Coal and Biomass Gasification: Implication and Preference

Abstract:

Energy, a valuable resource to humans and the basis of societal function, must develop to keep up with the fast-paced rapidly growing world of today. Gasification technology holds the future of energy production with its ability to produce energy and synthesis gas in an environmentally friendly manner. The paper entails an analysis of gasification technologies and attempts to determine which form of gasification, coal or biomass is most preferable. The implication of implementation of both forms of gasification is assessed along with experimentation to assess the energy potential of biomass and coal. After examining the process, benefits and problems faced by both types of gasification, it was concluded that coal gasification is superior to biomass gasification.

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Introduction:

Energy has been a sought-after commodity for decades. In this era energy in its variety of forms plays an essential role as fuel for our industrialized world. In order to keep up with the world's demand for energy, the energy field requires constant developments to maximize our use of resources and efficiency in power production. A new development that represents the next generation of energy development is gasification. Gasification occurs of both biomass and coal. This essay will center upon both coal and biomass gasification, since many hundreds of millions of dollars of public and private-sector investment funds have been committed in the United States, Europe, and Japan in the development of coal and biomass-integrated gasifier/gas turbine systems. This is due to the thermodynamic advantage offered by the gas turbine for extremely clean power generation, the abundance of coal and biomass, and production of synthesis gas and other high-value energy products (Johnansson 743). Therefore, gasification technologies potentially have the power to revolutionize the world of energy production as it is known. Thus, an understanding of gasification is important. The debate regarding gasification's practicality and benefits still continues. However, when examining the qualities of biomass and coal gasification, the benefits and practicality of coal gasification make coal gasification preferable to biomass gasification.

Sources of Error:

It is important to note that gasification is a rapidly developing area of study. Therefore, it was difficult to come across published works on gasification. Most of the sources used were private and government run websites. Also, since coal gasification is more popular than biomass gasification it was much harder to find sources detailing biomass gasification.

This essay was written in the United States, and since gasification development would hurt companies that President Bush and his business acquaintances are involved in, gasification research and development is not greatly supported by the administration. Hence, information on gasification is not readily available and if available may be written in a biased manner, because of the United States' status quo.

Due to difficulty in attaining information, no source alone was thorough in providing information about the details of the gasification process and the result of the technologies. Thus, the information from a variety of sources was collected and combined together to create one coherent document. Also, there was no means to determine the accuracy of the analysis and overall conclusions regarding the technology.

Gasification Process:

Coal:

Coal in a modern gasfier is exposed to hot steam and carefully controlled amounts of air or oxygen under high temperatures and pressures (http://www.clean-energy.us/). Under these conditions carbon molecules in coal break apart, setting into motion chemical reactions that produce synthesis gas, syngas, which is composed of carbon monoxide, hydrogen and other gaseous compounds (http://www.fe.doe.gov/coal_power/). Using commercially proven technologies that remove particulates and sulfur, the syngas can be cleaned and used for a variety of other purposes.

In the gasification process coal is fed into a pressurized vessel, the gasifier, where the reactors operate at pressures of 0.1 to 2.5 megapascals and the atmosphere of steam and/or oxygen are at moderately high temperatures (>1000 K) (Johnansson 886). In coal gasification the only way to bring about the high temperatures needed to attain sufficient gasification rates is through partial oxidation (887). Partial oxidation is exothermic and requires heat input as simplified in the equation below:

$$\text{Coal} + O_2 \rightarrow CO_2 + H_2O + \text{heat} + \text{carbon compounds} + \text{syngas} \quad \text{(partial oxidation)}$$

Biomass:

Gasification of biomass is similar to coal except for its high reactivity which allows for more gasification possibilities than with coal. In biomass gasification there is a high fraction of volatile material in the feedstock and the resulting char. Therefore, it is possible to use partial oxidation and thermal pyrolysis as the primary conversion process (887). The partial oxidation conversion (just like coal) is exothermic and requires heat, while the partial oxidation step is exothermic as shown in the simplified equations:

$$\text{Biomass} + O_2 \rightarrow CO_2 + H_2O + \text{heat} \quad \text{(partial oxidation)}$$

$$\text{Heat} + \text{biomass} + \text{steam} \rightarrow CO + H_2 \text{ (pyrolysis)}$$

Benefits and Problems of the Technology:

Coal:

Coal gasification offers a plethora of benefits, one of which is a more efficient electricity generating method than the conventional coal-burning power plant. In the classic plant, heat from the coal furnace boils water that creates steam for a steam turbine generator. A gasification based power plant uses the high pressure coal gases to fuel an Integrated Gasification Combined Cycle (IGCC). An IGCC system includes three basic components: a gas turbine, heat recovery steam generator (HRSG) and a steam turbine (http://www.clean-energy.us/). A high efficiency gas turbine burns the coal-made syngas creating hot exhaust that the HRSG then utilizes to generate incremental steam. Steam recovered from the gasification process combines with the steam generated in the HRSG and is then used to power a conventional steam turbine, producing a second source of power (http://www.clean-energy.us/). This dual turbine ability does not exist within classic coal combustion plants, and allows for major improvements in efficiency within gasification-based power plants. Conventional combustion plants typically have a 33-35%, from fuel to electricity, efficiency rate. Gasification plants currently have 45-50% efficiency rates, and with the advancements in the future will potentially have an efficiency rate of 60% (http://www.fe.doe.gov/coal_power/). Higher efficiencies mean less fuel use in generating the rated power. Also, this potentially results in lower costs for ratepayers and the formation of fewer greenhouse gases, since a 60% efficiency rate in a gasification power plant can cut the formation of carbon dioxide by 40% in comparison to the typical coal combustion plant (http://www.fe.doe.gov/).

Not only is coal gasification more efficient in electricity production, but gasification is the most environmentally attractive alternative to utilize coal, the worlds most abundant fossil energy resource. The syngas that is produced contains impurities like carbon monoxide, atmospheric mercury, sulfur oxides (SO_x) and nitrogen oxides (NOx) (United States). However, gasification technologies have the ability to extract 99% of these pollutant-forming impurities and greenhouse gases from the syngas. Gasification provides an effective method of capturing CO_2 by shifting carbon to CO_2 for pre-combustion sequestration. In addition, due to IGCC's high efficiency, less CO_2 is released per unit of electric power production (United States). Furthermore, extracted impurities can be converted into commercial products such as chemicals and fertilizers and sold instead of being thrown into landfills. With purification processes in combination with gasification, essentially pure hydrogen gas is made. Clean syngas can be used as chemical building blocks to produce a broad range of liquid or gaseous fuels and chemicals, as a fuel producer for highly efficient fuel cells, and as a source of hydrogen that can be separated from the gas stream and used as a fuel for hydrogen-powered cars or as feedstock for refineries (http://www.fe.doe.gov/).

Gasification technologies also help to remedy the problem of greenhouse gas emissions. Greenhouse gases, (CH_4, CO_2, chlorofluorocarbons, and nitrous oxides) are believed responsible for the trend of increasing temperatures and global warming, because of the correlation in the rise of these greenhouse gases and the rise in temperatures. A traditional source of these gases is from burning fossil fuels which occur in the conventional coal-based power plants. However gasification technologies allow for the removal of greenhouse gases before use. Therefore, not only does gasification allow for a more efficient energy and gas production, but in the process also helps reduce the emission of greenhouse gases and the incidental environmental damages.

Because of gasification's wide array of benefits, one would think gasification technology is widely accepted and practiced. However, the cost of implementation is high and the environment benefits are not economically beneficial for adopting companies. Current gasification-based power plants cost around an estimated $1200 per kilowatt, while conventional coal plants cost around $900 per kilowatt. The environmental benefits are not economically beneficial, because current environmental regulations would force technology development and the associated cost without providing an economic incentive for companies. Some in the gasification business feel they are being held to a higher environmental standard than typical coal plants, because of unfamiliarity with the technology.

Due to the unfamiliarity of groups like the Environmental Protection Agency (EPA), the uncertainty over environmental regulations and rules has further deterred the development of gasification technologies. The issuances of new regulations for CO_2 controls and the tightening of existing regulations and confusion over standards like nitrogen oxide emissions would require expensive development. For example, based on what appears to be a fundamental misunderstanding of the differences between IGCC and natural gas combined cycles (NGCC) technologies, regulators are pushing nitrogen oxides emissions from IGCC plants to be controlled by the same regulations as those for the NGCC plants. Gasification systems already meet a 9 ppm nitrogen oxides emission standard because of the gas turbines; however applying NGCC standard would require nitrogen oxide emissions to be reduced to 3 ppm. For plants to achieve the 3 ppm level, expensive selective catalytic reduction (SCR) units would have to be added to the IGCC system. However, as a result of adding SCR units the sulfur levels in the syngas would have to be reduced to 5 ppm, otherwise damage would occur to other parts of the system. To decrease the sulfur, instillation of Rectisol units is necessary. The Rectisol units would greatly increase the capital cost as well as lowering the efficiency reliability, availability and maintainability of the IGCC (United States). Another example: the new regulations may be enacted for trace metal emissions, notably mercury. Depending on regulation details, the mandated changes could become a costly obstacle to gasification. Although technologies are available to help gasification-based plants follow trace metal regulations, compliance would again increase cost. Companies predict that mercury regulations will be issued in the future. When issued the IGCC would have to capture mercury before the combined cycle part of the plant. Changes enacted to control trace metals will also affect which gas cleanup system the gasification plant uses. Mercury has been reported to pass through entire gasification plants, including the cold gas clean up phase which is meant to remove trace metals, however in the long run not enough mercury is released for severe environmental damage. With regulations in place on trace metal emissions, a carbon guard bed would be installed. Consequently, the guard bed would add to cost, because of the increase in the volume of gas that must be processed. Furthermore, the guard bed would add back pressure on the gas turbine, and therefore lower its output and reduce overall efficiency (United States).

Along with the expense of implementation and the uncertainty of environmental regulations and their affect, gasification has faced public dogma. The public's perception of coal and coke as dirty fuels, along with the belief that emissions from coal gasification plants are equivalent to other coal plants has limited the attractiveness of gasification. Public concerns over dust, smoke, water discharges and solid waste disposal also contribute to the difficulty of establishing a gasification plant.

Biomass:

A majority of the benefits and problems that exist with coal gasification are the same for biomass gasification. Hence, when discussing the benefits and problems with biomass gasification information details will not be repeated, since they are the same except for the slight alterations that occur since the input is biomass instead of coal. However, if the effect/implication differs greatly or there are additional benefits or problems faced by biomass gasification they will be detailed.

Just like coal-based gasification biomass has the same ability for more efficient energy production, to decrease the release of greenhouse gases, and to produce syngas that can be cleaned and used. However, unlike coal gasification biomass gasification does not utilize fossil fuels. Instead biomass which is composed of decomposing plant material is burned; biomass is both renewable and in abundance without mining. Therefore, biomass gasification has an added advantage. Furthermore, because of biomass's qualities it will be more easily attained and cost less than coal (Johnansson 957).

The cost of biomass gasification implementation is high and its environmental benefits are not economically beneficial just like with coal. Furthermore, the same uncertainty over environmental regulations and having to redesign plants to fit these regulations exist as well, but to a slightly lesser degree, since biomass when burnt does not release the same toxins into the environment as coal. In addition, public dogma associated with biomass gasification is much less than coal gasification, since again biomass does not create the same air pollutants as fossil fuels.

Comparison of Coal and Biomass Potential Energy:

To determine which substance has the most possibility of creating energy and thus syngas, I attempted to determine the amount of energy released by combusting one gram of biomass and coal. Then using the experiment's results, I came to a conclusion as to which input, coal or biomass, has the most potential to produce syngas.

Planning A:

Aim: To determine if coal or biomass has the most potential energy.

Question: What has more potential energy coal or biomass?

Logically an item with the most potential energy has the ability to yield the most product. Hence, to determine which has more potential energy, samples of coal and biomass will be burned in a calorimeter to find each sample's energy release. There will be three samples of both coal and biomass that will be burned. The conditions, in which the samples will be burned, like temperature of burning environment and location of test, will remain the same. The independent variable will be the coal and biomass samples. The dependent variable will be the effect of burning the coal or biomass on water temperature. There is no need for a control variable other than all the conditions remaining the same, since the change in temperature and mass of the burnt items will be plugged into the equation $Q = mc\Delta t$ to find the energy released from the two items. In the equation, Q is energy, m the mass of the sample, c the specific heat of the liquid used in the calorimeter, in this case water, and Δt the change in temperature of water.

Hypothesis: If coal and biomass are both burned separately in a calorimeter then the coal will cause the greatest increase in water temperature and therefore will have the greatest energy per gram output.

Planning B:

Materials: 3 pieces of coal, 3 samples of biomass, 6 bags, tape, writing utensil, calorimeter, lighter, lighter fluid, water, and thermometer

Procedures:

1. Weigh coal and piles of biomass and record weights. Then place each item in separate bags and lab bags with tape and writing utensil.
2. Fill calorimeter with water until the stop mark and take temperature and record.
3. Place a piece of coal or a sample of biomass in burning section of calorimeter and light the item and place the calorimeter lid on top. If need when lighting coal add a few drop of lighter fluid to begin burning.
4. Let item burn.
5. When the item is done burning remove calorimeter lid and take temperature of water and record value.
6. Remove ashes and replace water in calorimeter.

7. Repeat steps 2 through 6 five more times --- essentially until every coal and biomass sample has been burned.
8. Then clean up and calculate energy release using the equation $mc\Delta t = Q$.

Data Collection:

Table I: *Burning Results for Coal. The temperature of the fresh water in the calorimeter was taken then the coal was placed inside burning section of the calorimeter and lighter fluid was applied to light the coal on fire. Once the coal was done burning, water temperature was measured. Observations during burning process were also recorded.*

Trial	Weight (g)	Beginning Temp. of water (°C)	End Temp. of water (°C)	Observations
1	27.76	16	65	Boiled for period of time, could not tell when done burning
2	28.56	14	69	Boiled for period of time, could not tell when done burning
3	28.62	13	67	Boiled for period of time, could not tell when done burning

Table II: *Burning Results for Biomass. The temperature of the fresh water in the calorimeter was taken then the biomass was placed inside burning section of the calorimeter and lit. Once the biomass was done burning, water temperature was measured. Observations during burning process were also recorded.*

Trial	Weight (g)	Beginning Temp. of water (°C)	End Temp. of water (°C)	Observations
1	3.04	13	15	Material was repeated re-lighted, could not tell when done burning
2	4.49	14	17	Material was repeated re-lighted, could not tell when done burning
3	2.84	14	15	Material was repeated re-lighted, could not tell when done burning

Data Processing and Presentation:

Calculations

To determine the amount of energy released from coal and biomass the following calculations were done:

Step 1 – Find difference in temperature from before and after burning.

Table III: *Change in Water Temperature for Coal Trials.*

Trial	Beginning Temp. of water (°C)	End Temp. of water (°C)	End Temp -Beginning Temp = Δ Temp (°C)
1	16	65	49
2	14	69	55
3	13	67	54

Table IV: *Change in Water Temperature for Biomass Trails.*

Trial	Beginning Temp. of water (°C)	End Temp. of water (°C)	End Temp -Beginning Temp = Δ Temp (°C)
1	13	15	2
2	14	17	3
3	14	15	1

Step 2 – Plug into Energy Equation ($Q=mc\Delta t$)

m = mass of the sample (g)

c = specific heat of water = 1cal/g °C

Δt = change in temperature found in tables III and IV for coal and biomass respectively (°C)

Table V: *Energy Released from Coal.*

Trail	Mass (g)	Specific Heat of Water (cal/g °C)	Δ Temperature (°C)	mcΔt = Q = Energy Released (cal.)
1	27.76	1	49	1360.24
2	28.56	1	55	1570.80
3	28.62	1	54	1545.48

Table VI: *Energy Released from Biomass.*

Trail	Mass (g)	Specific Heat of Water (cal/g °C)	Δ Temperature (°C)	mcΔt = Q = Energy Released (cal.)
1	3.04	1	2	6.08
2	4.49	1	3	13.47
3	2.84	1	1	2.84

Conclusion and Evaluation:

Because the water began boiling during the experimental trials for coal, I cannot determine the actual energy released from the coal. However, my results indicate my hypothesis of coal producing more energy is correct. Nevertheless, there is a lot of error in the methodology of the experimentation. For example in the time it took for me to remove the burning tray from the calorimeter and take the water's temperature, the water would have already begun to cool. Furthermore, I burned the materials outside, and outside was cold, so obviously when the material starts to burn off the cold air caused the sample to cool faster. I also had a hard time lighting samples and then keeping them burning, especially the biomass. Thus, between the time of re-lighting heat was lost. In addition, I could not tell when the coal and biomass were done burning, therefore it is possible the entire item was not done burning, and I do not have an accurate measurement of temperature increase, and therefore my calculations of energy release are inaccurate. Another source of error is during the transfer of material to the calorimeter burner, since dust particles of the samples were lost. Basically the experimental design allowed for error. Important to note as well is the fact the water during the coal experimentation began to boil. Thus, I know for a period of time the temperature of the water had to be 100°C. However, by the time the item was done burning and I took the water's temperature the temperature had fallen.

If I were to do this experiment again and to limit error, I would take measurements of the quantity of water before and after burning so that I could calculate the energy used to evaporate the missing water along with taking the temperature of the water. I would continue to do the experiment outdoors, because of the toxic effects of carbon monoxide, but on a warmer day, so as to minimize the heat loss between the burning of the sample and the temperature taking. I also would wrap a few layer of insulation around all areas except the cap of the calorimeter to decrease heat loss throughout the experiment.

This experiment shows that more energy is released from coal and therefore we can assume that less coal will be need in the gasification process to produce a specific amount of syngas then biomass would require. This could also imply that the cost of purchasing biomass to create a specific amount of syngas could be equal to coal, because more biomass would have to be purchased to equal the effect of coal.

Conclusion:

Much potential lies within gasification and its technology. The basic benefits and problems exist with both forms of gasification, so the question still stands: what form of gasification, coal or biomass, is preferable? In the case of coal, coal is in great abundance in developing countries such as China and India. For these countries coal gasification could be the ticket for the development of their country and economy, because coal gasification would make these countries use their coal to establish their own gasification systems and inadvertently create jobs and markets that would aid their nations. This same potential is not within biomass gasification, since biomass is easier reached but more is required to produce the same effect as a smaller amount of coal. This is because, as the experiment illustrated, coal releases more energy per gram and thus would be more efficient then biomass. All the problems that coal gasification faces, like strict rules and public fear of polluting, are much less with biomass gasification. However, the cost of establishing the gasification system is the same for both biomass and coal.

Both types of gasification can help meet the energy demands of the humans, while at the same time being a bridge to further developments. The technology in general is environmentally friendly and efficient and opens the world to new technological opportunities. The hydrogen gas that is produced may enable the development of hydrogen powered cars and fuel cells. From this development we do not know what humans will develop next. Hence, regardless of the initial establishing cost, the cost of production and public phobia, gasification with time and dedication will be the future of energy development. We should concentrate our efforts in developing coal gasification, because the benefits are the same as biomass and coal releases more energy. Additionally, the most development in gasification technology has occurred within coal based gasification (Johnansson 956). Furthermore, although coal faces problems regarding it ability to not harm its surroundings, the economic development that will incur from better utilizing this natural resource will help countries develop, and the syngas that is created can still help push humans towards energy/technological developments.

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