DRAFT

Coal Gasification: A Clean Alternative to Combustion

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1 Combustion is too Dirty

A large component of the damage done by coal comes from the traditional power plant. Traditional coal fired power plants work be first grinding the coal dust into a fine powder. Then they inject this fine dust into a firebox where it is combusted to boil water. The water is then heated and compressed to temperatures of up to 1000 degrees Fahrenheit, and $3,500$ pounds per square inch. [10] The resulting steam the drives a turbine that generates water.

The problem with this traditional design is the combustion in the fire box. When the coal dust is burned it creates a large amount of pollutants, namely carbon dioxide, methane, sulfur dioxide, and NO_x. [6] Carbon dioxide and methane are widely known green house gases. Sulfur dioxide is the main cause of acid rain, but it is also harmful when inhaled. An NCR study estimated that sulfur dioxide emissions cost the state of Kentucky $2.85 billion dollar annually. [13] Nitrogen (NO_x) damages fresh water ecosystems, and causes acidification of oceans. [1] The pollution caused from the combustion of coal can seem "far away" when talking about ocean ecosystems. In reality it directly harms humans, and costs a lot of money.

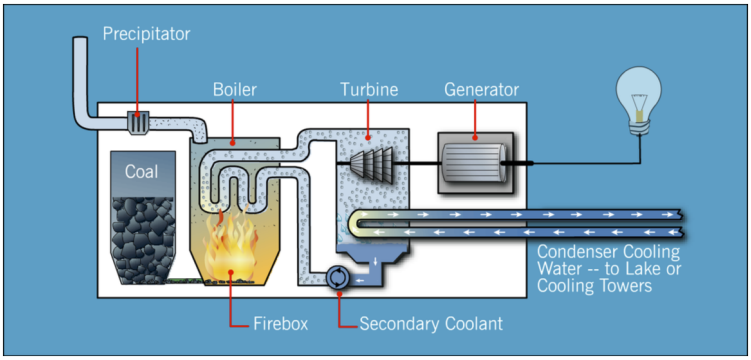

Figure 1: Coal Fired Power Plant [10]

Unlike in combustion, the vast majority of the coal is not burned in gasification. Instead the coal is heated at a high pressure so that it decomposes into syngas, a mixture of hydrogen, carbon monoxide, and small amounts of carbon dioxide. The heat and pressure come from a small amount of the coal being burned. [8] To fuel this combustion, there is a controlled amount of oxygen added to the mixture. The final ingredient in the chemical reaction is steam. This mixture of coal, oxygen, and steam produces the desired syngas.

2 Coal is Plentiful

Despite coal being incredibly pollutant it is still an amazing resource. Namely, coal is a cheap and plentiful. The main competitor with coal in the United States is natural gas. We can compute the relative costs of the resources themselves, per amount of energy they generate by using figures from the United States Department of Energy. The DOE estimates that it takes about $5.2 \cdot 10^{-3}$ short tonnes to generate a kilowatt hour. [11] And from their data bases the price of coal is currently about $35 per short tonne, so, [12]

$$\left(5.2 \cdot 10^{-4} \cdot \frac{\text{short tonnes}}{\text{kWh}}\right)\left(35 \cdot \frac{\$}{\text{short tonne}}\right) = 0.018\frac{\$}{\text{kWh}}$$

it costs about 1.8 cents to buy enough coal to generate a kilowatt hour. Now if we can look at the cost of natural gas using the same methods. The DOE estimates that it takes about $10,408$ Btu to generate a kilowatt hour. [11] And the current price of natural gas is about $1.5 per Btu, so, [12]

$$\left(10408 \cdot \frac{\text{Btu}}{\text{kWh}}\right)\left(1.5 \cdot 10^{-6} \cdot \frac{\$}{\text{Btu}}\right) = 0.015\frac{\$}{\text{kWh}}$$

it costs about 1.5 cents to buy enough natural gas to generate a kilowatt hour.At first this might make coal seem more expensive than natural gas, but this is at this moment in time. As can be seen in figure 2, the price history of coal is much more stable than that of natural gas. This is incredibly important because if natural gas rises just 0.4 than coal will be cheaper. This long term price security of coal is very important because power plants tend to have a relatively large upfront cost, and therefore, need to produce consistent income for several years to come. *Note: I want to do some amortizing comparing the to kinds of power generation*

This price security coal is also not likely to change because it supply is plentiful. The main reason behind this is that there is a lot of coal left in the United States. The coal reverses being in side the United States reduces the chance of a shortage because of some kind of international crisis, and ensures that the United States government has the ability to better control the flow of the coal.

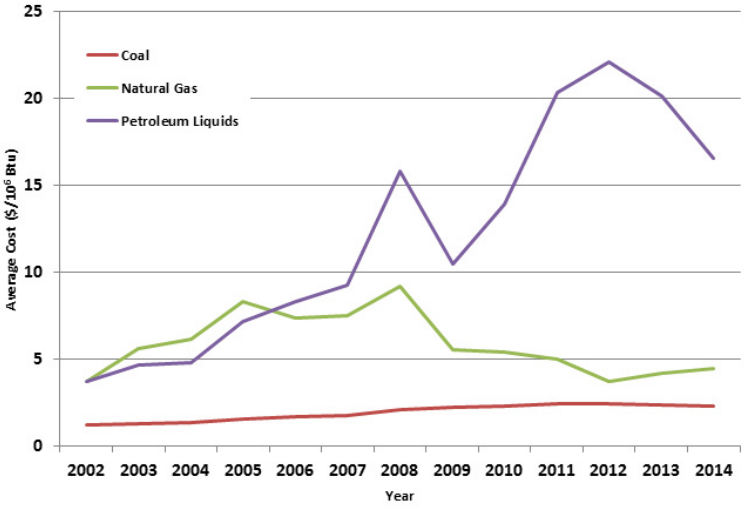

Figure 2: Price Histories [4]

Yet, even more important than the coal's location is its amount. The United States Department of Energy estimates that the United States has coal reserves of about 480 billion short tonnes. [15] The United States processed about 980 million short tonnes of coal in 2013, and the high estimates of coal production are just about 1250 million tonnes by 2400. Suppose only 380 tonnes of the coal reserve is obtainable (about 80 %), because of property rights or technology barriers. This leaves a reservoir of billion tonnes. Now suppose for some reason our coal production rose to $4,000$ million short tonnes a year immediately. Even with these unlikely estimates we still have about 95 years of coal left,

$$\frac{380 \cdot 10^9 \cdot \text{tonnes}}{4 \cdot 10^9 \cdot \text{tonnes} \ / \ \text{year}} = 95 \cdot \text{years}.$$

It seems unreasonable to waste such a stable and available resource.

3 How Gasification Works

Unlike in combustion, the vast majority of the coal is not burned in gasification. Instead the coal is heated at a high pressure so that it decomposes into syngas, a mixture of hydrogen, carbon monoxide, and small amounts of carbon dioxide. The heat and pressure come from a small amount of the coal being burned. [8] To fuel this combustion, there is a controlled amount of oxygen added to the mixture. The final ingredient in the chemical reaction is steam. This mixture of coal, oxygen,

and steam produces the desired syngas.

Just after the syngas is produced is the first step that generates power. Although the syngas is unprocessed and not ready to be used it is still incredibly hot. This excess heat is captured in water and use for power generation.

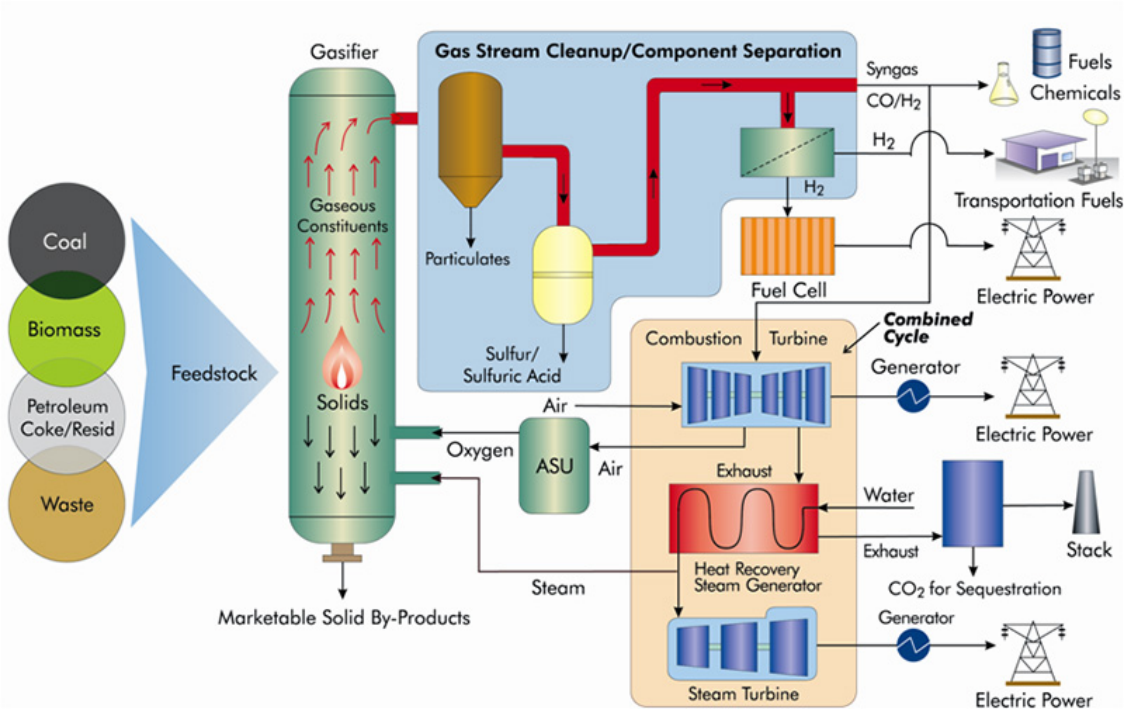

Figure 3: Diagram of Gasification Process [8]

To be further utilized the syngas produced from the gasifier needs to be cleaned. First, particulate matter still remaining in the gas is removed. Then, the gas is cleaned of remaining gas contaminants. Along with many other gases the two most voluminous removed are carbon dioxide and hydrogen sulfide. [8] Depending on the method used the sulfur may be obtained in either a solid or liquid form, but, either way, the sulfur is not a waste material and is sold for an additional profit. At first, the carbon dioxide may seem to be a waste. Yet, the carbon dioxide produced is in a high enough concentration that it may be sold for commercial. One, such use is to improve yields from oil drilling. [3] This now purified syngas is ready to be utilized for energy generation.

From this stage the exact use of the syngas differs between setups. At this point the syngas is mostly hydrogen. This means operations that are entirely focused on electricity generation will

now burn the syngas as a fuel in an on site turbine. [14] However, there are two other commonly utilized options. One is to not burn the syngas but further process it into synthetic natural gas. This is done in the Great Plains Dakota Gasification Plant. [7] A second is to further purify the syngas into just hydrogen gas. The natural gas or hydrogen would then be sold as a fuel. Regardless of the route chosen the energy obtained in the original coal has been converted into alternate energy sources.

4 Gasification is Cleaner

Gasification offers a potential use of coal because it almost entirely removes the pollution that combustion contributes. Chemically this is possible because the reaction takes place in a highly controlled environment. Unlike combustion the coal is not burned in the presence of raw air. Instead, the ingredients are limited to calculated amounts of oxygen, steam, and coal. This means there is far less nitrogen exposed to the reaction, which is commonly found in the air, and reduces the concentration of NOx. Furthermore, the toxins that do get produced, mainly carbon dioxide and sulfur compounds, are at a much higher concentration and at a much higher pressure. The higher pressure means less volume to clean compared to the near atmospheric pressure of a coal fired power plant. The higher concentration of makes filtering itself more effective [5]. This high concentration also has the benefit of allowing for the these toxins to be gathered in large enough quantities to be sold. Together these benefits can make gasification of coal just as clean as burning natural gas. [9]

Gasification also offers an improvement in efficiency over. We can calculate the efficiency of a coal fired power plant by taking the number of Btus in a kWh (3,412 Btu) and dividing it by the heat rate of the power plant. The United States department of energy reports that the average heat rate of coal power generation in 2014 was 10428 Btu, so,

$$\frac{3,412}{10,428} \approx 32.7\%,$$

coal power plants use about 32.7 % of the energy in the coal they burn to generate electricity. Yet, gasification plants with integrated turbines currently offer about 40 % efficiency and the US DOE expects this could rise to 80% or more with future technologies.

This increased efficiency has two major benefits. First, it reduces emissions even more by consuming less coal to produce the same amount of power—potentially less than half of what is currently used. Second, it means the coal reserve will last longer because it will be used slower. In addition, criticism of coal scrubbing technology argues that it will decrease the efficiency of generation by $25 - 40\%$, but this technique does the opposite. [1]

5 Economics of Gasification

Currently, there are four gasification plants operating in the United States that use coal as their fuel and generate electricity. The main force preventing the widespread adoption of the technology are currently low natural gas prices and momentum. The lack of commercial examples dissuades investors. The uncommonness means the equipment and facilities that gasification plants require are more expensive because they must be specially designed and made. [2]

However, this balance could easily change in the future when natural gas has a price raise. Or, when regulations become more stringent on pollutions coal fired power plants code become to expensive to run cleanly. Or, the widespread adoption of hydrogen as a transportation fuel would also raise the value of gasification because it can easily produce hydrogen. Or, the technology develops further. *I want to due some amortizing analysis on these cases, but I am having trouble finding economic data from the four companies*

The United State's Department of energy seems to believe in the gasification because they have invested billions of dollars into the technology, and continue to as it improves.

One such potential technology advancement would be a very dynamic gasification plant that could quickly switch between producing hydrogen gas and generating electricity. This kind of power plant would fit in perfectly with the inconsistent power generation of renewable technologies. Whenever the renewable are making energy it can shift to producing hydrogen. Then when the renewables stop producing—maybe at night for solar—the plant could switch back to electricity. This kind of hybrid power plant might be perfect in twenty years when the world is starting to become more reliant on renewable energy and the Toyota Mirai is driving the roads using hydrogen fuel cells.

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