Coal Gasification: A Clean Alternative to Combustion

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1 Coal is Damaging

A large component of the damage done by coal comes from the traditional power plants. The most common of which are pulverized coal plants. Pulverized coal plants work by first grinding the coal dust into a fine powder. Then injecting it into a firebox where it is combusted to boil water. The water is heated and compressed to temperatures of up to 1000 degrees Fahrenheit, and $3,500$ pounds per square inch. [11] The resulting steam the drives a turbine that generates water.

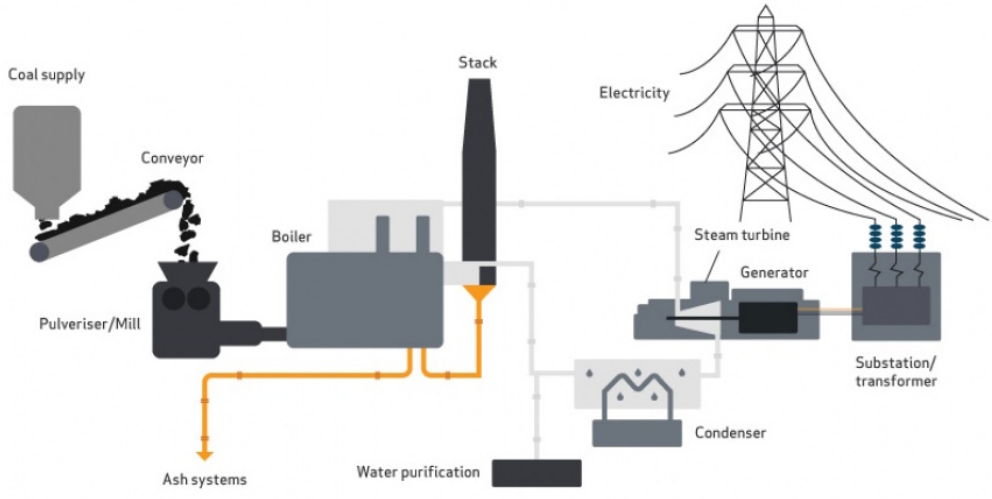

Figure 1: Pulverized Coal Plant [4]

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, NO_x, and sulfur dioxide. [7] Carbon dioxide and methane are widely known green house gases. Nitrogen oxides (NO_x) damage fresh water ecosystems, and cause acidification of oceans. [1] The pollution caused

from the combustion of coal can seem "far away" when talking about green house gases and ocean acidification, but these pollutants also have a direct effect on our lives. Sulfur dioxide is the main cause of acid rain in cities, and is also a health hazard when inhaled. A study from the National Research Council estimated that sulfur dioxide emissions cost the state of Kentucky $2.85 billion dollar in annual health expenditures. [15] Pollution from coal combustion does not just contribute to the long term effects of climate change. Coal's pollutants have a direct impact on people's health and cost a lot of money.

2 Coal is Plentiful

Despite coal being incredibly pollutant it is still an amazing resource. Coal is inexpensive and plentiful. These two qualities offer stability and security. This is important for investors and utilities who desire to make profits from energy production, but it is also important to the consumer. When fuel prices rise so will the cost of electricity for consumers.

To compare the cost of coal to alternative resources we will need to look at the levelized costs of the power plants that use them. The levelized cost of a power plant is a kind of amortized cost which attempts to determine the average price of the power generated over the plant's lifetime. The big expenditures that contribute to a levelized cost are: initial capital investment, fuel, maintenance, and operation.

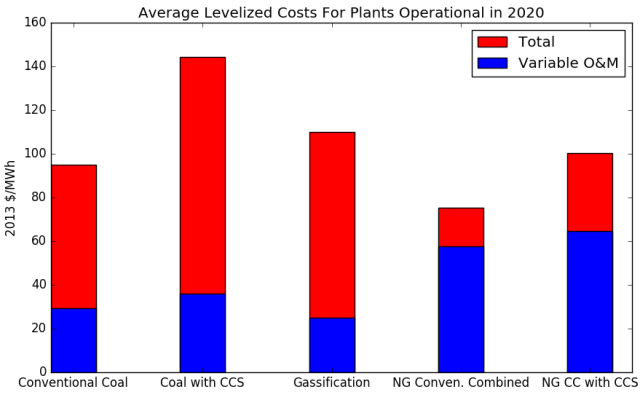

Figure 2: Levelized Costs [12][13]

Coal's main competitor for electricity generation is natural gas. As can be seen in figure 2 conventional coal plants are actually slightly more expensive than natural gas plants are. However, this bar plot does not tell the whole story. Natural gas prices are currently at an incredible low because of the recent increase in fracking. This sudden increase in supply has not been caught up with

by demand, which has caused many storage centers to near capacity, and drive prices way down. [14] These low prices are likely not to stay. Both the rising environmental concerns of fracking and low oil prices make these fracking wells unlikely to continue producing at the rate they currently are. When natural gas production falls, natural gas prices will rise again and may make coal the cheaper source again. Either way, coal is definitely in the fight for the cheapest resource to generate electricity.

Another aspect that makes coal appealing is its steady price. This recent volatility of natural gas prices is not uncommon. As can be seen in figure 3, the price of history of natural gas (green) is much more unstable than the price history coal (red). As of April 2016, natural gas is cheaper than coal for the amount of energy it generates. Yet, as can be seen in figure 3 in 2014 coal was cheaper than natural gas. 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. This security does not just benefit investors of power plants. This security also benefits citizens and commercial operations who utilize the electricity by providing them with a stable utility bill.

This historical price security of coal is also not likely to change because its supply is plentiful. Not only is coal's supply plentiful in the world, but specifically in the United States. The location of these reserves is important because coal reverses in the United States provide even more stability benefits. It reduces the chance of a shortage because of some kind of international crisis, and ensures that the United States government has the ability to control the price of the coal in an international or national crisis.

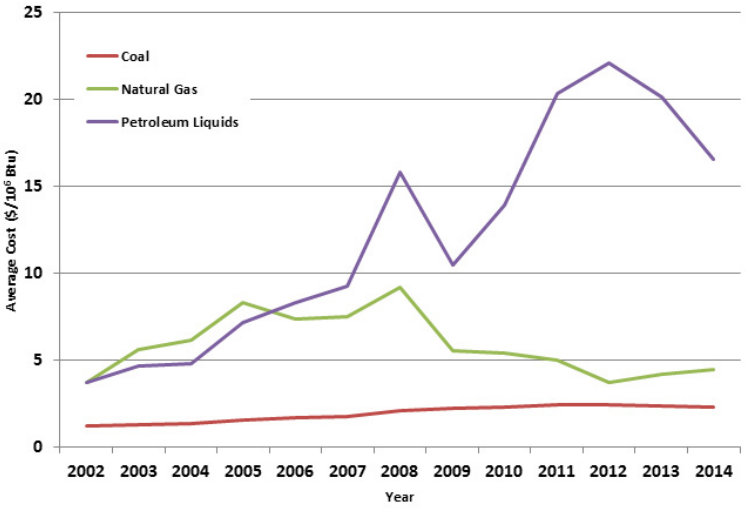

Figure 3: Price Histories [5]

The United States Department of Energy estimates that the United States has coal reserves of

about 480 billion short tonnes. [18] 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 that because of property rights and or technology barriers, only 380 tonnes of the coal reserve is obtainable (about 80 %). Now suppose our coal production instantly rose to $4,000$ million short tonnes a year. Even with these unlikely estimates we still have about 95 years of coal left,

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

Despite the enormous damage that coal pollution causes, it seems unreasonable to waste such an inexpensive and stable resource for generating electricity.

3 How Gasification Works

A potential solution to this conundrum of whether or not to utilize coal is gasification. Unlike traditional 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. (Coal actual has a large amount of hydrogen, and is where the much of the hydrogen gas comes from.) The heat and pressure come from a small amount of the coal being burned. [9] 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 proceeds through several chemical reactions to produce 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 used for power generation.

To be utilized as a fuel 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 contaminants. The two most voluminous gases removed are carbon dioxide and hydrogen sulfide. [9] This now clean syngas is ready to be utilized for energy generation.

This cleaning process is similar to techniques that modern pulverized coal plants use to reduce their pollution. However, since the reaction is much more controlled in gasification, the contaminants

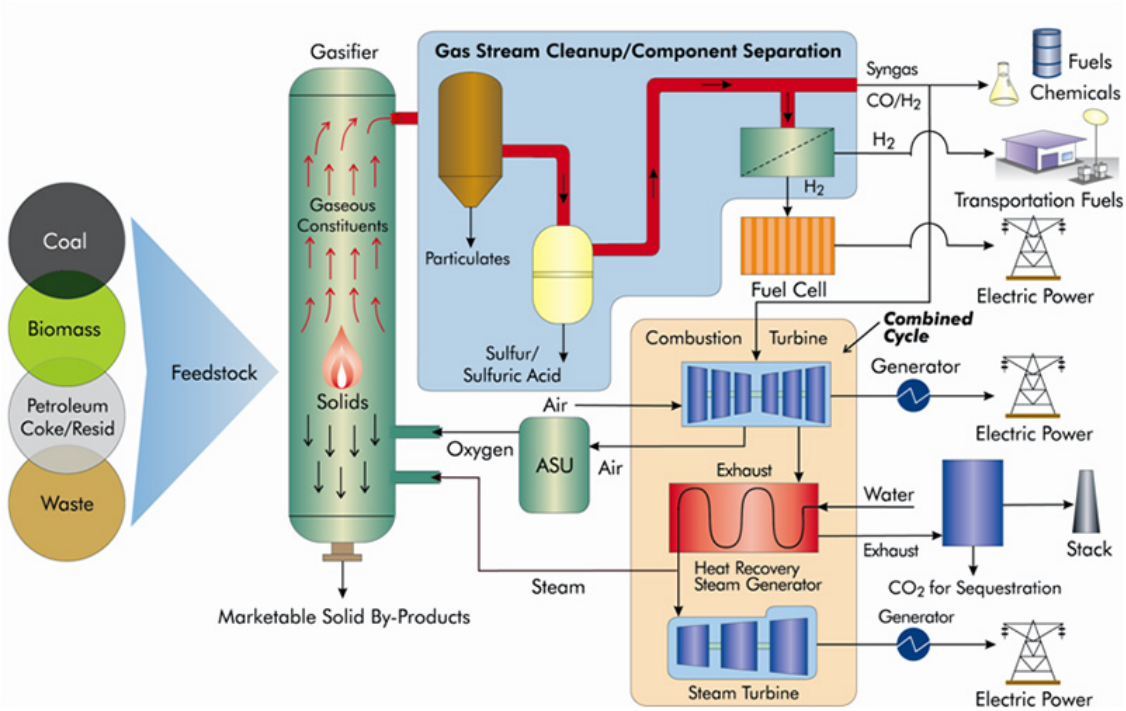

Figure 4: Diagram of Gasification Process [9]

are much more concentrated. This may seem bad at first, but depending on the method used the contaminant sulfur may be obtained in either a solid or liquid form. Either way, the sulfur is at a high enough concentration that it is pure enough to be sold as a commercial product—an additional income source. The carbon dioxide may seem to be a waste. Yet, in some cases it can also be sold for profit. One, such commercial use of carbon dioxide is to improve yields from oil drilling. [3] If there are no commercial markets for the carbon dioxide, then it can be safely piped into under ground storage and not be released as a pollutant.

Once the syngas is cleaned it contains mostly hydrogen gas. This means operations that are entirely focused on electricity generation will now burn the syngas as a fuel in an on site turbine. [16] However, there are two other commonly utilized options. One, is to further process the syngas into synthetic natural gas. This is done in the Great Plains Dakota Gasification Plant. [8] Another is to further purify the syngas into just hydrogen gas. The natural gas or hydrogen gas can then be sold as a fuel. Regardless of the route chosen, gasification has successfully converted the energy contained in the original coal to a clean energy source.

4 Gasification is Cleaner

Gasification offers a solution to our conundrum of using coal because it greatly decreases the pollution from the traditional combustion of coal. 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 virtually no nitrogen exposed to the reaction, which is commonly found in the air, and nearly eliminates the concentration of NOx.[6] 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 traditional plant. The higher concentration of pollutants makes the filtering more effective [6]. This high concentration also has the benefit of allowing for the these toxins to be gathered in large enough quantities to be sold—not just stored in some toxic waste facility. Together these elements of gasification can make it a cleaner process than burning natural gas.[10]

Gasification also offers an improvement in efficiency over traditional coal. 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% in the next couple of years. [10]

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. Furthermore, some criticism of coal argue that coal scrubbing technology will decrease the efficiency of generation by $25\% - 40\%$, which may be true for traditional coal plants, but gasification actually increases efficiency.[1]

5 Economics of Gasification

Currently, there are four coal gasification plants operating in the United States. But, the National Energy Technology Laboratory has a list of 61 proposed projects in the United States, 24 of which are in active construction as of March 2016. [17] The main force preventing the widespread adoption of the technology are momentum, low natural gas prices, and the lack of stronger pollution regulations.

The momentum to adopt the technology is low because there is a lack of previously successful commercial examples. This has two effects. One, it dissuades investors because the lack of previous examples makes the investment's success less certain. Two, the equipment and facilities that gasification plants require are more expensive than they could be because they must be custom designed and built for gasification.[2] However, since there are so many proposed plants, this lack of momentum is clearly not a big enough hurdle to prevent any startups. Thus the adoption of gasification plants might be slow to start up, but eventually the momentum issue will not be problem.

The current low natural gas prices are likely to change in the near future. As discussed in section 2, natural gas prices are not likely to stay as low as they currently are. Since coal and natural gas are so close in price just a small rise in natural gas prices could make gasification the more economically successful option.

Even more beneficial for gasification is more stringent pollution regulations. These will be a big help because gasification is expensive when its free to pollute, as seen in figure 2. However, gasification can be made to be cleaner than pulverized coal, and natural gas. Not only that, but this increase in cleanness comes at far less cost than it does for the pulverized coal and natural gas. As seen in figure 5, as carbon dioxide pollution becomes more expensive, the gap between the cost of gasification (green) and natural gas (red dashed) decreases. Thus gasification becomes more and more economically viable as the cost of pollution rises, which it is likely to do as the world becomes more concerned with global warming.

Another advantage that gasification has is its ability to be dynamic in what it produces. One reason that natural gas is currently out competing coal is its ability to run at a dynamic output level. This kind of dynamic "peak load" plant is much more efficient because it does not generate, and waste,

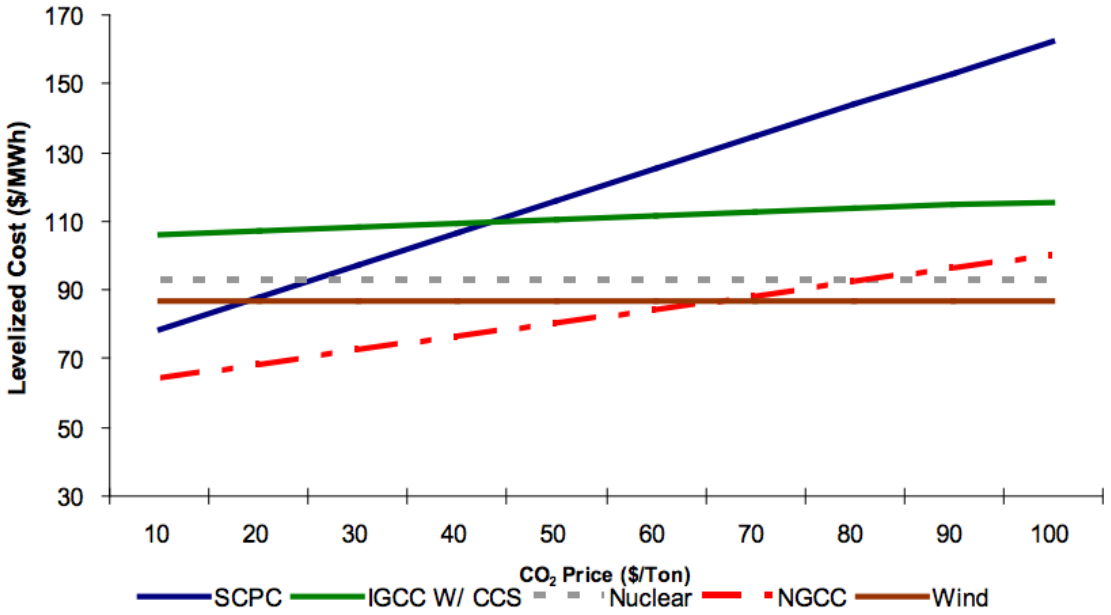

Figure 5: Levelized Cost vs. Pollution Cost [12]

excess electricity. Gasification also has the potential to be dynamic. A dynamic gasification plant will produce as much electricity is demanded for and use its excess syngas to producing hydrogen gas (or synthetic natural gas). This reduces the amount of coal it consumes compared to pulverized coal plants. Furthermore, this flexibility is even better than natural gas's because a gasification plant can always be operating at maximum output and use the excess energy for producing a fuel. This allows gasification to take advantage of more profit opportunities than natural gas. This is because when natural gas lowers its power output to meet demand—lowering profits—gasification uses that extra capacity to make fuel, which it later sells. This dynamic potential of gasification offers a lot of economic and environmental benefit.

In the end, gasification is on the cusp the being one of the best process for producing energy. Any of the factors discussed in this section could push it to the top. And, all of these factors are likely increase in gasification's favor in the near future.

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