Sunlight Ancient and Modern: The Relative Energy Efficiency of Hydrogen and Fertilizer from Coal and Current Biomass

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Abstract

Hydrogen production has gained increasing attention as a potential energy carrier, which can utilize many forms of renewable energy, such as biomass, wind and direct solar power. It has increased its significance as fossil fuels are being used up at a high rate and energy security is of greater importance to the United States and many other countries. Furthermore, hydrogen production offers the potential to alleviate concerns regarding global warming and air pollution, either through using renewable carbon or through point source carbon sequestration.

In this paper we will focus on examining the efficiency of hydrogen production from current biomass compared to that from fossil fuel coal, which is closely related to current terrestrial biomass sources. We are exploring the efficiencies of maximum hydrogen production from biomass and from coal under current conversion technologies. Pyrolysis was chosen to convert biomass because it is gaining increasing attention as a potential wide-spread method for biomass utilization with carbon sequestration. Gasification was chosen to be used in coal conversion because it is one of the most widely used processes on coal and could obtain high hydrogen yield compared to other processes on coal. In both conversion processes, steam reforming is required to convert the pyrolyzed or gasified products further to produce hydrogen, as shown in Figure 1.

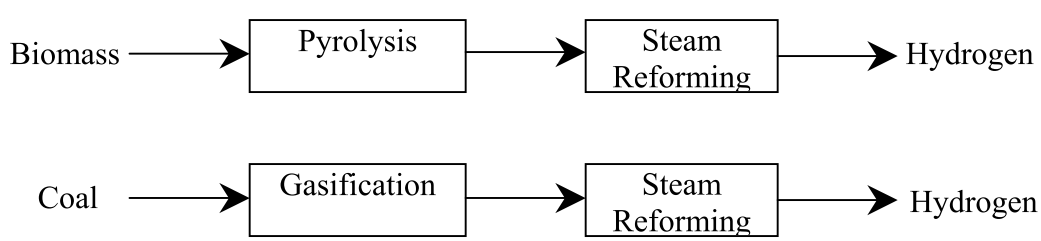

Figure 1 Conversion Process from Biomass and Coal to Hydrogen

Ultimately, it is sunlight that is stored in biomass and coal and then converted to hydrogen and other products. Therefore, it is worth exploring how much the solar energy is preserved and converted into hydrogen, in other words, how much solar energy is required for one unit mass of hydrogen produced. By including the sunlight to current biomass and coal as in Figure 2, this study will include the whole chain from sunlight to biomass growth and harvest and to biomass conversion to hydrogen. For the competing coal conversion system, the whole chain will include the process from sunlight to coal formation and mining and to hydrogen production from coal conversion technology. This will enable us to assess the ecological footprint associated with hydrogen production in terms of solar energy and other external energy inputs versus the use of fossilized sunlight.

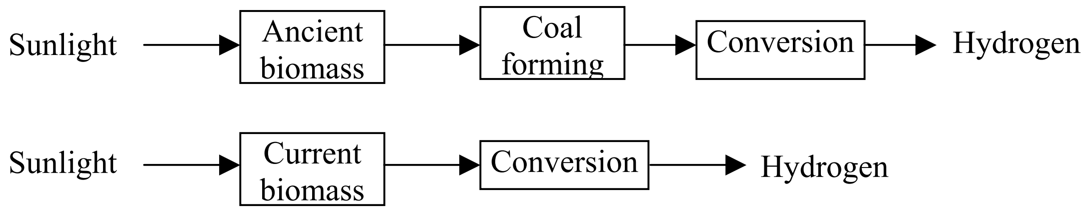

Figure 2 Process Outline from Sunlight to hydrogen through Current and Ancient Biomass

Pine was chosen to be the representative for current biomass because it is a common type of tree in the United States. We are studying the full life cycle from sunlight to hydrogen through current pine tree growth and through the competing fossil fuel system. The configurations of the conversion route mentioned above are expected to give us a good view on hydrogen production efficiencies and help direct later industrial hydrogen production technologies.

Bio-oil, the product from pyrolysis and precursor for steam reforming, is hard to define because its composition depends on reaction conditions, biomass composition, and could contain hundreds of components with various concentrations. On the other hand, the current pyrolysis experiments only cover a small range of biomasses. In addition, if the development of biomass conversion to hydrogen is to be generalized to other types of biomass, it becomes necessary to examine the potential bio-oil compositions that can be generated. A simulation tool was developed to estimate the pyrolytic bio-oil composition from various biomasses, using the limited experimental bio-oil information. The results showed that the estimated pine-derived bio-oil would produce less hydrogen after steam reforming than coal gasification products. Currently another statistical estimation tool is also under exploration in order to generate a range of bio-oil compositions and the same calculation will be conducted on the conversion processes to hydrogen on each composition. This is an important step in our study and the results are expected to help understand the accuracy that is needed for bio-oil composition prediction in the case it is converted to hydrogen and how different bio-oil compositions can influence the efficiency of hydrogen production.

Hydrogen production is energy intensive, which is why hydrogen still cannot beat the fossil fuels as energy supplier currently in spite of its many advantages over fossil fuels. Therefore, in this study, we will conduct heat integration to raise the overall thermodynamic efficiencies for both coal gasification and biomass pyrolysis. After raising the energy utilization to its maximum extent in heat integration, there will still be energy required externally in most cases. Therefore, there are optimal conditions as a result of the balance among hydrogen production, external energy inputs and the complexity of heat exchanging network for both of the two systems. And the optimal conditions are the basis for our comparisons. The heat integration of the conversion processes as a major component of our study.

Ammonia production is one of the most important areas for hydrogen utilization. And by making ammonia into ammonia bicarbonate, not only good nitrogen fertilizer is produced, but also carbon can be sequestered and so help reduce the green house gas, carbon dioxide in the atmosphere. So in this study, we will also look at the process from hydrogen to fertilizer through ammonia production. We will couple this process with the hydrogen production process and explore the whole hydrogen production and energy utilization efficiency.

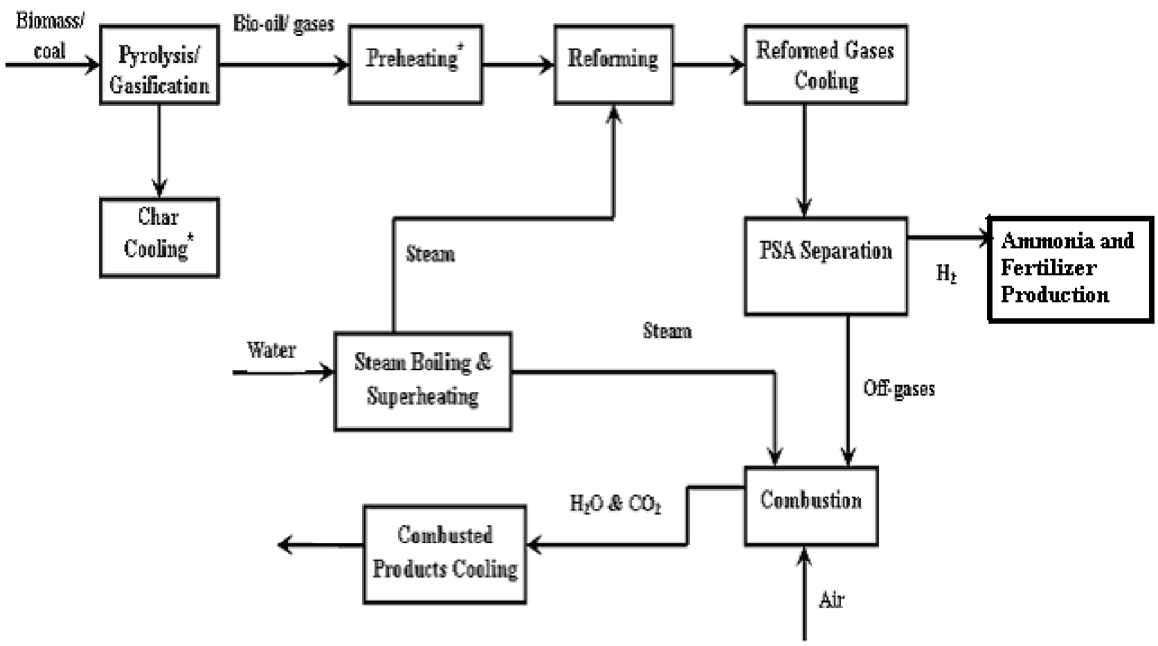

Figure 3 Whole Conversion Process from Biomass and Coal to Hydrogen and Fertilizer

In summary, in this work, we will study the full life cycle of hydrogen and fertilizer production from sunlight through current biomass and through the formation of coal, using pyrolysis and gasification followed by steam reforming as the conversion technologies. The whole conversion process is summarized in Figure 3. The proposition of the estimation method of bio-oil composition will be one of the major contributions as well as the comparison of hydrogen production and energy in hydrogen to help direct the hydrogen production industries. Besides, statistical estimation of bio-oil compositions will provide a good view on the influence of bio-oil composition on hydrogen production.