AlleyWatch

The Rise of Biofuels in the Age of Electric Vehicles

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Look around and you'll be surprised to see that biofuels are coming back in vogue. From 2004 to 2008, innovations in the biofuels sector fell to almost zero around the globe. While the future of the industry seems a bit uncertain, the immediate trends seem to suggest that things are coming back, at least for the moment. That said, we wanted to write a bit about this shift in opinion of this highly contested sector of the renewables market.

Discussion

Late last year, an article appeared in the NY Times concerning biofuels, which suggested that a retooling was quietly happening within the industry. We were very skeptical given that electric cars were gaining in popularity and technology costs for creating biofuels seemed to be increasing, rather than declining. Wherefore, it was our opinion that biofuels were quickly becoming another clean-technology which was becoming obsolete despite the good intentions behind it. Moreover, the recent debacle at VW further solidified our belief that biofuels were no more and electric transportation was all the rage. A series of recent conversations around the resurgence of a rather popular method of producing biofuels has reestablished my belief that biofuels might once again comeback, albeit not to the levels previously seen.

Back in the 1920's, a German scientist invented a process of making biodiesel called the "Fisher-Tropsch" method. The Fischer-Tropsch process is one of the advanced biofuel conversion technologies that comprises gasification of biomass feedstocks, cleaning and conditioning of the produced synthesis gas, and subsequent synthesis to liquid (or gaseous) biofuels. The Fischer-Tropsch process has been known since the 1920s in Germany, but in the past, it was mainly used for the production of liquid fuels from coal or natural gas. However, the process using biomass as feedstock is still under development. Any type of biomass can be used as a feedstock, including woody and grassy materials, and agricultural and forestry residues. The biomass is gasified to produce synthesis gas, which is a mixture of carbon monoxide (CO) and hydrogen (H_2). Prior to synthesis, this gas can be conditioned using the water gas shift to achieve the required H_2/CO ratio for the synthesis. The liquids produced from the syngas, which comprise various hydrocarbon fractions, are very clean (sulphur free), straight-chain hydrocarbons, and can be converted further to automotive fuels.

Fischer-Tropsch diesel can be produced directly, but a higher yield is achieved if first Fischer-Tropsch wax is produced, followed by hydrocracking. Fischer-Tropsch diesel is similar to fossil diesel with regard to its energy content, density, and viscosity and it can be blended with fossil diesel in any proportion without the need for engine or infrastructure modifications. Regarding some fuel characteristics, Fischer-Tropsch diesel is even more favorable, i.e. a higher cetane number (better auto-ignition qualities) and lower aromatic content, which results in lower NO_x and particle emissions.

For the production of Fischer-Tropsch diesel, the main technological challenges are in the production of the synthesis gas (entrained flow gasifier). These barriers also apply to other gasification-derived biofuels, i.e. bio-methanol, bio-DME, and biohydrogen. The synthesis gas is produced by a high-temperature gasification, which is already used for coal gasification. Biomass has different properties than coal and, therefore, several process changes are necessary. First, the biomass pre-treatment and feeding need a different process, because milling biomass to small particles is too energy-intensive.

While this method produces positive results, it has been found that small biomass particles can also aggregate and plug feeding lines. These blockages can cause issues with fuel efficiency, and, in some cases, prevent fuel from reaching the engine. However, pre-treatment processes like torrefaction or pyrolysis (which produces a liquid oil) could be developed to overcome these problems. This brings me to my next point, if the right technologies are combined, the Fisher-Tropsch method can produce some of the most clean and efficient fuels known to man.

Given the recent regulations to encourage the elimination of the use of coal by utilities to make electricity by 2025, the eventual complete elimination of coal mining jobs around the country, and the closure of factories due to off-shore manufacturing, the time is right for some real change.

Bring Biochar Into the Discussion

The natural balance of the earth has always included carbon storage in the plants and soil. The problem is that we have disrupted that balance. We have burned, in one century, much of the carbon that nature sequestered over millions of years. Coal is almost pure carbon, gathered by plants and sequestered by natural processes. We need to stop burning it! Though growing plants take CO_2 from the air and fix it in their cells, the carbon is only borrowed: 99% of that carbon ends up back in the atmosphere, as the plant is eventually burned or consumed by animals, termites, fungi, nematodes, or worms, which then return the carbon to the atmosphere. Pyrolysis is a way to grab the carbon in plants before it can become a meal for these creatures and return it to the soil as pure carbon biochar.

Pyrolysis mimics the natural process that turned ancient plants into coal: when biomass is heated up with no oxygen supply, it melts into carbon, syngas, and bio-oil. Pyrolysis was used thousands of years ago by the natives of Brazil to enrich their poor, acidic soil into Terra Preta, one of the richest, most productive soils known to man. Terra Preta still contains as much as 9% carbon. It is always found with pottery shards, and other evidence suggests that it was man made. It is so productive that it is bagged up and sold today as potting soil. We’re still trying to match their superb results. If we succeed, we will solve world hunger, global warming, and our energy shortage in one stroke.

The Amazon culture that made these soils was killed by conquest and disease. The primitive people in the area today practice slash and burn agriculture, which quickly depletes the soil and spews CO_2

and pollutants into the atmosphere. The Terra Preta was created by slash and char, which involves cutting off oxygen to the burning biomass. Without oxygen, little CO_2 is produced and the biomass melts into carbon with a very fine structure called biochar. The hydrogen in the plant molecules produces heat, syngas, and bio-oil as the plant molecules are reshuffled. The buried biochar retains some of the micro-cellular structure of the plant. It is activated charcoal with very high surface area. It can hold water and nutrients, and gradually releases them as needed. The nanoscale structure of biochar, like a coral reef, hosts a whole ecosystem of soil fungi and bacteria that feed the roots of plants and hold soil together. This part of the Terra Preta story is still not fully understood. It takes some time for this microscopic biological culture to develop and produce the amazing increases in yield for the soil. Experiments have shown that burying biochar in the soil can increase productivity significantly. For poor acidic soil, it has sometimes been known to double or triple production! The pyrolysis process converts cellulosic matter into syngas, bio-oil, and biochar by heating in the absence of oxygen. The bio-oil produced can be used like low-grade diesel fuel for heating and power generation. Syngas can be burned like natural gas or converted with catalysts to ethanol and chemicals usually made from petroleum.

As previously suggested, the energy in the bio-oil and syngas produced is much greater than what is obtained by fermentation to ethanol. For example, Miscanthus, a wild grass, can produce 340 GJ/hectare/year of bio-oil. For comparison, corn fermentation only produces 120 GJ/hectare/year (net) of ethanol. The fermentation process uses lots of energy and is only 3-5% efficient at converting plant energy into fuel.

Bring It All Together

In the 1970s, new concepts and processes targeting increased yield of liquid fractions provoked a renaissance in the pyrolysis of biomass. The basis of modern fast pyrolysis was developed at the University of Waterloo in the 1980’s (San Miguel et al 2011). From this time to the early 1990s, research performed in the U.S., Canada, and Europe has made fast pyrolysis what it is today. New and improved technologies such as: fluidization, ablation (the removal of material from the surface of an object by vaporization), and vacuums were being aggressively researched for application in new pyrolysis reactor designs (Pelaez-Samaniego et al., 2008).

Pyrolysis companies like Ensyn Technologies, Dynamotive, BTG, Fortum, Pyrovac, and Bioware developed due to extensive scale-up and new understanding of the thermochemical phenomena. Several different styles of reactors began to be used by these companies. Some of these reactors included the fluid bed, the circulating bed, the rotating cone, the ablative reactor, and the vacuum reactor. The state of the art pyrolysis technologies were reviewed extensively and published by Meier at el. (1999) and Bridgwater et al. (1994, 2001). All of these reviewed reactors were designed for converting fine particles of biomass only, excluding designs in which logged biomass was used (Pelaez Samaniego et al., 2008). Many of these pyrolysis reactors are capable of converting up to 70 mass % of the biomass into crude-oil (Bridgwater and Peacocke, 1994; Czernik and Bridgwater, 2004; Mohan et al., 2006), 40 mass % of which can be further refined into green gasoline and green diesel (Holmgreen et al., 2008a, b; Marinangeli et al., 2005). Nonetheless, numerous aspects of these technologies have the potential for improvement. These aspects include:

- Feedstocks with high alkaline content cannot be used in existing fast pyrolysis reactors.
- Despite the ability of lignin to be converted into precursors of green gasoline and green diesel, the conversion of cellulose to these precursors of transportation fuel (e.g. sugars) is not very efficient. This is because when the sugars breakdown, they form small molecules with little economic value.
- Corrosive and unstable bio-oils are a result of high levels of acetic acid derived from hemicelluloses.
- Using large volumes of inert carrier gases causes a dilution of the pyrolytic gases, making their energy recovery near impossible.

The market is limited for small condensable molecules with < 5 carbons which are the result of fragmentation reactions. Disposing of small condensable molecules that are not converted into valuable products can cause environmental issues. Our goal is to design a system that produces hydrogen or other valuable products from these burden bearing molecules.

Hydrotreatment of crude bio-oils could intensify coke formation and accelerate the deactivation of expensive catalysts which is of great concern for petroleum refineries. For this concept to be viable, it is critical that mobile pyrolysis units generate their own electricity using a fuel produced onsite (synthesis gas) to run diesel engines or fuel cells.

Lastly, in order to hydrotreat bio-oils, bio-oil refineries and mobile pyrolysis units need to generate their own hydrogen. Advancements made in pyrolysis reactor designs for the wood distillation industry can inform new designs. Ignoring these past advancements is a weakness in most pyrolysis designs today. The chemical industry influenced the academic world in developing current pyrolysis technologies. An important aspect of creating a new design is to make a critical evaluation of the existing designs and incorporate whatever device or practice that can contribute to an improvement on that design. The best design quality that a reactor can possess is the ability to be flexible. To be able to adapt components capable of both bio-oil recovery for bio-fuel, or biochar production for stable carbon soils, opens doors for opportunity.

Final Thoughts

The need for advanced fuels and bio-chemicals to reduce our dependency on imported oil, the need for advanced biochar to store carbon and enhance soil fertility, and the need for new technologies to convert waste biomass resources into valuable products, are the main market drivers for the development of pyrolysis technologies.

A balanced investment in the creation of new knowledge (science); in the design, testing, and scale up of new technologies (for pyrolysis reactors and for rural bio-oil refineries) (technology);and, in the development of new products (from bio-oil and biochar) (market) to build a shared vision that takes advantage of existing infrastructure and is achievable in small steps are all critical for the deployment of a viable biomass economy based on pyrolysis technologies.

Biochar and bio-oil production technologies, batch size, and marketing to the available resources and end user population needs to match up with the analysis of transport, marketing, and economics for specific conditions (Kammen et al, 2005). A proper analysis of these criteria is crucial to design policies at the state, federal, and international level.