were the infamous storage sites of several-story-high mounds of petcoke. Those piles have since been removed due to community objections.

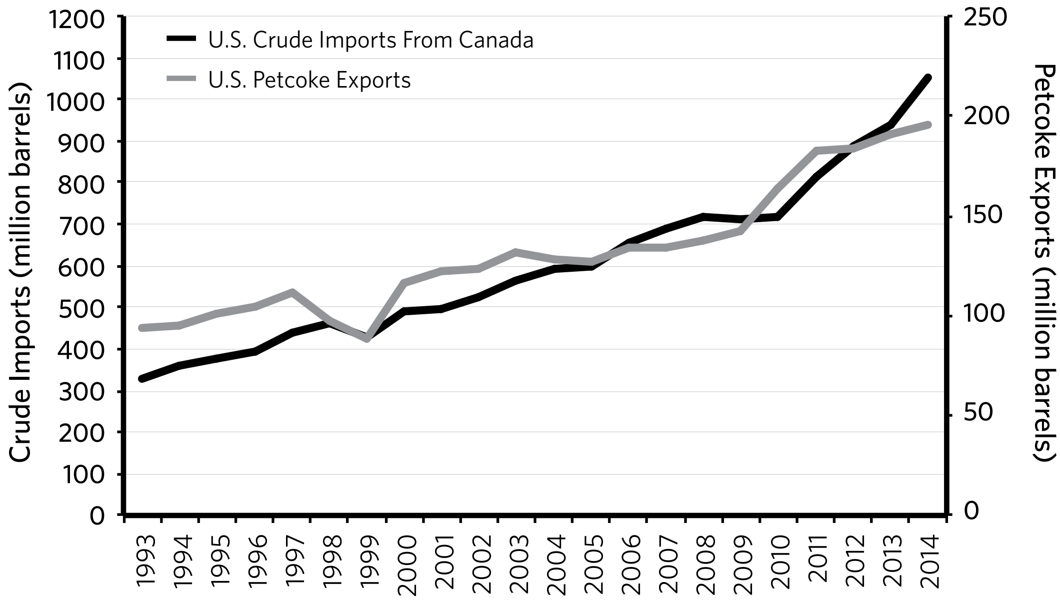
Faced with a substance that is produced in large volumes and costly to store, U.S. oil firms have become eager to sell petcoke to energy-hungry developing countries, and they are making handsome profits doing so.

## Petcoke Exports From North America

With the world's largest refinery capacity, the United States dominates the export market for petcoke; U.S. exports totaled nearly 200 million barrels, or 36 million metric tons, in 2014.[20]

The share of U.S. petcoke that was exported remained under 50 percent from 1981 through 2009. In 2010, however, the United States began to export more petcoke than it consumed.[21] In 2014, 61 percent of U.S. petcoke was exported, with the largest volumes shipped to Asia. The increase in U.S. petcoke exports correlates with increases in U.S. crude oil imports from Canada's oil sands (see figure 3).

Figure 3. **U.S. Crude Imports From Canada and U.S. Petcoke Exports**

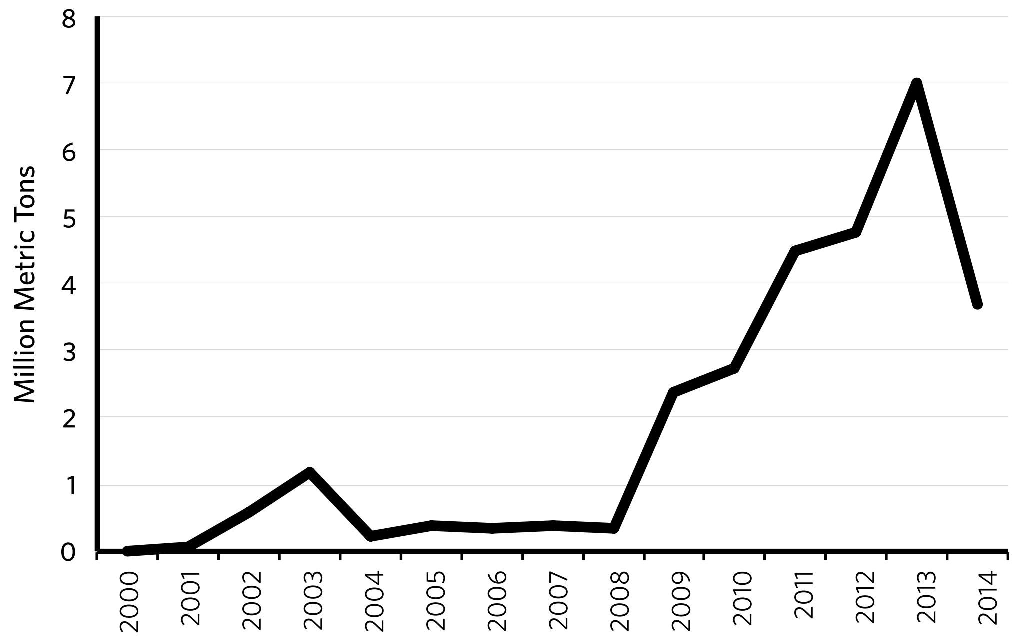



Source: U.S. Energy Information Administration data

As the price of coal in China surged to more than 1,000 yuan ($160) per metric ton in 2008, up from 200 yuan ($32) per metric ton in 2005, U.S. petcoke was about 25 percent cheaper than standard coal,[22] and it was competitive with natural gas and fuel oil for customers in China's glass and cement industries.

In 2013, China was the largest importer of U.S. petcoke, accounting for 20 percent of total U.S. exports (see figure 4). In 2014, China's petcoke imports from the United States decreased, creating a three-way tie among China, Japan, and India, which each imported over 20 million barrels (3.6 million metric tons) of petcoke.[23] Canada also exports petcoke that is produced in its own refineries, and in 2013 it was reported that nearly 50 percent of Canadian petcoke was shipped directly to China.[24]

Figure 4. **U.S. Petcoke Exports to China**




Source: U.S. Energy Information Administration

The proliferation of this substance, compounded with minimal understanding and evaluation of its effects on carbon emissions, climate change, and air quality, necessitates a closer analysis of its impact on Asia's hungry energy markets, particularly China. If left unchecked, petcoke will only worsen China's environmental record and further exacerbate global climate change.

## China's Petcoke Markets

China's miraculous economic growth since 2000 has been based on the rapid expansion of heavy industry, which helped double the demand for coal in less than a decade; by the end of 2013, China consumed more than half of the world's coal production.[25] But as high prices and transportation difficulties made it hard to obtain coal, small and private industries were forced to turn to alternative fuels such as petcoke. As a result, China's petcoke imports increased nearly 20 times between 2008 and 2013. Production of petcoke at small Chinese refineries, mostly in Shandong Province, also increased. In 2014, both petcoke and coal consumption declined. But it is unclear whether the reversal of these historic growth trends will continue without durable policy intervention.

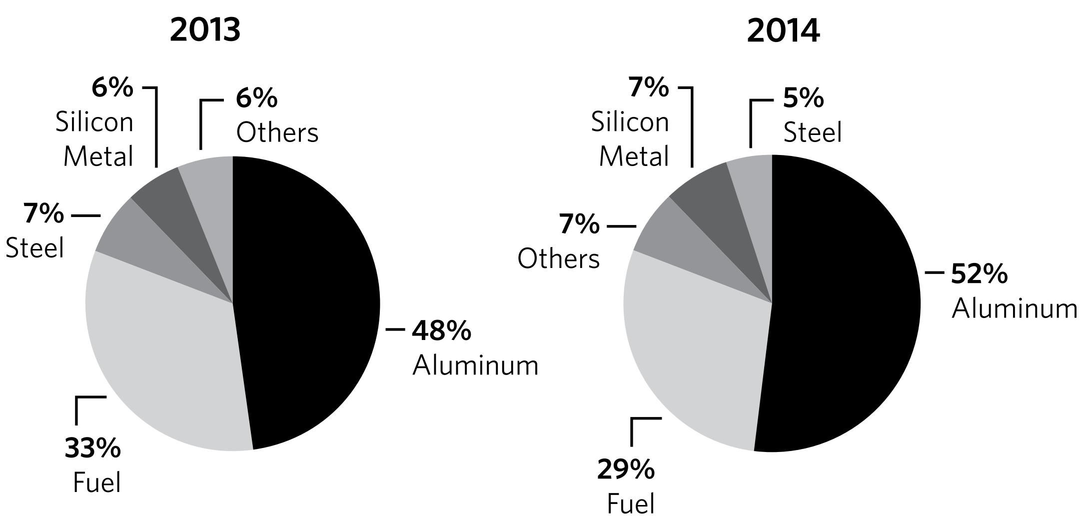
### Petcoke Demand

China's overall consumption of petcoke has grown substantially in recent years. In 2011, China used 27.5 million metric tons of petcoke. By 2013, it had jumped to around 33 million metric tons.[26] Demand decreased in 2014 due to high inventories, tight credit, a weak economy, and poor industrial performance across all sectors.

Petcoke has been particularly attractive since 2006, when Chinese industries were short of fuel. Petcoke's economic benefits and abundant supply are so obvious that its use as a replacement for heavy oil in the glass industry was even identified as one of the ten key energy-saving technologies to be promoted by the Chinese government during the eleventh Five Year Plan, between 2006 and 2010.[27]

But the single largest consumer of petcoke in China is aluminum manufacturing (see figure 5), which accounted for about half of China's total petcoke consumption in 2013 and 2014.[28] While petcoke is not combusted during this process, some 10–20 percent of the sulfur dioxide it contains is released from the surface of anodes during the production process.[29]

Figure 5. **Chinese Petcoke Consumption by Sector**




Source: ICIS China, *Petroleum Coke Market Annual Report, 2014–2015*

The aluminum industry is a clear beneficiary of China's latest heavy industrialization. Its capacity increased more than six times over the last decade, with growth averaging nearly 20 percent a year between 2002 and 2012.[30] China now accounts for nearly half of worldwide aluminum production.[31]

At the same time, China's metal industries have increasingly shifted to the use of high-sulfur petcoke for anodes due to its relatively low price. This higher sulfur content makes the anodes used in aluminum manufacturing less durable, requiring more to be used, thus boosting petcoke demand and increasing the sulfur dioxide emissions released during the production process.

An even greater environmental impact comes from the disposal of petcoke anode waste after the aluminum manufacturing process. This waste remains largely petcoke, and still has value as a cheap fuel. While the flow of anode waste has not yet been fully examined, it is easy to find petcoke anode waste being sold for fuel on the Internet in China, particularly in provinces with large aluminum manufacturing capacities. If the Chinese government hopes to win the war against pollution, this so far unchecked consumption of dirty fuel must be further investigated and addressed accordingly.

**If the Chinese government hopes to win the war against pollution, the so far unchecked consumption of dirty fuel must be further investigated and addressed accordingly.**

About one-third of China's petcoke demand is for fuel in various industries.[32] Fuel-grade petcoke is usually blended with coal to generate power and steam used in petroleum refineries and in some small power plants. Sinopec, China's largest petcoke producer, has used petcoke in its refineries' circulating fluidized bed (CFB) boilers for years to generate power and steam for its own use.

The CFB boiler process has the potential to absorb up to 95 percent of pollutants before they are emitted to the atmosphere.[33] While CFB scrubbers could remove sulfur dioxide emissions more cheaply and effectively than standard systems used in coal-fired power plants, the smaller capacity of these boilers means they cannot be used efficiently in China's new, large coal-fired power plants. And, because Sinopec produces much more petcoke than its own CFB boilers need, it sells its surplus to other users.

China's glass industry is another that has experienced exponential growth in the last decade, and it has increasingly turned to petcoke as a fuel. Glass manufacturers did not face stringent emissions controls until 2013, when air pollution became severe. Even in 2014, some large glass factories in northern China were still not equipped with desulfurization units, despite the increasingly high-sulfur petcoke burned in their kilns.

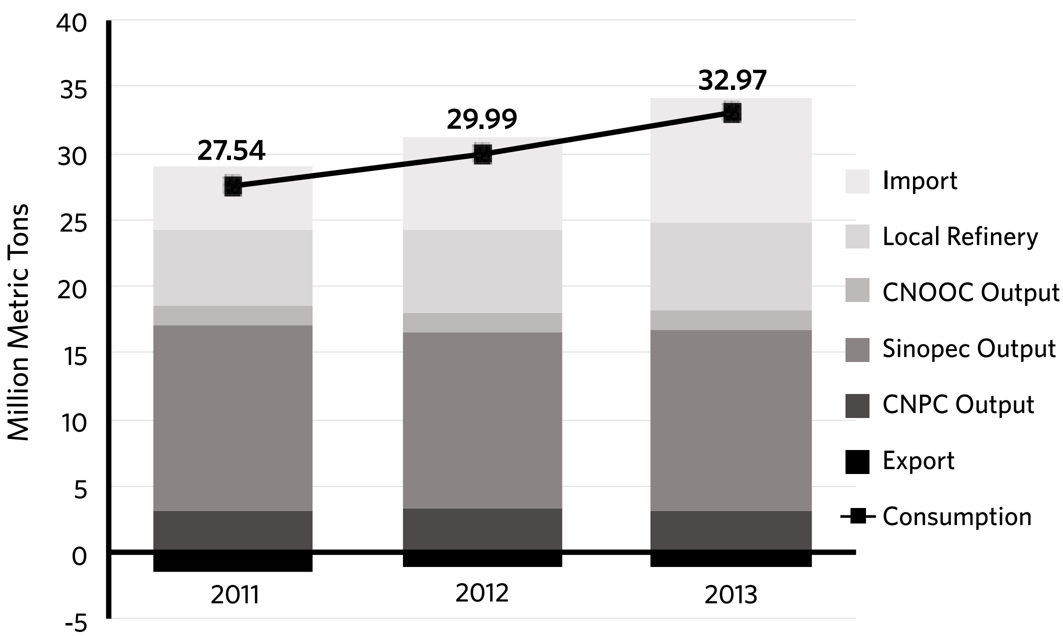
Petcoke is also widely used in ceramic and cement industries as a complementary fuel. These two sectors employ a large amount of lime in their production processes, making it easier to reduce sulfur dioxide emissions; with the addition of lime, sulfur dioxide can be converted to calcium sulfate, which has several industrial uses.

As heavy industries in China move higher in the value chain, higher quality requirements are beginning to make petcoke a less attractive option for some manufacturers. For example, one leading glass manufacturer I visited prefers to burn petcoke with a lower sulfur content (less than 2 percent) to prevent the erosion of kiln equipment and adverse impacts on the color and transmittance of its glass products. Some cement factories avoid petcoke because the whiteness of their product could be degraded by its impurities.

### Petcoke Production

With the world's second-largest refinery capacity, China is also a large petcoke producer. Domestically produced petcoke accounted for 70–80 percent of Chinese consumption between 2011 and 2013 (see figure 6).

Figure 6. **China's Petcoke Sources**




Source: Baininfo

More than half of China's petcoke production is from the national oil companies (NOCs), chiefly Sinopec, which traditionally has dominated the petroleum refinery sector. As Sinopec's petcoke production slowly decreased between 2011 and 2013, imports and local refinery production increased, by 93 percent and 18 percent, respectively.[34]

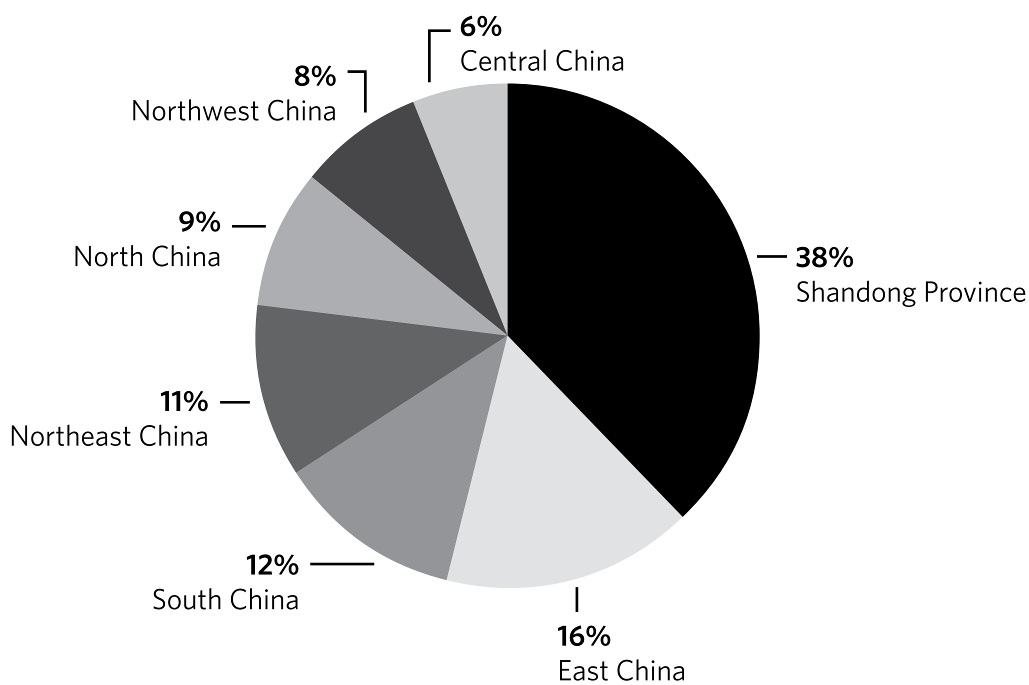
Imports of fuel-grade petcoke, like domestic production, are concentrated in certain regions in China—Shandong, Jiangsu, and Guangxi—which are all large producers of glass, cement, and ceramics. These three areas accounted for more than three-quarters of China's total high-sulfur petcoke imports in 2012 and 2013.[35]

Because of high transportation costs, imported fuel-grade petcoke is likely to be employed by local power plants and heavy industries. However, detailed information on the users of petcoke in these regions is not available. While the high sulfur content of imported petcoke means sulfur dioxide should be removed from emissions before they enter the air, it is unclear if these plants are equipped with desulfurization units, and how stringently environmental regulations are implemented and enforced at the local level.

The fast growth in China's refinery capacity, which almost doubled in less than a decade to over 600 million metric tons in 2013, was led by the NOCs.[36] But local refineries, whose coking capacity increased five times between 2005 and 2010,[37] are likely most responsible for the increased production of petcoke in recent years.

China's Shandong Province is home to many refineries, and has the largest coking capacity in the country (see figure 7). Many of these local "tea pot" refineries—generally small private companies with short production lines—are infamous for their poor environmental records.

Figure 7. **Distribution of China's Delayed Coking Capacity, 2014**




Source: ICIS China, *Petroleum Coke Market Annual Report, 2014–2015*

The local refineries rely on various feedstocks, including high-sulfur heavy oil from domestic oil fields, imported oil, and residual oil. Lack of capital and technology means these small refineries are more likely to deal with heavy and inconsistent feedstocks, thus generating more, and higher-sulfur, petcoke.

Petcoke produced by China's state-owned enterprises used to be lower in sulfur and metal content than imported petcoke, most of which is fuel-grade, with a sulfur content of 3 percent or higher. But with heavy and high-sulfur crude oil from the Middle East and South America, including Venezuela, making up a growing share of China's imports, the amount of high-sulfur petcoke that is produced domestically is increasing.[38] That trend is likely to continue as these unconventional oils penetrate the global supply.

Lower global oil prices are unlikely to change China's preference for heavier crudes, which are expected to remain discounted compared to light, sweet oils. Indeed, this may even favor the consumption of petcoke, as its price will fall further against that of coal and other alternative fuels.

### High-Sulfur Petcoke Exports

China exports a small proportion (less than 5 percent) of its high-sulfur petcoke. The majority of China's exports go to India and Bahrain, likely for their metal industries.

Despite the recent economic slowdown and weakened petcoke demand in heavy industries, China's crude oil imports and refinery capacity are expected to continue to grow. That could lead China to boost its exports of high-sulfur petcoke to other developing countries, an area now dominated by the United States. That shift would carry international environmental implications that need to be acknowledged and addressed.

## Petcoke and China's Fight Against Pollution

The Chinese government is investing huge resources in tackling air pollution and reducing coal consumption. But petcoke, with a sulfur content several times higher than that of coal, has largely been left out of the conversation.

The government does not closely monitor where and how petcoke is consumed in China, partly because it has been unaware of the increased presence of high-sulfur petcoke and its changing uses. Official statistics on petcoke consumption were not available until 2010, and their accuracy remains in doubt. And, as of early 2015, petcoke was still not subject to the kinds of rigorous reduction targets that have been imposed on coal.

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In a high-profile speech in March 2014, Chinese Premier Li Keqiang declared a war on pollution and made environmental protection a higher priority than it had been, putting it on a par with economic development. He also said the government was committed to promoting renewable energy and sustainable development.

Coal consumption and transportation emissions have been identified as the largest two sources of air pollution in China, and they are subject to tough abatement targets. But other industrial fuels are not subject to the same rigorous inspections and controls, and it is even unclear if there are any regulations that apply to petcoke consumption, or the changing oil supply chain, for that matter.

While petcoke has emerged as a serious source of pollution, it has so far drawn little notice from policymakers. Many Chinese environmental experts and other nonbusiness stakeholders appear to be unaware of its use and growth trajectory. Some people who work in related industries said in interviews that they had not heard of petcoke, while others had a poor understanding of the product, its different types, and its uses.

The lack of attention to petcoke can be partly explained by the way coal dominates the conversation in China. The nearly 4 billion metric tons of coal consumed in 2013 dwarfs petcoke's 33 million metric tons.[39] And the tens of millions of metric tons of petcoke burned in China do not make a notable dent in the overall emissions from billions of metric tons of coal.

There is another, perhaps more alarming, reason for the inattention to petcoke. While larger quantities of high-sulfur petcoke are being produced by Chinese refineries and used as an inexpensive fuel alternative in several industries, policymakers are not fully aware of this trend.

But petcoke should not be neglected if the Chinese government is to be serious about improving air quality. Due to its higher sulfur content, petcoke contributes much more sulfur dioxide to air pollution than coal for each metric ton that is burned. Some manufactured petcoke could contain as much as 7 percent sulfur, whereas the average sulfur content of Chinese coal is 1 percent.[40] Petcoke also has higher greenhouse gas emissions because of its higher carbon content. More importantly, it is a by-product of heavier and lower-quality crude oil, and extracting, transporting, and processing this oil itself can be more than 80 percent more GHG-intensive than lighter conventional crudes, making petcoke even more damaging to the climate than coal during its life cycle.[41]

**China's increasing imports of unconventional oil will likely be accompanied by increased petcoke and carbon emissions in China and abroad.**

An Action Plan on Prevention and Control of Air Pollution, released in 2013 by the State Council, China's top administrative authority, set targets that would require reducing coal consumption in the northern provinces near Beijing by 80–90 million metric tons by 2017.[42] The only mention of petcoke in the Action Plan was a call "to restrain high-sulfur petcoke imports," without any elaboration or details on targets. Shandong—with its high level of petcoke imports and glass, cement, and ceramic factories that burn it as fuel—was also tapped to cut coal consumption. But any accomplishment on that front could be severely compromised if tens of millions of metric tons of petcoke, with several times higher sulfur content, is burned without regulation.

These very local effects are also closely tied to changes in world energy markets. An emerging paradigm shift is already redirecting the global center of gravity of oil away from the Middle East and toward North America.

China's increasing imports of unconventional oil will likely be accompanied by increased petcoke and carbon emissions in China and abroad.

## Managing Petcoke's Future

Given the minimal public awareness of petcoke, and its omission from environmental impact evaluations of the industries that use it, there is not much of a policy landscape in China that considers how to best manage the commodity. To be fair, many countries (including the United States) are still grappling with understanding petcoke's implications for industrial production and wider GHG emissions.

This presents China with an opportunity to preemptively manage its use of petcoke and make concerted efforts to control the contributions to air pollution and climate change that come from the combustion and industrial use of this oil by-product.

### Monitor Usage

Petcoke in China is hard to track; information is clearly lacking. Data about petcoke production and consumption were not included in the China Energy Statistical Yearbook produced by the National Bureau of Statistics of China until 2010. While some information is now available, it is generally incomplete and often difficult to verify. This gap creates a challenge to the regulation of this new alternative fuel, and potentially an omission in sulfur dioxide and carbon dioxide emissions statistics.

Improved statistical data on petcoke and a strengthened monitoring system of pollutants such as sulfur dioxide are essential for any effective environmental regulation. Information about how much petcoke is consumed in China's industries, where it is consumed, and in what kind of boilers it is combusted, along with real-time online monitoring, should be both open and transparent.

The industrial users of fuel-grade petcoke are mostly small and in specific industries, and many may not be willing to report their emissions. This presents a difficult challenge for the Chinese government, especially for local statistics agencies. However, given the array of petcoke uses in different industries, it is also important to differentiate them in statistics, and implement appropriate measures to control them.

Close monitoring of pollutants from a large number of small industries is critical to China's battle against air pollution.

### Employ Economic Instruments

Petcoke is a popular alternative to coal because of its lower cost, so economic instruments such as emissions fees and carbon pricing would be the most effective policy tools to limit its use and abate its impacts.

The Chinese government is traditionally overreliant on command-and-control regulatory approaches, such as setting targets for the reduction of coal consumption and shutting down factories based on the scale of their production. This encouraged polluters to scale up production and indirectly caused overcapacity, which in turn forced industries to look for ways to reduce production costs by using lower-quality fuels or cutting corners in environmental treatment. It also had the unintended result of boosting the use of petcoke as a cheaper alternative fuel. Similarly, efforts to reduce the use of coal will be compromised if more polluters shift to one of the many other low-quality fuels that are not regulated, such as petcoke.

By contrast, internalizing the environmental costs of dirty fuels through emissions fees or carbon pricing would reward the most efficient producers, rather than the largest. Under this kind of scheme, the cost of pollution abatement could be reflected in the price of finished products.

Beginning in 2015, a new Chinese environmental law will take effect, giving the Ministry of Environmental Protection the power to charge emissions fees on polluters at much higher levels than before, based on the emissions they generate. The polluters could even face criminal charges if they fail to comply with emissions standards. This has the potential to correct price distortions and lessen the appeal of petcoke as an inexpensive alternative to coal.

Because a significant portion of petcoke fuel consumed in China is imported from countries like the United States, imposing import tariffs would also be an effective means of correcting the price advantage that petcoke enjoys. But given the strong incentives that U.S. refineries have to export petcoke, such an import tariff would need to be high enough to offset the price difference. To be most effective, import tariffs should be combined with direct controls on use. The Chinese government's 2013 Action Plan only ambiguously requested that imports of high-sulfur petcoke be limited. But due to the poor performance of China's industrial sector in 2014, especially the increasing deficits in the aluminum industry, a decision on import tariffs on high-sulfur petcoke had not been made eighteen months after the Action Plan was introduced.

A good next step would be to include petcoke users in carbon trading schemes that are being tested in several cities across China. This pilot program calculates emissions based on the fuel used in participating plants, and it is unlikely to include petcoke, let alone other alternative fuels such as anode waste from the aluminum manufacturing process. It is possible that there are no major users of petcoke in the existing carbon trade pilot cities. But because the Chinese government plans to extend the carbon market nationwide in 2016,[43] it is important that petcoke be included as quickly as possible.

### Promote Cleaner Technologies

The promotion of cleaner technologies, including CFB boilers and emissions treatment systems, is another way to reduce sulfur dioxide emissions from petcoke combustion.

Burning petcoke in CFB systems could effectively and cheaply remove sulfur dioxide from emissions while generating high thermal value. These boilers are particularly suited to coal that is of low and inconsistent quality, which makes them capable of handling the variety of petcoke inherited from crude oil. The CFB system is usually smaller than newly built coal-fired power plants in China, but it could be an option for some refineries and industries.

Because petcoke will continue to be produced by Chinese refineries, with higher sulfur content from crude oil that is getting heavier and dirtier, it is imperative that petcoke be burned in the least harmful way if China is to address its pollution problem. To ensure this, desulfurization equipment should be mandatory at plants that use high-sulfur petcoke or other alternative fuels.

### Reduce Production

Over the long term, increasing the production of cheap solid fuels such as petcoke at the expense of high-value liquids is not an ideal refining arrangement. In the refineries using heavy crude oil, roughly 7 percent of yields are in the form of petcoke.

Many new and planned Chinese refineries are considering the addition of a new system to reduce the amount of petcoke they generate. Adding excess hydrogen to convert otherwise solid oil residues into more diesel, asphalt, wax, or other fuel oils—through a process called residue fuel hydrogenation—is an attractive option for new refineries. While the installation of such equipment is expensive and requires better refinery management, the Chinese government should require these systems in new refineries and provide financial support to help old refineries upgrade their facilities.

## Conclusion

The Chinese coal industry has been depressed since 2013, and a slowing economy combined with the government's efforts to reduce pollution mean its prospects are not improving. The coal price in early 2015 was about half of what it was at its peak in 2008.

Petcoke prices, too, were lower in early 2015 than they had been a year before. Despite a declining price of coal, which—at least temporarily—has largely reduced petcoke's price advantage over coal, the collapse of oil prices that began in late 2014 means that petcoke's price may fall further in 2015 with a delayed price adjustment.

Users of petcoke do not yet face the kinds of tough environmental regulations that users of coal do. But this weakened demand provides a good window of opportunity to address the so far unchecked consumption of fuel-grade petcoke in China. As a by-product of heavy and dirty crude oil with a potentially high contribution to sulfur dioxide emissions, local smog, and greenhouse gas emissions, petcoke is a crucial part of China's war against pollution and climate change. The rapid growth in the use of petcoke since 2006 illustrates the need to build institutional capacity for a comprehensive pollution control scheme that combines both political campaigns and market forces, so that pollution is neither politically tolerable nor economically feasible.

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